Interference Avoidance Resource-Allocation for D2D-enabled 5G Narrowband Internet of Things

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***Abstract*— In dense, interference-prone 5G NB-IoT networks, device-to-device (D2D) communication can reduce the network bottleneck. We propose an interference-avoidance resource allocation for D2D-enabled 5G NB-IoT systems that consider the less favorable cell edge narrowband user equipment (NUEs). To reduce interference power and boost data rate, we divided the optimization problem into three sub-problems to lower the algorithm's computational complexity. First, we leverage the channel gain factor to choose the probable reuse channel with better quality of service (QoS) control in an orthogonal deployment method with channel state information (CSI). Second, we used a bisection search approach to determine an optimal power control that maximizes the network sum rate, and third, we used the Hungarian algorithm to construct a maximum bipartite matching strategy to select the optimal pairing pattern between the sets of NUEs and the D2D pairs. According to numerical data, the proposed approach increases the 5G NB-IoT system's performance in terms of D2D sum rate and overall network signal-to-interference plus noise ratio (SINR). The D2D pair's maximum power constraint, as well as the D2D pair's location, Pico-base station (PBS) cell radius, number of potential reuse channels, and D2D pair cluster distance, all influence the D2D pair's performance. The simulation results demonstrate the efficacy of our proposed scheme.**

***Index Terms*—Channel gain factor, D2D communication, 5G NB-IoT, Resource-allocation, Interference-avoidance.**

I. Introduction

As the internet of things (IoT) services continue to have promising and strategic values, increasing productivity and process efficiency in a wide range of applications, supporting digitalization and asset utilization, Narrowband IoT (NB-IoT) has steadily gained popularity. NB-IoT, a long-term evolution (LTE)-based technology, critical for mass connection of low-power machine-type communication, has multiple applications in different systems such as intelligent vehicle systems, healthcare systems, and industries that promote effective and convenient life. However, due to the inefficiency of the LTE eNodeB, which influences the overall system latency, 5G networks was proposed to serve a range of these exponentially growing NB-IoT devices to give higher productivity [1].

Co-channel and orthogonal approaches are used to coexist 5G and NB-IoT technologies as heterogeneous networks (HeterNets). An orthogonal deployment approach is used in this paper to provide coverage for the standalone NB-IoT device solution. The advantage of this approach is that it reduces interference at the expense of assigned frequency resources while maintaining NB-IoT small cell coverage [2]. The architectural distribution of NB-IoT pico-base stations (PBSs) on 5G macro-cells causes co-tier interference among the PBSs, affecting cell edge NB-IoT user equipment (NUE). The cell edge NUE receives a weak signal, limiting transmission performance, overall cell capacity, spectral efficiency, network performance, and user performance [1]. In addition, to improve coverage and reliability, traditional NB-IoT relies on repeated transmission as a foundation solution. If the direct link to the base station has poor channel quality, the technique may not be optimal, resulting in excessive interference, spectrum waste, and decreased system throughput. Besides, packet loss has an impact on uplink retransmission rates, which are larger for cell edge NUEs. As a result, to improve the performance of 5G NB-IoT networks, researchers in [3], [4], [5], [6], [7], [8] referred to the interference as narrowband interference (NBI) and, in some cases, narrowband noise [3],[6]. NBI, in contrast to additive white Gaussian noise (AWGN) [3], has limitations in its power spectrum density. This explains why some reviews, such as [4], [5], decided to reduce the interference from this perspective. Iterative sparse learning algorithm [6], block sparse Bayesian learning (BSBL) [7], and multiple NBIs suppression algorithm joined time-frequency domain for orthogonal frequency division multiplexing (OFDM) system [8] were the solutions proposed by [6], [7], [8]. However, the previous research findings did not support a solution to the combined challenges of NB-IoT networks' low data rate, poor channel quality, spectral efficiency, and limited coverage.

Several other conventional approaches, such as cooperative transmission, resource partitioning, intercell interference

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coordination (ICIC) [9], beamforming, and interference alignment (IA) [10], have been researched and applied to modern wireless systems, such as cellular and wireless local area networks (WLAN). These methods control interference in rare cases, and due to their high complexity, they may not be optimum in 5G NB-IoT network configurations. As a result, an efficient method of spectrum resources usage should be promoted. A robust localized D2D communication between proximal edge NUEs, as proposed by the Third-generation partnership project (3GPP) in 3GPP Rel-12 and Rel-13 time-frames [11], can be permitted to enhance the cell edge NUE experiences as well as guaranteed QoS for the existing cellular NUEs. The D2D pair and the cellular NUEs can coexist in the same channel through a frequency reuse mechanism. As a result, the devices can communicate directly without using Pico-base station (PBS). Hence, edge NUEs can have less path loss attenuation, reduced latency and a stronger received signal that promote faithful services.

Despite the benefits of D2D communication, the feasibility of D2D communication sharing the same resources as the cellular users depends on the distance restriction between the D2D pairs (i.e., the D2D transmitter and its receiver) and interference control between the cellular users in the same or different tier. This paper proposes an interference avoidance resource allocation (RA) for D2D-enabled 5G NB-IoT to maximize spectrum utilization and achieve a higher network sum-rate under QoS constraints. The satisfaction of QoS between the D2D pair and the cellular NUEs within the 180kHz physical resource block (RB) is a critical issue in the NB-IoT's resource allocation. Resource allocation tends to be more difficult due to the low complexity of the NB-IoT's RB. To implement an interference avoidance strategy for D2D-enabled 5G NB-IoT, the transmit power, data rate, or both, as well as the reuse channel selection, can all be adjusted in tandem to minimize reuse interference. Therefore, given the complexity, interference characteristics, and time-varying nature of the 5G NB-IoT wireless channel, the relationship between data rate and channel reuse selection are interdependent. The reason is that channel reuse selection affects the sets of interfering links and thus influences the optimal link rate selection. Typically, maximizing the minimal data rate under interference constraints will increase the spatial reuse and capacity [12]. As such, for the 5G NB-IoT system, the statistical channel link feature with a high priority gain is selected to obtain a channel with interference power below the interference threshold.

To the best of our knowledge, the selection of the optimal reuse channel allocation based on the channel gain's fraction has not been considered in the literature for balancing performance optimality and practicality for D2D-enabled 5G NB-IoT systems. The metric seeks to reduce the link loss probability of a channel with a higher gain due to the degree of interference and avoid costly computation of each D2D user on its predetermined channel sets as compared to the initial number of assigned channels. The process also avoids retransmission at the source which improves the signal-to-interference-plus noise ratio (SINR) and the network's sum-rate. In addition, the feature of an optimal resource allocation algorithm for D2D-enabled systems should have the following [13]; a) an effective frequency reuse mechanism, b) flexible power control for D2D pairs, and c) a feasible complexity to leverage on the gain acquired from D2D communication underlaying cellular networks. Realizing these features will maximize the cellular network spectrum and increase system throughput. Many approaches in D2D communication for selecting reuse channels among candidate sets involve maximum achievable throughput as proposed in [14], admission control and power allocation [15], social-aware selection [16], joint subcarrier assignment and power allocation [17], and CSI and delay constraint [18]. Our proposed work is similar to [13], [15] but takes a different approach to obtaining reuse candidate sets and power allocation. Unlike our proposed method, [13] used the product of the channel gain's fraction of the D2D pair to the reuse partners and the channel gain's fraction of reuse partner to the D2D pair. [15] used QoS-awareness and admission control to assign a reuse partner.

The proposed algorithm is also suitable for large-scale NB-IoT networks in which D2D users reuse an adjacent cell's uplink network resources based on their interaction with the environment. Consider the cognitive D2D communication system, where devices connect to various base stations linked by backbone networks via hopping [19]. This type of work can be found in [20] where cognitive radio (CR)-assisted D2D communications in a cellular network was proposed as a viable solution for D2D communication with mixed overlay–underlay spectrum sharing. The proposed algorithm could also be used for D2D communication handover in network system, when two D2D communications devices enter the same cell at the same time. They both go through a joint handover, as described in the speed-aware joint handover approach for D2D Clusters [21]. The preceding D2D communication features revealed the number cases in which the algorithm might be quite useful in improving the utility of D2D communications.

The main contribution of this paper is as follows.

- We propose a new framework for uplink interference-avoidance resource allocation for D2D-enabled 5G NB-IoT network problems to maximize the sum rate of the D2D pair underlying the NB-IoT network. To avoid any harmful interference on the NUE link, we identify and analyze the maximum interference limit for the D2D users.
- Due to the combinatorial of resource allocation, we formulate the resource allocation problem as a mixed-integer non-linear problem (MINLP) for D2D-pair communication under the PBS control.
- The optimization problem is section into three parts: the first is channel reuse selection, in which potential reuse channels for D2D pairs are determined. The second part involves the optimal power allocation for each D2D user and its reuse partner to maximize overall network throughput and, finally, we form a bipartite graph to find an optimal pairing pattern between the set of NUEs and the D2D users using the Hungarian scheme [22].
- Based on the proposed scheme, we evaluate the

network performance through extensive simulations. When compared to other algorithms, the algorithm significantly improves system performance in terms of sum-rate maximization and interference power minimization.

The remaining part of the paper is organized as follows: Section II discusses the related work, while Section III introduces the system model, network model and problem formulations. Section IV studies the optimal resource allocation algorithm for the formulated problems. Section V presents simulation results, and Section VI concludes the paper.

II. Related Work

Few studies on NB-IoT D2D communication have been conducted based on the vision of opportunistic crowdsensing applications involving traffic from battery-constrained IoT sensors [23], increasing the efficiency of resource allocation for D2D communication in NB-IoT [24], achieving the best-expected delivery ratio (EDR) and expected two-hop delay [25], and improving trust and security enhancement for opportunistic hop-hop forwarding schemes [26]. None of these studies considers the interference control between the underlay D2D pair and the cellular NUEs in three-tier NB-IoT HetNets. However, most research has attempted to balance resource allocation to boost network spectrum utilization to address interference control between the D2D underlay and the cellular NUE. Recent solutions, for example, include resource pooling [27], non-cooperative game or bargaining game [28], admission control and power allocation [15], clustering partitioning, greedy heuristic algorithms [29], and convex optimization-based methods [2]. These techniques presume perfect knowledge of the channel state information (CSI) and may necessitate a high level of computational complexity. They may also increase feedback channel overhead, which may be impractical in dense 5G NB-IoT networks.

By applying D2D communication, [2] investigated a transmit power restriction and distance between two pairs to find the best reuse candidates for each D2D device. In addition, [30] proposed a local awareness scheme for effectively controlling interference between multi-user diversity in the cellular network. Based on the Hungarian algorithm, the work in [31] investigated optimal channel reuse selection and interference coordination for D2D communication. In [32], a simulation based on an architecture and open source was developed to study the physical layer, application layer and queuing model for D2D NB-IoT uplink and downlink performance. The results reduce the power consumption, malicious attack and minimizes queuing delay in D2D NB-IoT networks. All the above researches motivated our proposed contributions.

III. System Model and Problem Formulation

This section introduces the system model, network model, and resource's problem formulation for interference-avoidance D2D-enabled 5G NB-IoT networks.

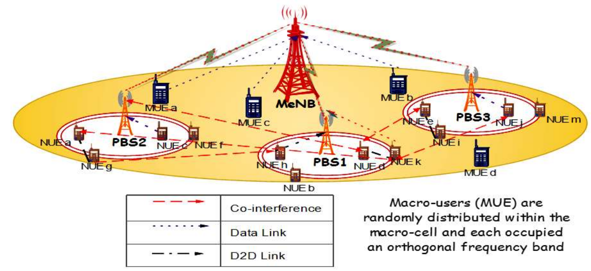

Figure 1. System Model

A. System Model

Consider an uplink channel in a 5G HeterNet where an NB-IoT network architecture is deployed as an access environment, as shown in Figure 1. The PBSs are configured with NB-IoT networks and linked to the central macro-eNodeB (MeNB) via the X2 interface for control information sharing. The total frequency bandwidth of the MeNB is B1. Assume that each PBS channel is used up, with a frequency bandwidth B2 and an equivalent resource value of $\mathcal{M}$kHz. The use of bandwidth B1 is orthogonal to the use of bandwidth B2 (i.e., no co-channel interference between the macro-cell and the PBSs). However, co-tier interference, on the other hand, emanates among the PBSs, affecting the channel condition of the cell edge NUE. Let ℓ denotes the PBS, where $\ell = \{1,2,..\mathrm{L}\}$. Assume that each PBS serves z orthogonal cellular NUEs and there are n D2D pairs[1]. Denote the corresponding sets by $\mathcal{Z}=\{1,2\ldots,z\}$ and $\mathcal{N}=\{1,2,..n\}$, respectively.

B. Network Model

In 5G NB-IoT systems, NUEs upload data to the PBS using single carrier frequency division multiple access (SC-FDMA) [1], [33][2]. To support D2D communication, $\mathcal{N}$ ($\mathcal{N}<\mathcal{Z}$) orthogonal channels can be reused by the D2D pair links, increasing spectrum utilization but incurring reuse interference to the reuse partners. To be more specific, the PBS serves the NUEs with an equivalent resource value of $\dot{M}\ kHz$ divided into $\mathcal{K}$ sub-channels, where $\mathcal{K} = \{1,\ 2\ldots\acute{k}\}$. When allocating resources for each D2D pair, there are two types of interference. The first is reuse interference, which occurs when NUEs and D2D pairs share the same channels. The second type of interference is co-tier interference, which occurs when different PBSs share the same resources. We assume that the scheme proposed in [34],[35],[36],[37] can effectively mitigate the latter, so we do not consider it in this paper. As a result, the interference analysis will only consider the reuse interference between D2D pairs and cellular NUEs.

D2D communication in uplink resource sharing only affect the PBS's operation, and incurred interference can be managed by the PBSs appropriately. To lower complex reuse interference between NUEs and D2D pairs, we propose that each PBS RB can be shared by one D2D user and that each D2D pair can only reuse one PBS-channel. We assume that the distance between the D2D pair transmitter and receiver is smaller to $\mathcal{D}_{max}$, and that the PBS is completely aware of the CSI of all network links

[1]The D2D pair consist of transmitter and receiver.

[2]SC_FDMA has the advantage of a single carrier multiplexing and a lower Peak-to-average Power Ratio when compared to OFDMA [33].

and responsible for resource allocation. Therefore, all network links are statistically obtained based on the long-term channel observation. In practice, the PBS obtain the CSI of all users based on classic channel estimation through the training sequence[3]. However, the instantaneous CSI of all network links consumes high signaling overhead for frequent CSI updates and resource allocation which might not be suitable for 5G NB-IoT networks. Furthermore, we assume that both the D2D pair and the NUE satisfied the minimum QoS requirement of the signal-to-interference-plus-noise ratio (SINR). For the sake of simplicity and mathematical tractability, we consider only one of the PBS and assume a general solution for the others.

The research employs 3GPP TR 38.901 pathloss model [38] and consider the fast fading due to multipath propagation and slow fading due to shadowing. Therefore, the channel gain, $g_{i\ell}$ between the NUE i and the PBS ℓ can be modelled as;

$$g_{i,\ell} = J h_{i,\ell} B_{i,\ell} D_{i,\ell}^{-a} \tag{1}$$

where J is a pathloss constant, $h_{i,\ell}$ is the fast-fading gain with exponentially distributed unit mean, $\mathfrak{B}_{i,\ell}$ is the slow fading gain with log-normal distribution, a is the pathloss exponent, and $\mathcal{D}_{i,\ell}$ is the distance between the NUE i and the PBS. Similarly, we denote the channel links $g_{i,j}, g_{j,\ell}$ and g_j as the channel from the NUE i to the D2D pair j, the D2D pair j to the PBS, and from the D2D pair's transmitter to its receiver respectively. The σ^2 is assumed to be the power of the additive white gaussian noise for each link.

C. Problem Formulation

The D2D pair must satisfy the minimum SINR requirement, and the incurred interference from the D2D user to the cellular NUEs must be less than the interference threshold I_0 for every pair link and frequency reuse. The SINR of both the NUE and the D2D pair can be express as;

$$\gamma_i^c = \frac{P_i^c g_{i,\ell}}{\sigma_n^2 + \rho_{i,j} P_j^d g_{j,\ell}} \tag{2}$$

$$\gamma_j^d = \frac{P_j^d g_j}{\sigma_n^2 + \rho_{i,j} P_i^c g_{i,j}} \tag{3}$$

where γ_i^c, γ_j^d, P_i^c and P_j^d are the SINR, transmit power of the NUE i and the D2D pair j respectively. Note that D2D communication was set up under two conditions: (i) if the NUE's link reliability (i.e., the wireless path between the NUE-to-PBS, $g_{i,\ell}$) is poor to ensure transmission quality, and (ii) when the NUE's transmit power incurred severe interference, resulting in a degradation of individual SINR and a lower total system throughput. As a result, the optimization problem $\mathcal{P}1$ due to resources sharing can be as follows to maximize the D2D pair's sum-rate;

$$p1 = \max_{\rho_{i,j}, P_i^c, P_j^d} \left\{ \sum_{j \in N} \left[\log_2 \left(1 + \gamma_j^d \right) \right] \right\} \tag{4}$$

$$\text{subject to } \gamma_i^c = \frac{P_i^c g_{i,\ell}}{\sigma_n^2 + \rho_{i,j} P_j^d g_{j,\ell}} \geq \gamma_{imin}^c \quad \forall \imath \in Z \tag{4a}$$

$$\gamma_j^d = \frac{P_j^d g_j}{\sigma_n^2 + \rho_{i,j} P_i^c g_{i,j}} \geq \gamma_{jmin}^d \quad \forall j \in N \tag{4b}$$

$$\sum_j P_j^d g_{j,\ell} \leq \sum_z I_0 \tag{4c}$$

$$\sum_i \rho_{i,j} \leq 1 \quad \rho_{i,j} \in \{0,1\}, \forall i \in Z \tag{4d}$$

$$\sum_j \rho_{i,j} \leq 1 \quad \rho_{i,j} \in \{0,1\}, \forall j \in N \tag{4e}$$

$$P_i^c \leq P_{max}^c \quad \forall i \in Z \tag{4f}$$

$$P_j^d \leq P_{max}^d \quad \forall j \in N \tag{4g}$$

where $\rho_{i,j}$ is the binary decision variable for the resources reuse indicator for the NUE i and D2D pair j as expressed in (5). P_{max}^d, P_{max}^c, γ_{imin}^c and γ_{jmin}^d denote the maximum transmit powers of the transmitter of the D2D pair j, NUE i, minimum SINR requirement of the NUE i, and the D2D pair j respectively. I_o is computed as given in (4).

$$\rho_{i,j} = \begin{cases} 1 & \text{when DUE } j \text{ reuses the resource of NUE} \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

$$I_o = \frac{P_i^c g_{i,\ell}}{\gamma_{i.\min}^c} - \sigma_n^2 \tag{6}$$

The interference threshold I_o is calculated for each NUE based on the minimum acceptable SINR received at the PBS. The computation in (6) allowed resources to be allocated to D2D pairs since the NUEs have equal transmit powers P_i^c. Constraints (4a) and (4b) defined the QoS requirement for each NUE i and D2D pair j respectively. Constraints (4c) restrict the aggregated interference between the D2D pair and the PBS to the tolerable interference estimated in (6). (4d) and (4e) ensures that the NUE's channel resource can only be reused by one D2D pair j and that each channel can only be used by one D2D pair j. The constraint is used in the D2D-enabled 5G NB-IoT communications to reduce the complexity of the interference scenarios. (4f) and (4g) ensures that the NUE and D2D pair transmit power is within the maximum power threshold.

The optimization problem $\mathcal{P}1$ is combinatorial, non-linear, and NP-hard due to resource sharing and the use of binary variables. As a result, in polynomial time, it is impossible. The resource allocation problem is segmented into three subproblems in order to find an efficient solution.

IV. OPTIMAL RESOURCE ALLOCATION

The optimization problem is section as follows: (i) reuse channel selection and QoS control of D2D pairs, of which NUE's CSI (i.e., channel gain factor) is used to determine the potential reuse channel that can maximize the sum rate of each D2D pair. (ii) The optimal power control strategy of each

[3]Note that the PBS only have the statistical information of $g_{j,\ell}$ and g_j *channel* gain. Since the D2D pair is not directly connected to it. The statistical CSI is assume to be more accurate and less costly than Instantaneous CSI [39], [40].

NUE-D2D reuse pair is then applied, considering constraint (4d) & (4e) that shows that interference also exists within the reuse pair. We also investigate the optimal power allocation to maximize the sum rate of multiple D2D users while ensuring the reliability of the reuse NUE partners against the interference threshold requirement for the PBS and annihilating infeasible pairs.

A. Reuse Channel Selection (RCS) and QoS Control for D2D Pairs.

Since the goal is to maximize the sum rate of the uplink D2D pair, the set of D2D pairs with the highest throughput compared to other D2D users is prioritized for NUE channel reuse[4]. Assume the jth D2D pair's channel gain factor β, on the kth channel is defined as;

$$\beta = \frac{g_j^k}{g_{i,j}^k} \tag{7}$$

For a given transmit power constraint of NUEs and D2D pairs, the jth D2D user with the highest value of β can achieve high throughput compared to other D2D users as verified by [13]. Therefore, these set of D2D users with the highest value of β allowed to reuse the kth channel can be grouped as $(\widetilde{D_k} \subseteq \mathcal{N})$. In addition, the set of potential reuse channel by the jth D2D user can be derived as $(\mathcal{R}_j^k \subseteq Z)$, $\forall j \in \widetilde{D_k}$ and $\forall i \in \mathcal{R}_j^k$. The selection of the reuse candidate channel on the kth channel reduces the computational cost for each jth D2D user on its pre-determined channel sets compared to the number of channels initially assigned to each D2D pair. Thus, the algorithm's complexity is further reduced as the number of reusable channels decreases.

To obtain an effective optimization in (4), the constraints in (4a), (4b), (4f), and (4g) must also be satisfied. i.e.

$$\begin{cases} \gamma_i^c = \dfrac{P_i^c g_{i,\ell}}{\sigma_n^2 + P_j^d g_{j,\ell}} \geq \gamma_{imin}^c & (8a) \\ \gamma_j^d = \dfrac{P_j^d g_j}{\sigma_n^2 + P_i^c g_{i,j}} \geq \gamma_{jmin}^d & (8b) \\ P_j^d \leq P_{max}^d, \quad P_i^c \leq P_{max}^c & (8c) \end{cases}$$

To this end, if the constraint (8c) is ignored, the minimum transmit power for the $j \in \widetilde{D_k}$ and $i \in \mathcal{R}_j^k$ can be computed as (9), to satisfy the minimum SINR requirement taken at a coordinate point $\mathcal{X}$, [15] and proved in the Appendix A.

$$\begin{cases} P_{j,\mathrm{X}}^d = \dfrac{\left(\gamma_{j\min}^d g_{i,\ell} + \gamma_{i\min}^c \gamma_{j\min}^d g_{i,j}\right)\sigma_n^2}{g_j g_{i,\ell} - g_{j,\ell} g_{i,j} \gamma_{j\min}^d \gamma_{i\min}^c} \\ P_{i,\mathrm{X}}^c = \dfrac{\left(\gamma_{i\min}^c g_j + \gamma_{i\min}^c \gamma_{j\min}^d g_{j,\ell}\right)\sigma_n^2}{g_j g_{i,\ell} - g_{j,\ell} g_{i,j} \gamma_{j\min}^d \gamma_{i\min}^c} \end{cases} \tag{9}$$

Hence, the transmission link reliability condition for QoS control is summarized as;

$$\begin{cases} 0 < \dfrac{\left(\gamma_{j\min}^d g_{i,\ell} + \gamma_{i\min}^c \gamma_{j\min}^d g_{i,j}\right)\sigma_n^2}{g_j g_{i,\ell} - g_{j,\ell} g_{i,j} \gamma_{j\min}^d \gamma_{i\min}^c} \leq P_{max}^d \\ 0 < \dfrac{\left(\gamma_{i\min}^c g_j + \gamma_{i\min}^c \gamma_{j\min}^d g_{j,\ell}\right)\sigma_n^2}{g_j g_{i,\ell} - g_{j,\ell} g_{i,j} \gamma_{j\min}^d \gamma_{i\min}^c} \leq P_{max}^c \end{cases} \tag{10}$$

B. Optimal Power control for single D2D pair

In this section, the optimal power allocation for each D2D pair $(\widetilde{D_k} \subseteq \mathcal{N})$ over the predetermined set $\mathcal{R}_j^k$ in section IIIA is computed to maximize the sum rate of the D2D users. The optimization problem can be formulated as;

$$\left(P_i^{c^*}, P_j^{d^*}\right) = \max_{\rho_{i,j}, P_i^c, P_j^d} \left\{ \sum_{j \in \tilde{D}} \left(1 + \gamma_j^d\right) \right\} \tag{11}$$

subject to

$$\begin{cases} \gamma_i^c = \dfrac{P_i^c g_{i,\ell}}{\sigma_n^2 + \rho_{i,j} P_j^d g_{j,\ell}} \geq \gamma_{imin}^c & (11a) \\ \gamma_j^d = \dfrac{P_j^d g_j}{\sigma_n^2 + \rho_{i,j} P_i^c g_{i,j}} \geq \gamma_{jmin}^d & (11b) \\ P_j^d \leq P_{max}^d, \; P_i^c \leq P_{max}^c & (11c) \end{cases}$$

Define $P_{1\max}^d = \dfrac{\gamma_{j\min}^d\left(\sigma_n^2 + P_{max}^c g_{i,j}\right)}{g_j}$, $P_{1\max}^c = \dfrac{\left(P_j^d g_j - \gamma_{j\min}^d \sigma_n^2\right)}{\gamma_{j\min}^d g_{i,j}}$

$P_{2\max}^c = \dfrac{\gamma_{i\min}^c\left(\sigma_n^2 + P_{max}^d g_{j,\ell}\right)}{g_{i,\ell}}$ and $P_{2\max}^d = \dfrac{\left(P_{max}^c g_{i,\ell} - \gamma_{i.min}^c \sigma_n^2\right)}{\gamma_{i\min}^c g_{j,\ell}}$

To solve the optimization problem in (11), we introduce the following preposition to illustrate the observation on the property of the sum-rate of the D2D pair proved in the Appendix B.

Preposition 1. Represent the $f\left(P_i^c, P_j^d\right) \triangleq \left(1 + \gamma_j^d\right)$, *the optimal power vector* $\left(P_i^{c*}, P_j^{d*}\right)$ *in (9) can be expressed as;*

$$\left(P_i^{c^*}, P_j^{d^*}\right) = \begin{cases} \max\limits_{\left(P_i^{c^*}, P_j^{d^*}\right) \in \Omega} f\left(P_i^c, P_j^d\right) \\ when \;\; \gamma_i^c > \gamma_{i\min}^c \;\; \text{and} \;\; \gamma_j^d \geq \gamma_{j\min}^d \\ when \;\; \gamma_i^c > \gamma_{i\min}^c \;\; \text{and} \;\; \gamma_j^d < \gamma_{j\min}^d \end{cases} \tag{12}$$

Based on the preposition, we have the closed form solution of the power allocation to (11) in the following theorem.

Theorem 1: The solution of the optimal power allocation to (11) is

$$P_j^{d^*} = \begin{cases} \min\left\{P_{max}^d, P_{1max}^d\right\}, if \;\; P_{max}^d \leq P_{j,\mathcal{X}}^d, \\ \min\left\{P_{max}^d, P_{2max}^d\right\}, if \;\; P_{max}^d > P_{j,\mathcal{X}}^d, \;\; and \;\; P_{max}^c > P_{i,\mathcal{X}}^c \\ P_{1max}^d, \qquad otherwise \end{cases}$$

[4] Note that the channel gain between the NUE-to-D2D links and the D2D links is used to determine the reuse partners, as we assume the D2D links are near the cell edges to avoid interference to the PBS.

and

$$P_i^{c^*} = \begin{cases} \min\left\{P_{max}^c, P_{1max}^c\right\}, if\ P_{max}^d \le P_{j,X}^d, \\ \min\left\{P_{max}^c, P_{2max}^c\right\}, if\ P_{max}^d > P_{j,X}^d,\ and\ P_{max}^c > P_{i,X}^c \\ P_{max}^c, \qquad\qquad otherwise \end{cases} \quad (13)$$

P_{1max}^c and P_{1max}^d, and P_{2max}^c and P_{2max}^d, are obtained from implicit functions of (12), hence $f_1(P_{1max}^d, P_{max}^c) = 0$ and $f_1(P_{max}^d, P_{1ma}^c\ ) = 0$. Also, $f_2(P_{2max}^d, P_{max}^c) = 0$ and $f_2(P_{max}^d, P_{2max}^c) = 0$. By adopting bisection search method and taken advantage of the monotonic relation between the P_i^c, and P_j^d in the implicit functions.

$$f_1\left(P_j^d, P_i^c\right) = \gamma_j^d - \gamma_{j\min}^d = 0\text{, when } P_j^d \in \left(P_{1max}^d, P_{j,X}^d\right) \text{ and}$$

$$f_2\left(P_j^d, P_i^c\right) = \gamma_i^c - \gamma_{i\min}^c = 0\text{, when } P_j^d \in \left(P_{j,X}^d, +\infty\right) \quad (14)$$

Remark: Based on the preposition above, the optimal power vector is divided into two parts, depending on whether $\gamma_j^d \ge \gamma_{jmin}^d$ or not. According to (9), the analysis of the two region's upper boundaries (as further shown by the implicit functions $f_1(P_j^d, P_i^c) = 0$ and $f_2(P_j^d, P_i^c) = 0$, respectively) intersect at $(P_{j,X}^d, P_{i,X}^c)$ which lies on the separating line $\gamma_j^d = \gamma_{jmin}^d$. Again, the two functions ($f_1(P_j^d, P_i^c) = 0$ and $f_2(P_j^d, P_i^c) = 0$) maintain a monotonically increasing relation between P_i^c and P_j^d in the range $(P_{1max}^d, P_{j,X}^d)$ and $(P_{j,X}^d,\ P_{2ma}^d\ )$ respectively [41] to ascertain that at least one device is transmitting at the peak power to maximize the overall sum rate. We could deduce from the constraint (11a) that the γ_i^c, increases with P_i^c and decreases with P_j^d. Therefore, the optimal solution must be located at the upper limit of the feasible region, which is jointly determined by the continuous line of $f_1(P_j^d, P_i^c) = 0$ and $f_2(P_j^d, P_i^c) = 0$. Additionally, investigation reveals that γ_i^c improves as P_j^d along the boundary line increases. As a result, the solution to the optimal power allocation for single NUE-D2D pair is determined by the relative magnitudes of P_{max}^c and P_{max}^d as well as their intersections with the boundary line, as summarized in the theorem 1. Following the solution to the optimal power allocation for each single pair, the next step is to find the optimal reuse partner for a D2D pair when more than one partner user is available.

C. Pair Matching for Multiple D2D Pairs

The optimal power allocation for a single NUE-D2D pair yields the D2D pair's sum rate and guarantees QoS for the reusing NUE partners. However, even after applying the optimal power allocation scheme in (13), it is necessary to eliminate those combinations of NUE-D2D pairs that do not satisfy the QoS constraints for the D2D pair in (4). To that end, we evaluate and discard NUE-D2D pairs that do not meet the interference threshold I_o constraint while satisfying the NUEs' minimum QoS requirement. As a result, such a NUE-D2D pair is not feasible, and we set the channel power gain to negative infinity. i.e.

$$f^*\left(P_i^{c^*}, P_j^{d^*}\right) = \begin{cases} f\left(P_i^{c^*}, P_j^{d^*}\right),\ if\ \ P_j^{d^*} g_{j,\ell} \le I_0 \\ -\infty, \qquad\qquad otherwise \end{cases} \quad (15)$$

With the satisfaction of constraint (15), P_j^d becomes a critical tuning parameter used to adjust the algorithm's power gain complexity. As a result, it can be determined dynamically based on network conditions and the number of NUEs and D2D users.

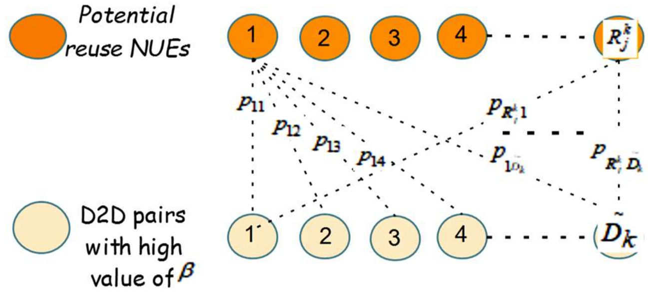

Fig.2. Bipartite graph for potential reuse NUEs and D2D pair with the higher value of β matching problem.

When compared to other algorithms that either set a static value for the interference threshold or do not consider the interference threshold, the proposed algorithm has the advantage of flexibility and dynamism, as well as lower complexity which creates fairness for indiscriminating services among all the users. After this evaluation for all possible NUE-D2D pair combinations, the resource allocation problem reduces to

$$\max_{\rho_{i,j}} \sum_{i\in R_j^k} \sum_{j\in \tilde{D}} \rho_{i,j} f^*\left(P_i^{c^*}, P_j^{d^*}\right)$$

$$s.t\ \ \sum_i \rho_{i,j} \le 1,\ \ \rho_{i,j} \in \{0,1\},\ \forall i \in R_j^k \ (16a)$$

$$\sum_j \rho_{i,j} \le 1,\ \ \rho_{i,j} \in \{0,1\},\ \forall j \in \hat{D} \ (16b)$$

which turn out to be a maximum weight bipartite matching problem and can be efficiently solved by the Hungarian method in polynomial time [22]. The bipartite matching problem in (16) is illustrated in Fig. 2, where the problem of resources utilization between the set $\widetilde{D_k}$ of D2D pairs with the higher value of β and the set $\mathcal{R}_j^k$ of potential reuse channels of the NUEs is considered as two groups of vertices in bipartite graph (i.e., $\mathcal{R}_j^k\ \cap \widetilde{D_k} = \emptyset$). Vertex i is joined with vertex j by an edge ij. Thus, the Kuhn-Munkres technique is used to solve the optimization objective in (16). Table 1 summarizes the optimal solution to the RA problem in (16) for the interference avoidance RA of D2D-enabled 5G NB-IoT networks.

TABLE 1: OPTIMAL RESOURCE ALLOCATION IN D2D-ENABLED 5G NB-IOT NETWORKS.

Algorithm1. Optimal Resource Allocation with RCS

1. Initialize $\forall i \in Z$, $\forall j \in \mathcal{N}$, $k \in \mathcal{K}$, $i \in \mathcal{R}_j^k$ & $j \in \widetilde{D_k}$,
2. for $i \in Z$ and $j \in \mathcal{N}$, do
3. Compute β from (5)
4. end for
5. for $j \in \widetilde{D_k}$
6. sort β ($i \in Z$) in a descending order and store in $\mathcal{R}_j$
7. set $\mathcal{R}_j = \underset{i\in Z}{argmax}\, \beta \quad \forall j \in \widetilde{D_k}$
8. set $\mathcal{R}_j^k = \mathcal{R}_j \quad \forall i \in \mathcal{R}_j^k$ & $\forall j \in \widetilde{D_k}$
9. end for

10. for $i \in \mathcal{R}_j^k$ and $j \in \widetilde{D_k}$, do
11. compute (P_j^{d*}, P_i^{c*}) from (11) for the single NUE-D2D pair.
12. Compute the sum-rate $f^*(P_j^{d*}, P_i^{c*})$ from (14)
13. If $P_j^d g_j \le I_o$
14. $f^*(P_j^{d*}, P_i^{c*}) = -\infty$
15. end if
16. end for
17. Apply Hungarian Algorithm [22] to obtain the optimal reuse pair based on $f^*(P_j^{d*}, P_i^{c*})$
18. Output the reuse pair $(\rho_{i,j})$ and the corresponding power allocation (P_j^{d*}, P_i^{c*})

The computational complexity of the proposed algorithm is expressed in terms of big O notation. The algorithm is sectioned into three steps. The first step selects the reuse partner for the $\mathcal{N}$ D2D links iterations, and the complexity is O$|Z\mathcal{N}|$. The second step generate the sum-rate $f^*(P_j^{d*}, P_i^{c*})$ with a complexity of O$|(Z\text{-}\mathcal{N})\ \mathcal{N}\log((Z\text{-}\mathcal{N})\ \mathcal{N})\ |$ where the bisection search method complexity is given as O$|\log(Z\text{-}\mathcal{N})|$. The complexity of the third step as regards to the Hungarian method is O$|(Z\text{-}\mathcal{N})^3|$ if $Z \geq \mathcal{N}$. The overall complexity can be expressed as O$|\ Z\mathcal{N} + (Z\text{-}\mathcal{N})\ \mathcal{N}\log((Z\text{-}\mathcal{N})\ \mathcal{N}) + (Z\text{-}\mathcal{N})^3|$.

V. PERFORMANCE ANALYSIS

In this section, we evaluate the performance of our proposed algorithm and present the numerical results of our simulations. Consider a single PBS with a radio R = 100m, randomly and uniformly distributed NUEs and D2D pairs, as shown in Fig. 1. The PBS provides a stand-alone NB-IoT solution to the growing number of IoT devices in a heterogeneous cell where the MENB and PBSs are orthogonal in terms of bandwidth usage. A D2D pair is established between neighboring cell edge NUEs to improve network throughput and avoid interference from a disadvantageous cell edge NUE. The NUEs are assumed to share the whole bandwidth equally. The results in each figure for the CDF are obtained by averaging a minimum of 10,000 iterations. Table 2 summarizes the simulation parameters used.

TABLE 2: SIMULATION PARAMETERS

Parameter	Value
Carrier Frequency	2GHz
Bandwidth	180kHz
Cell radius	100m
SINR Threshold	25dB
Number of NUEs, Z	20
Number of D2D pairs, $\mathcal{N}$	10, 20
Max. D2D distance	20m
Max. NUE Transmit Power	17, 23dBm
Max. D2D pair Transmit Power	17, 23dBm
Noise Power σ^2	-114
Pathloss Model	3GPP TR 38.901 [33]
Multipath fading	Rayleigh fading
Shadowing for NUE link	Log-normal distribution with standard deviation of 8dB
Shadowing for D2D link	Log-normal distribution with standard deviation of 3dB
Bisection Accuracy	10^{-6}

We validate the performance of our proposed algorithm with three other approaches as references;

1. DCORA algorithm, a device-device communication optimal resource allocation algorithm used in [15].
2. ARSAD algorithm used in [13] is an adaptive resource sharing algorithm for Device-Device underlying cellular networks.
3. The RRA algorithm is a device-to-device communication resource sharing allocation method that uses a random selection of reuse partners irrespective of the interference situations within the network. The reuse channel is selected at random from the potential reuse candidate sets. The first two algorithms are nearly identical to the one proposed here, with a difference in the channel selection strategy.

To get an understanding of channel deterioration at the cell edge, we model the channel gains between the PBS and the cellular NUEs using the 3GPP TR 38.901 [38] line of sight (LOS) and Non-LOS (NLOS) versions of Urban Microcell (UMi) for distances greater than 10m. We included shadowing to get the LOS and NLOS variation and show channel gain g as a function of distance d in Fig. 3.

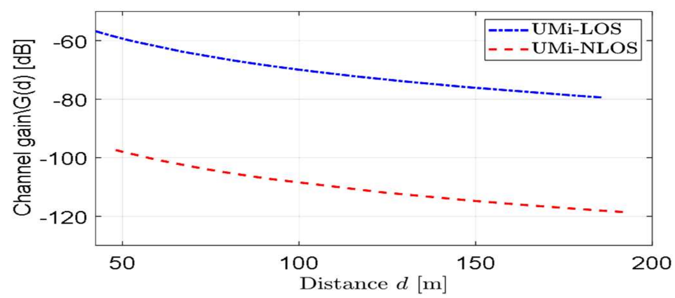

Fig. 3. Channel gain Vs Distance.

Fig. 3 depicts a very large channel gain for the NUEs, whereas a typical value generally ranges from -70 to 110dB [42]. The cumulative distribution function (CDF) and the sum-rate are two metrics used to evaluate the performance of our proposed algorithms. To better understand the effectiveness of our proposed algorithm, we referred to the RRA performance scheme as the proposed scheme without channel reuse selection.

Fig. 4 illustrates the SINR obtained by our proposed algorithm compared to the other three approaches mentioned earlier. Intuitively, the SINR achieved by the proposed algorithm in this paper is higher than that of ARSAD, DCORA, and RRA. Note that the SINR of the D2D pair is closely related to the interference from the PBS, even with the PBS's transmit power remaining constant. As a result, there would not be much difference in the RA algorithms' computation. The proposed algorithm tends to adjust the transmit power of the D2D pairs to minimize network interference rather than focusing on individual NUE interference. The proposed algorithm selects the NUE with the highest gain and allocates resources to the best NUE and D2D pairs to minimize reuse interference. Furthermore, the optimal power control allows D2D users to increase their transmit power without significantly degrading

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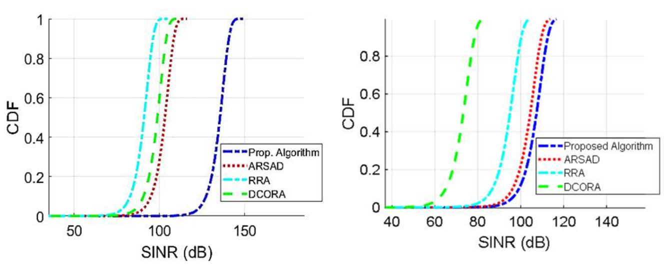
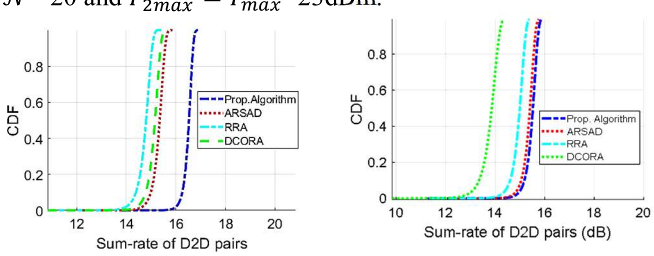
the transmission of the existing NUE, resulting in improved D2D pair performance. By contrast to the RRA scheme and the other two algorithms, the adopted channel reuse application results in an SINR performance trade-off. Fig. 4(a) is the SINR performance when the number of D2D pairs is less than the number of NUEs (i.e., Z=20 & $\mathcal{N}$= 10), the proposed algorithm achieves 28.35%, 31.33% and 39% performance than the ARSAD, DCORA and RRA respectively. In Fig. 4(b), the performance of the proposed algorithm was tested for equal numbers of both NUEs and D2D pairs. The result was very close to that of the ARSAD, achieving 2.52%, 14.80% and 39.89% for ARSAD, RRA and DCORA accordingly. As seen from Fig. 4(b), it was surprising to observe that the RRA scheme performs better than the DCORA scheme. The reason could be the introduction of more D2D pairs that creates intense interference to the NUEs within the network. However, it brings more diversities in channel selection and increases the chances of running into a better channel than the DCORA scheme that only select reuse candidate based on admission control. In summary, our proposed algorithm performs far better than the other three approaches due to a better choice of reuse channel candidate for the D2D pairs even as the D2D number increases.

Fig. 5 depicts the CDF of the D2D's sum rate of our proposed algorithm with three different approaches as observed from Fig. 5(a) when Z=20 & $\mathcal{N}$= 10. The proposed algorithm improves



(a) (b)

Fig.4. The SINR of D2D pairs of the proposed algorithm with three other approaches when (a) Z=20 & $\mathcal{N}$= 10, (b) Z=20 & $\mathcal{N}$= 20 and $P^d_{2max} = P^c_{max}$=23dBm.

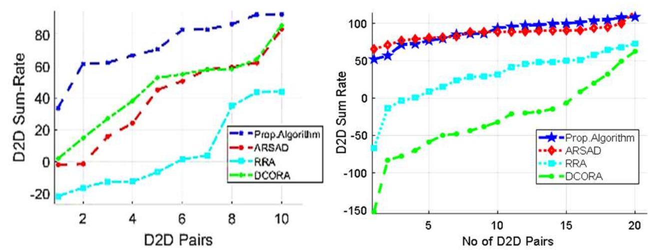


(a) (b)

Fig. 5. The cumulative distribution of D2D Sum-rate with three other approaches when (a) Z=20 & $\mathcal{N}$= 10, (b) Z=20 & $\mathcal{N}$=20 and $P^d_{2max} = P^c_{max}$=23dBm.

the sum rate of the D2D pair compared to the ARSAD, DCORA and RRA, which impact the overall network sum rate. The proposed algorithm achieves 9.23%, 11.26% and 13.92% higher than the ARSAD, DCORA and RRA. Fig. 5(b) is the results of the D2D's sum rate when Z=20 & $\mathcal{N}$= 20 which achieves 1.18%, 4.64% and 15.93% higher than the ARSAD, RRA and DCORA respectively. Just as observed in Fig 4(b), there was a close gap between our proposed algorithm and the ARSAD scheme due to a better choice of reuse channel candidate for the D2D pairs even as the D2D number increases. However, the performance of all the schemes decreases generally as the number of D2D pairs increases.

Fig.6 depicts the sum-rate of the D2D pair with three other approaches when (a) Z=20 & $\mathcal{N}$= 10 and (b) Z=20 & $\mathcal{N}$=20 respectively. Figures 6(a) and (b) show a linear increase in proportion to the number of D2D pairs, indicating an increase in the D2D sum rate for all three algorithms, including the proposed algorithm. However, in both figures, the proposed algorithm outperformed the three other approaches, except for the ARSAD scheme, which has a relatively close performance

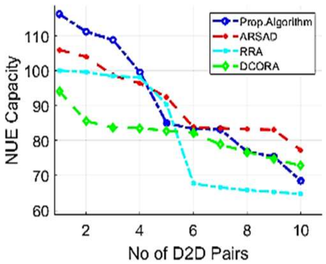


(a) (b)

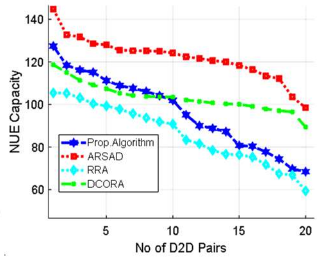
Fig. 6. D2D pair's Sum-rate against the number of D2D pairs for the different approaches when (a) Z=20 & $\mathcal{N}$= 10, (b) Z=20 & $\mathcal{N}$=20 and $P^d_{2max} = P^c_{max}$=23dBm.

to the proposed algorithm when the NUE and the D2D pair are equal in number. As a result, Fig. 6(b) implies that as the number of D2D pairs increases, the network becomes saturated and cannot serve more upcoming D2D pairs. Hence the diversity of multi-D2D users can only result in a lesser sum-rate gain. In summary, as the number of D2D pairs exceeds the number of NUEs, SINR deterioration of the NUEs may occur, limiting transmission performance, overall cell capacity, spectrum efficiency, network performance, and user performance of the 5G NB-IoT system. As a result, given the same amount of NUEs and D2D pairs, the proposed algorithm still outperforms the other three schemes.

In Fig. 7, the NUE's capacity was plotted against the number of D2D pairs when (a) Z=20 & $\mathcal{N}$= 10 and (b) Z=20 & $\mathcal{N}$=20. As shown in Fig. 7(a), our proposed algorithm maximizes the reuse resources of the NUE, causing minimal reuse interference on average as the number of D2D pairs grows compared to the ARSAD and DCORA schemes. The reason for this is that our proposed algorithm shares resources with a distant D2D user to reduce reuse interference using a combination of channel reuse selection and a power control mechanism. If the D2D pair's power and interference constraint do not exceed the maximum allowable threshold, the D2D pair's transmitter will maintain a high transmit power to maximize its sum rate while ensuring the NUEs' QoS according to constraints (4c) and (4g). Comparing the ARSAD and DCORA schemes to the proposed algorithm, the level of interference appears to be slightly higher than our proposed algorithm, but RRA produced an average rate of interference. Compared to Fig. 7(a), the result of Fig. 7(b) demonstrates a comparatively high degree of resource



(a)

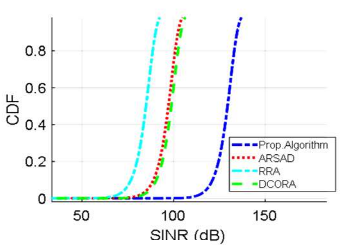


(b)

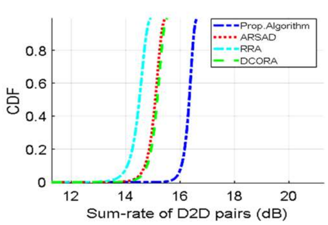
Fig. 7. NUE's capacity against the number of D2D pairs with three other approaches when (a) Z=20 & $\mathcal{N}$= 10, (b) Z=20 & $\mathcal{N}$=20 and $P^d_{2max} = P^c_{max}$=23dBm.

maximizing as the number of D2D pairs grows. However, as the number of D2D users increases, so does the interference generated inside the network, and the NUEs' link quality suffers. Our algorithm outperformed the other two algorithms (ARSAD and DCORA), which tend to increase their transmit power regardless of the number of D2D pairs. Given our algorithm's optimal power control, the D2D transmitter will always reduce its transmit power when there is a high level of interference to ensure the NUEs' QoS.

Fig. 8 shows the evaluation of the proposed algorithm when the transmit power of both the D2D pair and the NUE was reduced to 17dBm. The performance of the proposed algorithm is still significantly superior, as seen in Fig. 8(a) and (b). The DCORA scheme outperforms the ARSAD scheme in terms of performance. This is because the DCORA scheme continues to transmit at high power to meet the D2D pairs' channel gain and SINR constraints while ignoring the NUEs' minimum SINR requirement. In comparison to Fig. 4(a) and Fig. 5(a), the performance of the proposed algorithm, ARSAD, and RRA in terms of the required SINR and the sum-rate achieved reduces, as seen in Fig. (8c) vs Fig. 6(a). As the D2D cluster radius



(a)



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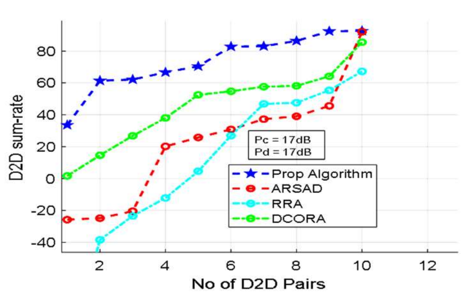
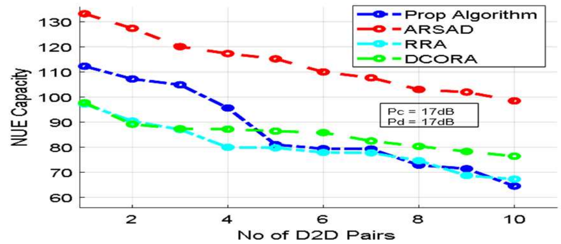


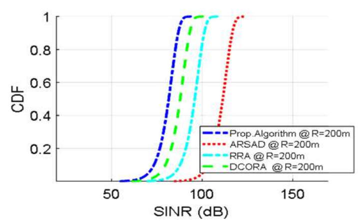
(c)



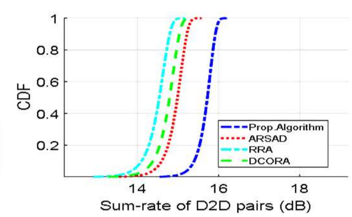
(d)

Fig. 8. (a) CDF of D2D's SINR, (b) CDF of D2D's Sum-rate, (c) D2D's Sum-rate against the number of D2D pairs and (d) NUE's Capacity against number of D2D pairs when $P^d_{2max} = P^c_{max}$= 17dBm for Z=20 & $\mathcal{N}$= 10.

grows, this decline accelerates, lowering the D2D pairs' chances of access. Furthermore, reducing the D2D user's transmit power will lessen interference to the NUE, aiding in satisfying the NUEs' minimal QoS criteria, as demonstrated in Fig (8d) versus Fig. (7a).



(a)



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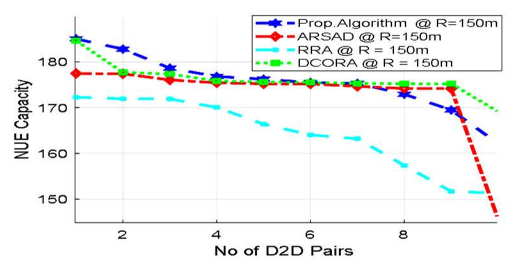
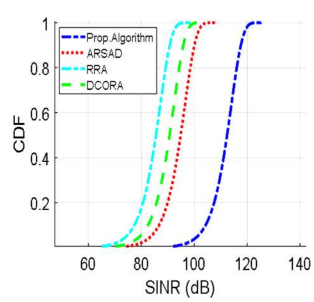
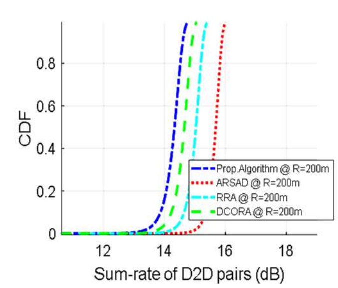


(c)

Fig.9. (a) The SINR, (b) Sum-Rate and the (c) NUE capacity against number of D2D pairs When R=150m and D2D pair's cluster distance = 14m for Z=20 & $\mathcal{N}$= 10.



(a)



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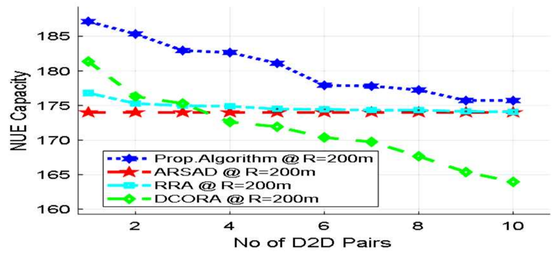
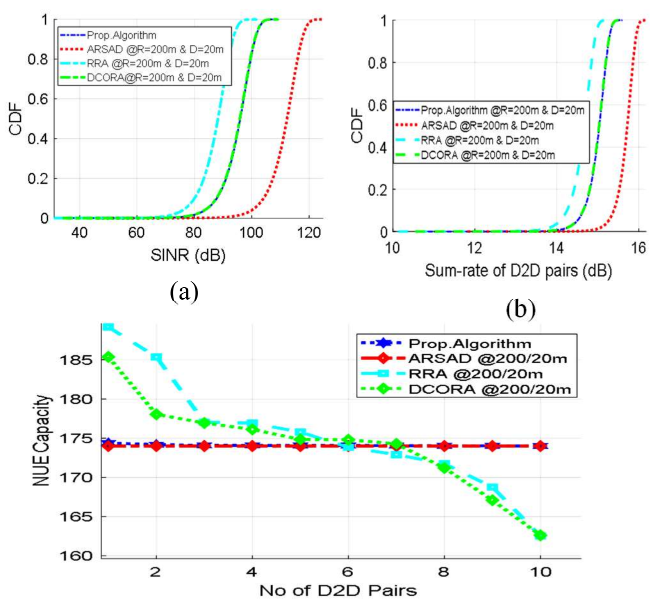


(c)

Fig.10. (a) The SINR, (b) Sum-Rate and (c) the NUE capacity against number of D2D pairs when R=200m and a Distance between D2D pairs = 14m.

Fig. 9 shows the simulation results when the cell radius is raised from 100m to 150m while maintaining the same D2D cluster distance of 14m. Within the cell, the density of NUEs and D2D pairs remains constant (i.e. =20 & N=10). As observed



(a) (b) (c)

Fig.11. (a) The SINR's CDF, (b) Sum-Rate's CDF and (c) the NUE's capacity against number of D2D pairs when R=200m and Max. D2D's cluster Distance = 20m.

from Fig. 9(a) & (b), the performance of our proposed algorithm continues to outperform the other three schemes as the cell radius grows. However, in contrast to Fig. 5(a), the performance of the proposed algorithm and the three approaches decreases when the distance between the NUE and D2D pair, as well as the PBS and the NUEs, increases. As a result, the channel power gain diminishes, which reduces the number of potential reuse partners who could provide reuse access. Furthermore, as shown in Fig. 9(c), the interference between the NUEs and the D2D pairs will rise, contradicting [15]. Interestingly, the ARSAD scheme flattened out, suggesting that it had achieved saturation and could no longer support the D2D pairs. In contrast to the ARSAD scheme, the proposed algorithm, DCORA and RRA, increased their transmit power in response to a bigger cell radius to grant access to the D2D pairs.

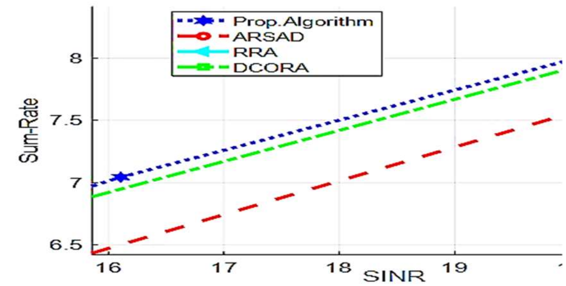


Fig. 12. The Sum-rate against the SINR of the proposed algorithm with three other approaches when Z=20 & $\mathcal{N}$= 10, and $P^d_{2max} = P^c_{max}$=23dBm

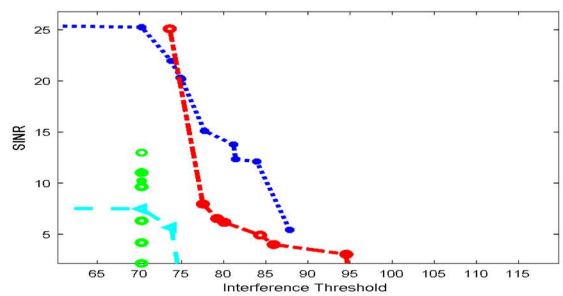


Fig. 13. The SINR against the Interference threshold of the proposed algorithm with three other approaches when Z=20 & $\mathcal{N}$= 10, and $P^d_{2max} = P^c_{max}$=23dBm.

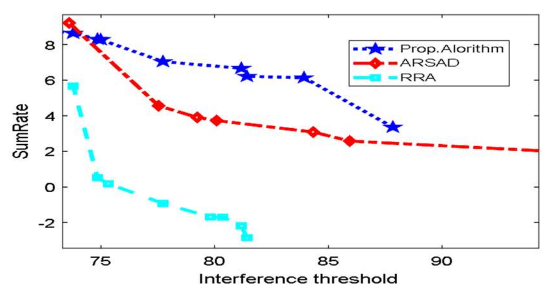


Fig. 14. The Sum-rate against the Interference threshold of the proposed algorithm with three other approaches when Z=20 & $\mathcal{N}$= 10, and $P^d_{2max} = P^c_{max}$=23dBm.

Fig. 10 confirms our findings in Fig. 9 that the overall performance of all the schemes declines as the cell radius grows under the same D2D cluster distance. Close inspection of Fig. 9(a, b, & c) reveals that the value achieved by any of the schemes in terms of SINR's CDF, Sum-rate's CDF and the level of generated interference are 98.22, 15 and 165.7 better than Fig. 10(a, b, & c) 96.45, 14.89 and 176.12 for the same CDF of SINR, Sum-rate's CDF and the level of generated interference. When compared to other schemes, the ARSAD and RRA schemes perform remarkably as the cell radius grows. The proposed algorithm and the DCORA scheme perform poorly as the radius of the cell increases, as shown in Fig.10 (a,b, & c). The reason for this is that the proposed algorithm could not locate any reuse candidate within the cell radius despite the increase in the transmit power of the D2D pairs. Furthermore, the maximum cell radius of the Pico-base station theoretically is less or equal to 200m, which could mean that the cell is out of coverage considering the cell's practicality. ARSAD and RRA schemes, on the other hand, were able to find a reuse candidate for each D2D user and deliver optimal power for each D2D pair and its reuse partner. In Fig.11, the performance of the proposed algorithm and DCORA improves slightly for SINR's CDF and Sum-rate's CDF as seen in Fig. 11 (a, b, & c) when the D2D cluster distance is raised from 14m to 20m. This is due to an increase in a channel power gain of the reuse channel selection of the NUEs to the PBS. As a result, the number of potential reuse channels for D2D pairs that provide access opportunities has increased. The interference power from D2D users to NUEs at the PBS is uniform for the proposed algorithm and the ARSAD scheme, as shown in Fig. 11c, which also guaranteed the NUE's QoS requirements.

The sum rate was plotted against the SINR for three schemes, including the proposed algorithm, in Fig. 12. The proposed algorithm outperforms the ARSAD and DCORA schemes by 2.86% and 7.14%, respectively. Every SINR improvement in the network results in a direct increase in the sum rate of the D2D pairs. This means that as the network dynamicity changes for each NUE's SINR requirement, the SINR conditions of the D2D users improve, increasing the D2D's sum rate. However, as the interference threshold rises, the SINR and sum rate of the D2D pairs decline, as shown in Figs. 13 and 14, respectively. In comparison to ARSAD, DCORA, and RRA in Fig 13, the proposed algorithm adjusts to changes in the interference threshold appropriately. While Fig 14 shows a decrease in the sum rate of the proposed algorithm, ARSAD and RRA. RRA has a significantly lower sum rate when compared to the proposed algorithm and the ARSAD scheme.

VI. Conclusion

For D2D-enabled 5G NB-IoT networks, we investigated and implemented an interference-avoidance resource allocation scheme. We design an optimization problem and address it through three sub-optimal solutions: reuse channel selection and QoS management for D2D pairs, optimal power control for the D2D user and its reuse partner, and maximum weighted matching to locate the optimal reuse partner for each pairing D2D user. When compared to other well-known schemes, simulation results demonstrate that our approach performs better in terms of D2D's sum rate and D2D's SINR. However, the D2D's SINR and D2D's Sum rate decreases as the interference threshold increases. This means that the network functions better when interference is maintained to a minimum at a value lower than the interference threshold that benefits networks.

Appendix A
Proof of QoS Control

Assume both NUE i and D2D pair j employs orthogonal resources (i.e., no interference between NUE i and D2D pair j). The SINR requirement for both NUE i and D2D pair j can be expressed as;

$$\begin{cases} \gamma_i^c = \dfrac{P_i^c g_{i,\ell}}{\sigma_n^2} \geq \gamma_{i\min}^c \\ \gamma_j^d = \dfrac{P_j^d g_j}{\sigma_n^2} \geq \gamma_{j\min}^d \end{cases} \tag{17}$$

A D2D pair j can reuse NUE i only when (17) holds which can be expressed as two inequalities in (18).

$$\begin{cases} \gamma_j^d - \gamma_{j\min}^d > 0 \text{ i.e. } P_{max}^d g_j - \gamma_{j\min}^d \sigma_n^2 > 0 \\ \gamma_i^c - \gamma_{i\min}^c > 0 \text{ i.e. } P_{max}^c g_{i,\ell} - \gamma_{i\min}^c \sigma_n^2 > 0 \end{cases} \tag{18}$$

The QoS constraint in (8) can be depicted as in Fig. 15, where lines I_i^c and I_j^d represent constraints (8a) and (8b) with equality respectively. The square area denotes the maximum transmit power constraint in (8c) for both NUE i and D2D pair j.

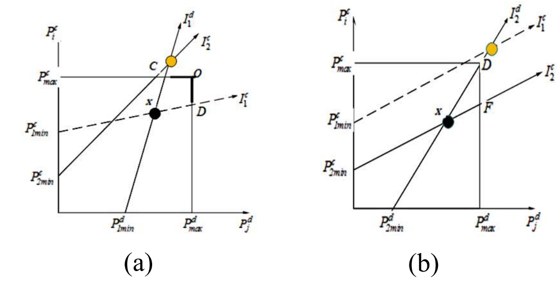


Fig. 15. The feasible region of optimal power Control for NUE and D2D user based on the magnitude of the (P_{max}^c, P_{max}^d).

The intersection at X of I_i^c and I_j^d in both Fig. 15 (a) and 15(b) is below the maximum transmit power satisfying constraint (8c). Thus, D2D pair j can reuse the NUE's resource. Therefore, the transmit power at X in (9) that satisfy the SINR condition is obtained from the following (19);

$$\begin{cases} \gamma_{i\min}^c = \dfrac{P_i^c g_{i,\ell}}{\sigma_n^2 + P_j^d g_{j,\ell}} \\ \gamma_{j\min}^d = \dfrac{P_j^d g_j}{\sigma_n^2 + P_i^c g_{i,j}} \end{cases} \tag{19}$$

When the SINR constraint is not met, the D2D pair is not allowed to reuse the NUE's resource. As a result, the algorithm eliminates such D2D pair. When no NUE is available or all D2D pairs have been tested, the process ends. It is also necessary that the intersection slope in Fig. 15(a&b) satisfies the following;

$$\frac{g_j}{\gamma_{j\min}^d g_{i,j}} > \frac{\gamma_{i\min}^c g_{j,\ell}}{g_{i,\ell}} \tag{20}$$

Which can be transformed into the following inequality

$$g_j g_{i,\ell} - \gamma_{j\min}^d \gamma_{i\min}^c g_{j,\ell} g_{i,j} > 0 \tag{21}$$

Appendix B
Proof of Preposition 1

According to [43], for any given power pair in the interior of the feasible region, there always exist another power pair $(\lambda P_i^c, \lambda P_j^d)(\lambda > 1)$ in the feasible region such that;

$$f\left(\lambda P_i^c, \lambda P_j^d\right) > f\left(P_i^c, P_j^d\right) \tag{22}$$

where $$f\left(P_i^c, P_j^d\right) \triangleq \log_2\left(1+\gamma_j^d\right) \tag{23}$$

This means that the peak power constraint will limit at least one power in the optimal power combination (P_i^{c*}, P_j^{d*}). Consider the two cases illustrated in Fig. 15 (a & b);

For case 1: $\gamma_i^c > \gamma_{i\min}^c$ and $\gamma_j^d \geq \gamma_{j\min}^d$, Fig. 15a shows the feasible zone. Line CO or OD will have the highest power. When the optimal power is on line CO, it is at point C or O. When the optimal power is on line OD, the optimal power pair is at point O or D. As a result, the optimal power allocation in this case can be expressed as;

$$\left(P_i^{c*}, P_j^{d*}\right) = \underset{\left(P_i^c, P_j^d\right)\in\Omega}{argmax}\ f\left(P_i^c, P_j^d\right) \tag{24}$$

where $$\Omega = \left\{ \left(P_{\max}^c, \left(\frac{P_{\max}^c g_{i,j} + \sigma_n^2}{g_j}\right)\gamma_{j\min}^d\right), \left(P_{\max}^c, P_{\max}^d\right), \left(\left(\frac{P_{\max}^d g_{j,\ell} + \sigma_n^2}{g_{i,\ell}}\right)\gamma_{i\min}^c, P_{\max}^d\right) \right\}$$

For case 2: $\gamma_i^c > \gamma_{i\min}^c$ and $\gamma_j^d < \gamma_{j\min}^d$, Fig. 15b depicts the feasible region. The optimal power pair will reside on line DF. On the line DF, $P_j^d = P_{max}^d$, and $f(P_i^c, P_{max}^d)$ is a convex function on Pc, hence the optimal power pair can be obtained at the corner point D or F. This means

$$\left(P_i^{c*}, P_j^{d*}\right) = \underset{\left(P_i^c, P_j^d\right)\in\Omega}{argmax}\ f\left(P_i^c, P_j^d\right) \tag{25}$$

$$\Omega = \left\{ \left(\left(\frac{P_{\max}^d g_j - \gamma_{j\min}^d \sigma_n^2}{\gamma_{j\min}^d g_{i,j}}\right), P_{\max}^d\right), \left(\left(\frac{P_{\max}^d g_{j,\ell} + \sigma_n^2}{g_{i,\ell}}\right)\gamma_{i\min}^c, P_{\max}^d\right) \right\}$$

From Fig. 15 (a & b), we used the assumptions of fixed P_{min}^d, and vary P_{min}^c and vice-versa to calculate the sum-rate of the D2D pair. The observation reveals that the optimal solution of (8a) and (8b) can only reside at the upper boundary line of the feasible region defined by the two functions $f_1(P_j^d, P_i^c)$ and $f_2(P_j^d, P_i^c)$ that maintain a monotonically increasing relation between P_i^c and P_j^d in the range $(P_{1max}^d, P_{j,X}^d)$ and $(P_{j,X}^d, P_{2max}^d)$ respectively [41] to ensure that at least one device is transmitting at the peak power.

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