Context-Awareness for Device-to-Device Resource Allocation

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https://doi.org/10.26636/jtit.2025.1.1934

Abstract — The paper investigates a context-aware approach to radio resource allocation for device-to-device (D2D) communication, focusing on solutions that leverage information on user equipment location and environmental features, such as building layouts. A system enabling direct communication by sharing uplink resources with cellular users is considered. Such a system introduces mutual interference between direct and cellular communications, posing challenges related to maintaining adequate performance levels. To address these challenges, various context-based resource allocation methods are analyzed, aiming to optimize spectral efficiency and minimize interference. The study explores the impact that different D2D device densities exert on overall network performance measured by means of spectral efficiency and the signal-to-interference ratio.

Keywords — cellular network, context-awareness, device-to-device, resource allocation

1. Introduction

Novel system concepts are being explored to address the growing demand for mobile data traffic in cellular networks.

Among these, device-to-device (D2D) communication, which enables direct wireless links between pieces of user equipment (UE), is particularly promising. Unlike conventional cellular connections that route traffic through the base stations (BSs) and the core network, D2D communication allows UE to communicate directly when the individual devices are close to each other, leading to higher data rates, lower energy consumption, and reduced transmission delays.

D2D communication is expected to help offload traffic from future radio access networks (RAN) and support a wide range of new services, including vehicle-to-everything communication. Such applications, however, introduce new design challenges for future systems, particularly related to ensuring strict quality of service (QoS) and reliability for applications that may involve large numbers of active users.

D2D communication is often envisioned to work as underlay to cellular networks, meaning that it shares the radio resources with the primary system. By allowing D2D devices to share the same radio resources with cellular users, direct communication may potentially push the frequency reuse factor (FRF) beyond one. However, this spectrum sharing poses challenges, particularly around managing interference, which calls for advanced power control and resource allocation mechanisms to maintain network performance.

The main focus of this paper is on resource allocation methods for D2D communications that leverage context-awareness in their operation.

The remainder of the paper is organized as follows. In Section 2, a short review of existing works is presented. Section 3 contains the description of the system model under consideration. Section 4 presents the proposed resource allocation solutions. Section 5 evaluates the considered approaches and discusses the results achieved, while Section 6 presents the conclusions.

2. Related Works

Many D2D-related studies ([1]–[7], and [8]) are focused on mitigating interference in D2D communications. The most commonly used approaches include power control and resource allocation solutions. For example, in [6], a D2D power reduction method was suggested to control interference with cellular users. In [9], a location-based power control mechanism was proposed to enhance the parameters of D2D communications. With regards to resource allocation solutions, a review of the literature focusing on this aspect, and D2D in general, may be found in [10]. Many solutions presented in the survey utilize slowly varying channel parameters, such as path loss or shadowing for resource allocation and D2D management, with paper [2] being one of the examples here.

A newer survey [11] showcases solutions utilizing artificial intelligence (AI) for resource allocation. It lists several data-driven machine learning (ML) approaches that could be used to enhance resource allocation in D2D communication networks. These approaches leverage the ability of ML models to learn complex patterns and make real-time decisions. For example, the authors in [3] present a weighted cooperative Q-learning-based resource selection (WCopQLRS) strategy. Unlike independent learning schemes, WCopQLRS incorporates weighted Q-value exchanges among D2D pairs within a defined cooperation range to minimize interference and optimize energy efficiency. This approach improves system throughput, energy consumption, and fairness by leveraging cooperative learning among neighboring D2D pairs.

Another paper utilizing ML for resource allocation is [12]. The authors developed a multi-agent deep Q-network (DQN) framework to optimize mode selection and channel allocation in heterogeneous cellular networks. This model maximizes the system sum rate while satisfying the QoS requirements of cellular and D2D users. Each D2D agent operates independently with partial information sharing, thus reducing system complexity. The proposed approach is claimed to achieve higher sum rates and QoS satisfaction rates while converging faster than the baseline methods under consideration. Additionally, its distributed architecture ensures scalability and robustness in heterogeneous environments. These are just two examples from the vast set of references included in [11]. The number of publications exploring the use of ML in the context of D2D communication shows that this is an area worth more attention in the future.

However, as mentioned in the introduction, this paper focuses on context-aware resource allocation methods for D2D communications, where resource allocation strategies leverage contextual information such as the location of users, with some works exploring the possibility of using this information for that specific purpose [9], [13]–[18]. For example, in [13] and [15] a power control mechanism and an interference control strategy using an interference limited area (ILA) constraint were proposed. The users located in this area were excluded from the resource sharing scheme. The purpose of the resource sharing area constraint is to ensure that the probability of a D2D communication outage caused by interference from cellular users is lower than a predefined threshold value.

In [18], a resource-sharing criterion with distance limitation was introduced to reduce the set of cellular users who can share resources with D2D users, resulting in a reduced probability of D2D link outage. An additional advantage of the solution proposed in [18] is that it does not require cellular users to reduce their transmission power, thus avoiding degradation in cellular link quality. Another paper utilizing context-awareness is [19]. Coverage performance in D2D networks, which is the main topic of the paper, has received less attention compared to throughput and energy efficiency studies.

The authors of [19] address this by constructing a cluster-based UE classification and spectrum-sharing allocation model for multi-tier hybrid heterogeneous networks. The presented approach classifies UEs into clusters based on their locations, distinguishing between cluster center and edge UEs. By analyzing the coverage probability of these clusters, the scheme dynamically adjusts spectrum sharing to enhance resource utilization and minimize interference. This location-aware classification ensures that edge devices, which typically face more interference, receive appropriate resource allocations.

D2D communication is often considered in the context of vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communications. In [21], a resource allocation scheme for D2D communication based on channel measurements is presented, ensuring proportional fairness among users while maximizing the overall throughput of the system. The proposed method uses allocation in long time slots to improve the system's efficiency and fairness. In [22], a resource allocation method for vehicle-to-everything (V2X) communication scenarios based on D2D is introduced, taking into account the realistic assumption of imperfect channel state information (CSI). The proposed algorithm aims to maximize the ergodic capacity of the user devices in the vehicle while meeting quality of service requirements.

However, to the best of the author's knowledge, not many studies consider using contextual information for V2V resource allocation, with [23]–[25] and [26] serving as good examples here. The authors of [26] propose a location-based approach to V2V communications, leveraging location stability to enhance energy efficiency for both cellular and vehicular users by reducing computational demands. A location-partition-based channel allocation and power control method for C-V2X networks is presented in [25], dividing the coverage area into zones to simplify resource allocation and improve latency while minimizing interference in high-density scenarios.

Additionally, [24] examines the robustness of location-based D2D resource allocation schemes against positioning errors, finding that these methods generally maintain strong performance despite inaccuracies in position estimates, with only minimal impact on throughput. Finally, [23] compares location-based and CSI-based methods for resource allocation in D2D-enabled networks, showing that while CSI-based approaches offer higher spectral efficiency, they also require significant feedback, especially in dynamic environments.

In this paper, methods utilizing context-awareness, in the form of device location and building layout information, in the radio resource allocation mechanism for D2D communication, are presented. Unlike the works listed above, which considered a single cell system, the proposed mechanism is evaluated in a multi-cell environment with an FRF of 1.

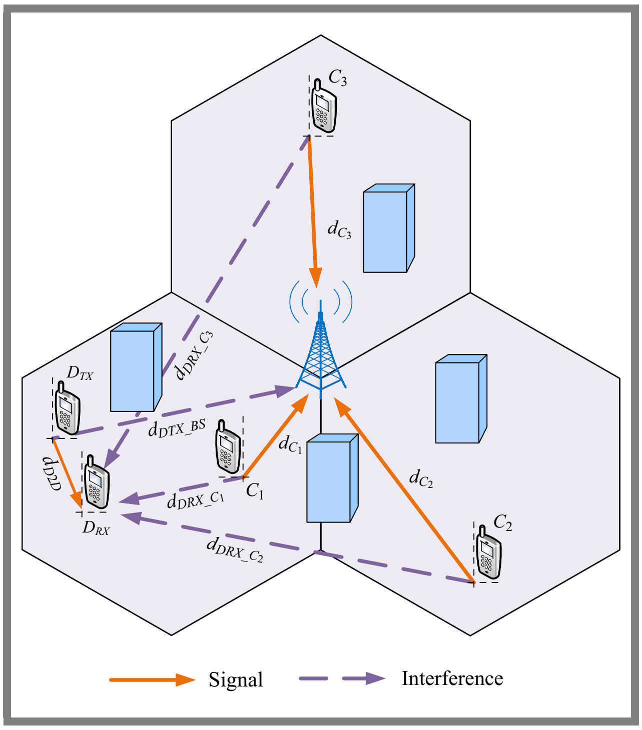

Fig. 1. System model [9].

3. System Description

In this paper, a multi-cell cellular system employing orthogonal frequency division multiple access (OFDMA) with a frequency reuse factor (FRF) of 1 is considered. D2D communication underlay is enabled by sharing uplink (UL) resources with cellular users (CUE, cellular user equipment). An illustrative diagram is presented in Fig. 1. It is worth mentioning that the considered system is generic and is not directly related to a particular cellular system standard. However, the solutions presented are applicable to widely used OFDMA-based systems, including LTE-A and 5G.

Sharing the uplink radio resources leads to the introduction of additional interference in the system for both cellular and direct communication. Interference affecting the receiving D2D device (DUE, D2D user equipment) occurs when cellular users transmit on the same radio resources. Conversely, from the perspective of CUE, interference caused by transmitting DUE is experienced by the serving base station. One way of mitigating this interference, as mentioned in Section 2, is to use a proper radio resource allocation method. The signal-to-interference ratio (SIR) for the DUE receiver γ_D and the base station for the k-th cellular user γ_{C_k} are given by:

$$\gamma_D = \frac{h_D(d)\, P_D}{\sum\limits_{i=1}^{N} h_{DC_i}(d) P_{C_i}} \tag{1}$$

and

$$\gamma_{C_k} = \frac{h_{C_k}(d)\, P_{C_k}}{\sum\limits_{i=1, i\neq k}^{N} h_{C_i}(d) P_{C_i} + h_D(d) P_D}\ , \tag{2}$$

where N is the number of neighboring cells using the same frequency, including the cell where the D2D pair is located.

The parameters $h_D(d)$ and $h_{DC_i}(d)$ represent the distance-dependent path losses between the D2D users and between the DUE receiver and the i-th CUE transmitter, respectively. $h_{C_k}(d)$, $h_{C_i}(d)$, and $h_D(d)$ represent path losses between the k-th and i-th cellular transmitters and the base station, as well as between the DUE transmitter and the base station, respectively. P_D is the transmit power of the DUE, and P_{C_i} is the signal power transmitted by the i-th CUE transmitter. In the considered system, an open loop power control (OLPC) mechanism is used to set the transmission power:

$$P_C = \min\left(P_0 + A\, h(d), P_{max}\right)\ , \tag{3}$$

where P_0 is the initial power level of the device, A is the path loss compensation factor, and $h(d)$ is the path loss between the transmitter and the receiver. The maximum transmission power is limited by P_{max}.

In developing the resource management method for D2D communication, several assumptions were made. First, the goal of the proposed solution is to minimize the impact of cellular traffic on direct communications. This assumption is based on the fact that the base station possesses greater processing capabilities, enabling the deployment of advanced mechanisms to reduce interference from direct communications.

The second assumption is a centralized management approach, meaning that a D2D control node is introduced into the system. This node is associated with a set of base stations serving a specific area and has knowledge of the locations of the devices it serves, as well as the layout of buildings in the area covered. The allocation of resources for D2D devices is implemented on top of the allocation of resources for CUE devices.

4. Proposed Solutions

In this study, two approaches to the resource allocation problem were considered, with both of them aiming to minimize interference at the D2D receiver. The first approach works by measuring the links between devices which are later reported to the control node. This solution requires knowledge of the channel state between all nodes in the system, not just between the users and the base station, which results in a significant signaling overhead. Therefore, this solution is impractical, but it serves as a reference point for the second approach in which contextual information is used for resource management purposes.

Two context-aware methods are considered: the first one relies solely on information concerning the location of users in the cellular network, while the other one uses not only location, but also knowledge of the layout of buildings in the covered area. All the mechanisms mentioned use the same resource allocation procedure, differing only in how resource-sharing

Algorithm 1 Find sharing candidates – Location

```
Input: Set of D2D pairs
Output: Lists of sharing candidates
for each BS attached to D2D control node do
    for each CUE scheduled for transmission do
        if $d_{DTX\_BS} > d_{d2d}$ and $d_{CTX\_DRX} > 0.5 \cdot d_{CTX\_BS}$ then
            Add CUE to list of sharing candidates
        end if
    end for
    Sort the list with $d_{CTX\_DRX}$ in descending order
end for
```

Algorithm 2 Find sharing candidates – Map

```
Input: Set of D2D pairs
Output: Lists of sharing candidates
for each BS attached to D2D control node do
    for each CUE scheduled for transmission do
        Evaluate line-of-sight conditions for the D2D receiver and the sharing candidate
        if $d_{DTX\_BS} > d_{d2d}$ and is NLoS then
            Add CUE to list of sharing candidates
        end if
    end for
    Sort the list with $d_{CTX\_DRX}$ in descending order
end for
```

candidates are selected from the set of CUEs scheduled for transmission at specific times.

For each transmission time interval (TTI), resources are first allocated to cellular users at each base station connected to the D2D control node. Then, a set of D2D pairs is selected according to the round robin algorithm. The size of this set depends on the length of the allocation (i.e. how many resource blocks are available for UEs) for CUE users at the base stations. Subsequently, for each D2D pair, a sorted list of candidates for resource sharing is created for each base station. Depending on the chosen approach, as described below, this list is created in a different way.

A method relying on the location of users (Location). In this method, the positions of UE pieces are known. Based on that information, distances between them are calculated. The procedure of finding the candidates is presented in Algorithm 1. The goal of this method is to maximize the distance between the sharing devices, as this potentially minimizes interference. Four distances are considered: distance between the D2D devices (d_{d2d}), distance from the D2D transmitter to the base station (d_{DTX_BS}), distance from the CUE sharing candidate to the D2D receiver (d_{CTX_DRX}), and distance from this candidate to its serving base station (d_{CTX_BS}).

For each scheduled CUE from each base station, these distances are evaluated. If the distance between the D2D transmitter and the base station is less than the D2D distance, and the distance from the sharing candidate to the D2D receiver is more than half of its distance to its respective base station, the candidate is added to the list. Once all candidates meeting these criteria are identified, the list is sorted, in descending order, according to the distance between each candidate and the D2D receiver.

A method relying on location and building layout (Map). This method is an extension of the location-based approach, where in addition to the information concerning the location of users, knowledge of the layout of buildings in the area under consideration is used. The procedure is presented in Algorithm 2. In this case, the condition for adding a given CUE to the list of resource-sharing candidates is further restricted by visibility conditions. The method assumes that only candidates without a direct line-of-sight are added to the list. Similarly to the location-based method, after considering all candidates, the resulting list is sorted in descending order based on the distance between the CUE candidate and the D2D receiver.

A method using channel state reporting (Min-int). Presented in Algorithm 3, this method assumes that path losses and expected transmit power levels are known. Based on this information, the level of interference between devices is determined, specifically the interference from the CUE sharing candidate to the D2D receiver is taken into consideration (I_{CTX_DRX}). The calculated interference level is used to sort the list of resource-sharing candidates in ascending order.

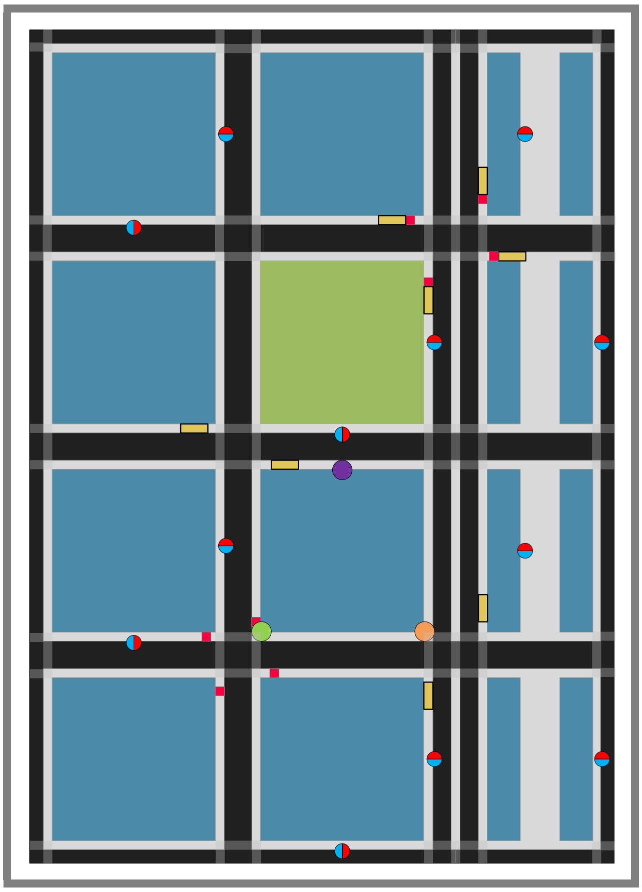

Fig. 2. Simulation deployment environment: Madrid grid model. Green, purple and orange dots represent the antennas of the considered macro BS.

The lists generated using the methods described above are used in the next step of the allocation procedure, i.e. in the selection of specific CUE devices for the D2D pairs considered in the allocation round. The order of processing the D2D pairs considered in the round is determined based on the distance between the devices forming a given pair. Resources are first assigned to pairs with the largest distance between devices. This is because the probability of low SIR at the receiver in such pairs, due to greater path loss between the pair, is higher than for pairs with a small distance between devices. It may happen that the same sharing candidate is selected for multiple D2D pairs. In this case, a simple conflict resolution mechanism is employed which involves selecting the next candidate from the list. If all candidates on the list have been

Algorithm 3 Find sharing candidates – Min-int

```
Input: Set of D2D pairs
Output: Lists of sharing candidates
for each BS attached to D2D control node do
    for each CUE scheduled for transmission do
        Based on known channel loss values and
        transmitted signal powers
        Calculate the interference from the D2D
        transmitter to the BS
        Calculate the interference from the CUE
        candidate to D2D receiver
        Add CUE to list of sharing candidates
    end for
    Sort the list with $I_{CTX\_DRX}$ in ascending order
end for
```

Tab. 1. Considered scenarios.

	Scenario 1	Scenario 2	Scenario 3
Pedestrian CUEs	320	335	305
In-vehicle CUEs	320	345	295
Pedestrian DUEs	60	46	76
In-vehicle DUEs	100	74	124

Tab. 2. Network spectral efficiency for different scenarios and resource allocation methods. All values are in [bps/Hz].

Scenario	Method	DL spectral efficiency	UL spectral efficiency
1	Location	3.97	2.98
	Map	4.05	3.07
	Min-int	4.14	3.04
	No D2D	2.54	1.61
2	Location	4.09	3.09
	Map	4.16	3.16
	Min-int	4.42	3.32
	No D2D	2.49	1.58
3	Location	4.02	3.02
	Map	4.08	3.10
	Min-int	4.19	3.07
	No D2D	2.53	1.58

considered, but not selected, the D2D pair is excluded from the current resource allocation round.

Once all CUE candidates are assigned to the D2D pairs considered in the round, the procedure's final step is to adjust the initial CUE transmission plan so that each pair of candidates shares the same resources.

5. Simulation and Results

5.1. Simulation Environment

The resource allocation solutions proposed in Section 4 were investigated using system-level simulations of an OFDMA-based cellular network with a frequency reuse factor of one. The simulation tool used in the experiments was co-developed by the author and implemented according to the guidelines set in the METIS project [27]. More details about the tool can be found in [28].

The simulation tool implements channel models defined by METIS [29]. These models, unlike the more commonly used ones, employ 3D map-based real-time methods to assess line-of-sight conditions between the nodes. METIS channel models are used for cellular users. For D2D users, a modified version of the D2D model defined by ITU-R [30] is applied. The modification involves using a map, instead of a statistical approach as defined in the ITU-R recommendation, to determine the visibility conditions between specific devices.

The study considers a cellular network deployed in an urban environment according to the Madrid grid model (MGM) (Fig. 2) [27]. The MGM deployment includes 12 micro base stations and a single macro base station and covers an area of 387 by 552 meters. The MGM incorporates essential environmental characteristics, such as building heights and detailed street layouts typical of a European city [27]. These elements are vital for reliably evaluation of signal propagation and interference, and thus offer a good point of departure for assessing resource allocation models.

The considered cellular network consists of a macro base station placed on top of the tallest building at a height of 50 m. The base station operates in the frequency division duplex (FDD) mode in three sectors with antennas placed on the edge of a building, as shown in Fig. 2. Each sector has a directional antenna with a pattern defined in [27]. The azimuths of sector antennas are 0°, 120°, and 240°, relative to the north. Each sector is operating on a 2.6 GHz carrier frequency using 80 MHz of bandwidth. The round robin method was used to allocate resources to CUE users, assigning successive resource blocks to each CUE device in turn.

In the simulation environment, 800 users were evenly distributed outdoors, either on sidewalks or in vehicles. These users were further divided into 4 groups:

- pedestrian CUE devices,
- in-vehicle CUE devices,
- pedestrian DUE devices,
- in-vehicle DUE devices.

Different configurations of these groups were considered in the investigations. The goal was to examine the impact of the number of D2D devices on network performance, assuming the use of the considered resource allocation methods. The configurations analyzed are grouped into three scenarios, as summarized in the Tab. 1. Scenario 1 considered 80 D2D pairs (160 UEs) with the distance between each device in a D2D pair randomly drawn from a range of 0 to 50 m, according to a uniform distribution, taking into account that the distance between users in cars is constrained by the assumed dimensions of the vehicle. Out of all the pairs in Scenario 1, 30 were pedestrian users, while the remaining 50 D2D pairs were placed in vehicles.

In Scenario 2, the allowable number of D2D pairs was reduced from 80 to 60 (a 25% reduction), while in Scenario 3, this number was increased by 25% to 100 pairs. In all cases, the maximum distance between D2D devices was 50 meters, and the ratio of pedestrians to in-vehicle users was approximately 0.6.

The mobility of the users (including vehicles) is also modeled according to the METIS guidelines. The simulations were repeated 50×, and each simulation lasted 10 s.

Various system performance statistics were gathered during the simulations, with the most important of them being:

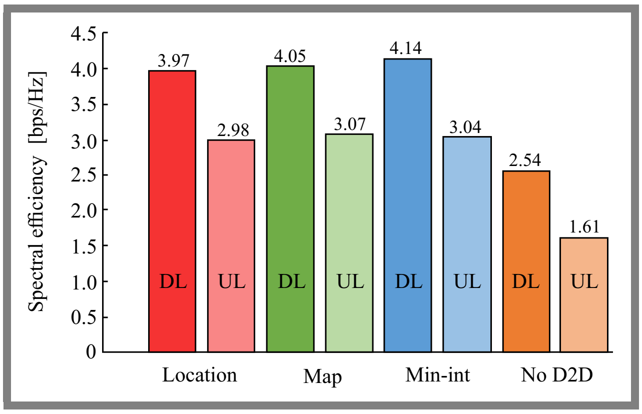

Fig. 3. Network spectral efficiency for Scenario 1.

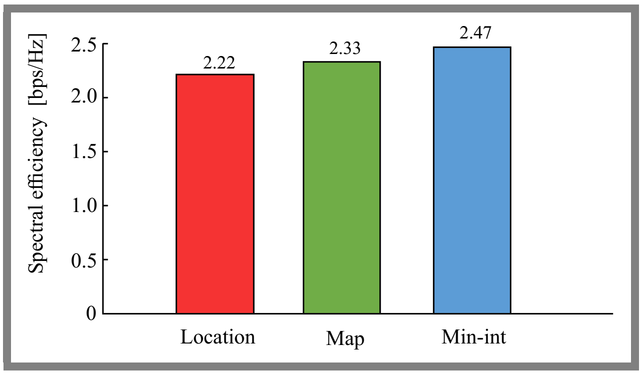

Fig. 4. D2D spectral efficiency for Scenario 1.

- spectral efficiency (expressed in bits/s/Hz) for downlink (DL) and uplink (UL) (Fig. 3 and Tab. 2), and for active D2D users (Fig. 4 and Tab. 3),
- cumulative distribution function (CDF) (Fig. 5 and Fig. 6) and related metrics (Tab. 4 and Tab. 5) of the signal-to-interference ratio for base stations and D2D communication receivers.

5.2. Results

The first set of results (Fig. 3) presents the overall spectral efficiency of the system for the downlink (left bar) and uplink (right bar) for each of the proposed resource allocation methods in Scenario 1. Additionally, for reference, simulation results where direct communication was not allowed (denoted as No D2D) are included. When analyzing the graph and focusing on the downlink results, one may notice that the reference measurement-based method (min-int) achieves the best results. The map-based method (map) is the runner up, followed by the location-based (location) approach. However, it is worth noting that the differences between them amount to several percentage points only. When analyzing the uplink results, we see that the differences are even smaller, with the map-based method performing the best. When comparing all the results with a system without any direct communications, the benefits of introducing D2D communication become clearly visible. The noticeable increase in the system's spectral efficiency is achieved by offloading the core network and raising the frequency reuse factor beyond one.

Tab. 3. D2D spectral efficiency for different scenarios and resource allocation methods. All values are in [bps/Hz].

Scenario	Method	Spectral efficiency
1	Location	2.22
	Map	2.33
	Min-int	2.47
2	Location	2.43
	Map	2.53
	Min-int	2.92
3	Location	2.19
	Map	2.29
	Min-int	2.44

The spectral efficiency of the network was determined for all the considered deployment scenarios. The results are summarized in Tab. 2. The conclusions from comparing allocation methods in each scenario are the same as above, but one can notice a certain difference between the scenarios. We can observe that an increased number of D2D pairs does not automatically improve the system's overall efficiency. In this case, a reduction of the number of devices, in relation to Scenario 1, has led to a greater efficiency gain. While increasing the number of pairs also improved efficiency compared to Scenario 1, the improvement was smaller than in Scenario 2. This suggests that there may be an optimal number of D2D pairs in a network that maximizes its overall spectral efficiency.

The simulations also provided results regarding the spectral efficiency of the devices capable of forming D2D pairs (Fig. 4). In this graph, a trend that is similar to the one visible in Fig. 3, may be observed. However, in this case, the differences between different allocation methods are larger, reaching a maximum of approx. 12%. As before, the location-based method achieves the lowest effectiveness. However, the incorporation of maps may enhance its performance. The method relying on channel state measurements delivers the best results, as it possesses the most precise knowledge of transmission conditions. However, as mentioned earlier,

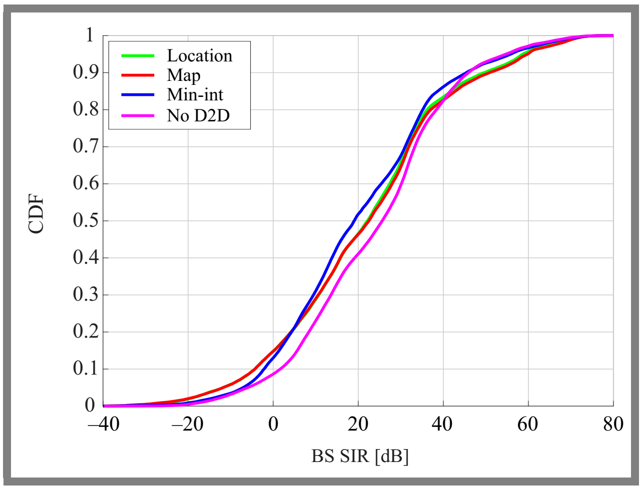

Fig. 5. SIR at the base station in Scenario 1.

Tab. 4. Median and 10th percentile SIR at the BS for different scenarios and resource allocation methods. All values are in [dB].

Scenario	Method	Median	10th perc.
1	Location	22.141	–4.3065
	Map	22.499	–4.3058
	Min-int	19.041	–2.1492
	No D2D	25.631	1.6646
2	Location	21.223	–4.9543
	Map	21.474	–4.6288
	Min-int	18.077	–2.5884
	No D2D	25.122	0.8034
3	Location	22.798	–3.7181
	Map	23.152	–3.5979
	Min-int	19.677	–1.5049
	No D2D	25.098	1.5184

Tab. 5. Median and 10th percentile SIR at the D2D receiver for different scenarios and resource allocation methods. All values are in [dB].

Scenario	Method	Median	10th perc.
1	Location	28.360	8.6160
	Map	30.249	8.6160
	Min-int	29.740	8.9721
	No D2D	25.887	9.2703
2	Location	27.750	8.9115
	Map	29.745	9.7949
	Min-int	30.466	9.3058
	No D2D	25.628	8.8109
3	Location	28.939	9.3148
	Map	30.559	10.7750
	Min-int	30.365	9.6873
	No D2D	25.550	9.3708

conducting measurements and reporting the channel state between all devices in the network would result in excessive signaling overhead. By comparing D2D spectral efficiency in different scenarios (Tab. 3), one may notice that an increase in the number of D2D pairs in the system leads to more competition for resources between D2D pairs, with the overall D2D communication performance suffering as a result. A possible solution to this problem could be a more sophisticated scheduling algorithm than the round robin approach used in the simulations.

The next investigated aspect was the impact of D2D communication on the signal-to-interference ratio at the base station. Fig. 5 shows the cumulative distribution function of SIR at the base station in Scenario 1. The differences between the considered cases are not very pronounced, with the median SIR equaling 22.1, 22.5, 19, and 25.6 dB for the Location, Map, Min-int and No D2D cases, respectively. It can be observed that the min-int method has the greatest impact on the base station's SIR. This is mainly due to the lack of additional constraints, such as distance or line-of-sight, when adding devices to the list of sharing candidates. We also see that the location-based method and the map-based approach exert very similar impacts on the base station's performance.

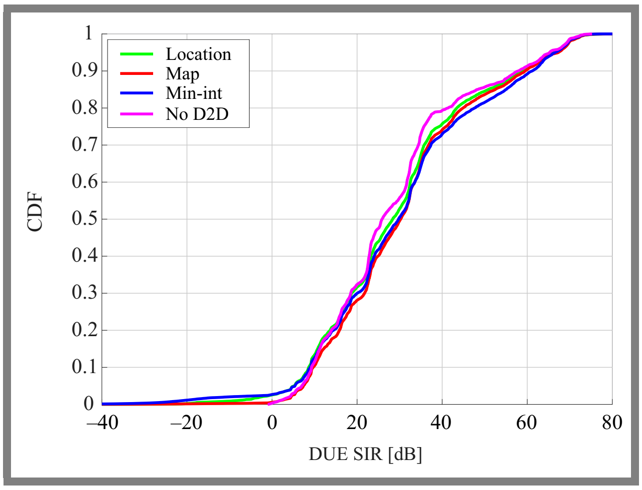

Fig. 6. SIR at the D2D receiver in Scenario 1

When analyzing the base station's SIR statistics for the considered deployment scenarios, as presented in Tab. 4, we find that a decrease in the number of devices (Scenario 2) results in a lower median SIR compared to the other cases. However, the differences in the median values are very small and we should also consider the reference SIR value for the No D2D case in each scenario in the comparison. More noticeable differences are visible in the 10th percentile statistic, but the trend according to which a lower number of D2D devices exerts a higher impact on SIR at the base station is still upheld.

SIR of the D2D pair devices may be analyzed in a similar manner (Fig. 6). It can be noted that all three methods protect D2D communication to a similar degree, with the location-based method slightly underperforming compared to the others, in the range from the median to the 90th percentile. For example, the difference in the median compared to the map-based method is approximately 2 dB (30.25 dB for the map-based method and 28.36 dB for the location-based method). This difference is a result of the additional protection imposed by the visibility conditions in the map-based method.

Such an approach increases the SIR but does not necessarily mean better system performance, as this restriction may result in fewer transmission opportunities. Looking at Tab. 5 in which the median and the 10th percentile statistics for D2D SIR in Scenarios 1–3 are presented, one may notice that once again a reduction in the number of D2D devices lowers the median SIR. However, the same cannot be said about the 10th percentile SIR. In this case, both an increase and a reduction in the number of D2D devices in relation to Scenario 1 lead to a higher value of this statistic.

When analyzing both spectral efficiency and SIR, it is worth considering why a reduction in the number of D2D pairs results in better spectral efficiency, despite worse SIR statistics.

This is likely due to the increased number of transmission opportunities for D2D pairs, as reduced competition allows for achieving higher spectral efficiency in this scenario, compared to other approaches.

6. Conclusions

The paper presents and analyzes resource allocation methods utilizing contextual information, such as the location of users and buildings layout. The context-aware methods are compared with each other and with a reference method that operates using measurements and channel state reporting. The study shows that context-aware methods may be used effectively to support resource allocation in direct communications.

Analysis of the impact that D2D device density exerts on the system's performance, performed in the course of this study, indicated that an excessive number of D2D devices can negatively affect overall performance measured by means of spectral efficiency.

Additionally, it is demonstrated that introducing direct communication in a cellular system brings several benefits, such as increased spectral and energy efficiency (due to transmissions over smaller distances). It was also shown that the impact of D2D communication on the performance of a cellular system turned out to be minimal in the scenarios under consideration.

In future work, a comparison with ML-based allocation methods could be conducted to further evaluate the proposed context-aware resource allocation solutions. Such a comparison would provide valuable insights into the performance trade-offs between pure context-based approaches and ML models.

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