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cDERSA: Cognitive D2D Enabled Relay Selection Algorithm to Mitigate Blind-Spots in 5G Cellular Networks

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ABSTRACT Blind-spots, where wireless signals do not reach within the coverage range, often emerge in a dynamic environment due to obstacles, geographical location or mobility of cellular users (CUs). Thus greatly reducing the overall system performance in terms of coverage and throughput. Relay-aided cognitive Device to Device (cD2D) communication system underlying the 5G cellular network can help mitigate blind-spots. Cognitive capability helps D2D users to acquire the spectrum opportunistically for proximity communication and establish a semi-independent network underlying the 5G network, which not only offloads 5G-New Radio (NR) base station but also enhances the overall system performance. In this work, we have developed a relay-aided cognitive D2D network that helps CUs falling into the blind-spots to retain access to the 5G network and increase wireless coverage. Relay selection requires mutual consent between the relay and the device in the blind-spot. The in-coverage devices are tempted to act as relays through incentive-based mechanism. For enhanced system performance a suitable match among the devices in blind-spots and the relays is required. cD2D enabled relay selection algorithm (cDERSA) is proposed in this work, in which a cognitive D2D user (cDU), which is a CU falling in the blind-spot, establishes a relayed cD2D link to access 5G-NR gNodeB. All cDUs as well as the tempted relays, i.e. cognitive D2D relays (cDRs), first scan their surroundings for devices capable of D2D communication and based on multi-criteria objective functions, build a priority table. A stable marriage problem is formulated and solved using a unique, stable, distributed, and efficient matching algorithm based on the Gale-Shapley algorithm. A new incentive mechanism is also developed to keep relays motivated to share their resources. Simulation is performed and their results show improvement in throughput and average user satisfaction, which validates our proposed cDERSA.

INDEX TERMS cD2D communication systems, blind-spots, SMP, GSMA, QoS, incentive mechanism, user satisfaction, throughput.

I. INTRODUCTION

5G cellular networks are expected to face intensive cellular user demands due to traffic load from exponentially increasing devices and bandwidth-hungry applications [1]–[3]. 5G-NR is equipped with many advance technologies that helps it meet these demands. These technologies include massive multiple-input and multiple-output (mMIMO), Edge Computing, Small Cell, Beam-forming, Non-orthogonal multiple access (NOMA), Software Defined Networking (SDN), Network Function Virtualization (NFV), Integrated Access & Backhaul (IAB), Millimeter-wave communication,

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5G-NR Vehicle-to-X (V2X) and D2D communication [4], [5]. To meet high bandwidth demands 5G network is expected to utilize high-frequency bands from 3-300GHz but wireless signals of higher frequencies are more prone to path loss, foliage loss and wireless signal absorption by water and oxygen, which can result in blind-spots within the coverage area of the network [6]–[8].

Blind-spots are referred to as a geographical portions of the network within the coverage range that either have very low or no wireless signal coverage [9]. They can emerge at any time and place because of obstacles and mobility of CUs, for example in the basement of a building or inside a tunnel. Blind-spots are virtually impossible to track for real-time mobile CUs but the majority of blind-spots can be removed by either installing extra antennas or by increasing the density of 5G-NR Nodes but these are not energy or/and cost-effective solutions. Out of the box solution is required to effectively address such a dynamic problem. A relay-aided cD2D communication system can be used to enhance system coverage and reduce blind-spots. It can connect CUs falling into blind-spots to the cellular network with the help of relays.

In cD2D communication a CU falling in the blind-spot changes its mode of communication from cellular to D2D and becomes a cDU [10], [11], i.e. the cognitive D2D user. cDU then scan the spectrum for free cellular channels and use them to establishes an opportunistic D2D communication session with a cognitive D2D relay (cDR), which provides access to 5G-NR gnodeB. This two-hop link, i.e. cDU-cDR-(5G-NR gNodeB), not only provides the network access to the cDUs, but also results in offloading 5G-NR gNodeB, increased throughput, enhanced spectrum efficiency, and reduced delays [12].

As the number of devices is growing fast so does the number of expected cDUs in a given area. Extending D2D to multi-hop and using cDUs as relays to reach out to CUs falling into blind-spots can help control blind-spots and improve coverage of overlay cellular networks [13], [14]. To reap the benefits of cognitive radio and D2D communication, a cDU-cDR link is formed using cD2D, which uses cellular spectrum opportunistically for communication. CUs being licensed users hold higher priority over cDUs, which means on the arrival of a CU, the cDU will have to vacate the resources for CU by either following switching or no-switching spectrum handoff. For switching spectrum handoff, cDUs will vacate their currently utilized channel and handoff to the next channel according to their already prepared target channel list. In non-switching spectrum handoff, on the arrival of CU, cDU will either reduce their transmit power which will reduce the data rate, or pause transmission and go into a waiting state until CU departs and the channel is free again [15]. The cDR-(5G-NR gNodeB) link will use a network-assisted D2D scheme to form a link between cellular and cD2D networks.

This relay-aided two-hop cD2D communication system will help mitigate blind-spots by providing communication links to CUs falling into blind-spots. A CU going into blind-spot will join the D2D network and become cDU by changing its mode and lease a relay to keep it connected to 5G-NR gNodeB. Forming a cDU-cDR pair by connecting a cDU with the most suitable cDR can significantly increase system performance in terms of throughput and user satisfaction level. The suitability of cDR depends on several parameters, such as the throughput it can offers, the delay it can incur in relaying the data, the available battery power, and buffer capacity. Based on these parameters, cDUs evaluate different cDRs and try to form a pair with the most suited one. On the other hand, cDRs are independent cD2D devices and system needs entice them to share their resources by offering them lucrative incentives. cDRs will also evaluate their surrounding cDUs based on the number of data loads of cDUs, the incentive offered and throughput needed.

A. CONTRIBUTIONS

The key contributions of this paper are highlighted below.

- A unique cellular network containing CUs, with cD2D network underlay containing cDUs and cDRs, is considered in this work, where out-of coverage CUs can change mode and become cDUs and use appropriate cDRs to establish a link to 5G-NR gNodeB.
- Multi-criterion objective functions are developed for both cDUs and cDRs, and based on these objective functions they will evaluate and select their partners.
- A novel incentive mechanism is proposed to attract D2D devices with good cellular signal strength to act as a relay by offering cellular spectrum sharing and tariff relief.
- Stable Marriage Problem (SMP) is formulated building upon the multi-criterion evaluations and QoS-based weight assignments.
- cDERSA: Based on Gale-Shapley Matching Algorithm (GSMA), a distributed relay selection algorithm is proposed in this work, which will provide a cDU optimal relay selection solution while enhancing the privacy of cDUs and relays.
- Simulation is performed and results obtained with cDERSA show improvement in throughput and user satisfaction when compared with Random Relay Selection Algorithm (RRSA) and Distance-Based Relay Selection Algorithm (DBRSA).

The rest of the paper is organized into the following sections. The related work and background is presented in section II. The system model and the use case are presented in section III. The proposed relay selection scheme, "cDERSA" is presented in section IV. Simulation and analysis results are presented In section V, and finally, conclusions are drawn in section VI followed by a future directions.

II. BACKGROUND AND RELATED WORK

D2D is considered a promising solution to enhance spectrum utilization and combined with Cognitive Radio (CR), cD2D communication provides more flexibility and autonomy to D2D users, particularly where the network coverage is low.

By exploiting the multi-hop relaying in cD2D communication, we can improve the coverage and offload cellular network without a noticeable additional signaling load. However, forming a cDU-cDR pair requires the best match and efficient relay selection can result in improved user satisfaction, enhanced throughput and reduced delay.

In this section, we will review existing literature addressing relay selection in CR and D2D communication underlying cellular networks. The comparison of existing literature is provided in Table 1. Different relay selection schemes for D2D and CR underlying cellular network are studied in this work and optimization parameters are identified to form an incentive based stable matching solution that ensure user privacy, enhance system throughput and reduce delays.

R. Ma *et al.* proposed a relay selection algorithm for multi-hop D2D communication underlying 4G LTE [16]. A multi-criterion cross-layer relay selection scheme is proposed based on end-to-end data rate and remaining battery time of relay. An estimated mathematical model is established based on queuing theory. The results are validated through simulations based on end-to-end transmission delay, aggregated data transmitted and battery load on relaying user but the work only focus of cDUs and cDRs and their preferences are totally neglected in this work. Asadi *et al.* proposed an opportunistic relay selection algorithm for out-band D2D communication also ensuring QoS requirements of the users [17]. Software-defined radio based experimental analysis is performed to check the validity of the algorithm following the architecture of 3GPP proximity-based services. The results only confirmed the feasibility and potential of out-band D2D communication without considering the preferences of cDRs in relay selection.

Social and physical domain-based adaptive relay selection model is proposed by Zhang *et al.* [18]. The performance of the algorithm is accessed based on the activeness of users on social domain and cooperation willingness. Link reliability is evaluated based on channel conditions and user encounter histories. Simulation results are presented to show improvement in successful relay selection and offloading base station but analysis did not consider the preference of relays and throughput, Delay of system. Tsiropoulos *et al.* [19] discussed cooperative communication framework in 5G HetNets. cooperation improves network efficiency in terms of energy efficiency, spectral efficiency, connectivity latency, and QoS. Integrating full-duplex and D2D communication with cooperative communication further improves the efficiency of dynamic spectrum access. Furthermore integrating all these into 5G-NR results in improved spectrum access but the proposed work did not provide any temptation to cDRs to work as relay and share their resources.

Gui and Deng [13] presented a coverage improvement mechanism in D2D communication underlying cellular network. Multi-hop relaying mechanism is used to improve the coverage and cellular down-link is optimized to enhance throughput and energy efficiency. The simulation results show an improvement in cellular network coverage. The proposed work can be further improved with opportunistic spectrum access and offering incentive to relays. A power-efficient social-aware relay selection algorithm is proposed by Ying and Nayak [20] to support multi-hop in D2D communication. Simulation results show that the proposed scheme performs better than existing schemes in terms of average power consumption but throughput, delay, relay incentive and opportunistic spectrum access can further improve the work. Dang *et al.* [23] presented a Multi-carrier OFDMA based D2D communication system. A multi-carrier relay selection algorithm is applied to it and its performance is optimized by power control to mitigate interference caused by D2D users in the cellular spectrum. Simulation results show improvement in outage probability but lacks to consider relay preference and throughput and delay.

Zhang *et al.* [24] proposed multiple cellular and D2D devices in closed proximity and using several social attributes creates overlapping community. To handle this overlapping community, deep exploring based relay selection algorithm to support multi-hop D2D communication is presented in this work. A social tie matrix is developed between D2D users and based on their interactions the matrix is updated using deep learning. An effective relay selection method is presented in this work and simulation results show improvement in delivery rate and power consumption. The relay incentive based throughput and delay analysis is missing in this work. Das *et al.* [25] proposed a multi-hop data forwarding algorithm in cognitive radio-based Internet of things (IoT) networks. Intermediate relay nodes are compensated in this letter with energy incentive to overcome energy loss during packet relaying. Simulation and analysis results show that despite scanning overhead the proposed schemes significantly improve the energy efficiency of the proposed system. However, the throughput and delay analysis of relay incentive is missing in this work.

Wang *et al.* [26] studied a trade-off between physical layer security and D2D throughput with relay selection. A socially stable matching model for secure relay selection in D2D communication is presented in this work. A stable matching over two independent graph models is derived and simulation results show the superiority of the proposed algorithm. A relay incentive, delay and privacy are the possible shortcomings of this work. Zhang *et al.* [27] proposed a deep reinforcement learning-based relay selection for D2D communication optimizing power allocation in mmWave vehicular networks. The study claims their relay-aided multi-hop D2D solution can help avoid dense base station deployment. Simulation results indicate that delay of the proposed scheme is better than the link-quality-prediction method and relatively close to the link-quality-know method however, the throughput analysis of this work is missing.

The performance of multi-hop wireless powered cognitive-D2D communication system underlying wireless sensor network is studied by Nguyen *et al.* [28]. The analysis is performed under the assumption that each D2D user will

TABLE 1. Related work comparison of relay selection schemes cognitive D2D communication system underlying cellular network.

	CR	D2D	Relay Selection	Underlay Cellular	Relay Incentive	Stable Matching	Privacy	Throughput	Delay
R. Ma *et al.* [16]	✗	✓	✓	✓	✗	✗	✗	✗	✓
Asadi *et al.* [17]	✗	✓	✓	✓	✗	✗	✗	✓	✓
Z. Zhang *et al.* [18]	✗	✓	✓	✓	✗	✗	✗	✗	✗
Tsiropoulos *et al.* [19]	✓	✓	✓	✓	✗	✗	✗	✓	✓
Gui *et al.* [13]	✗	✓	✓	✓	✗	✗	✗	✓	✓
Ying *et al.* [20]	✗	✓	✓	✓	✗	✗	✗	✗	✗
Uyoata *et al.* [21]	✗	✓	✓	✓	✗	✓	✗	✓	✗
B. Ma *et al.* [22]	✗	✓	✓	✓	✗	✓	✓	✓	✗
Dang *et al.* [23]	✗	✓	✓	✓	✗	✗	✗	✗	✗
P. Zhang *et al.* [24]	✗	✓	✓	✓	✗	✗	✗	✗	✗
Das *et al.* [25]	✓	✓	✓	✓	✓	✗	✗	✗	✗
B. Wang *et al.* [26]	✗	✓	✓	✓	✗	✓	✗	✓	✗
H. Zhang *et al.* [27]	✗	✓	✓	✗	✗	✗	✗	✗	✓
Nguyen *et al.* [28]	✓	✓	✓	✗	✓	✗	✗	✗	✗
Wu *et al.* [29]	✗	✓	✓	✓	✓	✗	✗	✓	✓
X. Wang *et al.* [30]	✗	✓	✓	✓	✗	✓	✗	✗	✗
M. S. Omer *et al.* [31]	✗	✗	✗	✓	✗	✗	✗	✓	✓
Huq *et al.* [32]	✗	✓	✗	✓	✗	✗	✗	✓	✓
S. Mumtaz *et al.* [33]	✗	✓	✗	✓	✗	✗	✗	✓	✓
D. Singh *et al.* [34]	✗	✓	✓	✓	✗	✗	✗	✓	✓
B. Li *et al.* [35]	✗	✓	✓	✓	✗	✗	✗	✓	✗
Datsika *et al.* [36]	✗	✓	✓	✓	✗	✗	✗	✓	✗
Proposed	✓	✓	✓	✓	✓	✓	✓	✓	✓

harvest energy from multiple power beacons and share spectrum resources with primary users using cognitive radio with imperfect channel interference knowledge. Network performance is improved with two proposed scheduling algorithms, dual-hop scheduling, and best-path scheduling. The proposed scheduling schemes are evaluated based on outage probability and outage floor. The results show that best-path scheduling performs better than dual-hop scheduling. The proposed work did not consider relay preference, throughput and delay of system.

Wu *et al.* [29] proposed a relay selection algorithm based on social-tie motivated non-edge cellular user underlying dynamic D2D communication. The performance of cellular-edge users is explicitly improved in this work by considering both physical and social ties of relaying users, moreover, social ties are also used as a metric to improve security performance. A generalized quality of experience index is introduced based on several quality of service parameters such as throughput, rate, and delay into a unified metric for optimization of the trade-off between relay selection resource efficiency and quality of experience. Finally, a dynamic resource optimization algorithm is presented studying the effects of channel randomness and user mobility using the Lyapunov framework and drift-plus-penalty algorithms. Numerical results are presented to validate the effects of the presented relay selection scheme. The proposed work did not cater relay preference and opportunistic spectrum access which can further enhance the work.

Wang *et al.* [30] proposed an energy-efficient relay selection algorithm using joint power allocation and relay selection scheme for relay aided D2D communication network. A mixed-integer non-linear fraction programming problem is first formulated based on the total energy efficiency of D2D pairs and solved using the Dinkelbach method and Lagrange dual decomposition method. Secondly, a relay selection problem is solved using a reinforcement Q-learning algorithm. Finally, a detailed theoretical analysis is presented considering signal overhead and the complexity of the algorithm. Simulation results are presented to verify the proposed algorithm but relay incentive, throughput and delay analysis is not considered in this work.

Omer *et al.* [31] proposed a stochastic geometry based approach to investigate down link performance of three tier Heterogeneous Networks (HetNets). The network consist of sub-6 GHz macro-cells along with small-cells which operate on both sub-6 GHz and mmWave bands. The system is evaluated in terms of energy efficiency, spectrum efficiency, rate, area and coverage. simulation results are provided to authenticate the validity of proposed model. Huq *et al.* [32] proposed mobile crowd-sensing (MCS) architecture for 5G cellular network based on C-RAN and D2D. The study focused on achieving a low delay by integrating D2D with C-RAN and moreover achieving high energy efficiency, increase system capacity, improve mobility and cost of 5G cellular network. Mumtaz *et al.* [33] propose energy efficient algorithms for communication between D2Dnd cellular users. The proposed work used Lagrangian duality theory to find an optimal power and rate control solution for D2D user. The interference limit of cellular users is kept below threshold and fairness between D2D and cellular user is achieved. Opportunistic spectrum access and incentive based relaying mechanism is not considered in [31]–[33].

Singh *et al.* [34] studied the D2D mmWave link under dynamic environment with obstacles. Relay selection problem is formulated using Partially observable Markov decision process (POMDP) and optimal policy is formulated which follows distributed implementation and evaluated based on packet delay and packet loss. Incentive based relaying and relay preference is not considered in this work. Li *et al.* [35] proposed multi-hop D2D communication system underlying cellular network to offload cellular base station, expend its coverage and improve its reliability. Relay scarcity problem is addressed by suggesting a relay which can serve multiple D2D users and network coding is used to increase system performance. A relay selection mechanism based on location of relay, content of communication, capacity and residual energy is proposed which is easy to implement. The opportunistic spectrum access, relay incentive and relay preference is not considered in this work. Datsika *et al.* [36] proposed an adaptive and cooperative D2D communication MAC protocol equipped with network coding. Analytical and simulation results are provided for validity of work in terms of energy efficiency without compromising quality of service however, delay and relay preference is not considered in this work.

TABLE 2. List of notations.

Description	Parameter
Number of cDUs	j
Number of cDRs	k
Mode selection threshold	σ
cDU objective function	O_{cDU}
cDR objective function	O_{cDR}
Link capacity	C
Traffic load	ρ
Throughput	ψ
Time	t
Bandwidth	W
Transmission power	T_p
Channel gain	h
Channel noise	N_o
Number of packets in buffer	α
Packet size	s
Buffer size	β
Link outage probability	p_{out}
Stationary probability	π
cDR-(5G-NR gNodeB) Link	L_{cDR}
cDU-cDR Link	L_{cDU}
Function of throughput	f_{th}
Function of end-to-end delay	$f_{\mathbb{D}}$
Function of residual energy	f_{ϵ}
Function of required buffer size	f_{β}
Function of load offered	f_{lo}
Function of Incentive	f_{ι}
Delay	$\mathbb{D}$
Energy	E
Amount of data	d
Round trip time	rtt
Number of flows sharing link	n
Weight	ω
Incentive	Θ
Queue length	Q

A detailed comparison of existing literature is presented in Table 1 shows that most of existing D2D relay selection schemes do not consider relay user preference during selection of relays, moreover they do not provide any incentive to relays [13], [16]–[18], [20]–[24], [26], [27], [30], [34]–[36]. Thus, a relay wont have any temptation to serve the out of coverage user. Energy Incentive based D2D relaying is proposed in [25], [28], [29] but they do not cater both relay and D2D user satisfaction. To the best of our knowledge, multi-hop D2D relay selection scheme with D2D user equipped with CR capability and offering an incentive based relaying through stable matching and increasing the satisfaction of both relay and D2D users is proposed first time in literature with increased throughput, reduced delay and enhanced privacy.

III. SYSTEM MODEL

We consider a relay-aided cD2D communication system underlay 5G cellular network where the network is divided among CUs, cDUs, and cDRs. cDUs are CUs falling into blind-spots with signal strength falling below mode selection threshold σ. The list of notations used in this paper are presented in Table. 2. cDRs are close proximity users of cDUs with good network coverage and they will act as a

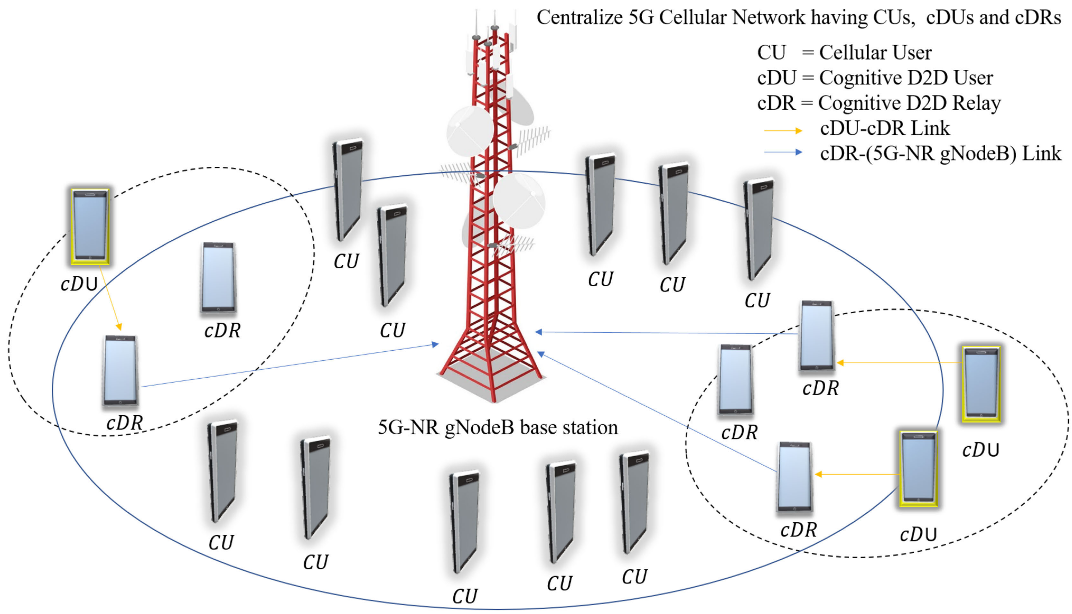


FIGURE 1. System model.

relay to help cDU access the cellular spectrum. cDU-cDR link will follow opportunistic spectrum access and cDR-(5G-NR gNodeB) link will follow a network-assisted approach.

The set of cDUs is represented as $cDU = \{cDU_1, cDU_2, \ldots, cDU_j\}$ with cardinality of j and set of cDRs is represented as $cDR = \{cDR_1, cDR_2, \ldots, cDR_k\}$ with cardinality of k. Both cDUs and cDRs are following full-duplex mode of communication. Theoretically, it doubles the throughput as compared to half-duplex mode of communication by virtue of simultaneous transmission and reception [37]. Each user is equipped with multiple antennas and separate antenna is used for transmission and reception of communication signals [38]. The self interference caused by full-duplex communication can be reduced by using interference cancellation techniques proposed in [39], [40].

We have proposed a distributed relay selection scheme who will perform matching between cDRs and cDUs based on $(j \times k)$ rating matrix. This rating matrix is developed by both cDRs and cDUs during parameter exchange. Rating matrix is developed based on cDR objective function presented in section $III-A$ and cDU objective function presented in $III - B$. For any cDU-cDR pair (j, k), the measure of preference of the j^{th} cDU about the k^{th} cDR is the maximal objective function of the cDU. Similarly, the measure of preference of k^{th} cDR about j^{th} cDU is the maximal objective function of cDR. The preference list is developed based on maximal objective functions of cDUs-cDRs and based on their preference order final cDU optimal cDU-cDR pairs are formed using cDERSA.

Figure 1 shows a system model containing a cD2D communication system with cDUs and cDRs underlying 5G cellular network with CUs. The propagation channel is considered as combination of large scale (slow) fading and small scale (fast) fading. The proximity link of cDU-cDR is expected to contain line of sight (LOS) component, which makes it responsible to model as Rician distribution moreover, the cognitive cDU-cDR link is represented with yellow line in Figure 1. A network assisted cDR-(5G-NR gNodeB) link which is represented with blue line in Figure 1. contains rich scattering components and there is a high probability of non line of sight (NLOS) link so it is modeled using Rayleigh distribution [41], [42]. Dotted areas represents the D2D coverage range and solid line is used to represent the coverage of 5G-NR gNodeB.

A. cDU OBJECTIVE FUNCTION

A cDU will rate all its surrounding cDRs based on O_{cDU} objective function. The O_{cDU} ranking is based on four parameters of each cDR which are as follows: throughput, delay, residual energy, and buffer. These parameters are acquired at the time of discovery and communicated along with the Channel State Information (CSI) exchange message as in [43]. Note that as CSI is exchanged anyways there are no additional messages involved and the only overhead is of the few additional bytes, which in the context is a negligible overhead.

1) THROUGHPUT

The amount of data transmitted through a system per unit time is called its throughput. The objective of this function is to maximize the throughput of each cDU-cDR pair and thus results in maximized system throughput. The throughput of any channel depends upon its capacity and outage probability. we can calculate average throughput as.

$$\psi = C(1 - p_{out}) \tag{1}$$

where, p_{out} is outage probability of link which shows that at what probability the links going in and out of a relay would be unavailable and C is the link capacity, which depends on the SINR of link and is governed by Shannon theorem.

$$C_{(Avg)} = W \log_2(1 + \frac{T_p h}{N_o}), \quad (2)$$

where W is channel bandwidth, T_p is transmission power,N_o is channel noise and h is the channel gain representing the cumulative effect of pathloss(H_p), slow (H_s) and fast (H_f) fading ($h = H_p + H_s + H_f$). The cDU is concerned with the throughput being offered from the cDR-(5G-NR gNodeB) link which is represented as L_{cDR}, cDRs with better Received Signal Strength (RSS) from 5G-NR gNodeB base stations can provide better throughput as it will increase the value of h in (2) for them. The value of function developed for throughput maximization of cDU will finally be calculated as.

$$f_{th} = \psi_{L_{cDR}} \quad (3)$$

2) DELAY

The delay is a measure of time a packet needs to spend unattended in buffer of cDU or cDR. The objective of delay function introduced in this work it to minimize the delay of network. It is achieved by selecting forming a link with less packets in its buffer. The value of ($f_{\mathbb{D}}$) which is end-to-end delay function, is calculated using little's theorem.

$$f_{\mathbb{D}} = \mathbb{D}_{(cDU)} + \mathbb{D}_{(cDR)} = \frac{Q_{cDU}}{\psi_{(D\rightarrow R)}} + \frac{Q_{cDR}}{\psi_{(R\rightarrow B)}} \quad (4)$$

$\mathbb{D}_{(cDU)}$ is delay of cDU, $\mathbb{D}_{(cDR)}$ is delay of cDR, Q_{cDU} is average queue length at cDU, Q_{cDR} is average queue length at cDR, $\psi_{(D\rightarrow R)}$ is average throughput of cDU-cDR link and $\psi_{(R\rightarrow B)}$ is average throughput of cDR-(5G-NR gNodeB) base station link. The value of ψ is calculated in (1). The average queue length at the buffer can be calculated as.

$$Q = \sum_{i=1}^{(Q+1)^N} \pi_i \alpha_i \quad (5)$$

where π_i is the stationary probability of state i, α_i is the number of packets in the buffer. N is the number of selected relays which is 1 in our case. The value of each $\mathbb{D}$ can be calculated with the respective version of (1) and (5) and their generalized version is calculated as.

$$\mathbb{D} = \frac{\sum_{i=1}^{Q+1} \pi_i \alpha_i}{C(1 - p_{out})} \quad (6)$$

3) RESIDUAL ENERGY

Battery consumption is a very crucial parameter of modern communication systems as almost all mobile communication devices are battery-operated. The amount of available energy is called residual energy and can be obtained with battery level information (BLI) of the user. All cDRs are running on a very tight energy budget, however, cDU will prefer a cDR that has an ample amount of energy to complete a transmission session reliably.

While selecting cDRs, it is important to select a cDR that has enough energy to receive, decode and re-transmit the required amount of data on wireless channels ensuring necessary SNR. The purpose of function f_ϵ is to transmit the maximum amount of data by consuming minimum energy so the minimum energy required (MER) is calculated as.

$$f_\epsilon = E_{min}(d_l) = T_p d_l (W \log_2(1 + \frac{T_p h}{N_o W})) \quad (7)$$

where E_{min} is the minimum amount of energy required to transmit data d_l, t_p is transmission power, h is channel gain, W is bandwidth and N_o is channel noise. cDRs can follow adaptive rate transmission with constant power or adaptive power transmission algorithm keeping rate constant where transmission power of cDR varies according to channel condition maintaining a certain level of SINR. power adoption results in better energy efficiency given a certain amount of transmission outage probability.

4) BUFFER STATE INFORMATION

In relay selection, the buffer is of paramount importance to ensure QoS and reduce delay. However, we have formulated our function based on the current buffer state (BSI) of each cDR as we are more interested in the available buffer capacity for cDU rather than the total buffer size. Buffer size requirements can be calculated depending upon the application.

$$\beta = rtt_i \frac{C}{\sqrt{n}} \quad (8)$$

where β is buffer size, rtt_i is average round trip time of i^{th} cDR, C is link capacity and n is number of flows sharing links. Based on [44] we calculated required buffer size defined as f_β.

$$f_\beta = (rtt_{max} - rtt_{min}) \frac{C}{s} \quad (9)$$

where s is the packet size. f_β is indirectly dependent on the value of SINR as

$$R = W \log_2(1 + SINR) \quad (10)$$

we assume each cDR has a finite buffer space of β, β_i^o shows the occupied buffer space of i^{th} cDR, and vacant buffer space can be calculated as $\beta_i^v = \beta - \beta_i^o$. The main constraint while selecting a cDR is that a cDR buffer should have enough buffer available to cater to relaying data.

Based on functions defined in (1), (4), (7) and (9) we formulated $O_{cDU}^{(j,k)}$ as cDU objective function of j^{th} cDU and k^{th} cDR, using weighted sum we determine the value as:

$$O_{cDU} = (\omega_{th} f_{th}) + (\omega_{\mathbb{D}}(1 - f_{\mathbb{D}})) + (\omega_\epsilon(1 - f_\epsilon)) + (\omega_\beta f_\beta) \quad (11)$$

Based on (11) a cDU preference vector is generated in descending order. The cDR with the highest priority is at the top of the vector and the cDR with the lowest priority is at the bottom. A cDU preference matrix of order $j \times k$ can be generated by combining the preference list of all cDUs. The computational complexity in evaluating the utility of cDRs increases linearly with the increase in number of cDRs and

TABLE 3. cDUs weight assignment.

	Throughput	Delay	Energy	Buffer
cDU Profile 1	1^{st}	2^{nd}	3^{rd}	4^{th}
cDU Profile 2	2^{nd}	3^{rd}	4^{th}	1^{st}
cDU Profile 3	3^{rd}	4^{th}	1^{st}	2^{nd}
cDU Profile 4	4^{th}	1^{st}	2^{nd}	3^{rd}

is $O(k)$, where k is the number of cDRs. The computational complexity is not a major concern here as we are using it for D2D communication, which is in a short range and thus there would be a limited number of cDRs offering relay service to a cDU.

5) WEIGHT ASSIGNMENT

Four relay selection parameters of cDU which can greatly influence reliable communication session are assigned different weights based on QoS requirements. In this section we have developed four QoS profiles for cDUs based on which they will rank cDRs.

B. cDR OBJECTIVE FUNCTION

cDRs will rank all its candidate cDUs based on three parameters. Throughput, Load offered and Incentive provided.

1) THROUGHPUT

To maximize cDR gain and system throughput a cDR will prefer to pair with the cDU with whom it can establish a link with better throughput. This cDU-cDR link is represented with L_{cDU} and each cDR will rank cDUs based on the quality of this link. The value of throughput of the link is calculated as.

$$\psi_{L_{cDU}} = W \log_2(1 + \frac{T_p h}{N_o})(1 - p_{out}) \tag{12}$$

The throughput of every cDU-cDR link is represented with $\psi_{L_{cDU}}$, and building upon (12), The function to rate cDUs is represented as.

$$f_{th} = \psi_{L_{cDU}} \tag{13}$$

2) LOAD OFFERED

Based on its QoS requirements cDU exerts a load on cDR which can be quantified as the amount of data that needs to be transmitted (d_l), amount of time the resources needs to be occupied(t_o) and amount of resources required(W_t) by cDU. The value of load can be calculated as

$$\rho = d_l t_o W_t \tag{14}$$

Load function of cDRs to rate cDUs is calculated based on (14) and is represented as.

$$f_{lo} = 1 - \rho \tag{15}$$

3) INCENTIVE

Relaying data of other users costs resources of the cDR in the form of battery consumption and processing load. An attractive incentive will tempt a cDR to act as a relay for the cDU.

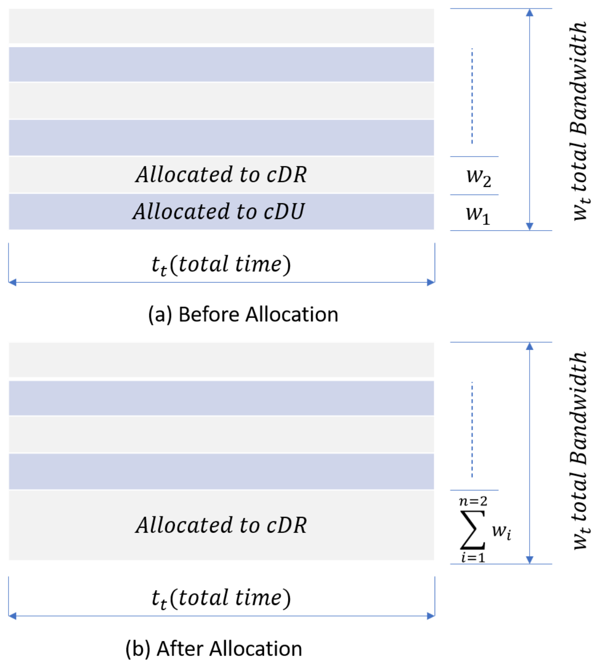


FIGURE 2. Spectrum before and after channel allocation.

Several different and interesting incentive mechanisms have been proposed in the literature like cDR can be assigned portion of the cellular spectrum, cDRs can use beam-forming to harvest energy and improve its energy efficiency, the cellular network can offer tariff relief to cDRs and cDUs can offer crypto-currency to cDRs for compensation [45]–[49]. We propose a novel incentive-based relaying where cDRs are handsomely rewarded in terms of (i) increase in bandwidth by dedicating cellular resources (ii) decrease in cellular tariff (iii) a combination of both. The capacity of cDU and cDR before forming cDU-cDR pairs is represented as.

$$C_{(cDU)} = W_1 \log_2(1 + \frac{T_p h}{N_o})t_i \tag{16}$$

$$C_{(cDR)} = W_2 \log_2(1 + \frac{T_p h}{N_o})t_i \tag{17}$$

where t_i is the time slot at i^{th} time instance. W_1 is bandwidth allocated to cDU and W_2 is bandwidth allocated to cDR.T_p is transmission power, h is the channel gain and N_o is channel noise. After the cDU-cDR pairs are formed the capacity of cDR will be increased as shown below.

$$C_{(cDR)} = \sum_{i=1}^{n=2} W_i \log_2(1 + \frac{T_p h}{N_o})t_i \tag{18}$$

Figure 2 represents the spectrum allocation before and after the channel assignment. Before cDR-cDU pairing, separate channel is assigned to each user from bandwidth by 5G-NR gNodeB. But after the cDU-cDR pair formation every cDR is rewarded with the cellular channel of cDU to cDR, which would increase the data carrying capacity of the cDR.

TABLE 4. cDRs weight assignment.

	Throughput	Load Offered	Incentive
cDR Profile 1	1^{st}	2^{nd}	3^{rd}
cDR Profile 2	2^{nd}	3^{rd}	1^{st}
cDR Profile 3	3^{rd}	1^{st}	2^{nd}

Dedicated cellular resource is an attractive incentive for cDRs but its not possible to rate users depending on it because resource dedicated are almost same to all CUs. to add a more depth in this work we have defined an incentive based on reduced cellular tariff where cDUs can offer their digital cellular resources to cDRs. this resource sharing formula will decrease tariff of cDR for its future use. These incentives can be in form of free airtime minutes or data in MBs and are represented with Θ. The incentive function is represented with f_ι and can be calculated as.

$$f_\iota = C_{(cDR)}\Theta \tag{19}$$

The cDR objection function is defined $O_{cDR}^{(k,j)}$ to find best match for k^{th} cDR to j^{th} cDU by generating a preference vector of each cDR. A relay wants to maximize its utility with maximum incentive, throughput, and minimum load. using weighted sum we have calculated the value of O_{cDR} as.

$$O_{cDR} = (\omega_{th} f_{th}) + (\omega_{lo} f_{lo}) + (\omega_\iota f_\iota) \tag{20}$$

All cDUs will share their utility with cDRs and each cDR will generate its preference vector. cDU with the highest value of O_{cDR} will be on top of the preference vector and lowest at the bottom. The combination of all cDR vectors can give cDR preference matrix with order $k \times j$. The computational cost for cDRs also increases with increase in number of cDUs and is $O(j)$, where, j is the number of cDUs. Again, the computation cost is not a major concern here as the algorithm is for D2D communication, where the range of communication is very limited and so are the number of cDUs in that range.

4) WEIGHT ASSIGNMENT

Each relay will assign different weight to its cDU selection parameters based on its QoS requirement. we have developed three QoS profiles for cDRs based on which they will rank cDUs.

We have formulated SMP from the preference vectors generated by all cDUs and cDRs. A privacy-aware distributed cDERSA is proposed in this work to form cDU-cDR pairs which are inherited from GSMA.

IV. PROPOSED cDERSA

In this work, we have proposed "cDERSA: cD2D enabled relay selection algorithm", A distributed mechanism in which CUs moving into blind-spots is provided a path to the network through cDRs with ensured privacy. As shown in Figure 3, CU will start to get low signal reception from the network when it approaches a blind-spot, The moment received signal strength (RSS) falls below a certain mode selection threshold level (σ) CU will scan its surroundings for possible D2D candidate devices which can provide services as a relay. Upon discovering cDRs, the CU falling into blind-spot changes its mode from cellular to D2D and becomes a cDU. cDUs and cDRs will exchange parameters based on which they will rate their surrounding candidate devices. Each cDU and cDR will prepare its preference vector containing the priority of candidate devices based on parameters exchanged. Now, this is a SMP, where both cDUs and cDRs have their own priorities, which we solve through our proposed cDERSA.

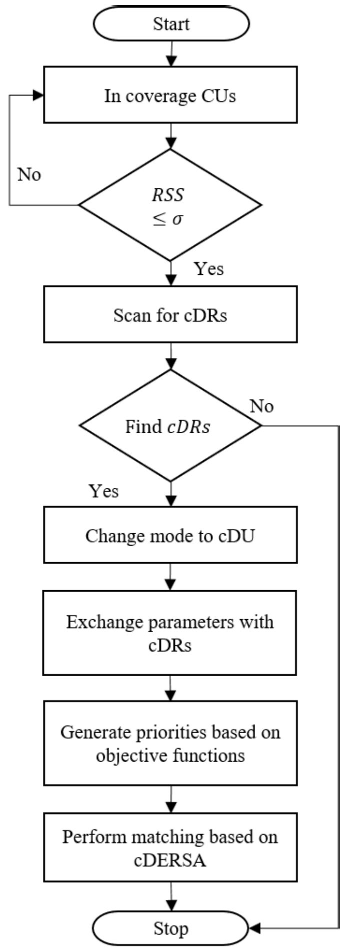


FIGURE 3. Problem explanation, from low signal reception to SMP.

In cDERSA, we use proposed a distributed matching algorithm inherited from GSMA. GSMA is centralized algorithm and a central entity collects preference table from each user and perform matching based on it. In our scenario we are using cD2D devices for communication unlike cellular communication where base station performs all the tasks and ensure privacy of user data. The privacy in this case cannot be trusted as cD2D users cannot always trust their surrounding devices. we proposed a distributed approach where users generate their preference table and do not share it with their neighboring devices thus increasing user data privacy. Our scheme formulate a cDU-optimal solution to form the best possible cDU-cDR matching pairs forming a relay-aided cD2D communication system underlying cellular network.

If the value of RSS improves and reaches above (σ) again the direct connection of CU with cellular network will be restored. In order to avoid ping pong affect there is small a guard band to assure the value of RSS is higher enough from (σ) that it will not fall back quickly.

A. PROPOSED DISTRIBUTED DEFERRED ACCEPTANCE ALGORITHM

A distributed deferred acceptance algorithm to find cDU-optimal stable matching solution is presented in this section whereby calculating O_{cDU} $\forall j$ in section III-A and O_{cDR} $\forall k$ in section III-B we have formulated a SMP. In this section, our proposed cDERSA is explained briefly which is inherited from GSMA and is presented in algorithm 1.

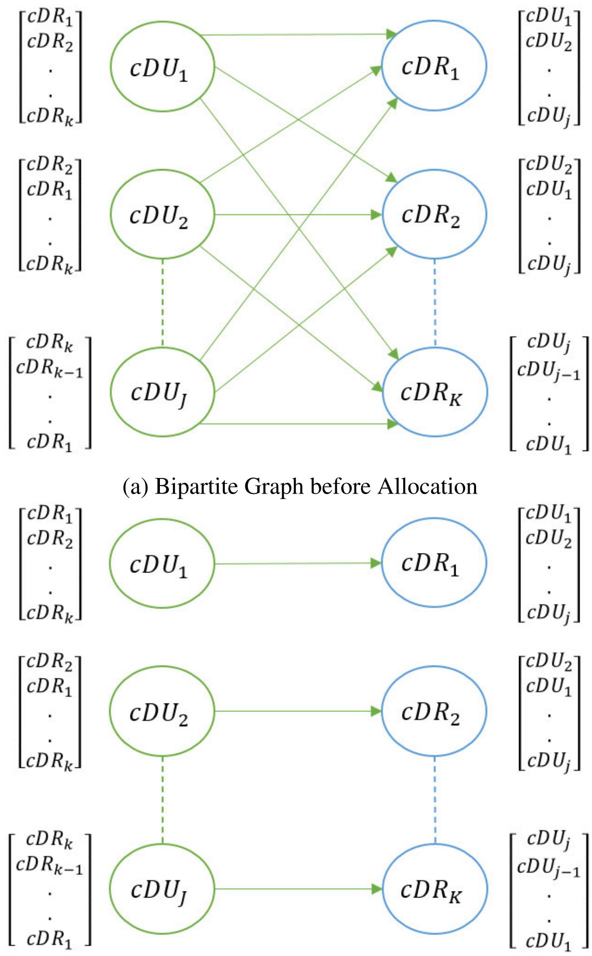
Algorithm 1: cDERSA Distributed Deferred Acceptance Algorithm

Input: cDUs preference list $P^{(j,k)}_{cDU}$, cDRs preference list $P^{(k,j)}_{cDR}$, set of unallocated cDUs $cDU_{unallocate}$, set of unallocated cDRs $cDR_{unallocate}$, allocation matrix A

The element of A set to 0;
while *(either $cDU_{unallocted}$ is non empty or cDU not rejected by all cDRs)* **do**
  cDUs Proposing:
  for $cDU_j \in cDU_{unallocated}$ **do**
    Propose to its best choice cDR in $P^{(j,k)}_{cDU}$
    element of A set to 1
    Remove this cDR from its preference list
  end
  cDRs make decision:
  for $cDR_k \in cDR_{unallocated}$ **do**
    if (cDU_k is not allocated)
    Accept the current proposing cDR_j
    Remove cDU_j from $cDU_{unmatch}$
    Inform accepted cDU_j
    else if (Preference of proposing cDU_j > Preference of allocated cDU)
    Accept the proposing cDU_j and break the existing allocation
    Inform both accepted and rejected cDUs
    Remove cDU_j from $cDU_{unmatch}$
    else
    Keep the existing allocation and reject the proposing cDU_j
    Inform rejected cDU
    end if
  end
end

In the first iteration, all cDUs who are un-allocated will propose their highest priority cDR to establish a D2D session. cDRs will check their priority vector and accept the highest priority cDU among the proposing and reject all others. The acceptance is permanent if proposing cDU is at top priority and cDR will reply permanent accept message and form a permanent cDU-cDR pair. If top priority cDU is not among proposing cDUs, the highest among proposing cDUs is selected provisionally, and provisionally accept message is send to cDU by cDR hence forming a provisional cDU-cDR pair. cDR will reply to all rejected cDUs with a reject message. In subsequent iterations, rejected cDU will propose their next highest ranked cDR to whom it has not yet proposed even if it is already allocated or not. Then, each cDR will either attach itself to the proposing cDU or will keep its currently attached cDU based on its own preference. If cDR changes its attachment the previously attached cDU will be notified that it is free and will try again in the next iteration. The process keeps itself repeating until all users are attached.

Figures 4a and 4b. shows a bipartite graph example of our proposed cDERSA.



(a) Bipartite Graph before Allocation

(b) Bipartite Graph after Allocation

FIGURE 4. cDERSA channel allocation.

B. USE CASE

A hypothetical scenario is considered in this section to further elaborate "cDU proposed deferred acceptance algorithm". cDUs preference matrix is shown in Table. 5, contains

TABLE 5. cDUs preference list.

	cDR_1	cDR_2	cDR_3	cDR_4
cDU_1	2^{nd}	3^{rd}	1^{st}	4^{th}
cDU_2	3^{rd}	4^{th}	2^{nd}	1^{st}
cDU_3	4^{th}	1^{st}	3^{rd}	2^{nd}
cDU_4	3^{rd}	2^{nd}	1^{st}	4^{th}

preferences of all cDUs calculated based on their objective functions O_{cDU} defined in (11).

Table 6 shows the preference list of cDRs which is calculated based on their objective functions O_{cDR} defined in (20). We have proposed cDU optimal solution so the algorithm starts with cDUs proposing and cDRs either accepting or rejecting proposals based on their preferences defined in Table 6. cDUs will target to attach themselves to their highest priority cDRs. At start cDU_1 and cDU_4 both will propose cDR_3, cDR_3 will accept cDU_1 due to its higher preference and rejects cDU_4. cDR_3 will sent permanently accept message to cDU_1 due to its highest priority and send reject message to cDU_4. cDU_2 and cDU_3 will propose cDR_4 and cDR_2. They both will be accepted as there is no other contestant, cDR_4 and cDR_2 will send provisionally accept message to cDU_2 and cDU_3.

TABLE 6. cDRs preference list.

	cDU_1	cDU_2	cDU_3	cDU_4
cDR_1	2^{nd}	4^{th}	3^{rd}	1^{st}
cDR_2	1^{st}	3^{rd}	2^{nd}	4^{th}
cDR_3	1^{st}	2^{nd}	3^{rd}	4^{th}
cDR_4	2^{nd}	4^{th}	3^{rd}	1^{st}

In the second iteration, cDU_4 being the only unattached user will try to attach itself to its 2^{nd} preference which is cDR_2. cDR_2 is already attached with cDU_3 and on receiving a proposal from cDU_4, will keep its current attachment because of its higher preference. cDR_2 will send reject message to cDU_4. In third iteration cDU_4 will propose it's 3^{rd} choice which is cDR_1 and will attach with it successfully as cDR_1 is idle. cDR_1 will send provisionally acceptance message to cDU_4. Finally, all users are attached after three iterations and all cDU-cDR pairs are formed as shown in bipartite graphs formed in Figure 5. The permanent pairs are (cDU_1, cDR_3), (cDU_4, cDR_1) and they will straight away start data transmission after formation. The provisionally formed pairs with the proposed distributed algorithm are (cDU_2, cDR_4), (cDU_3, cDR_2) and they will consider their pairs permanent after a specified time which is equal to the maximum number of message exchanged required to complete the algorithm. Its value is calculated using $2 \times min(j, k)$, which is also the measure of complexity of the algorithm i.e. $O(2 \times min(j, k))$. After this time, the cDU optimal matching is achieved and the data of cDU is relayed by its associated cDR. Note that the algorithm needs to be run only once to create the

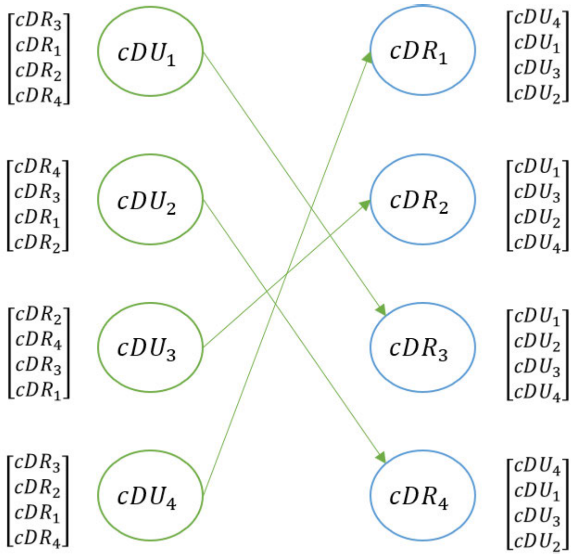


FIGURE 5. Use case.

association between the cDR and cDU. Only if the association breaks due to the change in scenario, such as the associated cDR moves out of the range of the cDU the algorithm is run again.

Providing coordination among the cDUs and cDRs in a distributed network is a challenge. One of the means of providing coordination is through a common control channel as in [50]. In order to remain focused on our problem of improving the user satisfaction we have assumed that on the similar pattern the coordination among the cDUs and the cDR can be achieved.

C. cDU SATISFACTION

The degree of choice achieved in terms of preferred cDR attachment is cDU's satisfaction level [50]. If cDU gets attached to its top preference his satisfaction level is 100%. As shown in Figure 5, cDU_1 cDU_2 and cDU_3 gets their 1^{st} preference and has 100% satisfaction and cDU_4 has 50% satisfaction because of its attachment to its 3^{rd} choice.

$$cDU_{sat} = \frac{(k+1) - x}{k} \tag{21}$$

cDU satisfaction is calculated in (21) where K represents the total number of cDRs and each cDU is getting an attachment to its x^{th} preference cDR.

$$\overline{cDU_{sat}} = \frac{\sum_{i=1}^{j} (k+1) - x_i}{k \times j} \tag{22}$$

The average cDU user satisfaction is calculated in (22), where j is the number of cDUs. As an illustration, we take a scenario where $j = 4$ and $k = 4$ and all cDUs get their first choice so by (22) 100 % average users satisfaction is achieved. On the contrary, if we take Figure 5, where $j = 4$ and $k = 4$ but instead of all four only three cDUs get their first choice and one cDU gets its third choice the user satisfaction drops to 87.5%.

D. cDR SATISFACTION

cDR satisfaction (cDR_{sat}) defines the preferred attachment of cDR to its cDU for transmission. We have j number of cDUs, so if a cDR gets allocated to its y^{th} preferred cDU, the cDR_{sat} is:

$$cDR_{sat} = \frac{(j+1)-y}{j} \tag{23}$$

The average cDR_{sat} of cD2D communication system having k number of cDRs is:

$$\overline{cDR_{sat}} = \frac{\sum_{i=1}^{k}(j+1)-y_i}{j\times k} \tag{24}$$

V. SIMULATION SCENARIO AND COMPARISON

This section presents the performance evaluation of our proposed distributed cDERSA matching scheme and its comparison with RRSA and DBRSA. We considered a cD2D relayed network underlying a 5G cellular network where cD2D users opportunistically utilize cellular spectrum holes and will vacate spectrum on the arrival of CUs. Simulation parameters and their values are presented in table 7. As cDERSA algorithm creates a one-one association among the cDUs and cDRs so the performance evaluation is with the assumption that there are equal number of cDUs and cDRs. The assumption is justified as the additional cDUs (or cDRs, if number of cDRs is greater than number of cDUs), which could not make the pair with the cDR would not be able to communicate in the blind-spot region. Monte-Carlo simulations are performed using MATLAB and their results are averaged over 10^6 iterations.

TABLE 7. Simulation parameters.

Parameter	Values
Number of CUs (n)	2∼20
Number of cDUs (j)	2∼20
Number of cDRs (k)	2∼20
Data Rate	$54Mbps$
weight factor (α)	0∼1

Following protocols are implemented in this work and extensive simulations are performed to show their comparison.

RRSA: In RRSA cDUs falling into blind-spots will randomly select relays to establish a connection with 5G-NR gNodeB base station [51], [52]. If more than one cDUs selects the same cDR collision will occur and it results in decreased system throughput and reduced user satisfaction.

DBRSA: In DBRSA, cDUs will try to select cDR which is closest in distance with itself [53]–[55]. This solution ensures the lowest possible SINR but this does not always prove to be a wise selection. In this case, closest cDU-cDR pairs are formed ignoring user preference which reduces user satisfaction, also all cDUs will go for closest cDRs which will increase collision probability.

cDERSA: we have proposed this scheme in which both cDRs and cDUs rate their surrounding based on weighted multi-objective functions. cDUs propose their highest-rated cDRs and in response cDRs either accept or reject based on their own rating matrix so we will get cDU optimal solution. Due to its distributed nature, no user is forced to share its preference vector with any central entity which ensures user privacy. The extra control messages users are forced to exchange are very light and at a close distance so their overhead is very negligible.

optimal cDERSA: For comparison we have used cDERSA and optimal cDERSA. In cDERSA each cDU assign equal weight to all parameters of its cDU objective functions. In optimal cDERSA, cDUs will assign more weights as required to parameters, like delay-sensitive users will assign higher priority to delay parameter and will ultimately select a cDR offering less delay. Similarly a user interested in achieving higher throughput will assign more weight to users offering higher throughput [37].

A. cDU SATISFACTION

The degree of satisfaction of cDUs is represented in this section. Figure 6 shows average cDU satisfaction with the different number of cDUs trying to obtain cDRs. The proposed optimal cDERSA and cDERSA, are compared with RRSA and DBRSA schemes.

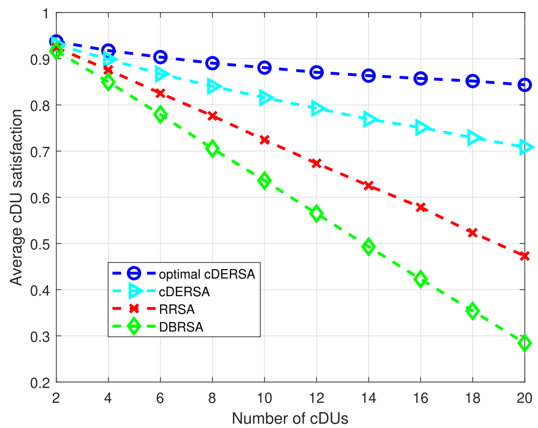


FIGURE 6. Average cDU satisfaction at different number of cDUs.

The results show that both variants of cDERSA outperform RRSA and DBRSA. The proposed algorithm by cognition performs better at higher user density with respect to other implemented algorithms. At cDU = 8 optimal cDERSA performs 25.7% better the DBRSA, 11.39% better than RRSA and 4.7% better than cDERSA. At cDU = 14 the performance of optimal cDERSA is 74% better than DBRSA, 40.3% better than RRSA and 11.5% better than cDERSA. Similarly, the performance of optimal cDERSA at cDU = 20 is 186.2% better than DBRSA, 69.38% better than RRSA and 16.9% better than cDERSA. This validates the performance gain in terms of cDU satisfaction of optimal cDERSA and cDERSA over DBRSA and RRSA.

Figure 7 shows number of cDUs at different levels of cDU satisfaction for $j = 10$. The proposed optimal cDERSA and cDERSA perform better than RRSA and DBRSA as most cDUs get their highest priority cDRs. For the case, $j = 10$

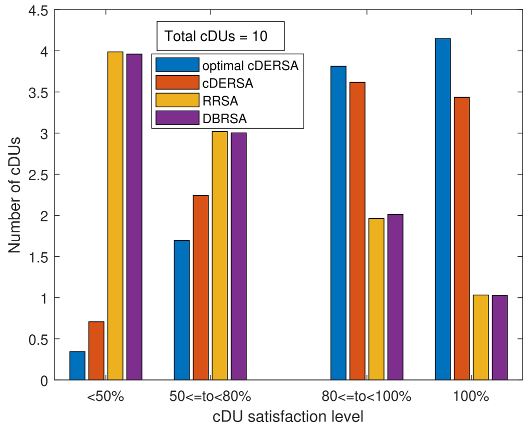


FIGURE 7. Number of cDUs at different cDU satisfaction levels with $j = 10$.

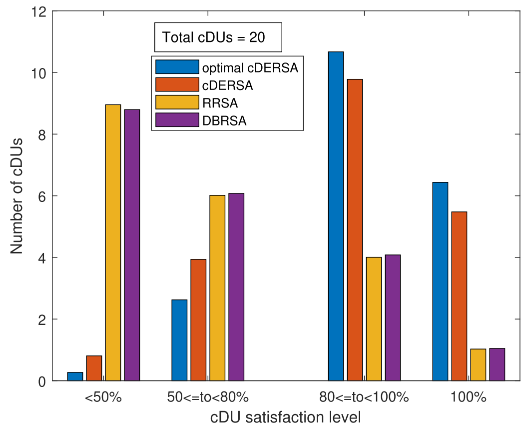


FIGURE 8. Number of cDU at different cDU satisfaction levels with $j = 20$.

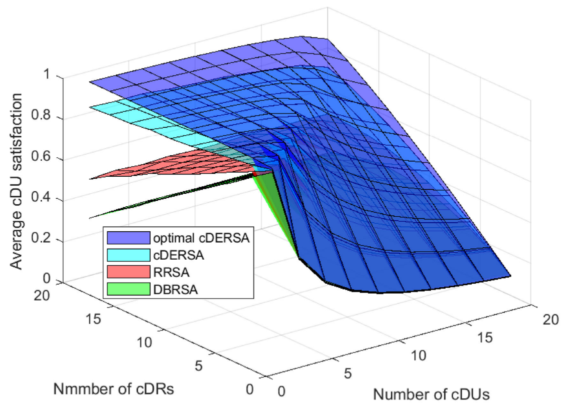


FIGURE 9. Average cDU satisfaction at different number of cDUs and cDRs.

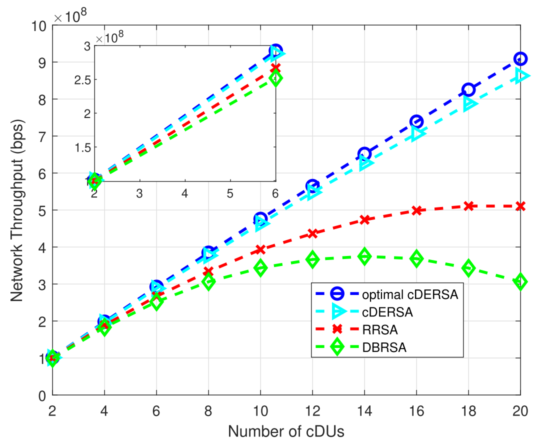


FIGURE 10. Network throughput at different number of cDUs.

more than 80% of cDUs following cDERSA achieve above 80% cDU satisfaction level. On the contrary, 40% cDUs following RRSA and DBRSA achieve less than 50% cDU satisfaction and only 30% achieve around 80% satisfaction level.

Figure 8 shows number of cDUs at different levels of cDU satisfaction for $j = 20$. 55% cDUs following optimal cDERSA achiever more than 80% satisfaction and 35% cDUs following cDERSA achieve 100% satisfaction. In totality, 90% cDUs following optimal cDERSA achieve more than 80% satisfaction, and 80% cDUs following cDERSA achieve more than 80% cDUs satisfaction. The cDU satisfaction of RRSA and DBRSA is much lower and around 75% cDUs achieve less than 80% cDU satisfaction.

In DBRSA all cDUs will try to connect with closest cDR which makes that cDR mostly occupied and most of the cDUs will end up retrying for next closest cDR. This will reduce the cDU satisfaction of DBRSA as most of cDUs needs retry several time to acquire cDR. The behavior of RRSA is little better due to randomly selecting cDRs for relaying their data. The optimal cDERSA and cDERSA performs better because every user develops its own rating matrix based on (11). This validates the superiority of proposed optimal cDERSA and cDERSA in terms of user satisfaction better over RRSA and DBRSA.

The Average cDU satisfaction for different number of cDUs and cDRs is presented in Figure 9. The figure shows the superiority trend of optimal cDERSA and cDERSA over RRSA and DBRSA. The graph presents the minimum cDU satisfaction when cDUs are maximum and cDRs are at their minimum. The graph reaches its maximum cDU satisfaction when maximum cDRs are available to serve cDUs.

B. NETWORK THROUGHPUT

Network throughput in bits per second (bps) is considered in this section up to 1000 Mbps.

Figure 10 shows the total network throughput comparison of optimal cDERSA, cDERSA, RRSA, and DBRSA for the different number of cDUs. At lower cDU density the performance margin is relatively small because cDUs don't have many cDRs to choose from, but at higher cDU density proposed optimal cDERSA and cDERSA performs better than RRSA and DBRSA because in DBRSA mostly cDU will select nearest cDR which will create collision, RRSA will have better response due to random selection. At cDU = 10 optimal cDERSA performs 50% better than DBRSA, 20% better than RRSA and 2.1% better than cDERSA. Similarly at cDU = 14, optimal cDERSA performs 61.5% better than DBRSA, 31.25% better than RRSA, and 3.27% better than

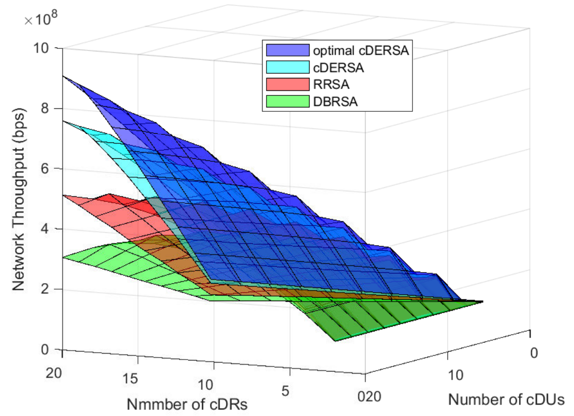


FIGURE 11. Network throughput at different number of cDUs and cDRs.

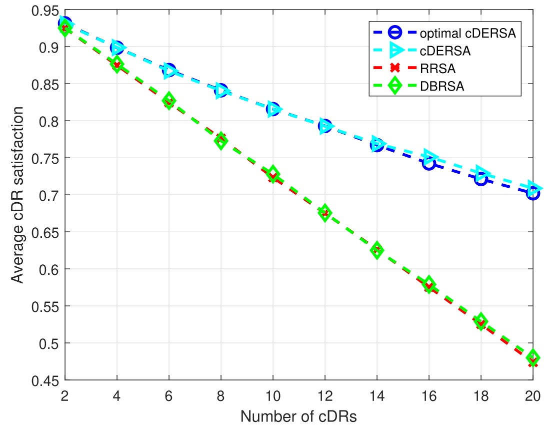


FIGURE 12. Average cDR satisfaction at different number of cDUs.

cDERSA. At a maximum load of cDU = 20, The performance of cDERSA is 193.5% better than DBRSA, 78.4% better than RRSA and 4.59% better than cDERSA.

Network throughput for different number of cDUs and cDRs is presented in Figure 11. The graph shows that at minimum numbur of cDUs and cDRs the network throughput is minimum but with the increase in number of users the throughput also increases. optimal cDERSA and cDERSA shows healthy throughput enhancement as compared to RRSA and DBRSA.

C. cDR SATISFACTION

The primary focus of cDERSA is to find cDU optimal solution but it also caters cDR satisfaction and Figure 12 shows that both variants of cDERSA almost performs the same but achieve much higher cDR satisfaction levels as compared to RRSA and DBRSA because of better cDR contention mechanism which creates less collisions. When the number of cDUs is at 6 the performance of optimal cDERSA and cDERSA is 5.4% better than DBRSA and 4.7% better than RRSA. At cDU = 12 this performance gap increases and reaches 20.45% for DBRSA and 18.65% for RRSA. Finally, at cDU = 20 the performance gap further increases to 48.9% for DBRSA and 52.17% RRSA with respect to proposed optimal cDERSA and cDERSA.

The Average cDR satisfaction at different number of cDUs and cDRs is presented in Figure 13. The result represents that Optimal cDERSA and cDERSA outperforms RRSA and DBRSA, specially at high user density.

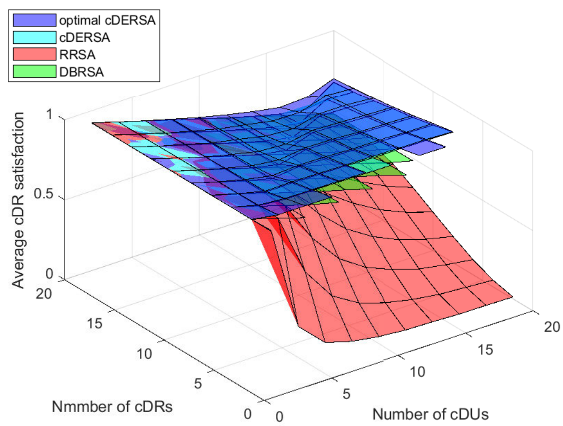


FIGURE 13. Average cDR satisfaction at different number of cDUs and cDRs.

D. DELAY

The delay of the proposed cDERSA is calculated in terms of the mean number of proposals cDU needs to make before successfully obtaining a cDR and is compared at different cDU densities to show its overall effect on the system.

Figure 14 presents the comparison in terms of mean cDU proposals before successfully acquiring cDRs. The quicker cDR is acquired by cDU the sooner cDU will start its data transmission. The comparison of our proposed optimal cDERSA and cDERSA is performed with RRSA and DBRSA and the results show that both variants of cDERSA outperform RRSA and DBRSA almost 3 times faster acquisition of cDRs at full cDU density because of efficient cDR contention mechanism which enables cDR acquisition with less retries. The efficient trend of proposed cDERSA can be observed for all values of cDUs throughout Figure 14.

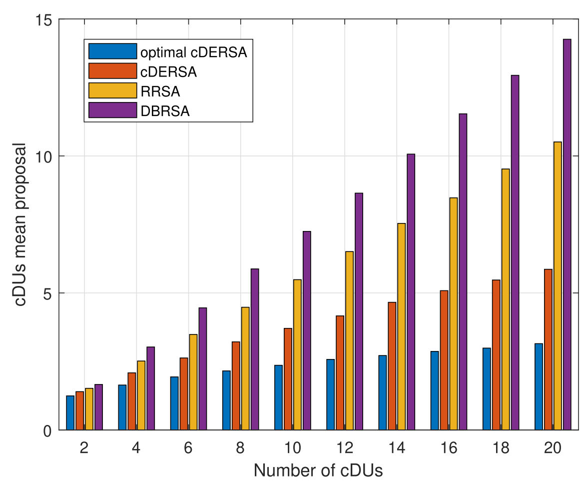


FIGURE 14. Mean number of cDU proposals at different cDU density.

E. PERFORMANCE AT HIGHER CU DENSITY

The performance of optimal cDERSA, cDERSA, RRSA and DBRSA is evaluated at different CU density in this section.

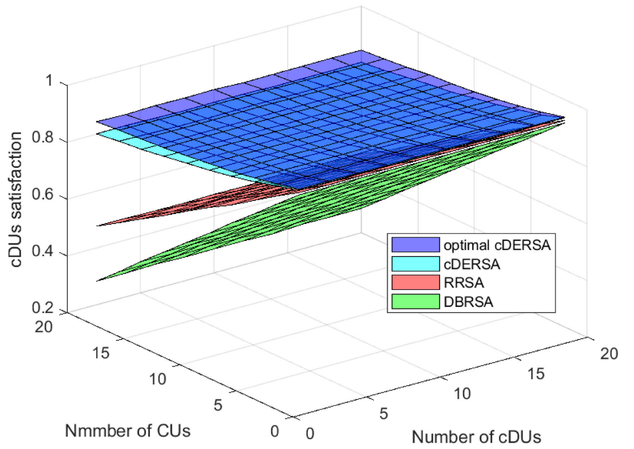


FIGURE 15. cDU satisfaction at different CU and cDU density.

Figure 15 shows the effect of CU load on the cD2D network, at higher CU load our proposed optimal cDERSA and cDERSA performs better than RRSA and DBRSA thanks to opportunistic spectrum access. At CU = 20 and cDU = 15 optimal cDERSA performs 171% better than DBRSA and 65% better than RRSA and 5% better than cDERSA. This shows the capability of the proposed algorithm to exploit the cognitive capabilities of cDUs and result in better user satisfaction and throughput.

VI. CONCLUSION AND FUTURE WORK

In this work, we have developed a relay-capable cD2D communication system to enhance coverage and remove blind-spots from the 5G network. Multi-criterion objective functions are formulated for cDUs and cDRs based on throughput, delay, energy, capacity and incentive. In order to increase the temptation for cDR to act as a relay, a novel incentive mechanism is proposed building upon cellular spectrum sharing and tariff relief. SMP is formulated based on multi-criterion rating and QoS-based weight assignment. Inherited form GSMA, cDERSA is proposed to solve this SMP and obtain cDU optimal cDU-cDR pairs. Monte-Carlo simulations are performed and their results are compared with RRSA and DBRSA. The proposed algorithm achieve higher cDU and cDR satisfaction and enhance throughput, which validate our proposed algorithm in terms of average user satisfaction and throughput. cDERSA also performs better in high cDU density and utilizes opportunistic spectrum access to keep its good performance even at a high CU load. The proposed framework is for one-to-one stable matching which can be extended to one-to-many, where cDU can use multiple relays and relays can serve multiple cDUs. Power control mechanism for multi-hop relays can also be explored. Moreover, It can also be extended for a large number of IoT edge mobile devices enabling multi-hop relaying through advanced machine learning and artificial intelligence algorithms.

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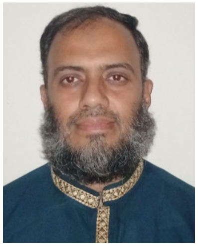

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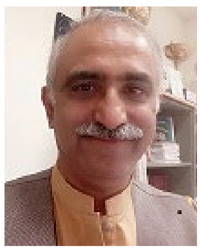

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