UMTS on the Road: Broadcasting Intelligent Road Safety Information via MBMS

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***Abstract*—In this work we explore the feasibility of implementing infrastructure-to-vehicle (I2V) communication through the UMTS infrastructure. We identify the problems that arise when providing I2V services on top of legacy UMTS networks as conceived in 3GPP Release 5 and consider an I2V architecture that exploits a new feature introduced by 3GPP Release 6, namely the multimedia broadcast/multicast services (MBMS). By means of an analytical model, we quantify the performance achievable with both releases in some realistic scenarios. We show that MBMS is able to provide I2V services efficiently on top of the UMTS network.**

I. INTRODUCTION

Traffic telematics has recently gained considerable interest in the research community and is now among the hot topics for industry-driven research. Several public co-funded projects and associations (e.g. [1]–[5]) are working on architectures, services, and application scenarios for intelligent transportation systems (ITS). Typical ITS services include high speed and safe distance warning, lane keeping support, intersection safety, road congestion warning, accident warning, etc. All these services aim at increasing road safety by providing timely information directly to the car and/or to the driver so as to prevent accidents. The problem of ensuring timely and reliable communication amongst all the involved entities (vehicles and infrastructure elements) remains a central issue in the development of any ITS. Most of the running projects (e.g. [1]–[3]) pursue the development of new standards and ad-hoc technologies for infrastructure-to-vehicle (I2V) and vehicle-to-vehicle (V2V) communication (e.g. 802.11p), while few others (e.g. [4] and [5]) focus also on the possibility to provide such services by reusing existing technologies (e.g. CEN TC278, DAB, GPRS/UMTS).

The traffic characteristics of ITS applications differ in general from the voice/data traffic patterns found nowadays in operational UMTS networks. Typical ITS traffic flows consist of small packets, sparse in time and directed to many different users. On the other hand, the mechanisms of dynamic radio channel assignment/release that are commonly in place in current UMTS networks are designed and optimized for relatively dense flows directed to a single user. In other words there is a mismatch between the requirements of most ITS applications and the connectivity services delivered by currently deployed networks based on Release 5. Such mismatch leads to an inefficient usage of the available resources imposing a severe limit to the sustainable number of users. In this work we quantify this limit in a realistic application scenario and propose to overcome the problem by means of the multimedia broadcast/multicast services (MBMS) as introduced in Release 6 [6]. In order to quantify the benefit of MBMS, we extended the analytical model presented in [7] by taking into account the MBMS channel overhead. Finally, we used the extended model to analyze the coexistence between dedicated channels (DCH) and MBMS channels. To the best of our knowledge this is the first work that addresses explicitly the technical and architectural aspects related to the adoption of MBMS for ITS services.

The remainder of this paper is organized as follows: In Section II we describe the analytical model. This is used as the basis for the analysis of ITS-over-UMTS performance presented in Section III. In Section IV we introduce MBMS and define a parametric model for system-level capacity requirement, taking into account the most critical system variables on the sides of the network (e.g. cell configuration, available bearer services), road (e.g. number of lanes and segments, road congestion), and applications. From this model we derive a worst case reference scenario used for exploring the feasibility of ITS-over-MBMS.

II. UMTS CELL CAPACITY MODEL

The UMTS cell capacity in the downlink is limited by the total available power at node B. A well-known method for estimating the required node B's transmission power (and thus its capacity) has been presented in [7]. The model is based on the assumption that user equipments (UE) in the DCH are able to get exactly the required E_b/N_0, i.e. the fast power control works ideally:

$$\left(\frac{E_b}{N_0}\right)_i = \frac{\dfrac{E_{c,i_{\rm DPCH}}}{L_{m,i}}\left(\dfrac{W}{R_i}\right)}{(1-\alpha_i)\,\dfrac{I_{\rm or}}{L_{m,i}} + \displaystyle\sum_{\substack{n=1\\n\neq m}}^{N}\left(\frac{I_{\rm or}}{L_{n,i}}\right) + P_N} \quad (1)$$

where $E_{c,i_{\rm DPCH}}$ is the expected transmission power at node B to UE i, W is the chiprate, R_i is the bitrate for the selected service, $L_{m,i}$ is the path loss from the serving node B to the UE i, $L_{n,i}$ is the path loss from another node B n to the UE i, N is the number of relevant neighboring nodes B, $I_{\rm or}$ is the total transmission power of the nodes B (assumed to be equal for all the surrounding nodes B), α_i is the codes orthogonality

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factor, and P_N is the thermal noise power. The first and the second terms in the denominator represent respectively the intra-cell and inter-cell interference. Solving (1) for $E_{c,i_{\mathrm{DPCH}}}$, we obtain the transmission power required at node B to serve the UE i on a dedicated channel,

$$E_{c,i_{\mathrm{DPCH}}} = \frac{\left(\frac{E_b}{N_0}\right)_i R_i}{W} \left[(1-\alpha_i + f_{\mathrm{DL}}) I_{\mathrm{or}} + P_N L_{m,i}\right] , \quad (2)$$

where $f_{\mathrm{DL}} = \sum_{n=1,n\neq m}^{N} \frac{L_{m,i}}{L_{n,i}}$ represents the interference factor. The maximum number of users in DCH would be reached when

$$\sum_{i=1}^{N_{\mathrm{users}}} E_{c,i_{\mathrm{DPCH}}} = I_{\mathrm{or}} \quad (3)$$

is satisfied. Equation (3) is valid when only DCH are provided within the cell. In the following we extend this model to take into account the power overhead caused by the introduction of MBMS. In fact, a fraction of the I_{or} needs to be assigned statically to the high bitrate FACH channel used to carry MBMS data. Equation (3) becomes

$$\sum_{i=1}^{N_{\mathrm{users}}} E_{c,i_{\mathrm{DPCH}}} = (1-\mu_{\mathrm{OH}} - \mu_{\mathrm{MBMS}}) I_{\mathrm{or}} \, , \quad (4)$$

where μ_{MBMS} is the power overhead due to the MBMS introduction and μ_{OH} is the power overhead due to the other common channels. Note that μ_{MBMS} depends only on the MBMS quality requirements and the MBMS bearer bitrate. By restricting the model to the traffic telematic services, it is reasonable to assume that all connections will present the same bitrate and quality requirement. Equation (4) would lead to

$$(1-\mu_{\mathrm{OH}} - \mu_{\mathrm{MBMS}}) I_{\mathrm{or}} = \\ = N_{\mathrm{users}} \left[\frac{\frac{E_b}{N_0} R}{W} (1-\alpha + f_{\mathrm{DL}}) I_{or} + \frac{\frac{E_b}{N_0} R}{W} P_N L \right] . \quad (5)$$

The estimated maximum number of users on the dedicated channels[1] is therefore given by

$$N_{\mathrm{users}} = \frac{(1-\mu_{\mathrm{OH}} - \mu_{\mathrm{MBMS}}) I_{\mathrm{or}}}{\frac{\frac{E_b}{N_0} R}{W} (1-\alpha + f_{\mathrm{DL}}) I_{\mathrm{or}} + \frac{\frac{E_b}{N_0} R}{W} P_N L} . \quad (6)$$

This model forms the basis of the following discussion, where we analyze the offered cell capacity for specific traffic telematic services.

[1]Note that we do not consider here the channelization code limit as we verified that in our scenarios it was much looser than the power limit

	Relative Delay (ns)	Relative Mean Power (dB)
1st detected path	0	0
2nd detected path	260	-3
3rd detected path	521	-6
4th detected path	781	-9

TABLE I
MOBILITY CHANNEL

III. ITS-OVER-UMTS

As a starting point we explore the performance that can be achieved when ITS services are offered through conventional dedicated channels. In other words, MBMS functionalities are not utilized, i.e. $\mu_{\mathrm{MBMS}} = 0$. During the study it turned out that the communication performance is affected by several operator-dependent parameters in the radio network: inactivity timers and thresholds, handover and cell-reselection parameters all have a strong impact on the global system efficiency. Moreover, the dynamic nature of the traffic conditions makes it very difficult to find an optimal static setting. The critical requirements change dramatically in the two extreme road situations: congestion and fluent high-speed traffic. In the case of congestion a larger cell capacity is needed, while for high speed traffic the support of mobility becomes critical. Notably different radio channel models have to be considered in the analysis of different road conditions. We evaluate the cell capacity both for the stationary and the high speed mobility case. For the latter we use the channel model defined as "case 3" in the UMTS standard [8] and described in Table I. Note that E_b/N_0 is mostly a function of the mobility channel and service requirements as defined in [8].

We analyze the performance of a UMTS Release 5 configuration in terms of the number of users that use the ITS services. The unicast nature of the DCH places a strict limitation on the maximum number of users-per-cell that can be served with ITS: a separate DCH must be setup for each user, causing multiple content duplications, hence wastage of the overall capacity. The spreading factor (SF) of the DCH plays an important role in the calculation of the maximum offered cell capacity. Table II summarizes the results considering that SF=256 is sufficient to meet the considered ITS service requirements, i.e. each user being able to receive simultaneously up to 8 service updates of 50 bytes. Note that the calculation in (6) does not consider the additional delay overhead caused by the channel assignment/release procedures. Hence, the values in Table II represent a theoretical performance bound.

Road Condition	Congested	Fluent
Channel Model	Stationary	High-speed mobility
$E_{c,\mathrm{DPCH}}/I_{\mathrm{or}}$	-22.6dBm	-19.8dBm
Max number of simultaneous users	136	71
Max Downlink Cell Capacity	1.6Mbps	866Kbps

TABLE II
DOWNLINK CELL CAPACITY

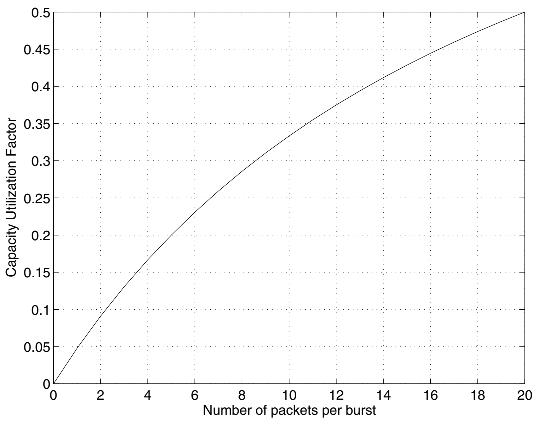

Fig. 1. Capacity Utilization Factor vs. Number of packets per burst

These additional delay components are much larger than the transmission time of a few packets and reduce the achievable capacity utilization. The latter depends on the number of service updates that are sent in the same transmission burst. In other words, the achievable cell capacity is obtained by multiplying the results in Table II with a capacity utilization factor γ defined as

$$\gamma = \frac{T_{\text{burst\_transmission}}}{T_{\text{assignment}} + T_{\text{release}} + T_{\text{burst\_transmission}}} \tag{7}$$

Figure 1 depicts the value of γ as a function of the number of packets per burst. We have considered an allocation delay of 900 ms (following [9, page 281]) and an inactivity timer of 100 ms. Although such a small inactivity timer is atypical in operational UMTS networks optimized for world wide web (www) and wireless application protocol (wap), it represents an optimal choice for ITS, where the minimization of resource consumption is of primary importance and the interval between traffic bursts is predictable.

From the values in Table II it can be seen that when 8 messages are sent in the same transmission burst ($\gamma = 0.29$) the effective achievable cell capacity would reach only 450 Kbps in the stationary scenario and 250 Kbps in the high speed case. In summary the "multiple unicast" transmission offered by DCHs is shown to be inefficient and the average capacity in terms of transferred data per second is inadequate to support ITS services.

IV. ITS-over-MBMS

A. MBMS Introduction

The lack of a real broadcast/multicast service in the UMTS network has been addressed in 3GPP Release 6 with the introduction of MBMS [6]. The latter introduces a new point-to-multipoint transmission bearer by using shared network resources in the service layer, in the core network, and in the radio access network. MBMS data uses a high rate forward access channel (FACH) that in turn is carried by the secondary common control physical channel (S-CCPCH). MBMS provides two modes of operation:

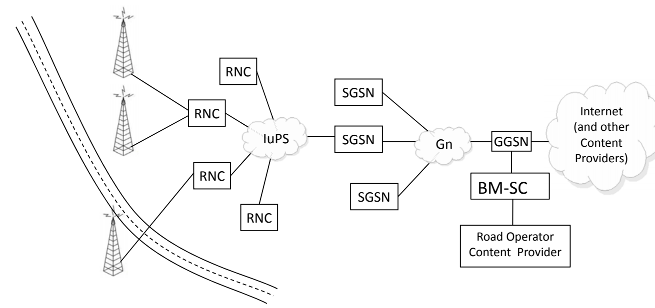

Fig. 2. ITS-over-UMTS Architecture with Release 6 functionalities

- **Broadcast Mode**: Data is transmitted to all the MBMS capable UEs in a broadcast service area without any subscription procedure;
- **Multicast Mode**: Data is delivered only to the UEs in a multicast service area that have joined a multicast group after a subscription procedure.

Both streaming and file download services are provided by MBMS [10]. In the streaming mode, a continuous data flow provides a stream of media with optional additional text and/or still images. In the file download mode, the MBMS bearer distributes binary files and utilizes file repair procedures for providing reliability. The bitrate of a single MBMS bearer can range between 10 Kbps and 384 Kbps.

B. Reference Architecture

In our vision each car is equipped with a full 3GPP Release 6 compliant on board unit (OBU). All the authorized OBUs join the multicast group where ITS messages are distributed. Each message is sent in the form of binary data by the road side units (RSU) through the file download service provided by the MBMS architecture. We assume that the UMTS network covers the road regions served by the ITS completely (the "multicast service area" in [6]). The road is divided into road segments. Each segment forms a "local multicast area", where the same content is delivered. Different local multicast areas may have different contents.

The proposed architecture is depicted in Figure 2. Note that some new entities are introduced in comparison to the conventional UMTS architecture: the broadcast/multicast-service center (BM-SC) and the road operator content provider (ROCP). The BM-SC belongs logically to the UMTS operator and can be implemented in the gateway GPRS support node (GGSN) or as an independent entity. It serves as an entry point for content delivery services, which are provided by an external content provider, i.e. the ROCP. In other words, the ROCP delivers binary data through the UMTS network in a real multicast mode to registered OBUs, where a higher layer client application decodes the information.

C. Model for System Capacity Requirements

The use of a real multicast transmission reduces the requirements in terms of downlink capacity: as the same content is distributed to different users the required capacity scales with the number of services and is independent on the number of receivers. In order to estimate the downlink capacity requirements of an I2V system based on any type of broadcast technology, a system-level capacity model is required, taking into consideration both the infrastructure (length of road, number of segments, number of lanes, speed limits, offered services etc.) and present traffic conditions (number of vehicles, average speed, weather conditions, traffic jams, etc.). Our model [11] is entropy-based and takes into consideration all of the above parameters.

One of the basic propositions of our model is that there exists a varying amount of overlap in the information being transmitted to various users in the broadcast system. This overlap can be exploited to compress the downlink data stream, effectively reducing the required downlink capacity. We use the concept of information entropy, as introduced by Claude Shannon [12], to describe the magnitude of this overlap.

Two independent entropy parameters exist in our system capacity model, being the user entropy, η, and segment entropy, ϕ. User entropy expresses the variety of information content for any given service across the various users in each segment, while segment entropy expresses the variety of information content for that same service across the various road segments that the I2V system comprises. Both entropy parameters are normalized, such that $\eta \in [0, 1]$ and $\phi \in [0, 1]$. When $\eta_j = 0$, this signifies that during the current update all the users in the given segment are receiving the same information for the particular service j. Conversely, if $\eta_j = 1$, this means that each individual user is receiving information content different to that of all the other users. An analogous interpretation holds for the values of segment entropy.

Along with the two forms of entropy, the model considers a number of other parameters, divided into five groups. The first set of parameters describes the construction of the road network which is served by the I2V system and includes parameters such as the number of segments the road network is divided into, the lengths of individual segments, and the number of lanes in each segment. The second set collects all parameters that describe traffic flow, such as the average speed in each segment, the following distance between vehicles, the number of users (i.e. vehicles) in each segment, the probability that a given segment is in the state of a traffic jam, etc. The third group of parameters models the set of services offered by the system, and hence includes the number of services in the system, the activity factor, data volume, and update period of each service, etc. The fourth group of parameters deals with the upper bound on the allowable update period for each segment and hence includes parameters such as the maximum allowable speed in the system and the minimum retention time for each segment. Finally, the fifth group of parameters describes the data rates present in the system, such as the data rates for each service in each segment, as well as the total data rate for the entire system, which is ultimately the output of the whole system capacity model.

D. Performance Evaluation

We considered as worst case a traffic jam scenario. Input parameters for the system capacity model are listed in Table III. The efficiency of an ITS-over-MBMS depends on the relative fraction of dedicated content over the total volume of ITS Traffic, captured by the variable η defined above. In fact, in some cases the ROCP is required to send dedicated content to single users (e.g. keep-lane support and high speed warning). This feature complicates the analysis of the ITS capacity requirements.

We propose two different methods for handling the transmission of dedicated content. The first strategy consists in using MBMS for multicast messages and the remaining DCHs for unicast transmissions of dedicated contents. In this case the limiting resource is again the available power at the base station. As MBMS consumes part of the available cell capacity, it limits the number of available DCHs that can be established. Recall that MBMS is typically carried by the FACH channel, in which no fast power control is implemented. Therefore the Base Station is required to pre-assign a certain amount of power to the MBMS services. Clearly the MBMS power overhead depends on the expected MBMS bearer bit rate (see [13] for more details). Once μ_{MBMS} is defined, equation (6) can be used for estimating the residual cell capacity on the DCH. The results for the combined MBMS/DCH scenario are presented in Table IV.

The alternative approach makes use of a so called "carousel transmission" inside the MBMS session. With this approach dedicated contents are broadcast in the whole area and an application layer addressing mechanism at the OBUs is in charge to selectively identify the messages to be processed or discarded. Two advantages can be achieved by using this approach: a single bi-sectorial macro-cell can meet the capacity requirements and coexistence with voice users is eased since the remaining DCHs remain untouched.

The choice between the two approaches depends on the

Parameter	Value
Segment length	2000 m
Car length + distance to the next car	7.5 m
Max number of lanes per direction	5
Message size	50 bytes
Update period	7 s
Number of services	8

TABLE III
CAPACITY MODEL PARAMETERS

MBMS datarate	Residual Sustainable Users	
	TX diversity Disabled	TX diversity Enabled
16Kbps	123	128
32Kbps	107	117
64Kbps	84	101
128Kbps	20	82

TABLE IV
COMBINED MBMS/DCH SCENARIO

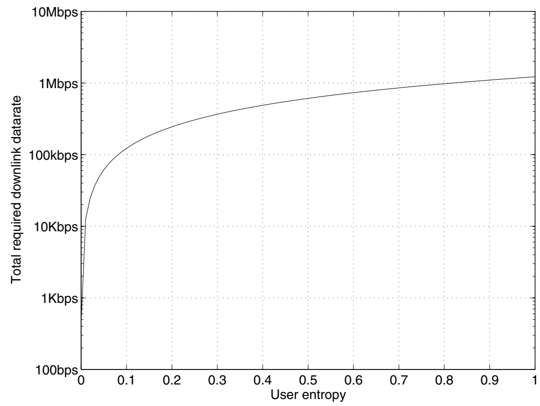

Fig. 3. MBMS capacity requirements in case of Road Congestion (semi-log scale)

value of η, which in turn determines the total required data rate. Figure 3 depicts the data rate requirements for different values of η in our reference scenario. At one extreme point $\eta = 1$, i.e. when only dedicated content is transferred to all users, up to ca. 1 Mbps is required. As expected, a typical ITS scenario, where $0 \geq \eta \leq 0.3$, requires only 300 Kbps.

We evaluate a hybrid bi-modal scheme that switches automatically between DCH and carousel transmission modes for dedicated content. The switching logic is based on thresholds on the number of registered OBUs present in the cell and on η. We consider the following cases:

1) free road;
2) congested road, low η;
3) congested road, high η.

In case 1 only few cars are on the road (e.g. during the night). The allocation of the MBMS multicast radio bearer is unjustified since the power that would be required to serve the users directly on the DCHs is less than the power required to setup an MBMS FACH transmission. Therefore, the users should be served via normal DCHs. When the number of cars with registered OBUs exceeds a certain threshold (case 2) the network switches automatically to the MBMS multicast transmission. In this case all the OBUs are served through the MBMS channel and dedicated contents are sent via "carousel transmissions". If ROCP needs to send several dedicated messages, i.e. high η (case 3), the remaining dedicated channels should be used in support of the MBMS multicast transmission. The feasibility of this approach is guaranteed by the "MBMS counting" functionality introduced in [6], which lets the radio access network identify the number of UEs with activated MBMS services within a cell.

V. Conclusions

In this work we have provided a quantitative assessment of the system performance of ITS over UMTS, with and without MBMS. We have highlighted the dependency between the required system capacity and the characteristics of the ITS content (dedicated vs. shared) and proposed an entropy-based metric to capture such dependency. Finally we have analyzed a hybrid bi-modal scheme that can handle the dynamic condition of the ITS content in a simple way.

The new capabilities introduced in UMTS Release 6 enable the efficient support of ITS services over legacy UMTS networks. The lower cost barrier due to the reuse of existing infrastructure is likely a critical advantage over alternative schemes requiring the deployment of new technologies, paving the ground for the concrete introduction of ITS applications in the near future.

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