International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 9 Sep. 2022, pp: 1204-1215 www.ijaem.net ISSN: 2395-5252

Downlink Resource Allocation Algorithm for Interference Mitigation for Device to Device Communication underlay Cellular Network

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Date of Submission: 17-09-2022 Date of Acceptance: 28-09-2022

ABSTRACT: Over the last decade, mobile communications have continued to record an exponential growth across the world due to increased demand for broadband services, increased number of connected smart phones and consistent improvement in cellular standards. In Africa for example, every family of five can boost of three (3) active smart phones on the average. This rise in the volume of traffic has rekindled researcher's interest in this area; with a common goal of solving endangering problems faced by cellular network. Research has shown that Device-to-Device (D2D) communication which provides communication for proximate user equipments (UEs) without traversing data traffic through the evolved NodeB (eNB), promises to relieve load at the base station (Bs). Apart from that, D2D communication has proved to improve the reuse gain, energy efficiency, link quality and energy efficiency. Regardless of these benefits, interference in cellular network still poses a great challenge. In this work, an efficient downlink resource allocation algorithm was developed to mitigate interference for improved quality of service (QoS) for both cellular and Device-to-Device communication. Simulation results showed that Greedy Heuristic algorithm offered a near optimal performance in terms of sum throughput gain and access rate. Results from the validation showed improvement over that in the literature in terms of access rate and throughput.

KEYWORDS: Interference, downlink, D2D, algorithm, resource, gain, SINR, access rate, throughput

I. INTRODUCTION

Cellular (Mobile) networks have been explained as radio networks deployed over lands through a number of geographic coverage areas called cells. Each of these cells contains at least a low power transceiver known as Base station (Bs). The Bs(s) which replaced high power transmitters used in the past provided support to one or more cell sites and radio spectrum for User Equipments (UEs) within the cell in order to enable UEs (such as cell phones & smart phones) communicate with each other through its network operator. Each UE uses radio spectrum (e.g., LTE) to communicate with the Bs via a pair of radio channels; one for Downlink (DL) (to enable transmission from BS to UEs) and the other channel for Uplink (UL) [1]. The cell's coverage range depends on a number of factors such as Base station's height and transmits power. Due to increase in network density, cellular networks have been undergoing several generational evolutions in order to tackle several technical challenges. Each of these generations is reviewed with the aim of improving its features. According to [2] change may occur in the following: nature of systems, processing speed, technology, frequency, data capacity, application, operation system, and latency. With the unprecedented demand of mobile traffic due to increased number of UEs, 5G mobile networks are anticipated to support 1000 times more data traffic [3]. This exponential growth in the usage of mobile devices has resulted to inadequate spectrum resources and increased power consumed by UEs. The plan of the International Telecommunication Union (ITU) towards 5G after 2020's, has been to achieve high transmission speed. In the light of this, all 5G base stations are expected to provide at least 20Gb/s downlink and 10Gb/s uplink in transmission bandwidth [4]. 5G has been proposed to address the current challenges especially in the area of high data rate, processing speed and power consumed by devices. Currently, a shift in cellular network allows node -to- node (D2D) communication. According to [5], Device-to-Device (D2D) communication is one of the next generations of wireless communication systems (5G) which promises to extend its coverage and increase spectral efficiency. The idea behind D2D communication is to decongest traffic at the BS. D2D communication therefore allows direct communication between two or more proximate devices without passing through a base station (Bs) [6]. This mode of communication contradicts the traditional way of traversing information through the Base station when communication is set up between two CUEs. D2D communication can occur in different modes. The decision on the best mode to use may be influenced by a number of factors: (i) Amount of energy to be consumed. (ii) Link quality (path with less signal loss/noise) and (iii) the load at the Bs (iv) the interference level. Paper [7, 8] highlighted different modes of communication available to DUE to include: reuse (underlay) mode, cellular mode and dedicated (overlay) mode. In Underlay Mode, CUEs share downlink and uplink resources with DUEs. Although, spectral efficiency is improved but then interference is introduced. In cellular Mode, D2D pairs communicate with each other through the BS just like CUE does while in dedicated mode, DUE uses dedicated links which are orthogonal to CUE link. Although interference is bigoted, at the same time spectral efficiency is underutilized.

Under unlicensed industrial and medical (ISM) band, DUEs communicate via Bluetooth, Wifi etc. Having said that DUEs have the choice of selecting their mode of communication all to themselves; mode selection still remains a lingering problem facing DUEs underlay cellular network. This decision making is usually between D2D transmitter and D2D receiver.

However, during mode selection Bs may assist with tasks such as peer discovery and synchronization [9, 10]. According to [11] mode selection involves two main processes: Prose discovery and Prose communication of devices in close physical proximity. During ProSe discovery one of the D2D pairs sends discovery signal which announces to any nearby UE within its proximity of its intention to transmit. After the other UE has acknowledged, both devices exchange their identity. Thereafter, ProSe communication (monitoring) follows suit. This is one of the methods D2D UEs uses in minimizing interference. The traffic load on the cellular system is decreased, the coverage is increased, and performance metrics such as throughput, energy consumption, outage probability, and spectral efficiency are improved. However, the introduction of D2D requires revisiting the resource management techniques used to date for traditional cellular systems. D2D communications generate interference to the CUE if the radio resources are not properly allocated [12]. In addition, multiple D2D pairs sharing the same channel also create mutual interference. For example, when uplink resources are reused by the DUEs in the cell, the BS becomes a victim and receives interference from the D2D transmitters. At the same time, the D2D receivers will receive interference signal from the nearby CUEs. Uplink resources are more favourable because they are usually less utilized compared to downlink resources. Thus, interference management becomes one critical issue for D2D communications underlying cellular networks [13–15]. In this work, a resource allocation algorithm was developed for maximizing the sum throughput gain between the cellular user Equipment (CUE) and D2D pairs and between CUE and Bs without altering the quality of service (QoS) and to efficiently allocate spectrum to communicating devices in cellular network both for uplink scenario.

II. SYSTEM MODEL

2.1 Introduction

This section presents a Greedy Heuristic resource allocation algorithm as a solution to interference menace in D2D communication underlying cellular network. The choice of Greedy Heuristic algorithm is because it provides an optimal solution at each step in selecting a reuse path for CUE and DUE and/or a path with minimum SINR so as to maintain QoS in each sub frame. A scenario where a cell situated at the centre having the UEs (consisting of the CUEs and D2D UEs) round the Bs where considered. The DUE and CUE is assumed to reuse downlink radio resources. The D2D UE known as the secondary user must not interfere with CUE in trying to coexist with CUE. Nevertheless, the problem of resource allocation was Optimized using mixed integer non linear programming (MINLP). Later, a suboptimal solution which exploits the relative channel gains between the BS and user equipments (CUE and DUE) and that between the CUE and DUE were proposed so that resource blocks (RB) can be greedily allocated to D2D users without hampering the CUE.

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2.2 Problem Formulation

Here, a single cell system comprising of one BS with an omni directional single antenna located at the cell center with a circular coverage area of radius R was considered. The scheduling of CUE's resource is done by the Bs by some existing online and offline scheduling algorithm in each sub frame n. The CUEs (CUE1 and CUE2) which communicate directly to the BS in both downlink and uplink are considered as primary users, while DUEs (UE_3R_x and UE_4T_x) are the secondary user and as such, communicate in direct mode. In the system model, R is considered as the number of available resource blocks for the uplink. The number of RBs is the same with the number of cellular user and only one RB can be assigned to each cellular user at any given time. Again, we considered central resource allocation coordination for both the cellular users and the D2D pairs. This model assumed a perfect CSI at the receiver and as such all the channel gains between BS and CUEs, the interfering links between the BS and D2D transmitter as well as the link between the CUE to the D2D receiver are known to the BS before scheduling decisions are taken. Let the Bs serves as a set C = {1, ..., N_c} of cellular users and a set D = {1, ..., N_D} of D2D pairs respectively. Assuming that $N_C \geq N_D$, we can then formulate the problem of assigning appropriate RBs for underlying D2D communication as an optimization problem that achieves higher throughput without interfering with the existing primary users.

2.3 Downlink Resource Allocation System Model and Analysis

When the CUEs and D2D pairs share downlink resources, co-channel interference occurs. Firstly, CUE_1 receives interference from UE_4 (D2D Tx). Secondly, the Bs causes interference to D2DRx (UE_3) as shown in Fig 1.0 below. The interference depends on the transmit power of the base station and channel gains between the D2D transmitter, cellular users and the BS itself.

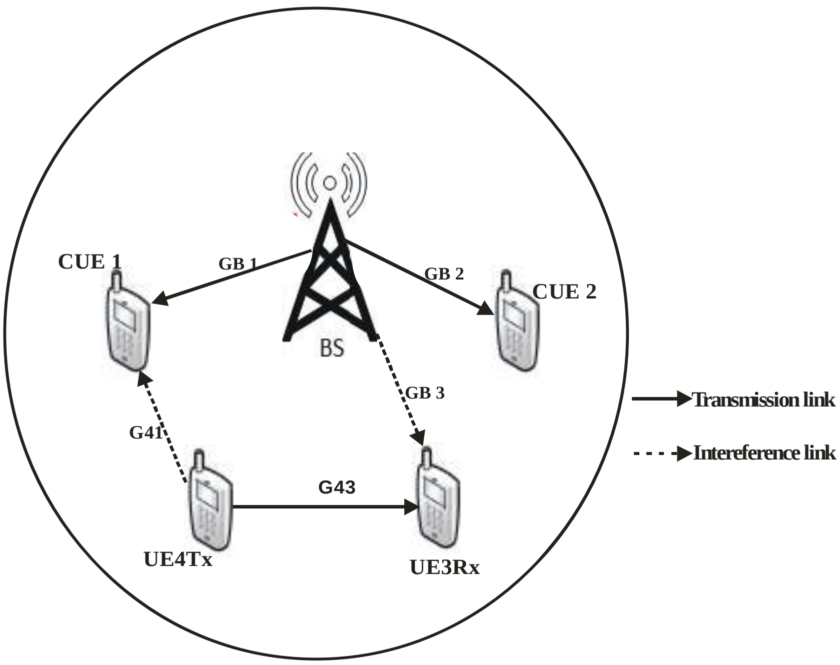

Fig 1.0: Downlink system model for D2D communication underlay cellular network

Recall that the aim is to maximize the throughput gain (achievable rate) of CUEs and D2D pairs while satisfying the requirements of all CUEs in downlink channel scenario. The mathematical model of the achievable rate is designed basically from Shannon's capacity model.

$$C_{AWGN} = B\log_2\left(1+\frac{P_r}{N_o W}\right) \qquad (2.1)$$

If the dth D2D pair shares downlink Resource Block (RB) as the CUE c, the received SINR of the link between CUE_1 (UE_1) and UE_4 Tx can be calculated as:

$$(\gamma_c^{DL}) = \frac{P_B G_{B1}}{N_0 + \sum_d y_c^d P_d G_{41}} \qquad (2.2)$$

Let:
P_B= Base station transmit power
G_{41} = Channel gain at link between UE_4 Tx and the CUE_2
G_{43} = Channel gain at link between UE_4 Tx and UE_3 Rx (D2D pairs).
G_{B3} = Channel gain at link between the Bs and UE_3 Rx.
$G_{B1,}$ = Channel gain at link between the Bs and the $CUE_{1.}$
Assuming that the transmit power is fixed, the received SINR of the link between the Bs and UE_4 (D2D Tx) can be calculated as follows:
Received SINR at Bs (γ_{Bs}^{UL})

$$\gamma_{Bs}^{UL} = \frac{P_c G_{2B}}{N_o + \sum_d x_c^d P_d G_{4B}} \quad (2.2)$$

Similarly, the CU causes the interference to the D2D receiver. The SINR received by D2D UE_3 can be calculated as:

$$\gamma_d^{UL} = \frac{\sum_c x_c^d P_d G_{43}}{N_o + \sum_c x_c^d P_c G_{23}} \quad (2.3)$$

Where
Optimization variable, x_c^d is an indicator function is defined as

$$x_c^d = \begin{cases} 1, & \text{if D2D pairs d reuses RB with CUE c} \\ 0, & \text{otherwise} \end{cases}$$

The maximum achievable rate at the Base station:

$$M_{Bs}^{UL} = W\log_2(1 + \gamma_{Bs}^{UL}) \quad (2.4)$$

Maximum achievable rate at D2D Rx,

$$M_d^{UL} = W\log_2(1 + \gamma_d^{UL}) \quad (2.5)$$

The total system sum rate, $\boldsymbol{R_{sum}^{UL}}$ is expressed as:

$$R_{Sum}^{UL} = (M_{Bs}^{UL} + M_d^{UL}) \quad (2.6)$$

Similarly, since the aim is to maximize total achievable rate throughput which is constrained on P_c = CUE transmit power
P_d = D2D transmit power.
satisfying minimum SINR requirement for both CUE and D2D pairs, a mixed Integer non-linear programming is formulated (MINLP).

$$Maximize \quad \sum_c^C R_c M_{Bs}^{UL} + \sum_d^D \sum_c^C \sum_c x_c^d R_c M_d^{UL} \quad (2.7)$$

$$P_c G_{2B} \geq \gamma_{Bs,tgt}^{UL} \left(N_o + \sum_d x_c^d P_d G_{4B} \right), \forall_c \in C \quad (2.8)$$

$$\sum_c x_c^d P_d G_{43} \geq \gamma_d^{UL} \left(N_o + \sum_c x_c^d P_c G_{23} \right), \forall_c \in D \quad (2.9)$$

$$\sum_c x_c^d \leq 1, \forall_d \in D \quad (2.10)$$

And

$$\sum_d x_c^d \leq 1, \forall_c \in C \quad (2.11)$$

R_c denotes the number of RBs allocated to the cellular user cat each time slot during downlink time. The constraints in (2.8) and (2.9) guaranty the target SINR of the CUE and D2D communication respectively. The constraint (2.10) ensures that each device shares at most one user's RB(s). While the constraint in (2.11) ensures that at most one D2D pair shares any user's RB(s).

M_{Bs}^{UL} and at D2D Rx, (M_d^{UL}) are calculated as using Shannon model capacity. The maximum achievable rate at Bs,

Algorithm 1: Downlink D2D Resource Block Allocation Scheme

1. C: Sorted list of CQIs for all DL UEs in decreasing order
2. D: set of D2D pairs in the network
3. G_{41}: Channel gain between CU c and CU d
4. G_{43}: Channel gain between D2D pair d
5. G_{thresh}: Channel gain threshold value
6. G_{B2}: Channel gain between Bs and CU c
7. G_{B3}: Channel gain between Bs and D2D pair d
8. Pc: Transmit power of CU c

9. Pd: Transmit power of D2D transmitter d
10. Pb: Transmit power of Bs
11. R_c: Number of resource blocks allocated to CU c
12. **Begin**
13. c $\longleftarrow$ 1
14. **while** D ≠ null or c = = C **do**
15. initialize target SINRs of CUE c and D2D pair
16. $\gamma_{c,thresh}^{DL} \longleftarrow G_{thresh}$
17. **If** (c^{th}value = c_{max})select c **else** Return
18. Find the D2D user d with minimum channel gain;
19. $\gamma_{c,tgt}^{DL} \leftarrow \frac{P_B G_{B1}}{N_o + \sum_d \gamma_c^d P_d G_{41}}$;
20. $\gamma_{d,tgt}^{DL} \leftarrow \frac{\sum_c \gamma_c^d P_d G_{43}}{N_o + \sum_c \gamma_c^d P_B G_{B3}}$;
21. **if** $\gamma_c^{DL} \geq \gamma_{c,tgt}^{DL}$ and $\gamma_d^{DL} \geq \gamma_{d,tgt}^{DL}$ **then**
22. Share all RBs of the UE c with D2D pair d;
23. D = D - {d};
24. **else**
25. **if** $\gamma_c^{DL} \geq \gamma_{c,thresh}^{DL}$ **then**
26. Share all RBs of the UE c with D2D pair d;
27. D = D - {d};
28. **else**
29. Do not assign RB to D2D pair d;
30. **end if**
31. c ←c + 1;
32. **endwhile**

Table 1.0: Notations and Definitions for Uplink RB Allocation

Notation	Definitions
γ_{Bs}^{UL}	Received Downlink SINR at the Bs between CUE1 and DUE_4 Transmitter
γ_d^{UL}	Received Downlink SINR at the dth DUE_3 Receiver
P_B	P_B= Base station transmit power
P_c	P_c = CUE transmit power
P_d	P_d = D2D transmit power.
G_{2B}	channel gain between CUE_2 and base station
G_{43}	Channel gain between the D2D pairs (i.e DUE_3 & DUE_4)
G_{2B}	Channel gain between CUE_2 and Base station
G_{4b}	Channel gain between DUE Tx and base station
G_{1B}	G_{B3} = Channel gain at link between the Base station and CUE_1
M_c^{UL}	Maximum achievable rate of CUE during uplink
M_d^{UL}	Maximum achievable rate of DUE receiver during uplink

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UE_4 Tx	Device –to - Device transmitter
UE_3 Rx	Device – to - Device receiver
CUE_1	Cellular User Equipment 1
CUE_2	Cellular User Equipment 2
x_c^d	Indicator function
R_c	Number of resource Block allocated to CUE in sub frame n during uplink

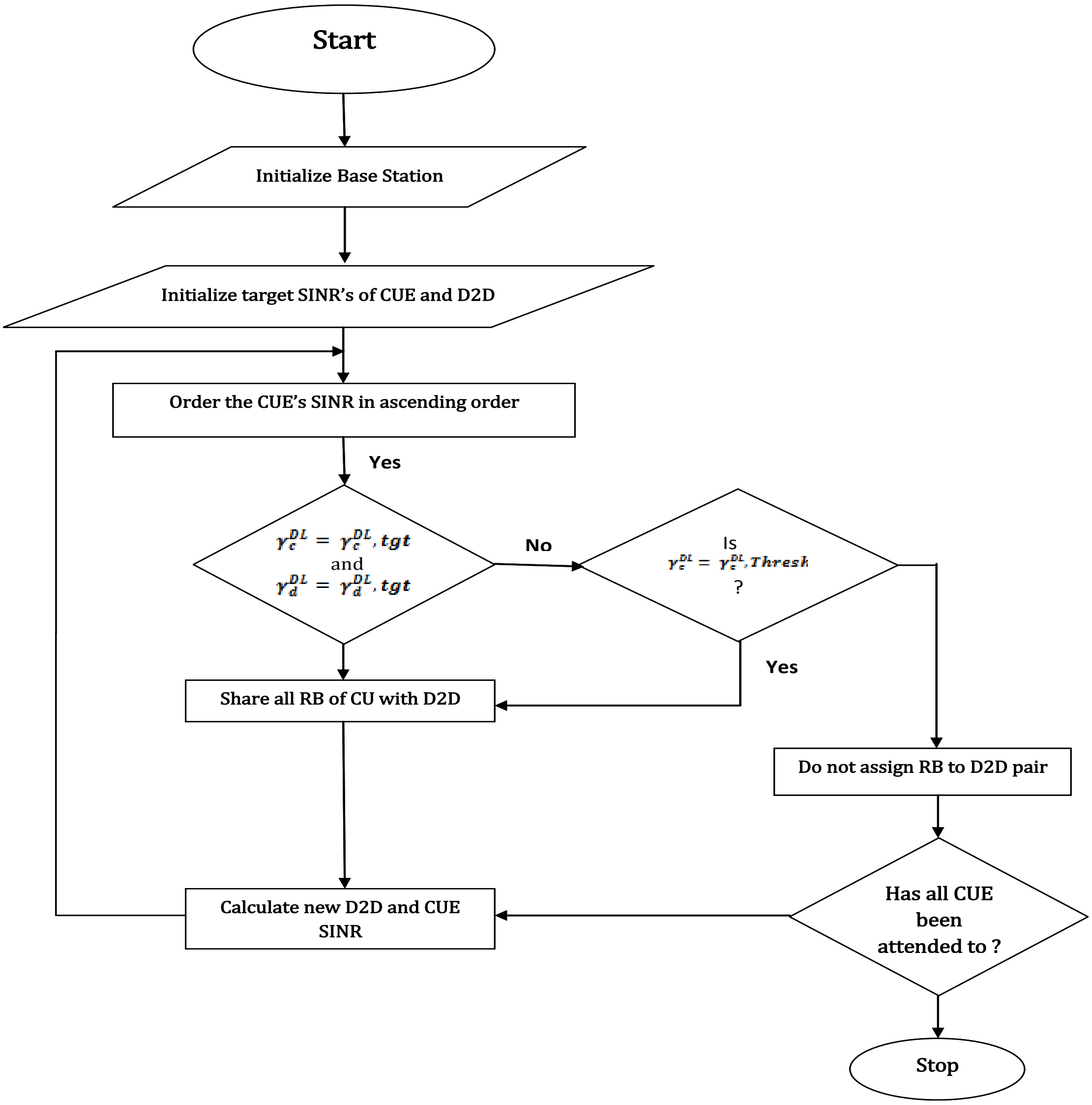

Fig 2.0: Flow chart of Downlink interference mitigation algorithm.

III. NUMERICAL RESULTS AND ANALYSIS

In this work, the simulation was conducted using MATLAB software. The testbed was designed and simulated to emulate real life scenarios. The performance of the developed system was validated using an already existing design by Saied .A. et al (2021). The system is such that the CUEs are

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uniformly distributed, and the transmitter (DUE-Tx) and the receiver (DUE-Rx) of each D2D pair are also uniformly distributed in a cluster. The simulation parameters are shown in Table 2.0.

Table 4.1 Simulation Parameters

PARAMETER	VALUE
Pathloss factor	3.2
Cell radius	1000m
Channel Bandwidth	250kHz
Noise Power	-109dBm
Maximum distance between DUE-Tx and DUE-Rx	10, 20, 30, 40, 50, 60, 70, 80, 90, 100m
Maximum transmit power for CUE	24dBm, 21dBm
Maximum transmit power for DUE-TX	24dBm, 21dBm
Maximum transmit power of eNB	44dBm,41dBm
Maximum Cellular UE's number	50
Simulation type	MATLAB

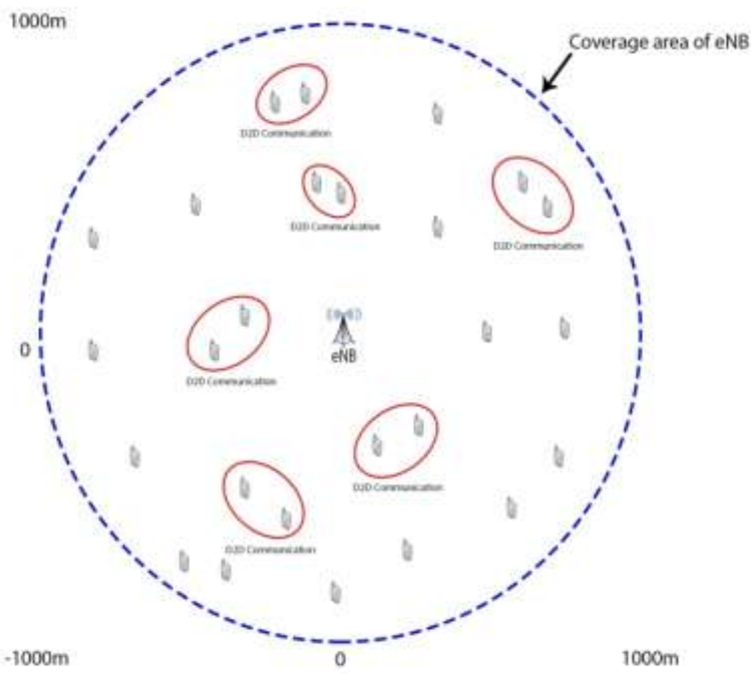

Figure 3.0: Image of D2D network topology and user placement

In this work, two important metrics were used to evaluate the performance and efficiency of the proposed resource allocation scheme. The metrics considered are access rate and the D2D throughput gain.

The access rate explains the rate at which DUE can access resources with CUEs. At the other hand, D2D throughput shows the throughput of the network as a result of the accessed DUEs.

3.1 Uplink Resource Allocation Scenario

In this scenario, when the uplink resources are being reused by the DUEs in the cell, the eNB receives interference from the D2D transmitters. Also, the D2D receiver would also receive interference signal from the nearby CUEs. By reusing uplink resources, interference can be minimized as the interference can be better handled by the eNB. The performance of the DUEs in terms of access rate and D2D throughput gain at various minimum value of SINR for the uplink scenario will be evaluated using Matlab. The results of the simulation are shown from figure 4.0 to figure 6.0 below.

3.2. Evaluation of Access rate and distance between D2D pair with varying minimum SINR

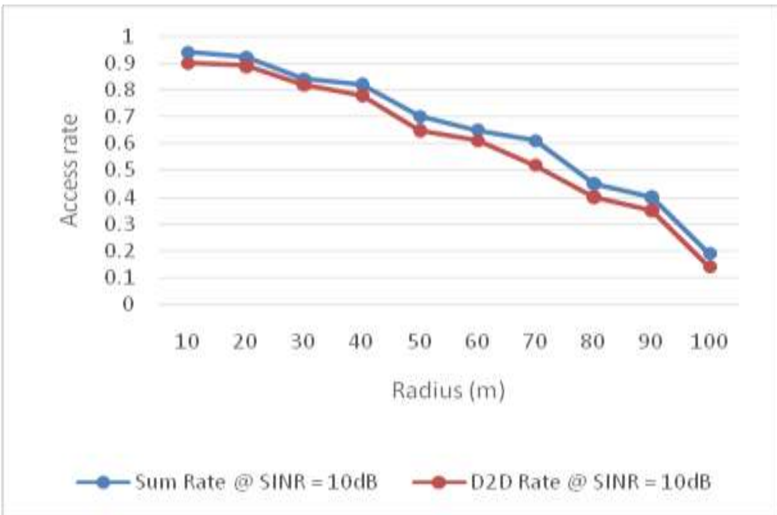

Figure 4.0: Access rate of system when the minimum SINR was 10dB with CUEs = 25 and DUEs = 15 for uplink scenario.

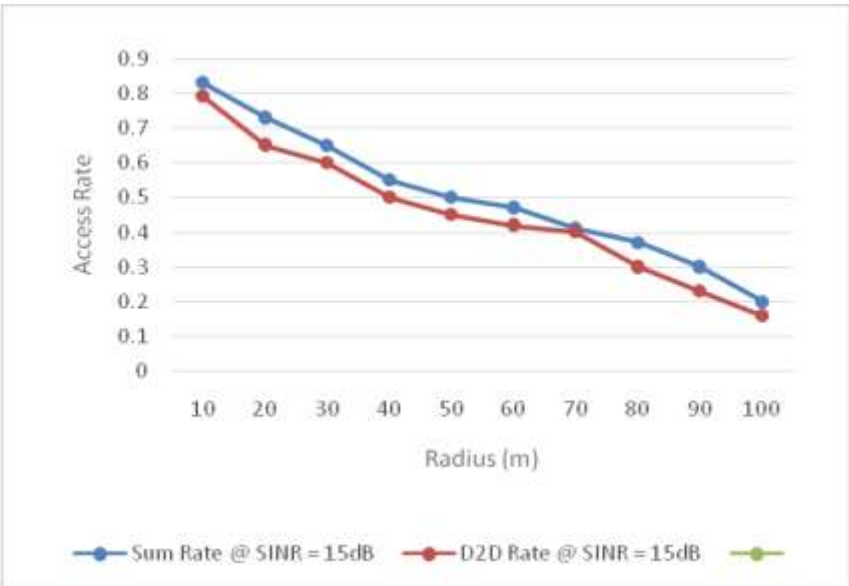

Figure 5.0: Access rate of system when the minimum SINR was 15dB with CUEs = 25 and DUEs = 15 for uplink

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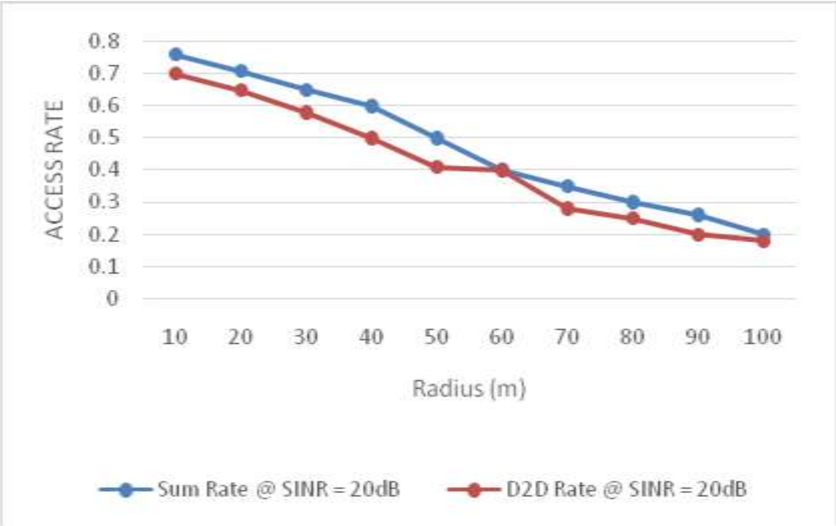

Figure 6.0: Access rate of system when the minimum SINR was 20dB with CUEs = 25 and DUEs = 15 for uplink

From figure 4.0 to figure 6.0, it was observed that in the uplink scenario, as the SINR requirement increased, the access rate of the system was reduced. This action allowed more DUEs to be admitted, which would share the same channels with CUEs, and consequently increasing the access rate and vice versa. The impact on the D2D throughput gain is as shown from figure 7.0 to 9.0.

3.3. Evaluation of D2D Throughput gain and Distance between D2D pair with varying SINR

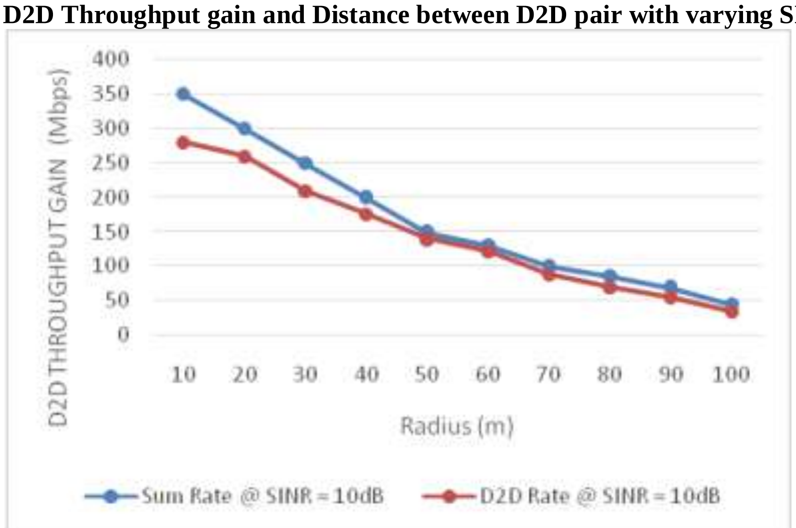

Figure 7.0: D2D Throughput gain of the system when the minimum SINR was 10dB with CUEs = 25 and DUEs = 15 for uplink.

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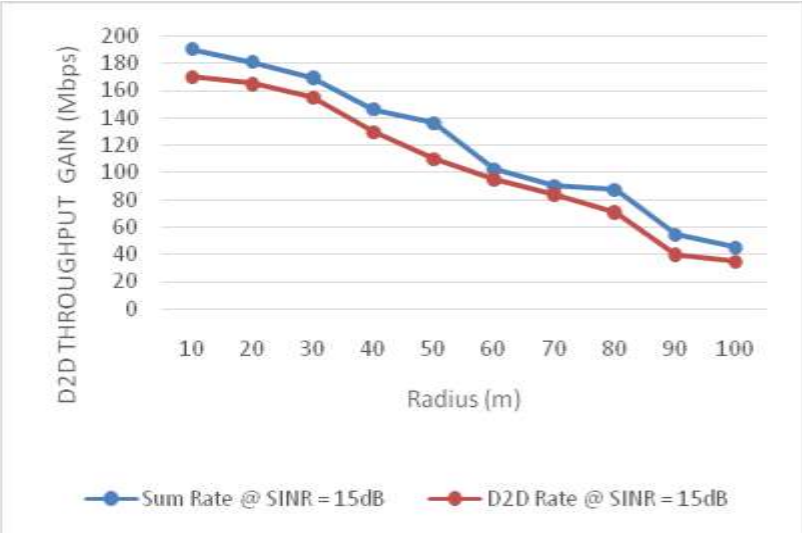

Figure 8.0: D2D Throughput gain of the system when the minimum SINR was 15dB with CUEs = 25 and DUEs = 15 for uplink.

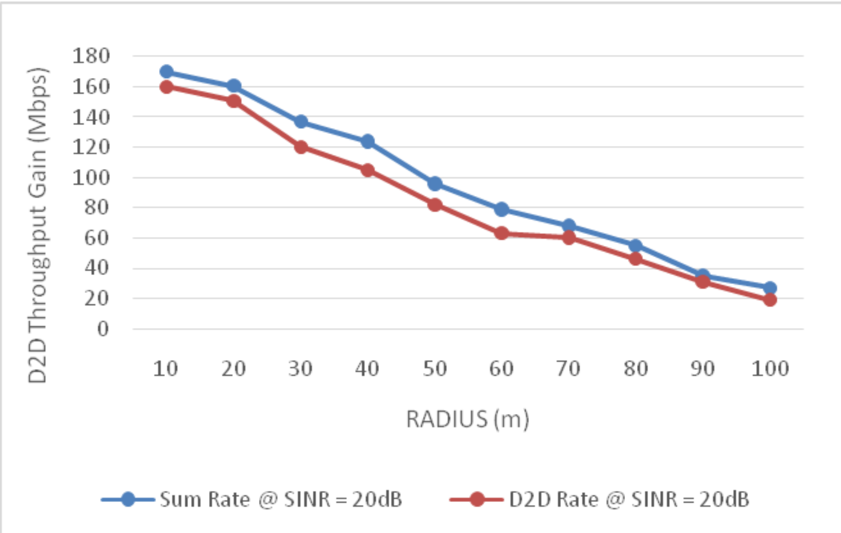

Figure 9.0: D2D Throughput gain of the system when the minimum SINR was 20dB with CUEs = 25 and DUEs = 15.

The results obtained from figure 7.0 to figure 9.0 also shows that as the SINR requirement increased, the D2D throughput of the system was reduced for uplink scenario. Also, when the SINR requirement was reduced, the D2D throughput of the system increased. Note that the reduction in the SINR requirements for users led to an increase in the maximum allowable interference for the eNBs. This action allowed more DUEs to be admitted into the system, thus increasing the D2D throughput gain.

3.4. Validation of the developed Algorithm

The performance of the developed algorithm in this work was validated with that done by Çelik A. et al (2017), on the impact on the D2D throughput gain for different SINR requirement was compared to the result obtained by

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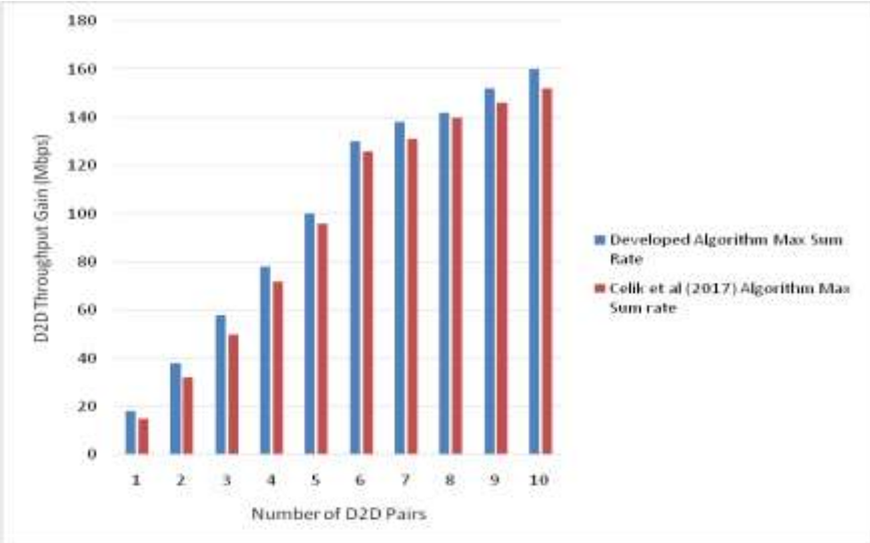

Figure 10.0: Graph showing the compared D2D throughput gain at different number of D2D pairs.

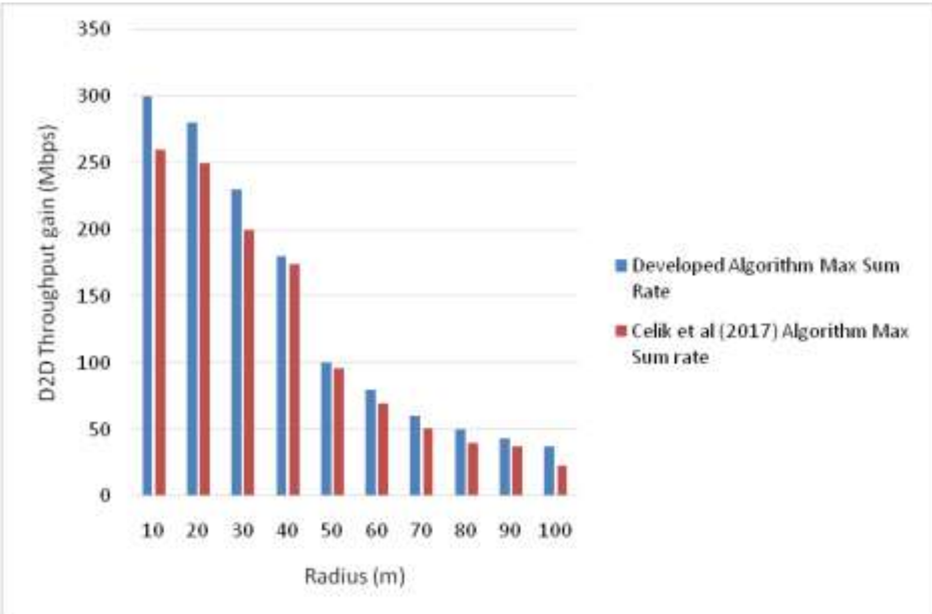

Figure 11.0: Graph showing the compared D2D throughput gain at different radius

Figure 10.0 and figure 11.0 shows the D2D throughput gain for the developed algorithm in comparison with the other algorithms, under different numbers of DUEs and distance separating DUE_{Tx} and DUE_{Rx}. The results obtained showed that the developed method outperformed the method by Çelik A. et al (2017) for both instances. Although the two methods leveraged the greedy heuristic algorithm, the method used in this work increases the achievable throughput by introducing an additional threshold for minimum SINR requirement, such that the throughput is increased as the access rate is increased. For instance, in figure 10.0, when the number of DUEs was 10, the developed method showed a throughput gain of 160Mbps, while that of Çelik A. et al (2017) showed a throughput of 152Mbps. This represents a 5.3% improvement over the method by Çelik A. et al (2017). Also, when the maximum distance between the DUE-Tx and DUE-Rx was 100m, the developed method showed a throughput gain of 37Mbps, while that of Çelik A. et al (2017) showed a throughput of 23Mbps. This represents a 60.9% improvement over the method by Çelik A. et al (2017).

IV. CONCLUSION

The current data explosion has consistently posed a significant challenge for current cellular networks, and has pioneered several advances in the architecture of mobile networks. Many 5G solutions have been proposed with the goal of either increasing the efficiency of existing resources or providing new radio resources or infrastructure. This work when implemented will minimize interference which limits communication of DUE underlay cellular network. As a result, improve the overall throughput of the network and the QoS .

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