Scalability of V2V and V2I Communications in the Context of Sustainable Mobility

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Abstract: - Fuel economy and environmental sustainability are currently under the spotlight of research in the area of Intelligent Transport Systems. The project CARMA introduces the novel concept of sharing and distribution of the "travelling experience" acquired by the vehicles, rendering them capable of learning over time to predict (and thus avoid) energy-consuming routes. Special focus is given on V2V and V2I interfaces and interactions, as a means of sharing this travelling experience and creating a large database of travelled routes. V2V interactions will allow a direct (decentralized) distribution of information, while V2I interactions will enable the central platform to have a global view of travelling experiences (historical data) as well as context information (near real-time data). This paper identifies the main types of data and corresponding communication flows, and focuses on the scalability issues of the information exchange for different types of wireless access networks.

Key-Words: - vehicle-to-vehicle, vehicle-to-infrastructure, mobile communication technologies, wireless networks, 802.11p

1 Introduction

In our days, the transportation sector accounts for around a quarter of EU greenhouse gas emissions making it the second biggest greenhouse gas emitting sector after energy [1]-[2]. For this reason, research on sustainable mobility attracts a lot of attention worldwide with relevant research projects getting significant funding from both European and national agencies. Fully Electric Vehicles (FEVs) appear as a promising solution towards this direction and should not be neglected when designing innovation schemes for energy efficiency [3]. Their vast use is expected to contribute significantly against urban air and noise pollution as well as fuel consumption.

CARMA [4] is a Greek national funded project whose ambition is to equip both conventional vehicles, i.e. with internal combustion engines, as well as FEVs with innovative ICT solutions so that the driver will be always in position to know with a high degree of assurance: how much fuel/energy will be spent to reach his destination; whether a destination is reachable with the remaining fuel/battery energy; how to efficiently reduce the fuel/energy required to reach the destination; and when and where it is better to refuel or recharge his vehicle. All of these features will contribute towards the selection of environmental friendly driving approaches and routes as well as increase the reliability offered by the FEVs and will build up the driver's confidence in his electric vehicle.

CARMA will innovate and introduce a range of advanced technologies and functionalities. A new, yet untapped, concept is to develop in-vehicle intelligent computing functions, and machine learning and reasoning methods in order to process multi-source information on real-time basis, and thus provide tailored driver support, via exploitation of past experiences and knowledge, prediction of traffic, optimisation of route planning, and optimisation of recharging strategy. CARMA's vision is, thus, to infuse intelligence and learning functionalities to the vehicle, in order to provide enhanced on-board driver support and assistance.

In this context, CARMA-enabled vehicles will be rendered capable of learning over time to predict (and thus avoid) congested routes, based on the experience they gather while travelling within urban road networks. This training process will eventually render each CARMA-enabled vehicle capable of: (a) autonomously classifying routes as congested or not (and thus selecting the optimal one to reach the desired destination) and (b) extracting useful policies based on contextual data (such as time, day, location, destination, weather conditions, etc.) including the past experiences and knowledge.

CARMA will, also, enable sharing and distribution of the composed knowledge (learning-based classifications and extracted policies), through new types of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) interfaces and interactions. The new V2V interactions will enable CARMA to establish a distributed cooperation model among vehicles, while the new V2I interactions will allow CARMA to have the capability of centralised traffic prediction and management, performed by a traffic management and traffic information services platform, based on the data and experience collected by the CARMA vehicles.

Some of the main foreseen V2V interactions include: (i) direct sharing of recent measurements (near real-time information), that is recently acquired traffic data that most probably are still valid; and (ii) direct sharing of historical measurements, which mainly serve as training data for the machine-learning engines of the system, while some of the main foreseen V2I/I2V interactions include: (i) centralized sharing of recent measurements (near real-time information), that is recently acquired traffic data that most probably are still valid; (ii) centralized sharing of historical measurements, which mainly serve as training data for the machine-learning engines of the system and (iii) exchange of information concerning fuel/recharging points availability and booking.

2 Main Data Types and Communication Flows

One of the key concepts of the project is to enrich a standard map definition with a living and growing set of information, in order to enhance standard routing algorithms and obtain the highest possible rate of energy efficiency for FEVs. According to the identified system architecture [4], there are three main types of map information: (a) static data; (b) historical data; and (c) real-time data. Static data are supplied by a commercial map content provider. The term "static", under the CARMA perspective, has two distinct meanings: (i) they are simply consumed, and not owned, by the system; in other words, the system will only read static data (and consume the associated services), and will not change, delete or generate them; (ii) they will not be exchanged between different components (Advanced Driver Assistance System - ADAS, central platform, simulation platform), but will be installed and consumed locally. Possible upgrades of static data (e.g. periodic map updates) will be carried out according to vendor's distribution policy (e.g. over-the-air provisioning, installation of redistributable media, installation by authorized service/maintenance centres), without involving the CARMA communication platform.

On the other hand, historical and real-time data will be continuously exchanged between the CARMA system components through the communication platform. Most of them will be generated aboard, by processing field measures (gathered from on-board sensors and from the surrounding context –e.g. other vehicles), while a minor part will be generated on the central platform, by interfacing external traffic management and information systems. In order to be as much compatible as possible with present and future traffic infrastructures, the format of exchanged messages will be based upon an ITS-scoped standard. More specifically, the format of such messages will comply (whenever possible) with the TPEG protocol and its derivatives (e.g. TPEG-TEC, TPEG-TFP, TPEG-LOC) [8], which is the most promising traffic-oriented standard.

The communication channel to be used between the ADASs and the central platform depends on the type of the data to be exchanged. The synchronization of historical data is basically an offline process, due to the non-time-critical nature and the possible large amount of data to be uploaded/downloaded. According to these remarks, it seems quite acceptable to wait for a convenient communication resource to become available (e.g. the short-range V2I/I2V transport), rather than using more widely accessible public communication networks (e.g. 3GPP-based technologies). Depending on use case scenarios, different synchronization policies may be implemented, each having its own communication requirements.

For example, for captive fleets (car-sharing, taxis, delivery vans), it seems reasonable to perform the synchronization when vehicles return to their operating bases (car-sharing parking lots, taxi stands, logistics bases, police stations). In this scenario, a short-range V2I/I2V transport could be used (e.g. 802.11p or similar). Nonetheless, regarding private cars, one possible option is to setup a domestic WiFi connection with the CARMA platform, to be used during overnight recharges. Another option is to use a short-range V2I/I2V transport, by means of the RSUs (Road-Side Units) encountered along the trip, and to upload/download small blocks of data as long as it is possible to. A further option is to use a long-range V2I/I2V transport, such as 3GPP-based technologies, and to exhange data on a regular basis.

In the latter case, the central platform should implement some policies to guarantee the load balancing and to avoid channel saturation.

On the other hand, real-time data are far much lighter and intrinsically time-critical, since they refer to dynamic conditions that may change in a very short time, and thus they must be uploaded/downloaded just-in-time. All this considered, a long-range V2I/I2V transport seems the most suitable solution (although a short-range V2I/I2V transport via RSUs, where available, could provide a valuable contribution). For both types of data, the V2V transport will certainly improve the readiness and the reliability of exchanged data. In a wider perspective, the V2V transport could also be used to propagate automatic safety alarms (e.g. accident in case of airbag explosion, emergency stop in case of hazard, etc.). These aspects have been deeply investigated by a number of specific projects, following the eCall initiative [9].

3 V2V Communication

The V2V communication interface can be based on technologies that allow for Peer-to-Peer connectivity, at adequate data rates for ITS (Intelligent Transport Systems) [6], at short and medium ranges depending on a number of configuration parameters. The IEEE standardized mobile data communication protocols, namely 802.11a/g, 802.11b, and 802.16d/e [10], are the most widely used ones. At the same time, the IEEE 802.11p [11]-[12] protocol has been designed especially for short range ITS interfaces. The maximum theoretical bitrate of each of these technologies is presented in [13]-[14].

These maximum bitrates, however, refer to Transmitter-Receiver (thus V2V) distances of a few meters, with optimal radio conditions, only one session per connection and only to the air interface. In practice, the commonly measured bitrates deviate a lot from the theoretical ones, and can range from a few Kbps up to a few decades of Mbps. More specifically, the achieved bit rates may vary depending on the air interface conditions (propagation path loss depending on distance, interference, fast fading, multipath etc.), the selected encoding and modulation techniques, the MAC layer priorities defined (per user or per service), the selected compression mechanisms, and above all, the number of connections, thus the accommodated traffic. The usual minimum -corresponding to quite heavy traffic conditions- and average -corresponding to average traffic conditions- end-to-end bitrates at application layer reported in bibliography for each of the most common V2V technologies are presented in [13]-[14]. By using the term “heavy traffic conditions” more than one session per vehicle and/or long distance between the vehicles (e.g. more than 200m) is assumed, while the term “average traffic conditions” is used to refer to an average distance between two vehicles (e.g. less than 50-100m) and/or two sessions per vehicle.

Considering that a vehicle traverses a route of about 400 road-segments every day, and that the V2V communication supports the transmission of the collected measurements –from the beginning of the daily route up to the time of the V2V communication session start– an average number of road-segments for which information is transmitted over the V2V interface could be, for instance, about 200, 50, 100 etc.; that is, only a part of the daily records, either because the vehicle has traversed only a part of the daily route/tree or because it is configured to transmit only information on road-segments close to its current position. Assuming also that for each road-segment –at initial steps of an CARMA-like deployment– each vehicle may have a few more records received from another vehicle and stored in ADAS, the average number of records per road-segment could be besides 1 -if no additional records have been stored-, 2, 3, 5 or even much more, e.g. 25 in future scenarios; thus, the average number of records transmitted over a V2V session could be calculated by multiplying the number of road segments for which information exists and the average number of records per road segment that is transmitted. For example, assuming 200 road segments, 2 records per segment and 53 bytes per record, the expected transmission time required for each technology is presented in Fig. 1.

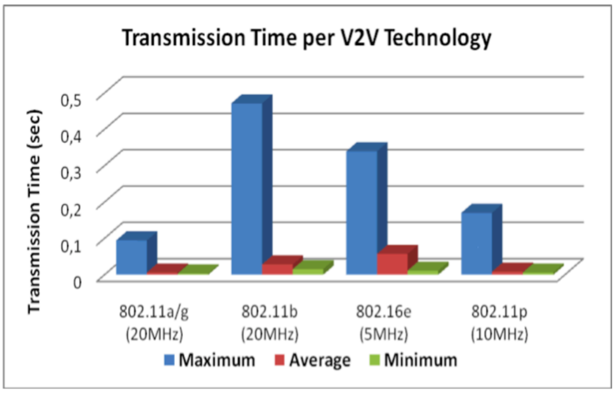

Fig. 1. Maximum, Average and Minimum Transmission Time per V2V Technology

From another perspective, for system design purposes, it is important to calculate the number of records that could be transmitted during a V2V communication session, which can take place for example while two vehicles wait in front of a traffic light (e.g. 10, 30 seconds), or while a vehicle by-passes another one (e.g. 0.5, 1 second), etc. (Fig. 2)

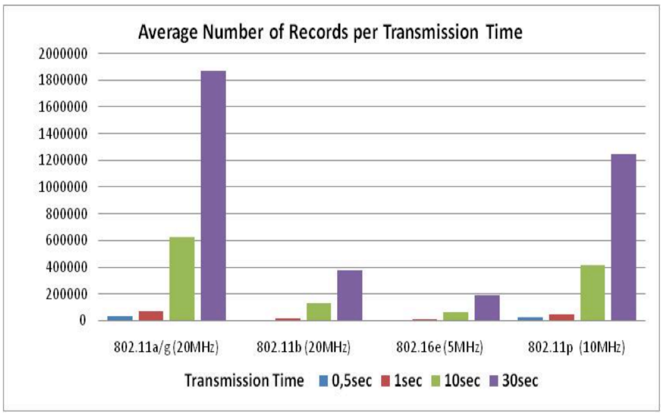

Fig. 2. Average Number of Records Transmitted during a certain V2V Communication Timeframe

4 I2V Communication

In general, the I2V/V2I communication (external interface) can be based on the mobile communication technologies standardized by 3GPP, and more specifically on the following technologies: GPRS (or even EDGE), which has been used in a number of trials; UMTS, more specifically on the UMTS PS RABs (of theoretically 64, 128 and 364Kbps); HSDPA at a maximum of 14.4Mbps per cell and potentially per user if only one user resides in a single cell; HSPA+, combined with various MIMO schemes and at various bandwidth, allowing for higher data rates compared to the previous standards; or LTE, which is highly considered as a candidate technology to support a wide range of applications for ITS.

On the other hand, the I2V/V2I interface, especially for short-range static communication between a vehicle and a Road Side Unit (RSU), can be supported by the IEEE standardized data communication networks based on the following protocols: the 802.11a/b/g, which have been used in a number of projects; the 802.16d and especially the 802.16e (and WiMAX-m in future) protocol which allows for the communication between a stationary and a moving end; or the aforementioned 802.11p protocol, which is practically the same as the ETSI standardized protocol for DSRC. The maximum theoretical bitrate of each of these technologies is presented in [13]-[15].

However, as in V2V communications case, the maximum bitrates refer to short Transmitter-Receiver distances, with optimal radio conditions, only one session per connection and only to the air interface. In practice the commonly measured bitrates deviate a lot from the theoretical ones, and can range from a few Kbps up to a few decades of Mbps, depending on the radio interface conditions mentioned above. The usual minimum and average end-to-end bitrates at application layer reported in bibliography for each of the most common I2V technologies are presented in [13]-[16].

More specifically, as expected, the cell capacity, thus the number of users and the offered user data rates, increase with the progress of 3GPP standards, and the transmission time respectively decreases. At the same time the IEEE standardized technologies allow for shorter cell ranges; of about 100m – compared to an average cell range of 2500m or more in the case of 3GPP technologies-, with the exception of the 802.16e/d standards –with an average cell range of about 1000m. Therefore, the IEEE technologies can accommodate usually a smaller number of connections with a higher bitrate.

Considering that each CARMA enabled vehicle traverses a route of about 400 road-segments per day on average and the V2I synchronization session takes place once a day, one can assume that the daily new records that are uploaded and stored in the central platform are 400 multiplied by the number of CARMA enabled vehicles that belong to a certain subset (e.g. the fleet of taxis, the fleet of patrol vehicles, or the fleet of shared cars). These measurements-records are downloaded to an CARMA enabled vehicle upon request. Depending on how often the download-I2V session is triggered, the number of daily uploaded records shall be multiplied by the respective number of days, in order to obtain the total amount of information that is exchanged during an I2V session. For instance, assuming a fleet of 100 or 300 CARMA enabled vehicles, and a synchronization period of 1, for 7 days, the indicative I2V scenarios presented in Table I are considered.

Table 1. Scenarios of I2V Communication Sessions regarding Data Volume

	Record size (Bytes)	#Vehicles in CARMA Subset	I2V Synch. Period (Days)
I2V Scen1	53	100	1
I2V Scen2	53	300	1
I2V Scen2	60	100	7

In the following diagrams, the average transmission time for the 3 scenarios described previously is presented. As the differences in transmission times are significant, it is impossible to present the average transmission times for all the scenarios in one diagram due to scaling problems. For example, in Fig. 3 the transmission times for the technologies with the higher bit rates are not visible. For this reason, these transmission times are presented in Fig. 4 that has a more appropriate scale.

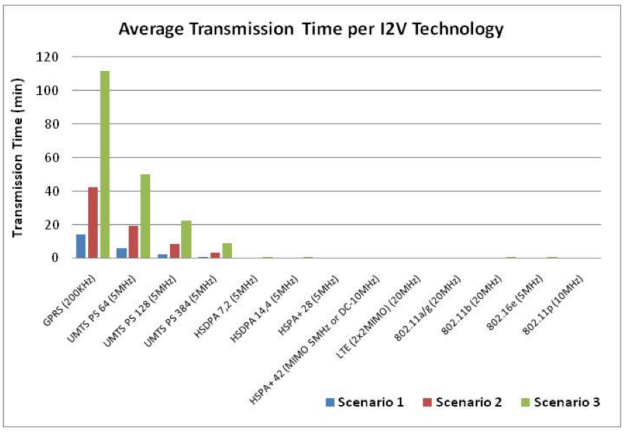

Fig. 3. Average Transmission Time per I2V Technology

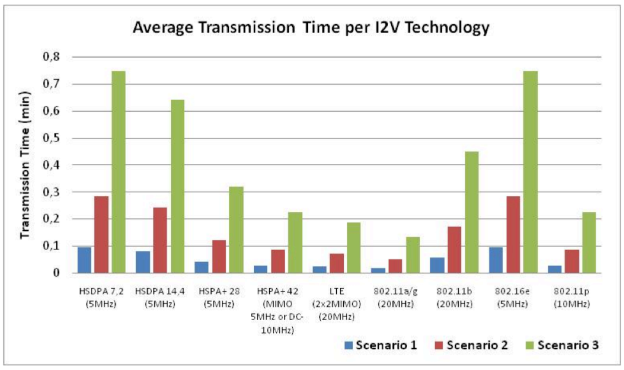

Fig. 4. Average Transmission Time per I2V Technology -HSDPA and beyond-

5 V2I Communication

In the opposite direction, the V2I communication can also be based on the uplink interface of the mobile communication technologies standardized by 3GPP and IEEE, and more specifically, on: GPRS (or even EDGE); the uplink UMTS PS RABs (of theoretically 64, and 128Kbps); HSUPA at a maximum of 5.4Mbps per cell and potentially per user if only one user resides in a single cell; HSPA+, at a maximum of 11.5Mbps per cell and potentially per user if only one user resides in a single cell; LTE, at variable maximum data rates depending on the MIMO schemes and the bandwidth allocated; the 802.11a/b/g protocols; the 802.16d and especially 802.16e protocol; or the 802.11p protocol. The maximum theoretical uplink bitrate of each of these technologies is presented in [16]-[18]. The limitations and assumptions expressed in the case of the minimum and average data rates of the I2V technologies are valid also in the case of the V2I ones.

Considering that a vehicle traverses a graph of about 400 road-segments per day on average and that it collects one record of size 53 or 60 Bytes per road segment [7], the daily records collected by a vehicle would be about 400. In order to avoid duplication of the transmitted information, each vehicle uploads to the CARMA central platform only the measurements it has collected by traversing each road-segment itself –not the ones it has collected from other vehicles through the V2V interface. Therefore, the number of records transmitted from the vehicle to the CARMA central platform would be a multiple of 400 depending on the period of the V2I upload session of the records. In case the records are uploaded twice a day, 200 records would be uploaded in each V2I session. Assuming that the records are uploaded to the central platform with frequency of once a day or twice a day, the expected transmission time required for each V2I technology is presented in Fig. 5. Furthermore, as presented in Fig. 5 and Fig. 6, in case of frequent synchronization -V2I sessions- the transmission time is a fraction of a second for the latest 3GPP standards and IEEE WLAN technologies, and a few seconds for the existing low rate GPRS and UMTS technologies.

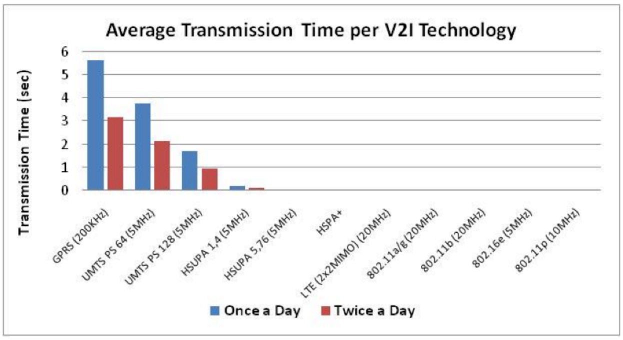

Fig. 5. Average Transmission Time per V2I Technology (Once a Day, Twice a Day)

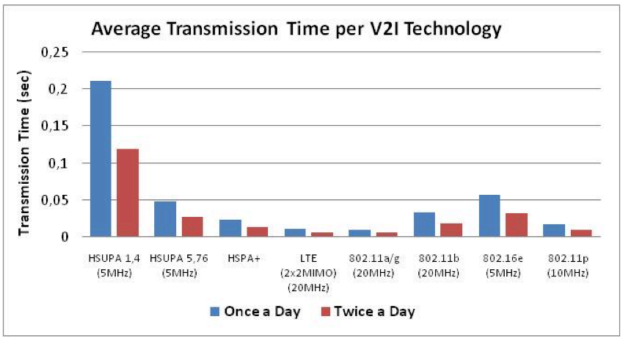

Fig. 6. Average Transmission Time per V2I Technology –HSUPA and beyond- (Once a Day, Twice a Day)

6 Evaluation & Conclusions

It becomes apparent from the above, that all IEEE 802.11x and 802.16e protocols seem to be efficient for V2V communication, in terms of data rates and thus expected transmission delay, as the transmission time remains a fraction of a second for all expected scenarios. Comparatively, 802.11a/g protocol outperforms all other IEEE protocols in terms of expected data rates and thus transmission delay at the maximum spectrum bandwidth of 20MHz. IEEE 802.11b protocol offers the lowest data rates even at a maximum of 20MHz bandwidth, while 802.16e is more suitable for base-station (BS) to mobile terminal communication, providing connection to a wide number of moving terminals from a single static BS, rather than between only two moving ends -and it has been standardized as such. 802.11p, on the other hand, has been deliberately standardized for vehicles' communications, thus presents good performance regarding the expected data rates and good quality of signal in continuously changing environment. More specifically, from the presented figures, it can be noticed that the 802.11a/g protocols present the lowest average transmission time compared to the other protocols. In particular, the transmission delay remains below 0.05sec even for a heavy traffic/large amount of data scenario. The average number of records per transmission time is respectively high, reaching the volume of 600 thousand records in 10sec (which is a considerably low expected waiting time in front of a traffic light). Considering the probable case of implementing V2V communication over the 802.11p protocol -which has been specifically designed for this task-, we can observe that the transmission delay numbers are satisfactory. Obviously, the 802.11p protocol is also very efficient in terms of transmitted records during a given timeframe, as can be seen in Fig. 2.

Regarding I2V, as shown, in the case of a small subset of CARMA enabled vehicles and of frequent synchronization transactions (once a day/week), namely scenarios 1, 2 and 3, the transmission of the synchronization data over the slow 3GPP technologies (up to UMTS PS 384) may take from a few minutes (UMTS) up to two hours (GPRS). More specifically, for scenario 1, all transmission technologies can be regarded as acceptable. For scenario 2, technologies such as UMTS PS 128 and beyond are advisable, while, for scenario 3, UMTS PS 384 and beyond are more adequate. Unsurprisingly, for all of these three scenarios, HSDPA and faster technologies perform very efficiently. In general, when using low-speed access technologies, it seems that short synchronization periods of a maximum of a week are advisable, in order for the transmission delay of the synchronization data to be kept to levels that can be efficiently handled by the network. Apparently the I2V communication can be better supported by the latest 3GPP standards, such as HSDPA for large CARMA enabled vehicle volumes, and HSPA+ and LTE (or IEEE 802.11a/g/p) for very large ones.

In conclusion, regarding the I2V synchronization transactions, as presented above, high-speed technologies, particularly HSPA+, LTE or 802.11a/g/p, are able to efficiently support the CARMA communication needs even in cases of very large deployments. HSDPA can also provide satisfactory results in a wide range of scenarios. For smaller deployments and for small synchronization periods, older technologies, such as UMTS, can still be utilized up to an extent. Especially for short range deployments, where for instance the synchronization process of the CARMA enabled vehicles is performed upon arrival at a certain stand (e.g. parking lot of taxis, parking lot of shared vehicles, premises of a transport company for the shuttle buses etc.), I2V short-range communication technologies (802.11a/g and especially 802.11p) can be used.

In case V2I synchronization sessions less often, the respective transmission time can be from less than a few seconds - especially when the communication technology used for the V2I interface is LTE-, up to a few minutes where the underlying technology is GPRS or UMTS. Therefore, the transmission delay of V2I synchronization sessions is not a critical factor for the selection of the underlying technology. Even in the worst-case scenario (less frequent synchronizations) it is feasible that the V2I session can be supported over legacy technologies such as GPRS.

To sum up, any IEEE WLAN/short range technology is sufficient enough in terms of transmission delay to support the CARMA V2V communication interface, as the delay remains a fraction of a second for all simulated scenarios. At the same time, the transmission delay of V2I communication sessions is not a critical factor that determines the underlying technology, since the exchanged amount of data is considerably low, and can be transferred efficiently over any public mobile or WLAN/short range network technology. Hence, the most critical part in the design of the CARMA communication interfaces is not the V2I but the I2V interface, since the amount of data exchanged in the latter is considerably larger, so that it often requires sufficiently high data rates. In any case, as a general conclusion for ITS Communications, the CARMA solution is currently feasible in terms of scalability of communication interfaces for large deployments. Future work will include further results from the utilization of next generation wireless access schemes.

Acknowledgment

This work has been performed under the Greek National project CARMA (11ΣΥΝ_10_877), which has received research funding from the Operational Programme "Competitiveness & Entrepreneurship" of the National Strategic Reference Framework NSRF 2007-2013. This paper reflects only the authors' views, and the Operational Programme is not liable for any use that may be made of the information contained therein.

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