Short Paper: A LTE-Direct Broadcast Mechanism for Periodic Vehicular Safety Communications

Laurent Gallo and Jérôme Härri
Mobile Communications Department, EURECOM
06410 Biot Sophia Antipolis - France
Email: {gallo, haerri}@eurecom.fr

***Abstract*—LTE-Direct is an upcoming LTE rel. 12 extension to allow UEs to communicate directly without going through an eNB. LTE-Direct is expected to be used in future LTE-A networks for unicast Proximity Services, and has not been envisioned so far for broadcast transmissions. In this paper, we propose an eMBMS-inspired mechanism to allocate LTE-Direct resources for dedicated broadcast/multicast vehicular safety communications. The mechanism does not require any connection procedure for LTE-Direct broadcast transmissions, and proposes to reserve identical LTE downlink resources over multiple eNB for dedicated communications between UEs. We apply this concept to the periodic broadcast of BSM/CAM and illustrate that the mechanism's flexibility and extensibility makes LTE-Direct a good complementary technology to DSRC for periodic vehicular safety communications.**

I. INTRODUCTION

Vehicular Safety Communications satisfy the purpose of making vehicles aware of the traffic conditions in their surroundings, enabling local self driving decisions that proactively improve the safety of the occupants. Cooperative Awareness Messages (CAMs) are periodically broadcast by vehicles to provide the neighbors with updated information about one's position and speed. These transmissions are supported by the DSRC technology (a.k.a IEEE 802.11p), an extension of the WiFi standard for communications in a vehicular environment.

The current focus of Vehicular Safety Applications is primarily vehicle-centric, so their future implementation as a smartphone feature is being discussed. In this way, safety applications could be extended to vulnerable road users, while at the same time compensating for an initial low market penetration of DSRC-equipped vehicles. DSRC-enabled mobile devices would serve the purpose, but miss the opportunity of a much wider integration. On the other hand, a CAMs transmission mechanism based on LTE would open to new applications thanks to internet connectivity, easier integration with LTE-based first responder communications and with growing technologies as LTE-connected sensors and LTE-equipped cars. The lower operational frequencies of LTE with respect to DSRC can then provide better NLOS reception performance at intersections [1], while mobile devices can benefit from the power-efficient design of LTE.

Differently from DSRC, LTE requires the User Equipments (UEs) to be connected to an eNodeB (eNB) to be able to transmit. Maintaining a connection with the network as in [1] may not be convenient for safety applications, as the time overhead necessary to obtain scheduling grants before every packet transmission can be overly large for short machine-based communications [2]. Massive handover requests due to high user mobility could then cause undesired delay. Moreover, the eNB would represent a *single point of failure*, interrupting all communications within an area in case of malfunctioning. Said LTE-based system will then have to ensure a capacity sufficient to support a number of users comparable to DSRC, with similar probability of successful packet reception.

In this paper, we then propose a mechanism for *broadcast* LTE-direct transmissions divided in two phases, *a) Resource allocation* and *b) Distributed Resource Access Scheduling*. The first phase is inspired by an innovative interpretation of the eMBMS standard, which allows the allocation of a quasi-static pool of resources on a wide area. This set of resources can be accessed by the UEs without the need of undergoing the protocol steps to set up a connection with the eNB. Thanks to this mechanism, the multiple access scheme can be treated as a TDMA-like scheme, whose performance can be optimized applying the same Decentralized Congestion Control as in DSRC. The capacity obtained through said mechanism allows for encouraging performances, and the quasi-static and uniform nature of the resources provides a certain degree of robustness against eNB failure.

The rest of the paper is organized as follows: in section II the eMBMS service of LTE is overviewed; in section III LTE-direct broadcast resource allocation is presented and the distributed resource access scheduling scheme, currently under research, is discussed; finally, the discussion and the outlook presented in section IV conclude the paper.

II. MULTIMEDIA BROADCAST MULTICAST SERVICE

eMBMS is the LTE implementation of the Multimedia Broadcast Multicast Service (MBMS) available since UMTS rel. 6, which allows the network to broadcast or multicast contents over a wide area. eMBMS transmissions take place over a *Multicast Broadcast Single Frequency Network* (MBSFN), meaning that the set of dedicated resources must be constant all over the area of interest, as illustrated in fig. 1. eNBs can allocate from 10% up to 50% (for TDD LTE) or

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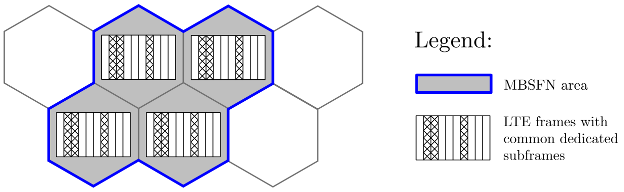

Fig. 1: Common dedicated resources in each cell belonging to MBSFN

60% (for FDD) of their DL resources to eMBMS. Within the dedicated resources up to 8 Multicast Channels (named MCH1 to MCH8) can coexist.

As shown in fig. 2, single MCH channels are multiplexed in time, according to a periodic scheme. The base period is the *Common Subframe Allocation* (CSA), which corresponds to the minimum time lapse during which all the MCH channels are scheduled, one after the other and without overlapping. CSA can be set from a minimum of 80 ms to a maximum of 10.24 s. Within the CSA, every service is assigned a certain number of subframes according to the MSI (MCH Scheduling Information); further, the MSP (MCH Scheduling Period) tells once every how many CSA periods every service is scheduled. Services that require high data rates are scheduled every CSA period (as MCH1 in the figure), while less demanding ones can be allocated more sporadically (as MCH2 in the figure).

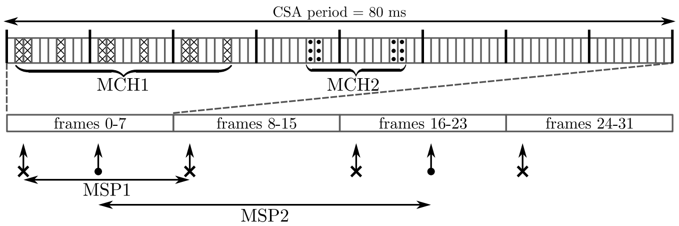

Fig. 2: Time distribution of eMBMS services.

The transport layer MCH channels each contain two logical channels, the MTCH (Multicast Traffic Channel) and the MCCH (Multicast Control Channel): the former transports the payload content, while the latter provides all the control information mentioned in this section. UEs can acquire the location of the MCH channels by reading the SIB13 (System Information Block 13) periodically transmitted by the eNBs. In table I are listed the operations UEs must perform to receive an eMBMS service of interest (for more details please see [3]).

The most important aspect of the described procedure is that *no connection procedure with an eNB is required*: UEs can in fact receive eMBMS contents without the eNBs even noticing.

TABLE I: UE procedure to receive an eMBMS service

1: Synchronize to the eNB receiving PSS and SSS;
2: Decode the MIB (Master Information Block), to find the location of SIB (System Information Blocks);
3: Read SIB13 to find the location of MCHs;
4: Decode MCCH to find the service of interest and gather the following information: CSA period, CSA pattern, MSP, MSI;
5: Receive MTCH;

Furthermore, since the resource allocation is constant all over the MBSFN area, no handling of mobility by the network is necessary. These are the key points we aim to exploit to allocate resources for the broadcast LTE-direct transmissions.

III. LTE-DIRECT BROADCAST

eMBMS provides a flexible and connectionless system to define quasi-static resources over a wide area. In this work, we propose to use the same concept for LTE-Direct broadcast resource allocation; unlike eMBMS, in our mechanism the network does not utilize such allocated resources. Instead, these can be accessed by the UEs applying a distributed *TDMA-like* scheme, currently in phase of investigation.

A. Resource Allocation

Let the network allocate the resources for the broadcast LTE-direct transmissions in the same way it would allocate resources for an eMBMS service (MCH channel). The specific MBSFN area can be calibrated according to the needs of the specific service: for instance, to allow broadcast communications between urban public transportation vehicles, this area can be set to cover the surface of a city. Let then the network transmit the MCCH, containing all the control information required by the UEs to access these resources. After allocating them, the network will not use these resources.

MCCH is assigned the first two OFDM symbols of each RB dedicated to MCH, while MTCH occupies the remaining ten symbols. Each RB will then provide the broadcast LTE-direct UEs with a total of 120 (12 subcarriers times 10 symbols) OFDM symbols. The maximum rate $R_b|_{fr}$ *per LTE frame* that can be obtained using the channel portion allocated in this fashion can be computed as follows:

$$R_b|_{fr} = 120 \cdot \mu \cdot BW_{RB} \cdot N_{sf} \qquad \text{[bits/frame]}$$

where μ is the spectral efficiency of the chosen modulation scheme in bits per symbol, BW_{RB} is the cell bandwidth expressed in number of resource blocks and N_{sf} is the number of subframes per frame the network allocates to the LTE-direct transmissions. As there are 100 frames per second, the total rate R_b is obtained as $R_b = 100 \cdot R_b|_{fr}$[bits/s]. In case the resources were allocated only for a fraction of the time, the actual achievable rate is reduced proportionally.

As an example, a 10% allocation of a 20 MHz DL channel ($BW_{RB} = 100$) to LTE-direct transmissions (1 subframe per frame, *i.e.* $N_{sf} = 1$) continuously in time and transmitting using QPSK modulation, the scheme adopted by DSRC, will then sustain a maximum rate $R_b = 2.4$ Mb/s. If in this same configuration the eNB allocates 60% of its totally available resources ($N_{sf} = 6$), the maximum rate increases to 14.4 Mb/s. Table II shows the maximum rates depending on the amount of allocated resources and on the modulation scheme.

Adopting the proposed technique, the network has the flexibility to adapt the allocation parameters over time, respecting the eMBMS standard, in case of necessity. The UEs will be notified of the changes via the aforementioned control-plane channels applying the previously described procedure,

TABLE II: Maximum capacity vs. modulation scheme and resource allocation (Mbit/s)

	DL resources allocated to LTE-direct					
	10%	20%	30%	40%	50%	60%
BPSK	1.2	2.4	3.6	4.8	6.0	7.2
QPSK	2.4	4.8	7.2	9.6	12	14.4
16-QAM	4.8	9.6	14.4	19.2	24	28.8
64-QAM	7.2	14.4	21.6	28.8	36	43.2

without the need of undergoing the protocol steps to set up a connection with the eNB. Moreover, in case of eNB failure, no new UE will be able to join the broadcast LTE transmissions in the specific cell, but the UEs that already received the MCCH control information at least once can continue exploiting the same set of resources, provided they can locally maintain timing. Such continuity of service is important in a safety-critical scenario.

B. Distributed Resource Access Scheduling

The procedure described in the previous section allows the LTE network to allocate part of its time and frequency resources to broadcast direct transmissions. In this section it is shown how UEs can access this specific subset of resources according to a distributed half-duplex TDMA-like scheme.

The first step consists in establishing a technique that allows the UEs to locally and univocally identify every resource block according to a common scheme. Let us then divide the time resource into TDMA-like *frames* (not to be confused with LTE frames), whose length corresponds to the period of the vehicular safety communications. CAM standard sets the maximum transmission frequency to 10 Hz [4], making it convenient to choose frames 100 ms long. Since the UEs acquire the timing from the eNB, it can be reasonably assumed the frames for all the users are synchronous. Within each frame is available a number of RBs dependent on the allocation parameters, spread in both time and frequency. To allow for some complex distributed channel access mechanisms, every RB within a frame should be identified with a number, to be deterministically and locally computed by each UE. Figure 3 represents one LTE frame (10 subframes of 1 ms each) of a cell with bandwidth $BW = 1.4$ MHz, *i.e.* $BW_{RB} = 6$ resource blocks, in which 3 subframes (shadowed) are allocated to the LTE-direct transmissions. Every RB in it is labeled as RB_x, where x is an integer that identifies a specific resource within the frame. In the showed example the numbering starts from the RB *earlier in time* and *higher in frequency* (top left in the figure). The value increments by one unit moving one RB down in frequency until the bottom of the cell bandwidth is reached. The same scheme is then applied for the following subframes assigned to LTE-direct transmissions until the end of the 100 ms frame is reached (in the figure it stops after one 10 ms LTE frame for reasons of space). Then the numbering restarts from the beginning. Any similar policy is equally acceptable as long as it is shared by all the UEs.

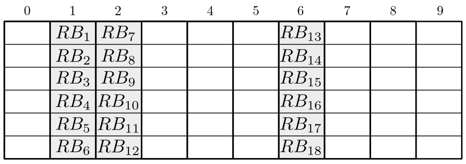

Fig. 3: example of distributed RB numbering technique.

In our scenario, we assume that all the CAM packets to be broadcast have the same size of l_B bytes. This size is meant at physical level and includes all the signaling needed by the receiver to correctly decode the packet. The integer number of resource block required per packet l_{RB} is then given by:

$$l_{RB} = \left\lceil \frac{l_B}{120 \cdot \mu/8} \right\rceil$$

where $\lceil x \rceil$ is the smallest integer larger than or equal to x and the denominator represents the capacity in bytes of the portion of the RBs dedicated to LTE-direct broadcasting, given a specific modulation format. Under this assumption, it is convenient to divide time frames into *slots*, each composed by l_{RB} resource blocks numbered in sequence, as in fig. 4:

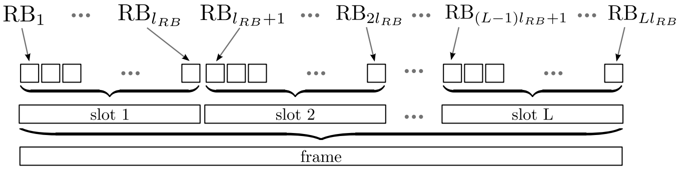

Fig. 4: grouping RBs into *slots* and slots into a *frame*.

Slots represent resource units the size of a CAM packet which are composed by RBs whose disposition in the LTE time-frequency grid depends on the adopted numbering policy. The number L of slots available per frame depends on the amount of the resource allocated by the basestation and on the LTE-direct eMBMS parameters (MSP, MSI, etc.). It is worth noting that in case of reallocation of resources by the eNB, every UE can locally recompute the composition of the slots by applying the mechanisms presented in this section.

The multiple access can now be treated as like a half-duplex TDMA scheme, in which UEs are in reception mode in all the slots, except for those they transmit in. In the following, we present an initial analysis of the per-frame probability of success (P_s) of a transmission versus the number of UEs, in the case of a network of N UEs, all within each other transmission range. In this scenario, a packet transmitted in a slot is successfully received if all the other UEs are in reception mode in the same slot, as no collision takes place.

The Optimal Resource Allocation (ORA) in terms of channel utilization is obtained when a centralized system univocally assigns to every UE one slot in each frame: in this way, up to L users are supported with $P_s = 1$.

The simplest decentralized solution is the Random Slot Choice (RSC): every user randomly chooses, according to a uniform distribution, one slot per frame in which to transmit. In this configuration P_s can be computed vs. the number of slot L and number of UEs N as follows:

$$P_s = [1 - \mu_p/L]^{N-1}.$$

μ_p represents the probability for UEs to transmit in the current frame: $\mu_p = 1$ means the UEs will transmit in all frames, lower values will make the transmissions statistically less frequent.

More complex solutions take advantage of multiple retransmissions per frame, such as the Orthogonal Optical Codes (OOC) TDMA access system proposed in [5]: every user randomly chooses an OOC binary codeword of length L and Hamming weight w. Every bit of the frame-long codeword corresponds to a slot: UEs are in transmit mode in correspondence of '1' bits and in reception mode in correspondence of '0' bits: w thus corresponds to the number of slots accessed per frame. A CAM is successfully received if at least one of the retransmissions within the frame succeeds. OOC codewords are built so that the maximum cross-correlation between two different words is less than or equal to a integer value λ. For $L \gg w$ and $L \gg \lambda$ it is reasonable to assume that no UEs within interference range choose the same word. In this case P_s can be computed as follows:

$$P_s = \sum_{k=1}^{w} (-1)^{k+1} \binom{w}{k} \left[1 - \sum_{j=1}^{w} p_j \sum_{i=1}^{\min(j,k)} \binom{k}{i} \binom{w-k}{j-i} \right]^{N-1}$$

where p_j is the probability of having an interference pattern with weight j:

$$p_j = \mu_p \cdot \binom{L-w}{w-j} \cdot \left[\sum_{l=0}^{\lambda} \binom{w}{l} \binom{L-w}{w-l} \right]^{-1}$$

Fig. 5: example of UEs with $\mu_p = 0.5$ (crossed arrow) and $\mu_p = 1$ (dotted arrow).

TABLE III: CAM packets characteristics

Size:	Coding:	Max frequency:	DSRC channel:
300 bytes	QPSK	10 Hz	CCH

The value of μ_p affects the frequency of transmissions: for example, in fig. 5 one UE with $\mu_p = 1$ transmits in one slot per frame in all the frames, while the second UE transmits in two slots per frame (OOC with $w = 2$), but in average only once every two frames ($\mu_p = 0.5$). In fig. 6 are plotted the theoretical performances of the mentioned access schemes: RSC and OOC with $w = 2$ and $\lambda = 1$, for values of $\mu_p = 1$ and $\mu_p = 0.5$, are compared to the ORA scheme. The reference scenario assumes a 20 MHz bandwidth, 10% time-continuous allocation. In such scenario, L = 100 slots are available for CAM packets as defined in table III. The performance metric we evaluate is the number of UEs that can be supported, provided that the per-frame probability of successful reception is above 0.85, as required by DSRC. Such threshold is indicated by a dashed horizontal line in fig 6. OOC supports more UEs while achieving $P_s \geq 0.85$: with $\mu_p = 1$ up to 25 users can be supported versus the 17 of RSC. Halving the statistical frequency of transmissions ($\mu_p = 0.5$), OOC supports 49 users versus the 33 of RSC. However, when the number of users increases, the retransmission-based techniques tend to saturate the available resources, causing rapid performance degradation. In fig. 6 the points in which the curves for equal values of μ_p cross are circled.

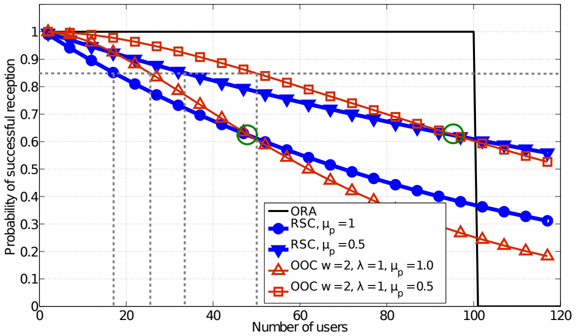

Fig. 6: P_s versus number of users. $L = 100$.

IV. Discussion and Outlook

The mechanism presented in this work takes inspiration from eMBMS to provide a connectionless, wide-area and eNodeB failure-resilient resource allocation technique for LTE-direct broadcast transmissions. The decentralized access to these resources, a topic still under investigation, is introduced by comparing three classes of techniques in a basic network scenario. In future, other sophisticated techniques and more realistic scenarios will be considered.

The parameters that allow to optimize the performances are the same as in the Decentralized Congestion Control applied to DSRC. Modifying the transmission power it is possible to adapt the transmission range to different density scenarios. In dense networks, a shorter transmission range will increase the probability of successful transmissions with closest neighbors, the most important for safety applications. Further, increasing the statistical inter-packet period also improves the probability of successful reception while increasing the delay between two successive transmissions in a controllable fashion.

The flexibility of the network resource allocation mechanism and the independent distributed access scheduling, other than being suitable for vehicular safety communications, open to new possibilities of extending the LTE technology for broadcast device-to-device communications.

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