On the Frequent Acquisition of Small Data through RACH in UMTS for ITS Applications

Alessandro Bazzi, Barbara M. Masini, and Oreste Andrisano

Abstract—Wireless communications are nowadays considered as the most promising solutions to provide real-time traffic information, suggest alternative routes and help in reducing congestions. These new services are all based on the real-time acquisition of traffic information directly from vehicles, which act as sensors travelling on the roads. With the idea of having new widespread and real-time infomobility services in the short-medium term, neither installations on board nor new roadside infrastructures set up can be taken into account. Hence, in this work we aim at verifying the feasibility of the real-time acquisition of traffic information from vehicles in dense areas through the universal mobile telecommunication system (UMTS). In particular, we first analytically evaluate the capacity and the coverage of a UMTS cell when multiple users frequently transmit their traffic measurements to a remote control center through a shared (common) channel. Then, we extend our results to a realistic urban scenario by investigating, through simulations, the feasibility of the service and its impact on the quality of service (QoS) perceived by other users (voice, as an example).

Index Terms—Intelligent transportation systems (ITS), universal mobile telecommunication system (UMTS), real-time services, analytical model, realistic simulated scenario.

I. INTRODUCTION

Drivers ask for the optimal route in real time, where optimal can be intended on the bases of traffic conditions, pollution, accident management, etc. In this context, vehicular networks are gaining an increasing interest and many efforts are underway from the academic community, automotive manufacturers and governments to face the challenges offered by the provision of new services through wireless communications. Several international projects and consortia and relevant standardization bodies are working on the development of new standards to define common intelligent transportation systems (ITS) communication architectures allowing vehicles, roadside units and wireless infrastructure to communicate and cooperate. However, we are still a long way from a real convergence towards a set of European or worldwide standards granting traffic safety and efficiency [2].

In spite of the application, different wireless access technologies can be exploited in vehicular contexts, from short-range ad-hoc networks to cellular systems. Regarding the former ones, several standardization processes and research work are currently being carried out [3], [4], giving particular attention to the wireless access in vehicular environments (WAVE) [5], based on IEEE 802.11p [6], which represents the evolution of wireless local area networks toward vehicular communication. Nonetheless, for a really effective traffic management, a connection to a remote control center is still necessary, and even if all vehicles were equipped in a near future with vehicle to vehicle and vehicle to roadside communication technologies, it can only be viewed as a long-term solution due to the huge investment that the implementation of a roadside infrastructure to the operational control center requires.

Hence, in short-term thinking, cellular systems appear as the most feasible solution, already guaranteeing high penetration and wide coverage worldwide. Note, in fact, that, on the one hand the last generation on board navigators are already equipped with a cellular interface, and, on the other hand, smart phones embed navigation functionalities.

Given this scenario, in this paper we focus on the uplink collection of data from vehicles through cellular systems. This work is carried out in the behalf of the Italian PEGASUS project [7], which relies on over one million vehicles already equipped with on board units (OBUs) periodically transmitting their position and speed to a control center. With the perspective of an increasing number of equipped vehicles, it is presumable that this service will significantly put impact on the resources, arising doubts on whether it is sustainable [1]. Hence, focusing on the universal mobile telecommunication system (UMTS) as the enabling technology and its random access channel (RACH) as a way to rapidly and efficiently transmit data, in this work we aim at answering the following questions:

- Is the acquisition in the uplink of small but frequent amounts of data from many vehicles feasible? Is the UMTS capacity sufficient for these kinds of multiple connections?
- What is the impact of this service on the others already available on the UMTS network?

To answer these questions, we firstly propose a mathematical model to evaluate the impact of the envisioned service on the UMTS capacity and coverage in simplified scenarios. Then, we investigate how this service affects the quality of service (QoS) perceived by other users through simulations performed in a reference urban scenario, taking into account the details of the protocol pillar layers, an accurate modelling of radio propagation, and both realistic radio access network settings and users’ mobility. Simulations are also exploited to validate the analytical model.

The paper is organized as follows: in Section II the scenario
of investigation is clarified and the state of the art is given. In Section III, the solution adopted for the uplink transmission through UMTS is detailed. In Section IV the service classes and the figures of merit to quantify the performance are given, while in Section V the analytical model and the simulation platform for performance evaluation are described. In Sections VI and VII analytical and simulation results are reported. Final discussion and future work are discussed in Section VIII and our conclusions are drawn in Section IX.

II. SCENARIO AND 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 potentially retransmit them to on board dynamic navigators avoiding new set-ups or expensive installations [8], [9]. Various activities are ongoing [10], [11], [12], [13], and some products based on cellular technologies are already on the market.

To provide updated traffic information to the drivers, real time knowledge of the state of the traffic is needed. Besides the deployment of sensors and cameras, it is interesting to exploit vehicles as sensors: Units mounted on board measure parameters such as position and speed, and periodically transmit them to a remote control center. This is the case, for example, of the vehicle fleet at the basis of the Italian PEGASUS project [7], which is one of the first initiatives aiming at providing a traffic information service in the short medium term. It should also be noted that, even if OBUs were not available, the same information could be provided by smart phones and hand-held devices with geo-localization functionalities.

Hereafter the focus will be on the uplink collection of data, whereas the way the information is elaborated and sent to drivers is out of the scope of the present work. The scenario under investigation, with vehicles equipped with OBUs connected to a remote control center, is shown in Fig. 1. Among the available cellular technologies, GPRS is nowadays the most adopted for uplink measurements transmission. However, to transmit data over the GPRS network, the user equipment (UE) must first send a message on a common channel asking for a dedicated resource, with procedures requiring a non-negligible access time, in the order of seconds [14]; the introduced signalling overhead implies that tens to hundreds of measurements are nowadays collected by the OBU before transmitting them in a single packet. This approach obviously increases the data acquisition delay at the control center, giving the traffic update to final users with certain latency. Differently to this, UMTS also allows the transmission of small amounts of data over the shared signalling channel RACH, avoiding the set-up of dedicated resources [15]. 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.

Some studies on the cellular performances in vehicular applications are coming out (see, e.g., [16], [8]), 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. In particular, in the Aktiv CoCar project [17], [18], a distinction was made between the transmission of critical (i.e., safety) messages and regular messages. As far as the critical messages are concerned (cellular hazard warning is the primary focus of the CoCar project), the CoCar system is handled by the use of the Fast Traffic Alert Protocol (FTAP). The messages size is below 100 byte and is transmitted on the RACH. The regular upload of less time critical traffic data is performed through the Traffic Probe Data Protocol (TPDP) that allows the regular upload of road traffic data using dedicated UMTS channels (DCHs). After evaluating the average end-to-end transmission delay, CoCar concludes that it is recommended to use common channels with an average transmission delay (intended as the delay between the transmission from a vehicle to the UMTS system and back to the receiving vehicle) of 300 ms for a critical scenario. Dedicated and shared channels make sense for downloads and uploads or peer-to-peer applications exchanging larger amounts of data. No investigations on the impact on system coverage and capacity are deepened in CoCar.

In [19], the suitability of UMTS and long term evolution (LTE) for safety communications at intersections is investigated in terms of loads and traffic demands when short cooperative awareness messages at high rate are transmitted by each vehicle, showing the advantages of LTE in meeting higher capacity requirements and lower latencies.

None of these works, however, evaluate the impact of new info-mobility services on the performance and the QoS of other services already provided by existing cellular systems. Hence, in this work, originally with respect to all other contributions, we aim at discussing the impact of the real time data acquisition on capacity and coverage of UMTS, foreseeing the realistic perspective of an explosion in the number of equipped vehicles.

Preliminary results of this investigation were presented in [1], where a similar scenario was considered; besides a more complete discussion of the topic and original numerical results,
differently from [1] here an analytical framework is also shown allowing to give general results, although obtained in a simplified scenario; moreover, a realistic vehicle mobility is here considered taking advantage of the microscopic traffic simulator VISSIM [20], as detailed further on.

III. CONSIDERATIONS ON THE UMTS RANDOM ACCESS CHANNEL

We consider the frequency division duplex (FDD) operating mode of UMTS, where two separate bands of 5MHz are used for the uplink and downlink, respectively. Although code division multiple access (CDMA) is used, due to the non-idealistic of real communications (e.g., the impossibility of perfect synchronization among signal sources and the presence of multipath propagation), signals partially interfere with each other; in order to minimize this interference, all signals transmitted over the dedicated channels are adjusted through a very fast power control (PC) (1500 Hz) in both directions (i.e., uplink and downlink), called inner loop PC. This way all transmissions are maintained at the minimum power level that guarantees a satisfactory QoS; given a target signal to noise ratio, the transmission power is increased if the quality is not sufficient, but it is reduced whenever possible in order to minimize the interference with 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 spreading factor (SF) and the channel code rate; note that, given a desired error probability, a higher bit-rate requires a higher power level at the transmitter, thus causing higher interference with other communications.

The transport and physical random access channels. To transmit small amounts of information, UMTS users are not required to activate a dedicated channel, but can directly exploit the random access channel (RACH) mapped on the physical RACH (PRACH); this allows significant reduction of the signalling overhead, thus reducing the transmission duration and increasing the number of contemporary connections. The RACH is an uplink common channel mainly used for control operations when other channels are not accessible, such as the update of the terminal’s position at terminal power on, modification of the location area when a dedicated channel is not present, requests for dedicated resources (i.e., when a new voice call or a data connection with more than a few bytes to transmit must be activated). Although a random access channel was also provided for GPRS connections for the above described signalling operations, differently from UMTS it was not possible to adopt the RACH to carry small amounts of data.

In a UMTS cell, up to 16 RACHs can be configured and access to them can be controlled limiting the use of sub-channels to some services or giving different levels of priorities. Given one RACH channel, the UE chooses its transmission instant in a random way following a modified slotted ALOHA algorithm at the medium access control (MAC) layer [21] (resulting in potential collisions), and a ramping procedure at the physical layer [22]. Each UE 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 UE 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.

At the physical layer, the problem is how to transmit with a power high enough to be heard at the Node-B, still minimizing the generated interference. Note that no inner loop PC is available on the PRACH. Hence, the UE performs a procedure called ramping or open loop PC: it roughly estimates the power needed, transmits a preamble (4096 chips long), and listens over the downlink acquisition indicator channel (AICH) for an acknowledgment message from the Node-B; if the acknowledgment is not received, it then raises the transmission power of a multiple of 1dB and tries again. The packet is transmitted as soon as an acknowledgment is received, lasting either 10ms (38400 chips) or 20ms (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 rate matching) can be used, while a spreading factor from 32 to 256 is possible [23]. Please note that, although collisions are possible, in most cases they will occur during the ramping phase among preambles, since the adoption of the AICH almost guarantees that packet transmission is performed collision free.

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 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.

RACH configuration for the envisioned service. Although the access parameters could be set so that services of major importance (like signalling) have higher priority with respect to other services on the same RACH, here we assume that one RACH channel is fully adopted for uploads from vehicles (recall that up to 16 RACHs may be configured in a cell), and that other operations exploit other RACHs. This allows the OBUs to transmit over it without performing contention with other services, thus avoiding risks of congestions in a channel that involves control operations; this implies that interference is the only effect of the new service to other RACH functions.

Given this assumption, in each cell the RACH dedicated to the ITS service is communicated over the broadcast channel: on the one hand this allows a gradual implementation over the territory, and on the other it avoids the use of RACH in those areas where it is not justified due, for instance, to a reduced number of vehicles.

RACH capacity limits. When used only for signalling pur-
or file transfer protocol (FTP), would only mean different traffic flows as background traffic, such as web browsing behavior, thus obtaining results with general validity. Using its stringent QoS requirements and for its typical stationary generality, voice traffic is assumed as background, both for through cellular phones (hereafter voice users). Without lack (hereafter ITS users), and pedestrians performing voice calls with OBUs performing packet transmissions over the RACH.

Sections.

Our considerations brought us to assume vehicles transmitting 80 byte packets every 10 seconds. Discussing the frequency of measurement collection, the optimum value follows considerations that are besides the scope of this paper. However, let assume a speed of 40, 80, and 120 Km/h for vehicles in urban, extra-urban and highways scenarios respectively; in this case, it can be noted that performing measurements every 10s, at least one update will be given from each car crossing an urban road segment longer than 110m, an extra-urban road segment longer than 220m, or a highway segment longer than 330m. Whereas a higher frequency than every 10s appears excessive, a lower frequency would surely be sufficient (especially for non urban roads), and the results shown should be considered as bounds.

With regard to the size, if we assume that 8 bytes univocally identifies the vehicle, 16 bytes are used for time stamp, 8 bytes are sufficient for a precise definition of both latitude and longitude, 8 bytes convey speed and direction information, 16 bytes must be left for other measurements (e.g., related to produced or sensed pollution), and some overhead is needed from the application to the data link layer (24 bytes at the most), the only solution is to adopt a SF=32 and 20ms messages, which allows an 80 byte maximum payload. If, in the future, applications should require the transmission of a higher amount of data, these could be fragmented into segments of maximum 80 bytes each transmitted inside a RACH packet payload. It must be noted, however, that as soon as more accesses to the RACH channel are required for a single measurement, the proposed approach reduces its effectiveness and the use of dedicated resources may be preferable.

**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 from the specific source.

As stated in Section III, a transmission scheduled by the MAC may fail in two cases: when the ramping procedure is unsuccessful, 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 by 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 the following figure of merit:

<table>
<thead>
<tr>
<th>SF</th>
<th>Duration</th>
<th>Payload</th>
<th>Limits on packets/s per cell per RACH/PRACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>10ms</td>
<td>20 bytes</td>
<td>62</td>
</tr>
<tr>
<td>64</td>
<td>20ms</td>
<td>40 bytes</td>
<td>37</td>
</tr>
<tr>
<td>32</td>
<td>10ms</td>
<td>40 bytes</td>
<td>62</td>
</tr>
<tr>
<td>32</td>
<td>20ms</td>
<td>80 bytes</td>
<td>37</td>
</tr>
</tbody>
</table>

**TABLE I LIMITS ON RACH/PRACH CAPACITY.**

poses, the capacity of the RACH/PRACH channels (hereafter RACH) does not represent a limitation. However, planning to use it for the envisioned service, the maximum number of packets that can be transmitted could become a bottleneck.

Depending on the message duration (10ms or 20ms) and the adopted SF, a different amount of bytes can be transmitted in a single packet over the RACH. Taking into account all the overhead at the data link and physical layers, in [24] 320 bits (40 bytes) payloads are supposed for data packets transmitted in 20ms with SF equal to 64 or in 10ms adopting a SF equal to 32. It follows that 20 bytes can be accommodated in a 10ms message with SF=64 and 80 bytes in a 20ms 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 [15], the authors demonstrate that in saturated conditions (i.e., when there is always at least one user trying to access the RACH) 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 10ms and 20ms messages, respectively. These results mean that, when messages of duration $T_{\text{msg}}^{(1)} = 10$ms are transmitted over the RACH, 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 20ms messages.

Following these considerations, in Table I the size of the payload and the maximum number of packets per second per cell per RACH are shown as a function of the adopted SF and transmission duration. Since a transmission every second by any vehicle is clearly much more than needed, these numbers make the RACH capacity far from being the bottleneck of the service. Note, however, that these evaluations only represent upper bounds for the system load, completely neglecting the system limits in terms of transmission power, interference levels, etc.; this limitation will be overcome in the following Sections.

**IV. SERVICE CLASSES AND FIGURES OF MERIT**

In the rest of the paper, numerical results will be obtained considering two classes of service: vehicles equipped with OBUs performing packet transmissions over the RACH (hereafter ITS users), and pedestrians performing voice calls through cellular phones (hereafter voice users). Without lack of generality, voice traffic is assumed as background, both for its stringent QoS requirements and for its typical stationary behavior, thus obtaining results with general validity. Using other traffic flows as background traffic, such as web browsing or file transfer protocol (FTP), would only mean different parameters for the physical channels (SF, coding gain, target signal to noise ratio), with bursty behavior that would heavily put impact on numerical outputs hardly making them general.

**A. ITS Service Settings and Figures of Merit**

To define convenient service settings for ITS users, we tried to answer the following questions:

- How frequently do we need to collect traffic measurements to guarantee an effective real time service?
- How many bytes do we need to transmit from the vehicles to the control center to collect sufficient traffic information?

How many bytes do we need to transmit from the application to the data link layer (24 bytes at the most), the only solution is to adopt a SF=32 and 20ms messages, which allows an 80 byte maximum payload. If, in the future, applications should require the transmission of a higher amount of data, these could be fragmented into segments of maximum 80 bytes each transmitted inside a RACH packet payload. It must be noted, however, that as soon as more accesses to the RACH channel are required for a single measurement, the proposed approach reduces its effectiveness and the use of dedicated resources may be preferable.
• 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 equipment.

B. Voice Service Settings and Figures of Merit

To evaluate the UMTS performance in the considered scenario, the quality perceived by users belonging to other services, different from the ITS one, is also of main interest. Without lack of generality, here we focus on random walking users performing voice calls as an interfered service.

Figures of merit. The evaluation of the quality of service perceived by the 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 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 be submitted to the following situations: 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 \( (R_S) \), 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.

V. INVESTIGATION TOOLS

Once discussed the scenario of interest, in this section the analytical model and the simulation platform that will be adopted for numerical results are described.

A. Analytical model

We propose an analytical model to evaluate the maximum UMTS cell capacity: We firstly derive the maximum distance of a UE from the Node-B as a function of the path loss and the other system parameters (such as the useful power, interference, noise, etc.); Secondly, we detail the analysis to the envisioned service, assuming voice users performing voice calls on dedicated channels and vehicular users transmitting traffic data packets on the RACH.

Assumptions. We base the model on the following assumptions that will be discussed in detail at the end of this Subsection:

• we consider a single cell scenario;
• we focus on the uplink communication direction.

General case. Due to the characteristics of the CDMA technology, to the high number of involved signal sources, to the unsynchronized transmissions by the terminals, and to the effects of multipath, the interference received at the Node-B can be assumed white and Gaussian in the band of interest, with variance equal to the interfering received power.

By defining \( \gamma^{(j)} \) as the average signal to noise plus interference ratio (SNIR) received at the Node-B from the \( j \)th user while he is transmitting\(^1\), it can be written as (see, e.g., [23])

\[
\gamma^{(j)} = \frac{P_t^{(j)} G_p^{(j)}}{P_t^{(TOT)} - P_t^{(j)}}
\]

where \( P_t^{(j)} \) is the average received power, \( G_p^{(j)} \) is the processing gain (i.e., the ratio between the chip rate and the useful bit rate), and \( P_t^{(TOT)} \) is the total received power at the Node-B given by

\[
P_t^{(TOT)} = \sum_{k=0}^{N_u-1} P_t^{(k)} v^{(k)} + P_N
\]

where index \( k \) accounts for the \( N_u \) users, \( v^{(k)} \) is the activity factor (i.e., the percentage of time the terminal is actively transmitting), and \( P_N \) the noise power. By assuming the number of users sufficiently high, the power received from the interested user is negligible with respect to the total received power; hence, (1) becomes

\[
\gamma^{(j)} \simeq \frac{P_t^{(j)} G_p^{(j)}}{P_t^{(TOT)}}
\]

Let us now recall the definition of two important metrics [23]: the load factor and the noise rise. The uplink load factor is defined as

\[
\eta^{(UL)} \triangleq \sum_{k=0}^{N_u-1} \eta^{(UL,k)}
\]

where

\[
\eta^{(UL,k)} \triangleq \frac{P_t^{(k)} v^{(k)}}{P_t^{(TOT)}}
\]

represents the average amount of power received at the Node-B from the \( k \)th user. Hence, by firstly substituting (5) in (4) and then considering (3), we obtain

\[
\eta^{(UL)} = \sum_{k=0}^{N_u-1} \frac{P_t^{(k)} v^{(k)}}{P_t^{(TOT)}} = \sum_{k=0}^{N_u-1} \frac{\gamma^{(k)}}{G_p^{(k)}} v^{(k)}.
\]

Note that \( \eta^{(UL)} \in [0,1] \).

The uplink noise rise is defined in the range \([1,\infty]\) as

\[
\text{NR}^{(UL)} \triangleq \frac{P_t^{(TOT)}}{P_N} = \frac{P_t^{(TOT)}}{P_t^{(TOT)}(1 - \sum_{k=0}^{N_u-1} \eta^{(UL,k)})} = \frac{1}{1 - \eta^{(UL)}}
\]

and represents the increase in disturbance due to the interference from other communications with respect to the noise power.

During the transmission of the \( j \)th user, (3) can also be written as

\[
\gamma^{(j)} = \frac{P_t^{(j)} G_p^{(j)}}{A_t^{(j)} L[d^{(j)}] P_N \text{NR}^{(UL)}}
\]

where \( P_t^{(j)} \) is the average transmitted power (during active transmission), \( G_t^{(j)} \) is the UE antenna gain in the direction of the dedicated channel opened, a transmission is performed when data is present; silence periods are also possible, and the transmitted power is assumed negligible in this case.
the Node-B, $G_i^{(j)}$ is the Node-B antenna gain in the direction of the $j$th terminal, $A_t^{(j)}$ and $A_r^{(j)}$ take into account implementation losses at the transmitter and the receiver, respectively, and $L[d^{(j)}]$ is the path loss due to propagation as a function of the distance $d$.

By solving (8) with respect to $L[d^{(j)}]$, and taking into account that the path loss is a function of the distance $d$, we can finally obtain the maximum distance $d_{\text{max}}$ of user $j$ from the Node-B, defined as the distance corresponding to the maximum transmitted power from user $j$, $P_{\text{max}}^{(j)}$, as

$$L[d_{\text{max}}] = \frac{P_{\text{max}}^{(j)} G_i^{(j)} G_t G_p^{(j)} 1}{A_t^{(j)} A_r^{(j)} \gamma^{(j)} P_{\text{N}} \text{NR}^{(UL)}}.$$  \hspace{1cm} (9)

Please note that the exact position of each terminal does not impact on the above equations; in fact, the system performance is a consequence of the PC mechanism, that is of the power received at the Node-B and not of the power transmitted from the UE.

**Case study.** Specifying to the envisioned service, we consider now the two classes of users stated in Section IV: pedestrian and vehicular users, performing voice calls and packet transmissions over the RACH, respectively, and denoted with superscript (v) for voice traffic and (I) for ITS traffic. All users belonging to the same traffic class are assumed to have the same parameters.

As previously discussed, we assume one RACH channel fully reserved for the ITS traffic. Since it is the presence of the ITS service that can potentially limit the overall network capacity, and since a single user is transmitting at a time, we will equivalently assume a single ITS user ($N = 1$) fully occupying the RACH ($\gamma^{(I)} = 1$).

The RACH that is not used for ITS is neglected in numerical evaluations; this is motivated by two considerations: first of all in that case packets are transmitted using a spreading factor equal to 256, which means a very high coding gain and consequently a very low transmitted power; secondly, accesses to the RACH channel for normal operations are very reduced: the most common use is in fact the dedicated channel request, and even assuming 60 Erlang of traffic with an average of 90 second session duration, they are on average 0.67 per second.

Following these considerations, (4) and (9) thus become:

$$\eta^{(UL)} = N^{(v)} \frac{\gamma^{(v)}}{G_p^{(v)}} + \frac{\gamma^{(I)}}{G_p^{(I)}}$$ \hspace{1cm} (10)

$$L[d_{\text{max}}] = \frac{P_{\text{max}}^{(v)} G_i^{(v)} G_t G_p^{(v)} 1}{A_t^{(v)} A_r^{(v)} \gamma^{(v)} P_{\text{N}} \text{NR}^{(UL)}}.$$ \hspace{1cm} (11)

$$L[d_{\text{max}}] = \frac{P_{\text{max}}^{(I)} G_i^{(I)} G_t G_p^{(I)} 1}{A_t^{(I)} A_r^{(I)} \gamma^{(I)} P_{\text{N}} \text{NR}^{(UL)}}.$$ \hspace{1cm} (12)

**Discussing the model.** Let us discuss in depth the limits of the assumptions on which the model is based.

First: we focus on the uplink, neglecting the downlink direction. In most cases this is correct, since the UMTS network is designed considering the uplink as the limiting direction (worst case). However, the model can be easily extended to include the worst between downlink and uplink, following the well known equations that can be found, for instance, in [23].

Second: we consider a single cell case. This assumption can be easily relaxed considering the factor $i = \frac{\text{other cell interference}}{\text{own cell interference}}$ [23], which relates the inter-cell interference (i.e., from other cells) to the intra-cell interference (i.e., in own cell). In this case the total received power at the Node-B given by (2) becomes

$$P_{t}^{\text{TOT}} = (1 + i) \sum_{k=0}^{N-1} P_t^{(k)} + P_N$$ \hspace{1cm} (13)

and, after few elaborations (10) modifies in

$$\eta^{(UL)} = (i + 1) \left( N^{(v)} \frac{\gamma^{(v)}}{G_p^{(v)}} + \frac{\gamma^{(I)}}{G_p^{(I)}} \right).$$ \hspace{1cm} (14)

Equations (7), (11), and (12) remain unchanged. A good congruity between analysis and simulation could be shown for different values of $i$. However, results are heavily impacted by the effective distribution of the users, which makes the parameter $i$ largely varying from case to case. Since trends are not modified by the introduction of $i$ and its introduction does not add a great value to numerical results, only the single cell case is analytically investigated; a realistic multi-cell scenario will be then discussed through simulations.

**B. Simulation platform.**

To reproduce a realistic scenario we exploit the SHINE simulation platform, which accurately models all the aspects of a real network [25]. Vehicle positions and movements, in particular, are generated either through an in-built feature or through integration with the microscopic traffic simulation tool VISSIM [20], [26]. In the former case, vehicles statistically start from one road, with uniform distribution within cells (hence not uniform in the whole scenario), and move constrained on roads with variable speeds and random turnings; in the latter, vehicles have realistic sources and destinations, and their movements are constrained not only by roads, but also by their 3-D structure and rules of the road.

In SHINE, particular attention was given to the physical level aspects; link level simulations were firstly performed offline, generating two files to be used in the network simulator: one file contains the average BER or the average block error rate (BLER) per transport block, varying the average $\gamma$ in that transport block; the second file contains the fading coefficients perceived by the generic connection in each time slot. The latter file, in particular, reproduces a time correlated fading at the network level, which is often approximated or even neglected in most network simulators.

As an instance, in Fig. 2, the trend for two fading gain, corresponding to the ITU Pedestrian A channel model with the UE moving at 3km/h and the ITU Vehicular A channel model [27] with the UE at 30km/h are shown. Please note that the coherence time of the channel allows us to consider the channel channel as constant in each time slot, whereas the frequency selectivity is correctly taken into account in the off-line link simulator. An example of BLER curve is depicted in Fig. 3 (refer to the right-most curve) for the particular case of packet transmissions over the RACH.
The fading gain is added to the received power together with a distance dependent average path loss, and a shadowing gain depending on the users’ positions (thus correlated in space) and log-normal distributed. Thus, $\gamma$ is evaluated per each connection in each time slot taking into account all the useful link parameters and variations as well as all the interfering links. All aspects able to reflect the real system behavior are reproduced, including for example a non-uniform positioning of Nodes-B, any specific antenna pattern, realistic users’ mobility, and hard, soft, and softer handover mechanisms.

With regard to the simulation of RACH transmissions, in our scenarios the number of ITS packets is always lower than the capacity limit. Hence, we assume that the ramping procedure is performed by users contending for the channel in a first-in-first-out (FIFO) order, and we neglect the effects of collisions due to multiple accesses. Although the former assumption does not perfectly correspond to reality, this does not have impact on our results, since we aim at verifying the success of data transmissions, not the exact delays; the order to access the RACH only impacts on the time spent by a packet in the MAC queue, which is significantly lower than the interval between packet generations, as confirmed by [18]. As for neglecting the effects of collisions, it must be remarked that they mainly occur among preamble transmissions (see Section III), which are shorter than data transmissions (1.07ms) and require less power thanks to a 9dB higher processing gain, with a negligible produced interference.

VI. RESULTS FOR THE SINGLE CELL SCENARIO AS A CASE STUDY

In this Section, we show the impact on the system performance of the adoption of the RACH channel for the ITS service in a single cell scenario. Analytical results derived from the model described in Section V-A will be compared with simulations.

The parameters adopted in our evaluations are summarized in Table II. Among them, $\gamma^{(I)}$ requires further discussion. Its value, in fact, should be kept as low as possible in order to limit the interference of the ITS service on voice users; however, a reduction of $\gamma^{(I)}$ gives a higher packet loss probability for the ITS service at the receiver. To reduce the impact of packets losses without increasing $\gamma^{(I)}$, some retransmissions may be allowed, but retransmissions have an impact on the RACH occupation. Figs. 3 and 4 show the relationship among $\gamma^{(I)}$, $R_D$ and the RACH capacity, assuming 80 bytes as data payload. In Fig. 3, in particular, the probability of having $x$ consecutive fails varying $\gamma^{(I)}$, with $x = 1, 2, 3, 7$. It corresponds to $R_D$ if ramping fails are neglected. The curve with no retransmissions is obtained through link level simulations, assuming the Vehicular A channel model with vehicles at 30km/h; all other curves are obtained assuming independent errors.

![Fig. 2. Example of fading gain for Pedestrian A channel with terminals at 3km/h and Vehicular A channel with terminals at 30km/h.](image)

**TABLE II**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Voice</th>
<th>ITS</th>
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<tbody>
<tr>
<td>$\gamma$</td>
<td>6.4dB</td>
<td>9dB or 11dB</td>
</tr>
<tr>
<td>$G_f$</td>
<td>25.0dB</td>
<td>20.8dB</td>
</tr>
<tr>
<td>$\nu$</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>$ERP_{\text{max}}$</td>
<td>21dB</td>
<td>21dB</td>
</tr>
<tr>
<td>$G_f + A_f$</td>
<td>0dB</td>
<td>0dB</td>
</tr>
<tr>
<td>$P_f$</td>
<td>-133.4dBW (base station noise figure 3dB)</td>
<td></td>
</tr>
<tr>
<td>$PL(d)$</td>
<td>$31.8 + 35.2\log_{10}(d) + M_F$ (d in [m]; no shadowing)</td>
<td></td>
</tr>
<tr>
<td>$M_F$ (*)</td>
<td>12dB</td>
<td>7.5dB</td>
</tr>
</tbody>
</table>

The fading gain is added to the received power together with a distance dependent average path loss, and a shadowing gain depending on the users’ positions (thus correlated in space) and log-normal distributed. Thus, $\gamma$ is evaluated per each connection in each time slot taking into account all the useful link parameters and variations as well as all the interfering links. All aspects able to reflect the real system behavior are reproduced, including for example a non-uniform positioning of Nodes-B, any specific antenna pattern, realistic users’ mobility, and hard, soft, and softer handover mechanisms.

For neglecting the effects of collisions, it must be remarked that they mainly occur among preamble transmissions (see Section III), which are shorter than data transmissions (1.07ms) and require less power thanks to a 9dB higher processing gain, with a negligible produced interference.

![Fig. 3. Probability of having $x$ consecutive fails varying $\gamma^{(I)}$, with $x = 1, 2, 3, 7$. It corresponds to $R_D$ if ramping fails are neglected. The curve with no retransmissions is obtained through link level simulations, assuming the Vehicular A channel model with vehicles at 30km/h; all other curves are obtained assuming independent errors.](image)

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The parameters adopted in our evaluations are summarized in Table II. Among them, $\gamma^{(I)}$ requires further discussion. Its value, in fact, should be kept as low as possible in order to limit the interference of the ITS service on voice users; however, a reduction of $\gamma^{(I)}$ gives a higher packet loss probability for the ITS service at the receiver. To reduce the impact of packets losses without increasing $\gamma^{(I)}$, some retransmissions may be allowed, but retransmissions have an impact on the RACH occupation. Figs. 3 and 4 show the relationship among $\gamma^{(I)}$, $R_D$ and the RACH capacity, assuming 80 bytes as data payload. In Fig. 3, in particular, the probability of having $x$ consecutive fails is depicted as a function of $\gamma^{(I)}$, corresponding to $R_D$ whenever the ramping failures are negligible with respect to the errors at the receiver. The curve with no retransmissions is obtained through link level simulations, assuming the Vehicular A channel model with vehicles at 30km/h; all other curves are obtained assuming independent errors. Fig. 3 highlights that the choice of $\gamma^{(I)}$ is heavily influenced by the maximum number of retransmissions that will be provided. As an example, if a maximum $R_D = 10^{-2}$ is targeted, $\gamma^{(I)} \approx 10$dB is required with no retransmissions, while $\gamma^{(I)} \approx 7$dB is sufficient if the packet is discarded after three consecutive failures. The drawback of allowing a higher number of retransmissions is a reduction of the upper bound on useful data transmitted on the RACH. Hence, in Fig. 4 the maximum average number of useful packets that can be transmitted per second in one RACH (taking into account retransmissions) is shown as a function of $R_D$ for various retransmission limits. Results are obtained starting from the maximum value shown in Table I (i.e., 37 average packets per second) and assuming negligible the ramping failures. As an example, if three attempts and
In particular, in Fig. 5, two scenarios are compared: scenario 1 refers to voice users only; hence, the maximum coverage distance for the voice service is assessed. In scenario 2 one ITS user is also considered, continuously transmitting over the RACH (that is equivalent to consider many users sharing one RACH), and both voice and ITS maximum coverage distance are individuated.\(^2\) Two ramping thresholds \((\gamma^{(I)}=9\text{dB} \quad \text{and} \quad \gamma^{(I)}=11\text{dB})\) are considered for comparison. As can be observed, by fixing the number of voice users, the presence of the ITS service reduces the coverage for the voice service, and a further reduction is caused by an increase of \(\gamma^{(I)}\). However, these reductions are not so critical; if both services are provided, in fact, the system planning is limited by the terminals with the ITS application: in order to guarantee the same coverage to all users as without the ITS service, a more stringent limitation to admitted voice users is required. For example, if 400 meters coverage is planned, more than 120 voice users can be served when no ITS service is offered, whereas this value falls to 105 with \(\gamma^{(I)}=9\text{dB}\) and less then 85 with \(\gamma^{(I)}=11\text{dB}\).

It can also be noted that the effect is heavier where larger cells with lower capacity are planned, such as in interurban areas. Observing, for example, results with 650 meter planning, the ITS service cannot be supported even assuming no ongoing voice calls and the lower \(\gamma^{(I)}=9\text{dB}\).

The interest on the proposed service feasibility is mainly for dense urban areas, which are more sensitive to capillary and real time updates of traffic conditions; hence, a realistic urban scenario is deeply investigated through simulation in the following Section VII; results will confirm in their essence the provided concepts.

### VII. Numerical Results in a Realistic Scenario

Simulation results obtained in realistic conditions (i.e., considering mobility, soft and softer handovers, sectorial antennas, vehicular and pedestrian fading, etc.) are presented here with focus on an urban area. The considered scenario is shown in Fig. 6: it represents a portion of the medium sized Italian city of Bologna, consisting of a rectangular area of the city center measuring 1.8km (longitude) x 1.6km (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. A single frequency planning is considered. In each cell, one RACH is exclusively used by the ITS service. The main parameters assumed in the simulation are listed in Table III.

With regard to mobility, whereas pedestrians can move everywhere in the scenario, vehicle movements are constrained on
TABLE III
REALISTIC SCENARIO: SIMULATION PARAMETERS.

<table>
<thead>
<tr>
<th>Group</th>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Base station</td>
<td>Maximum power Range</td>
<td>10dBW or 3UMW (see Fig. 4)</td>
</tr>
<tr>
<td></td>
<td>Power per broadcaster voice channel</td>
<td>Min. 4dB max. 10dB (relative to Inter-cell, 7 command per time slot)</td>
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<tr>
<td></td>
<td>Interconnected channel</td>
<td>3 channels, each with 10dB power relative to 7 km average</td>
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<tr>
<td></td>
<td>Attributes</td>
<td>1.5 with 0.5 max gain (excluding implementation losses)</td>
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<tr>
<td></td>
<td>reception antennas</td>
<td>5.5 with 0.5 gain relative to inter-cell antenna bias</td>
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<tr>
<td></td>
<td>Power</td>
<td>Min. 36dBm max. 36dBm</td>
</tr>
<tr>
<td></td>
<td>Antennas</td>
<td>Omnidirectional with 0.5 gain (inter-cell implementation losses)</td>
</tr>
<tr>
<td></td>
<td>Receiver characteristics</td>
<td>0.5 tin square, 1.5 hexagon case</td>
</tr>
<tr>
<td></td>
<td>Mobility</td>
<td>Random walk, no constraints (realistic) mean random variable speed distributed between 4km/h and 5km/h, 2 km/h average, 2 km/h standard deviation</td>
</tr>
<tr>
<td></td>
<td>Scenarios</td>
<td>Randomly distributed for equal density per cell. Poissonian random density 16 vehicles in average 500m²</td>
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<tr>
<td></td>
<td>Vehicle cell birth average</td>
<td>Vehicle cell birth average factor 3% (gain in interference calculations)</td>
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<tr>
<td></td>
<td>Vehicle cell birth average factor</td>
<td>Vehicle cell birth average factor 3% (gain in interference calculations)</td>
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<tr>
<td></td>
<td>Quality measurement</td>
<td>Quality measurement; Each user is satisfied if in both directions the average BER per transport block is lower than 2% for 95% of the time</td>
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<tr>
<td></td>
<td>Mobility (statistical distribution)</td>
<td>Mobility (statistical distribution)</td>
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<tr>
<td></td>
<td>Traffic</td>
<td>A single radio channel, 600 in uplink</td>
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<tr>
<td></td>
<td>Traffic (statistical distribution)</td>
<td>200 (corresponding to 3/bps)</td>
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<td></td>
<td>Traffic</td>
<td>52 (bps) (excluding)</td>
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<td></td>
<td>Inner loop power control</td>
<td>No inner loop power control</td>
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<td></td>
<td>Quality measurement</td>
<td>Quality measurement</td>
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<td>Average path loss</td>
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<td>Average path loss</td>
<td>3dB - 10dB as per each in angular (128)</td>
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<td>Maximum path loss</td>
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<td>Eaves</td>
<td>3dB - 10dB as per each in angular (128)</td>
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<td>Indoor loop power control</td>
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<td>Outer loop power control</td>
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<td>Quality measurement</td>
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<td>Average BER per transport block</td>
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<td>Link budget</td>
<td>Link budget</td>
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<td>Quality of service</td>
<td>Quality of service</td>
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<td>Minimum BER</td>
<td>Minimum BER</td>
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<td>Handover settings</td>
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<td>Min-min, Max-max</td>
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<td>Maximum number of packets in uplink</td>
<td>Maximum number of packets in uplink</td>
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<td>Maximum number of packets in downlink</td>
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|                     | Number of cells                               | Number of vehicles without concentrating traffic. The latter approach, also used in [1] and hereafter denoted as statistical, is adopted for comparison; in this case, vehicles are randomly generated in the scenario with the same birth probability in each cell and an average offered load $\Lambda^{(i)}$ (Erlang per km$^2$); then, they randomly move constrained on roads but neglecting rules and physical constrains; this allows us to investigate what would happen in heavier traffic conditions.

In Fig. 7, the distribution of vehicles inside cells is discussed assuming the realistic distribution and the statistical distribution with $\Lambda^{(i)} = 220$; these two situations correspond to a similar average number of vehicles in the overall scenario. In particular, the left (vertical) histogram shows the mean number of vehicles per cell, while the right (horizontal) histogram shows the number of cells with a close number of vehicles.
shows the amount of cells that have a close mean number of vehicles (using steps of 5 mean vehicles). In the realistic case, a very high variability from few vehicles to almost 60 vehicles can be observed. In the statistical case, instead, the distribution is more homogeneous; note that in this case a uniform distribution is used for initial points and that movements slightly privilege cells with more road segments.

Also note that with the realistic heavy traffic distribution, even in the most crowded cell vehicles are always much less then one hundred; thus, even if OBUs perform measurements every ten seconds, transmissions are far from exceeding the limit of 37 per second per cell discussed in Section III.

Given these distributions of vehicles, as for the single cell case, we now evaluate the impact of $\gamma(I)$ on the users’ performance (consider that in the multi-cellular case the probability to lose a packet following a ramping failure plays an important role, and directly relates the optimal $\gamma(I)$ also to the background voice traffic).

In Fig. 8, $R_D$ is shown as a function of $\gamma(I)$, for various values of $\Lambda^{(v)}$, assuming either a realistic distribution or a statistical distribution with $\Lambda^{(I)}=1100$; a maximum of three retransmissions before discard is assumed where not specified differently. The bottom-most two curves refer to the absence of voice traffic in the two vehicular traffic cases, the upper-most curve refers to absence of voice traffic and no retransmissions allowed after packet loss with realistic traffic, and the other curves refer to the presence of voice traffic in various conditions. We remark that the probability to lose a packet due to an error on the channel follows the average $\gamma$ perceived during the transmission, which is equal to $\gamma(I)$ only during the first time slot. In all cases (both realistic and statistical traffic and for all values of $\Lambda^{(v)}$), the trend of the curve is a consequence of two opposite effects: increasing $\gamma(I)$, on the one hand increases the probability that the device do not have enough power to complete the ramping procedure (thus increasing the probability of ramping failure), but on the other hand it reduces the BLER once the ramping procedure succeeds. For this reason, there exist always a target $\gamma(I)$ that gives a minimum $R_D$ following the network load conditions; please note, however, that our objective is not to follow the minimum by far, but to follow the minimum target value of $\gamma(I)$ which makes $R_D$ lower than $10^{-2}$, thus minimizing the generated interference while guaranteeing a sufficient QoS. Focusing on the curves behavior, it can be noted that a very high $\gamma(I)$ is needed if no retransmissions are allowed, even without any voice traffic interfering. Moreover, it is important to observe that the increasing of $\Lambda^{(v)}$ drastically put impact on $R_D$, and that the optimum choice of $\gamma(I)$ is heavily dependent also on the vehicular traffic: in fact, the probability of ramping failures increases as much as the background voice traffic or the ITS interference increase. Aiming to obtain an $R_D$ lower than $10^{-2}$, we choose $\gamma(I)=9\text{dB}$ as the most suited target value to be adopted further on.

The $R_S$ for voice users and the $R_D$ for ITS service are plotted in Fig. 9 and Fig. 10, respectively, as a function of $\Lambda^{(v)}$ for different vehicular traffic conditions. The highest average number of considered vehicles is $\Lambda^{(I)}=2200$; this number is still lower than the RACH capacity limit stated in Section V-B and is almost 10 times the one obtained through the VISSIM simulator. Moreover, it should be noted that in congested conditions, acquiring a packet every 10s from each vehicle would be redundant, and that the communication traffic load could be thus reduced by diminishing the frequency of collection.

In Fig. 9, $R_S$ of voice users is depicted and the case with no ITS service is shown for comparison. Considering the realistic traffic distribution and the statistical one with $\Lambda^{(I)}=220$, no relevant losses are noticeable. For further vehicular traffic load, by fixing a target $R_S$, $\Lambda^{(v)}$ decreases with the increasing of vehicular traffic. For instance, if $R_S=0.95$, the loss in terms of $\Lambda^{(v)}$ reaches 70 (≈10%) voice users per Km² with $\Lambda^{(I)}=2200$. The number of attending voice users is thus affected by the ITS service only if a very crowded situation is considered.

In Fig. 10, the $R_D$ as a function of $\Lambda^{(v)}$ is plotted for different vehicular traffic conditions. Also in this case, no particular difference can be appreciated comparing the realistic distribution and the statistical distribution with $\Lambda^{(I)}=220$. Furthermore, the higher the network load, the higher the $R_D$, and the QoS of
the ITS service results deteriorated. If $\Lambda^{(v)}=740$, 710, and 670 (corresponding to $R_S=0.95$) are taken as reference values for $\Lambda^{(i)}=220$, 1100, and 2200, respectively, a packet loss higher than 7% can be observed, meaning that guaranteeing a $R_S=0.95$ to voice users, does not imply that the ITS users are also served. Thus, to improve the QoS of the ITS service, a lower number of voice calls must be accepted by the system. 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%), 150 (20.3%), and 200 (27.0%) average voice users per Km² must be considered for $\Lambda^{(i)}=220$, 1100, and 2200, respectively, drastically reducing the voice users’ capacity.

VIII. FINAL DISCUSSIONS AND FUTURE WORK

Focusing on a dense urban scenario where small but crowded cells are planned and observing both analytical results (Section VI) and simulations in a realistic scenario (Section VII), it can be concluded that the acquisition through the RACH of small but frequent measurements from vehicles is possible, although at some cost. It was shown in fact that the ITS service is affected by interference more than the voice service and this leads to the need in a reduction of more than 10% of the capacity in order to guarantee a full coverage, even with a limited number of vehicles. This effect is essentially due to the absence of softer handovers for the RACH (that allow 2-3dB gain [23]), to a high required signal to noise ratio (9dB compared to 7dB for voice), and to a low coding gain (20.8dB compared to 25dB for voice). The effect would be more or less the same considering data traffic as background; note that, in fact, at cell edge the reasonable data rates correspond to a lower processing gain with respect to voice but the required signal to noise ratio is reduced thanks to more robust channel coding and to retransmissions.

Furthermore, analytical results highlight that the considered strategy “as it is” could not be feasible where cells are planned for high coverage with low capacity, such as in interurban scenarios; in such a case, in fact, there are areas too far from all Nodes-B for the envisioned ITS service, even with no other ongoing traffic. Note however that in such scenario the reduced number of roads and the limited alternatives do not motivate the acquisition of measurements from all vehicles with such strict delay constrains.

In any case, advanced strategies could be investigated in order to limit these drawbacks, such as: the fragmentation of packets into smaller parts that can be transferred with a higher processing gain, but with an increased occupation of the resources in the time domain; the storing of data until a better coverage is not reached, implying a higher average delivery delay; the use of vehicle to vehicle communication in order to quickly collect higher amounts of measurements in one vehicle and then justifying the use of unicast transmissions. Future work will also investigate the impact in the uplink of small but frequent packets through the oncoming long term evolution (LTE) technology, which will complement or replace UMTS in the next years. Adopting LTE, the focus will not be on the use of RACH, since the RACH is used in the uplink for control purposes only and does not carry data. This choice in LTE is due to a significant reduction in latencies introduced from the beginning in its design. Hence, envisioning the real time transmission from vehicles to control center via LTE, shared channels must be considered.

IX. CONCLUSIONS

We considered UMTS as the enabling technology for the real time traffic acquisition from vehicles. By assuming that each vehicle periodically transmits at least its position and speed to a control center through the common RACH channel, we evaluated the impact of such a communication on other services already provided by UMTS. This evaluation has been performed both analytically and by simulation: we analytically evaluated coverage and capacity in a single cell case, we validated the mathematical model by simulations, and we extended our simulations also to a realistic urban scenario with multiple cells and users mobility. 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 non-negligible loss in capacity for the other services must be accounted for in order to guarantee a satisfactory quality of service.

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Barbara M. Masini (S’02-M’05) received the Laurea degree (with honors) and the Ph.D. degree in telecommunications engineering from the University of Bologna, Italy, in 2001 and 2005, respectively. In 2002, she joined the Department of Electronics, Informatics and Systems at the University of Bologna, to develop his research activity in the area of wireless communications. Since 2005, she is a researcher at the Institute for Electronics and for Information and Telecommunications Engineering (EIIT), of the National Research Council (CNR), working on wireless transmission techniques. Since 2007 she is external lecturer at the University of Bologna where she holds the courses of Telecommunication Laboratories including experimental implementation of telecommunication systems on digital signal processing platforms. Her research interests are mainly focused on the physical layer of OFDM and MC-CDMA systems, short-range wireless communications, and coexistence among different wireless systems. She is now interested in intelligent transportation systems (ITS) working on research projects sponsored by industries and Ministries in the field of vehicular networks. Dr. Masini is a member of the IEEE Communication and Vehicular Technology Societies and acts as Reviewer and technical program committee for several IEEE journals and conferences.

Alessandro Bazzi (S’03-M’06) received the Laurea degree (with honors) and the Ph.D. degree in telecommunications engineering from the University of Bologna, Bologna, Italy, in 2002 and 2006, respectively. In 2003 he joined the Institute for Electronics, and for Information and Telecommunications Engineering (EIIT), of the National Research Council (CNR), in Bologna, working as researcher. Since the academic year 2006/2007 he teaches as external lecturer in courses at the University of Bologna and the University of Ferrara, Italy. His research interests include performance investigation of wireless systems such as Wi-Fi, WiMax, cellular technologies, and heterogeneous networks, with focus ranging from physical level to medium access control and radio resource management. Recent studies also include wireless technologies applied to intelligent transportation systems (ITS). Dr. Bazzi also acts as reviewer and technical program committee for several IEEE journals and conferences.

Oreste Andrisano (M’83) received the Dr. Ing. degree in electronic engineering cum laude from the University of Bologna, Bologna, Italy, in 1975. In the same year he joined the University of Bologna, where he became a Professor of Electrical Engineering in 1985. He has been Director of CSITE (Centro di Studio per l’Informatica e i Sistemi di Tele comunicazioni, C.N.R.) in the period 1993–2002, and Director of the Laboratorio Nazionale di Comunicazioni Multimediali (CINT) in Naples since the foundation to 2002. His research activity deals with digital signal processing, wireless local area networks, and cellular systems. He has been coordinator of different research projects at international and national level in the area of Multimedia, Intelligent Transportation Systems, and e-learning. He has been a consultant for various industries, such as Siemens Mobile, Telecom Italia Mobile and Alcatel Alenia Space. Dr. Andrisano is a member of the IEEE Communication and Vehicular Technology Societies and of the IEEE Radio communication Committee.