Reliable Vehicular Broadcast using 5G Device-to-Device Communication

Mozhdeh Gholibeigi[‡], Nora Sarrionandia[‡§], Morteza Karimzadeh[‡],
Mitra Baratchi[‡], Hans van den Berg[*‡], Geert Heijenk[‡]
[‡] University of Twente, The Netherlands
[*]Netherlands Organization for Applied Scientific Research (TNO), The Netherlands
[§] DeustoTech-Fundacion Deusto, Deusto Foundation, Spain
Email: [m.gholibeigi, m.karimzadeh, m.baratchi, geert.heijenk, bergjl]@utwente.nl, nsarri9@opendeusto.es

***Abstract*—With the ever-increasing call for connected vehicles and intelligent transportation applications, vehicular networking have been of significant focus recently. Demands for highly reliable communication challenge the current underlying technology and transformations in vehicular communication are discussed. The uMTC service of the next generation mobile networking system (*i.e.* 5G), which is based on D2D broadcast communication, is a promising enabler for broadcast-based C-ITS applications with strict reliability requirements. In this paper, we look at the resource management aspect of D2D communication technology to contribute to vehicular broadcasting with a higher level of reliability. In this regard, we propose a resource allocation scheme which is adaptive to the varying state of a vehicular network. With focus on the network load and topology as the main criteria, our scheme aims for management of the system capacity and interference situations, in order to meet the performance requirement of D2D vehicular broadcast, in terms of reliability. The results confirm the effectiveness of our approach and provide insight on the optimal network design regarding the allowed data rate and resource assignment according to application requirements.**

***Index Terms*—vehicular ad hoc networks, broadcast, 4G, 5G, uMTC, D2D communication, resource allocation, reliability.**

I. INTRODUCTION

Intelligent Transport Systems (ITS) have been of significant growth recently, as a means of enabling safe roads, efficient traffic and ultimately the future Internet of Vehicles (IoV). Reliable wireless communication between vehicles is crucial for high-performance ITS applications. In this regard, broadcasting as the main communication type receives much interest. However, existing technologies [1] fail to meet the ever-challenging scalability and quality demands of novel applications. Namely, highly reliable transmission of data, cannot be guaranteed [1].

IEEE 802.11p, as the main standard for vehicular communication, has shortcomings mainly due to its intrinsic characteristics, namely in scalability, coverage extension due to the short communication range, fixed and inefficient utilization of the 5.9 GHz frequency band, no acknowledgement technique for broadcast and delay due to the overhead of central security management.

Motivated by all these shortcomings, new alternatives for vehicular communication are sought. In this regard, Device-to-Device (D2D) communication technology [12] [8] [4] [3] is considered as an enabler for high performance vehicular applications. This method enables direct discovery and communication of users in the proximity of each other without traversing the infrastructure of the cellular network. The availability of the cellular infrastructure as a central management entity eliminates issues like collision and resource detection. On the one hand, D2D communication benefits from scheduling capabilities of the infrastructure and on the other hand, it does not undergo two-hop (*i.e.* uplink / downlink) conventional cellular communication. This results in gains in terms of spectral efficiency, low latency, low transmission power and high data rate. Accordingly, D2D-based vehicular broadcasting is considered as a promising approach to fulfill requirements of safety-critical vehicular applications regarding high reliability and low latency. D2D broadcast communication is the basis for ultra-reliable Machine-Type Communication (uMTC), which is one of the main three services of the next generation mobile networking system (*i.e.* 5G) and the safety critical vehicular applications with strict latency and reliability requirements are proposed to be addressed by this service [2].

Having an efficient way of managing resources, is an essential factor in realizing advantages of D2D communication. As shown in Figure 1, D2D communication can be classified into two main categories, from resource utilization point of view, as out-band (*i.e.* using unlicensed bands for D2D transmission) and in-band (*i.e.* using the licensed cellular spectrum for D2D transmission). The out-band D2D is out of the scope of this paper, since we are interested in utilizing the scheduling capabilities of the cellular infrastructure. The in-band D2D can be further divided into underlay and overlay schemes [7] [10]. The first refers to the case where the radio resources are shared between the cellular users and D2D users and this may lead to interference between transmissions using the same resources. As a means of avoiding interference, dedicated resources may be considered for D2D communication. This is called the overlay in-band D2D. The base station defines these resources and either accordingly allocates them (*i.e.* scheduled / mode1) or users may access them randomly on their own (*i.e.* autonomous / mode2) [5].

There are different challenges in realizing resource efficient and reliable D2D communication. It is important to take into account the system capacity and interference conditions, while allocating resources. The first aspect is about the problem of instantaneous network load management, given non-stationary

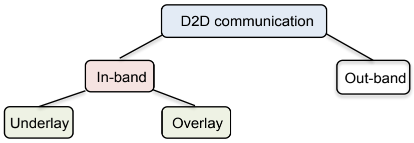


Figure 1: D2D classification.

demand for D2D communication. With regard to the second aspect, spatial resource reuse plays a crucial role. The problem is, while having many concurrent D2D communications is targeted as a means for better resource utilization, it may lead to increasing interference and accordingly performance degradation, in the case of resource reuse. All these imply the fact that a fixed resource allocation scheme cannot fit into the varying state of a vehicular network.

In this work, we study the application of D2D communication overlaying the cellular spectrum for vehicular broadcasting. By considering the current fourth generation of the mobile networking system as the baseline, we focus on the network management aspect of resource allocation to address the mentioned problems. For this, we propose a D2D resource allocation scheme which is adaptive to the network load and topology, aiming management of the system capacity and interference situations and accordingly supporting reliable V2V broadcast. The main contributions of this paper are summarized as follows:

(i) we propose a centralized resource allocation scheme for D2D vehicular broadcast, with adaptive functionality according to the varying network condition.
(ii) we develop a system for analyzing performance of vehicular broadcast groups, given the proposed resource allocation scheme.
(iii) based on the developed system, we confirm the effectiveness of the proposed scheme via numerical results from both the system and end-user point of view.

The rest of the paper is structured as follows. The related work is discussed in Section II. The details of the system model are provided in Section III, including the scenario and data dissemination aspects. The adaptive resource allocation scheme is introduced in Section IV. Section V presents the numerical results, followed by conclusion and directions for future work in Section VI.

II. RELATED WORK

In this section, we refer to some recent work of relevance to the fundamental aspect of resource management in D2D communication.

In [17] the authors considered a distributed resource allocation scheme and proposed a MAC protocol for data channel competition. However, the amount of time needed to get access to the medium may give rise to scalability issues in dense scenarios, in particular for safety critical ITS applications. In [19] it is proposed using a MAC protocol which is functioning similar to RTS/CTS in WiFi. Receivers measure the SIR of the received control signals by the transmitters and accordingly decide to respond to the one with the highest level of SIR.

In [15] it is proposed an underlay D2D resource and power allocation scheme in a two step joint optimization. Though the authors proposed a less complex sub-optimal solution, full knowledge of the Channel State Information (CSI) is assumed which is not a reasonable assumption, due to the overhead and the amount of required time. A similar work in [18] proposed for a single cell considering all possibilities for resource allocation permutations and the corresponding levels of Signal to Interference plus Noise Ratio (SINR). Though they proposed a sub-optimal version of the scheme with less complexity, it may not be tolerable the overhead of computing the interference level of each resource for all D2D users.

The work in [16] assumes the knowledge regarding resource allocation for cellular users is available both for other cellular and also D2D users. That is, each D2D transmitter predicts the interference from all cellular users and accordingly selects for reuse the resource of a cellular users which results in the least interference. In [13] the authors proposed to define a set of transmission patterns. It is assumed that each user obtains the information regarding the transmission patterns and path losses from all users and chooses a pattern that the resultant interference is less than a predefined threshold which is a computationally expensive approach. The scalability is another issue, in terms of the transmission patterns for higher number of users.

The authors in [9] proposed dividing a cell area into non-overlapping sections and considering a predefined set of resources for each section. The resources of a section can be reused in another section with enough distance, as a means of interference management. However, such a fixed area division and resource grouping may not meet the dynamicities of the network and as a result resources can be inefficiently underutilized.

Besides the main focus on the D2D unicast communication, most of the existing work assume the CSI of all links to be available at the base station, in order to efficiently manage allocation of resources. This is probably not a reasonable assumption, in particular considering the computation overhead for dynamic networks. Very limited work is available for overlay D2D and also the majority of the previous studies consider the radio resources to be reused by at most one other user and evaluate the performance of a single D2D pair. Whereas intelligent reuse of resources by as many as possible users will significantly improve spectrum efficiency. Arguable is also the scalability of the distributed resource management schemes.

Considering the aforementioned limitations, in this work we develop and analyze a dynamic mechanism of central resource management for D2D broadcast communication, overlaying the cellular network. For this, the base station does not rely on the CSI of the involved links. Rather, the location information of D2D transmitters are sufficient which is often available in ITS applications via GPS data, hence lightening the overhead of control signaling. Dynamicity of our approach is two-fold, in terms of the network load and topology. To be more specific, we propose a resource management scheme, where first the maximum affordable data rate is computed, given the current network load and system bandwidth. This specifies the number of obtainable resources, out of the available bandwidth (*i.e.* system capacity). Then given the network topology, D2D transmitters are spatially grouped, as a means of interference-controlled reuse of the specified resources.

III. SYSTEM MODEL

In this section, we first present the modeling scenario. Then, we detail the resource allocation preliminaries and assumptions. The data dissemination approach for the broadcast groups is introduced next and this completes the modeling in order to be implemented, as discussed later in the relevant section.

A. Scenario

In this section, we present the model of our study that characterizes D2D vehicular broadcasting for a given application. We consider a scenario where there are multiple vehicular users demanding for instantaneous broadcast of information to their neighborhood, using D2D links enabled by the LTE wireless communication interface. Such a situation may arise in the wake of an emergency (*e.g.* safety applications).

In more detail, we assume that as a result of emergency situations in various locations in a cell, the vehicles which are aware of such situations, get active at the same time as D2D transmitters to inform the vehicles around, given the transmission range, specified by the application. For this, they are supposed to broadcast a given number of messages with high reliability within reasonable time to their neighborhood successively, for a short period of time following occurrence of an emergency. Hence, they seek for radio resources and upon access, ensuing the allocation mechanism, they broadcast to all the intended receivers within their coverage. We call D2D transmitters along with the vehicles in their coverage a Broadcast Group (BG).

The formation of multiple broadcast groups in a cell may turn the system capacity into a bottleneck. What we are interested in, is to evaluate performance of the system, over the course of broadcast of a certain number of active groups in a cell. The aim of such a scenario is to evaluate the performance of applications demanding such instantaneous transmission opportunities (*e.g.* safety services), given the proposed resource management approach. For this, the following settings are applied. We consider N_{V_T} D2D transmitters are distributed following uniformly random positions in the area of a cell with one base station, each of them having N_{V_R} number of receivers, also with uniformly distributed random positions within the coverage R_{V_T} of the transmitter. Note that, due to the overlay resource allocation scheme in this work, the cellular users do not have any interference effect on D2D broadcast groups of the same cell and hence they are not considered in the cell. Given this, the intra-cell interference would be due to the resource reuse between broadcast groups in the cell. As a means of considering the interference also at the inter-cell level, we consider a second cell with the same assumptions, except the fact that we also consider cellular users with uniformly distributed random positions. Therefore, the inter-cell interference can be originated by cellular users and/or broadcast groups in the second cell, reusing resources of broadcast groups in the main cell. Figure 2 shows the modeling scenario and Table I lists for each cell the parameters and the corresponding values used for the modeling, unless otherwise mentioned.

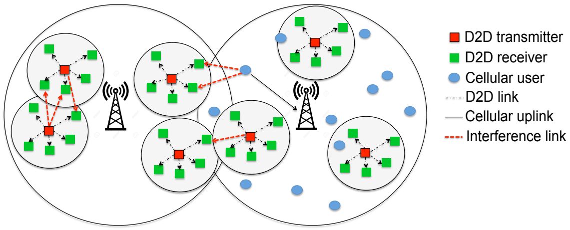


Figure 2: The modeling scenario.

Table I: Parameters.

Parameter	Definition	Value
BW	The bandwidth of the system	10 MHz
N_{RB}^{UL}	The total nr. of uplink Resource Blocks (RBs)	50
$N_{RB_{D2D}}^{UL}$	The nr. of uplink RBs for BGs	20
N_{V_T}	The nr. of D2D BGs	1-20
N_{V_R}	The nr. of receivers per BG	10
N_C	The nr. of Cellular Users (CUs)	10-20
R_{V_T}	The transmission range of D2D transmitters	2km
R_{eNB}	The coverage range of the eNB	5km
$PoolPeriod$	The time duration of the resource pool	40-120 ms
$bitmap$	The time resource pattern	bitmap pool
TTI	Transmission Time Interval	1 ms
I_{MCS}	Modulation and coding scheme index	10
MS	The size of the message to be transmitted	5-15 Packets
N_{MS}	The number of the messages to be transmitted	100
L_{CRB}	The predefined nr. of contiguous RBs per BG	5
TBS	The predefined transport block size	872 bits
P_T^D	The D2D transmitter power	30 dBm
P_T^C	The cellular user transmitter power	40 dBm
$SINR_T$	The tolerable SINR level at a node	-174 dBm/Hz

B. Resource allocation preliminaries and assumptions

Based on the 3GPP standardization framework, D2D uses the uplink spectrum or uplink sub-frames, in case of Frequency Division Duplex (FDD) or Time Division Duplex (TDD), respectively. We consider the uplink spectrum (*i.e.* in FDD) for D2D communication. The physical data channel for D2D follows the structure of the Physical Uplink Shared CHannel (PUSCH), using Single Carrier-Frequency Division Multiple Access (SC-FDMA) scheme [5] [3].

The smallest resource allocation unit that we consider in the model, is a Resource Block (RB). That is, 180 KHz (*i.e.* 12 × 15KHz subcarriers) in frequency and 1 ms (*i.e.* 1 subframe) in time. For a given user, the transmission occurs in a set of subframes within the resource pool and in a set of RBs within those subframes. The set of subframes is specified by a bitmap, such that only the subframes with the corresponding status 1 in the bitmap are used for the transmission and from now on we call them "on" subframes / bits [5]. As for the resource blocks, the allocation is based on the Uplink type 0, specified by a Resource Indication Value (RIV). RIV specifies for each user the ID of the starting RB for allocation, denoted by RB (RB_{start}) and a length in terms of the contiguously allocated RBs, denoted by RBs (L_{CRB}) [5].

In LTE the MAC PDU transmitted over the Physical channel is called the transport block and its size varies for each user, depending on the value for L_{CRB} and the modulation and coding scheme, specified by its index as I_{MCS} [5]. This will determine how much resource is required to complete message transmission.

The scheduling interval for D2D users is $PoolPeriod$ (*i.e.* the time duration of a resource pool). For cellular users the scheduling interval is semi-persistent, composed of 8 Transmission Time Intervals ($TTIs$) which is a bitmap length and is scheduled by the base station in an orthogonal manner.

D2D broadcast is an open-loop communication, with no $HARQ$ feedback scheme. Hence, transmission repetitions (in four consecutive subframes) are assumed as a means of reliability improvement [5]. Figure 3 shows an example allocation for 4 broadcast groups within a part of a resource pool with eight subframes (*i.e.* the length of a bitmap).

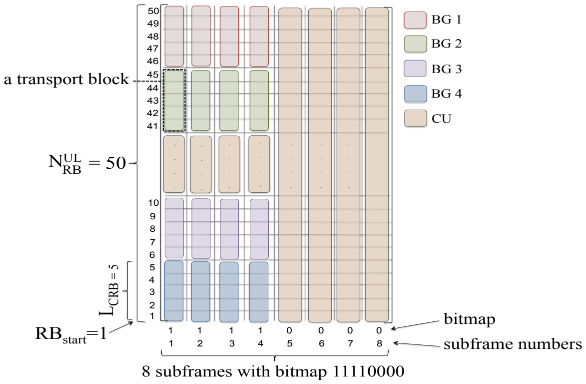


Figure 3: An example resource allocation.

C. Propagation model

The power of the received signal P_{RX} at a given receiver is computed according to

$$\log_{10} P_{RX} = \log_{10} P_{TX} - L \tag{1}$$

where P_{TX} and L are the transmission power and the propagation loss in dB, respectively. Many factors influence the propagation loss L, namely path loss, shadowing and fast fading effects due to multipath propagation of the signal. The impact of fast fading and shadowing on the system performance can be neglected. Mainly, this is the path loss affecting the signal degradation and for D2D communications, it is modeled using the Hata path loss model [2] [6] as

$$L = 148 + 40\ \log_{10}(d), \tag{2}$$

where d is the distance between the given transmitter and receiver, in kilometer. With this, P_{RX} can be computed and the SINR determines if this is enough to realize successful reception of data at a given receiver, in the presence of noise and the interfering signals IS as

$$SINR(P_{TX}, L, IS, N) = \frac{P_{RX}}{N + \sum\limits_{\forall r \in IS} P_{rX}}, \tag{3}$$

where N is the noise power in dB and P_{rX} is the received power of the interference signal $r \in IS$.

IV. ADAPTIVE RESOURCE ALLOCATION MECHANISM

In this section, we introduce our resource management approach with an adaptive function, driven by change in the network state, characterized by the network density and topology. Such network state awareness aims the system capacity management and tackling the dynamic topology of a varying number of vehicular broadcast groups, via a resource-efficient and interference-aware resource allocation mechanism and accordingly keeping desirable performance. Note that our approach aims D2D resource management in a cell where as explained earlier in scenario, the cellular users can not be the source of interference. Accordingly, they are not considered in the design of the approach. However, in Section V a second cell composed of both D2D broadcast groups and cellular users is considered as a means of evaluating performance of the approach in the presence of inter-cell interference.

We specify the network state as the average channel load level. To quantify this, we define the network parameter $load\ index$, denoted by LI, as the statistical number of D2D transmitters to be competing for the same resource. From now on, we call them co-transmitters. We assume that the base station has the knowledge about the number of transmitters (N_{V_T}) requesting for D2D broadcast [3], at the beginning of each transmission scheduling interval. Given this and considering all resources as equally probable to be occupied, the ratio of the number of broadcast groups (N_{V_T}) to the available number of resources would be a reasonable approximation of LI, known at the base station. For example, for $N_{V_T} = 8$ and the number of available resources $N^{UL}_{RB_{D2D}}/L_{CRB} = 20/5 = 4$, we have $LI = 8/4 = 2$.

We also define an upper limit for LI, denoted by LI_T, as the maximum tolerable channel load (*i.e.* the maximum number of co-transmitters per channel) to avoid interference. Considering the area of a given cell with radius R_{eNB} and the transmission range R_{V_T} of broadcast groups, LI_T can be characterized as the maximum number of co-transmitters in the cell with pairwise distance no less than $2 \times R_{V_T}$, in order to avoid interfering co-transmissions, as demonstrated in the example Figure 4. This is a circle packing problem and LI_T is reasonably approximated by $LI_T = \lfloor 0.83 \times (R_{eNB}/R_{V_T})^2 - 1.9 \rfloor$ [14] [11].

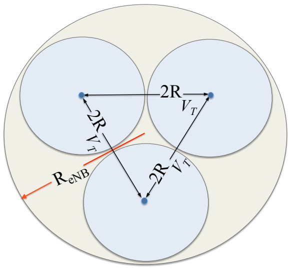


Figure 4: Three non-overlapping D2D transmitters within a cell.

As demonstrated in Algorithm 1, the base station acquires LI and LI_T at the beginning of each transmission scheduling interval (*i.e.* $PoolPeriod$) and takes the appropriate action accordingly, based on the three possibilities for the traffic regime ($LI \leq 1$, $1 < LI \leq LI_T$, $LI > LI_T$) and also the network topology which we explain in what follows.

$\mathbf{LI \leq 1}$. Such a traffic regime implies that the number of D2D transmitters, seeking for resources, is less than the number of available resources. In such a case there is no need for resource reuse and the base station schedules the resources for D2D transmitters, in an orthogonal way. Hence, there would be one-to-one correspondence between each user and a resource.

$\mathbf{1 < LI \leq LI_T}$. In this case, resource reuse is inevitable as the number of D2D transmitters is more than the number of available resources. Since LI is less than the upper limit, presumably the users can be served interference-free with the current data rate, based on which LI is computed. This would be checked by the base station as follows. Given the availability of users' location information at the base station, the adjacency graph of the current D2D transmitters is obtained. Such that, each D2D transmitter represents a vertex in the graph and there exist edges between every two D2D vertices, with distance less than $2 \times R_{V_T}$. Given this, the base station separates all vertices into as few as possible disjoint maximal independent subsets. The D2D transmitters represented by corresponding vertices in each subset are supposed to use an identical resource, since they are pairwise non-adjacent and we call them a reuse group/subset. If the number of these reuse groups is less than or equal to the number of radio resources R, there would be one-to-one correspondence between each group/set and a resource. That is, all users belonging to a group/set can safely reuse their assigned resource, without experiencing any interference. We consider all the resources equally probable to be assigned to a group/set. Note that as a means of resource efficiency, the algorithm tries to keep the number of the reuse groups as few as possible.

It can also happen that due to topology limitation, it is not feasible to achieve the grouping of users into R or fewer number of disjoint subsets of independent vertices. In such a circumstance, depending on the application requirement, either of the following procedures would be adopted. The first option is keeping the data rate and accordingly the number of resources unchanged. Given this, the users are grouped into R disjoint subsets which are no longer independent. This implies that some users will inevitably experience interference. However, in order to keep the number of these users as low as possible, the subsets are created with the minimum possible number of edges, as clarified in the algorithm. Once formed, each of these R subsets would be corresponded to a resource. According to the second option the users would be served with a lower data rate. Note that a minimum limit for the data rate must be considered, in order not to violate the application latency limitation. In this work, we consider 0.328 Mbps, corresponding to 2 RBs. The rationale for this is that lowering the data rate, implies lowering L_{CRB}. This gives room to obtain a higher number of resources out of $N^{UL}_{RB_{D2D}}$ number of resource blocks. Hence, more users can be served at the expense of a lower data rate. It is desirable to keep the new data rate as high as possible (*i.e.* close to its current value) and to achieve this, LI would be set equal to its upper limit LI_T and the new number of resources R would be extracted from this equation. Subsequently, the new L_{CRB} and data rate are derived. Once these new parameters are obtained, the reuse groups/sets would be formed and associated to resources, as explained earlier.

$\mathbf{LI > LI_T}$. In this case LI exceeds its upper limit and serving the users with the current data rate may lead to significant performance degradation, due to the increasing number of interfering users. At this point, again it would be checked if it is still feasible to classify all D2D transmitters into R or even fewer number of disjoint sets of independent vertices. If so, the users can be served interference-free with the current data rate. Otherwise, data rate would be adjusted according to the procedure, explained earlier for the case $1 < LI \leq LI_T$.

V. PERFORMANCE EVALUATION

In this section, we first introduce the performance measures and accordingly present the obtained results. For this, we implement the introduced model and resource management scheme in Matlab and then by considering key parameters as inputs to the system, evaluate its performance in terms of the introduced metrics.

A. *Metrics*

1) Complete Message Delivery Ratio (CMDR): Considering the reliability requirement of D2D broadcasting for safety-critical vehicular applications, the complete message delivery ratio is a relevant metric, representing the average percentage of receivers of an arbitrary broadcast group that successfully receive "all" the broadcast messages.

2) Spectrum Efficiency (SE): Due to the rapidly growing demand, efficient utilization of the scarce spectrum is of significant importance, mainly from the system point of view. This metric indicates how efficiently the available radio resources are utilized and is obtained according to Eq. 4.

$$SE = \frac{\#BG \times (DR/100)}{\#utilized\ resources}, \tag{4}$$

indicating the success ratio per unit bandwidth.

3) Packet Loss Ratio (PLR): Most applications demand timely delivery of data. To assure this timeliness transmissions are considered over a limited range of the time domain of the spectrum (specified via $PoolPeriod$ by the application) and it is indicated in terms of the packet loss ratio if this timeliness is met. For an arbitrary receiver, this metric shows the ratio between the lost packets and the total number of broadcast packets.

Algorithm 1: Adaptive resource allocation

```
**Input**: $N_{V_T}, BW, L_{CRB}, N^{UL}_{RB_{D2D}}, R_{V_T}, R_{eNB}$
**Output**: Load and location aware "BG-resource" coupling
initialization:
    $LI = \lceil N_{V_T} / \lfloor (N^{UL}_{RB_{D2D}} / L_{CRB}) \rfloor \rceil$
    $LI_T = \lfloor 0.83 \times (R_{eNB}/R_{V_T})^2 - 1.9 \rfloor$
    $G(N_{V_T}, E) \leftarrow$ the adjacency graph of BGs
    $R \leftarrow$ the set of radio resources
if $LI \leq 1$ then
    $f : N_{V_T}(G) \rightarrowtail R$                // one-to-one correspondence
1 else if $1 < LI \leq LI_T$ then
    $DIS \leftarrow$ the disjoint set of maximal independent subsets of $N_{V_T}(G)$;
    if $|DIS| \leq |R|$ then
        if $N_{V_T}(G) \setminus DIS = \emptyset$ then
            $f : DIS \rightarrowtail R$
        else
            $L := \{N_{V_T}(G) \setminus DIS\}$
            $DISL \leftarrow$ the disjoint set of maximal independent subsets of $L$;
            if $|DISL| + |DIS| \leq R$ then
                $DIS := \{DIS \cup DISL\}$;
                $f : DIS \rightarrowtail R$
            else
                $x = (|DIS| + |DISL|) - |R|$;
                $y = |DISL| - x$;
                $DISL_y := \{y \text{ largest subsets of } DISL\}$;
                $DIS := \{DIS \cup DISL_y\}$;
                $DISL = flatten(DISL \setminus DISL_y)$;
                for $i \in DISL$ do
                    for $j \in DIS$ do
                        $EdgeCount_i[j] := E(DIS[j] \cup DISL[i])$;
                    $DIS[j] := \{DIS[j] \cup DISL[i] \mid \min\{EdgeCount_i\} = EdgeCount_i[j]\}$;
                $f : DIS \rightarrowtail R$
    else
        $L := \{N_{V_T}(G) \setminus DIS\}$; $x = |DIS| - |R|$;
        $DIS_R := \{R \text{ largest subsets of } DIS\}$; $DIS_x = \{DIS \setminus DIS_R\}$;
        $L := L \cup DIS_x$; $DIS = DIS_R$;
        for $i \in L$ do
            for $j \in DIS$ do
                $EdgeCount_i[j] := E(DIS[j] \cup L[i])$;
            $DIS[j] := \{DIS[j] \cup L[i] \mid \min\{EdgeCount_i\} = EdgeCount_i[j]\}$;
        $f : DIS \rightarrowtail R$
else
    $LI = LI_T$;
    $R = N_{V_T}/LI$;
    $L_{CRB} = N^{UL}_{RB_{D2D}}/R$;
    go to 1
```

B. Numerical Results

The performance of the system, evaluated in terms of the above-mentioned metrics, is the focus of this section. Considering effective factors such as the number of broadcast groups N_{V_T}, the message size MS, the time duration of the resource pool $PoolPeriod$ as inputs to the system, we analyze the system functionality. Note that being within 5% confidence intervals, the results for each numerical setting are obtained by averaging over twenty random topologies of a given number of broadcast groups, uniformly distributed in the area of the main cell. The number of broadcast groups N_{V_T} is considered different in two cells as a means of a more realistic setting. The results help providing insight on how the system performs under different assumptions.

The complete message delivery ratio for an arbitrary receiver, against increasing density of D2D broadcast groups is shown in Figure 5 for the proposed adaptive approach and the random reuse approach, as the baseline for comparison. Note that in this figure both the single cell and two cell cases are considered. With a single cell in isolation, it is better seen the improvement provided by the proposed approach, independent of the inter-cell interference in a multicell scenario. Also, in this figure no data rate adjustment is yet taken into account to better see the impact of spatial reuse, distinctly. What is first observed in this figure, is that even without data rate adjustment in case of dense scenarios, the proposed approach succeeds in keeping the delivery ratio significantly higher than the baseline approach.

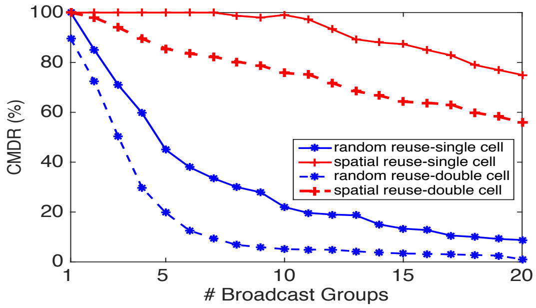


Figure 5: CMDR PoolPeriod=40ms, MS=1500Byte.

Note that in the setting for the two cell scenario, a uniformly distributed random number of broadcast groups between 1 and 10 are considered in the second cell, with the baseline resource allocation approach. Despite the corruptive effect of the inter-cell interference on the delivery ratio, compared to the single cell case, it is recognized a significant improvement against the random reuse scenario.

Figure 6 shows the spectrum efficiency against increasing number of broadcast groups, for the same setting. Despite increasing density of D2D broadcast groups in the cell, the radio resources are used in a more conservative way via the proposed approach, due to the purposive spatial reuse. Whereas, the random reusing of the resources comes significantly short of successfully serving denser scenarios. Due to the one-to-one correspondence between each user and a

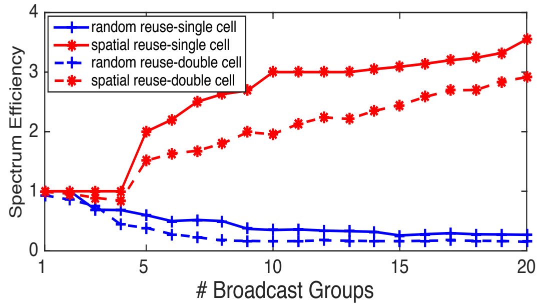


Figure 6: Spectrum efficiency, PoolPeriod=40ms, MS=1500Byte.

resource in our approach, the spectrum efficiency equals the delivery ratio for the first four broadcast groups. After this point, due to the spatial reuse of the resources, the number of utilized resources is less than the number of served broadcast groups. Recalling from Eq. 4, this results in the significant increase in the spectrum efficiency, as traceable in the figure. Though by taking the effect of inter-cell interference into account, the resource efficiency is shrinked compared to the single cell case, we still see a significant gap between two curves. Note that the resource allocation in the second cell follows the baseline approach.

The average packet loss ratio for a receiver of an arbitrary broadcast group is shown in Figure 7, against the increasing density of D2D broadcast groups, for the proposed adaptive approach and the random one. While the random approach deteriorates quickly towards denser scenarios, our approach performs noticeably more reliable and scalable.

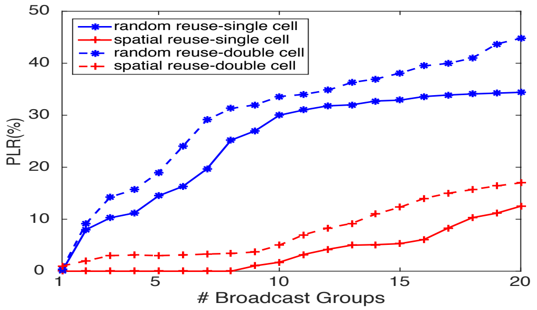


Figure 7: PLR, PoolPeriod=40ms, MS=1500Byte.

The complete message delivery ratio against increasing number of broadcast groups and the message size is demonstrated in Figure 8 for a two cell scenario. Besides the decreasing flow of the delivery ratio in both directions as expected, it is clearly visible that our approach distinctly outperforms the baseline approach. Again with significant difference between two approaches, Figure 9 shows the packet loss ratio for the same setting.

In Figure 10 we can see the effect of the data rate adjustment on the delivery ratio, in dense scenarios. Note that here the data rate adjustment is applied only for the cases where $LI > LI_T$. That is, for the number of broadcast groups more than 13, given $LI_T = \lfloor 0.83 \times (5/2)^2 - 1.9 \rfloor = 3$. The improvement of the delivery ratio is achieved at the expense of a lower data rate as shown in the figure. As mentioned earlier, the criteria for data rate adjustment is derived by the application requirements on the data rate and delivery ratio. Hence, it could be adopted a system either serving an increasing number of broadcast groups and decreasing the data rate within the allowed range (if needed) or blocking the new broadcast groups, in order to keep the data rate unchanged. In this figure, we consider the first case and with the maximum number of 20 broadcast groups, the data rate is not less than the minimum we considered (*i.e.* 0.328 Mbps, corresponding to 2 RBs).

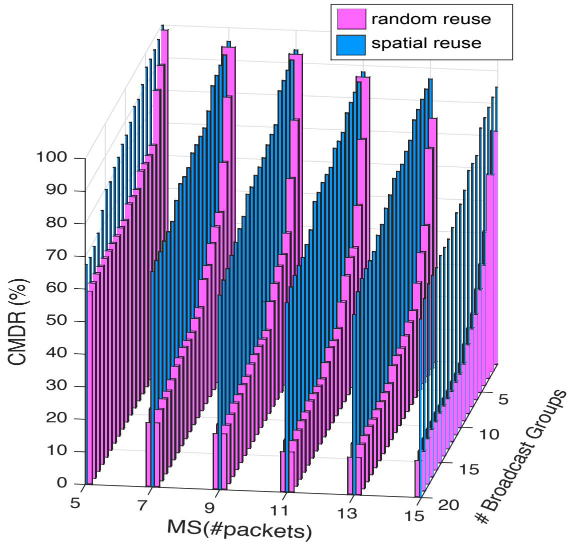


Figure 8: CMDR, PoolPeriod=100ms.

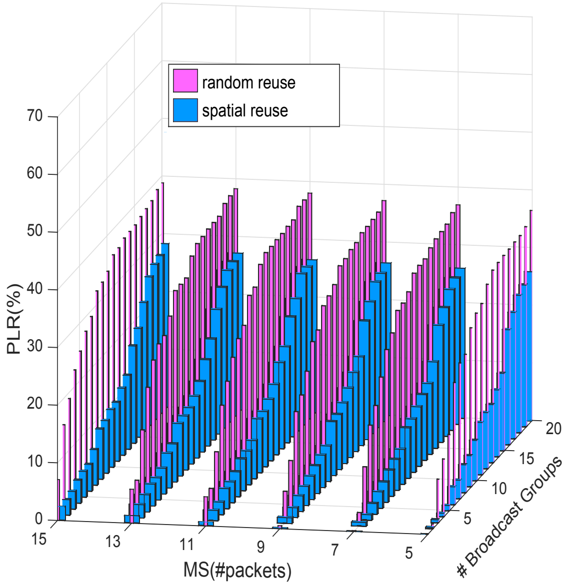
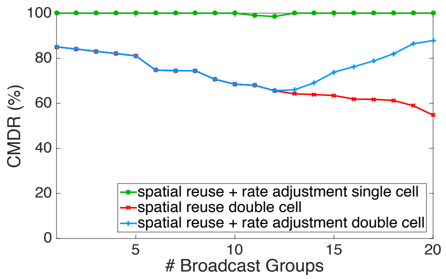


Figure 9: PLR, PoolPeriod=100ms.

VI. CONCLUSION AND FUTURE WORK

In this paper, we studied D2D vehicular broadcast, overlaying the cellular network, with the main focus on radio resource management. Motivated by the fact that a fixed resource management scheme cannot meet the performance of ITS applications with stringent reliability requirement, given dynamics of a vehicular network, we proposed a resource management scheme which is adaptive in two aspects. That is, by considering the fourth generation of the mobile networking system as the basis, we developed a resource allocation mechanism based on load control and spatial resource reuse. Accordingly, by taking effective factors as inputs into the system, we evaluated the performance of the system and broadcast groups in terms of relevant measures. Extensive numerical results of various scenarios confirm the flexibility and optimality of the proposed resource management scheme, particularly in comparison with the baseline approach of random resource reuse. These observations provide insight on the network design regarding the optimal allowed data rate and resource assignment according to application requirements.



# Broadcast Group	1-12	13	14	15	16	17	18	19	20
Data Rate (Mbps)	0.872	0.782	0.714	0.640	0.640	0.640	0.572	0.328	0.328

Figure 10: CMDR, PoolPeriod=100ms, MS=1500Byte.

As mentioned earlier in this paper and also confirmed by our results, radio resource management is an essential factor in realizing resource efficient and reliable D2D communication. Taking this into consideration, D2D communication is a promising technology for safety ITS applications, demanding highly reliable communication.

Our approach is not limited to a specific network setting and as a result can be further extended by introducing more details into the modeling. For instance, one could think of a scenario with a longer time scale and taking mobility and varying density of the vehicles during the runtime into account. Further, D2D resource management in a multi-cell scale, for underlay and overlay schemes, can be considered as a relevant direction for future studies.

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