# Location Dependent Resource Allocation for Mobile Device-to-Device Communications

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***Abstract*—Device-to-device (D2D) communication as an underlay to future cellular networks has been recently considered as an efficient cell offloading and capacity increasing solution. In this paper, we propose to use the D2D underlay as a carrier for automotive safety applications with very strict quality of service and reliability requirements. We propose a location dependent resource allocation scheme (LDRAS) for mobile D2D communications that fulfills the requirements of such services, while reducing the signaling overhead and guaranteeing a certain maximum interference level within the primary network and the D2D underlay, respectively. The former is ensured by applying persistent resource allocation to the vehicular D2D network. The latter is achieved with a spatial reuse scheme with fixed resource reservation, exploiting the localized nature of vehicle-to-vehicle communications. Initial simulation results, comparing the proposed LDRAS to a state-of-the-art radio resource management algorithm, are provided as a proof-of-concept and illustrate the benefits of our solution.**

## I. Introduction

### A. Motivation

Recent advances both in the capabilities of mobile devices and the performance of wireless networks have led to an increasing demand for mobile multimedia content. Cisco estimates a mobile data traffic growth of 70% in 2012 and a tendency of a further 13–fold increase by 2017 [1]. Faced with such high capacity requirements, future cellular systems will struggle to provide adequate service by merely increasing the available bandwidth. Device-to-device (D2D) communication as an underlay to cellular networks (e.g., LTE-Advanced or future 5G) is currently being investigated as a mechanism to provide an efficient Radio Access Network (RAN) offloading alternative [2], [3].

In such a system, communication between user equipment (UE) in close proximity is carried out directly between the devices, bypassing the cellular infrastructure. The localized nature of the D2D transmission allows for the reuse of cellular resources while maintaining network control over the additionally introduced interference. In this manner, the traffic handled by an evolved NodeB (eNB) can be efficiently reduced while still providing high aggregate cell throughput.

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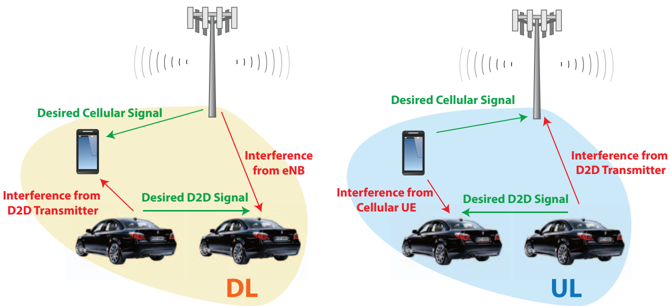
Future 5G wireless communication systems will not only have to cope with the astonishing increase in mobile traffic, but will also need to serve novel applications and services with very stringent requirements on latency and reliability. In this regard, D2D communication is a key component that can satisfy both of these demands. A significant contribution to the future mobile data traffic increase will be credited to modern vehicles which rely on cellular communication systems in order to deliver infotainment content (i.e., audio/video streaming, e-mail, software updates, etc.) [4]. In order to increase traffic safety and efficiency in the future, cooperation between vehicles is required. Driver assistance services (DAS) based on vehicle-to-vehicle (V2V) communications have very strict Quality of Service (QoS) requirements. As an example, the EU project METIS [5] outlined that future 5G systems need to cope with latency requirements of $5\,\mathrm{ms}$ and message sizes of up to $1600$ bytes and periodic transmissions of $10\,$Hz [6] in order to support traffic safety and efficiency services. The strongly localized nature of V2V applications may allow for an implementation as a secondary D2D underlay operating in the spectrum of a cellular network. Hence, D2D communication can serve as an enabler for automotive applications in the cellular network with no additional spectrum costs. Realizing such services in a cellular D2D underlay requires dynamic as well as reliable transmission and resource allocation schemes that can cope with mobile D2D terminals and that keep the additionally introduced interference at a minimum.

### B. State of the Art

The main issue faced in the context of D2D-enabled cellular networks is the novel type of interference introduced in the system due to radio resource reuse. Based on the transmission modes in the RAN, i.e., Downlink (DL) or Uplink (UL), two fundamentally different models have to be considered. A D2D transmitter utilizing DL resources causes interference at the respective cellular UE (C-UE), while the D2D receiver is disturbed by the eNB signal (see Fig. 1). In the reciprocal case, the D2D transmitter disturbs the UL signal at the eNB, while the D2D receiver suffers from interference by C-UE. Many different approaches to the radio resource management (RRM) problem in such a system have been proposed in the literature, mostly focusing on finding a capacity optimal solution.

Jänis et al. [7] investigated interference-aware resource




(a) Downlink (b) Uplink

Figure 1. Intra-cell interference caused by transmissions in a cellular D2D underlay in (a) downlink and (b) uplink transmission mode.

allocation schemes for a D2D underlay using both DL and UL resources. Their approach relies on measurements of the interference level caused by the active cellular users and eNB at each potential D2D receiver. This data along with information about the cellular links is accumulated at the eNB, which then determines the resource allocation according to the solution of an optimization problem that maximizes the performance of the D2D underlay while maintaining a target level of performance in the primary cellular network.

Zulhasnine et al. [8] proposed heuristic RRM algorithms for DL or UL resource reuse in the D2D underlay, exploiting a similar idea. In their work, channel state information (CSI) for every potential link in the network (i.e., between eNB and all other nodes, and between potential D2D transceivers and all C-UEs) is required at the eNB. Radio resources are allocated to each C-UE in a conventional fashion according to the network operator's policy, while the potential D2D transmitter that would cause the least interference to the considered cellular link is identified. This most favorable D2D transmitter is then allowed to reuse all of the radio resources allocated to the considered C-UE if the interference levels at the concerned eNB, C-UE and D2D receiver remain below certain thresholds. Otherwise, D2D communication in the respective radio resources is prohibited.

A network level optimization problem (OP) for jointly optimizing mode selection (i.e., reuse of DL or UL resources), resource allocation and power assignment has been introduced by Belleschi et al. [9]. Although solving the OP is not feasible in practical implementations, it provides a capacity optimal solution to the RRM problem in D2D enabled networks. Furthermore, this approach also relies on full CSI knowledge at the eNB for each potential link within the cell.

Many of the proposed state-of-the-art schemes consider static or slowly moving D2D terminals in the network, which renders the assumption of full CSI knowledge at the eNBs realistic. Nevertheless, such an approach is associated with a vast amount of signaling and therefore significantly reduces the efficiency of the cellular network. Moreover, since fast moving terminals such as vehicles induce shorter channel coherence times, complete CSI acquisition is not feasible in most practically relevant deployments. The CSI required for the RRM algorithms is therefore likely to to be outdated, thus rendering their performance no longer optimal. Moreover, in the current state-of-the-art, D2D communication is often considered as opportunistic and the availability of these secondary links is not guaranteed.

### C. Contributions of this Work

In this paper, we propose a heuristic location dependent UL resource allocation scheme for mobile D2D terminals based on persistent resource assignment. This approach allows for periodic transmission opportunities and enables services with strict latency and reliability requirements [6], such as automotive safety services based on V2V communications. Due to the localized nature of such services, we propose spatial resource reuse which guarantees an average Signal-to-Interference-and-Noise-Ratio (SINR) for the primary network as well as for the D2D underlay. Moreover, our approach eliminates the need for full CSI knowledge at the eNB, thus reducing signaling overhead. The proposed scheme shows promising performance compared to state-of-the-art algorithms. Note that due to space limitations we only introduce the basic concept of our scheme based on the example of an isolated sector of a three-sector LTE cell.

The rest of the paper is organized as follows. The proposed resource allocation scheme is introduced and discussed in detail in Section II. Simulation setup and results are shown in Section III and IV, respectively. Finally, the conclusions of our study are summarized in Section V.

## II. Location Dependent Resource Allocation Scheme

### A. Basic Concept

In this work, we assume that the D2D underlay is utilized by a certain class of UE, e.g., vehicular terminals (V-UE) running V2V applications. Many future V2V services (in particular, safety services) have very strict QoS and reliability requirements. For example, a beacon marking a road hazard (e.g., accident site) needs to be periodically (typically every 10 ms) and reliably transmitted after such an event is detected. Similarly, many DAS (e.g., cooperative collision avoidance applications [10]) rely on the periodic exchange of small status update messages and position information, thus generating a steady load in the D2D underlay as opposed to opportunistic communication. Therefore, the aim of the proposed heuristic Location Dependent Resource Allocation Scheme (LDRAS) is to guarantee continuous (or periodic) transmission opportunities for such services in the D2D underlay, while reducing the control overhead and the interference within the primary network. Note, however, that apart from V2V applications LDRAS may also be applied to other services which require continuous or periodic transmission opportunities.

The proposed scheme reuses the available UL resources for data transmissions in the underlying D2D network. In this manner, only the eNBs suffer from additional interference caused by transmissions in the underlay, rendering the task of interference management less complex. Note that only a single V-UE within a cell sector is allowed to reuse specific cellular radio resources in the D2D underlay. In the example of a LTE network this translates to at most one source of intra-cell interference in a specific resource block within each sector. In order to fulfill the service characteristics described above, LDRAS relies on persistent resource allocation. Each cell sector is divided into $Z$ spatially disjoint zones, where in each zone a set of resource blocks (RBs) $\mathcal{RB}_z$ is dedicated for D2D communication; here, the sets $\mathcal{RB}_z$ $(z = 1, \ldots, Z)$ are disjoint and $z$ denotes the zone index. The same sets of RBs $\mathcal{RB}_z$ are then also reused within the primary network. However, here the sets are assigned to different zones with sufficient spatial separation in order to guarantee a certain maximum interference level caused by C-UEs in the D2D underlay. An example zone layout and a corresponding example RB reservation assignment are illustrated in Fig. 2.

The zone layout and RB sets are then fixed and do not change over time. We assume that this data can be stored in the memory of each V-UE, which uses its built-in positioning system in order to track its location. Upon entering a new zone, a V-UE signals the zone index $z$ to the eNB which then assigns a subset of RBs from the set $\mathcal{RB}_z$ to the V-UE. Note that the size of the subset is chosen according to the data rate requirements of the considered V2V service and RB availability. In the primary network the resources are assigned to C-UEs according to the network operator's scheduling policy, with the additional constraint that only RBs of the set which has been assigned to the respective zone for C-UEs can be allocated. In this manner, the need for full CSI knowledge at the eNB is eliminated and thus the necessity for extensive channel measurements and signaling overhead. Signaling can be further reduced by allowing the V-UEs to autonomously sense and claim the free RBs upon entering a new zone. Nevertheless, only centralized RB allocation by the eNB is considered in this paper.

### B. Load Dependency

Since our scheme uses static resource reservation in the D2D underlay, variations in the instantaneous load in each zone may result in inefficient resource usage. If only a few V-UEs are requesting D2D transmissions in a specific zone, naturally, some RBs may be left unused. In this case, C-UEs utilizing these resources in the primary network will not cause interference to the D2D underlay and LDRAS is allowed to lift the strict reservation policy. Determined by the network operator's preferences, such RBs can be used for cellular communication in any zone. On the other hand, a very high number of V-UEs in a zone results in RB shortage. Hence not all V-UEs can be served simultaneously and LDRAS instructs conflicting D2D transmitters to share specific RBs in time.

### C. Zone Design

For the zone design, two sources of interference need to be considered: (a) the interference caused at the eNB from the signals of the D2D transmitters in the underlay network and (b) the interference caused at the D2D receivers from the UL signals of the C-UEs in the primary network. We therefore define three important system parameters that allow for specifying the resource reuse zones: the SINR threshold $\gamma_{\mathrm{C}}$ (in dB) guaranteeing a certain average SINR at the eNB, the SINR threshold $\gamma_{\mathrm{D2D}}$ (in dB) guaranteeing a certain average SINR in the D2D underlay, and the required maximum transmission distance $d$ (in m) between communicating D2D terminals.

In order to satisfy the minimum SINR threshold $\gamma_{\mathrm{C}}$ a dedicated set of RBs has to be used for the D2D underlay in a certain distance $r_1$ around the considered eNB; in the following, this zone is denoted as Zone #1. Note that this set of RBs is solely used for D2D communication within this zone and is not reused in the primary network. Assuming that the interference power at the eNB is much greater than the noise power, the SINR threshold $\gamma_{\mathrm{C}}$ can be satisfied by setting

$$r_1 \geq \overline{PL}^{-1}\left(\gamma_{\mathrm{C}} - R_0 + P_{\text{V-UE}} + G_0\right), \tag{1}$$

where $R_0$ denotes a certain target Received Signal Strength (RSS) at the eNB, $P_{\text{V-UE}}$ the transmit power of V-UE, and $G_0$ the maximum eNB antenna gain. Here, $\overline{PL}\left(.\right)$ denotes a specific path loss model for the links between the interfering V-UEs and the eNB. In order to satisfy the minimum SINR threshold $\gamma_{\mathrm{D2D}}$, a minimum distance $r_2$ between zones (or equivalently, between V-UEs and C-UEs) that spatially reuse the same resources $\mathcal{RB}_z$ has to be maintained such that

$$r_2 \geq PL^{-1}\left(\gamma_{\mathrm{D2D}} - P_{\text{V-UE}} + PL\left(d\right) + P_{\text{C-UE}}\right). \tag{2}$$

Here, $P_{\text{C-UE}}$ denotes the maximum transmit power of C-UEs and an isotropic, zero dB gain antenna at the V-UEs is assumed. Note that $PL\left(.\right)$ denotes a specific path loss model for the links between the interfering C-UEs and the receiving V-UEs as well as for the links between two V-UEs. It should be noted that the power, gain and threshold parameters in (1) and (2) are considered in dB scale. Moreover, shadowing and multipath induced fading are not explicitly considered in the above inequities because of their stochastic nature. However, their negative impact on the instantaneous link quality can be reduced by choosing a higher SINR threshold.

It should be further noted that the number of zones depends on the size of the sector and on the number of available UL RBs (i.e., the system bandwidth). Furthermore, the number of zones, excluding Zone #1, has to be even in order to allow for pairwise spatial resource reuse and the size of the RB sets $\mathcal{RB}_z$ should be chosen proportional to the load in each zone.

Fig. 2 illustrates one possible zone design example as well as a corresponding example resource assignment for the network parameters given in Tab. I. Here, only one isolated sector of a three-sector LTE cell is considered. Setting the minimum SINR thresholds to $\gamma_{\mathrm{C}} = \gamma_{\mathrm{D2D}} = 7\,\mathrm{dB}$ and the maximum D2D distance to $d = 20\,\mathrm{m}$ allows for evaluating (1) and (2). Considering a sector range of $800\,\mathrm{m}$, the zone design parameters can then finally be set as $r_1 = 100\,\mathrm{m}$ and $r_2 = 200\,\mathrm{m}$. The path loss models used for these computations are described in Section III. Based on these design parameters, the sector is split into a total of $Z = 11$ zones. Polygonal zone shapes were chosen in this example since they allow for a simplified map representation of the zone topology with just a

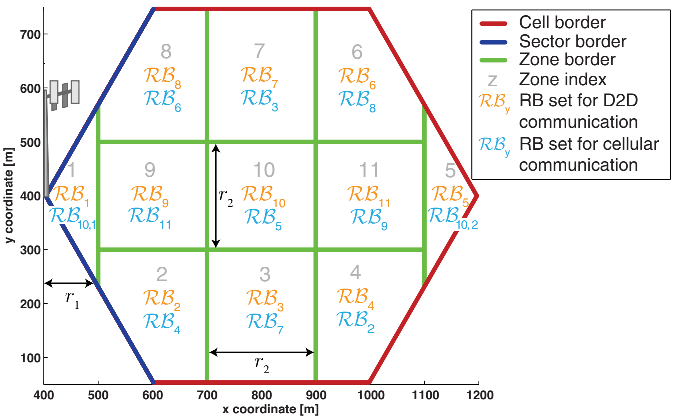



Figure 2. Example zone design and resource assignment for a single sector.

few points in space. Assuming a uniform user distribution, the number of reserved RBs for each zone is selected proportional to its size. Hence, 2 RBs are reserved in $\mathcal{RB}_{1/5}$, 8 RBs are reserved in $\mathcal{RB}_{9/10/11}$, and 12 RBs are reserved in each of the remaining RB sets. It should be noted that resource set $\mathcal{RB}_1$ is never reused by C-UEs and the RBs of $\mathcal{RB}_{10}$ are split into two disjoint, but equally sized, subsets for C-UEs in Zone #1 and Zone #5 (denoted as $\mathcal{RB}_{10,1}$ and $\mathcal{RB}_{10,2}$, respectively). In Fig. 2, the exact RB set assignment is shown, where each zone depicts the zone index $z$, the RB set reserved for the D2D underlay, and the set used in the primary network.

It should be noted that an extension of the proposed LDRAS to multi-sector deployments is possible by means of graph coloring [11]. However, due to space limitations, a corresponding method will be presented in future publications.

## III. Simulation Setup

The performance of the above described LDRAS has been investigated in a Matlab simulation framework emulating the uplink of a Long Term Evolution (LTE) network and an underlying D2D sub-network.

### A. System Setup

Considered is an isolated LTE sector operating in FDD mode with a carrier frequency of 800 MHz and a bandwidth of 20 MHz for UL communication. The sector range is assumed to be 800 m, where radio coverage is provided by a three-sector eNB located at the sector boundary (see Fig. 3). The radio resources are organized in 100 RBs following the LTE single carrier frequency division multiple access scheme used in the UL [12]. The system performance is determined in terms of the availability and the instantaneous link capacity of the communication links in the D2D underlay as well as in the primary network. The computations are based on the number of allocated RBs per user and per transmission time interval (TTI), and the measured instantaneous SINR at the receiving V-UEs and the eNB, respectively. The link capacity is calculated under the assumption that each RB carries 12×6 Gaussian modulated symbols [13]. The transmit power of the C-UEs is calculated by means of fractional power loss compensation, as described in [14]. The path loss of

| Parameter | Value |
|---|---|
| Cell radius | 800 m |
| eNB antenna height | 25 m |
| Cellular UE height | 1.5 m |
| Vehicular UE height | 1.5 m |
| Distance between communicating V–UE $d$ | fixed, 20 m |
| Minimum SINR thresholds $\gamma_C = \gamma_{D2D}$ | 7 dB |
| Log–normal shadow fading standard deviation | 8 dB |
| Log–normal shadow fading correlation distance | 20 m |
| Maximum eNB antenna gain $G_0$ | 14 dBi |
| eNB horizontal antenna beamwidth | 70° |
| Maximum eNB antenna isolation | 20 dB |
| Vehicular UE transmit power $P_{\text{V-UE}}$ | -2 dBm |
| Maximum C-UE transmit power $P_{\text{C-UE}}$ | 24 dBm |
| Target RSS $R_0$ | -75 dBm |
| Power loss compensation factor | 0.8 |
| eNB noise floor | -117.45 dBm |
| Vehicular UE noise floor | -104.5 dBm |
| Vehicular UE speed | 50 km/h |

Table I
System and Simulation Parameters.

the links in the primary network as well as for assessing the interference caused by the underlay D2D network (see also (1)) is computed according to the WINNER II typical urban macro-cell model [15] (adapted to the considered system model) as

$$\overline{PL}(x) = 24.3\,\text{dB} + 35.74\,\text{dB}\,\log(x)\,, \tag{3}$$

where $x$ denotes the communication link distance (in m). The path loss model for the computation of the signal attenuation between two communicating V-UEs, or between a D2D receiver and the interfering C-UE (see also (2)) is given by

$$PL(x) = 17.18\,\text{dB} + 43.7\,\text{dB}\,\log(x)\,.$$

Here, a similar model as for (3), merely adapted to the specific height of the respective transmitters, is used.

Moreover, we consider log-normal distributed shadow fading taken from a 2D correlated fading map (as described in [16]); here, a correlation distance of 20 m and a standard deviation of 8 dB is assumed. The power gain due to multipath induced fading is modeled as a chi-squared distributed random variable with 6 degrees of freedom [17]. A horizontal antenna pattern according to [18] is adopted for the calculation of the gain at the eNB. Isotropic, zero dB gain antennas are assumed for the C-UEs and V-UEs. All relevant system and simulation parameters are summarized in Table I.

### B. User Traffic, Mobility Models, and Resource Assignment

Although the automotive services deployed in the D2D underlay are likely to be comprised of small periodic status update messages, we use a common full-buffer traffic model for all UEs in our simulations for the sake of simplicity.

Cellular users are uniformly distributed throughout the entire cell sector (cf. Fig. 3), while the distribution of V-UEs is restricted to fixed roads. The road topology builds a Manhattan grid with a distance of 200 m between adjacent roads in the x-direction and 230 m in the y-direction. Different mobility models are used for the two different UE categories: C-UEs are assumed to be static, while V-UEs are traveling at a fixed speed of 50 km/h along the defined roads. The positions of the UEs in the cell are assumed to be exactly known.

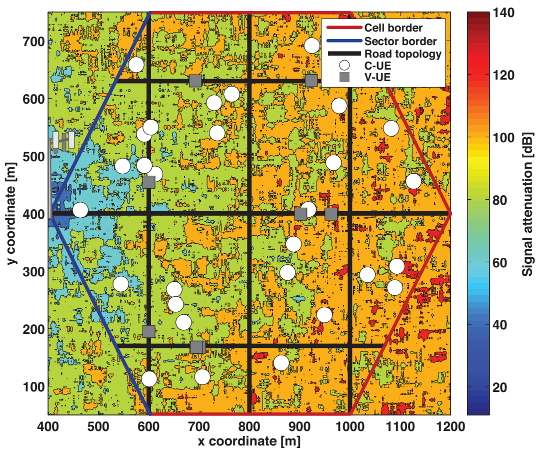



Figure 3. Sector layout including road topology, distribution of transmitting users, and macroscopic path loss and shadowing distribution.

The zone design and resource assignment are chosen as described in the example in Section II-C and depicted in Fig. 2. For our simulations we further assume a V2V application with end-to-end transmission delay requirements of $5\,\mathrm{ms}$ and a reduced message size of $600\,\mathrm{bytes}$. Hence, only one of the reserved RBs in a specific zone needs to be allocated to each transmitting V-UE in order to fulfill the data requirements of the considered automotive safety services in the D2D underlay. In the primary network a Round Robin scheduling algorithm is applied to each zone separately.

## IV. Results

Statistical data is gathered in $100$ independent simulation runs, each lasting for $60\,\mathrm{seconds}$. The performance of the proposed LDRAS is assessed under different load conditions. Low load is emulated by $10$ transmitting V-UEs in the LTE sector and $30$ active C-UEs, medium load is simulated with $30$ transmitting V-UEs and $50$ active C-UEs, and a rush hour scenario is modeled by $50$ transmitting V-UEs and $30$ C-UEs. Hereby, the considered values are adapted from the studies in [19] and [4]. Furthermore, we compare the performance of the proposed method to a state-of-the-art reference scheme; the UL resource allocation algorithm by Zulhasnine et al. [8] has been selected because of its comparable heuristic nature.

We base our analysis on two different KPIs: availability of RBs (frequency of transmission opportunities) and instantaneous link capacity. Note that high link capacity is not required for the considered V2V applications being utilized by V-UEs in the D2D underlay. As we motivated previously, such services rely on rather small messages and require periodic transmission opportunities allowing for short latency and reliability. In contrast, the services accessed by C-UEs in the primary network are usually likely to be less sensitive in terms of ultra-short latency, but require higher link capacity in order to transfer greater amounts of information.

Fig. 4 shows the discrete probability density function (pdf) of the number of RBs allocated to V-UEs on TTI basis in the D2D underlay. In other words, it quantifies the transmission opportunities provided by the proposed LDRAS and

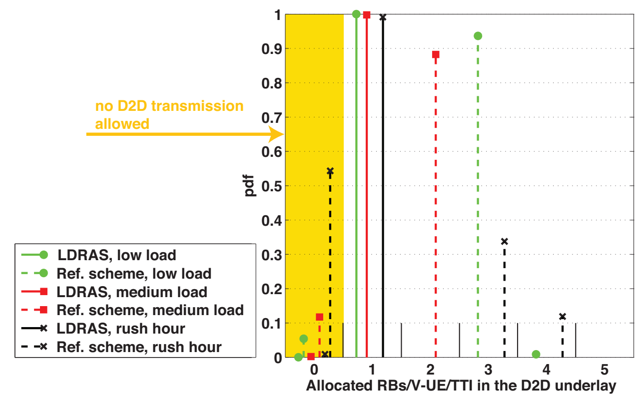



Figure 4. Probability density function of the number of allocated RBs per V-UE and TTI under different load conditions and RRM algorithms for the D2D underlay.

the reference scheme to the V-UEs in the underlay network. It can be seen that LDRAS fulfills its design goals and realizes stable performance: the scheme enables continuous transmission opportunities under all of the considered load conditions, where the required number of one RB is always available to each of the transmitting V-UEs. A small deviation is only observed in the rush hour scenario. Due to the higher instantaneous number of moving V-UEs in a certain zone, the number of reserved RBs is momentarily exceeded, such that LDRAS forces some V-UEs to share a single RB in time. However, this behavior only occurs in less than $1\%$ of the simulated transmissions in the D2D underlay. Hence, the additional latency due to lack of resources is upper bounded by $1\,\mathrm{ms}$ under the considered load conditions.

In contrast, the reference state-of-the-art scheme allows for the allocation of multiple RBs to an individual V-UE. However, it does not guarantee continuous transmission opportunities for all V-UEs. While satisfactory behavior is achievable in the low load scenario, the frequency of the transmission opportunities provided to V-UEs in the underlay declines with their increasing number. It can be seen that in the rush hour scenario, the reference scheme prohibits more than $55\%$ of the potential transmissions in the D2D underlay. Moreover, it tends to constantly allocate resources to some of the V-UEs with most favorable channel conditions and does not ensure timely transmission opportunities for the remaining V-UEs. Hence, it is evident that the reference scheme was designed to enable high-rate D2D communication links for capacity offloading purposes, but – in contrast to LDRAS – is not able to provide the required reliability level for the implementation of V2V safety services in the D2D underlay.

Fig. 5 shows the cumulative distribution function (cdf) of the respective instantaneous link capacities in the D2D underlay. It can be seen that LDRAS realizes an average link capacity of approximately $1200\,\mathrm{bits/ms}$ for the V-UEs, independent of the load conditions, reflecting the stable RB allocation assignments and the controlled interference environment enabled with our scheme. Note that the reference scheme allows for a higher instantaneous link capacity than LDRAS. This can

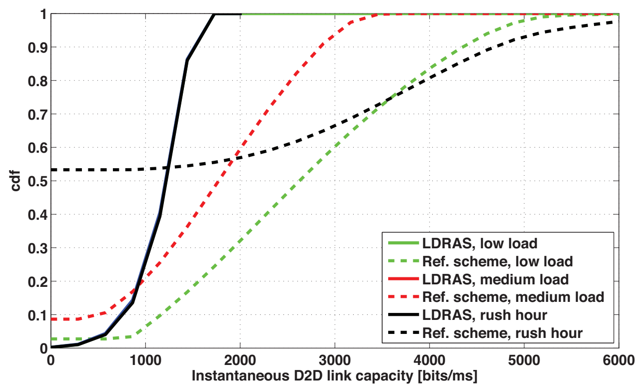



Figure 5. Cumulative distribution function of the instantaneous capacity under different load conditions and RRM algorithms for the D2D underlay.

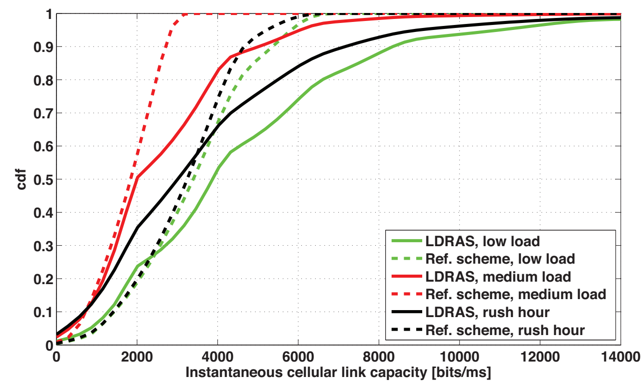



Figure 6. Cumulative distribution function of the instantaneous capacity under different load conditions and RRM algorithms for the primary LTE network.

be attributed to the fact that in our simulations LDRAS limits the resource allocation for each V-UE to only one RB in each TTI. Nevertheless, the reference algorithm does not show the same reliability in terms of guaranteed channel quality. For example, in the low load scenario, in more than 90% of the time the reference scheme allocates three times as much RBs to the V-UEs as compared to LDRAS (see Fig. 4). However, a corresponding threefold increase of the instantaneous link capacity is only achieved in about 30% of the simulated transmissions. We once again underline the assumption that the considered V2V safety services have low demands in terms of link capacity which can be satisfied with one RB per TTI.

Next, we assess the impact of the considered resource reuse schemes on the primary network. The cdf of the corresponding cellular link capacities is shown in Fig. 6. It can be seen that the coexistence of the primary network and the D2D underlay is possible since both schemes lead to satisfactory link capacities. Some deviations are observable where LDRAS allows for higher instantaneous link capacities in zones with only a few C-UEs, while the link capacity in more crowded scenarios suffers. The fact that only the minimum required RBs are allocated to V-UEs in the D2D underlay (i.e., here only one RB per V-UE) helps to reduce the interference to the primary network. This leads to a better performance of LDRAS under low load conditions. However, this advantage disappears in the rush hour scenario. Although both scenarios consider the same amount of C-UEs, the higher number of V-UEs leads to increased interference in the primary network and, therefore, slightly lower cellular link capacities.

## V. Conclusions

A heuristic location dependent resource allocation scheme for future cellular networks with a D2D underlay, customized to the case of vehicular services, is proposed. Above all, the aim of LDRAS is to satisfy the requirements of V2V safety services while reducing the signaling overhead and interference within the primary network. The demonstrated stable performance of LDRAS in the considered isolated cell sector deployment enables control over the QoS and, in contrast to the state-of-the-art algorithms, allows for the implementation of services with strict reliability requirements. The extension to deployments considering multiple cells and sectors will be subject of future publications.

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