Wireless Communications Enabling Smart Mobility: Results from the Project PEGASUS

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***Abstract*—Wireless communications for real time traffic information are considered to efficiently provide smart mobility in congested cities. In this work, we aim at summarizing objectives the results of the Italian project PEGASUS, where wireless communications have been exploited, in real time, to: i) acquire traffic information directly from vehicles (uplink) and ii) retransmit updated information to interested vehicles (downlink) after a proper processing at a control center. Specifically we focus on i) the uplink collection of data from vehicles through the universal mobile telecommunication system (UMTS), ii) the downlink transmission of updated information to vehicles through UMTS, iii) the cellular resource saving through the exploitation of short range communications based on wireless access in vehicular environment (WAVE)/IEEE 802.11p, and iv) the impact of updated information on travel time. Results are provided through the development of an integrated simulation platform that jointly takes into account vehicular traffic behavior in urban environment, data processing at the control center, and performance of the communication networks at the different layers of the protocol pillar.**

***Keywords*-Intelligent transportation systems (ITS); real time services; simulations in realistic scenarios.**

I. Introduction

Keeping traffic moving is a challenge that governments, industries and researchers are facing worldwide nowadays. Effective solutions can only be obtained with a capillary real time knowledge of the traffic conditions and a prompt communication to the drivers; without updated and dynamic traffic information, only particular events or repetitive situations can be handled. The creation of an infrastructure for communication between vehicles, service centers and sensors, is thus one of the main needs identified by international institutions, service providers and car manufacturers to address with satisfactory results the problems generated by traffic, justifying the big efforts that are being pushed both in Europe and in the rest of the world [1]. To this scope, different wireless access technologies could be exploited, from short-range ad-hoc networks to cellular systems. Regarding the former ones, wireless access in vehicular environment (WAVE) [2], based on IEEE 802.11p [3] represents the future for vehicle-to-vehicle (V2V) communications. This technology, well suited for safety applications, entertainment, gateway access, and road charging, can also be used for traffic management service, on condition that a connection to a remote control center is available. Vehicles, in fact, must periodically collect their position and speed and send such data to a control center, that is in charge of retransmitting back aggregated traffic information. Even in the case that all vehicles were equipped with such technologies, the need for an infrastructure makes the adoption of IEEE 802.11p for traffic management services a long term solution, due to the investment that the deployment of a communication infrastructure requires.

Hence, thinking to short term, cellular systems appear as the only feasible solution, already guaranteeing high penetration and wide coverage worldwide, also allowing continuity of service at vehicular speeds. And this is particularly true noting that, on the one hand, the last generation of on board navigators are already equipped with a cellular interface, and, on the other hand, smart phones embed navigation functionalities (often for free). However, the expected increase of vehicles equipped with on board units (OBUs) could lead to an overload of the cellular access network, and, consequently, to a degradation of the quality of service provided to voice and data users [4].

This work is carried out in the framework of the Italian project PEGASUS [5] and aims at summarizing the obtained results. Most of them have been already published (see, e.g., [4], [6], [7], [8], [9], [10]), but this is the first paper that summarizes the project as a whole. PEGASUS relies on over one million vehicles already equipped with OBU periodically transmitting their position and speed to a control center. Considering this scenario, we focus on i) the uplink transmission of data from vehicles through cellular systems, ii) the downlink transmission of updated traffic information to vehicles through cellular systems, iii) the exploitation of short range V2V and vehicle-to-roadside (V2R) communications to save cellular resources, and iv) the impact of updated traffic information on travel time.

In particular, firstly focusing on the universal mobile telecommunications system (UMTS) as the enabling technology for uplink and downlink information, we aim at:

- investigating the feasibility of the acquisition of small but frequent amount of data from many vehicles (*uplink performance*). Is the UMTS capacity sufficient for these kinds of multiple connections?

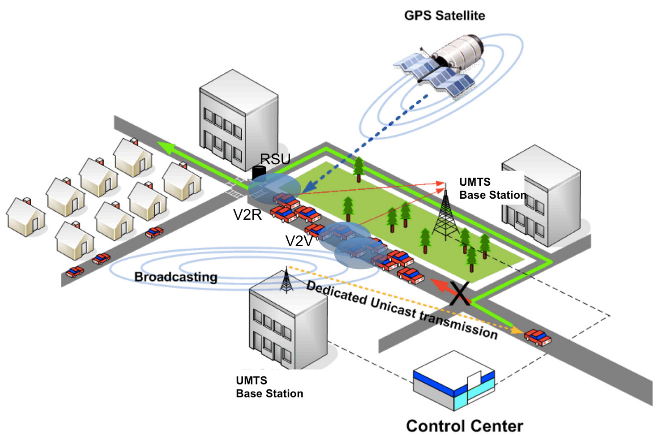

Figure 1. Scenario: real time traffic information exchange and enabling technologies.

- verifying the feasibility of real-time transmissions to vehicles of traffic information, both in unicast and multicast mode (*downlink performance*);
- investigating the impact of this service on the others already supported by the network (both in uplink and downlink). Is the quality of service (QoS) perceived by the final user sufficient, or does the network (or the service) need enhancements?
- evaluating the QoS perceived by the users of the traffic management service.

Then, considering also WAVE/IEEE802.11p-based V2V and V2R communications, we:

- investigate the impact of V2V and V2R communications (*short range communications*) to share and aggregate traffic information with the aim to reduce the cellular network load and the delivery delay. How many road side units (RSUs) are needed? which is the impact of multi hop V2V communications?

Finally, to also evaluate the impact of real time communications on traffic management, we:

- estimate the travel time of vehicles equipped with smart navigators (*smart navigation service*).

To address these issues, we developed a realistic simulation platform taking into account the details of the protocol pillar, the mobile propagation conditions, and the users' mobility.

The paper is organized as follows: In Section II related works are reported; In Section III, the considered scenario is depicted and the main characteristics and motivations of enabling technologies are provided; In Section IV, the simulation platform developed to investigate the considered scenario is described; In Section V, the simulation settings and output figures are given; In Section VI, numerical results are provided; Finally, in Section VII conclusions are drawn.

II. Related Works

Cellular systems are nowadays widely recognized as drivers of innovation in a wide range of technical fields, and represent the shortest term solution to collect data from vehicles and retransmit them to on board navigators avoiding new set-ups or expensive installations [11], [12]. Various activities are ongoing [6], [7], [13], [14], and products based on cellular technologies are already on the market.

A. Uplink

Some studies on the cellular performances in vehicular applications are coming out (see, e.g., [11]), but still few investigations are performed on the impact that these new services have on other cellular services (such as voice) in terms of resource sharing and consequent QoS guaranteeing. A study on the feasibility of data acquisition from vehicles through cellular systems has been performed in the German project Aktiv CoCar [15], [16], that defined a new protocol, called "traffic probe data protocol" (TPDP), to upload traffic data through UMTS common channels. However, results are given only in terms of cumulative distribution function (CDF) of the end-to-end delay, and no evaluation of the impact of this service on the network and user's QoS is given, which is, in turn, provided in [4] and here summarized and reported in the context of the PEGASUS project.

B. Downlink

Focusing on communications from a control center to vehicles, due to the widespread diffusion of connected on-vehicle navigators and smart phones with positioning applications, cellular systems represent the short term solution to solve the problem of real time traffic information to and from vehicles, so to suggest alternative routes and avoid congestions. This is confirmed by recent publications [11], [17], [18] and market trends: many vehicles are worldwide equipped with connected smart navigators receiving via general packet radio service (GPRS) updated traffic information. Again focusing on UMTS, the objective is to investigate which solution between unicast or multicast transmission has to be preferred and which is the impact on the QoS experienced by vehicular users and other users.

C. Short Range Communications

In the context of V2V and V2R communications, several standardization processes and research works are currently carried out (see, e.g.,[19], [20]) giving particular attention to WAVE [2] based on IEEE 802.11p [3]. In [21], the performance of WAVE/IEEE 802.11p vehicular ad hoc networks (VANETs) are evaluated in terms of packet delivery rate and delay assuming roadside access points. [4], [7], [13] investigate the real time acquisition of traffic information through cellular systems and its impact on both the network load and users' satisfaction when no V2V communications are considered. The novelty in this work is to share and

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aggregate traffic information with the aim to reduce the cellular network load and the delivery delay when real time traffic information systems are concerned through the exploitation of short range V2V and V2R communications.

III. Scenario and Enabling Technologies

The considered scenario is shown in Fig. 1: vehicles are equipped with on board units (OBUs) acting as traffic sensors and periodically transmitting their position and speed to a remote control center through the cellular network. The data collected at the control center are processed in real time to evaluate the actual traffic conditions (i.e., the travel time) on each monitored road segment; when the control center detects traffic conditions different from those foreseen by the static roadmap data base, it updates the roads status on a dynamic data base that will be queried for the best route evaluation. Updated measurements are then transmitted from the control center to the interested vehicles through the cellular network. We assume that updated traffic conditions can be transmitted from the control center to on board navigation systems or to the user's personal smart phone, hereafter simply denoted as *smart navigator*. Hence, the smart navigator receives information on the traffic conditions for each road segment from its current position to the destination and calculates the optimal route; on a real time basis, it updates its data and, in case, modifies the route in order to avoid any slowdown.

A. Uplink

Among the cellular technologies, GPRS is nowadays the most adopted for uplink measurements transmission. However, to transmit data over the GPRS network, the mobile station (MS) must first send a message on a common channel asking for a dedicated resource, with procedures requiring a not negligible access time, in the order of seconds [22]; for this reason, OBU collects tens of measurements before transmitting them in a single packet. This approach obviously increases the data acquisition delay at the control center. Differently to this, UMTS also allows the transmission of small amount of data over the shared signalling channel random access channel (RACH), avoiding the set-up of dedicated resources [23]. This way, any measurement can be transmitted by the OBU as soon as it is taken, with minimum delay and reduced signalling overhead. This solution appears promising especially considering the forecasted increase in the number of equipped vehicles, but it clearly requires investigations on feasibility and resources occupation.

Here, we discuss the impact of the real time data acquisition on capacity and coverage of existing cellular systems, foreseeing the realistic perspective of an explosion in the number of equipped vehicles.

B. Downlink

We exploit UMTS as the enabling technology either in unicast mode via dedicated unicast channels (DCHs), or in multicast mode via multimedia broadcast multicast service (MBMS). The objective is to evaluate if the network can support the additional new load and the impact it has on the performance perceived by other UMTS users.

Due to the adoption of code division multiple access (CDMA) [4], the number of active channels in UMTS is a consequence of the trade-off between coverage and capacity, and the amount of resources occupied by each transmission is given in terms of used power: on the one hand, a higher data rate as well as a higher distance from the base requires a higher power for a sufficient QoS; on the other hand, a higher power reduces the cell capacity. The power is, in fact, a limited resource at the base station (in downlink) and each transmission turns into an interference to all other active communications (in both directions).

As far as MBMS is concerned, it allows to share resources among many user. Hence, power is allocated to MBMS channels only once for any number of users in the cell receiving the service. We assume that vehicles are equipped with MBMS units joining the multicast group where traffic-related messages are distributed. It has to be remarked that MBMS uses part of the available power at the base station, thus limiting the number of DCHs that can be established. Moreover, the broadcast/multicast nature of the channel does not allow to exploit the fast power control feature that is of main importance for an interference limited system like UMTS; the base station pre-assigns a certain amount of power to MBMS services depending on the coverage planning and the desired bit rate.

The following strategies, thoroughly described in [7], are assumed for traffic updates:

- For the unicast mode, the update involves *road segments encompassed by an ellipse* whose focuses are the actual vehicle position and either the next intermediate point or the final destination. This strategy avoids the transmission of information related to road segments too far from the actual vehicle position, which would be out of date when the vehicle needs it. Moreover, since only the transmission of the coordinates of two points is needed from the navigation system to the control center, the amount of data transmitted in the uplink is very small, thus limiting costs and resource occupation. Following [7], 1000 road segments are updated every 5 minutes.
- For the multicast mode, a *progressive coverage* strategy is considered, consisting in the transmission to the on-board navigator of the information related to the most important roads at national level and regional level, and to the minor roads at local level only. Following [7], 12000 road segments are updated in average.

Independently on the unicast or multicast communication technology, we assume the adoption of the transport protocol experts group (TPEG) technology [24] at the highest layers of the protocol pillar with 60 bytes packet per each road segment (one packet per direction) [14].

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C. Short Range Communications

When UMTS is the only available communication interface, each OBU autonomously transmits collected data through the cellular system either after a given time out or when a certain amount of data has been collected. If also V2V and V2R communications can be exploited, information can be exchanged also between vehicles and between vehicles and RSUs. In this case, OBUs communicate one with each other exchanging information and aggregating redundant data referring to the same road segment. Both the aggregation of information and the transmission through RSUs allow to reduce the UMTS load toward the control center, thus saving the limited capacity of the cellular network and the related costs. We assume that, when vehicles are also equipped with technologies for short range communications, WAVE/IEEE 802.11p [3] is adopted as the standard for communication and OBUs know the positions (i.e., the coordinates) of RSUs and are able to associate any measured data with the correspondent road segment. In particular, the following routing strategy is assumed throughout the paper: communications occur between two vehicles a time; each vehicle identifies among its neighbors the one nearest to a RSU, which is elected as master. The master is in charge of receiving the data, merging the received data with its own if redundant, and transmitting them as far as it is within the coverage distance of the RSU. Since this procedure is performed iteratively, data can rapidly reach a RSU even from a relatively far distance if a sufficient density of vehicles is equipped with OBUs. Packets that cannot be transmitted to a RSU are transmitted via UMTS when one of the following conditions occurs: after a maximum number of packets is reached in the transmission queue or at a given time out. To detect which vehicle is the nearest to a RSU, GPS coordinates are also exchanged.

In the further, we show the advantages achievable by sharing and aggregating the collected traffic information through the exploitation of V2V and V2R communications, and the impact of number and positions of the RSUs.

IV. Investigation tools

The investigation of the considered scenario requires a complete simulation of the cellular network, both in the uplink and in the downlink, as well as a realistic simulation of vehicles' movements. In fact, the vehicular mobility significantly impacts on the performance of the telecommunication network and on the traffic redistribution itself. A realistic mobility model is thus needed, and it has to take into account all roads, with their speed limits, vehicles acceleration and decelerations, queues at traffic lights, etc. Hence, we developed a simulation platform which integrates VISSIM [25] as vehicular traffic simulator and the simulation platform for heterogeneous interworking networks (SHINE) [26] as cellular network simulator, thus allowing us to provide realistic results both in terms of vehicular traffic

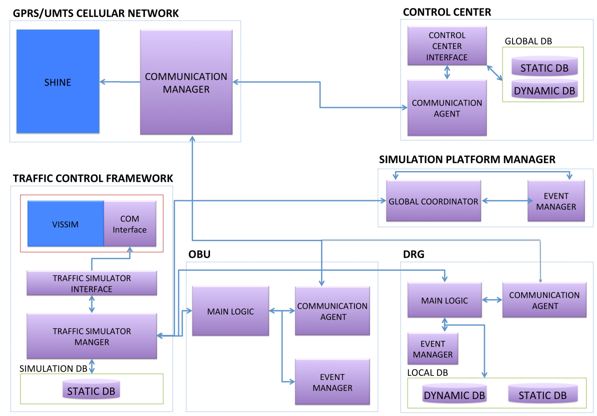

Figure 2. Integrated platform for the simulation of smart navigation.

(with queues, number of lanes, one way roads, etc.) and communication systems [8].

Vehicular simulator: VISSIM [25]. It is a microscopic simulation tool modelling traffic flow in urban areas as well as interurban motorways, and allowing to reproduce car-following and lane changing as in real scenarios. It uses a psycho-physical car following model for longitudinal vehicles movement and a rule-based algorithm for lateral movements. VISSIM allows to be controlled by external applications with the use of a component object model (COM): by the adoption of dynamic link libraries (DLL), it is possible for an application to control the movement of vehicles and to manage the whole simulation.

Cellular network simulator: SHINE [26]. It is an event driven dynamic simulator which allows to jointly take into account the whole cellular network architecture from the application layer to the physical layer, also carefully reproducing the time and frequency correlated behavior of the wireless medium, which is often approximated or even neglected in most network simulator. All relevant aspects of the real system are reproduced, including for example a not uniform positioning of Nodes-B, any specific antenna pattern, and hard, soft, and softer handover mechanisms.

Integrated platform. We realized a flexible architecture integrating VISSIM with SHINE, enabling the realistic simulation of vehicular traffic together with real-time networks communications [8]. This integrated platform allows the simulation of the whole smart navigation scenario: the vehicular mobility and the OBUs's transmissions, the data processing at the control center, the data base update with dynamic data, and the retransmission of personalized dedicated information to the smart navigators. The architecture of the overall simulation platform is depicted in Fig. 2; each component interacts with the others through sockets and remote procedure calls (RCPs). In particular, the following main blocks can be identified: *OBU*, which simulates the on board device collecting and transmitting position and speed; *DRG*, which stands for dynamic rout guidance and

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represents vehicles fleet equipped with a smart navigator device, able to receive updated traffic information from the control center; *Control Center*, which is responsible of the gathering of data transmitted by the OBUs to update the dynamic data base; *Communication Technology*, which simulates the cellular network from the application layer down to the physical layer; *Traffic Control Framework*, which is charge of controlling vehicles and their interactions and is based on VISSIM simulator; *Simulation Globals*, which manages the overall architecture from the traffic to the network simulation. More details are available in [8].

V. Service Classes and Figures of Merit

The road-network layout of the reference scenario consists of the medium sized Italian city of Bologna. In particular, we considered 13.636 road segments, corresponding to a length of about 600 Km. The digital-maps of the Italian road network have been provided by TeleAtlas, the world's provider of location and navigation solutions, and given as input to VISSIM. Results will be obtained considering two classes of service: vehicles equipped with OBUs performing packet transmissions over the cellular networks (hereafter intelligent transportation system (ITS) users), and pedestrians performing voice calls through cellular phones (hereafter voice users) as background traffic. Pedestrians can move everywhere in the scenario and are randomly generated in the scenario, with the same birth probability in each cellular cell (this means that a higher density of users is assumed where smaller cells are considered). Differently, vehicles' positions are managed by VISSIM.

A. Uplink

The portion of Bologna considered for extracting UMTS simulations results is shown in Fig. 3 and consists of a rectangular area of the city center sized 1.8 km (longitude) x 1.6 km (latitude) with 35 UMTS cells covered by 15 Nodes-B (1, 2 or 3 cells per Node-B are assumed). An approximated area of coverage is depicted for each cell with random colors. Black segments represent roads where vehicles movements are constrained. Hereafter, $\Lambda^{(v)}$ indicates the average offered voice load in Erlang per km^2, while $\Lambda^{(I)}$ indicates the average offered ITS load expressed in vehicles per Km^2. A single frequency planning is considered. In each cell, one RACH (out of the available ones) is exclusively used by the ITS service in the uplink. Propagation channels are realistically represented both for UMTS and IEEE 802.11p. Vehicles transmit 80 byte packets every 10 seconds. For further details the reader may refer to [4].

Figures of merit. To evaluate the quality of the ITS service, we aim at investigating the probability that each measurement stored in vehicles is correctly received by the control center, independently on the specific source.

A scheduled transmission fails in two cases: when the RACH ramping procedure is unsuccessful, meaning that

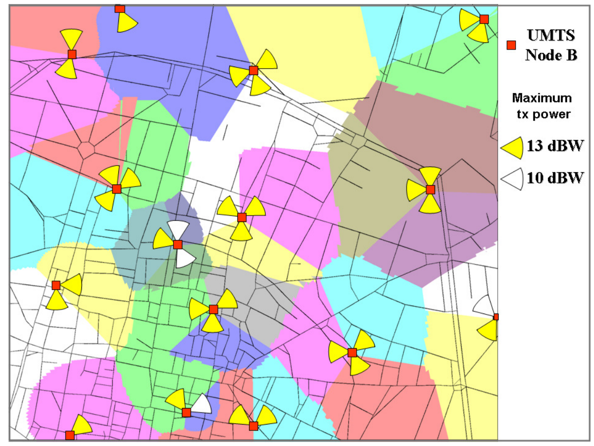

Figure 3. Map of the city center of Bologna and UMTS planning. Filled black squares correspond to Nodes-B locations. An approximated area of coverage is depicted for each cell with random colors.

the propagation conditions and the perceived interference level are so disadvantageous that the maximum transmission power is not sufficient, and when an error is checked at the receiver. In any case, the MAC layer may attempt a number of retransmissions before discarding the packet.

Focusing on the ITS service, results will thus be expressed in terms of *packet discard rate* (R_D), that is the ratio between the number of discarded packets and the total number of packets generated by all on-board equipments.

B. Downlink

The portion of Bologna and the city planning of UMTS are those of the uplink described in Section V-A.

1) Unicast Mode: Following the assumptions made in Section III, vehicles receive updated traffic information through a 60000 bytes download (i.e., 1000 road segments $\times$ 60 bytes) every 5 minutes. Data are transmitted adopting the TCP protocol at the transport level, that assures data reception. A 64 kb/s bearer is considered, corresponding to a logical dedicated traffic channel (DTCH), a transport DCH, and a physical dedicated data channel (DPDCH).[1] The DPDCH is transmitted adopting a spreading factor (SF) equal to 16 in uplink (note, in fact, that a dedicated unicast communication is required also in the uplink direction for the TCP acknowledgment transmission) and 32 in downlink. A transmission time interval (TTI) of 10 ms is assumed.

Figure of merit. An ITS user is satisfied if the update is received with a delay lower than 15s (please consider that less than 10 seconds would be required if data were transmitted at 64 kb/s with no errors and no TCP redundancy).

2) Multicast Mode: Data are transmitted adopting the user datagram protocol (UDP) at transport level, which

[1]The low amount of bytes and the relaxed delay requirements do not justify the use of more consuming bearers.

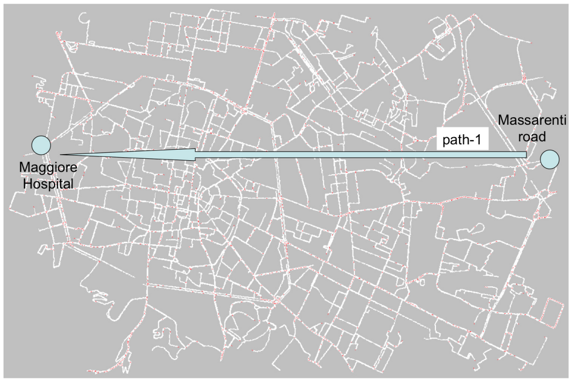

Figure 4. Origin and destination of path-1 in the considered scenario.

introduces limited redundancy but do not grant reliable communications; in this case, in fact, the absence of the uplink connection does not allow the transmission of acknowledgments. Two bearers at 64 and 128 kb/s are considered, each corresponding to an MTCH (MBMS transport channel) logical channel, a FACH (forward access channel) transport channel and a S-CCPCH (secondary common control physical channel) physical channel. The S-CCPCH is transferred (obviously, in downlink) adopting a SF equal to 64. A TTI of 40 ms is assumed.

Figure of merit. An ended ITS session is assumed in outage if less than the 95% of packets are correctly received.

C. Background Voice Traffic

To evaluate the UMTS performance in the considered scenario both in the uplink and in the downlink, the quality perceived by users belonging to other services than the ITS one is also of main interest. Without lacking of generality, here we focus on random walking users performing voice calls as interfered service both in the uplink and downlink.

Figures of merit. The evaluation of the quality of service perceived by users is based on the following definitions: per each frame lasting 10ms, a user (i.e., a voice call) is defined in outage if the BER after channel decoding of that frame is greater than 2% (uplink and downlink are evaluated independently to each other); an ended *voice call* is then considered *in outage* when either in downlink or in uplink, the outage intervals exceed a threshold of 5%. Hence, we have an outage voice call when one user is able to talk to the other party, but with poor audio quality.

A voice call may also incur in the following situations: it may be blocked by the call admission control algorithm due to insufficient resources, or it may drop due to an excessive reduction of the received signal power.

For this reason, results will be presented in the following in terms of *satisfaction rate (SatR)*, that is the ratio between the number of users which are not blocked, neither dropped, nor in outage, and the total number of call requests.

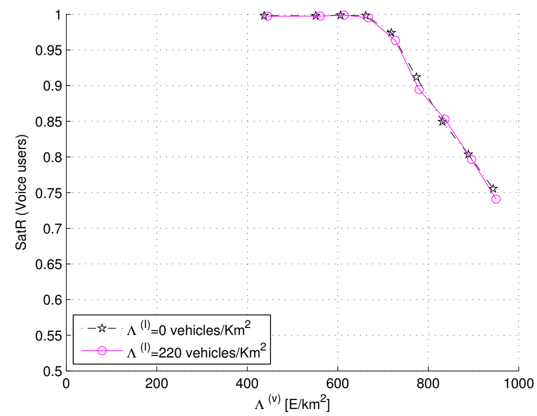

Figure 5. Voice traffic performance: voice *SatR* vs. the offered voice traffic $\Lambda^{(v)}$. Comparison between no ITS and ITS service on the network.

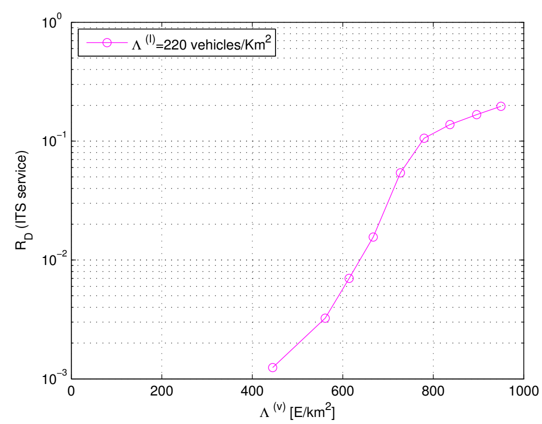

Figure 6. ITS traffic performance: ITS packets R_D varying the offered voice traffic $\Lambda^{(v)}$, with $\Lambda^{(I)} = 220$ vehicles/Km^2.

D. Short Range Communications

The use of V2V and V2R is envisioned in order to reduce both the cellular network load, which represents the main component of the service cost, and the delivery delays, that impact on the accuracy of vehicular traffic estimation (lower delays, in fact, mean a more frequent update of traffic conditions). In the simulations, a parametric percentage of vehicles is assumed equipped with an OBU that every τ seconds acquires several vehicle parameters, such as speed and position (which are referred in the following as *measured data*). Measured data are stored in the OBUs transmission queues and then transmitted according to the transmission strategies described in Section III-C. Both fluent traffic conditions and congested traffic conditions with car-queues arising in the proximity of some crossroads are considered. The former case is characterized by $\Lambda^{(I)} = 150$ vehicles/km^2 in average, whereas an average density of $\Lambda^{(I)} = 220$ vehicles/km^2 characterizes the latter case.

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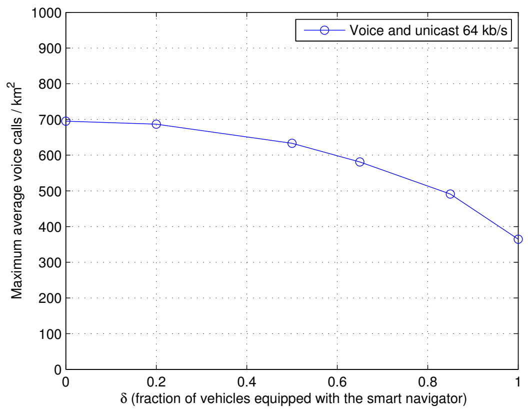

Figure 7. Voice capacity as a function of the fraction of vehicles receiving dedicated traffic information in unicast mode. $\Lambda^{(I)} = 220$ vehicles/Km^2.

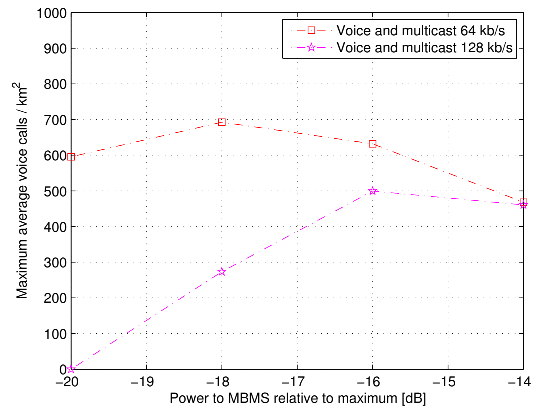

Figure 8. Voice capacity as a function of the Node-B power dedicated to MBMS multicast service. $\Lambda^{(I)} = 220$ vehicles/Km^2.

Curves will show the ratio of saved cellular resources S_R, i.e. the number of packets not delivered through cellular network exploiting the adoption of the considered strategy over the number of generated packets; considerations on delivery delay are not reported here for the seek of conciseness, and can be found with other details in [10].

E. Smart Navigation Service

To also evaluate the impact of a timely communication on traffic management, we evaluate the travel time to destination of a vehicle equipped with smart navigator. To this aim, the following are the simulation settings. In this case we considered non stationary traffic conditions, with a vehicles density that during each simulation vary in the range 1-10 vehicles/Km.

A parametric percentage of vehicles is assumed equipped with OBUs. No V2V and V2R communication is assumed in this case; every τ seconds, each OBU transmits the actual position and speed to the control center. Measured data are stored in the control center queue and averaged on a parametric T_{int} interval time.

Then, every T_{update} seconds, the control center retransmits the processed data back to those vehicles equipped with smart navigators. To avoid altered measurements in those roads where no vehicles or a too low percentage of them passed, we set up an average speed equal to that given by the static roadmap provided by TeleAtlas lowered by the 30%: this allows to not overestimate the speed. In addition, when the measured speed is lower than 15Km/h, we force the measurements exactly to 15Km/h: this avoid to overestimate the travel time in the involved road segment. As a case study, the origin-destination couple, denoted as *path-1* and represented in Fig. 4, has been considered in simulations.

VI. Numerical results

A. Uplink

The *SatR* for voice users and the R_D for ITS service are plotted in Fig. 5 and Fig. 6, respectively, as a function of $\Lambda^{(v)}$. $\Lambda^{(I)} = 220$ vehicles/Km^2 is assumed, which corresponds to a heavy traffic condition with many traffic queues.

In Fig. 5, the *SatR* of voice users is depicted, and the case with no ITS service ($\Lambda^{(I)}$=0) is shown for comparison. Observing Fig. 5, the presence of the ITS service seems not to impact on voice users, since their satisfaction remains almost unchanged. In Fig. 6, however, the R_D as a function of $\Lambda^{(v)}$ is also plotted for the same value of $\Lambda^{(I)}$. As can be observed, the higher is the network load, the higher the R_D, and the QoS of the ITS service results deteriorated. If $\Lambda^{(v)}$=740 (corresponding to *SatR*=0.95) is taken as reference value, a packet loss higher than 5% can be observed, meaning that guaranteeing a *SatR*=0.95 to voice users, does not imply that the ITS users are also served. To improve the QoS of the ITS service, a lower number of voice calls must be accepted. For instance, if R_D lower than 10^{-2} is targeted, with respect to a maximum of $\Lambda^{(v)}$=740 in the absence of the ITS service, a reduction of about 100 (13.4%) average voice users per Km^2 must be considered, drastically reducing the voice users' capacity.

B. Downlink

In Fig. 7, the maximum voice capacity normalized in a one Km^2 area is plotted as a function of the number of equipped vehicles receiving updated traffic information via a dedicated unicast channel. In particular, the x-axis represents the ratio δ of vehicles that are equipped with the smart device. The y-axis represents the maximum amount of voice calls that allow the system to serve both traffic classes with a satisfaction rate (i.e., ratio of satisfied users over the number of users of that class) grater than 95%. When the number of equipped vehicles is zero, we obtain results referred to

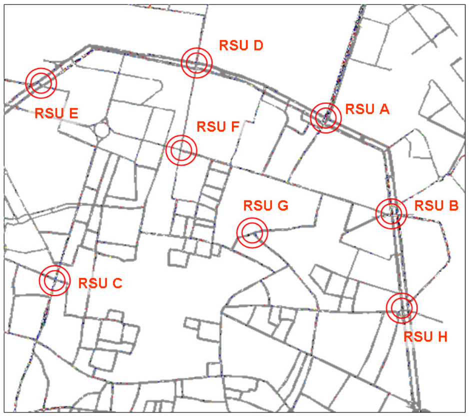

Figure 9. RSUs positions in the considered scenario.

the presence of voice only, considered as a benchmark (695 average voice calls). We can observe that, as the number of equipped vehicles receiving updated information increases, the maximum number of voice calls (i.e., the number of voice users) decreases, due to larger resources dedicated to the ITS service. However, we can note that, if the 50% of vehicles were equipped with smart navigators receiving updated information in unicast mode, the system could serve them also satisfying about 620 voice calls per Km^2. If all vehicles were equipped ($\delta = 1$), the capacity of the system in terms of servable voice calls would, instead, be halved.

Multicast results, shown in Fig. 8, are obtained varying the power used to transmit the S-CCPCH carrying the MTCH channel of the MBMS channel (which is used for the ITS service). More specifically, a constant fraction of the maximum available power at the base station is reserved for this use. In Fig. 8 results are presented assuming the fraction of Node-B power dedicated to MBMS in the x-axis and the maximum amount of voice calls (per km^2) that allow the system to serve both classes of traffic with at least 95% satisfaction rate in the y-axis. Multicast at 64 kb/s and 128 kb/s are compared. As can be observed, independently on the adopted bearer, the number of voice calls increases with the power dedicated to MBMS until a maximum, then it start decreasing: low power levels to the MBMS service, in fact, require low interference in order to guarantee a full coverage to the ITS service, while high power levels generate strong interference that limits the number of servable voice calls. We can thus note that a trade off between voice and ITS service can be obtained for both 64 kb/s and 128 kb/s, corresponding to -18 dB to MBMS with 690 average voice calls and -16 dB to MBMS with 500 average voice calls, respectively. These numbers also highlight that the adoption of a 128 kb/s bearer greatly reduces the number of voice calls with respect to 64 kb/s.

C. Short Range Communications

Numerical results are initially given considering a single RSU in the most crowded junction and then modifying the position and number of active RSUs. To increase the probability to reach the RSU before the time out for transmission over the cellular link expires, the maximum number of packets that can be queued is here set to a very high number (1000); with this assumption, in our results, the time out is always reached before the threshold on stored data.

In Fig. 9, the sites we considered for RSUs deployment in the reference scenario of Bologna are shown, corresponding to the mostly crowded junctions (note, in fact, that major junctions are suitable sites also owing to the likely presence of lighting, traffic lights, and therefore of power supply).

As first case we assume that only RSU A is available for communication in the entire scenario depicted in Fig. 9. RSU A is positioned, in particular, in the busiest crossroad of the whole scenario. The average ratio of saved cellular resources that can be achieved in this case taking advantage of both V2V and V2R communications is shown in Fig. 10 as a function of the sampling interval τ, varying the traffic conditions and the percentage of vehicles equipped with the OBU. Results show that even when a single RSU is properly positioned in a large area, a significant amount of data can be transmitted to it. Let us observe, in fact, that even with τ lower than 30 s and only the 10% of vehicles equipped with OBU, S_R is still significant (more than 10%). It could be verified that also delivery delays are reduced [10].

The impact of RSUs position on the benefit they can provide is quite relevant: in order to investigate this aspect we report, in Fig. 11, S_R considering different positions of a single RSU (RSU A, RSU B, and RSU C) and the deployment of all RSUs depicted in Fig. 9. For the sake of conciseness, only the case of heavy traffic and 100% equipped vehicles is considered. Curves are shown as a function of the sampling interval τ. We can observe that RSU B and RSU C, being located in less busy junctions, are less effective than RSU A, owing to a reduced amount of vehicles passing in their proximity. Comparing the benefit provided by RSU A to the one achievable with all RSUs simultaneously active we can infer that the advantage obtained deploying all RSUs is not very high with respect to the one achievable deploying only RSU A and would not justify the financial investments required. The great effectiveness of RSU A suggests that a relevant role is played by V2V communications. It is likely, in fact, that also vehicles not passing in the proximity of RSU A are successful in the attempt to transmit their information without cellular transmissions by means of multi-hop V2V communications and the strategic position of RSU A. Here we can observe that the effectiveness of the roadside infrastructure is significantly enhanced by the joint adoption of V2V communications. If V2V interface was not available, then the number of deployed RSUs would

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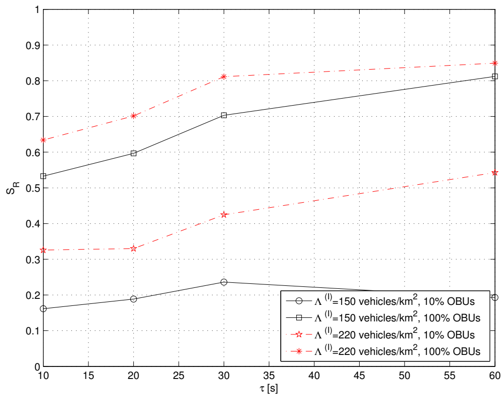


Figure 10. S_R as a function of τ, with RSU A only.

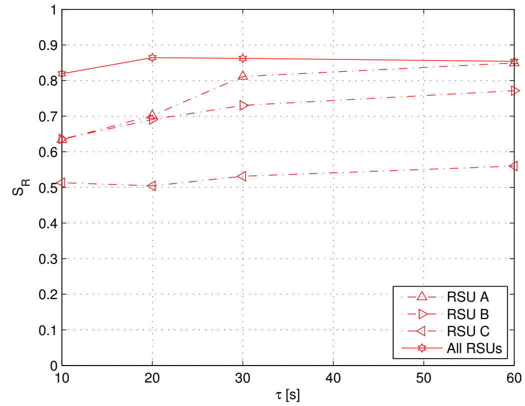


Figure 11. Impact of RSUs position and number. S_R as a function of τ with $\Lambda^{((I))} = 220$ vehicles/Km^2 and 100% vehicles equipped with OBUs.

be decisive to reduce the cellular load.

D. Smart Navigation Service

Results are presented for $T_{\text{int}} = 10$ s, $T_{\text{update}} = 20$ s, and τ equal to 10, 30, or 60 s. Figures show the travel time, from origin to destination, of a controlled vehicle equipped with the smart navigator for different percentage of equipped vehicles and different scenarios. In each figure, results are compared with the following three cases adopted as benchmarks: i) *Free running*, referred to the case of a single vehicle moving alone on the entire scenario; ii) *Best case with smart navigation*, referred to a vehicle equipped with a smart navigator continuously updated with the best route, iii) *No smart navigation*, referred to the the same route as in Free Running in the presence of traffic (a navigator may be present, but without knowledge of real time traffic).

In Fig. 12, the travel time to destination is shown for path-1. These results follow an extensive simulation campaign, where also other paths were considered; similar results have been however obtained in all cases, and other plots are here omitted for length limitation. Figures 12(a), 12(b), and 12(c) refer to three different (uplink) transmission times τ: 10 s, 30 s, and 60 s, respectively. For each percentage of OBU equipped vehicles, six results are presented, corresponding to six different simulations providing time and space randomness (i.e., different vehicles are equipped with OBU, and the sampling process starts at different instants). By observing Figs. 12(a), 12(b), and 12(c), it can be noted that the time to destination increases with τ, showing a not negligible impact of a timeliness update of road segments status. Focusing on Fig. 12(a), the impact of the percentage of OBU equipped vehicles can be appreciated: with a so prompt update in the uplink ($\tau = 10$ s), the 10% of vehicles equipped with connected OBUs is sufficient to have a time to destination very near to the best case (i.e., about 600 s). When the transmission time τ from vehicles to the control center is higher (see Figs. 12(b), and 12(c) referring to $\tau = 30$ s and $\tau = 60$ s, respectively) the 10% of vehicles is no more sufficient to obtain optimal results, that can be instead achieved only when all vehicles are equipped with OBUs.

VII. Conclusions

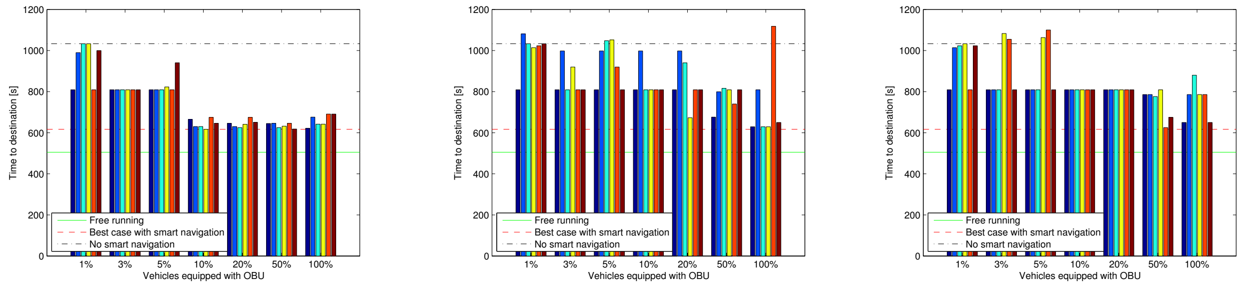
In this work, we summarized the results of the Italian project PEGASUS with focus on wireless technologies for smart mobility. Specifically, we considered UMTS as the enabling technology for the real time acquisition and transmission of traffic information. We discussed the feasibility of the service and we evaluated the impact of such a communication on other services already provided by UMTS. Our studies highlighted that the service appears feasible and that the number of equipped vehicles does not seem a critical issue; we also pointed out, however, that a not negligible loss in capacity for the other services must be accounted for in order to guarantee a satisfactory quality of service. The benefits arising from the adoption of V2V and V2R communications have also been explored. We finally showed that the knowledge in real time of the traffic conditions allows an efficient smart navigation and a not negligible saving of travel time.

References

[1] P. Papadimitratos, A. La Fortelle, K. Evenssen, R. Brignolo, and S. Cosenza, “Vehicular communication systems: Enabling technologies, applications, and future outlook on intelligent transportation,” *Communications Magazine, IEEE*, vol. 47, no. 11, pp. 84 –95, 2009.

[2] *IEEE Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-Channel Operation*, Std., 2006.

[3] *Standard for Information Technology- Telecommunications and Information Exchange between Systems- Local and Metropolitan Area Networks-Specific Requirements Part 11 - Amendment 6: Wireless Access in Vehicular Environment*, IEEE Std. 802.11p, 2010.



(a) $\tau = 10$s. (b) $\tau = 30$s. (c) $\tau = 60$s.

Figure 12. Travel time to destination for several percentage of vehicles equipped with OBU.

[4] A. Bazzi, B. Masini, and O. Andrisano, "On the frequent acquisition of small data through RACH in UMTS for ITS applications," *Vehic. Tech., IEEE Tran. on*, vol. 60, no. 7, pp. 2914 – 2926, Sep. 2011.

[5] PEGASUS project. Accessed on Oct. 2012. [Online]. Available: http://pegasus.octotelematics.com

[6] A. Conti, A. Bazzi, B. Masini, and O. Andrisano, *Vehicular Networks: Techniques, Standards, and Applications*. Auerbach Pub., CRC Press, Taylor & Francis Group, 2009, ch. Heterogeneous Wireless Communications for Vehicular Networks, pp. 63–107, ISBN: 9781420085716.

[7] A. Bazzi, B. Masini, G. Pasolini, and P. Torreggiani, "Telecommunication systems enabling real time navigation," in *IEEE ITSC*, Sep. 2010, pp. 1057 – 1064.

[8] A. Toppan, A. Bazzi, P. Toppan, B. Masini, and O. Andrisano, "Architecture of a simulation platform for the smart navigation service investigation," in *IEEE WiMob*, Oct. 2010, pp. 548 – 554.

[9] A. Bazzi and B. Masini, "Real time traffic updates via UMTS: Unicast versus multicast transmissions," in *IEEE VTC Fall,*, Sep. 2011, pp. 1 – 6.

[10] A. Bazzi, B. Masini, and G. Pasolini, "V2V and V2R for cellular resources saving in vehicular applications," in *IEEE WCNC*, Apr. 2012, pp. 1–5.

[11] P. Belanovic, D. Valerio, A. Paier, T. Zemen, F. Ricciato, and C. Mecklenbrauker, "On wireless links for vehicle-to-infrastructure communications," *Vehic. Tech., IEEE Trans. on*, vol. 59, no. 1, pp. 269 – 282, Jan. 2010.

[12] D. Valerio, A. D'Alconzo, F. Ricciato, and W. Wiedermann, "Exploiting cellular networks for road traffic estimation: A survey and a research roadmap," in *IEEE VTC Spring 2009*, april 2009, pp. 1 –5.

[13] The aktiv CoCar project. Accessed on Oct. 2012. [Online]. Available: http://www.aktiv-online.org/english/aktiv-cocar.html

[14] S. Cho, K. Geon, Y. Jeong, C.-H. Ahn, S. I. Lee, and H. Lee, "Real time traffic information service using terrestrial digital multimedia broadcasting system," *Broadcasting, IEEE Transactions on*, vol. 52, no. 4, pp. 550 –556, Dec. 2006.

[15] U. Dietz, "CoCar Feasibility Study: Technology, Business and Dissemination," CoCar Consortium, Report, May 2009.

[16] C. Sommer, A. Schmidt, R. German, W. Koch, and F. Dressler, "Simulative Evaluation of a UMTS-based Car-to-Infrastructure Traffic Information System," in *IEEE GLOBECOM*. New Orleans, LA: IEEE, December 2008.

[17] C. Sommer, A. Schmidt, Y. Chen, R. German, W. Koch, and F. Dressler, "On the feasibility of umts-based traffic information systems," *Ad Hoc Networks*, vol. 8, no. 5, pp. 506 – 517, 2010.

[18] I. Lequerica, P. Ruiz, and V. Cabrera, "Improvement of vehicular communications by using 3G capabilities to disseminate control information," *Network, IEEE*, vol. 24, no. 1, pp. 32 – 38, Jan.-Feb. 2010.

[19] B. Bai, W. Chen, K. Letaief, and Z. Cao, "Low complexity outage optimal distributed channel allocation for vehicle-to-vehicle communications," *Selected Areas in Communications, IEEE Journal on*, vol. 29, no. 1, pp. 161 –172, 2011.

[20] J. Karedal, N. Czink, A. Paier, F. Tufvesson, and A. F. Molisch, "Path loss modeling for vehicle-to-vehicle communications," *Vehicular Technology, IEEE Transactions on*, vol. 60, no. 1, pp. 323 –328, 2011.

[21] C. Campolo and A. Molinaro, "Vehicle-to-roadside multihop data delivery in 802.11p/WAVE vehicular ad hoc networks," in *IEEE GLOBECOM*, 2010, pp. 1 –5.

[22] P. Benko, G. Malicsko, and A. Veres, "A large-scale, passive analysis of end-to-end TCP performance over GPRS," in *IEEE INFOCOM*, vol. 3, Mar. 2004, pp. 1882–1892.

[23] I. Vukovic and T. Brown, "Performance analysis of the random access channel (RACH) in WCDMA," in *IEEE VTC Spring.*, vol. 1, May 2001, pp. 532–536.

[24] *Traffic and Travel Information (TTI) via Transport Protocol Expert Group (TPEG) data-streams: Parts 1 to 6*, ETSI Std. ISO 18 234.

[25] Vissim. Accessed on Oct. 2012. [Online]. Available: http://www.english.ptv.de/cgi-bin/traffic/traf_vissim.pl

[26] A. Bazzi, G. Pasolini, and C. Gambetti, "SHINE: Simulation platform for heterogeneous interworking networks," in *IEEE ICC*, vol. 12, 2006, pp. 5534 –5539.