SAFETY ON THE ROADS

LTE Alternatives for Sending ITS Messages

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This article discusses different alternatives for sending intelligent transportation systems (ITS) messages using long-term evolution (LTE) networks. Specifically, it compares the unicast and evolved Multimedia Broadcast Multicast Services (eMBMS) transmission modes by means of system-level simulations and a cost modeling analysis. The optimum configuration of the eMBMS carrier is studied for the case of ITS services. This article also includes some recommendations on the configuration of the ITS server in charge of distributing safety messages as well as on its interaction with the mobile network operator (MNO). The results show that eMBMS is significantly more efficient in terms of resource consumption than the unicast mode, implying an important reduction of the delivery costs.

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Introduction

The recent advances in wireless communication networks, together with the technological development of the automotive industry, have paved the way for a totally new approach to vehicular safety that integrates multiple equipment and technologies in one autonomous and intelligent vehicle. In this context, the term *ITS* [1] refers to a new set of information and communication technologies that allow vehicles to exchange information with each other and with the infrastructure to improve road safety, traffic efficiency, and travel comfort.

In 2013, the European Committee for Standardization and the European Telecommunications Standards Institute (ETSI) finalized a basic set of standards necessary for the implementation and deployment of cooperative ITS systems, as requested by the European Commission [2]. This set of standards is mainly based on the IEEE Standards 802.11p access technology for ITS

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communications, which are defined as ITS G5 communications by the ETSI [19]. The system is well suited to active road safety use cases due to its very low delays and communication range of several hundred meters. However, the channel congestion experienced in dense scenarios and its decentralized ad-hoc nature is motivating the research of other technologies, such as cellular networks, as alternatives for ITS communications.

The latest iteration of Third-Generation (3G) Partnership Project standards, known as LTE, promises better levels of quality in terms of throughput and latency compared with the 3G systems. However, it is not clear whether LTE networks can support ITS applications in an efficient manner by means of unicast transmissions. Similarly to IEEE 802.11p, there is a scalability problem related to the fact that ITS messages have to be delivered to potentially all vehicles in a certain geographical area and with stringent delay requirements. If the unicast transmission mode is used, the amount of resources required for the delivery of ITS messages might result in elevated costs for the MNOs as well as for the service providers (e.g., car manufacturers). In this context, the utilization of broadcast technologies, such as eMBMS in LTE, appears as a possible solution to solve the scalability problem of ITS in cellular networks.

Other studies in this area focus on the unicast delivery in both 3G [3], [4] and LTE [4]–[7] cellular networks. Regarding broadcast delivery, previous studies were only performed in 3G cellular networks [4], [8], [9]. This article analyzes the benefits of broadcast technologies for the provision of ITS applications in LTE networks and addresses open issues to support this kind of applications over the current eMBMS architecture.

ITS Applications and Use Cases

ITS applications can be divided into three main categories [10]: 1) cooperative road safety, 2) cooperative traffic efficiency, and 3) cooperative local services and global Internet services. ITS applications related to cooperative road safety can be further divided into two types: 1) those associated with cooperative awareness (CA) and 2) those associated with road hazard warnings (RHWs). This article focuses on both types of cooperative road safety services.

CA Applications

CA applications are based on the periodic interchange of status data among neighboring vehicles. The ETSI defines the cooperative awareness message (CAM) [11] to exchange information of the presence, position, and basic status. By receiving CAMs, the ITS vehicle is aware of other vehicles in its neighborhood area as well as their positions, movement, basic attributes, and basic sensor information.

Most of the CA applications require a minimum CAM transmission frequency of 10 Hz and a maximum end-to-end latency of 100 ms [11]. According to the message format specified by the ETSI, the status information provided by a CAM is divided into four containers: 1) basic, 2) high-frequency, 3) low-frequency, and 4) special vehicle containers [11]. Both basic and high-frequency containers are mandatory, whereas low-frequency and special vehicle containers are optional. In addition, the size of the containers depends on several optional fields. This entails that the CAM payload is of variable size. As an example, the maximum payload size of a CAM with only mandatory containers is around 50 B, whereas it increases up to 250 B when including the low-frequency container.

In addition to this CAM format, the ETSI specifies the formats of the security header, 96 B, and certificate, 133 B, used for securing ITS G5 communications. A remaining question regarding the transmission of CAMs via cellular networks is the inclusion of the security overhead. Some works assume that no security payload is needed as it should be possible to provide access control via subscriber identity module cards [5]. However, the addition of security overhead could be needed to provide end-to-end security.

RHW Applications

On the other hand, the ETSI defines the dissemination of decentralized environmental notification messages (DENMs) [12] by RHW applications to alert road users about dangerous events. The main purpose is to warn the rest of the vehicles in the network about an unexpected situation. DENMs are triggered by specific events on the road and must be disseminated with a certain transmission frequency to as many ITS vehicles located within the relevant area as possible.

The message format described by the ETSI [12] specifies that a DENM is divided into four containers: 1) management, 2) situation, 3) location, and 4) à la carte containers. Only the management container is mandatory. Similarly to CAM, the DENM payload size depends on optional containers and optional fields. For example, the maximum payload size of a DENM with only the management container is around 45 B. If both situation and location containers are included, the DENM payload size ranges between 250 and 1,500 B.

ITS over LTE Cellular Networks

LTE networks offer two modes of data transmission: 1) unicast and 2) eMBMS delivery. For the provision of ITS applications, both modes require an ITS back-end server that receives messages from the vehicles and the traffic infrastructure, processes the information, and redistributes it to the vehicles and the traffic infrastructure [4], [6].

Unicast delivery must be used for the uplink and is an optional mode for the downlink communication. Figure 1(a) shows an example of an RHW application where a vehicle sends a DENM with its identification, event cause, and position via the cellular network to the ITS server. This information is then distributed to all vehicles in the neighborhood. The ITS server needs location information about every single vehicle to identify the vehicles potentially interested in the RHW information within a certain area. One option is that the ITS server uses the location information provided by the CAMs that are sent in the uplink. Another option is to make use of grid-based methods in which the vehicles send location information updates to the ITS server every time they enter a new cell within the grid area [5].

The eMBMS delivery mode can be used exclusively for the downlink distribution of ITS messages. In this case, all vehicles belonging to the broadcast area are addressed collectively rather than individually. In the exemplary broadcast scenario represented in Figure 1(b), the ITS server addresses the broadcast multicast service center (BM-SC) to distribute data via eMBMS. To this purpose, the ITS server has to identify the broadcasting area that is better suited to the RHW information. It is important to note that eMBMS can maintain different broadcast areas, which consist of a set of cells specified by the MNO.

The main difference compared with the unicast scenario is that the whole broadcast area is addressed instead of a single user. In this manner, a significant amount of resources can be saved due to the fact that every message is only transmitted once per broadcasting area instead of once per vehicle. At the same time, the location information of potential recipient vehicles is not needed in the broadcast case, and therefore, an important amount of resources is also saved in the uplink.

On the other hand, the broadcast delivery mode prevents the information from being personalized on a user basis. As a result, the vehicle has to filter the relevant information out of all the information delivered in the broadcasting area. Larger broadcasting areas offer potentially greater resource savings, but they increase the amount of processing that has to be done in the vehicle.

In other words, unicast delivery requires extensive processing in the ITS server to select the receivers of each message, reducing the processing requirements in the vehicle, whereas eMBMS delivery shifts the processing efforts from the ITS server to the end user, thus distributing the computational burden.

eMBMS Architecture for ITS Services

The management of both eMBMS content and resources is performed through a multicell/multicast coordination entity (MCE), which is a control entity responsible for admission control and resource allocation. On the other hand, the main function of the MBMS gateway (GW) is to forward the eMBMS packets to the evolved NodeBs (eNodeBs) involved in the eMBMS transmission using Internet protocol (IP) multicast. Finally, the other entity involved in the provision of eMBMS services is the BM-SC. It is located

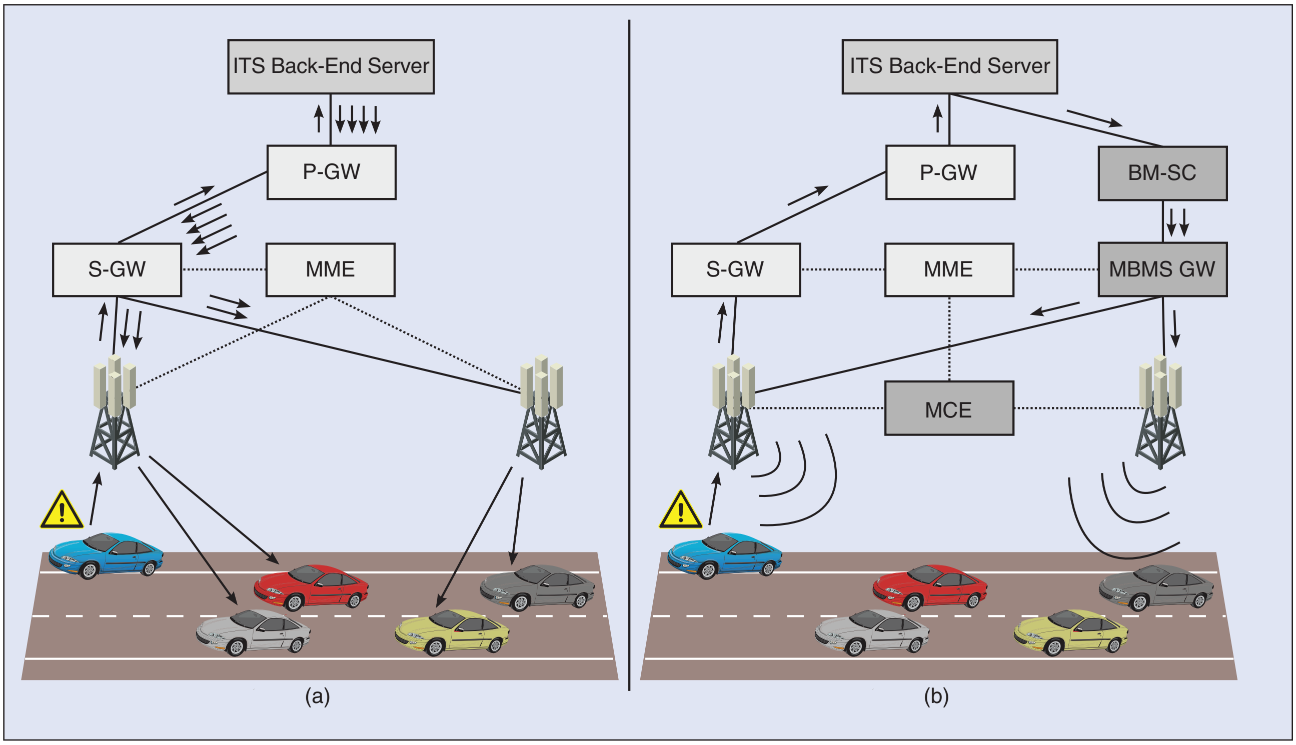

FIGURE 1 The (a) unicast and (b) broadcast delivery modes of a DENM over LTE cellular networks.

HIGHER TRANSMISSION FREQUENCIES OF CAM REDUCE THE NUMBER OF VEHICLES THAT CAN BE SUPPORTED WITH ACCEPTABLE DELAY.

between the core network and the content provider and is the entry point of the eMBMS contents. The BM-SC controls the start and end of eMBMS transmissions, service announcements, security, billing tasks, and so on. In the specific case of ITS applications, the content provider entity corresponds to the ITS server. There is no specification concerning the interface between the content provider and the BM-SC. Therefore, the configuration of the server shall require the common work of operators and car manufacturers. Due to the relevance and tight interactivity of the ITS server and the BM-SC, it is likely that both entities would be integrated in the same physical device.

Another aspect to be considered is the logical location in the IP domain of the ITS server. From a latency point of view, it would be beneficial that the ITS server was located within the operator network, with a private IP address valid in the operator domain. However, this alternative would prevent cars belonging to different operators from getting connected. Therefore, the ITS server should be located in the Internet, with a public IP address so that it is reachable by all MNOs. To reduce the latency, each ITS server should be regional-wise, with a limited number of route hops until the MBMS GW in the mobile network. Note that the MBMS GW, the BM-SC, and the content provider are entities with public IP addresses. This article proposes that the BM-SC and the content provider share the same IP being reachable by all operators. Vehicles shall subscribe to the service in the same entity, which shall distribute the relevant and filtered information to the same areas covered by different operators. The functionality of this new node, the one that merges BM-SC and ITS server duties, is described in the following section.

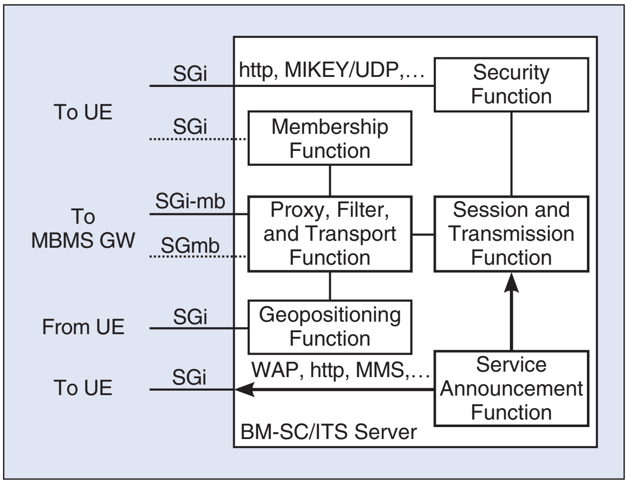

FIGURE 2 The main functionalities of the proposed BM-SC/ITS server node.

Functionality of the BM-SC/ITS Server Node

According to the specifications [13], the BM-SC is responsible for the following subfunctions in the Evolved Universal Terrestrial Radio Access Network membership function, session and transmission function, proxy and transport function, service announcement function, security function, and content synchronization for MBMS.

New functionalities must be added to support ITS applications. More specifically, the new entity must receive information from vehicles—instead of only sending the information as in the BM-SC—and filter the data streams according to the geolocalization of these vehicles. Therefore, a new geopositioning function must be included to allow for this smart filtering. This functionality would be in charge of selecting the broadcasting area for each message to be delivered. In addition, it is worth stressing again here that all communication with the user equipment (UE) and the MBMS GW is made through a conventional IP connection that requires the appropriate domain name system resolution in the UE side and a complete registration process. The new characteristics of the BM-SC/ITS server node are shown in Figure 2.

ITS Services Configuration for eMBMS Delivery

In eMBMS terminology, an MBMS user service is the entity in charge of providing the service to the end user and controlling its activation or deactivation. For ITS, two MBMS user services could be defined: one for the CA service and another for the RHW service.

A single MBMS user service can contain several multimedia objects or streams, which might require multiple MBMS sessions. Each MBMS session might be associated with more than one MBMS bearer and a set of delivery parameters, including the broadcasting area. By using multiple MBMS sessions, the same MBMS user service can transmit different contents in each broadcasting area of the network. In this manner, the relation between broadcasting areas and content is transparent for the vehicles, i.e., they just activate the reception of the service and receive the content according to their location.

The BM-SC controls the ITS content to be delivered in each broadcasting area by establishing a separate MBMS bearer for each ITS content data flow. All MBMS bearers of the same MBMS user service share the same temporary mobile group identity (TMGI) but contain a different flow identifier. The BM-SC allocates the flow identifier during the MBMS Session Start procedure and initiates a separate session for each content data flow. Besides, for IP multicast support, the MBMS GW allocates an IP multicast address based on the TMGI and flow identifier.

To receive an MBMS service, vehicles must subscribe to the service, and whenever data are available, the BM-SC starts the session. The session is first announced via the MBMS control channels, and after that, the data channel can be established and used. This implementation is resource efficient in terms of transmission power since vehicles are able to perform discontinuous reception to save battery power. Nevertheless, the Session Start and MBMS Notification phase takes time, making this procedure not recommended for time-critical traffic warnings.

To enable a broadcast channel with minimal transmission delays, a continuous eMBMS service for traffic safety should be configured. In this manner, the vehicle only has to join the eMBMS service at the beginning of each session (e.g., when the vehicle is started) and receives the data continuously until the session ends (e.g., when the vehicle is shut down). By using a continuous eMBMS service, it is possible to minimize the delays associated with the Session Start and MBMS Notification procedures.

Although the current eMBMS standard specifies two delivery methods for the MBMS user services, namely download and streaming, other delivery methods may be added beyond the current release of specifications. In principle, ITS content could be provided through eMBMS using the download delivery of binary files. However, this method is not suitable for services with very stringent delay requirements, such as those of ITS. Thus, the provision of ITS content using eMBMS could only be performed by defining a new delivery method suited for time-critical requirements. In the next sections, we have assumed the use of this new delivery method.

ITS Services Scheduling for eMBMS Delivery

The eMBMS services provided over LTE are multiplexed in time with unicast services using MBSFN subframes. Among the ten subframes included in an LTE radio frame, the maximum number of subframes allocated to MBSFN is six.

To inform users about the eMBMS scheduling, specific eMBMS control information is used [14]. Most of the eMBMS control data are carried by the multicast control channel (MCCH). The MCCH provides control information for eMBMS traffic data, which is conveyed in multicast traffic channels (MTCHs). Both the MCCH and MTCH are mapped into the multicast transport channel (MCH). The MCE provides to eNodeBs a semistatic allocation of radio resources for each MCH and also a scheduling period where all eMBMS traffic data channels—MTCHs—must be multiplexed. The MTCH multiplexing is configured and indicated by the eNodeB in the first subframe of each scheduling period.

The eNodeB can allocate eMBMS resources in a persistent or dynamic manner. If the resources for eMBMS are allocated persistently, the continuously maintained data channel would allow for the immediate transmission of

IN A DYNAMIC eMBMS SCHEDULING, THE RESOURCE ALLOCATION IS ADAPTED TO THE AMOUNT OF ITS DATA TO BE TRANSMITTED IN EACH SCHEDULING PERIOD.

ITS information. While this approach minimizes the delay for the downlink transmission, it might lead to a waste of resources when the amount of ITS information to be transmitted is lower than the amount of resources allocated to eMBMS. A solution to this problem is that the eNodeB performs a dynamic scheduling of eMBMS resources. The proposed configuration consists in adapting the resource allocation to the amount of data to be transmitted in each scheduling period, whose lowest value is 80 ms. The empty subframes not used for eMBMS in each scheduling period can be used for unicast services to avoid a waste of resources. It should be noted that, although this approach results in more efficient resource utilization, it might increase the delay of ITS applications. In particular, the maximum latency of a message in the downlink would be about 80 ms, which corresponds to the worse situation in which the message arrives at the beginning of the previous scheduling period.

Simulation Model and Results

To assess the delivery of ITS services in LTE networks, we have used a system-level simulator developed in the framework of the WINNER+ project [15], one of the International Mobile Telecommunications-Advanced (IMT-Advanced) evaluation groups of the International Telecommunication Union Radiocommunication Sector (ITU-R).

Table 1 summarizes the configuration parameters, which follow the ITU guidelines for the IMT-Advanced candidate evaluation [16]. The analysis focused on a real motorway scenario deployment, which consists of several base stations arranged along a stretch of motorway of 20 km. The LTE deployment is based on a frequency carrier of 800 MHz and an intersite distance of 10 km with wraparound. As a result, a total of two sites cover the total road length. Each site has two sectors, which cover both directions of the motorway. The distance from the center of the highway to the site is 50 m.

Vehicles are randomly dropped over the six different lanes—three lanes per direction—with different speeds. Three different speeds were assumed for the three different lanes per direction. These speeds are 100, 120, and 180 km/h. Each user keeps the same lane, and its speed is constant during all the simulation time. Besides, when a vehicle gets the lane end, it reappears at the beginning of the lane. Simulations are dynamic, and handover processes occur due to the vehicles' mobility.

The following sections compare the performance of unicast and eMBMS delivery modes for CA and RHW applications.

TABLE 1 Simulation parameters.

Parameter	Value
Bandwidth	10-MHz frequency division duplex
Central frequency	800 MHz
Tx/Rx antennas	Unicast: multiple-input, multiple-output (MIMO) 2/2 eMBMS: single-input, multiple-output 1/2
eNodeB antenna height	20 m
eNodeB transmit power	46 dBm
eNodeB antenna gain	14 dBi
eNodeB antenna beamwidth	70°/10° (H/V)
eNodeB antenna downtilt	6°
eNodeB cable loss	2 dB
Vehicle antenna height	1.5 m
Vehicle antenna gain	2 dBi
Vehicle cable loss	0.2 dB/m (2 m of cable length)
Vehicle implementation loss	5 dB
Vehicle noise figure	7 dB
Path loss	Based on rural macrocell model [16]: $PL = PL_{LOS} \cdot P_{LOS} + PL_{NLOS} \cdot (1 - P_{LOS})$
Shadowing parameters	Standard deviation (σ) 6 dB Correlation distance (d_{corr}) 100 m
Multipath channel model	Extended vehicular A power delay profile [17]
Thermal noise level	−174 dBm/Hz
Orthogonal frequency- division multiplexing symbols to control channels	Unicast: two symbols (six assignments) eMBMS: one symbol
Channel quality indicator (CQI) reporting period	20 ms (CQI wideband)
Scheduling algorithm	Proportional fair
CAM payload size	270 B
DENM payload size	800 B
Internet protocol version 6 (IPv6)/UDP header size	48 B
IPv6/transmission control protocol header size	60 B
Header compression	RoHC is only applied for unicast: 48 to 3 B for CA, 60 to 4 B for RHW

CA Application Analysis

In this article, it was assumed that every vehicle sends messages in the uplink to a back-end server with a transmit rate of ten CAMs/s, as defined by the ETSI. To illustrate the system behavior with a lower transmit rate, additional results for a transmit rate of two CAMs/s are also provided. The payload size of each CAM was assumed to be 270 B, including security headers and excluding IP and user datagram protocol (UDP) headers. For the downlink, the information transmitted by the eNodeBs depends on the delivery mode (unicast or broadcast).

In the case of unicast, the back-end server, after receiving and processing uplink CAMs, sends to each vehicle a downlink CAM packet with the aggregation of all CAMs belonging to vehicles within the area of interest. It was assumed an area of interest of 362 m, which corresponds to the breaking distance computed for a reaction time of 1 s, a breaking deceleration of 4 m/s^2 (sand or concrete), and a velocity of 180 km/h.

In the case of eMBMS, CAMs are transmitted to all vehicles inside the broadcasting area in which they were originated. In addition, the CAM updates from vehicles that are outside the broadcasting area, but within 362 m of the edge, are also delivered inside the broadcasting area. For the sake of simplicity, it was assumed that every broadcasting area corresponds to the coverage area of one cell.

Figure 3 shows the average downlink resource usage depending on the cell load (i.e., the number of vehicles) for the unicast and eMBMS delivery modes. For eMBMS, it was assumed two different modulation and coding schemes [18]. Quadrature phase shift keying (QPSK) with code rate 0.44 is the highest mode that achieves a coverage level greater than 95%, whereas QPSK with code rate 0.3 is the highest mode that achieves a coverage level greater than 98%. In addition, it is worth remembering that the maximum resource usage for eMBMS is 60% of the channel capacity (six subframes out of ten). For unicast, the LTE system automatically adapts the transmission mode to the current channel conditions of each user.

As can be observed in the figure, unicast outperforms eMBMS in terms of resource usage when the number of vehicles per cell is low. The reason for this is twofold. On the one hand, unicast transmissions benefit from link adaptation and advanced retransmissions mechanisms based on the feedback information from the receivers, which increase the spectral efficiency compared with broadcast transmissions. On the other hand, a low vehicle density entails a small number of downlink CAM packets to be delivered by the infrastructure. In unicast mode, each CAM packet transmitted by the vehicles in uplink has to be sent in downlink once to each vehicle within the area of interest. The higher the number of vehicles in the area, the higher the number of unicast transmissions that is needed and vice versa. In broadcast mode, downlink packets only needed to be sent once in the broadcast area regardless of the number of vehicles within the area of interest. As a result, eMBMS only starts outperforming the unicast mode when the number of vehicles per cell increases above a certain value.

Figure 4 shows the downlink packet delay with an increasing number of vehicles per cell. The average and 95th percentile are shown in Figure 4(a) and (b), respectively. For eMBMS, it was assumed that the eNodeBs perform a dynamic eMBMS resource allocation using the lowest scheduling period, i.e., 80 ms. In this figure, it is shown that the downlink delays in unicast mode are reasonable up to a certain number of vehicles per cell, where they begin to grow exponentially. Higher transmission frequencies of CAM reduce the number of vehicles that can be supported with acceptable delay. On the contrary, the highest latency of a downlink message in the case of eMBMS does not depend on the number of vehicles and is limited to 80 ms, which corresponds to the worse situation

THE COOPERATIVE ROAD SAFETY SERVICES, SUCH AS CA AND RHW APPLICATIONS, REQUIRE A MAXIMUM END-TO-END LATENCY OF 100 MS.

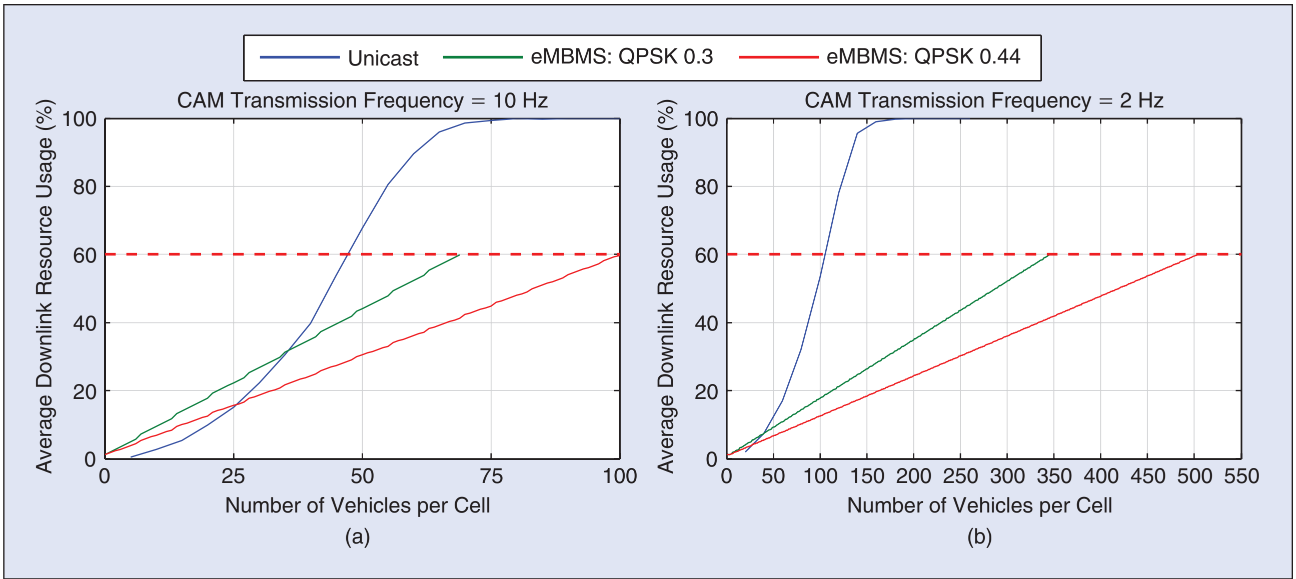

FIGURE 3 The downlink resource usage of CA application depending on cell load with unicast and eMBMS delivery modes for a CAM transmission frequency of (a) 10 Hz and (b) 2 Hz.

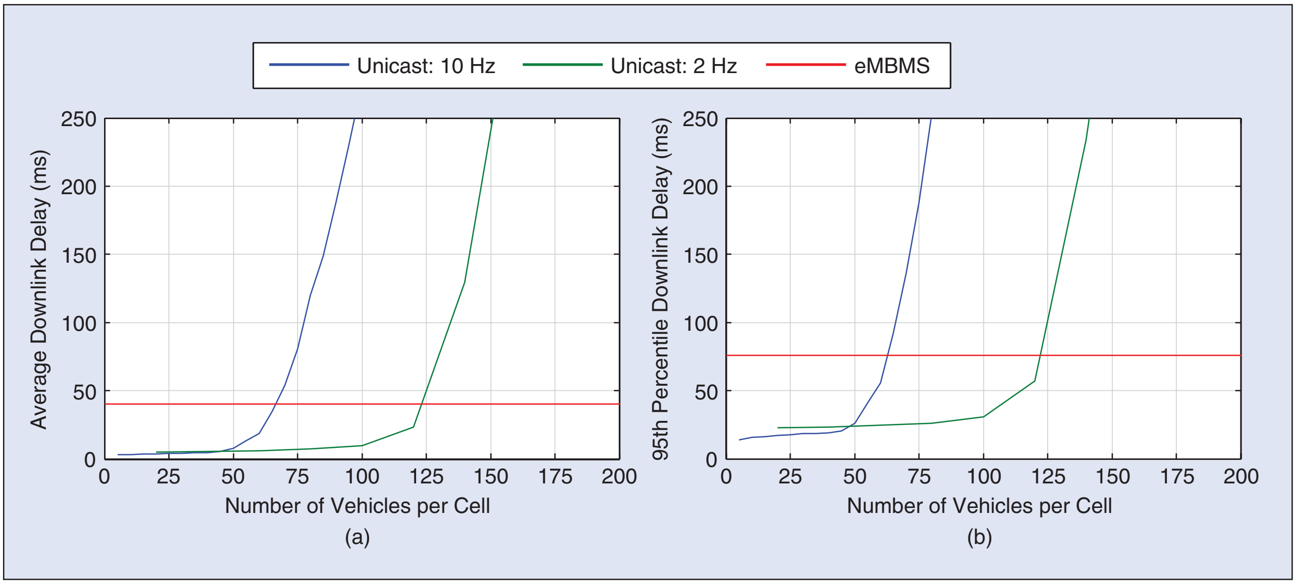

FIGURE 4 The downlink packet delays of CA application depending on the cell load with unicast and eMBMS delivery modes: (a) the average downlink delay and (b) the 95th percentile downlink delay.

in which the message arrives at the beginning of the previous scheduling period.

RHW Application Analysis

In the RHW delivery scenario, the transmission of DENMs is event-triggered. This means that an event (e.g., an accident or mechanical failure) triggers the transmission of DENMs during a certain period of time in which the event is considered to be active. In this study, it was assumed that no more than one event can be active at any given moment of time within a certain area. The event vehicle sends a DENM of 800 B to a back-end server that must deliver the message to all vehicles in the simulation scenario.

In the case of eMBMS, after receiving and processing the information, the ITS server sends the resulting DENM to the relevant eNodeBs by means of multicasting. Following this, each eNodeB broadcasts the DENM in downlink within its coverage area with a repetition period of 1 or 10 Hz. In the case of unicast, the back-end server sends the corresponding DENM in downlink to all the vehicles in the simulation scenario by means of point-to-point connections. Contrary to eMBMS, the DENM is not periodically repeated but rather transmitted only once to each vehicle using the transmission control protocol.

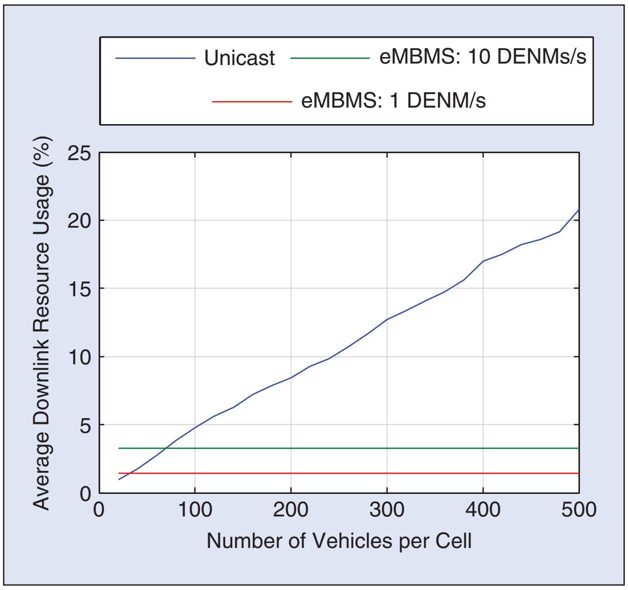

FIGURE 5 The downlink resource usage of an RHW application depending on the cell load with unicast and eMBMS delivery.

Figure 5 shows the average downlink resource usage with an increasing number of vehicles per cell for the unicast and eMBMS delivery modes. For eMBMS, it was assumed the use of QPSK 0.3 and two different DENM transmission rates, one and ten DENMs/s.

The results show that the capacity required when delivering RHW applications is much lower than in the case of CA applications. Furthermore, the gain of eMBMS in terms of resource savings compared with the unicast mode is much higher than in the CA case, which is explained by the localized nature of CA applications as opposed to the broadcast nature of RHW applications (the same message is delivered to all the vehicles in a wide area).

Figure 6 shows the downlink packet delays of DENMs depending on the cell load for unicast and eMBMS delivery modes. This figure also illustrates that the downlink delay with unicast delivery increases with the number of vehicles per cell, whereas it does not depend on the cell load using eMBMS delivery mode.

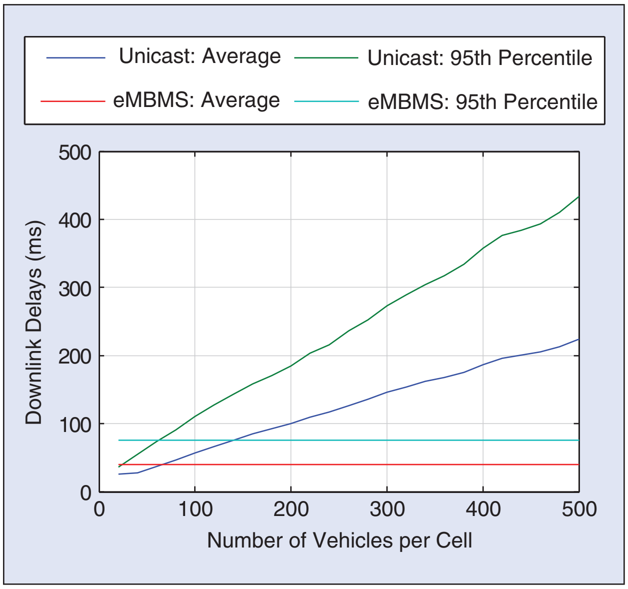

FIGURE 6 The downlink packet delays of an RHW application depending on the cell load with unicast and eMBMS delivery modes.

Cost Analysis

One of the objectives of this article is to demonstrate the advantages of broadcasting technologies for the provision of ITS applications in LTE networks not only in terms of radio link performance but also in terms of delivery costs. To this end, a cost modeling calculation must be first defined, followed by a fair comparison of costs. For the sake of simplicity, only the cost in downlink for the CA use case is analyzed.

Cost Modeling and Assumptions

The state of the art in Europe for pay per use ranges €0.01–0.05/MB. With these considerations in mind, a model including a fare of €0.01/MB was assumed. Other assumptions concerning the cost analysis are summarized in Table 2. Regarding the modeling of the costs, it was first assumed a win–win situation in which all the stakeholders, i.e., the MNOs, governments, citizens, and car manufacturers, are satisfied. These assumptions are the following.

- From the government's point of view, ITS applications improve road safety, reduce accidents, and lower the

TABLE 2 Cost assumptions.

Concept	Value
Life expectancy of a car	9 years
Car use per day	79 min
MNO income per megabyte	€0.01
MNO sustained throughput/cell	17.3 Mb/s
MNO income/cell in car use period	€97.75
Average number of cars per cell	60

costs in terms of rescues and medical care. Therefore, ITS capabilities were assumed to be enforced by governments in all the cars and MNOs to guarantee the coverage, prioritization, and interoperability of the service.

- From the citizens' point of view, it is unforeseeable that users would be willing to pay for the additional cost derived from the data exchange in ITS applications. Provided the enforcement from governments, users are not charged directly by this service, although the final cost of cars could be increased by car manufacturers to compensate for the extra cost.
- From the automotive industry point of view, ITS capabilities have to be incorporated in the majority of the cars to enable ITS applications. Together with the operators, the automotive industry will pay for the ITS deployment and the cost of the data traffic exchange. In compensation, car manufacturers may increase the price of cars to encompass part of the costs incurred by the new service.
- From the MNOs point of view, it is necessary to adapt the network to support ITS applications. This requires modifying algorithms via software updates and including new servers and GWs among different operators. Moreover, the provision of ITS applications with eMBMS entails a certain loss of resources to other conventional users. To identify a win–win scenario, the cost modeling shall find the situation in which the benefits derived from eMBMS overcome the loss of revenue derived from the loss of unicast resources.

Cost for CA Application

For the sake of simplicity, this cost analysis only focuses on the CA application. Figure 7 shows the cost per car and day derived from the delivery of CA application messages with a CAM transmission frequency of 10 and 2 Hz. For this calculation, we have previously obtained the maximum traffic carried by the LTE network in the real motorway scenario deployment assuming full resource usage. Using the income per megabyte, we derive the total income of the MNO per resource unit. Then, using simulations, we calculate the required amount of resources to deliver CA messages for a certain number of vehicles and, therefore, the cost per vehicle and day, after normalizing by the average car usage per day.

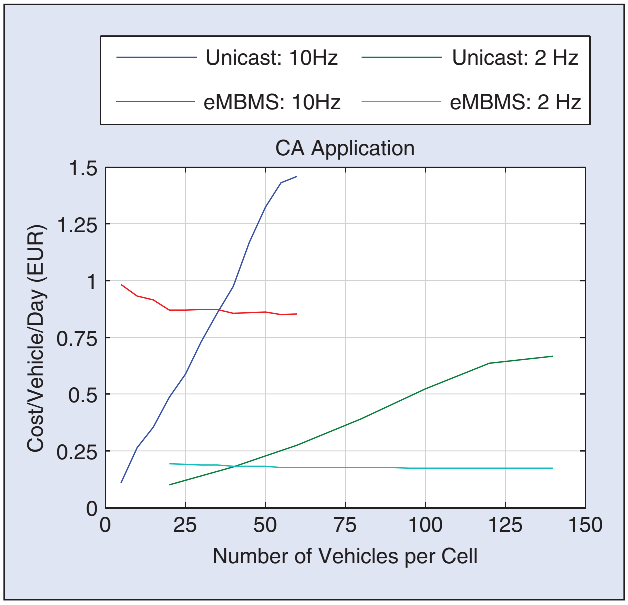

FIGURE 7 The cost per car per day for a CA application.

In the case of unicast, the cost per car increases with the number of vehicles per cell due to the higher utilization of radio resources. For eMBMS, the cost actually decreases with the number of vehicles, and broadcasting transmissions become more profitable when the number of active vehicles increases beyond a certain value.

Finally, Table 3 summarizes the increase in the cost per car caused by the transmission of CAM messages in CA applications for 60 vehicles per cell on average and different percentages of market penetration. This calculation is made considering an average life expectancy of a car of nine years. Note that, in the case of eMBMS, the cost per car significantly decreases when the percentage of cars using ITS services grows toward the full integration of the

TABLE 3 The price increase per car comparing unicast and eMBMS delivery for different frequencies in the CAM transmission.

CAM Transmission Frequency	Market Share	Unicast Delivery Cost (€)	eMBMS Delivery Cost (€)
10 Hz	25%	1,158.95	3,003.56
	50%	2,393.29	2,866.55
	75%	3,838.92	2,820.88
	100%	4,792.06	2,798.04
2 Hz	25%	324.33	639.03
	50%	550.49	612.88
	75%	779.04	592.79
	100%	906.10	582.30

service. As a result, while the unicast mode is preferable in early markets with a penetration below 50%, the use of eMBMS is the most economical option in developed markets with penetration values above this value.

Conclusions

This article has demonstrated the interest of LTE eMBMS for the provision of ITS applications based on CA and RHW applications. The results in terms of resource consumption and cost modeling support the conclusion that eMBMS is more efficient than the unicast delivery mode when the number of vehicles on the road is high and when the market penetration rate of the service is over 50%. This article has also discussed a possible configuration of the LTE network for the delivery of ITS messages with eMBMS. In particular, a solution based on a continuous eMBMS service for ITS applications, together with a dynamic allocation of eMBMS resources, has been proposed for latency and network efficiency reasons. Concerning the architecture, we have analyzed the impact of the ITS back-end server and the possibility to merge it with the BM-SC for the feasibility of multioperator scenarios.

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