On the Impact of Real Time Data Acquisition from Vehicles through UMTS

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Abstract—Intelligent transportation systems (ITS) make use of wireless communication technologies to provide traffic efficiency and road safety without altering the existing road infrastructure. To really impact on traffic management, ITS should act in real-time, requiring updated traffic information; hence, the collection of small amounts of information frequently transmitted from a high number of vehicles is needed. Cellular systems represent the most suitable technological solution to achieve this service, since they do not require any further installation of network infrastructures. However, they were designed for different applications: voice, web browsing or e-mailing. In this paper we aim at discussing the feasibility of frequent acquisition of small amount of data from vehicles through the universal mobile telecommunication system (UMTS), and at investigating its impact on the services already provided by the network. Numerical results are obtained by means of simulations, paying particular attention to realistic scenarios, both in terms of wireless systems and users mobility.

I. INTRODUCTION

Wireless communications are driving and accelerating the development of intelligent transportation systems (ITS) for safe and efficient driving. All over the world, several projects and consortia [1], [2] are working on the development of common ITS communication architectures letting vehicles, roadside units, and wireless infrastructure communicate and cooperate to offer new services. However, big efforts have still to be done to realize such objectives and make communication networks work in vehicular scenarios.

In this work we focus on the real-time collection of information (such as position, direction, speed, etc.) from a large number of vehicles. This kind of application is gaining more and more interest; in Italy, for instance, within the framework of the national project PEGASUS [3], the real-time collection of traffic information from vehicles is performed: the number of equipped cars able to transmit information was about 1,000,000 in May 2010 and this number is going to quickly increase. These data, once processed, can be exploited for real-time dynamic navigation or forwarded to public or private institutions for traffic management.

To handle and make available this amount of data in real time, the following wireless access technologies could be exploited: short-range ad-hoc systems, cellular systems, and metropolitan area networks (MANs). Among short-range ad-hoc systems, IEEE 802.11p represents the evolution with respect to ad-hoc vehicular communication. Nonetheless, an infrastructure to connect the hot-spots to the operational control center is needed; moreover standardization entities are still working to reduce latency and improve real-time communication quality. For what concern MANs, mobile worldwide interoperability for microwave access (mobile-WiMAX) is starting its deployment in these years and it is not clear, yet, if and when it will spread its coverage giving access also to users moving at medium and high speeds. However WiMAX may be a key technology for rapid backhauling deployment to connect roadside devices to control centers.

Hence, cellular systems, represent the promptest solution to collect data from vehicles and potentially retransmit them [4], [5]. Cellular networks, in fact, guarantee high penetration in the market, covering users worldwide, and allow continuity of service also at vehicular speeds. However, these networks were not initially designed to support ITS; for this reason, in this paper, we aim at evaluating the feasibility of frequent uplink transmissions of small amount of data from a large number of vehicles and investigating the impact of this service on the others already available on the cellular network.

The paper is organized as follows: in Sec. II the scenario and its requirements are described, and in Sec. III the main characteristics of the universal mobile telecommunication system (UMTS) considered for the envisioned service are given. In Sec. IV, the theoretical limit to the number of users accessing a UMTS cell is evaluated, while in Sec. V a realistic UMTS and urban traffic scenario is considered and described. Simulation results are reported in Sec. VI and our conclusions are given in Sec. VII.

II. SCENARIO AND REQUIREMENTS

To let communication technologies allow new travel and traffic management applications, information have to be collected in real time directly from a high number of vehicles. Assume, in fact, that vehicles (cars, trucks, buses) are equipped with a wireless system able to periodically communicate in real-time information, such as position, direction, average speed, and its variance, to a control center, as shown in Fig. 1. The control center collects and processes the data to send information to vehicles, government institutions or automotive associations for traffic management, infomobility services, optimal routes suggestions, etc.

This envisioned scenario is not far from reality since some vehicles are already equipped with smart navigators integrating cellular devices [3][6]; as an alternative, personal devices could be used without any set up on board.
An increasing number of vehicles is worldwide integrating devices able to periodically store car parameters, including position and speed, and to connect, at a lower frequency, to a wireless network, thus sending the data to a control center. In Europe, in particular, the on-board devices integrate the general packet radio service (GPRS) system at this scope. To access the GPRS network, a mobile station (MS) has to ask for a dedicated resource by sending a message on a common signalling channel shared with all the other users in that cell; once the MS has obtained the acknowledge from the base station (BS), it can finally transmit the data on a dedicated channel established for it. As can be expected, these procedures require a not negligible access time, in the order of seconds [7], especially in crowded conditions. This is the reason why, nowadays, the on-board unit collects tens of measurements and transmit them in a single packet, instead of sending each measurement as soon as it is taken. Considering that the number of vehicles transmitting their information is going to increase and that, in order to provide a real time service, the sending frequency has to increase too, GPRS seems not to represent the most promising technological solution to provide the foreseen service.

On the contrary, UMTS allows the transmission of small packets directly through the shared signalling channel, avoiding the set-up of a dedicated channel, thus granting smaller delays and reduced access times [8], [9]. Hence, UMTS will be considered and deeply investigated in this paper. In particular, we assume to periodically collect few but frequent measurements (at least position, direction and actual speed) from each vehicle travelling on the road; our aim is to evaluate the feasibility of this service through the UMTS system and to determine the impact it would have on the quality of service (QoS) perceived by the users accessing the network for other services (with particular reference to the voice service).

III. UMTS and the Random Access Channel

UMTS overview. In this paper we consider the frequency division duplex (FDD) operating mode of UMTS, where two separate bands of 5 MHz are used for the uplink and downlink, respectively. All communications are performed through either a common or a dedicated physical channel. Due to the adoption of the code division multiple access (CDMA) technique, all UMTS channels share the same bandwidth and the same time, and are separated one to each other through orthogonal spreading codes and pseudo-orthogonal scrambling codes. Because of the non ideality of real communications (e.g., the impossibility of perfect synchronization among signal sources and the presence of multipath propagation), signals partially interfere to each other; for this reason, all signals transmitted over the dedicated channels are adjusted through a very fast power control (1500 Hz) in both directions (i.e., up-link and downlink), called inner loop power control. This way all transmissions are maintained at the minimum power level that guarantees a satisfactory QoS; the transmission power is increased if the quality is not sufficient, but it is reduced whenever possible in order to minimize the interference to the other transmissions.

Stated that the chip rate is always equal to 3.84 Mchip/s, the data link level bit rate of a channel depends on the chosen parameters at the data link and physical layers; in particular, it depends on the spreading factor (SF), which ranges from 4 to 512 (a higher SF corresponds to a lower bit rate), and the channel code rate, which is, on its turn, composed of a turbo code with rate 1/3 or a convolutional code with rate 1/2 or 1/3, and a variable puncturing or duplicating operation. Note that a higher bit-rate requires a higher power level at the transmitter (considering the same probability of error), thus causing higher interference on other communications.

The (transport) random access channel. In order to transmit a small amount of information, UMTS users are not required to activate a dedicated channel and may also adopt the random access channel (RACH) mapped on the physical RACH (PRACH), thus reducing the transmission duration and increasing the number of contemporary connections. The RACH is an uplink common transport channel intended to be used by the terminals to carry control/signalling information or small amounts of data [9]. Although the RACH/PRACH channel was provided also to GSM and GPRS users, in the second generation cellular systems it could carry only control and signalling information: it could be used by the MSs to ask for dedicated resources, but not to transmit data packets.

UMTS MSs choose their transmission time on the RACH/PRACH in a random way following a modified slotted ALOHA algorithm at the medium access control (MAC) layer (resulting in potential collisions), and a ramping procedure at the physical layer. A complete description of the protocols is out of the scope of this paper, however some details are required for a better comprehension of the results that follow. Each MS is allowed to begin a transmission only in certain instants and with a certain probability, as defined, per each
class of traffic, by the operator. At the MAC layer, the MS checks for the first possible instant, verifies that a transmission is not already present on the PRACH, randomly determines if it is allowed to transmit, and then passes the packet down to the physical layer. If a failure is returned, a random backoff procedure is entered and the transmission is delayed.

The physical random access channel. At the physical layer, the problem is how to transmit with a power high enough to be heard by the BS, still minimizing the generated interference. Note that no inner loop power control is available on the PRACH. Hence, the MS performs a procedure called ramping or open loop power control: it roughly estimates the needed power, transmits a preamble (4096 chips long), and listens over the downlink acquisition indicator channel (AICH) for an acknowledgment message from the BS; if the acknowledgment is not received, then it rises the transmission power of a multiple of 1 dB and tries again. The packet is transmitted as soon as an acknowledgment is received. The packet will be finally transmitted in either 10 ms (38400 chips) or 20 ms (76800 chips), depending on the bit rate of the channel and the size of the packet itself; only convolutional coding with rate 1/2 (with puncturing or duplications) can be used, while a spreading factor from 32 to 256 is possible [9]. If no acknowledgment is received after a defined number of preamble transmissions, a failure message is returned to the MAC layer, possibly followed by a new backoff, and a transmission retry. A failure message may also be returned if the ramping procedure succeeds but the packet is not correctly detected at the receiver (an error message is supposed on a downlink common channel in this case).

Comparing the PRACH channel to physical dedicated channels, it must be remarked that the validity of the power level obtained with the PRACH power ramping procedure lasts only for a short period (depending on the environment) and will not be able to follow possible fluctuations of the channel; furthermore, transmitting on the PRACH, a higher power level is required (with respect to dedicated channels) when the terminal is near to the edge of the cell, since soft/softer handovers are not possible in this case.

IV. THEORETICAL LIMIT ON CONNECTED VEHICLES

In this section we aim at giving a preliminary evaluation of how many vehicles can access the UMTS radio resource as a function of the amount of data to be transmitted and their transmission frequency.

Depending on the message duration (10 ms or 20 ms) and the adopted SF, a different amount of bytes can be transmitted in a single packet over the RACH/PRACH channel; furthermore, up to 16 RACHs/PRACHs can be configured in an UMTS cell. Taking into account all the overhead at the data link and physical layer, in [10] 320 bits (40 bytes) payloads are supposed for data packets transmitted in 20 ms with SF equal to 64 or in 10 ms adopting a SF equal to 32. Hence, 20 bytes can be accommodated in a 10 ms message with SF=64 and 80 bytes in a 20 ms message with SF=32. Once defined the SF and the message duration, a shorter length for the packet is not possible, thus padding bits are added if the data dimension is not enough to fill the provided payload.

In [8], authors demonstrate that in saturated conditions (i.e., when there is always at least one user trying to access the PRACH) the ratio of wasted resources due to the access procedure and to the unavoidable collisions is of about $R_{\text{waste}}^{(1)} = 0.38$ and $R_{\text{waste}}^{(2)} = 0.26$ for 10 ms and 20 ms messages, respectively. This means that, when messages of duration $T_{\text{msg}}^{(1)} = 10$ ms are transmitted over the PRACH, a maximum of $(1/T_{\text{msg}}^{(1)}) \cdot (1 - R_{\text{waste}}^{(1)}) = 62$ messages per seconds on average are possible. This number is reduced to 37 for 20 ms messages. Another important aspect in the network design consists in determining how often a vehicle should transmit its information. While on the one hand information should be frequent enough to guarantee real time measurements, on the other hand the data traffic should be minimized to not overload the communication network. Moreover, the sending frequency could be related to covered distances and, thus, variable with speed. As an example, in Tab. I, the distances covered in 5, 10 and 20 s are calculated for reasonable average speeds in urban, extra-urban and highway scenarios. As the covered distance increases from the urban to the highway scenario, we assume that transmitting the packets every 10 s from the vehicles to the control center represents a good compromise in any of them; this way, a vehicle will certainly send at least one measurement when crossing a urban road segment that is longer than 110 m or a highway segment that is longer than 330 m.

Following these considerations, and, thus, assuming each user in the UMTS cell transmitting a packet every 10 s,

<table>
<thead>
<tr>
<th>Environment</th>
<th>Considered speed</th>
<th>5 s</th>
<th>10 s</th>
<th>20 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>40 Km/h</td>
<td>55 m</td>
<td>110 m</td>
<td>220 m</td>
</tr>
<tr>
<td>Extra-Urban</td>
<td>80 Km/h</td>
<td>110 m</td>
<td>220 m</td>
<td>440 m</td>
</tr>
<tr>
<td>Highways</td>
<td>120 Km/h</td>
<td>160 m</td>
<td>330 m</td>
<td>660 m</td>
</tr>
</tbody>
</table>

![Fig. 2. Theoretical maximum number of users per cell for each RACH channel reserved to ITS vs. the payload dimension. Packets are transmitted every 10 seconds.](image-url)
in a realistic scenario are shown by means of simulations. Overcoming this limitation, in Sec. V and VI numerical results bound for the system load, but completely neglect the system configured to be exclusively used for the envisioned service. Users per cell can be served per each RACH/PRACH channel a 20 ms message with SF=32. With this configuration, 370 observe that a 80 bytes payload can be transferred only in overhead, a total payload of 80 bytes will be considered further on for the envisioned service. From Fig. 2, it is possible to observe that a 80 bytes payload can be transferred only in a 20 ms message with SF=32. With this configuration, 370 users per cell can be served per each RACH/PRACH channel configured to be exclusively used for the envisioned service. Please note that these evaluations only represent an upper bound for the system load, but completely neglect the system limits in terms of transmission power, interference levels, etc.; overcoming this limitation, in Sec. V and VI numerical results in a realistic scenario are shown by means of simulations.

V. DATA COLLECTION FROM THE VEHICULAR USERS IN REALISTIC SCENARIOS

In order to verify the impact of such an ITS service in a realistic scenario, hereafter we consider a medium sized city with vehicles periodically transmitting their data and pedestrian users performing voice calls, and we evaluate the system performance through simulations.

Simulations are performed adopting SHINE (simulation platform for heterogeneous interworking networks) [11], which allows to jointly take into account both the territory map with roads and users mobility and the UMTS network architecture from application to physical layers, carefully reproducing the time and frequency correlated behavior of the wireless medium. Numerical results will be discussed in Sec. VI.

A. Scenario and Simulation Settings

The reference scenario is shown in Fig. 3: it represents a portion of the medium sized Italian city of Bologna, consisting in 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. Due to the CDMA scheme adopted by UMTS and to the soft/softer handover capability a single frequency planning is considered.

At Nodes-B the available power is assumed within the range [10 - 13] dBW (see Fig. 3), antennas are 120° with 15 dB maximum gain, and the receiver noise figure is 3 dB. At the mobile terminals 0 dB gain is assumed with maximum transmit power -6 dBW and 7 dB noise figure at the receiver. Concerning the propagation, we assume an average path loss according to the Hokumura-Hata model for urban macro cell environment ($PL[dB] = 137.4 + 35.2 \log_{10}(D)$, with $D$ distance in Km), with shadowing attenuations modeled by means of correlated log-normal random variables with 8 dB variance, and correlated fast fading following the ITU pedestrian A channel (pedestrian users) or ITU vehicular A channel (vehicular users). Three downlink channels with SF=256 are supposed to be always active (common pilot channel CPICH, paging indicator channel PICH, and the time multiplexing of primary common control physical channel P-CCPCH and synchronization channel SCH); other common channels are assumed negligible. Downlink intra-cell interference is reduced to 30% due to the orthogonality of spreading codes.

Two classes of users are taken into account: vehicles moving on roads and equipped with the on-board units (hereafter ITS users), and pedestrians randomly walking and performing voice calls through their cellular phones (hereafter voice users). An uniform distribution of both classes of users per each cell is supposed, with the same average amount of traffic in all cells; this means that a higher density of users is assumed where smaller cells are considered.

B. ITS Service Settings and Figures of Merit

As already stated, in order to collect position, direction, and speed measurements, 80 bytes per packet including overhead from higher layers will be considered. Hence, as motivated in Sec. IV, 20 ms messages are adopted with SF=32. One RACH/PRACH per cell is exclusively used for the ITS service. Although the sending frequency should be adapted to the specific traffic conditions and dynamically optimized when the service will be on the field, in our numerical results we assume that it is fixed to 1 packet every 10 s, as discussed in Sec. IV.

We consider a number of ITS users sufficiently far from the theoretical limit evaluated in Sec. IV (i.e., 370 users per cell), thus allowing to neglect the effects of collisions due to the multiple access algorithm. Having this in mind, we also assume that the ramping procedure is performed by users contending for the channel in a first in first out order. Although this order is not always respected in reality, this does not impact on our results, since we aim at verifying the success of data transmissions, not the delays; the access order to the PRACH impacts on the time spent by a packet in the
MAC queue only, and it is significantly lower than the interval between packet generations (i.e., 10 s), as confirmed by [12].

**Mobility.** Vehicles move on roads at a variable speed modelled as a Gaussian random variable truncated between 0 km/h and a 50 km/h, with 30 km/h as average and 10 km/h as standard deviation. Speed or direction are randomly changed and 1 km/h standard deviation. Speed or direction are randomly changed at a variable speed modelled as a Gaussian random variable truncated between 0 km/h and 3 km/h with 1.5 km/h in average and 10 km/h as standard deviation. Speed or direction are randomly changed at a variable speed modelled as a Gaussian random variable truncated between 0 km/h and 3 km/h with 1.5 km/h in average and 10 km/h as standard deviation.

Having this in mind, we have to set a critical parameter for the control center, independently on the specific source.

**Figures of merit.** In order 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.

Having this in mind, we have to set a critical parameter for the ramping procedure, that is the $E_b/I_0$ ramping target threshold (hereafter $E_b/I_0$ ramp), where $E_b/I_0$ the average energy per bit before coding and spreading over noise-plus-interference power density ratio; the ramping procedure successfully ends (and the packet transmission starts) when the mean $E_b/I_0$ at the receiver is higher than $E_b/I_0$ ramp. Due to the absence of the inner loop power control on the RACH/PRACH, once the packet transmission is started, no power variations are performed at the transmitter.

As stated in Section III, a transmission scheduled by the MAC may fail in two cases: when the ramping procedure fails, meaning that 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 attempts a number of retransmissions before discarding the packet. In our simulations, the maximum number of attempts is three.

Focusing on the ITS service, results will be expressed in terms of the following figure of merit:

- **packet discard rate** ($R_D$), that is the ratio between the number of discarded packets and the total number of packets generated by the on-board equipment.

**C. Voice Service Settings and Figures of Merit**

In order to evaluate UMTS performance in the considered scenario, the quality perceived by users belonging to other services is also of main interest. In particular, random walking users performing voice calls are supposed.

**Mobility.** Pedestrians are not constrained on roads and move at a variable speed modelled as a Gaussian random variable truncated between 0 km/h and 3 km/h with 1.5 km/h in average and 1 km/h standard deviation.

**Figures of merit.** The evaluation of the quality of service perceived by the users is based on the following definitions: per each frame (10 ms) one user (i.e., a voice call) is defined in outage if the mean bit error rate (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 suffer of two other kinds of problems: it may be blocked by the call admission control algorithm, thus not accepted in the system due to insufficient resources; or it may drop against the will of the user, due to an excessive reduction of the received signal power. Hence, the following figure of merit will be considered in the numerical results:

- **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.

**VI. RESULTS AND CONSIDERATIONS**

Following the assumptions detailed in Sec. V, numerical results are here shown and discussed. The amount of traffic is taken into account through the average number of potentially active users per Km² (indicated as $N^v$ and $N^H$ for voice and ITS users, respectively), obtained multiplying the number of call attempts by the average duration of each call (i.e., 90 s in the investigated scenario), divided by the duration of the simulation and normalized in one Km². This value corresponds to the average number of calls that would be active in the scenario if none of them was blocked and no abnormal releases occurred. No advanced call admission control is considered in order not to impact on numerical results.

In Fig. 4, the ITS service performance is shown in terms of $R_D$ as a function of $E_b/I_0$ ramp for different values of $N^v$. It can be noted that, both a too high and a too low choice of the threshold have to be avoided. This is due to the fact that an increase of $E_b/I_0$ ramp causes a lower probability of error at the receiver, but an higher probability of ramping failure. In the definition of the most appropriate value for the threshold, it should also be considered that a high probability of failure in the ramping procedure means that there are territory areas too far from the bases; hence, some roads may suffer of a reduced probability to have updated measurements; this case shall be always avoided for the envisioned service. Observing Fig. 4, $E_b/I_0$ ramp = 9dB represents the optimum choice in spite of $N^v$, and it is thus taken as reference target in further simulations.

The SatR for voice users and the $R_D$ for ITS service are plotted in Fig. 5 and 6, respectively, as a function of
$N_{\text{av}}$ varying $N_{\text{ITS}}$. The highest average number of vehicles assumed is $N_{\text{ITS}}=2200$, which is far enough from the limit of 4500, corresponding to 370 vehicles per cell of the considered scenario (as shown in Fig. 2). Also note that 2200 vehicles per Km² represent a very high traffic density: to give an idea, if a Manhattan scenario with a road every 100 m was considered, there would be 20 roads, 1 Km long, every Km²; hence, $N_{\text{ITS}}=2200$ would correspond to 1 vehicle every 9 m.

In Fig. 5, the $SatR$ of voice users is depicted and the case with no ITS service ($N_{\text{av}}=0$) is shown for comparison. If a target $SatR$ of 0.90 is assumed, the reduction of $N_{\text{av}}$ increases with $N_{\text{ITS}}$. In fact, we observe a loss ranging from 10 ($\approx 1.5\%$) to 40 ($\approx 6\%$) voice users per Km² for $N_{\text{ITS}}$ going from 220, to 2200. This means that an high density of vehicles requiring for the UMTS network, affects the number of attending voice users. It should be noted, however, that in such a case, we could not need to acquire a packet every 10 s from each vehicle.

In Fig. 6, the $RD$ of ITS service as a function of $N_{\text{av}}$ is plotted for different values of $N_{\text{ITS}}$. As can be observed, the higher is the network load, the higher the $RD$, and the QoS of the ITS service results deteriorated. If $N_{\text{av}}=600$, 595, and 570 (corresponding to $SatR=0.90$) are taken as reference values for $N_{\text{ITS}}=220$, 1100, and 2200, respectively, a packet loss between 6% and 7% can be observed, meaning that guaranteeing a $SatR=0.90$ to voice users, does not imply that the ITS users are also served. To improve the ITS QoS, a lower number of voice calls should be accepted. For instance, if $RD$ lower than 0.01 is targeted, a further reduction of about 125, 120, and 90 voice users per Km² should be considered for $N_{\text{ITS}}=220$, 1100, and 2200, respectively, drastically reducing the voice users’ capacity.

VII. CONCLUSIONS

In this paper we evaluated the impact of real time data collection from vehicles through UMTS. We assumed to frequently collect location and speed information from vehicles moving in a urban scenario, and we evaluated the impact of this service on the UMTS network performance in terms of maximum number of contemporary radio accesses and QoS perceived both by ITS users and voice users. Results have been obtained through simulations carried out in a realistic scenario, showing that the envisioned service is feasible at the expense of a not always negligible capacity reduction for other UMTS services.

VIII. ACKNOWLEDGMENTS

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