Interference-Aware and Coverage Analysis Scheme for 5G NB-IoT D2D Relaying Strategy for Cell Edge QoS Improvement

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***Abstract*—In an interference-limited 5G Narrowband internet of things (NB-IoT) heterogeneous networks (HetNets), device-to-device (D2D) relaying technology can provide coverage expansion and increase network throughput for cell-edge NB-IoT users (NUE). However, as D2D relaying improves the network's spectral efficiency, it makes interference management and resource allocation more difficult. To improve cell-edge user quality of service (QoS), we propose an interference-aware and coverage analysis scheme for 5G NB-IoT D2D relaying. We divide the optimization problem into three sub-problems to reduce algorithm complexity. First, we use the max-max signal-to-noise plus interference ratio (Max-SINR) to select an optimal D2D relay with the highest channel-to-interference plus noise ratio (CINR) to relay the source NUE information to the NB-IoT base station (NBS). Second, we optimize the transmit power (TP) of the cell-edge NUE to the relay under the peak interference power constraints using a Lagrange dual approach to ensure the user's service life. We fixed the TP between the D2D relay and the NBS and then transformed the D2D relay's coverage problem that maximizes the network uplink data rate into a 0-1 integer programming problem. Then, we propose a heuristic algorithm to obtain the system performance. Due to the high channel gain between the two communicating devices, the simulation results show that the Max-SINR selection scheme outperforms the other relay selection schemes except for the D2D communication scheme in efficiency, data rate and SINR.**

***Index Terms*—Cell-edge NUE, CINR, D2D Relaying, 5G NB-IoT, Max-SINR, Interference-aware, QoS.**

I. INTRODUCTION

WITH the rapid proliferation of the internet of things (IoT) devices and data applications for NB-IoT systems, increasing capacity and achieving seamless coverage of NB-IoT networks have become urgent issues. As an LTE-based technology, NB-IoT supports broader applications in systems such as intelligent agriculture [1], [2], advanced health systems, and industrial internet of things (IIoTs) to promote a more effective and convenient way of life [3]. The D2D relaying technology has the potential to improve the QoS of cell-edge NUEs. D2D relaying with uplink spectrum sharing in a 5G NB-IoT HetNet improves spectral efficiency. As a result, the system's co-channel interference power rises, affecting other signals in the network.

D2D relaying, as opposed to traditional relays, provides much greater networking flexibility by responding to user pairing and traffic through dynamic deployment and resource allocation [4]. However, the technology's performance greatly depends on the optimal D2D relay selection method and interference control produced by the signal relaying strategy. As a result, the coverage area of the D2D relay is impacted by the resource allocation due to the adopted D2D communication. A few existing solutions are channel capacity analysis [5], user pairing stability, and user acceptability to establish a link between the metric proposed and system performance [4]. In a HetNet, two-stage D2D relay selection to offload the unevenly distributed load [6], analyze coverage [7], allocate power design algorithms [8], and allocate resources [9] are applied. Although these studies demonstrated the effectiveness of D2D communication in a wireless network, none of the above methods considered interference control and coverage analysis as part of the D2D relaying strategy.

This paper proposes an interference-aware and coverage analysis scheme for 5G NB-IoT D2D relaying to improve cell-edge NUE (CeNUE) QoS. Under interference constraints, the data from the CeNUE can be transmitted to the NBS via the D2D relaying strategy using idle NUEs with perfect coverage. Given the network heterogeneity, a D2D relay can improve network coverage and throughput and reduce interference constraints. D2D relay network enhances long-distance transmission, delays, low bandwidth utilization, and high system overhead, impacting network performance. To address the interference issue in D2D relaying, we designed a reuse mechanism and optimized the cell-edge NUE TP under the peak interference power constraints to guarantee the user service life. The interference power constraint depends on the cellular NUE average SINR output to achieve QoS for the CeNUE. Thus, we leveraged the Max-SINR approach to select an optimal D2D relay with the highest CINR to relay the CeNUE data. As a

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result, given the complexity of this network system, the CINR selection affects the interfering links set that determine the suitable link rate selection. Thus, CINR and improving the throughput are interrelated. Maximizing the D2D relay link minimal data rate under interference constraints will improve spatial reuse and throughput [10]. Therefore, a D2D relay with a higher CINR link feature will have interference power lower than the interference threshold. As a result, we optimize the D2D relay coverage problem and convert the optimization problem into a 0-1 integer programming problem to analyze the network spectrum efficiency and rate of throughput increments. An 0 -1 integer programming optimizes an objective function with the use of integer variables constrained to 0 or 1 while adhering to set of constraints. Unlike the authors of [11] and [12], who considered co-tier interference from neighboring sources, as well as spectrum utilization trade-off and fairness, respectively, and no relay selection, our metric reduces network overhead and interference power caused by signal relaying within the network by adaptively selecting a D2D relay candidate with the highest maximum CINR and efficiency to maximize the D2D link data rate.

To the best of our ability, no research has been conducted on a D2D relay performance in 5G NB-IoT systems based on the D2D relay selection strategy, the average interference power constraint, and the coverage analysis. The study aims to improve the quality of experience (QoE) of CeNUE with poor link quality by selecting links with high coverage quality, low interference, and delay to avoid costly retransmission at the source while ensuring the cellular NUE transmission requirement. As a result, the network SINR and throughput also improve, guaranteeing the system's performance. The proposed scheme can be applied to a large-scale cognitive NB-IoT network where a secondary user cannot access its allocated spectrum unless an intermediate node from among B terminals relays its signal to the destination under interference constraint, as considered in [13]. The main contributions of the proposed scheme are as follows:

- We propose a new framework for interference-aware and coverage analysis scheme for the 5G NB-IoT D2D relaying problem to improve the QoS of the CeNUE. We analyzed the D2D relaying strategy of a standalone NB-IoT access mode in a two-tier HetNet to limit harmful interference power of 5G NB-IoT D2D relay on cellular NUE links.
- Due to the combinatorial and non-linear nature of resource-sharing (RS), we formulate the RS problem as an NP-hard problem for the D2D pair communication under the Macro-base station (MeNB) control.
- The RS problem is sectioned into three (3): the first is D2D relay selection, which employs the Max-SINR approach to choose an optimal D2D relay with the highest CINR from a set of R available D2D relays. Second, we developed a closed-form expression for power allocation for the D2D pair and fixed the relay's TP to the NBS. Finally, we formulate and solve the optimal D2D relay coverage problem that maximizes the system data rate as a domain optimization problem. Then convert the optimization problem into a 0-1 integer programming problem and propose a heuristic algorithm.
- We evaluate the coverage issue for spectrum efficiency value and rate increase per D2D bandwidth. We compare the proposed scheme performance to the relay selection policies and the D2D communication scheme in [29] for data-rate maximization, efficiency value and minimum interference power. The proposed approach outperforms the other relay selection schemes except for the D2D communication scheme due to the high channel gains of the two communicating pairs.

The remainder of this paper is structured as follows: Section II provides a synopsis of the related work. Section III describes the system and the problem formulations. Section IV discusses the optimal RS procedure for the formulated problem. Section V presents the simulation results, and the paper concludes in Section VI.

II. RELATED WORK

Matching users for optimal resource usage becomes a significant issue when using a D2D relaying network due to variations in the interference degree and path loss of each D2D link. Transmission delays may occur if the wrong D2D relay link under interference conditions is chosen. D2D relaying channel conditions differ for each D2D relay link. Recent research on NB-IoT D2D relay networks uses a set of D2D relays operating on a duty cycle [14] and devises two optimization problems to achieve an optimal-expected ratio (EDR) and expected two-hop delay. [15] envisions an opportunistic crowd-sensing application that uses vehicle-mounted mobile relays to provide reliable connection, transmission latency, and energy efficiency for low-cost and battery-constrained IoT sensors. The study promotes network operations throughout the human-aware IoT ecosystem. The work in [16] achieves a 10% to 15% rate improvement for multi-user diversity of allocation strategy in the context of mutual interference between D2D NB-IoT terminals and cellular terminals transmitting in the same resource block (RB).

The study [17] investigated NB-IoT architecture to develop an efficient relay scheme that reduces the overall energy consumed within NB-IoT cells. The author employs a greedy algorithm to achieve a similar result with less computation complexity. [18] proposes a novel mechanism for relay selection and optimal relay scheduling with the goal of cell edge user repetition to save energy while maintaining system performance and QoS. [19] propose a theoretical derivation and an experimental simulation to address the identified D2D relay network coverage issue using stochastic geometry. Simulation results that exclude the D2D relay validate the theoretical solution, demonstrating optimal coverage in an irregular shape. Optimal relay locations and performance improvements outperform the existing schemes. Prior interference research in the NB-IoT network [20], [21], [22], [23], [24], [25], has never addressed the challenges of low data rate, poor channel quality, spectral efficiency, and limited coverage in NB-IoT networks.

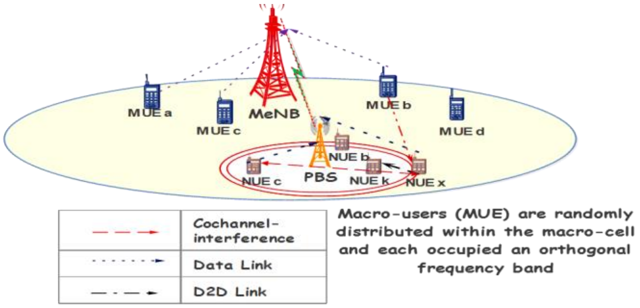

Fig. 1. System Model

III. SYSTEM, NETWORK MODEL AND PROBLEM FORMULATION

A. *System Model*

Fig. 1 depicts a 5G NB-IoT HetNet uplink (UL) channel, with an NB-IoT network as an accessible environment. The NBS[1] is a pico-base station (PBS) equipped with NB-IoT technology with an area of $\mathcal{S}^2$ and communicates with the central macro-eNodeB (MeNB) with an area of $\mathbb{R}^2$ via the X2 interface to share control information. To provide indoor/outdoor coverage for NB-IoT devices, the NBS reuses the MeNB frequency with a bandwidth of $\mathcal{W}$Hz. As a result, co-channel interference (CCI) exists. CCI influences the cell edge NUE channel condition. Let M and $\mathfrak{b}$ denote the MeNB and NBS, respectively. Assume the MeNB serves m orthogonal macro-users (MUEs), while the NBS serves z orthogonal active cellular NUEs and r idle NUEs acting as D2D relays, respectively. Let $\mathcal{N}$= {1, 2,.., m}, $\mathcal{Z}$= {1,2…, z}, and R ={1,2,...., r} denote corresponding sets of MUEs, active NUEs and D2D relays (idle NUEs). Assume that each NUE is equipped with a single antenna. The MUEs and NUEs are distributed spatially using a homogeneous Poisson point process (PPP) with densities λ_m and λ_a, respectively. To concentrate our efforts on the D2D relaying process, we assume an absence of a link between the cell-edge NUE and the NBS (i.e., the source-destination channel is in deep fade) and that transmission only takes place via D2D (two-hop) relaying by allowing proximity services. This assumption aids the analysis of the interference from D2D pairs during the relaying process (e.g., LTE-A using two-hop transmission with no direct link [26]). Again, the relay selections do not affect direct links.

B. *Network Model*

Fig.1 shows the cellular NUEs communicate with the NBS via cellular mode. The cell-edge NUE-$\varkappa$ communicates with the NBS via the selected D2D relay NUE (i.e., D2D communication, also known as D2D relaying), reusing the existing cellular users' uplink resources. As a result, each communication link receives interference from cellular users accessing the channel simultaneously. However, due to different channel patterns at the relay node and the NBS, the D2D communication link may differ in channel gains in various hops, which defines the relay node's heterogeneous environment. To avoid complex resource reuse, we assume that each D2D pair can only reuse one channel and that a channel can be reused at most by one D2D user. In addition, accommodating all transmission requests without causing significant interference is impossible. As a result, spectral efficiency suffers when the interference level exceeds a certain threshold, which impacts the QoS requirements for individual NUE communications. Therefore, an interference control for the D2D relay underlay cellular NUEs in HetNet is desirable to achieve the desired system performance while ensuring cellular NUE QoS. Assuming all the wireless channels exhibit Rayleigh fading, the channel models for all links employ 3GPP TR 38.901 path loss model [28] and exhibit the large effect and small effect fading within terminal *i* to terminal *j*. Therefore, the channel coefficient, $\square_{\varkappa,k}$ between the NUE-$\varkappa$ and NUE-k can be modeled as:

$$g_{x,k} = Jh_{x,k}B_{x,k}D_{x,k}^{-a} \qquad (1)$$

where J, $\hbar_{\varkappa,k}$, $\mathfrak{B}_{\varkappa,k}$, a, and $\mathcal{D}_{\varkappa,k}$ are the pathloss constant, large-effect gain, small effect gain, pathloss exponent and the distance between the cell-edge NUE-$\varkappa$ and the relay NUE-k. Similarly, the links, $\square_{\mathrm{k,b}}$, $\square_{\square,x}$ and $g_{m,x}$ are refer to as the channel from the relay NUE-k to the NBS $\mathfrak{b}$, the cellular NUE-$\mathfrak{c}$ to the CeNUE-$\varkappa$, and from the MUEs to the CeNUE-$\varkappa$, respectively. The σ^2 is additive white Gaussian noise (AWGN) (i.e., circularly symmetric complex Gaussian noise and subject to $\mathcal{C}\sigma^2(0,\sigma^2)$).

C. *Problem Formulation*

The proposed two-hop D2D communication operates in two separate phases simultaneously. The CeNUE-$\varkappa$ sends its data to the selected relay (NUE-k) in the transmission phase 1, reusing the cellular NUE-c uplink resources, and will be interfered with by the cellular NUE-c as the relay node retransmit the data to the NBS in the transmission phase 2. Section IV discusses the optimal D2D relay selection process. The SINR, $\gamma_{i,j}$, from NUE-$\varkappa$ to the selected D2D relay and from the chosen relay NUE to the NBS, can be expressed as follows:

$$\gamma_{x,k} = \frac{P_x g_{x,k}}{P_c g_{c,x} + I_m + \sigma^2} \text{ and } \gamma_{k,b} = \frac{P_k g_{k,b}}{I_m + \sigma^2} \qquad (2)$$

where $\mathrm{I}_m = \sum_n P_m g_{mx}$, is the co-channel interference generated from the MUEs as a result of resource reuse. P_c and P_m are the transmit power of the cellular NUEs, and MUEs respectively. The Decode and forward (DF) protocol is used. Assuming that the relay NUE-k correctly decodes the information and that the NBS only receives information in transmission phase 2 of each transmission cycle, the joint SINR, $\gamma_{x k \mathrm{b}}$, at the NBS can be expressed as follows:

$$\gamma_{xkb} = \min\left\{\gamma_{x,k}, \gamma_{k,b}\right\} \qquad (3)$$

Thus, the D2D relaying link's instantaneous data rate $R_{\varkappa \mathrm{kb}}$, can be expressed as:

$$R_{xkb} = \sum_{z}^{Z} \sum_{r}^{R} \log_2\left(1 + \gamma_{xkb}\right) \qquad (4)$$

Due to the heterogeneous nature of the system, co-channel interference is experienced by MUEs and NUEs due to spectrum resources sharing with the selected D2D relay. The magnitude of the interference, however, varies depending on

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[1] NBS uses single-carrier frequency division multiple access (SC-FDMA) as UL and downlink transmission schemes, as a result no intra-cell interference or near-far effects [27].

the transmission phase. The NUE-$\varkappa$ will cause additional interference to the cellular NUEs (with in the NBS) in the first transmission phase (i.e., from the NUE-$\varkappa$ to the selected D2D relay NUE-k) in addition to the co-channel interference within the system. While in the second transmission phase, from the relay NUE-k to the NBS, there is only the co-channel interference. As a result, the SINR received by the cellular NUEs at the NBS will be:

$$\gamma_{cb} = \begin{cases} \dfrac{P_c g_{c,b}}{P_x g_{c,x} + I_m + \sigma^2}, \ \textit{first phase} \\ \dfrac{P_c g_{c,b}}{I_m + \sigma^2}, \ \textit{second phase} \end{cases} \tag{5}$$

The cellular link's instantaneous data rate from NUE-c to the NBS, R_{cb}, can be expressed as;

$$R_{cb} = \log_2\left(1+\gamma_{cb}\right) \tag{6}$$

Given the transmission priority of NUEs under interference control, we express the optimization problem P1 due to RS to maximize QoS satisfaction of the D2D relaying link and to determine the optimal D2D relay that maximizes the data rate as follows:

$$P1: \max_{P_x^{opt}}\left(R_{xkb}\right) \tag{7}$$

$$\cdot\begin{cases} P_x \le P_{\max} & \text{(8a)} \\ R_{cb} \ge R_{c-min} & \text{(8b)} \\ I_t \ge \sum\limits_{z\in Z} P_x^{opt} g_{c,x} & \text{(8c)} \\ R_{xkb} \ge R_{min} & \text{(8c)} \end{cases}$$

$$\textit{where } I_t = \sum_z \left(P_c g_{c,x} + I_m\right)$$

where $P_{\max}$ is the maximum source transmit power, $\mathcal{R}_{c-min}$ is the minimum data-rate allowed for the cellular uplinks, $P_{\varkappa} g_{c\kappa}$ is the interference power at the source that should not be greater than the total generated interference, I_t, within the HetNet and $\mathcal{R}_{min}$ is the minimum achievable data-rate by the relay to successfully decode the signal. The total generated interference, I_t, is estimated based on the NBS's minimum SINR requirement for each NUE. The operation allocates resources to the D2D link based on NUE equal transmit powers, P_c. Constraint (8a) ensures that the cell edge NUE transmit power is within the $P_{\max}$. Constraint (8b) defined the cellular uplink minimum data rate. Constraints (8c) restrict the interference generated by the D2D link within the NBS network to a tolerable threshold.

The optimization problem P1 is NP-hard, combinatorial, and non-linear due to RS. As a result, it cannot be determined in polynomial time.

IV. OPTIMAL RESOURCES SHARING

The optimization problem is section as: 1) Cellular user TP is determined to account for potential maximum interference to the NBS based on resources reuse mechanism, and then, D2D relay selection strategy is applied to select an optimal D2D relay with the highest CINR that maximizes the system data rate based on the Max-SINR approach. 2) the optimal power allocation (OPA) strategy is obtained for the CeNUE to the D2D relay based on the calculated cellular NUEs TP[2] under the constraint (8c) that shows the reuse interference among the D2D pairs, and lastly, we derive the optimal D2D relay coverage that maximizes the system uplink data rate to analyze the network spectrum efficiency value and rate of throughput increments.

A. D2D Relay Selection Strategy Using Max-SINR

To obtain the optimal D2D relay at the CeNUE, first, we calculate the cellular user (NUE-c) optimal power control, $\mathrm{P}_{c-opt,}$ and consider the potential maximum interference power to the NBS caused by the CeNUE-$\varkappa$ and I_m to justifies the resources reuse scheme. As a result, the minimum data-rate allowed for the cellular uplinks can be express as:

$$R_{c-\min} = \sum_z^Z \log_2\left(1+\frac{P_c^z g_{c,b}}{P_x g_{c,x} + I_m + \sigma^2}\right) \tag{9}$$

However, equation (9) includes variables P_m and P_x in addition to variable P_c. As a result, we re-write (9) to include potential maximum interference power for each NUE based on the NBS's minimum SINR requirement as follows:

$$R_{c-\min} = \sum_z^Z \log_2\left(1+\frac{P_{c-opt}^z g_{c,b}}{max\left\{P_{max} g_{x,c} + I_m\right\} + \sigma^2}\right) \tag{10}$$

From (10), the optimal transmit power at NUE-c is express as:

$$P_{c-opt}^z = \left(\frac{2^{R_{c-\min}} - 1}{g_{c,b}}\right)\left(max\left\{\sum_z P_x g_{x,c} + I_m\right\} + \sigma^2\right) \tag{11}$$

To achieve full diversity under interference control, we use the D2D relay with the highest CINR to relay the CeNUE-$\varkappa$ information to the NBS, assuming fixed transmit power at the relay node to the NBS. From (5), we express the CINR from cell-edge NUE to the D2D relay and from the relay to the NBS as:

$$\eta_{xk} = \frac{g_{x,k}}{P_{c-opt}^z g_{c,x} + I_m + \sigma^2} \text{ and } \eta_{kb} = \frac{g_{k,b}}{\mathrm{I}_m + \sigma^2} \tag{12}$$

where $\eta_{\varkappa k}$ and $\eta_{k\mathfrak{b}}$ are the CINRs from the NUE-$\varkappa$ to the relay and from the relay to the NBS, respectively. To obtain optimal D2D relay NUE-k, we employ Max-SINR approach as described in (13).

$$k = argmax\left(\gamma_{xk_i}, \gamma_{kb_i}\right), \ i \in R \tag{13}$$

$$\textit{where } \gamma_{xk_i} = max\left(P_{x_i}^{opt} \eta_{xk_i}\right) \textit{ and } \gamma_{kb_i} = max\left(P_k \eta_{kb_i}\right)$$

Eqtn (13) is adopted and modified from the signal-to-noise ratio (SNR) selection scheme in [29]. $SNR_{x,k} = \max\left(\gamma_{xk}\right)$, $SNR_{k\mathfrak{b}} = max(\gamma_{k\mathfrak{b}})$, $P_{\varkappa}^{opt}$ and P_k are the SNR of the CeNUE-$\varkappa$ to relay NUE-k, relay to NBS **b**, CeNUE optimal transmit power and D2D relay transmit power, respectively. The CeNUE optimal transmit power, $P_{\varkappa}^{opt}$ is derived in section IV.B. The channels are assumed to be static and precisely estimated throughout the relay selection process. Similarly, the transmission power at the source is optimized, and the transmit

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[2] Note that the TP from the cell-edge NUE is optimized to guaranteed service life of the cell-edge user while the TP from the D2D relay to the NBS is fixed.

power at the relay to NBS remains fixed. The process will conserve CeNUE energy while minimizing interference.

B. Optimal Transmit power at the cell-edge NUE

The OPA for the CeNUE is computed to maximize the QoS satisfaction of D2D relaying link. To obtain the optimal transmit power at the CeNUE, we deduced that the objective function is a reducing function with respect to P_c as observed from the optimization problem P1. The D2D relaying strategy has a greater impact in the first phase. As a result, to obtain the maximum data rate, $R_{\varkappa k \mathfrak{b}}$, the optimal transmit power $P_{\varkappa}^{opt}$, at the cell-edge NUE-$\varkappa$ must be determined. We described the optimization problem P1 following the preposition 1 based on the analyses above.

Preposition 1: $\gamma_{xkb} = \min\left(\gamma_{xk}, \gamma_{kb}\right) = \gamma_{xk}$. Assuming that $P_{\varkappa}\eta_{\varkappa k} \leq P_{\kappa}\eta_{k\mathfrak{b}}$, P1 can be replaced with P2.

$$P2: \max_{P_x^{opt}}\left(R_{xkb}\right) \tag{14}$$

$$s.t. \begin{cases} P_x \leq P_{\max} & (14a) \\ I_t \geq \sum\limits_{z\in Z} P_x\, g_{c,x} & (14b) \\ R_{xkb} \geq R_{min} & (14c) \\ P_x \geq 0 & (14d) \end{cases}$$

$$where\ I_t = \sum_z \left(P_{c-opt}^{z}\, g_{c,x} + I_m\right)$$

From (14b), the interference generated by the D2D link is solved by the NUE's previous power allocation and the interference channel gain between the cellular NUE and the CeNUE. Based on this information, the MeNB computes the correlation between the interference generated within the NBS and the total generated interference, I_t, in the system. The correlated results are sent to the NBS for power optimization at the CeNUE. As a result, we employ the following preposition 2.

Preposition 2: The optimization problem $\mathscr{P}2$ is a concave problem as proofed in the appendix.

According to the duality principle [30], [31], there is no difference between the optimal solution to P2 and the dual problem's solution, so we use the concave maximization problem's optimization structure to solve the dual problem of P2. As a result, we apply the Lagrangian function to P2 as follows:

$$L\left(\lambda,\mu,\phi,P_x\right) = \sum_{z\in Z}\sum_{r\in R}\log_2\left(1+\frac{P_x g_{x,k}}{P_{c-opt}^{z} g_{c,x} + I_m + \sigma^2}\right) + \lambda\left(I_t - \sum_{z\in Z} P_x g_{x,c}\right) + \mu\left(P_{max} - P_x\right) + \sum_{r\in R_i}\phi P_{x_i} \tag{15}$$

$$= \sum_{z\in Z}\sum_{r\in R}\left[\log_2\left(\beta + P_x\right) + \alpha\right] + \lambda\left(I_t - \sum_{r\in R}\varsigma P_x\right) + \mu\left(P_{max} - \sum_{r\in R} P_x\right) + \sum_{r\in R}\phi P_x \tag{16}$$

where $\alpha = \log_2\left(\dfrac{g_{x,k}}{I_t + \sigma^2}\right)$, $\beta = \dfrac{I_t + \sigma^2}{g_{x,k}}$, $\varsigma = \sum\limits_{z\in Z} g_{x,c}$

$\&\ \mathrm{I}_t = \left(\sum\limits_{z\in Z} P_{c-opt}^{z}\, g_{c,x} + I_m\right)$

Also, λ, μ, ϕ are the Lagrangian multipliers. To solve (16), we apply the KKT conditions. The first-order partial derivative of P_x is expressed as:

$$\frac{\partial L\left(\lambda,\mu,\phi,P_x\right)}{\partial P_x} = \frac{1}{\ln 2}\frac{1}{\beta + P_x} - \lambda\varsigma - \mu + \phi \tag{17}$$

$$\frac{\partial L\left(\lambda,\mu,\phi,P_x\right)}{\partial P_x} = 0, \quad \therefore\ \mathrm{P}_x = \frac{1}{\ln 2}\frac{1}{\lambda\varsigma + \mu} - \beta \tag{18}$$

It is clear from (17) that ϕ is a slack variable vector that can be discarded [32]. Thus, P3 can be obtained by substituting (18) into (16) as:

$$\mathrm{P3}: \min \Psi\left(\lambda,\mu\right) = \min \max_{P_x} L\left(\lambda,\mu,P_x\right) \tag{19a}$$

$$= \min_{\lambda,\mu}\sum_{z\in Z}\sum_{r\in R}\left[-\log_2\left(\mu + \lambda\varsigma\right) + \beta\left(\mu + \lambda\varsigma\right)\right] + \lambda I_t + \mu P_{max} + \sum_{z\in Z}\left[\log_2\left(\frac{1}{\ln 2}\right) - \left(\frac{1}{\ln 2}\right) + \alpha\right] \tag{19b}$$

$$\text{s.t.}\ \ \lambda \geq 0,\ \ \mu \geq 0$$

The properties of the objective function allow us to classify P3 as a convex optimization problem (i.e., concave minimization function with convex constraints). To address P3, the KKT condition can be employed. Again, the minimization function in (19) is utilized to validate the obtained solution. One method for solving an objective function with no constraints is the Newton-Raphson (NR) method [29], [32]. As a result, in two cases, the optimal solution to (19) can be considered under the partial derivative of (19) as: $\mu = 0\ or\ \lambda = 0$.

Case 1: when $\lambda = 0$, then $\psi(\lambda,\mu) = \psi(0,\mu)$. Hence, solving $\frac{\delta\psi(0,\mu)}{\delta\mu} = 0$ and Optimal μ^* is obtained as;

$$\mu^* = \frac{1}{\ln 2}\frac{1}{\sum\limits_{z\in Z}\sum\limits_{r\in R}\beta + P_{max}} \tag{20}$$

Case 2: when $\mu = 0$, then $\psi(\lambda,\mu) = \psi(\lambda,0)$. Hence, solving $\frac{\delta\psi(\lambda,0)}{\delta\lambda} = 0$ and Optimal λ^* is obtained as:

$$\lambda^* = \frac{1}{\ln 2}\frac{1}{I_t + \sum\limits_{z\in Z}\sum\limits_{r\in R}\beta\varsigma} \tag{21}$$

To obtain the optimal power $P_{\varkappa}^{opt}$, substitute the optimal μ^* and λ^* values into (18). Because we discard ϕ, we must ensure that the optimal power for all D2D links is greater than zero (i.e., $P_{x}^{opt^*} \geq 0, \forall r \in R$). As a result, if $P_{x}^{opt^*} \geq 0, \forall r \in R$, the optimal power is the solution to P2, otherwise we must discard those $P_{\varkappa}^{opt} < 0$ values and solve P3 again until a solution for $P_{x}^{opt*} \geq 0, \forall r \in R$ is obtain. Algorithm 1 presents the power optimization algorithm.

ALGORITHM I

POWER OPTIMIZATION ALGORITHM FOR THE D2D RELAYING SCHEME

Algorithm 1: *Optimal power allocation for cell-edge NUE*

```
Initialize: $\lambda = 1, \mu = 1,$
Obtain $P_x$ using equation (18)
If $P_x \geq 0, \forall r \in R, \forall z \in Z$, then
$P_{\varkappa}^{opt} = P_x$
else
    While $P_x \leq 0$, do
        Solve for P3 (dual Problem) using NR Method in eqtn (19)
        Solve the two scenarios in eqtn (20) & (21)
        If $\lambda = 0$, obtain $\mu^*$ in eqtn (20)
      End
      If $\mu = 0$, obtain $\lambda^*$ in eqtn (21)
      End
      Update $P_x$ with $\mu^*$ and $\lambda^*$ in eqtn (18)
      If $P_x \geq 0, \forall r \in R, \forall z \in Z$,
    Break
    else
    Find the D2D relay $r_{\varkappa}^{*}$ with minimum Power
$P_{\varkappa}^{opt} = min(P_x)$
    End
  End
End
```

The data rate of the D2D link under the interference power constraint is maximized using Algorithm 1 and the proposed D2D relay scheme. Due to the random distribution of NUEs within the NBS, the interference constraint becomes necessary. The interference constraint creates flexibility and dynamism and redistributes the total generated interference across all paired D2D links to achieve fairness, reduce complexity, and avoid discriminating services among all users with different QoS. The source transmits power is varied depending on the location and position of the D2D relays, influencing the data rate of the D2D link.

C. Optimal D2D Relay Coverage Problem

Assume that for any arbitrary CeNUE at location x, there are two transmission options, i.e., D2D relay transmission and cellular transmission.

Considers the optimal D2D relay coverage at location k$\in \mathcal{S}^2$ in the NBS cell area that maximizes the system uplink data rate. We aim to quantify the D2D relay coverage performance. To begin, establish the D2D relay coverage as a domain optimization problem and convert it into a 0-1 integer programming problem[3]. Then, a heuristic algorithm is proposed that analyzes the performance of the system. Thus, given the optimal D2D relay k (k$\in \mathcal{R}$), where $\mathcal{R}$ is the decoding set, let $\mathcal{R} \subseteq \mathcal{S}^2$ denote the D2D relay coverage domain where the cell-edge NUE uses the D2D relay transmission option and the cellular NUEs ($x \notin \mathcal{R}$) adopt cellular transmission. The uplink data rate of the CeNUE at position x, represented by $R^s(x)$ is expressed as:

$$R^{s}(x) = \begin{cases} R_{xkb}(x) & \mathrm{x} \in R \\ R_{cb}(x) & \mathrm{x} \notin R \end{cases} \quad (22)$$

The expected system uplink data rate is calculated integrally as follows:

$$\begin{aligned} \mathrm{E}\left[R^{s}{}_{sum}\right] &= \int_{s^2} R^{s}(x)\, dx \\ &= \int_{R} \lambda_a R_{xkb}(x)\, dx + \int_{S^2-R} R_{cb}(x)\, dx \quad (23) \end{aligned}$$

The Achievable data rate of the D2D-link coverage is the first term on the left-hand side (LHS), and the right-hand side (RHS) is the cellular NUEs sum rate excluding D2D coverage.

Then the optimization problem is formulated as a domain optimization problem as [7]:

$$\begin{aligned} P4: \max & \int_{R} \lambda_a R_{xkb}(x)\, dx + \int_{S^2-R} \lambda_a R_{cb}(x)\, dx \\ st. & \int_{R} \lambda_a R_{xkb}(x)\, dx \ \geq \ R_{min} \quad (24) \end{aligned}$$

To optimize the problem, we introduce a domain indication function, $\Phi(x)$, where $\Phi(x) = 1$ indicates that $x \in \mathcal{R}$, and $\Phi(x) = 0$ indicates $x \notin \mathcal{R}$. As a result, we re-write the expected system uplink data rate as:

$$\begin{aligned} \mathrm{E}\left[R^{s}_{sum}\right] &= \int_{S^2} \lambda_a R_{xkb}(x)\Phi(x)dx + \lambda_a R_{cb}(x)\left(1-\Phi(x)\right)\, dx \\ &= \lambda_a \int_{S^2} \left(R_{xkb}(x) - R_{cb}(x)\right)\Phi(x)dx + \lambda_a \int_{S^2} R_{cb}(x)dx \quad (25) \end{aligned}$$

The values of λ_a and $\int R_{cb}(x)dx$ are specified and unrelated to the indication function, $\Phi(x)$. Thus, P4 is converted to a 0-1 integer problem as:

$$\begin{aligned} P5: max & \int_{S^2} Q(x).\Phi(x)\, dx \\ st. & \int_{S^2} R_{xkb}(x)\, dx \ \geq \ R_{min} \quad (26) \end{aligned}$$

$Q(x) = R_{xkb}(x) - R_{cb}(x)$ denotes the rate increment by D2D relay transmission at location x over the cellular transmission and $\mathcal{R}_{min}$ is the minimum achievable data-rate by the D2D relay to successfully decode the signal.

To solve the optimization problem, P5, we use a heuristic algorithm that analyzes the system performance. The optimal D2D relay coverage performance is expressed as the rate increment per D2D bandwidth by D2D relay transmission over the cellular. Algorithm 2 presents the heuristic algorithm. The rate increment per D2D bandwidth, known as the spectrum efficiency value of a D2D relay location [7] measures the optimal D2D relay location suitability for optimizing the network performance in terms of reliability, speed, and energy efficiency. As a result, we express the optimal D2D relay location's efficiency value, $\Theta(x)$ as:

$$\Theta(x) = \frac{Q(x).R_{xk}}{R_{kb}} = \frac{Q(x).log_2\left(1+\gamma_{xk}\right)}{log_2\left(1+\gamma_{kb}\right)} \quad (27)$$

where the D2D bandwidth, $\mathcal{B}(x)$ is defined from (27) as:

---

[3] 0-1 integer programming, alternatively referred to as binary programming, is an optimization method that involves the use of integer variables constrained to the values of 0 or 1, aiming to optimize the objective function while adhering to the set of constraints [34].

$$\mathrm{B}(x) = \frac{\log_2(1+\gamma_{kb})}{\log_2(1+\gamma_{xk})} \tag{28}$$

$\mathcal{B}(x)$ is obtained through the theorem, $R_{xkb} = min(R_{xk}, R_{kb})$ as $R_{xk} = R_{kb}$ to avoid bandwidth wastage. Several factors, including signal strength, interference, distance, bandwidth, and power consumption, can be used to calculate the efficiency value of a D2D relay location. As a result, for two communicating devices, the stronger the signal, the lower the interference, the shorter the distance, the higher the bandwidth, and the lower the power consumption will always result in a higher efficiency value. Algorithm 3 presents the system algorithm of the interference-aware and coverage analysis scheme for 5G NB-IoT D2D relaying strategy for CeNUE QoS improvement.

ALGORITHM 2
HEURISTIC-BASED D2D RELAY COVERAGE ALGORITHM

Algorithm 2: *Optimal D2D Relay Coverage Algorithm*

```
Initialize: Set $\rho_1 = 0$ and $\rho_2 = R_{max}$
For y = 1: $\mathcal{S}^2$
    Compute equation (26)
    If $R_{xkb} < R_{min}$
        $\mathbb{Q}(x) = \rho_1$
        Break
    End if
    If $R_{xkb} \geq R_{min}$
        $\mathbb{Q}(x) = \rho_2$
        Continue
    End if
    Compute equation (27)
End For
```

ALGORITHM 3

Algorithm 3: *Interference-Aware and Coverage Analysis for 5G NB-IoT D2D relaying Strategy for Cell-edge NUE QoS Improvement.*

```
Initialize: $x, \mathcal{N}, \mathcal{Z}, \mathcal{R}, P_{max}, I_m$
for $a = 1: x$
    for $i = 1: \mathcal{Z}$  $\forall z \epsilon \mathcal{Z}$ do
        Calculate $P_{c-opt}^{z}$ $\forall z \epsilon \mathcal{Z}$ using eqtn (13)
    end
    for $b = 1: \mathcal{R}$ $\forall r \epsilon \mathcal{R}$ do
        Compute $\eta_{xk}$ and $\eta_{kb}$ $\forall r \epsilon \mathcal{R}$ using eqtn (9)
        Determine the optimal D2D relay using Max-SINR schemes in subsection C.
        solve the power allocation problem in (18) using algorithm 1.
End
    Compute the interference Threshold in (14b)
    Calculate $\mathcal{R}_{xkb}$ using eqtn (4)
    If $P_x^{opt} g_{xc} \geq I_t$ and $\mathcal{R}_{xkb} \leq \mathcal{R}_{min}$
        $\mathcal{R}_{xkb} = 0$
    End if
Compute the optimal D2D relay Coverage problem and efficiency value using Algorithm 2
End.
```

The proposed algorithm complexity is written in big O notation. The algorithm has three steps. The first step computes the channel-to-interference-plus-noise ratio (CINR) for the cell-edge NUE x iterations, which selects the optimal D2D relay, and the complexity is $O|x\mathcal{Z}|$. The optimal transmit power of the cellular NUEs, P_{c-opt}^{z} as well as the cell-edge NUE x to the relays, $\mathcal{R}$ is determined in the second step. Although, the power computation's complexity cannot be directly expressed due to first and second-order partial differentiation. As a result, the Newton-Raphson method iteration times are denoted as $O|x\mathcal{Z}\mathcal{R}|$ and the sum-rate complexity is $O|x\mathcal{R}|$. The last step determines the optimal D2D relay coverage and the efficiency value with a complexity of $O|2\mathcal{Z}\mathcal{R}|$. The overall complexity can be expressed as $O|x\mathcal{Z} + x\mathcal{Z}\mathcal{R} + x\mathcal{R} + 2\mathcal{Z}\mathcal{R}|$.

V. PERFORMANCE ANALYSIS

The proposed algorithm performance is evaluated within MATLAB environments using extensive simulations. MATLAB enables efficient implementation of models and facilitates data manipulations and analysis, which provide robust capabilities for performance analysis. In this section, we present the numerical results of the simulations. As shown in Fig.1, we consider a HetNets of macro cell with a radius of 500m and NBS with a radius of 100m. MUEs and NUEs (including idle NUEs) are distributed randomly within the MBS and NBS with densities $\lambda_m = 250$ users and $\lambda_a = 60$ users, respectively. The CeNUE is randomly placed at a distance slightly greater than 150m. The NBS is an NB-IoT stand-alone solution for emerging IoT devices in a HetNet where the MeNB and NBSs share resources, resulting in co-channel interference that affects signal reception at the cell edge. To improve the network data rate, and guarantees cellular NUEs' QoS under interference power constraints, a D2D relaying strategy is employed to relay between the CeNUE and the NBS. Table 1 summarizes the parameters of the simulation.

TABLE 1. Simulation Parameters Used

Parameter	Value
Frequency	2GHz
Bandwidth	180kHz
MeNB and NBS Cell Radius	500m and 100m
Active NUE, $\mathcal{Z}$,	30
Idle NUEs, R	30
Number of Active MUEs, $\mathcal{N}$	250
Minimum Throughput, $\mathcal{R}_{min}$	1
Noise Power, σ^2	-112
NUE Antenna Gain	5dBi
Distance between MeNB and NBS	350m
Max. NUE Transmit Power	20dBm
Max. MUE Transmit Power	23dBm
Pathloss Model	3GPP TR. 38.901
Reference Distance	10m
Reference Power	30dB
Path loss exponent	2
Multipath fading	Rayleigh fading
Shadowing for NUE link	Log normal distr. with standard

The following relay selection schemes and the D2D communication scheme from [29] are employed to validate the proposed algorithm's performance. Since there is no well-known systematic performance study for D2D relay, the relay schemes are modified and adapted to our proposed algorithm. As a result, we present the performance of D2D relay coverage in terms of spectrum efficiency value and rate increase per D2D relay bandwidth.

1. *Harmonic Mean Selection*

The relay with the highest harmonic mean is $\left(|h_i|^{-2} + |g_j|^{-2}\right)$. As a result, we modify the selection function and assume that all the nodes within the NBS have equal transmit power (i.e., $P_\kappa = P_\varkappa = P$) as follows[4] [33]:

$$k = argmax\left\{P\left(\frac{\eta_{xk_i} + \eta_{kb_i}}{\eta_{xk_i} * \eta_{kb_i}}\right)\right\},\ \mathrm{i} \in R \quad (29)$$

2. *Best Worse channel Approach*

The best worse relay channel is given as [33]: $\min\left(|h_i|^2, |g_j|^2\right)$. We adapt the selection function as[4]:

$$k = \max\left\{\min\left(P_{x_i}\eta_{xk_i}, P_k\eta_{kb_i}\right)\right\},\ \mathrm{i} \in R \qquad (30)$$

3. *Half-duplex Relay Selection Scheme*

Half-duplex (HD) relaying is widely used as a performance benchmark for all relaying schemes because it eliminates self-interference and uses half the resources of Full Duplex transmission mode. As a result, there is no interference within the NBS, except for the co-channel interference from the MeNB due to resource sharing. The goal is to maximize cell edge NUE throughput while satisfying MeNB's reuse interference constraint. The modified relay selection function is as follows:

$$k_i = \min\left(P_{x_i}^{opt}\eta_{xk_i{}^*} + P_k\eta_{kb_i{}^*}\right),\ \mathrm{i} \in R \quad (31)$$

$$k^* = \max\left(k_i\right),\ \mathrm{i} \in R$$

$$where \quad \eta_{xk^*} = \frac{g_{x,k}}{I_m + \sigma^2} \text{ and } \eta_{kb^*} = \frac{g_{k,b}}{I_m + \sigma^2}$$

The line of sight (LOS) and non-line of sight (NLOS) signal reception of cellular NUEs with the NBS for distances greater than 10m using 3GPP TR. 38.901 version Urban Microcell (UMi) is depicted in Fig 2. We use shadowing to plot the channel gain g versus distance d to understand the signal variation within the NBS. The typical LOS and NLOS signal reception value is between -70 and 110dB [42].

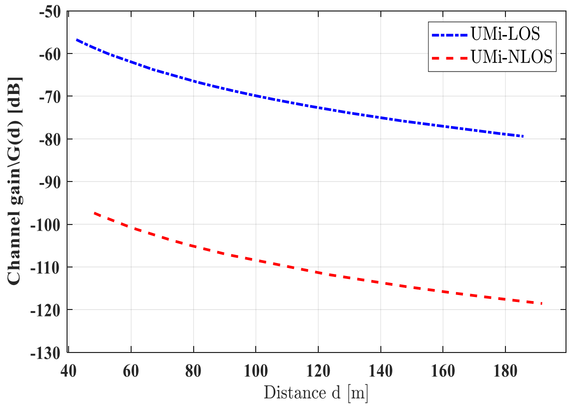

Fig. 2. Channel gain Vs Distance

We employ the following metrics: the cumulative distribution function (CDF), efficiency value, rate increment per D2D bandwidth and the data rate to measure the proposed algorithm's effectiveness. Fig. 3 depicts the achievable data rate CDF of our proposed algorithm (max-SINR scheme) alongside four (4) other techniques, including the D2D communication scheme. The proposed algorithm outperforms the other three (3) relay schemes (i.e., best-worst, harmonic, and the half-duplex scheme), except for the D2D communication scheme. Compared to the 19.45% harmonic scheme and the 17.26% half-duplex scheme, the proposed algorithm improves the CeNUE achievable data rate by 27.51%. On the other hand, D2D communication outperforms the proposed technique by 23%. Furthermore, at a zero-data rate, the half-duplex and the harmonic scheme lost 40% of the data rate to interference against the 20% data rate lost in the proposed technique. The CDF plots in Fig. 3 have proven the efficacy of our proposed algorithm.

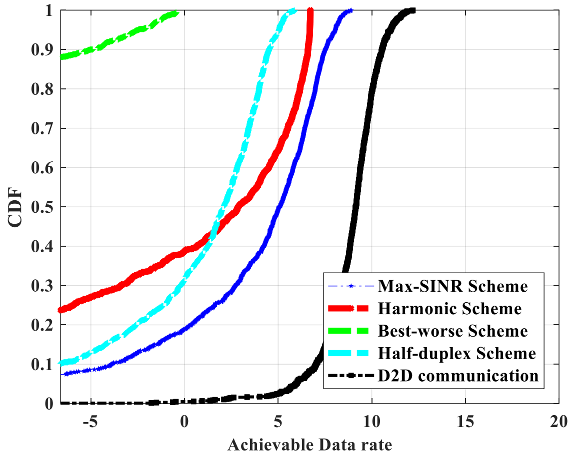

Fig. 3. The CDF of Cell-edge NUE’s data rate with four other schemes including the D2D communications

The SINR's CDF of the proposed algorithm and four other schemes, including the D2D-enabled communication, are shown in Fig. 4. The proposed algorithm outperforms the Best-worst and Harmonic schemes by 81.27% and 40.29%, respectively, but achieves 21.27% SINR value that is approximately equal to the 21.23% SINR value of the half-duplex technique. However, the D2D communication scheme outperforms the proposed algorithm. The relay schemes' poor performance could be a lack of interference knowledge since their operations are limited to interference-free isolated networks. However, the system SINR improved as the implemented interference power constraint decouples the signal from the induced interference.

Fig. 5 illustrates the plot of the four (4) D2D relay schemes' data rates and that of the D2D communication scheme against the SINR. On the indication point, the proposed algorithm outperforms the harmonic, best-worst, half-duplex, and D2D communication schemes. However, as observed in the open

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[4] Note that η_{xk} and η_{kb} are the CINRs from (9) and Rt is the decoding set of the relay.

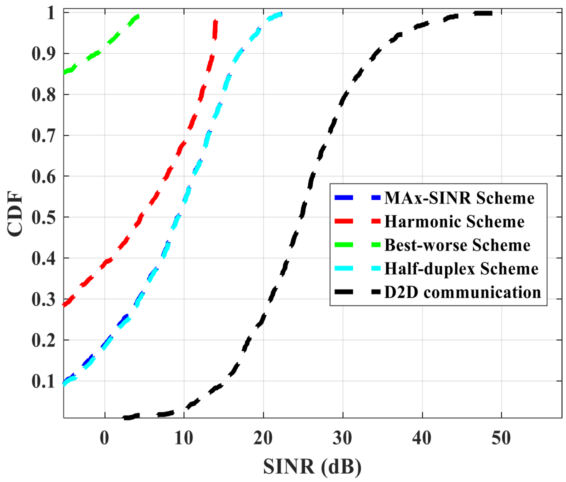


Fig.4. The SINR's CDF of the proposed algorithm and the four (4) other schemes including the D2D communications.

window of the indication point, both the proposed algorithm, the harmonic technique, and the D2D communication scheme have approximately equal performance and outperform the half-duplex performance. The plot indicates a corresponding increase in the achievable data rate as the SINR values of all the techniques increase.

The D2D relay's data rate against the number of relays for the four schemes and the D2D communication scheme is in Fig. 6. As the number of relays increases, the data rate also increases. The proposed algorithm (max-SINR technique) outperforms the other three approaches (i.e., harmonic, half-duplex, and the best-worse scheme), except for the D2D communication scheme. The D2D communication achieved 41.40% high performance than the proposed algorithm, while the proposed algorithm achieved 14.10% and 47.19% higher performance than the half-duplex and harmonic techniques. The efficient performance of the D2D pair could be the high channel gain between the two D2D communicating sets, as opposed to the D2D relaying scheme, where signals may be delayed or dropped depending on the condition of the relay device. Again, in two-hop communication, the first hop is always the bottleneck. As a result, the difference between the first-hop channel gain and the second-hop channel gain will always influence the system's data rate.

Fig. 7 (a and b) shows the achievable data rate versus the interference threshold and interference power of all the schemes, including the proposed scheme. In Fig. 7 (a), the D2D communication scheme outperforms the proposed scheme by 20.46%, whereas the proposed scheme outperforms the harmonic scheme by 22.27% as the interference threshold is applied. However, as the interference threshold increases, the data rate of the D2D relay link and D2D pair link increases steadily, except for the best-worst relaying scheme, which degrades and submerges. It implies that as the network dynamics changed, the CeNUE could still find a D2D relay with a high SINR value, which leads to full diversity benefit and also increases the D2D relay data rate. In Fig. 7 (b), as the data rate rises, so does the interference power. The best-worst scheme transmits with more interference power than the other deployed schemes due to poor channel quality and the desire to achieve a data rate higher than the minimum data rate. It is the reason why the best-worst approach lost most of its signal to interference when the interference threshold was applied. The proposed scheme, the harmonic scheme, and the D2D communication scheme adjust their transmit powers as the SINR changes to achieve a data rate higher than the minimum data rate while meeting the NUE SINR requirements.

Fig. 8 (a and b) shows the plot of SINR versus the interference threshold and interference power for all the schemes, including the D2D communication scheme. In Fig. 8 (a), the D2D communication scheme outperforms the proposed algorithm by 32.86%, whereas the proposed algorithm outperforms the harmonic by 30.67%, and the best-worst technique retrogresses with the applied interference threshold.

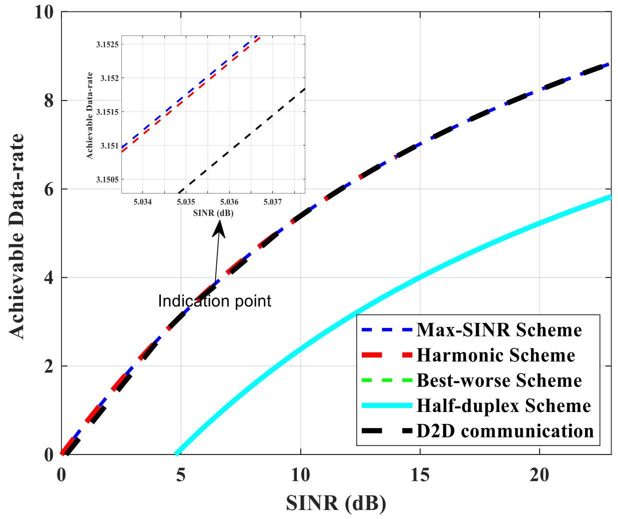


Fig. 5. The achievable data rate versus SINR for the proposed algorithm and the four other schemes, including the D2D communication scheme.

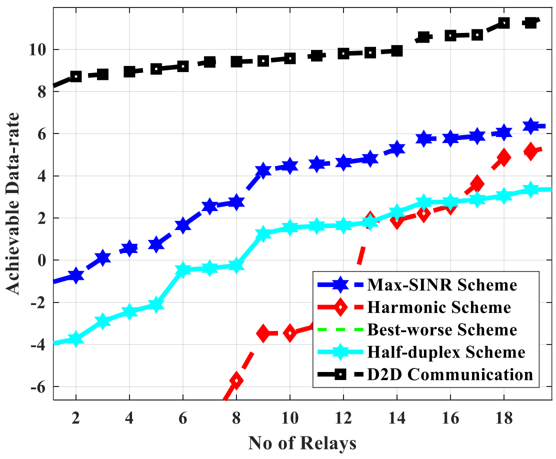
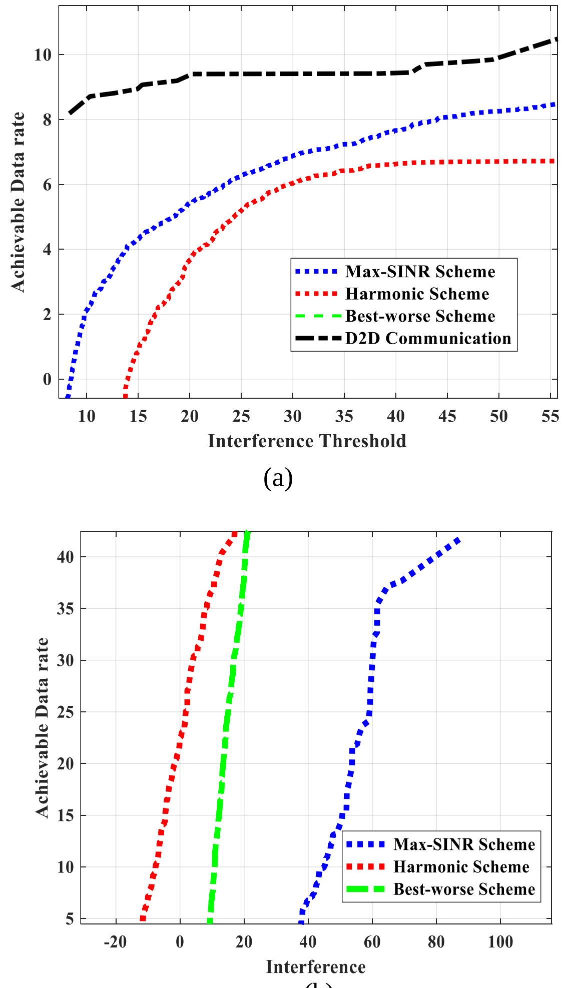


Fig. 6. Achievable data rate versus the number of relays.

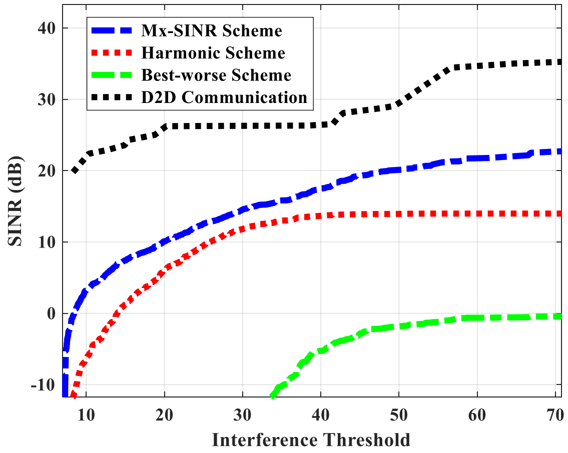
The D2D relay and D2D pair link SINR values increase as the interference threshold rises, except for the best-worst scheme, which regresses as the network dynamics change. The D2D



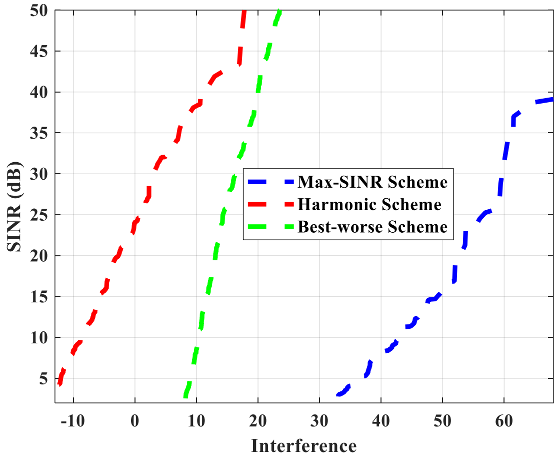
(a)

(b)

Fig. 7. The Achievable Data rate against the (a) Interference Threshold and (b) the interference Power.



(a)



(b)

Fig. 8. The SINR versus (a) Interference Threshold and (b) Interference Power.

data rate increases for every SINR improvement within the NBS. In Fig. 8 (b), as the network's SINR rises, the interference power within the NBS also increases, reducing the SINR of individual NUEs and limiting network performance. The poor performance of the Best-worst scheme is related to inadequate transmit power to transmit the signal to meet the D2D relay link's minimum data-rate requirement, even when the channel gain has a small positive value and doesn't translate to suitable performance. A high positive channel gain corresponds to system performance in D2D relay networks. As a result, most of the signals corrupted by the interference for the best-worst technique were unrecovered due to the high probability of decoding error.

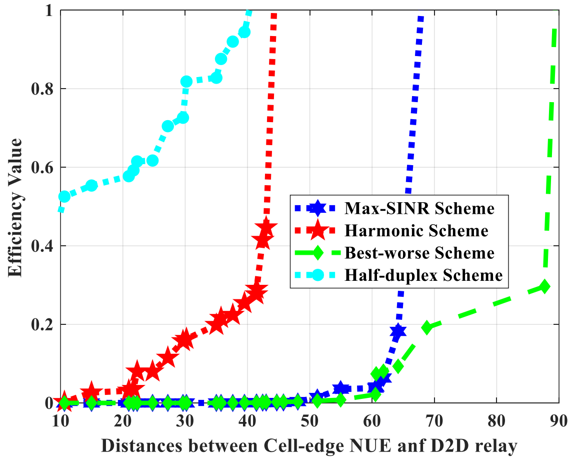


Fig. 9. The Efficiency value against Distances between the cell-edge NUE and the Optimal D2D relay node.

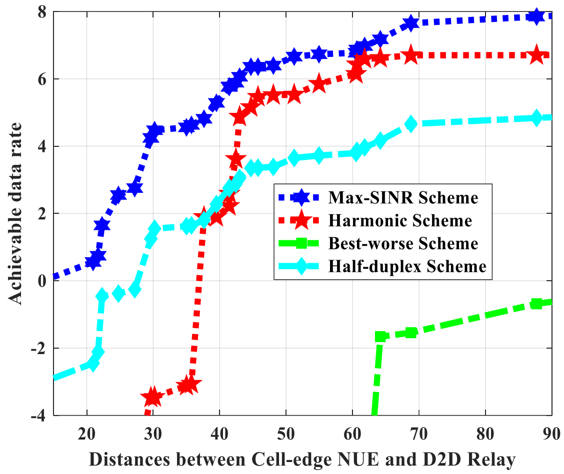


Fig. 10. Achievable data rate against Distances between Cell-edge NUE and the Optimal D2D relay node.

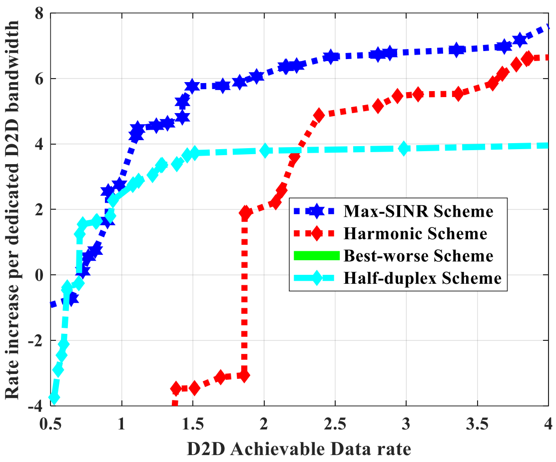


Fig. 11. Rate increase per dedicated D2D bandwidth against the D2D data rate.

Fig. 9 depicts the plot of the efficiency value versus the distances between the CeNUE and the optimal D2D relay node. As shown in the Figure, the proposed scheme outperforms the other relay selection schemes (harmonic and half-duplex) due to its ability to mitigate the interference power within the network as the signal travels between the CeNUE and the optimal D2D relay node. Generally, the efficiency value decreases as the distance between two devices increases because signals are subjected to attenuation (interference) as they travel through the air medium, lowering the SINR and decreasing the data rate. However, the best-worst scheme achieves high performance as the distance between the CeNUE and the D2D relay increases. The reason for this performance could be an improvement in second-hop transmission, as the first hop is always the scheme's performance bottleneck.

Figure 10 shows the plot of the achievable data rate versus the distance between the CeNUE and the D2D relay node. The proposed scheme outperforms the other relay selection schemes owing to the applied interference threshold and its ability to limit harmful interference power within the network. The proposed approach achieves 4.59% and 10.23%, high performance than the Harmonic and Half-duplex schemes. The initial Best-worst scheme performance in the first hop is greatly affected by the interference level but later improves as the interference threshold is applied.

Fig. 11 plots the rate increase per dedicated D2D bandwidth by the D2D relay transmission over the cellular communication against the data rate. The D2D data rate increases as the rate per dedicated D2D bandwidth rises, which improves system performance. The proposed scheme outperforms the Harmonic and Half-duplex by 0.06% and 19.08%. As a result, the service reliability of the network leads to a better user experience and higher customer satisfaction.

IV. CONCLUSION

This paper studied an interference-limited 5G NB-IoT D2D relaying strategy in HetNet and proposed an interference-aware and coverage analysis scheme. We design a three-part optimization problem: first, we use the Max-SINR approach to select an optimal D2D relay with the highest CINR under peak interference constraint. Second, we employ the Lagrangian-dual method to optimize the transmit power of the CeNUE and fix the relay transmit power to ensure the CeNUE's service life. Lastly, we formulate and transform an optimal D2D relay coverage problem that maximizes the system uplink data rate into a 0-1 integer problem and use a heuristic algorithm to obtain the system performance. The simulation results confirmed that the proposed approach outperforms the other relay selection schemes except for the D2D communication scheme in efficiency, data rate, SINR, and interference minimization.

Appendix

- Proof of concavity

Given the P2 first-order derivative with regards to P_x, we have (16), which satisfies the constraints 14(a) - 14d (i.e., the constraints are convex sets) respectively. The Hessian matrix of P2 can be expressed in diagonal matrix as:

$$\nabla\theta = \begin{bmatrix} \partial_{xk_1} & & & \\ & \partial_{xk_2} & & \\ & & \ddots & \\ & & \ddots & \partial_{xk_i} \end{bmatrix} \forall r \in R \quad (32)$$

$$\text{where } \partial_{xk_i} = \frac{1}{\ln 2}\frac{-1}{\left(P_{x_i} + \left(\frac{\sigma^2 + I_{t_i}}{g_{c,k}}\right)\right)^2}, \forall i \in R$$

We express the total co-channel interference I_t, on each D2D relay channel as a constant. The $\nabla\theta$ shown in (32) is a diagonal and negative semi-definite matrix due to its first-order minor. However, given the second-order conditions [32], we concluded that P2 has a concave function.

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