Online Games on Wheels: Fast Game Event Delivery in Vehicular Ad-hoc Networks

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***Abstract*— With a number of participants that is continuously growing in number, the online game market is demonstrating its revenue potentialities. From a research point of view, online games embody a very interesting topic especially when plunged into extremely challenging scenarios such as vehicular networks. Indeed, regardless of the very high and fast mobility of vehicles, inter-vehicular communications are soon going to become a reality thanks also to the ongoing development of the IEEE 802.11p/DSRC standard. Car passengers will soon ask for utilizing all their favorite networking applications, including online games, even when traveling. To this aim, we consider the case study of a group of vehicles traveling along the same road while passengers are engaged in a shared online game through multi-hop wireless communications. As interactivity is one of the most important properties of online games, we have designed a novel scheme that is able to reduce the number of hops, and thus the time, required to broadcast every game event to all other players in the considered vehicular network. The main component of our scheme is a transmission range estimator, which is exploited to prioritize farther vehicles in becoming the next forwarder of a game event.**

I. Introduction

INTERACTIVE, massive online games are becoming popular and begin to receive the attention of researchers. Wireless, mobile gaming represents a particularly interesting case because of the proliferation of smart personal devices, the increasing availability of high speed wireless access points, and the emergence of vehicular networks and applications.

Indeed, vehicles represent the next frontier in mobile communication for the forthcoming years as demonstrated also by the progressive development of vehicular communication standards, such as the IEEE 802.11p/DSRC [2]. Moreover, the marketplace shows that about one million of new cars every year are sold within the US with preinstalled TV/DVD systems [1]; this demonstrates the willingness of customers to accept new entertainment technology in their vehicles. It is hence easy to foresee the merging of the vehicular networking and entertainment trends into a highly mobile scenario that includes also online games.

A typical example is represented by a family, or a group of friends, driving toward a remote destination. Passengers seated in the back seats may spend their time engaging in online game sessions with other players.

However, as vehicular networks are still far from being supported by an epidemic set of access points (APs) specifically deployed to this aim, ad-hoc connectivity represents a fundamental resource to support online gaming in vehicular networks. Indeed, ad-hoc networking could be exploited to connect various players seated in cars traveling in the same area and in the same direction, thus avoiding the need of infrastructure on the curb. We call this group of vehicles engaged in a shared online game session a *gaming car platoon*.

Each game event generated by a player in the considered gaming car platoon is followed by the transmission of a game message that has to reach all other players in the same platoon within a strict game threshold in order to preserve the interactivity level of the game [11].

Communications in a gaming car platoon follow a many-to-many paradigm. Since the wireless nature of the utilized channel the best solution to propagate game messages to all other players is that of exploiting (multi-hop) broadcast over the vehicular network. Moreover, the longer these broadcast hops, the quicker all players will be reached by a game event. This is a well known property that is exploited in vehicular scenarios when developing time sensitive applications such as driving safety and remote video triggering [4, 5, 9, 14].

Unfortunately, all preceding works on this topic have been based on the unrealistic assumption that the transmission range of each vehicle is constant and known a priori. Instead, the main contribution of our work is the relaxation of this unrealistic assumption; we achieve this by designing a multi-hop broadcasting scheme for game message exchange in a gaming car platoon that is able to dynamically adapt to the different (transmission range) conditions a vehicular network may encounter. We name our scheme *Fast Multi-Broadcast Protocol* (FMBP).

FMBP includes the utilization of priorities so that, when a car sends a game event, the farthest car in its transmission

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range will be the one that will take upon itself the task of forwarding the message onto the next hop. The main component and contribution of FMBP is represented by a transmission range estimator we designed to work in a distributed way and to exploit only regular game messages with no need for control message overhead. Our transmission range estimator allows each vehicle to be aware of how far game messages will go and compute its own probability in becoming the next forwarder of those messages. As a result, game messages are propagated over the gaming car platoon through the longest hops thus reducing the time needed to reach all participants and improving the perceived performance of the game.

The rest of the paper is organized as follows. Section II places assumptions of the setting we are considering. Section III surveys algorithms proposed for fast multi-hop delivery of messages in a V2V communication context. The Fast Triggering algorithm is discussed in Section IV. Section V details the simulative environment we have adopted to evaluate the performance of schemes for forwarding video triggering messages. Experimental results are reported in Section VI. Finally, in Section VII, a conclusion is drawn.

II. INTER-VEHICULAR COMMUNICATION: SYSTEM MODEL

We consider a strip-shaped portion of road, e.g., a highway, where vehicles pass by different surroundings, i.e., buildings, hills, curves. Vehicles travel at high speed and with potentially high density thus exposing their communications to high variations in terms of transmission range and available bandwidth.

In this framework, vehicles are assumed to be endowed with on board systems for communication, entertainment, and self-localization. In particular, we consider each vehicle able to communicate with other vehicles both directly and through multi-hop; transmissions may happen between any two connected vehicles or even in broadcast. To this aim, the IEEE 802.11p/DSRC technology has been declared able to guarantee a maximum range of 1000m under optimal conditions, or a smaller range at very high speeds (around 300 m for a car traveling at 200 Km/h) [2].

Vehicles can hence be part of mobile networks and, in these networks, traveling passengers can be engaged in online game sessions through on board entertainment systems. Indeed, considering the exponential growth of online game subscribers [17], it is immediate to foresee a future with entertainment systems present in every car, allowing passengers to play games.

Finally, the popularity of GPS-based devices is increasing as they are becoming less and less expensive. This technology can indeed be put to good use in a multitude of ways when placed on board of vehicles. The availability of accurate information about current position and trajectory can be exploited for several applications such as traffic safety, navigation, geographical based advertisement, general context-related information, and also entertainment (e.g., online games).

III. FAST INTER-VEHICULAR GAMING: BACKGROUND

Having online games played among passengers in a group of vehicles traveling along the same road represents a scientific challenge that has not yet received the proper attention by researchers. In this section, first, we define in general terms the problem we are going to address; then, we review techniques that have been proposed in scientific literature for similar topics and assess their applicability in supporting online gaming among vehicles.

A. Problem Statement

One of the most prominent issues in vehicular networks regards the quick, epidemic, and scalable delivery of data among all participants sharing the same application. Here, we focus on broadcasting game events among all players in a vehicular network. In this context, it is well known that a high interactivity degree represents a fundamental feature for online games [11]. Indeed, fast paced games requires a game event delivery time under the threshold of 150-200 ms. However, professional players and/or frenetically paced games put this interactivity threshold around 50-100ms; whereas other slow paced games could afford a delivery delay in the order of 300-400 ms, which could become even few seconds for certain strategic games [11, 20]. Furthermore, the importance of interactivity also resides in the fact that another fundamental gaming property can be guaranteed trough it: networking delay fairness among online players [19].

Needless to say, these considerations hold even in the case of online games played by vehicles' passengers. As inter-vehicular communications is wireless, and hence shared in nature, it would be highly inefficient to utilize a scheme that, for every game event, generated as many unicast (multi-hop) transmissions as the number of engaged players. Rather, the fastest and less resource-consuming way to perform this operation is clearly represented by multi-hop broadcast of messages over the gaming car platoon.

Yet, if no intelligence is applied to the multi-hop broadcasting scheme, any node in the network would simply try to forward every received message. The consequent explosion in terms of the number of messages being transmitted would lead to high congestion, collisions, delays, and even to transmission paralysis of the vehicular network. This phenomenon is known in mobile ad-hoc networks' literature as the *broadcast storm problem* [3].

In the following subsection, we review existing techniques aimed at providing quick and efficient message broadcasting over a vehicular network. Since the lack of specific works that analyzed this problem from an online gaming standpoint, we have delved into the literature related to other applications that shares with online games a similar need for high interactivity (e.g., traffic safety and live video triggering [4, 7]).

B. *Multi-Hop Broadcast: Related Work*

It is widely accepted in literature that an efficient multi-hop broadcast passes through having as few redundant transmissions as possible, so as to keep the channel available for other transmissions [5, 6, 8]. Indeed, a slow broadcast delivery can be generated by a non-optimal number of hops experienced by a message to cover all the involved cars and, more in general, by an excessive number of vehicles that try to simultaneously forward the message.

To tackle this problem a theoretically optimal broadcast algorithm has been recently proposed which propagates messages to cars making use of the notion of Minimum Connected Dominating Set [12]. This leads to great practical difficulties in the implementation of such algorithm as it would require a complete and continuously updated knowledge of the network topology. For instance, in the attempt to implement this algorithm with n cars, its authors have developed a scheme employing as many as $O(n \log n)$ control messages [13]. It goes without saying that this is not a scalable solution, especially in a highly crowded and mobile environment such as a vehicular network.

Addressing the fast-delivery broadcast problem from a more practical standpoint, various 802.11-based solutions have been proposed. For example, [7] proposes a backoff mechanism that reduces the frequency of message retransmissions when congestion is causing collisions. In [8], as soon as a car receives a broadcast message from a following vehicle along a strip, it refrains from forwarding it as the reception of this message is a clear confirmation that subsequent cars have already received it. Unfortunately, both these two schemes do not consider a very important factor in determining the final propagation delay of a message: the number of hops a broadcast message traverses before covering its whole area-of-interest.

In [6], hops' minimization is achieved by individuating the farthest car within the source's backward transmission range, which has to forward the message. To this aim, jamming signals are emitted by each car with durations that are directly proportional to the distance between the considered car and the message's source. The car with the longest jamming signal is with no doubt the farthest car from the source that received the message. Even if this guarantees a minimum number of hops to cover the whole area-of-interest, the time wasted to determine the next forwarder through jamming signals makes this scheme not suitable for a tight time delay application as online gaming.

Last but not least, a scheme that tries to statistically achieve a minimum number of hops when propagating a broadcast message is discussed in [5]. In particular, different contention windows are here assigned to each car. The contention window represents the maximum number of time slots a car waits before taking upon itself the task of propagating the broadcast message: each car randomly select a waiting time within its contention window. In [5], the authors propose that nodes set their respective contention windows with an inverse proportion of the distance from the sender. With this scheme, no control traffic is generated, thus eliminating this overhead. Yet, it is assumed that there is a unique and constant transmission range for all cars in every moment. This is obviously not realistic, especially in a highly mobile environment such as a vehicular network. As a consequence of having a wrong information about the maximum transmission range of each vehicle, broadcasting performances could result greatly affected [14].

Instead, we propose in this paper a position-aware broadcasting scheme that is able to reduce the number of forwarding hops based on the transmission range estimation. With our scheme, broadcast game messages are forwarded after a delay that depends on the node distance from the source and, peculiar of our algorithm, on a continuously estimated transmission range.

IV. FAST MULTI-BROADCAST PROTOCOL

Fast Multi-Broadcast Protocol (FMBP) is designed to quickly deliver game events to players in a certain gaming car platoon. Specifically, FMBP is run by all vehicles whose passengers are engaged in the online game session and its main feature is that of allowing each vehicle to estimate its current transmission range, both frontward and backward. Along with game actions/events, vehicles include in the game messages they transmit also their current estimation. This way, vehicles receiving broadcast game events can exploit this information to determine their relative position with respect to the sender's transmission range and assign themselves a priority in becoming the next forwarder of the received message. By putting this information to good use the number of hops (and the delay) that a game event will experience in its trip to destination can be reduced. Needless to say, backward or frontward estimation is used when the game event has to be sent backward or frontward, respectively.

The rationale of this scheme is clearer with the help of Fig. 1, which shows a group of cars belonging to the same gaming car platoon. For simplicity, we suppose that cars in the figure are located 200 m apart and that the transmission range along the road is variable due to environmental conditions. Cars move from right to left and each circled area represents the backward transmission range of the leftmost vehicle in that area. Therefore, in Fig. 1 we have that car A has a transmission range of about 400 m, thus being able to reach within a single transmission hop cars B and C; then, car C has a transmission range of about 600 m thus being able to be heard directly by cars D, E, and F; and so forth. In this situation, if we pretend that car A sends out a game message that has to reach all vehicles in the gaming car platoon, then the optimal solution is represented by having only cars C, F, and G forwarding it.

However, this optimal solution can be generated only if cars can be aware of their position within the sender's transmission range. This is the reason for having a continuously updated transmission range estimation: by including this estimation in game messages: cars C, F, and G can realize that they probably are the farthest car in the transmission range that has heard the last message and decide to take upon themselves the task of being the next forwarder.

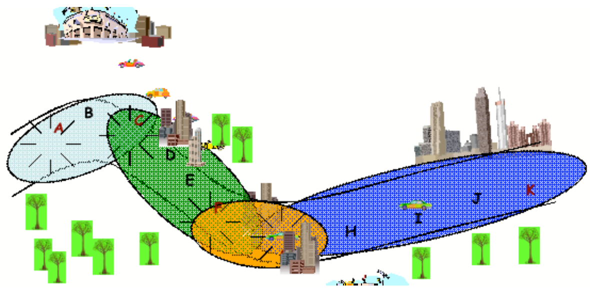

Fig. 1. Transmission ranges in a gaming car platoon: an example.

A. Embedding an Efficient Transmission Range Estimator into Regular Game Message Exchange

To compute transmission range estimations, FMBP does not need to generate any overhead message (i.e., *hello messages* or *busy tones* [6, 9, 14, 18]); rather, it just relies on regular game event transmissions. In particular, each vehicle includes information about the range of transmissions that it has been able to hear and, at the same time, it collects data included in game messages sent by other vehicles. Consequently, a vehicle can update its transmission range every time a game message is received from some other vehicle.

More in detail, every game message generated by a vehicle also includes i) its own position, ii) its *backward maximum distance* (BMD) parameter, iii) its *frontward maximum distance* (FMD) parameter, iv) its *backward maximum range* (BMR) estimation, and v) its *frontward maximum range* (FMR) estimation.

Parameters BMD and FMD represent the maximum distance from which another vehicle, backward or frontward respectively, has been heard by the considered one. Supposing that cars K and F in Fig. 1 embodies the backward and frontward farthest cars, from which G's game message has been heard, then G computes BMD = 800 m and FMD = 200 m. Data utilized to determine these parameters are kept by each vehicle only for a certain amount of time, after which they are considered obsolete and excluded from the transmission range computation.

Vehicles exploit game messages' fields about position, BMD, and FMD to compute their BMR and FMR; both the longest distance from which another vehicle has been heard sending a game message and the longest maximum distance advertised by heard game messages are employed. BMR is obtained by considering only game messages coming from following vehicles; its value is computed as the largest among all their included FMD values and all distances from vehicles that generated them. Instead, FMR utilizes only game messages sent by preceding vehicles; its value corresponds to the largest value among all distances from preceding vehicles that have sent game messages and all BMDs advertised within these messages.

Indeed, each car can be both a sender and a receiver of game messages. Considering for simplicity only the case where game messages are always sent backward (the frontward case is just specular), we have the following purpose and semantics for the information included by FMBP in each broadcast message:

1) Game messages received from the front allow the receiver to compute FMD; its value will then be declared by the receiver in its game messages in order to claim: *"This FMD value represents the farthest distance from which I have been able to hear another car in front of me"*.
2) Game messages received from the back includes the sender's FMD and position. They hence provide the receiver with information about the hearing capabilities of following cars. This is what the receiver needs to know in order to compute its BMR, which will then be sent along with game messages to declare: *"This BMR value is the maximum backward distance at which some car would be able to hear me"*.

B. Game message propagation by leaps and bounds

During a game session, each player continuously generates game messages that have to be sent very quickly from that player's vehicle to all others. As discussed in Section III, this can be achieved through a reduction of the number of hops a message traverses during its trip; this is exactly what we try to achieve using BMR and FMR.

More in detail, upon players' actions, game messages are broadcast along the gaming car platoon, both backward and frontward. Each of these messages contains information about the game evolution, but also the sender's position and its current BMR and FMR. To avoid cyclic back and forth transmissions of the same game event, each message also includes its propagation direction and a unique identifier.

BMR and FMR represent how far a transmission is expected to go before the signal becomes to weak to be intelligible; BMR refers to backward propagation, whereas

FMR refers to frontward propagation. Their values are used by vehicles on the message's path to determine which one among them will have to take upon itself the task of forwarding it onto the next hop. Since our aim is that of minimizing the number of hops to reduce the propagation delay, we want the farthest possible vehicle from the sending one to perform this task. Therefore, the longer the relative distance of the considered vehicle from the sender with respect to the transmission range estimation, the higher the priority of the considered vehicle in becoming the next forwarder.

In particular, vehicles' priorities to forward a game message are determined by assigning different waiting times from the reception of the message to the time at which they will try to forward it. This waiting time is randomly computed based on a contention window value, as inspired by classical backoff mechanisms in IEEE 802.11 MAC protocols [15].

If, while waiting, some farther vehicle with respect to the direction of propagation had already forwarded the game message, all vehicles between the sender and the forwarder abort their countdowns to transmission as the message has already surpassed them. Instead, all vehicles after the forwarder in the direction of propagation will participate to a new "forwarding contest" for the next hop. Obviously, the larger the contention window utilized by a vehicle, the more likely some other vehicle will be faster in forwarding the game message. For the sake of clarity, we also want to point out that BMR and FMR values advertised in the game message are updated at each hop with the value computed by the forwarder. This way, on each hop a proper transmission range estimation is computed through information related to that specific area.

The contention window of each vehicle is measured in slots and varied between a minimum value (*CWMin*) and a maximum one (*CWMax*). More in detail, it depends on the distance from the sending/forwarding vehicle (*Dist*) and on the advertised estimated transmission range, which corresponds to BMR if the message is directed backward, or to FMR if the message is directed frontward. The case for BMR is summarized by (1).

$$\left\lfloor \left(\frac{BMR - Dist}{BMR} \times (CWMax - CWMin) \right) + CWMin \right\rfloor \qquad (1)$$

This scheme ensures that the farthest vehicle within the transmission range of the sender/forwarder will be statistically privileged in becoming the new forwarder. For instance, considering the setting in Fig. 1, if G forwards the triggering message advertising a correct BMR of 800 m, then the contention windows computed by H, I, J, and K based on (1), will be 776, 528, 280, and 32 slots, respectively. Consequently, K is more likely to become the next forwarder of the game message and with a high probability the final forwarder-chain will coincide with the aforementioned optimal solution presented in Fig. 1, i.e., A, C, F, and G.

V. Experimental Assessment

We report outcomes of an extensive campaign of simulative experiments we run to test our scheme and compare it with other possible schemes inspired by scientific literature.

In these experiments, the length of the vehicular network is set to 8 Km and vehicles with communicating capabilities are placed in average every 20 m, thus having 400 vehicles that are involved in the transmission/forwarding process (even if not directly engaged in the online game session). Note that this does not imply that there were not other vehicles on the road with no communication capabilities or that refuses to act as relay for other vehicles' transmissions; indeed, considering the case of a highway with multiple lanes, several vehicle densities are possible.

Among vehicles with communication capabilities, 50 of them are playing among each other. This means that game events are periodically generated in these nodes and broadcast, even through multi-hop, to all other players in the network. Actually, different sending rates are considered to test how the system behaves in presence of different kind of games, from frenetic fast-paced games, to slower strategic games, i.e., 100 ms, 300 ms, 500 ms, whereas the size of each game event was 200 Bytes, constantly [16]. The actual transmission range varies from 300 m to 1000 m in order to test extreme values that have been declared by the IEEE 802.11p/DSRC developing committee [2].

Focusing on FMBP's parameters, we have set *CWMin* and *CWMax* equal to 32 and 1024 slots, respectively, as inspired by the standard IEEE 802.11 protocol [15]. Two different slot sizes have been compared: 9 μs, which corresponds to the value utilized by IEEE 802.11g [10] and 200 μs, which allows a larger time distribution of contention delays among communicating cars. In particular, in the latter case, we expect to witness a reduced number of collisions among game events even if at the cost of an increased total delivery time.

We have compared our FMBP with a scheme inspired by [5]. This scheme is similar to FMBP in that it utilizes (1) in the attempt of having the farthest node in the transmission range to become the next-hop forwarder. However, it differs from FMBP because it simply assumes to have the transmission range parameters BMR and FMR constantly set to a predetermined value, rather than being able to dynamically compute them according to the factual channel conditions. Specifically, we name this scheme *Static300* if it considers 300 m as the transmission range parameter, and *Static1000* if it uses 1000 m.

Needless to say, Static300 and Static1000 represent the ideal scheme when the factual transmission range is indeed 300 m and 1000 m, respectively. In any other situation, the utilization of a wrong parameter in (1) could result in performance degradation. Indeed, results in Section VI also show that FMBP performs as well as the ideal Static algorithm. Prominent advantage of our approach, this result is achieved without requiring perfect knowledge of the network topology; just employing the transmission range estimator we designed.

VI. Measured Performance

To compare the various schemes, we analyze their ability in quickly deliver online game events to players under various conditions.

To this aim, we utilize the following metrics: i) the average number of hops that a game event experiences to cover the whole gaming car platoon and ii) the average transmission time required by a game event to cover the whole gaming car platoon

For the chosen metrics, we consider only game events belonging to the worst case: those sent by the player within the car leading the gaming car platoon. Indeed, these messages experience the longest transmissions both in terms of hops and delivery time, as they have to cover the whole platoon to reach all participants. Instead, a game event generated by a player located in the middle of the gaming car platoon is simultaneously forwarded frontward and backward through two replica messages that have to cover, in average, just half of the platoon's length.

A. FMBP's Time Slot Choice

First, we evaluate the ability of FMBP in ensuring interactivity in the considered scenario. Specifically, Fig. 2 reports the transmission times experienced by a sequence of game events to reach all players in the gaming car platoon when FMBP is employed. Moreover, two possible time slot sizes, 9 μs, and 200 μs, are compared. Both time slots generate transmission time that are suitable for most of online games; however, the former one generates transmission delays that are low enough to allow also very fast paced games.

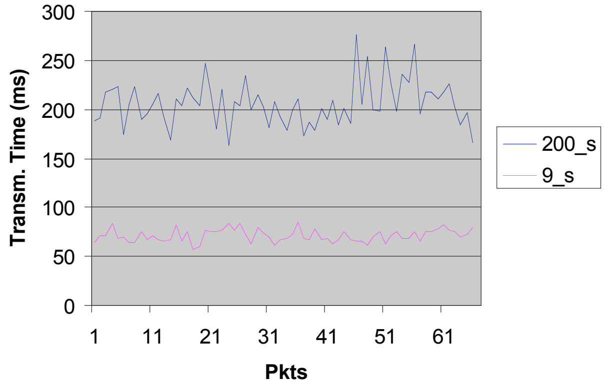

Fig. 2. Transmission time trend by messages that have to cover the whole gaming car platoon; FMBP employed, 300 ms of message generation interval for each player, 300 m of factual transmission range.

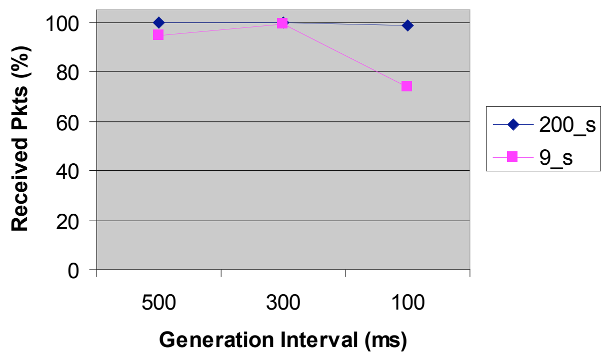

Fig. 3. Percentage of received game events that succeed in covering the whole gaming car platoon; FMBP employed, 300 m of factual transmission range.

We also evaluate the reliability of FMBP by verifying the percentage of game messages sent by a vehicle that are then received by all other players in the gaming car platoon. To this aim, Fig. 3 shows that with a slot size of 200 μs, almost all sent messages are received by all players regardless of the event generation rate at each player. Instead, when employing a slot size equal to 9 μs, the reliability of the scheme significantly descends with the intense game message generation rate (74% with a message generated every 100 ms by each player).

B. Comparing FMBP and Other Schemes

We are aimed at comparing the performance of FMBP with those achieved by other possible schemes for game event broadcasting. As anticipated in Section V, we compare FMBP against Static300 and Static1000. The three schemes are tested for the configuration employing 200 μs of slot duration. Different generation rates for game events at each player have been considered. Specifically, game events were generated at each vehicle in the gaming car platoon every 100 ms, 300 ms, or 500 ms.

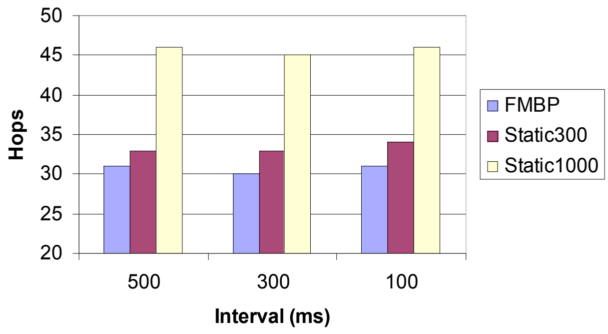

Fig. 4. Average number of hops required to cover the whole gaming car platoon; 200 µs slot, 300 m of factual transmission range.

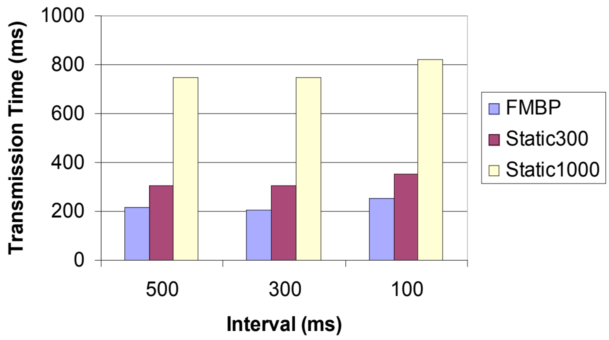

Fig. 5. Average transmission time required to cover the whole gaming car platoon; 200 µs slot.

Outcomes for the considered metrics in a scenario with 300 m of factual transmission range are presented in Fig. 4 and Fig 5. The first property that emerges is represented by the fact that achieved results are independent of the considered message rates. Only at the highest message sending rate (i.e., 100 ms of inter-departure time) we can observe a little degradation of the performance due to the increased congestion in the network.

The second evident property is that FMBP always obtains better results than the other two schemes, even better than Static300 that is supposed to be the ideal scheme in a scenario with 300 m of transmission range. This exceptional result is not due to any mistake. Rather, it is due to the fact that even if we have set the transmission range to be 300 m, yet, the adopted wireless model realistically generates interferences as it would happen in real life; these interferences make the factual transmission range oscillate around 300 m. Whereas FMBP dynamically adapts to the changing transmission range conditions to maximize its performance, Static300 cannot.

To complete our comparison of FMBP's performance with respect to Static300 and Static1000 we have evaluated them in a scenario with 1000 m of factual transmission range. The number of hops required to cover all the gaming car platoon is shown in Fig. 6. As expected, in this case Static1000 performs much better than Static300 because with 1000 m of factual transmission range Static1000 corresponds to the ideal scheme. Yet, without any predetermined knowledge, FMBP succeeds in properly estimating the transmission range for each vehicle and performs as Static1000. The chart also shows that the number of hops experienced by FMBP is not affected by the game message sending rate; whereas for Static300 and Static1000 the number of hops increases with the more intense game message generation rate (i.e., 100ms).

However, if we also analyze the factual transmission time required to propagate a message over the whole gaming car platoon, we notice that if the game application generates a message on each vehicle every 100 ms, the total transmission time is considerably higher than with the other two considered rates for all the tested schemes (see Fig. 7). This is clearly due to an excessive increment in the traffic on the wireless channel that causes collisions and time consuming retransmissions.

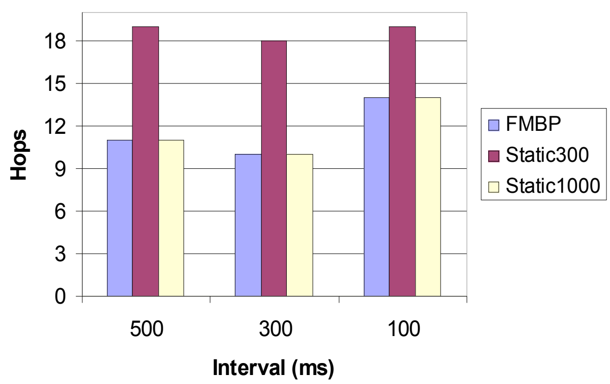

Fig. 6. Average number of hops required to cover the whole gaming car platoon; 50 players, 1000 m of factual transmission range.

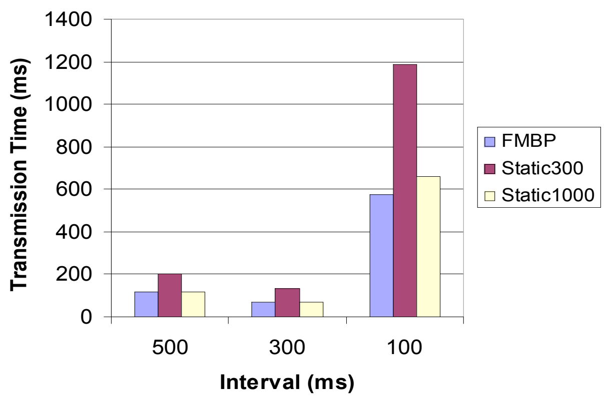

Fig. 7. Average transmission time required to cover the whole gaming car platoon; 200 µs slot, 1000 m of factual transmission range.

VII. Conclusion

We are living in a world which is faster and faster spinning toward a continuous, ubiquitous, and seamless wireless connectivity that will involve even vehicular scenarios. Customers are more and more attracted by high quality entertainment; for this kind of applications, vehicular networks represent the next frontier of employment. On the other hand, real-time applications such as online games have very stringent interactivity requirements. In essence, game events generated by a player have to be delivered in a very small time to all other players in order to ensure an enjoyable gaming experience to participants. Needless to say, this interactivity requirement is even harder to be accomplished when considering the highly mobile scenario of inter-vehicular communications.

Scientific literature related to driving safety and remote video triggering reports that the best strategy to deliver any message to all participants in a vehicular ad-hoc network is represented by multi-hop broadcasting that minimizes the number of transmissions for each message delivery. This is generally translated into the utilization of priority mechanisms by which the farthest vehicles in the transmission range of a message sender becomes the next forwarder of that message over the vehicular network. In other words, as few vehicles as possible have to be involved in the forwarding of each game event and, thereby, hops experienced by a game message to cover the whole gaming car platoon have to be as long as possible.

These considerations hold even when considering online games in place of driving safety and remote video triggering. Unfortunately, whatever broadcasting applications we consider. The state-of-the-art in scientific literature is based on the unrealistic assumption that the transmission range of each vehicle is a constant that is known a priori by the system: clearly, it is not.

The main contribution of our work is that of relaxing this unrealistic assumption through the utilization of a novel transmission range estimator that we designed. Through our FMBP scheme, each vehicle becomes aware of how far each game message will go and is hence able to compute its own probability in becoming the next forwarder.

Presented results demonstrate the ability of FMBP in reacting to different transmission range conditions and reducing the transmission time required to cover the whole gaming car platoon. Indeed, FMBP experiences as few hops as if considering an ideal scheme that possessed exact knowledge about the transmission range of each vehicle.

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References

[1] Consumer Electronics - IT Facts. http://www.itfacts.biz/index.php?id=P1861

[2] ASTM E2213-03, "Standard Specification for Telecommunications and Information Exchange Between Road-side and Vehicle Systems – 5.9GHz Band Dedicated Short-Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications", ASTM International, Jul 2003.

[3] M. B. Yassein, O. Khaoua, S. Papanastasiou, "Performance Evaluation of Flooding in MANETs in the Presence of Multi-Broadcast Traffic", *in Proc. of 11th International Conference on Parallel and Distributed Systems - Workshops (ICPADS)*, Fukuoka, Japan, Jul 2005.

[4] M. Guo, M. H. Ammar, E. W. Zegura, "V3: a Vehicle-to-Vehicle Live Video Streaming Architecture", *in Proc. of 3rd IEEE International Conference on Pervasive Computing and Communications*, Kauai, HI, Mar 2005.

[5] E. Fasolo, R. Furiato, A. Zanella, "Smart Broadcast Algorithm for Inter-vehicular Communication", *in Proc. of Wireless Personal Multimedia Communication (WPMC'05)*, Aalborg, DK, Sep 2005.

[6] G. Korkmax, E. Ekici, F. Ozguner, U. Ozguner, "Urban Multi-hop Bradcast Protocol for Inter-vehicle Communication Sustems", *in Proc. of 1st ACM Workshop on Vehicular Ad-hoc Networks (VANET'04)*, Philadelphia, PA, Oct 2004.

[7] X. Yang, J. Liu, F. Zhao, N. Vaidya, "A Vehicle-to-Vehicle Communication Protocol for Cooperative Collision Warning", *in Proc. of MobiQuitous'04*, Boston, MA, Aug 2004.

[8] S. Biswas, R. Tatchikou, F. Dion, "Vehicle-to-Vehicle Wireless Communication Protocols for Enhancing Highway Traffic Safety", *IEEE Communication Magazine*, 44(1):74-82, Jan 2006.

[9] M. Roccetti, M. Gerla, C. E. Palazzi, S. Ferretti, G. Pau, "First Responders' Crystal Ball: How to Scry the Emergency from a Remote Vehicle", *in Proc. of IEEE NetCri 07 - IPCCC 2007*, New Orleans, LA, Apr 2007.

[10] IEEE 802.11g, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, Amendment 4: Further Higher Data Rate Extension in the 2.4GHz Band.

[11] L. Pantel, L. C. Wolf, "On the Impact of Delay on Real-Time Multiplayer Games", *in Proc of NOSSDAV'02*, Miami, FL, USA, May 2002.

[12] A. Zanella, G. Pierobon, S. Merlin, "On the Limiting Performance of Broadcast Algorithms over Unidimensional Ad-hoc Radio Networks", *in Proc. of WPMC04*, Abano Terme, Italy, Sep 2004.

[13] P. J. Wan, K. Alzoubi, O. Frieder, "Distributed Construction of Connected Dominating Set in Wireless Ad hoc Networks", *in Proc. of IEEE INFOCOM 2002*, Jun 2002.

[14] C. E. Palazzi, S. Ferretti, M. Roccetti, G. Pau, M. Gerla, "How Do You Quickly Choreograph Inter-Vehicular Communications? A Fast Vehicle-to-Vehicle Multi-Hop Broadcast Algorithm, Explained", *in Proc. of IEEE CCNC/NIME 2007*, Las Vegas, NV, USA, Jan 2007.

[15] IEEE, "Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (Phy) Specifications," Specifications, ISO/IEC 8802-11:1999(E), 1999.

[16] J. Färber, "Network Game Traffic Modelling", *in Proc. of NetGames2002*, Braunschweig, Germany, Apr 2002.

[17] MMOGCHART. http://www.mmogchart.com/

[18] S. Dashtinezhad, T. Nadeem, B. Dorohonceanu, C. Borcea, P. Kang, L. Iftode, "TrafficView: A Driver Assistant Device for Traffic Monitoring based on Car-to-Car Communication", *in Proc. of IEEE VTC'04, Milan*, Italy, May 2004.

[19] S. Ferretti, C. E. Palazzi, M. Roccetti, G. Pau, M. Gerla, "FILA in Gameland, a Holistic Approach to a Problem of Many Dimensions", *ACM Computers in Entertainment*, 4(4):1-16, Oct 2006.

[20] F. Fitzek, G. Schulte, M. Reisslein, "System Architecture for Billing of Multi-Player Games in a Wireless Environment Using GSM/UMTS and WLAN Services", *in Proc. of NetGames2002*, Bruanschweig, Germany, Apr 2002.