Real Time Traffic Updates via UMTS: Unicast versus Multicast Transmissions

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Abstract—Real time traffic information systems represent a growing sector of the wireless communication industries. To provide traffic information to drivers in a short term, cellular systems represent the answer: on the one hand many vehicles are equipped with global positioning system (GPS) navigators integrating cellular devices; on the other a large percentage of people has smart phones integrating advanced positioning systems. In this paper we aim at evaluating the feasibility of real time traffic information transmission to drivers by exploiting the universal mobile telecommunication system (UMTS) as the enabling technology. In particular, we compare the performance in the downlink of a urban scenario of the UMTS adopted in unicast and multicast mode, in terms of service feasibility and impact on the capacity left for other services. Results, performed through a simulation platform integrating a vehicular simulator tool together with a UMTS network simulator, will show which between unicast and multicast has to be preferred as a function of the considered environment.

I. INTRODUCTION

To let information technologies really impact on traffic management, real time information has to be communicated to vehicles on a real time basis, providing up-to-date personalized and scaled information related to traffic conditions and suggesting alternative routes in case of congestions [1] [2] [3]. Many efforts are underway from the academic community, automotive manufacturers and governments to face the challenges offered by new vehicular applications and services. To this aim, a large standardization process has to be established; in Europe, several projects and consortia [4], [5] and relevant standardization bodies are working on the development of new standards to define common intelligent transportation systems (ITS) communication architectures letting vehicles, roadside units, and wireless infrastructure communicate and cooperate. Also in USA [6] and in Japan [7] big efforts are being pushed to solve problems generated by traffic. However, still some years have to be spent before a real convergence toward a set of European or worldwide standards for ITS.

Different wireless access technologies could be exploited, from short-range ad-hoc networks [8], [9] to cellular systems. However, vehicular ad-hoc networks (VANETs) can only be viewed as a long term solution since standardization is not come to a complete decision and some problems has still to be solved. Moreover, huge investments have to be foreseen both for in-vehicle and roadside infrastructure.

Due to the widespread diffusion of connected on-vehicle navigators and smart phones with positioning applications, cellular systems represent the short term solution to solve the problem of real time traffic information to and from vehicles, so to suggest alternative routes and avoid congestions. This is confirmed by recent publications [10]–[13] and market trends: for instance, in Italy over one million vehicles are already equipped with on board units (OBUs) periodically transmitting their position and speed to a remote control center through the general packet radio service (GPRS) [14], and many vehicles are worldwide equipped with connected smart navigators receiving via GPRS updated traffic information.

In this work we envision to transmit in the downlink information concerning the roads of interest to all users equipped with connected smart navigators in order to dynamically help in defining the best route on a real time and personalized basis. At this scope we consider the wideband code division multiple access (WCDMA) technique, adopted in the universal mobile telecommunication system (UMTS) [15] in the frequency division duplex (FDD) version as the enabling technology, exploiting the already existing and worldwide developed infrastructure, without additional set-ups.

In particular, we aim at comparing the performance of UMTS in unicast and multicast mode for the provision of the envisioned real time service when voice traffic is assumed as background.

A preliminary investigation of only the multicast service for infomobility application was given in [2], but without considering soft handovers (for voice calls) and soft combining technology (for infomobility sessions) that are typical of the UMTS service and increase the quality of service (QoS) itself.

Please also note that even if the UMTS performance has been widely investigated in the literature, it has not been designed for this kind of services. Hence, due to the increasing number of equipped vehicles and to the growing request for new real time infomobility services, the performance of the UMTS network in this new context has to be investigated. In particular, we:

- Verify the feasibility of the foreseen real-time service (hereafter ITS service) both in unicast and multicast mode;
- Evaluate the impact on system capacity with reference to satisfied voice users that can be served when part of the
available resources are dedicated to the ITS service;
- Evaluate the QoS perceived by the ITS users.

The paper is organized as follows: in Section II the considered scenario for the envisioned service is described; in Section III, UMTS as the enabling technology is briefly described in its main characteristics for the unicast and multicast modes. In Section IV, the simulation platform developed for the evaluation of the realistic scenario is highlighted. In Section V, ITS and voice services characteristics are given, and in Section VI numerical results are presented. Our conclusions are drawn in Section VII.

II. SCENARIO AND TRANSMISSION STRATEGIES

We exploit the existing UMTS architecture to allow the provision of real time information to vehicles, thus helping the management of traffic, and drive dynamic navigation systems choices. The reference scenario is exemplified in Fig. 1: vehicles can receive updated traffic information either through dedicated unicast channels or via multimedia broadcast multicast service (MBMS).

Pedestrian users perform voice calls as background traffic to remark that the ITS service shares the same resources of the already available UMTS services.1

As reference scenario, we consider the city of Bologna, Italy, which is a densely populated medium-size city affected by traffic and congestions in many areas. As depicted in Fig. 2, a realistic number of UMTS Nodes-B are distributed in the city-center and in the first suburbs.

The following strategies, thoroughly described in [3], are assumed for traffic updates.

- For the unicast mode, the update involves road segments encompassed by an ellipse whose focuses are the actual vehicle position and either the next intermediate point or the final destination. This strategy avoids the transmission of information related to road segments too far from the actual vehicle position, which would be out of date when the vehicle needs it. Moreover, since only the transmission of the coordinates of two points is needed from the navigation system to the control center, the amount of data transmitted in the uplink is very small, thus limiting costs and resource occupation. Following numerical considerations of [3], in this work 1000 road segments (if updates are needed in both directions, they count as two road segments) are supposed to be updated every 5 minutes.

- For the multicast mode, a progressive coverage strategy is considered, consisting in the transmission to the on-board navigator of the information related to the most important roads at national level and regional level, and to the minor roads at local level only. Following numbers discussed in [3] and noting that not all road segments are congested at the same time, in this work 12000 road segments will be updated in average (corresponding to the 2% of about 300000 road segments practicable in two directions).

Independently on the unicast or multicast communication technology, we assume the adoption of the transport protocol experts group (TPEG) technology [16] at the highest layers of the protocol pillar. TPEG, in fact, will represent the European high layers standard protocol to transmit information to vehicles. TPEG specifications define in details few main applications but do not limit the use of TPEG to them; among these it also defines the road traffic message (RTM) application to transmit updated traffic information, that is the application considered in this work. TPEG standard does not define the size of the message; following the experimental implementation performed in the Korean city of Daejeon [17], in this work we assume to transmit a 60 bytes packet per each road segment (one packet per direction).

III. UMTS AS THE ENABLING TECHNOLOGY

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

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

As far as MBMS is concerned, it is intended to efficiently exploit the radio resources by transmitting data over a common radio channel, both in the core network and in the radio access network [18]–[20]. One of the most important properties of MBMS is the sharing of resources among many user

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1Note that we could also consider internet data packets as background, but, due to its variability and its dependency on the particular traffic type, it would not be possible to give answers with general validity. For this reason we consider voice as background traffic.
equipments (UEs), meaning that many users can listen to the same MBMS channel at the same time. Hence, power is allocated to the MBMS channels only once for any number of UEs in the cell receiving the service. MBMS can operate both in broadcast (data transmitted to all the capable UEs without any subscription procedure) and multicast mode (data transmitted to only the UEs that have joined a multicast group after a subscription procedure). In our scenario, we assume that vehicles are equipped with MBMS units joining the multicast group where ITS messages are distributed.

It has to be remarked that MBMS uses part of the available power at the base station, thus limiting the number of DCHs that can be established. Moreover, the broadcast/multicast nature of the channel does not allow to exploit the fast power control feature that is of main importance for an interference limited system like UMTS; the base station pre-assigns a certain amount of power to MBMS services depending on the coverage planning and the desired bit rate [21].

IV. EVALUATION TOOLS

The investigation of the highlighted scenario, clearly put in evidence that, to give significant evaluations, we require not only a complete UMTS simulator jointly taking into account all the aspects of the protocol pillar, but also realistic vehicular scenarios. In fact, the position in time of the vehicles significantly impacts the performance of the telecommunication networks; for example, having vehicles grouped in small areas does not impact the wireless communication as it does having an uniform distribution of cars in the scenario. A realistic mobility model is thus needed, and it has to take into account all roads with speed limits, vehicles speed acceleration and decelerations, queues at traffic lights, etc.

Hence, we exploit the simulation platform developed in the context of the Italian project PEGASUS [14], which integrates VISSIM [22] as vehicular traffic simulator and the simulation platform for heterogeneous interworking networks (SHINE) [23] as UMTS network simulator, thus allowing us to provide realistic results both in terms of vehicular traffic (with queues, number of lanes, one way roads, etc.) and communication system [24].

Vehicular simulator: VISSIM [22]. It is a microscopic simulation tool modelling traffic flow in urban areas as well as interurban motorways, and allowing to reproduce car-following and lane changing as in real scenarios. It uses a psycho-physical car following model for longitudinal vehicles movement and a rule-based algorithm for lateral movements. VISSIM allows to be controlled by external applications with the use of a component object model (COM); by the adoption of dynamic link libraries (DLL), it is possible for an application to control the movement of vehicles and to manage the whole simulation.

UMTS simulator: SHINE [23]. It is an event driven dynamic simulator which allows to jointly take into account the whole UMTS network architecture from the application layer to the physical layer, also carefully reproducing the time and frequency correlated behavior of the wireless medium.

Vehicular and network simulator integration. We realized a flexible architecture integrating VISSIM with SHINE through sockets and remote procedure calls (RPCs), thus enabling the realistic simulation of vehicular traffic together with real-time networks communications.

V. SERVICE SETTINGS AND FIGURES OF MERIT

Users belong to two classes: pedestrian and vehicular. Pedestrians users move on the entire scenario, without being constrained on roads, and perform voice calls; vehicular users move constrained on road following realistic mobility models, and receive ITS information.

A. ITS Service

1) Unicast Mode: Following the assumptions made in Section II, vehicles receive updated traffic information through a 60000 bytes download (i.e., 1000 road segments × 60 bytes) every 5 minutes. Data are transmitted adopting the transmission control protocol (TCP) that assures data reception: since retransmissions are provided also at transport level, in fact, losses at link level will affect delay rather than reducing data reliability.

Bearer A 64 kb/s bearer is considered, corresponding to a logical dedicated traffic channel (DTCH), a transport dedicated channel (DCH), and a physical dedicated data channel (DPDCH)." The DPDCH is transmitted adopting a spreading factor (SF) equal to 16 in uplink (note, in fact, that a dedicated unicast communication is required also in the uplink direction for the TCP acknowledgment transmission) and 32 in downlink. A transmission time interval (TTI) of 10 ms is assumed. Turbo code with rate 1/3 is used.

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

2The low amount of bytes and the relaxed delay requirements do not justify the use of more consuming bearers.
2) Multicast Mode: Data are transmitted adopting the user datagram protocol (UDP) at transport level, which introduces limited redundancy but do not grant reliable communications; in this case, in fact, the absence of the uplink connection does not allow confirmations and retransmission by receiving devices.

Bearers. Two bearers at 64 and 128 kb/s are considered, each corresponding to an MTCH (MBMS transport channel) logical channel, a FACH (forward access channel) transport channel and a S-CCPCH (secondary common control physical channel) physical channel. The S-CCPCH is transferred (obviously, in downlink) adopting a SF equal to 64. A TTI of 40 ms is assumed. Turbo coding with rate 1/3 is used. Note that the adoption of soft combining considerably improve the MBMS performance [25].

Figure of merit. An ended ITS session is considered in outage when it does not correctly receive at least the 95% of packets (no retransmissions are possible due to the multicast nature of the service).

B. Background Service: Voice

Bearer. A 12.2 kb/s bearer is considered for the voice traffic, corresponding to a logical dedicated traffic channel (DTCH), a transport dedicated channel (DCH), and a physical dedicated data channel (DPDCH). The DPDCH is transmitted adopting a spreading factor (SF) equal to 64 in uplink and 128 in downlink. A TTI of 10 ms and convolutional code with rate 1/3 are assumed.

Figures of merit. 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 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. Thus, voice users are satisfied if they are not blocked, neither dropped, nor in outage.

VI. Numerical Results

Numerical results are here shown and discussed with reference to the scenario of Fig. 2: 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 and roads with vehicles in a random instant are also shown. Dense vehicular traffic with several queues is considered.

To give an idea of the amount of vehicles in the scenario, we plot in Fig. 3 the average number of equipped vehicles in each cell. As can be observed, the maximum average number of vehicles is below 70 (the most crowded cell is the number 17, see Fig. 2) and corresponds to a dense populated scenario with vehicles in queue in some points. Please note that the traffic is not uniformly distributed over the territory; moreover, there are cells with many vehicles and cells with almost none, following the fact that coverage was planned with other services in mind.

In Fig. 4 the maximum voice capacity normalized in a one Km² area is plotted as a function of the number of equipped vehicles receiving updated traffic information via a dedicated unicast channel. In particular, the x-axis represents the ratio δ of vehicles that are equipped with the smart device. The y-axis represents the maximum amount of voice calls that allow the system to serve both traffic classes with a satisfaction rate (i.e., ratio of satisfied users over the number of users of that class) greater than 95%. When the number of equipped vehicles is zero, we obtain results referred to the presence of voice only, considered as a benchmark (695 average voice calls). We can observe that, as the number of equipped vehicles receiving updated information increases, the maximum number of voice calls (i.e., the number of voice users) decreases, due to larger resources dedicated to the ITS service. However, we can note that, if the 50% of vehicles were equipped with smart navigators receiving updated information in unicast mode, the system could serve them also satisfying about 620 voice calls per Km². If all vehicles were equipped (δ = 1), the capacity of the system in terms of servable voice calls would, instead, be halved.

Multicast results, shown in Fig. 5, are obtained varying the power used to transmit the S-CCPCH carrying the MTCH channel of the MBMS channel (which is used for the ITS service). More specifically, a constant fraction of the maximum available power at the base station is reserved for this use. This parameter is given in decibels; for instance, if −20 dB is considered for the multicast/broadcast channel in a cell where the maximum power is 10 dBW, it means that the S-CCPCH is transmitted at −10 dBW. In Fig. 5 results are presented...
assuming the fraction of Node-B power dedicated to MBMS in the x-axis and the maximum amount of voice calls (per km$^2$) that allow the system to serve both classes of traffic with at least 95% satisfaction rate in the y-axis. Multicast at 64 kb/s and 128 kb/s are compared. As can be observed, independently on the adopted bearer, the number of voice calls increases with the power dedicated to MBMS until a maximum, then it start decreasing: low power levels to the MBMS service, in fact, require low interference in order to guarantee a full coverage to the ITS service, while high power levels generate strong interference that limits the number of servable voice calls. We can thus note that a trade off between voice and ITS service can be obtained for both 64 kb/s and 128 kb/s, corresponding to -18 dB to MBMS with 690 average voice calls and -16 dB to MBMS with 500 average voice calls, respectively. These numbers also highlight that the adoption of a 128 kb/s bearer greatly reduces the number of voice calls with respect to the 64kbps case.

Whereas Figs. 4 and 5 show the impact of the ITS service from the point of view of system capacity, in Fig. 6 the perceived delay is shown. In particular, the cumulative distribution function (cdf) of the time required by the receiving device to update road segments conditions is shown for both unicast and multicast services. Note that, since multicast information is transmitted at constant bit rate with no retransmissions, updates delay is a constant value in this case. The cdf for the unicast case has been plotted assuming $\delta = 0.65$ and $\delta = 1$ with the maximum number of voice calls. Fig. 6 shows that observing perceived delays, the unicast solution always outperforms the multicast solution, and that a 64 kb/s multicast transmission have significant update delays; it must be considered, however, that in the multicast case the information is continually retransmitted (in a carousel way), whereas in the unicast case updates are sent only every 5 minutes.

Finally, in Fig. 7, the impact of the load introduced by the new service on the core network is depicted; in particular, the amount of data (in terms of kbytes per minute) that are transferred in the downlink from the service provider is shown both in the unicast and in the multicast case. In the unicast case, each connection requires new information, whereas in the multicast case information is shared and resources in the core network are thus not uselessly wasted. It can be noted that, from this point of view, the unicast solution has a heavier impact as soon as more than the 50% of vehicles are receiving traffic updates.

VII. CONCLUSIONS

In this paper we considered UMTS as the enabling technology to provide real time traffic information to vehicles. Results have been obtained through simulations performed in realistic traffic and network conditions, by exploiting an integrated simulation platform jointly considering both realistic road maps, traffic, and UMTS systems characteristics, from transmission, medium access, up to the application level. We showed that the envisioned service is feasible via UMTS both in unicast and multicast mode with some resources reduction for the voice service assumed as background traffic. In particular, results demonstrated that in order to guarantee a satisfactory quality of the considered service and maximize the capacity for the others, multicast should be preferred for high densities of vehicles, whereas unicast transmissions can be considered with low densities; with unicast transmissions, in fact, when a limited number of vehicles is served only a slight reduction of capacity available for other services was observed, whereas multicast transmissions may have a higher impact on the available resources, but do not depend on the number of served vehicles. Moreover, in the multicast case an accurate choice of the transmitted power is needed in order to maximize the system capacity and such optimization depends on the assumed bit rate; in particular, 64 kb/s and 128 kb/s data transmissions were compared, highlighting that the latter, although requiring half the time for an update, reduces...
resources for the other services of more than 25%. Note also that we adopted soft combining at multicast receivers, that contributes to improve the multicast QoS, especially for higher order bearers.

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Fig. 6. Cumulative distribution function of the delays for the updates of traffic information to vehicles. Comparison between unicast and multicast.