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Clustering technique for dense D2D communication in RIS-aided multicell cellular network

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ABSTRACT

Device-to-device (D2D) communication and reconfigurable intelligent surface (RIS) are well-known as two promising technologies for next-generation cellular communication networks. D2D users operate on the same spectrum as traditional cellular users, potentially leading to increased interference and reduced efficiency in frequency resource usage. RIS provides a remedy for clearing blocked signals from obstructions by reflecting the desired signals to the intended receiver. However, RIS elements reflect not only the desired signals but also the interference signals. This paper proposes a distance-based clustering method aimed at creating a grouping algorithm for neighboring D2D users using different channels, thereby reducing co-channel interference. The simulation indicates that the proposed clustering method for D2D users' equipment (DUEs) leads to a 0.72 dB increase in signal-to-interference-plus-noise ratio (SINR), enhances throughput to 11.25 Mbps, and reduces the bit error rate by up to 24×10^{-2} compared to the baseline system. The study findings also indicate that cellular users' equipment (CUEs) experience satisfactory signal quality, even with the presence of DUEs on the cellular network. Our clustering algorithm is feasible to deploying D2D densely in RIS-aided cellular network without significantly affecting CUE performance.

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1. INTRODUCTION

In order to meet the increasing demand for higher data rates, researchers, industry professionals, and experts across various fields have been exploring innovative concepts that could revolutionize mobile cellular communication. Device-to-device (D2D) communication has become what is identified as a preferred strategy in this regard [1]. This technology enables mobile devices to connect directly with each other, removing the need for a base station [2]. Originally intended for public safety applications, D2D communication has rapidly broadened to encompass a range of user- and network-related scenarios, including social networking and data offloading. Recently, there has been a substantial increase of interest for D2D communications in both academic and commercial sectors [3].

Device-to-device (D2D) communications enable two nearby users to communicate directly without going through the base station (BS), making it as a promising solution for maximizing the use of limited frequency spectrum. In cellular networks that support D2D communication, two operational modes are established. D2D user equipment (DUE) can communicate with each other similarly to how cellular user equipment (CUE) interacts with the base station. Additionally, DUEs can communicate directly while remaining controlled by the BS [4]. Therefore, D2D could mitigate transmission delays, alleviate traffic congestion in cellular networks, lower end-to-end latency, and improving the spectral efficiency [5], [6].

D2D communications can reuse the frequency resources assigned to CUEs, enabling more efficient spectral usage and improving network spectral efficiency [6]. DUEs can access this spectrum either through a dedicated approach i.e., overlay or a shared approach i.e., underlay, with D2D interactions occurring within the spectrum allocated to cellular operators. A major challenge with in-band underlay is managing co-channel interference, which arises from simultaneous transmissions in both cellular networks and D2D communications. When D2D devices operate on the same cellular spectrum at the same time, it can lead to significant multiuser interference, destructively impacting both D2D and cellular networks due to intercell interference (ICI) [2], [7]. Additionally, D2D can also use an in-band overlay, which divides the cellular spectrum between D2D and cellular users, resulting in less efficient channel usage [7].

On the other hand, among the emerging technologies currently under research, reconfigurable intelligent surfaces (RISs) are becoming a promising solution for creating intelligent and adaptable wireless channel propagation environments. An RIS generally consists of a flat surface covered with many passive reflecting elements, each of which can independently modify the amplitude and/or phase of incoming signals [8]. These surfaces can be programmed to customize the properties of the electromagnetic field. Each RIS unit consists of reflective arrays that utilize varactor diodes or similar technologies to manage the resonant frequency [9]. Figure 1 depicts a typical RIS use case. When a user tries to receive a direct signal from an evolved NodeB (ENodeB) serving as a base station but encounters obstacles, the RIS can offer supplementary signals. This allows the user to receive two constructive signals: one directly from the ENodeB and another from the signal reflected by the RIS.

RIS provides several benefits compared to traditional relays, including lower energy consumption, reduced costs, and the potential for higher data rates [10], [11]. This is achieved because printed metamaterials eliminate the need for amplifiers, relying only on power dissipation within the reconfigurable hardware. However, a limitation of RIS is its restricted signal range due to the lack of amplification [12]. Additionally, RIS is easy to install and can be made from environmentally friendly materials. Its low cost allows it to be deployed on various structures, such as indoor walls, roadside billboards, aerial platforms, and highway poles [13].

By applying RIS to a D2D-communication in wireless network, it can improve signal quality to receivers. However, with the addition of RIS and DUEs in which are dispersed across multi-cell cellular networks, interference becomes an issue and more complicated, especially during downlink transmission of cellular networks (when ENodeB as transmitter provides signal power to CUE as the receiver). The ENodeB and other DUEs transmitters will cause quite slight interferences for DUEs and CUEs. Using in-band underlay presents a challenge because of interferences between DUEs and CUEs. As the RIS element reflects the desired signal while also providing interference signals from other transmitters, its presence can lead to a reduction in signal power. To overcome these issues, an appropriate clustering technique is required, particularly when applied to DUEs in order to reduce co-channel interferences. There are several well-known clustering techniques, including the *k*-means clustering [14] and Poisson cluster process [15] and, which can be improved with certain optimization methods [16] to produce more accurate data grouping outcomes. Thus, the clustering used in this research can be applied effectively and is appropriate for D2D-based cellular network scenarios.

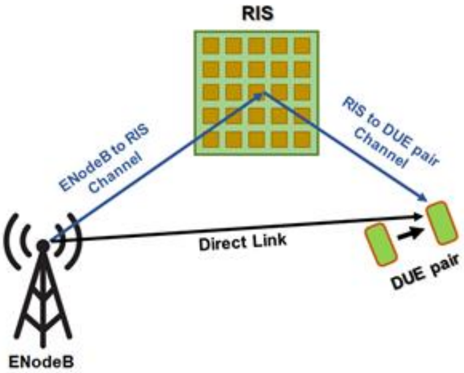

Figure 1. The implementation of RIS on cellular network

Tang *et al.* [15] suggests the schemes of power allocation for performance optimizations with the Poisson clustered in out band D2D network using the joint coverage probability for distributing the transmit power to DUEs in both the target cluster and the entire network. The simulation findings prove that, as compared to traditional LTE open loop and fixed power schemes, the suggested method approaches maximized combined coverage probability and power usage. Yang *et al.* [17] proposes user clustering method for D2D users by choosing a cluster head (CH) that may fulfill content requests (CR) as a D2D receiver for energy efficiency. The CH selection algorithm uses social maximum weight (SMW) in selecting CHs from the initial users. The user chosen as a CH must first be considered and have a high-quality link between its own and the BS, so that the BS can efficiently provide the desired content and serve as many CRs as possible via the D2D link at the lowest possible cost. Aslam *et al.* [18] evolves a machine learning (ML) strategy for categorizing users into clusters that could communicate via user D2D clustering or receive services directly from the ENodeB. Certain information from users, such as position or distance and channel conditions, are required to create a cluster and can be collected during the D2D discovery process, which occurs prior to communication. The findings demonstrate that introducing user segregation could result in significant gains in throughput, energy usage, and fairness.

Solaiman *et al.* [19] initiates the integration of D2D communications in a mmWave-based downlink MIMO-NOMA (multiple input multiple output- non-orthogonal multiple access) cellular network, which has been divided into three subproblems, these are user clustering, beamforming design, and power allocation. CUEs are organized into clusters, and MIMO-NOMA beamforming signals are transmitted to them. Furthermore, D2D pair clusters are assigned to CUE clusters, allowing D2D pairs to reuse mmWave resource blocks previously occupied by CUEs in a particular cluster. The idea for the integration can strengthen the network's spectral and energy efficiency while also ensuring QoS for both CUEs and D2D pairs and providing interference guarding in the radius of coverage. Lyu *et al.* [20] explored two scenarios in this network, which are single D2D pairs and multiple D2D pairs. In the single D2D pair scenario, only one D2D pair is present per cell, which reduces the redundant rate in the coding scheme. Compared to the multiple D2D pairs scenario, the proposed scheme increases the number of D2D pairs per group of clusters, maximizing spatial throughput and providing a higher maximum spatial throughput. For both scenarios, the scheme calculated various outage probabilities for CUE and DUE, along with network's spatial throughput.

Buzzi *et al.* [21] offers an algorithm for estimating the mobile user-to-RIS and RIS-to-BS channel components independently. The SNR of a single-user system is enhanced by adjusting the base station's (BS) beamformer and RIS phase shifts. In a multi-user, two-cell system, gradient algorithms and alternating maximization methods are used to optimize downlink signal-to-interference-plus-noise ratio (SINR) in connection with BS transmit powers and RIS phase configurations. In this case, the RIS is located at the cell edge, allowing some users to be served jointly by two BSs, hence improving performance. The numerical results indicate the use of RIS and the proposed optimization procedures significantly improve system performance. Yang *et al.* [22] searches toward a RIS-enabled underlaying D2D communication network. The study proposes a problem to maximize the network's spectral efficiency for DUEs and CUEs. This is accomplished by optimizing the resource reuse indicators, transmit power, and the RIS's passive beamforming simultaneously, while keeping the SINR to DUEs and CUEs constraints in thoughts. Numerical results reveal that the proposed design outperforms traditional systems without RIS in terms of both spectral and energy efficiency. Furthermore, the design results in only a minor performance degradation when compared to the best-achievable results under ideal user pairing. Kumar *et al.* [23] proposes NOMA-based multi-receive diversity network (MRDN) model appears at outage and throughput performance on Rician fading channels. To ensure practical applicability, the impact of imperfect successive interference cancellation (SIC) is explored, as it plays a substantial part in NOMA systems. The model investigates both the primary non-line-of-sight (NLoS) and line-of-sight (LoS) conditions for the proposed MRDN. To improve the user experience, the network includes multiple RISs. The number of RIS elements has a significant impact on the MRDN's performance.

As a result, this paper proposes a clustering technique that groups DUEs based on the distance and frequency channels based on their proximity, aiming to minimize interference between DUEs and CUEs that operate on the same frequency channel. We apply underlay D2D by considering the frequency channel efficiency which is better than overlay D2D. RIS technology is placed at the edge of a microcellular model based on a two-ray model to increase the signal power from reflecting signal towards the desired users. This paper discusses a comparison between the proposed clustering technique and a baseline system to improve signal quality by analyzing performance parameters i.e., SINR, throughput, spectral efficiency, network energy and bit error rate (BER) in multicellular network with RIS-aided. Our clustering technique is widening the D2D using co-channels such that it is reducing the interferences among D2D communications. The findings in this paper contribute to extend an application of RIS-aided wireless cellular networks with dense D2D communications enabled. Moreover, the proposed clustering technique facilitates to mitigate the occurrence of complex interferences in the considered RIS-aided D2D wireless cellular networks in which substantially extending the knowledge in the fields.

This paper is organized as follow. Following this introduction section, Section 2 of methodology discuss the proposed clustering technique, system model, performance parameters, and assumptions. Section 3 presents research results and its analysis. Section 4 of conclusion gives the remarks of research finding.

2. METHOD

This paper considers three cells of a microcellular network. An RIS is deployed in this network i.e., RIS-aided cellular network. To evaluate the suggested clustering approach, it is crucial to look into the interferences caused by DUE in this designed RIS-aided multicell microcellular network. This section addresses the case under consideration, the suggested clustering technique, models, assumptions and performance analysis.

2.1. System models for baseline system and system with proposed clustering technique

The first step in analyzing the impact of interferences between conventional cellular system and D2D system is to take a consideration of microcellular network with three microcells that have a random deployment of DUEs and CUEs within each microcell. The deployment of DUEs and CUEs follow a uniform probability distribution function. Frequency reuse factor (FRF) for these microcells is one. The RIS is implemented at the periphery of three microcells. The frequency channel division between DUE and CUE is illustrated in Figure 2. The DUE and CUE use the same frequency channel with a total bandwidth of B Hz, with DUEs utilizing 75 percent of the overall bandwidth. Its goal is to protect several CUEs from interferences caused by the presence of DUEs.

Figure 3 depicts the setting of an RIS-aided multicellular cellular network consisting of three microcells with DUEs and CUEs deployment in each area of the microcell. Sharing frequency channels among DUEs and CUEs has the advantage of improving the spectrum efficiency in which the entire system uses the total of available channel bandwidth. The channel assignment for this setting is based on the order of DUE appearances (D2D pair). It should be noted that using the same channel while sharing it with these two distinct user types result in co-channel interferences. The DUEs face a reduction in signal quality because of the presence of other DUEs assigned to the same channel and situated near the observed DUE, as no interference management strategy is applied in this scenario. Consequently, a solution is required to mitigate co-channel interference. The network scenario depicted in Figure 3 is utilized for the simulation experiments in this paper and is referred to as the baseline system. It should be noted that the first scenario is aimed to explore the interferences occurring in the RIS-aided cellular communication system when D2D are present.

In the network system under consideration, a clustering technique is employed to minimize the interference experienced by DUEs, particularly interference from other DUEs. This approach groups three DUE pairs using different frequency channels and is applied to optimize the allocation of DUE channels. DUEs are kept apart from each other using this proposed technique to keep each other allocated on the same frequencies. By applying the clustering technique, the distance between DUEs using the same channel is increased, as shown in Figure 4, which helps reduce co-channel interference (interference caused by sharing the same channel). As a result, the clustering method emphasizes increasing the distance between the separated DUEs to minimize co-channel interference. Figure 5 illustrates how the proposed clustering technique is implemented in the simulation scenario.

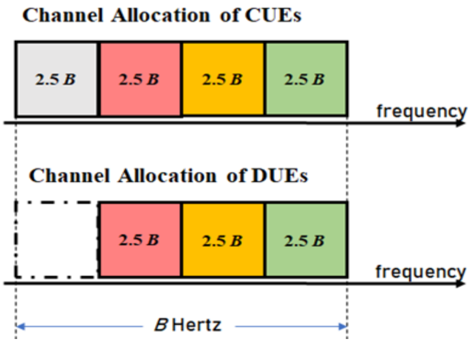

Figure 2. Channels allocation of CUEs and DUEs

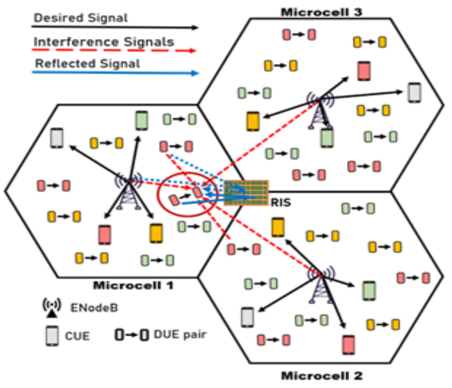

Figure 3. Conventional cellular network scenario

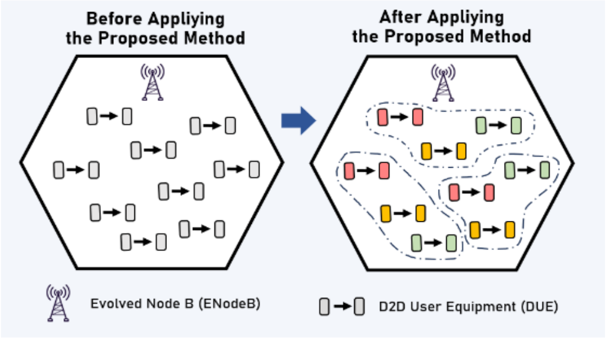

Figure 4. The proposed clustering method

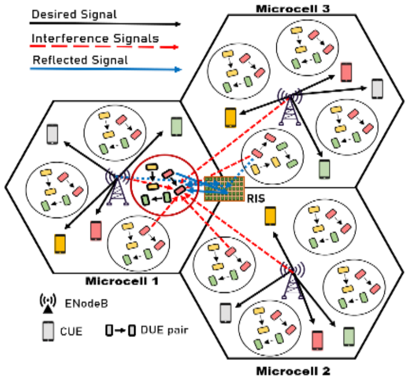

Figure 5. The proposed clustering method

The clustering process starts by selecting a reference DUE pair from the available DUE pairs within a microcell area to form a cluster. The distance between this reference pair and the surrounding DUE pairs is then calculated. Using these distances, the reference DUE pair determines its cluster members. The two nearest DUE pairs are selected as cluster members, as this study employs a frequency reuse factor (FRF) of 3 for D2D communications. Consequently, each cluster consists of three DUE pairs. Once a cluster is formed, the reference DUE pair chooses the next DUE pair to act as the new reference. This new reference is selected from the third closest DUE pair to the previous reference. The clustering process then repeats with the new reference until all DUE pairs within the microcell have been assigned to clusters. DUE pairs that have been included in a cluster are removed from the list of pairs eligible for clustering. Figure 6 presents the flowchart illustrating the cluster formation process.

2.2. Channel models and assumptions

The network models illustrated in Figures 1 and 3 are expected to include two transmission paths: a direct line of sight (LOS) path and a non-line of sight (NLOS) path. This paper applies the well-known free-space path loss (FSL) channel model in dB for the LOS path, as described in (1) [24]. Conversely, obstacles cause additional loss for the NLOS path, which is accounted for in the path loss calculation for NLOS conditions, as detailed in (2) of the FSL model:

$$L_{LOS} = 20log_{10}(d) + 20log_{10}(f) - 27.45 \tag{1}$$

$$L_{NLOS} = L_{LOS} + L_{Obs} \tag{2}$$

where f represents the working frequency in megahertz (MHz), and d denotes the distance between the transmitter and receiver, in meters. L_{Obs} refers to the obstacle loss, which varies based on the type of material causing the additional loss, such as metal, concrete, and others.

This paper utilizes and examines the two-ray channel model proposed in [25] for a system with RIS. Figure 7 illustrates the two-ray channel model. The received power at the receiver in this model can be calculated using (3) [25].

$$P_r = (H+1)^2 P_t \left(\frac{\lambda}{4\pi d}\right)^2 \tag{3}$$

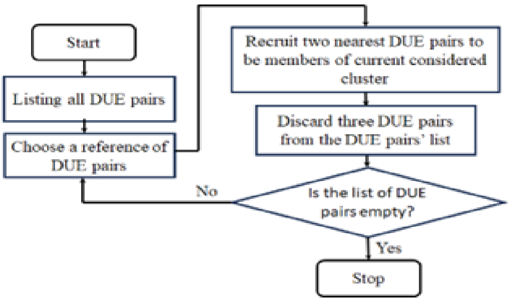

Figure 6. The flowchart of clustering algorithm

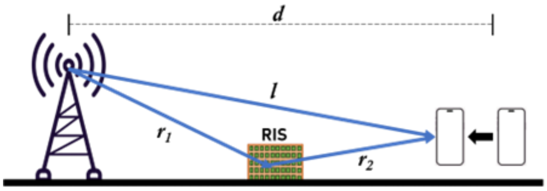

Figure 7. Two-ray propagation model as a basic propagation model for RIS as used in [25]

Here, H denotes the total number of RIS elements, while P_r and P_t represent the receiver and transmitter powers, respectively, measured in watts. λ is the wavelength of the transmitted signal in meters, and d is the distance between the transmitter and receiver, also in meters. It is important to note that, according to this model, the received power at the receiver, as described in (3), depends solely on the distance between the transmitter and receiver, as emphasized in [25].

2.3 Signal-to-interference-plus-noise-ratio (SINR) analysis

The SINR is an important performance metric for wireless systems. This paper considers downlink transmissions for the considered system models previously described in Figures 3 and 5. In order to derive the SINR, let's consider the network shown in Figure 8 which represents the presence of D2D in RIS-aided cellular network. When a DUE pair is observed, at DUE receiver there are an expected received power from its DUE transmitter pair and its RIS reflected expected power, and there are a number of interferences caused by ENodeB and another DUE that uses the same frequency channel. In addition, RIS is reflecting the interferences as well caused by other DUEs and ENodeB. Therefore, the SINR can be expressed in (4) [24].

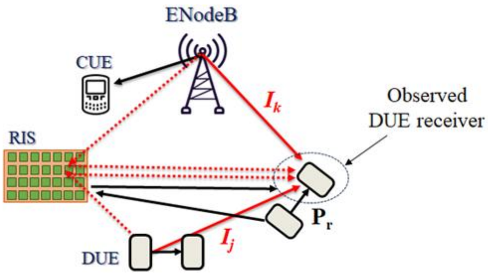

Figure 8. DUE analysis on a considered network scenario

$$\gamma = \frac{P_r}{\sum_{j=1}^{x} I_j + \sum_{k=1}^{y} I_k + P_n} \tag{4}$$

In this context, P_r denotes the received power (in mW or W) at the observed DUE receiver from the intended transmitter. The variables x and y represent the total number of interferences from other DUEs and ENodeBs, respectively. I_j indicates the interference power level from the j-th DUE sharing the same frequency, while I_k represents the interference power level from the k-th ENodeB. Moreover, P_n signifies the noise power at the observed UE.

2.4. Throughput and spectral efficiency performances

Throughput is the amount of data received over a given time period or the maximum data rate that a communication system can transmit. The Shannon-Hartley equation forms the theoretical basis for calculating throughput (T), as it relates the maximum possible transmission bit rate of a communication channel to its noise and bandwidth characteristics. Therefore, T in bits per second (bps) can be derived using (5) [26]:

$$T = B \log_2(1+\gamma) \tag{5}$$

where B represents the total system bandwidth in hertz (Hz), while γ denotes the actual measured SINR and hence T represents the system throughput. Spectral efficiency is related to the throughput in which represents the data rate per bandwidth unit. Thus, the spectral efficiency, δ, is analyzed using (6) [27].

$$\delta = \frac{T}{B} = \log_2(1+\gamma) \tag{6}$$

2.5. Network energy

According to [28], network energy consumed (NEC) by deploying D2D communications can be calculated as in (7).

$$NEC = \frac{\sum_{i=1}^{n} P\_DUE_i}{T} \tag{7}$$

where P_DUE_i is i-th DUE transmitter consumed power, T is the network throughput and n is the number of DUEs in the network. Therefore, the average network energy can be calculated as in (8) [28].

$$AVE\_NEC = \frac{NEC}{n} \tag{8}$$

2.6. Bit error rate performance

Bit error rate (BER) is a metric that evaluates the proportion of received bits with errors compared to the total number of bits transmitted to the receiver. The BER is influenced by the type and level of the modulation scheme used in the system. In this paper, the 16-QAM quadrature amplitude modulation (QAM) scheme is used for modulation scheme. As a result, the BER calculation in this paper is conducted using (9) [29],

$$BER = \frac{3}{4} Q\left(\sqrt{\frac{4}{5} E_b/N_0}\right) \tag{9}$$

where $Q(.)$ denotes the Q-function of the argument in brackets, and E_b/N_0 represents the ratio of energy per bit to noise power spectral density. E_b/N_0 acts as a normalized measure of the SINR per bit. The relationship between E_b/N_0 and E_s/N_0 (energy per symbol to noise spectral density) is demonstrated in (10) [26], where M represents the number of distinct modulation symbols.

$$\frac{E_s}{N_0} = \frac{E_b}{N_0} \log_2 (M) \tag{10}$$

2.7. Cumulative distribution function

Cumulative distribution function (CDF) represents probability of random variables X less than or equal to a constant of *x*. CDF is denoted in (11) [29]. CDF implies the probability of outage when it is related to the network performance metrics. In this paper, the performance metrics that are represented in CDF are SINR and throughput.

$$CDF(x) = Prob\ (X \leq x) \tag{11}$$

3. RESULTS AND DISCUSSION

A comprehensive simulation experiment was conducted and the results based on the performance parameters described earlier were collected and analyzed. This paper compares the SINR, throughput, BER, spectral efficiency, and network energy values with and without the proposed clustering technique, as shown in Figures 3 and 5, respectively. As mentioned earlier, the system in Figure 3 is referred to as the baseline system, while the system in Figure 5 represents the proposed method/system. All figures in this section are labeled accordingly, based on the systems in Figures 3 and 5. Additionally, CDFs are presented to illustrate the probability distribution of the simulation results. The analysis focuses on the impact of increasing CUEs and DUEs in RIS-assisted cellular networks. It is important to note that the proposed method is applied only to DUEs. Table 1 provides a summary of the simulation parameters and settings used in the network scenarios. This paper analyzes 120 DUE pairs and CUEs each to examine the interference effects caused by an increasing number of distributed users.

This section also presents the analysis results of the DUE receiver during downlink transmission in the cellular network. Figure 9 shows a comparison of the SINR values for different numbers of DUEs in the network scenario. It is evident that when the number of DUEs reaches 120, the SINR of the baseline system drops from 3.35 dB to 0.47 dB, while the proposed method decreases from 4.16 dB to 0.72 dB. Therefore, the proposed clustering technique effectively increases the signal power received by DUEs compared to the baseline system, leading to improved service quality. The clustering process, along with the allocation of different frequency channels to DUEs in separate clusters works effectively.

Furthermore, a comparison of the SINR values at CUEs' side with and without the proposed technique is also shown in Figure 9. The resulting graph indicates a decreased value as the number of CUE increases. In general, the proposed clustering technique gets lower than the baseline system. The baseline system obtains the value of 22.4 dB, which decreases to 16.99 dB, while the proposed technique achieves an initial value of 22.34 dB, and decreases to 16.35 dB. Even though the proposed technique gets a lower SINR value, the CUEs value does not experience significant degradation due to the presence of DUEs in the cellular network. It implies that by the presence of D2D communication in RS-aided cellular communication and proposed clustering technique, the network does not sacrifice the performance of CUEs which are likely having higher priority for services on the network. Our clustering technique works well in reducing the interference effects by widening the distances among co-channel D2D pairs.

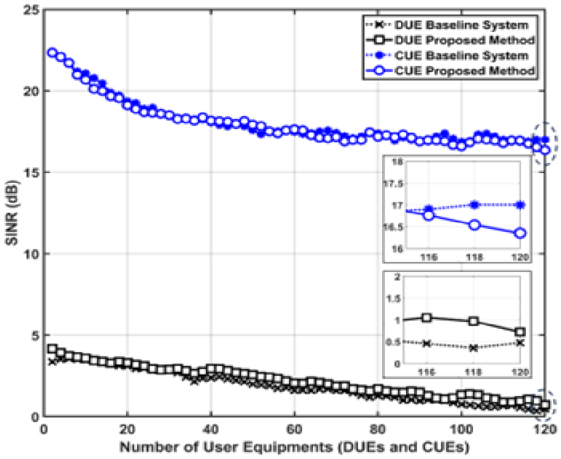

Figure 9. The SINR simulation results

Table 1. Setting of simulation parameters

No.	Parameter	Value
1	The number of microcells	3
2	Frequency reuse factor of microcells	1
3	Microcells radius [30]	500 meters
4	Base station's transmit power [30]	40 dBm
5	Transmit power of DUE [31]	23 dBm
6	DUE pair distance [32]	10 meters
7	Number of CUE (each microcell)	120 users
8	Number of DUE pairs (each microcell)	120 users
9	Element of RIS	100
10	Bandwidth system, *B*	10 MHz
11	Frequency	1,900 MHz
12	Simulation iterations	10,000

Figure 10 presents the CDF analysis of SINR results for 120 DUEs and 120 CUEs. For an SINR value of 2 dB for DUEs, the figure shows that 58.3% (or 0.583) of the SINR values for the baseline system are at or below 2 dB, while 45.8% (or 0.458) of the SINR values for the system with the proposed clustering technique fall within that range. This suggests that the proposed technique yields a better SINR distribution than the baseline system. Furthermore, the CDF of SINR for the CUEs shows that the proposed clustering method slightly outperforms the baseline system. For SINR values of 20 dB or lower, the baseline system has a CDF value of 62%, while the proposed clustering technique achieves a CDF value of 64% at the same SINR threshold.

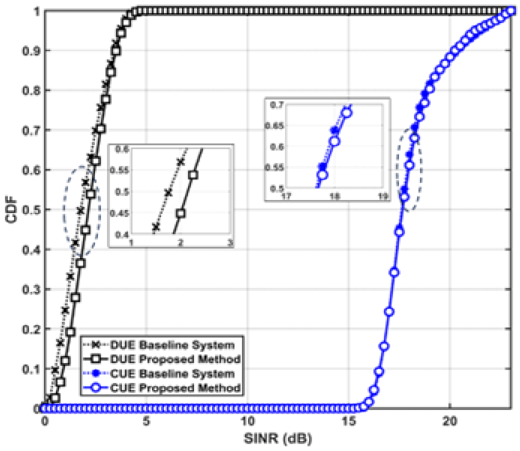

Figure 10. The CDF of SINR simulation results

Figure 11 represents simulation results of throughput comparison values for DUEs and CUEs. The simulation results obtained for the DUEs of the baseline system, as the number of DUEs increases the throughput slightly decreases from 16.63 Mbps to 10.8 Mbps and for the proposed technique as the number of DUEs increases, the throughput decreases from 18.51 dB to 11.25 Mbps. When the number of DUE pairs of 120, therefore, by applying the proposed clustering technique to DUEs, the data transmission rate (throughput) of the DUEs further increases. Regarding the analysis of CUEs, the resulting graph shows a similar trend to the SINR results for CUEs discussed earlier. When there are 120 CUEs, the system baseline achieves a throughput of 56.75 Mbps, whereas the proposed clustering technique perceives 54.65 Mbps. It means that by applying clustering technique, CUEs do not significantly experience performance degradation.

A more detailed comparison of throughput performance is shown in Figure 12, which analyzes the CDF values for throughput. In general, the system using the proposed clustering technique outperforms the baseline system for DUEs. The CDF results reveal that the baseline system achieves 48% for DUEs without the proposed technique, while the system with the proposed clustering method reaches 60% for throughput values of 14 Mbps or less. For CUEs, the CDF values for throughput at or below 60 Mbps are 65% for the baseline system and 64% for the proposed technique. Therefore, the proposed technique shows a slight improvement in data delivery compared to the baseline system.

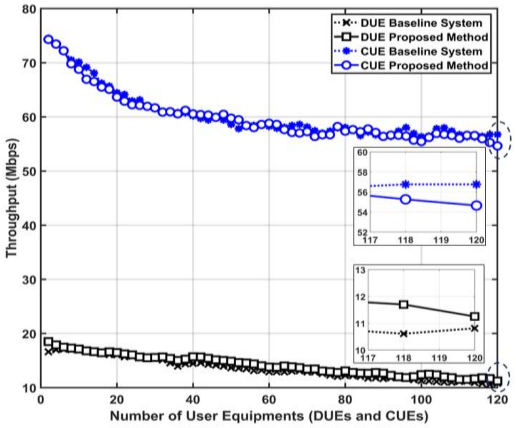

Figure 11. The throughput simulation results

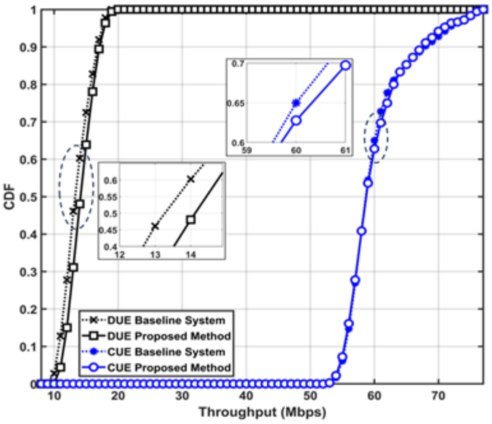

Figure 12. The CDF of throughput simulation results

Figure 13 depicts spectral efficiency simulation results to the increasing number of DUEs or CUEs. As it can be noticed that both for DUEs and CUEs, the spectral efficiency of the baseline system and proposed technique is slightly different. It confirms the results of throughput, since the spectral efficiency is related to the system throughput. Figure 14 shows the simulation results of network energy for both baseline system and the proposed technique for both D2D (DUEs) and cellular (CUEs). For DUEs, it is evident that the proposed technique uses significantly less energy compared to the baseline system. This indicates that, in the baseline system, interference is higher than in the system with the proposed technique. As a result, the baseline system experiences more transmission errors, leading to retransmissions and, consequently, higher energy consumption.

In contrast, at the CUEs side, the system with the proposed technique uses more energy than the baseline system. This can be explained by the fact that the clustering technique is applied only on the DUEs side, and does not account for the interference experienced at the CUEs side. As a result, errors are more likely to occur, leading to retransmissions and, consequently, higher energy consumption. It is interesting to also consider the interference management that considers both DUEs and CUEs sides.

Additionally, Figure 15 presents the BER comparison results for both systems as the number of users in the network increases. The final BER for the 120-th DUE in both systems is nearly the same, at 24×10^{-2}. However, a closer examination of the entire graph shows that the proposed technique consistently achieves lower BER values compared to the baseline system. This suggests that the proposed clustering technique is more effective in reducing the error rate, with a BER of 0.24, meaning 24 errors out of 100 bits transmitted. In contrast, for the CUEs, the BER comparison reveals that the proposed technique results in a higher BER than the baseline system. Specifically, the proposed clustering technique leads to a bit error rate of 12 errors out of 10,000 bits transmitted (1.2×10^{-3}), while the baseline system shows a bit error rate of 6 errors out of 10,000 bits transmitted (0.6×10^{-3}).

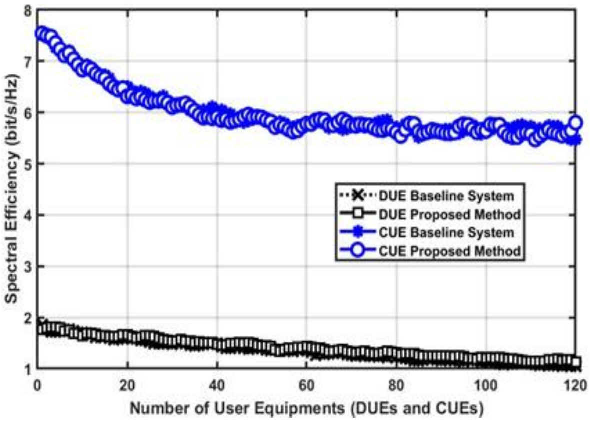

Figure 13. The spectral efficiency simulation results

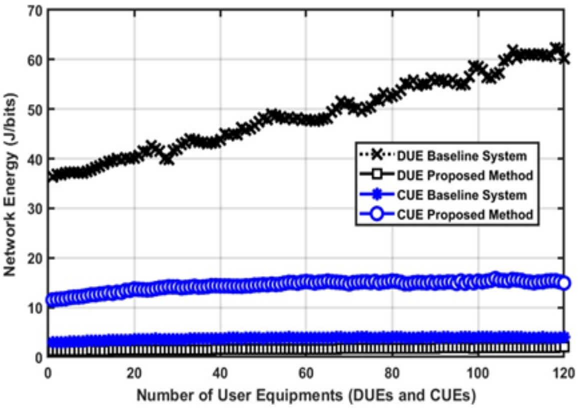

Figure 14. The network energy simulation results

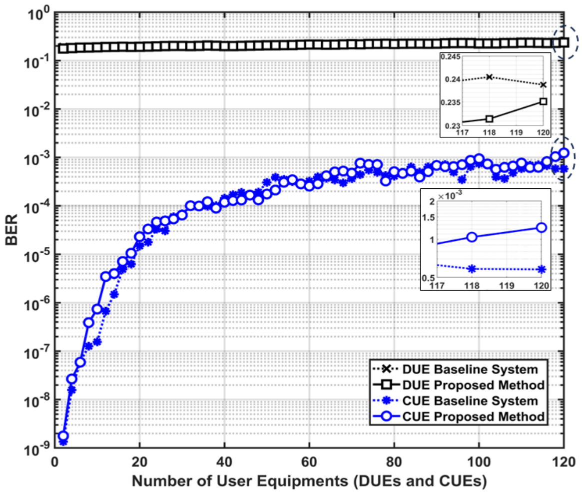

Figure 15. The BER simulation results

Table 2 compares the works in this paper to related clustering techniques of other papers that have been carried out previously by other researchers. This paper examines the powers received by DUE and CUE during downlink transmission in an RIS-aided multicellular network scenario. As a result, applying the proposed clustering technique to the network scenario can boost the SINR value by as much as 0.72 dB compared to the baseline system.

Table 2. The comparison to previous research results

Ref.	Technique/Method	Results
[14]	Users D2D clustering in multicast content sharing scenario.	The suggested strategy achieves an energy efficiency of up to 7%.
[15]	Optimizing the power allocation with the Poisson clustered in out band D2D network	Increasing spectral efficiency to 60-bit/s/Hz for DUEs reaching 80 users while increasing the number of clusters to 8 groups.
[33]	Clustering methods with Random-Based Clustering (RBC) and Channel-Gain-Based Clustering (CGBC) schemes,	The proposed method can reduce the delay to less than 20 milliseconds.
[34]	In-band communication with a Poisson cluster as a component of a cluster-centric caching strategy.	For the number of requests, the cluster-centric caching strategy increases the probability of a DUE cache hit by up to 80%.
[35]	Hybrid resource allocation for D2D communication	DUE SINR values reach 80% for SINR values below 40 dB, in single cell networks

4. CONCLUSION

The proposed distance-based clustering technique is implemented in a RIS-assisted micro-multicellular in-band underlying network to assess performance metrics by analyzing DUE receivers and CUEs during downlink transmissions. Simulation results demonstrate that the proposed technique offers better quality of service compared to the baseline. Specifically, it achieves an increase in SINR to 0.72 dB, an improvement in throughput to 11.25 Mbps, and a decrease in the bit error rate to 24×10^{-2}. The spectral efficiency results further corroborate the improvements in throughput and SINR, as they are closely related. Notably, energy consumption on the CUE side increases with the system applying proposed technique compared to the baseline system, suggesting that the clustering strategy primarily benefits the DUEs. This presents a challenge for developing techniques that consider both DUEs and CUEs. Our proposed clustering technique works well to reduce the interference problems and to improve the performance of D2D communications deployed in RIS-aided wireless cellular network. Despite this, the technique enhances overall system performance without harmfully impacting CUE signal quality, ensuring that CUEs maintain acceptable performance even with a high number of DUEs in RIS-aided networks.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available within the article. Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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