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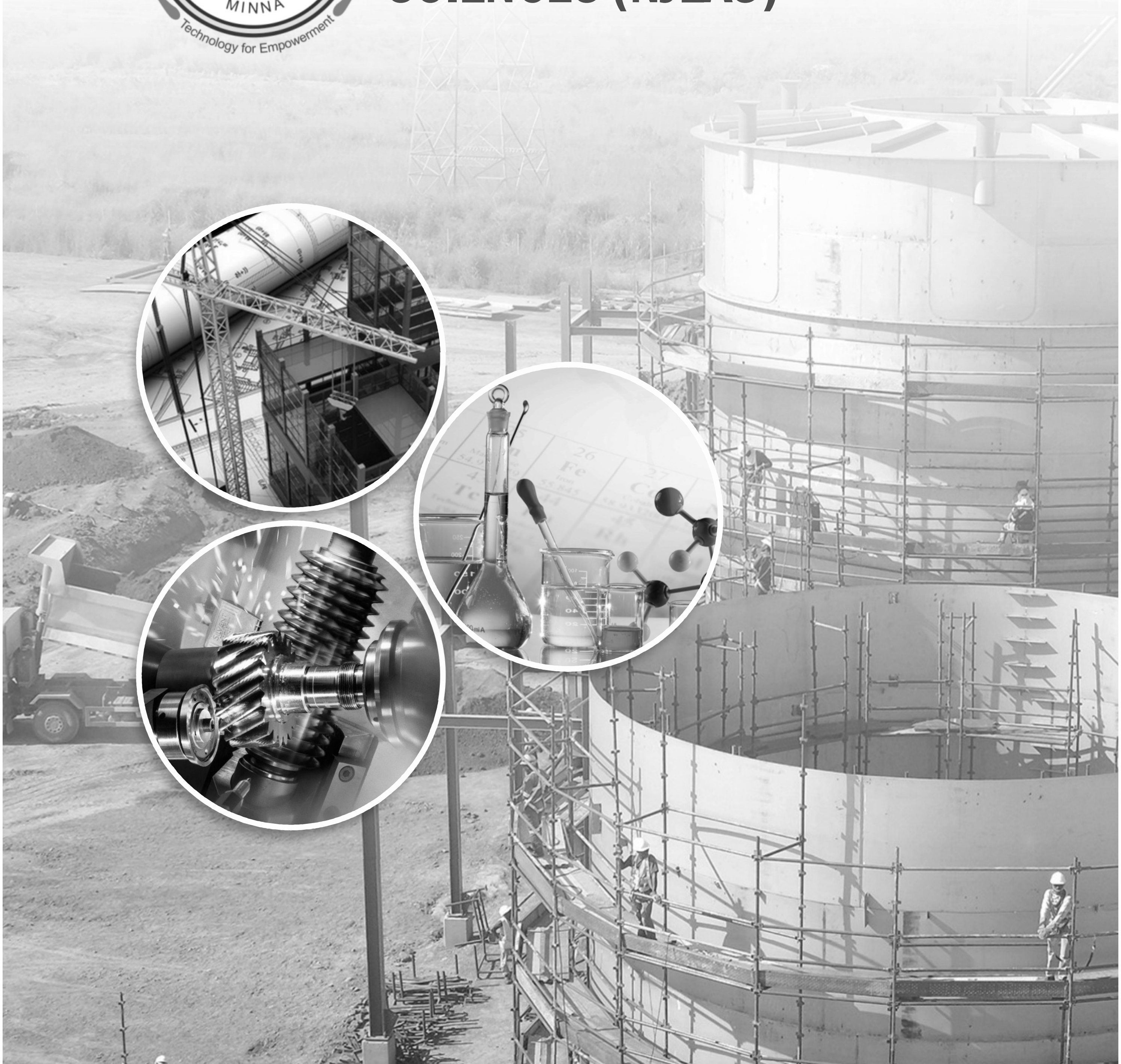

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INTEGRATED MODE SELECTION AND BANDWIDTH ALLOCATION SCHEME FOR INTERFERENCE MITIGATION IN D2D NETWORKS

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Abstract

As the steep growth in mobile data traffic continues to gain lots of attention in recent years, discussions of the next generation of mobile networks - the fifth generation (5G), have gained significant traction both in the academia and industry. In addition to more capacity, stringent requirements for improving energy efficiency, decreasing delays, and increasing reliability have been envisioned in 5G. Many solutions have been put forward, one of them being Device-to-Device (D2D) communications where users in proximity can communicate directly with one another. Interference management between Cellular User Equipment (CUE) and D2D user Equipment (DUE) is one of the most critical issues when D2D is introduced to cellular network because D2D users share the same licensed spectrum with cellular users. This work considers an overlaying network scenario where a Mode Selection and Bandwidth Allocation Scheme (MS-BAS) is developed to mitigate cross-tier interference, while delivering an average data rate of more than 50 Mbps across the network, indicating an over 12% improvement when compared with the existing Selective Overlay Mode Operation (SOMO). The results obtained show the efficacy of the algorithm in significantly mitigating cross tier interference in the network.

Keywords: Interference mitigation, cross-tier, D2D communication, User Equipment.

INTRODUCTION

With an ever-growing number of connected devices using the cellular network, service providers are faced with the challenge of improving spectrum reuse, throughput, energy consumption, coverage, and reduction of end-to-end latency. Network performance would rise if closely located user pairs are allowed direct communication with each other, rather than through the traditional Up-link and Down-link communication channels of the Base Stations (BS) (Safaei *et al.,* 2017). Additionally, the creation of new peer-to-peer services and location-based applications would all be driven by an efficient Device-to-Device (D2D) communication system, which incidentally, is one of the identified enabling technologies for the 5G cellular network. This, of course, comes with its challenges, chief among which is interference between the User Equipment (UEs). With enabled D2D communication between devices in proximity, there would be an introduction of interference between D2D User Equipment (DUEs) and other D2D Users, known as Co-Tier Interference, as well as interference between D2D users and traditional Cellular User Equipment (CUEs), the Cross-Tier Interference.

There are numerous problems inherent with Macro-D2D Heterogenous Networks which include handover, neighbour discovery, security, interference, mobility management, etc. (Asadi *et al,* 2014). This research focuses on the mitigation of cross-tier interference in the two-tiered network, by developing schemes towards the optimization of throughput.

In this work, a Mode Selection and Bandwidth Allocation Scheme was developed to mitigate cross-tier interference in the network, and the performance of the scheme was evaluated through simulations on MATLAB and comparison with related works.

Interference Management

Interference is an undesired signal picked by neighbouring receivers. It has a mathematical relationship with signal-to-interference-plus-noise ratio (SINR), throughput and transmit power as expressed below:

i. $Interference \propto transmit\ Power$

ii. $Interference \propto \frac{1}{throughput}$

iii. $Interference \propto \frac{1}{SINR}$

iv. $Interference \propto \frac{transmit\ power}{SINR * throughput}$

Enabling D2D links within a cellular network pose a big threat of interference to the cellular links in the network. D2D links can cause interference between cellular users and D2D users, resulting in an increase in co-tier interference. Cross-tier interference is also possible with D2D communication underlaying cellular communication. Interference can be mitigated through mode selection, optimum resource allocation, and power control. Setting the maximum transmit power limits of the D2D transmitter is an effective technique of limiting the interference between DUEs and CUEs (Noura and Nordin 2016). A general scenario of interference in D2D underlayed cellular networks is depicted in Fig. 1:

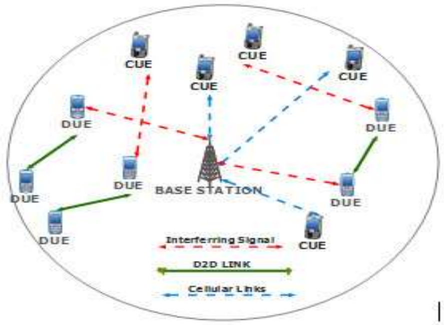

Fig. 1: An interference scenario in D2D underlayed cellular network.

Some interference mitigation techniques are briefly described below:

Bandwidth Allocation

The easiest way to coordinate the cross-tier interference between the cellular and device tier is to use bandwidth allocation, which will simplify the interference between DUEs and CUEs. Cho and Jantti (2013) used bandwidth allocation, where the spectrum band was divided into two parts, as shown in Fig. 2. One part would be dedicated to CUEs and the other part would be assigned to DUEs. However, effective resource allocation in heterogenous networks is required to balance the amount of bandwidth assigned to DUEs and the amount of bandwidth to be allocated to CUEs. A large amount of bandwidth allocated to CUEs will enhance the throughput of CUEs; nevertheless, this improvement is achieved at the expense of DUEs. Similarly, allocating a large amount of bandwidth to DUEs increases the throughput of DUEs but the throughput of CUEs will decrease (Shami *et al.*, 2019).

Investigation shows that the existing interference mitigation techniques are broadly categorized as centralized, distributed and semi-distributed (Barik *et.al,* 2020). Although both centralized and distributed methods have benefits and drawbacks, trade-offs can be made between them. Interference management strategies of this type are referred to as semi-distributed or hybrid. Various levels of participation can be established in the strategies of semi-distributed interference management. Such strategies can be appropriate for relatively massive networks (Alzubaidi *et al.,* 2022).

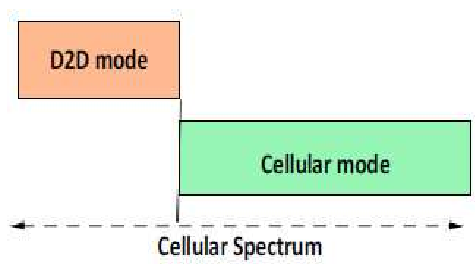

Fig. 2: Spectrum Allocation

Power Control

Although higher transmit power of D2D users can provide wider coverage and better signal quality, it can, at the same time, cause tremendous interference to the cellular network. The power control (PC) mechanism is one approach to deal with cross-tier interference generated from DUEs to the cellular network for both the UL and the DL case, as well as the co-tier interference between DUEs in a two-tiered cellular network with D2D communication. It coordinates the interference imposed by DUEs to the cellular network and the interference from a DUE to a neighbouring DUE by controlling the transmit power levels of DUEs to improve system capacity, coverage, and reduce power consumption (Koushik and Shahedur, 2021). To meet these goals, PC schemes aim at maximizing the transmit power and at the same time limiting the generated interference, but they may lead to increased power utilization or degraded energy efficiency of the system (Nasser *et al,* 2019).

Mode Selection

Selecting transmission mode (Cellular or D2D mode) is one of the difficult tasks in communication for potential D2D users after discovery. Although they may be in proximity to each other, it might not be optimal for them to operate efficiently and effectively (Alquhali *et al*., 2020 and Ansari *et al.,* 2018). Therefore, mode selection enables the BS and the D2D users to decide which communication mode to operate in, based on some distinguishing criteria like interference among D2D pairs, distance between D2D pairs, and Cellular users. The quality of the channel condition and Signal-to-interference plus noise ratio (SINR) is one of the most common selection metrics. Predefined SINR threshold is often considered as the mode selection criteria for D2D communication. Therefore, proper mode selection determines the performance of D2D communication (Librino & Quer, 2018).

Each of the communication modes affects the amount of interference between cellular users and D2D users or between multiple DUEs (Chen *et al,* 2018).

Related Works

Zhai *et al.* (2017) proposed a unified resource management scheme to minimize the total transmit power of all UEs by jointly optimizing mode selection, resource allocation, and power control, to tackle the incidence of interference and power consumption by UEs arising from complicated spectrum sharing pattern. The work achieved an enhancement of energy efficiency and network capacity, although it was not validated through comparison with other schemes.

Yang *et al*. (2017) considered the effects of both the interference caused by the generic D2D transmitter to others, and the interference caused by all others to the generic D2D receiver. The work achieves higher energy efficiency compared with the blind power control scheme, although increasing the energy means increasing the interference and hence decreases the spectrum efficiency.

Swetha and Murthy (2017) proposed the resource management scheme in overlay D2D network where bandwidth is allocated to D2D overlay devices by the base station, based on the bandwidth resource blocks earmarked for D2D mode. The challenge is the maximization of the reserved bandwidth if not optimally utilized. When the resource block assigned for D2D mode is exhausted the base station assigns subsequent UE to CUE mode. Equations (1) and (2) were used to compute both line of sight (LOS) and non-line of sight (NLOS) pathlosses for the transmissions.

$$P_{LOS} = 65 + 21log_{10}(d) \quad (1)$$

$$P_{NLOS} = 71.1 + 34log_{10}(d) \quad (2)$$

The static allocation of bandwidth to communication tiers without recourse to the number of UEs per tier was a limitation of this work. This lead to wastage of scarce spectral resources, leading to degraded data rates.

Li *et al*., (2018) considered a relay mode for D2D UEs. Additionally, they proposed an evolutionary game-based approach for D2D mode selection in order to address a potentially large population of DUEs. The evolutionary game was formulated with a utility function that takes into account both the achievable throughput of DUEs and the radio resource consumption. The work yielded a higher number of D2D connections than the baseline schemes, although it did not consider other D2D communication modes.

Li (2019) proposed SFR for both the licensed and unlicensed band. Using unlicensed band that considers resource allocation based on SFR gives a good design.

Song *et al.* (2019) adopted an interference limited area control method; this constraint is used to reduce interference between D2D communication and cellular network.

Hassan and Gao (2019) proposed an Active Power Control (APC) technique, which not only reduces cross-tier interference in a Macro User Equipment (MUE), generated from the downlink transmission power of an inadequately deployed femtocell, but also reduces unnecessary power consumption to achieve a green femtocell network. The work, however assumed all UEs were static throughout their simulation. This is very unrealistic in a mobile communication network.

Gao *et al*. (2019) proposed an energy-efficient resource block (RB) assignment and power control strategy for underlay device-to-device (D2D) communication in multi-cell networks, where more than one D2D pair is allowed to share the same RBs with cellular user equipments (CUEs). Although there was significant reduction in energy loss, there was inconsistency in network energy efficiency, as it first increases and then decreases when the transmit power increases.

Adejo *et al*. (2020) employed SFR to adequately model an interference frame considering the overlapping bandwidth allocation. The result obtained allowed BS to be tuned to achieve desired network performance which may be a disadvantage.

Authors in Rana *et. al.* (2021) proposed two D2D interference mitigation scheme referred to as power control scheme 1 (PCS1) and power control scheme 2 (PCS2) which both centred on the difference between computed SINR and target SINR to basically mitigate interfernce caused by number of D2D pairs in a D2D cellular communication network. The difference between the two Power Control Schemes is in the scaling factors used. In PCS1 a scaling factor of 2 dBm was used and that of PCS2 used power scaling factor of 3 dBm. Equation (3) was used in computing the path loss between different communication paths; from D2D Transmitter (D2DT) and macro base station during uplink transmission or from macro base station to D2D Receiver (D2DR) during downlink transmission.

$$PL_{diff_{layer}}(dB) = 128.1 + 37.6 * logd(KM) \quad (3)$$

where $PL_{diff_{layer}}(dB)$ is path loss either base station to D2DR or from D2DT to CUE, d is the distance between transmitter and receiver in *Km*. Equation (4) was used to measure the path loss between D2D communication path.

$$PL \quad (dB) = 148 + 40 * logd(Km) \quad (4)$$

SINR was computed using (5) and compared with the target SINR value:

$$\gamma_B = \frac{P_x G_x}{\sum_1^N wP_y G_y + N_o} \quad (5)$$

where γ_B is receiver's SINR, P_x is desired transmit power of D2DT, G_x is channel gain when considering the desired transmitter and receiver. P_y is the transmit power of aggressor, G_y is the channel gain of aggressor, N_o is noise and w is an SINR factor that is either 0 when D2D and CUE do not use the same resources otherwise it is 1.

When γ_B is greater than target SINR, the next transmit power will be less than the present power by power scaling power within the range of accepted minimum and maximum transmit power. When γ_B is less than the target SINR, the next transmit power will be greater than the present power by same power scaling factor. And when γ_B is equal to the target SINR, the next tranmit power will be the same with the present transmit power.

Although the power control schemes were consistent in their output, they, however, utilized very high power for their operation. This lead to increased noise and interference. Energy consumption by the UEs was also high, and the pathloss model used also lead to high losses when compared with other works.

From these reviews, it is evident that a lot of work has been done towards the mitigation of interference in D2D enabled networks, using a wide variety of schemes ranging from mode selection, resource block assignment, soft frequency reuse, etc., to power control, link adaptation, as well as a combination of two or more of the schemes. Some of the works yielded good results, but with complex or cumbersome methodologies. Energy inefficiency, as well as ease of system manipulation (simplicity of system parameters) were partly or wholly lacking in various schemes. Being the primary users of the network, the cellular tier of the Macro-D2D network tended to receive greater priority in bandwidth allocation schemes, which was simply borne of the assumption that more users would be operating in cellular mode, whereas this might not always be the case. This assumption led to spectrum wastage, as well as the partial loss or complete non-realization of such benefits of D2D connections as coverage expansion (more connections within the network), energy conservation (especially from less pressure on the base station), reduced latency (improved response time), improved data rates (due to spectral efficiency), improved signal quality (due to higher SINR), as well as reduced interference within the network.

RESEARCH SYSTEM MODEL

The research system model as shown in Fig. 3 captures transmission in cellular communication. It gives an illustration of D2D communication between a D2D user equipment (DUEs) and communication between a cellular user equipment (CUE) and its serving base station.

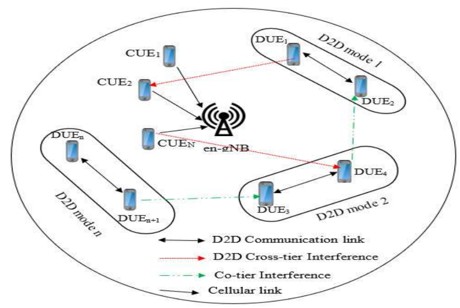

Fig. 3: Research System Model.

The simulation of the D2D communication schemes on MATLAB was guided by the research system parameters in Table 1, where cellular user equipment were represented as $CUE_1, CUE_2 \ldots CUE_N$; macrocell base station as $en - gNB$; and D2D user equipment as $DUE_1, DUE_2\, DUE_3$, $DUE_4 \ldots CUE_{n,}\, CUE_{n+1}$ The system pictured co-tier interference scenario were signal from neighbouring D2D pair is received as interference by nearby D2D pair and cross tier interference as a result of common bandwidth shared among macro – tier and D2D-tier network. Table 1 presents the system parameters sourced from referenced literatures, viz (Swetha and Murthy, 2017), and (Rana *et al.,* 2021).

Table 1: System Parameters

No.	Parameter	Value
1.	Minimum transmit power of UE (DUE and CUE)	0 dBm
2.	Maximum transmit power of UE (DUE and CUE)	23 dBm (Rana *et al*., 2021)
3.	System bandwidth	60 MHz
4.	Carrier frequency	2.6 GHz (Rehman *et.al.,* 2020)
5.	Thermal noise density	-174 dBm/Hz (Rana *et al*., 2021)
6.	Number of macrocells	1
7.	Number of D2D pairs	1 – 10
8.	Initial transmit power of CUE and DUE	20 dBm
9.	Target D2D distance	10m
10.	Target SINR for DUEs	0 dB

Mode Selection and Bandwidth Allocation Scheme (MS-BAS)

The mode selection and bandwidth allocation begins with communication mode selection, which is determined based on receiver's SINR and distance between transmitting UE and receiving UE. While the bandwidth allocation phase of the scheme is centered on the mode of UE communication, and the number of UEs in that mode. Being the primary users of the network, a greater priority is given to CUEs during bandwidth allocation; they receive a higher reserve of the bandwidth at 60%, while 30% is reserved for D2D communication. The number of UEs in D2D mode determines the allocation of the remainder 10% bandwidth.

Fig. 4 is the block diagram of the MS-BAS.

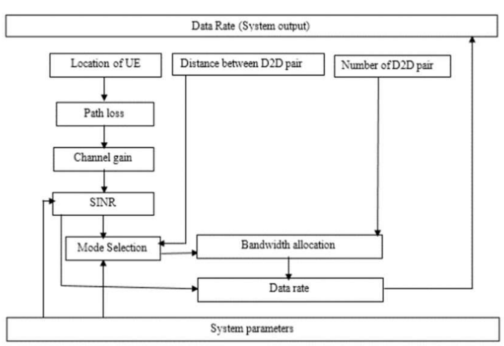

Fig. 4: Block Diagram of the MS-BAS.

From Fig. 4, the path loss block works with inputs from location of UE and specified path loss model to compute the propagation path loss between a transmitter and receiver. The path loss model for D2D communication is presented in equation (6) adopted from Swetha and Murthy (2017); and that of cellular communication is captured in equation (7), Jiale *et al.,* (2018); Zhao *et al*., (2018); Hassan *et al*., (2018).

$$L_{D2D} = 65 + 21log_{10}(d(m)) \quad (6)$$

$$L_{cell} = 15.3 + 3.7log_{10}(d(Km)) \quad (7)$$

where *d* is the distance between the transmitter and the receiver.

The channel gain block computes the propagation channel gain based on computed propagation path loss between a transmitter and a receiver, using equation (8) Onu *et al*., (2018); Zhao *et al*., (2018); Swetha and Murthy (2017).

$$G = 10^{(-\,Path\ loss)/_{10}} \quad (8)$$

The SINR block computes the receiver's SINR using specified thermal noise value from system parameters block, channel gain and SINR mathematical model in equation (9) (Junjie *et al*., 2021; Jiale *et al.*, 2018; Xiaoqin, and Yang 2018).

$$SINR_{rx} = \frac{P_{tx}G_p}{\sum_{co=1}^{co=n} P\prime_{tr}G\prime_p + \sum_{cx=1}^{cx=n} P\prime_{tr}G\prime_p + N_o} \quad (9)$$

Where:

$SINR_{rx}$ = receiver's SINR,

P_{tx} = desired transmit power,

G_p = channel gain between transmitter and its receiver,

P'_{tr} = interfering signal transmit power,

G'_p = propagation channel gain of the aggressor and its victim,

N_o = thermal noise,

$\sum_{co=1}^{co=n} P'_{tr} G'_p$ = summation of all co-tier interfering signals in the network, and

$\sum_{cx=1}^{cx=n} P'_{tr} G'_p$ = summation of all cross-tier interfering signals in the network.

The number of D2D pairs determines the D2D co-tier interfering signals in the network. For n^{th} D2D pairs, there would be (n – 1) D2D interfering signals. Likewise, the number of CUEs in the network determines the CUE co-tier interference.

The mode selection algorithm determines the mode of communication of all UEs in the network. The criteria for mode selection are based on the distance between D2D pairs, and computed D2D SINR. When the distance between the D2D pair is less than or equal to a target distance of 10m (Swetha and Murthy, 2017), the UE is assigned to D2D mode subject to reference computed SINR, otherwise it is assigned to cellular mode. When the reference SINR of UE is greater than the set target SINR of 0 (Swetha and Murthy, 2017), the UE is assigned D2D mode, otherwise, it is assigned cellular mode.

Equation (10) explains the mode selection mathematically.

$$\begin{cases} if\ d_{D2D} \leq d_{target}\ and\ SINR_{computed} \geq SINR_{target} & assign\ UE\ to\ D2D\ Mode \\ otherwise & assign\ UE\ to\ CUE\ mode \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The bandwidth allocation block assigns bandwidth to both cellular and D2D communication modes. The allocation of bandwidth is centrally done by the base station based on the number of UE in cellular and D2D modes at a particular time. 60% of the network bandwidth is reserved for CUE mode, 30% of network bandwidth is reserved for D2D mode and the remaining 10% is allocated dynamically to either D2D or cellular mode based on the user traffic. When the number of DUEs is greater than or equal to the number of CUEs, the 10% dynamic network bandwidth is allocated to D2D mode; otherwise, it is allocated to cellular mode. The mathematical expression for bandwidth allocation by nodes to either D2D or cellular mode, within a macrocell is presented in equations (11) and (12).

$$if\ N_{DUE} \geq N_{CUE} = \begin{cases} BW_{D2D\ mode} = 40\%\ of\ network\ bandwidth \\ BW_{CUE\ mode} = 60\%\ of\ network\ bandwidth \end{cases} \quad (11)$$

$$if\ N_{DUE} < N_{CUE} = \begin{cases} BW_{D2D\ mode} = 30\%\ of\ network\ bandwidth \\ BW_{CUE\ mode} = 70\%\ of\ network\ bandwidth \end{cases} \quad (12)$$

where N_{DUE} is the number of of DUE, N_{CUE} is the number of CUE, $BW_{D2D\ mode}$ is the bandwidth allocated to D2D mode, and $BW_{CUE\ mode}$ is the bandwidth allocated to cellular mode.

The mode selection and bandwidth allocation scheme allocate spectrum to UEs based on the communication mode of the UEs. When the computed SINR is greater than the target SINR, and their distance apart is not greater than the target distance, the two UEs will proceed into D2D mode of communication and exchange information. Otherwise, the two UEs will communicate in cellular mode.

After mode selection, spectrum is centrally allocated by the base station, based on the distributed traffic density of UEs on the network. UEs periodically update the base station with their current operating mode, so that it maintains an updated number of UEs in a particular mode (D2D or cellular) per time. The base station reserves 60% of the spectrum for CUEs, and 30% for D2D. The remaining 10% is dynamically allocated based on the conditions in equations (11) and (12) to minimize spectrum redundancy in the network. The number of DUE is limited by distance of D2D devices, which often accommodate less UE compared to CUE mode. To avoid large quantity of bandwidth been redundant; 30% of the system bandwidth was allocated to DUE; being the secondary users, as its fixed operating bandwidth. 60% of the system bandwidth was allocated to CUEs being the primary users, where number of UEs operating in such mode is not restricted by distance between transmitting and receiving user accommodating more UEs. The reserved 10% system bandwidth is to compensate the operating mode with the higher UEs per time. The system output of mode selection and bandwidth allocation scheme displays the data rate of DUE, CUE, both CUE and DUE, and average data rate of both DUE and CUE all computed at data rate block using equations (13), (14), (15) and (16);

$$D_{D2D}{}^{MSBAS} = BW_{D2D\,mode} log_2(1 + SINR_{D2D}) \quad (13)$$

$$D_{CUE}{}^{MSBAS} = BW_{CUE\,mode} log_2(1 + SINR_{CUE}) \quad (14)$$

$$D_{UE}{}^{MSBAS} = BW_{D2D\,mode} log_2(1 + SINR_{D2D}) + BW_{CUE\,mode} log_2(1 + SINR_{CUE}) \quad (15)$$

$$D_{UEs}^{Average} = \frac{\sum_{i=1}^{i=p}(D_{D2D}{}^{1}) + \sum_{i=1}^{i=n}(D_{CUE}{}^{1})}{(p+n)} \quad (16)$$

where:

$D_{D2D}{}^{MSBAS}$ = data rate of D2D

$D_{CUE}{}^{MSBAS}$ = data rate of CUE

$D_{UEs}^{Average}$ = average data rate when considering both D2D and CUE

$SINR_{D2D}$ = signal-to-interference-plus-noise ratio of D2D

$SINR_{CUE}$ = signal-to-interference-plus-noise ratio of CUE

p, n = maximum number of iterations (D2D, CUE).

Table 2 is the Pseudocode for the Mode Selection and Bandwidth Allocation Scheme (MS-BAS).

Table 2 Pseudocode for the Mode Selection and Bandwidth Allocation Scheme

Pseudocode for MS-BAS

1. Initialization: Booting of UEs and base station
2. Load input parameters into the memory of UEs and base station
3. Idle State of UEs:
   - Neighbour discovery using broadcast packet
   - Update neighbour Table
4. Active state of UEs:
   - Exchange packets with discovered neighbours
   - Compute:
     - Path loss using (6) and (7)
     - Channel gain using (8)
     - SINR using (9)
   - Decision:
   - $if\ D_{D2D} <= D_{target} \begin{cases} Yes: then\ SINR_{D2D} \geq SI \\ No: then\ assign\ UE\ to\ C \end{cases}$

   $if\ SINR_{D2D} \leq SINR_{target} \begin{cases} Yes: then\ assign\ UE \\ No: then\ assign\ UE\ to \end{cases}$
5. Base station updates Active UE Mode Table
6. Base station Computes Number of Active DUE and CUE
7. Bandwidth Request by UEs
8. Decision:

   $N_{DUE} < N_{CUE} \begin{cases} Yes: then\ B_{DUE} = 30\%\ of\ Ba \\ Yes: then\ B_{CUE} = 70\%\ of\ Ba \end{cases}$

   $N_{DUE} \geq N_{CUE} \begin{cases} Yes: then\ B_{DUE} = 40\%\ of\ Ba \\ Yes: then\ B_{CUE} = 60\%\ of\ Ba \end{cases}$
9. Compute data rate using equations (13) – (16)
10. Output computed data rate
11. End

Fig. 5 is the Flowchart of the integrated Mode Selection and Bandwidth Allocation Scheme (MS- BAS). After communication modes have been assigned to UEs based on the design constraints

The performance of the mode selection and bandwidth allocation scheme (MS-BAS) was compared with that of Selective Overlay Mode Operation (SOMO) for D2D communication, as presented in Swetha and Murthy (2017) (Separation distance between UEs, and target SINR), bandwidth is allocated based on the number of UEs per communication tier.

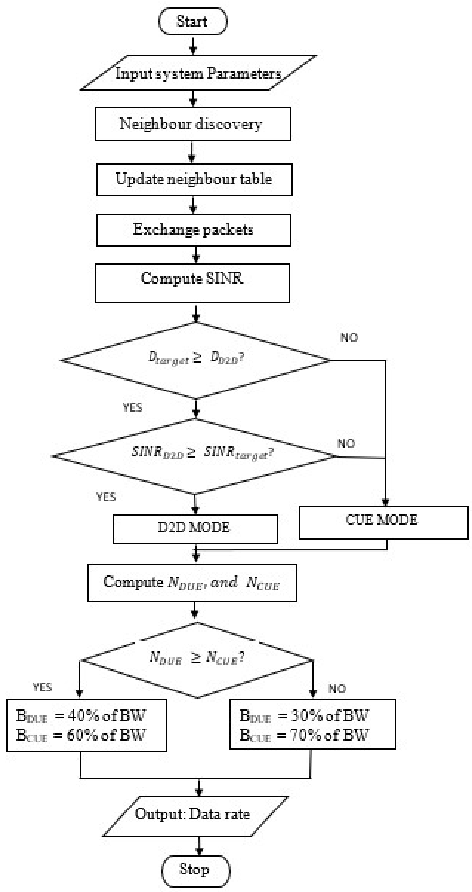

Fig. 5: Flowchart of MS-BAS

RESULTS AND DISCUSSION

The performance of the mode selection and bandwidth allocation scheme (MS-BAS) was analyzed based on varying distance between DUEs, and the number of D2D pairs. The results are presented in Figs. 6-13. At constant number of D2D pair, the distance between DUE was varied and the corresponding MS-BAS data rate was computed. The evaluated performance of MS-BAS is presented in Figs. 6 – 9, which shows data rate variation of DUEs when N_{DUEs} and N_{CUEs} are 12 and 8 respectively, assuming 20 UEs. The distance between DUEs ranges from 0 – 10 m. The range of distance used was in accordance with the adopted D2D target distance of 10m (Swetha and Murthy, 2017). N_{DUEs} and N_{CUEs} were kept constant and $N_{DUEs} > N_{CUEs}$. Fig. 6 presents the data rate of DUE as DUE distance changed.

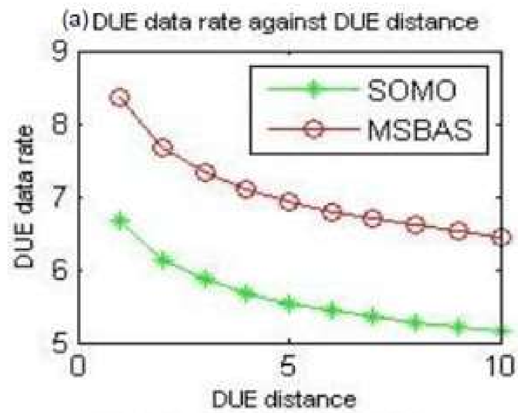

Fig. 6: Data rate of DUE as DUE distance changed.

As the distance between DUE increased, the data rate decreased. The change is attributed to increase in path loss due to increase in distance. As path loss increases, SINR and data rate decreases. The data rate performance of MS-BAS scheme at DUE distances ranging from 0 – 10 m, when compared outperformed that of SOMO.

Fig. 7 presents CUE data rates when DUE distance changed from 0 – 10m.

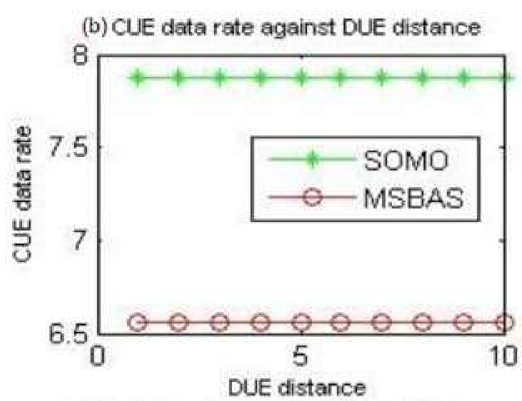

Fig. 7: CUE data rate with varied DUE distance.

The result indicated that SOMO CUE data rate outperformed that of MS-BAS when compared. The higher CUE data rate of SOMO is due to the larger CUE mode operating bandwidth of 70%, compared to that of MS-BAS of 60% when ($N_{DUEs} > N_{CUEs}$).

Fig. 8 is a plot of the entire system performance (all UEs) of the network.

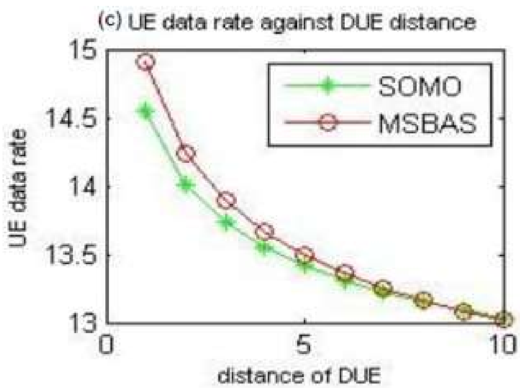

Fig. 8: UE data rate with varied DUE distance.

The result shows that MS-BAS outperformed SOMO.

Fig. 9 is the average data rate representation for both schemes.

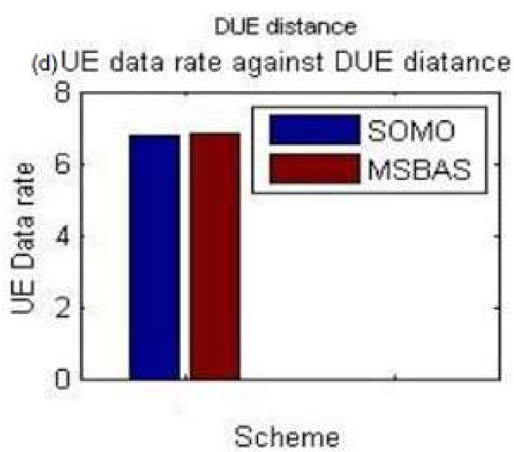

Fig. 9: Average data rates of UEs

The UE average data rates of SOMO and MS-BAS were 7.09 Mbps and 7.26 Mbps respectively. MS-BAS average UE data rate performed better than SOMO by 2.34 %.

From results presented in Figs. 6-9, when N_{DUEs} and N_{CUEs} are 12 and 8 respectively and DUE distance ranges from 0 – 10 m, MS-BAS tradeoff CUE data rate for DUE data rate. The entire UE average data rate of MS-BAS was slightly higher than that of SOMO.

To analyze the impact of the number of D2D pairs on the communication network with respect to interference, the distance of DUEs was kept constant and the number of D2D pairs were varied. The simulation results show the impact of increased number of D2D pairs on DUE, CUE and UE data rate performance, as presented in Figs. 10 - 13.

Figs. 10-13 presents the data rate of DUE, CUE, entire UE (DUE and CUE), and average UE data rate when the DUE distance was kept constant and number of D2D pairs were altered from 1 – 10 pairs, assuming 20 UEs. The initial N_{CUE} and N_{D2D} were 18 and 2 respectively. As the number of D2D pairs increased by 1; N_{DUE} increase by 2 and N_{CUE} decreased by 2.

Fig. 10 is a plot of the DUE data rates with increasing number of D2D pairs.

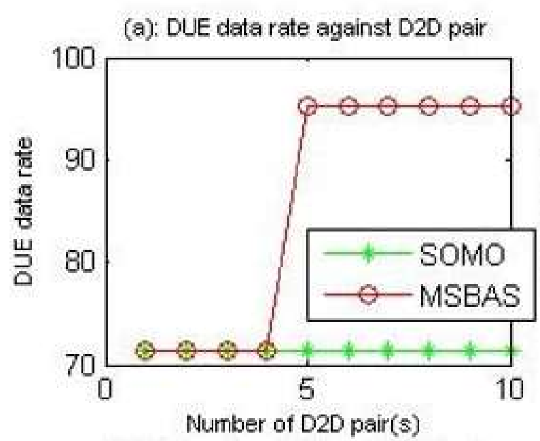

Fig. 10: DUE data rates with increasing DUE pairs

From Fig. 10, when $N_{DUE} < N_{CUE}$ (4 D2D pairs, 8 DUE, 12 CUE), the MS-BAS DUE data rate is equal to that of SOMO. This is so because when $N_{DUE} < N_{CUE}$, MS-BAS bandwidth would be 30% of system bandwidth and likewise SOMO bandwidth; both MS-BAS used the same DUE distance, D2D path loss, SINR, and data rate models.

When the number of D2D pairs increased to 5 (10 DUE and 10 CUE); $N_{DUE} = N_{CUE}$ and MS-BAS bandwidth would change to 40% of system bandwidth, while SOMO bandwidth remains 30% of system bandwidth. Also, when number of D2D pairs increased from 5 – 10 pairs ($N_{DUE} > N_{CUE}$); MS-BAS would use 40% of system bandwidth. The difference in operating bandwidth accounted for the two different data rate levels. MS-BAS operating at 30% of system bandwidth when number of D2D pairs was four and below had same data rate with the SOMO scheme. But when MS-BAS operated at 40% of system bandwidth, from 5 – 10 D2D pairs, the data rate of MS-BAS scheme outperformed that of SOMO by 25%.

Fig. 11 is a plot of CUE data rates with increasing number of D2D pairs.

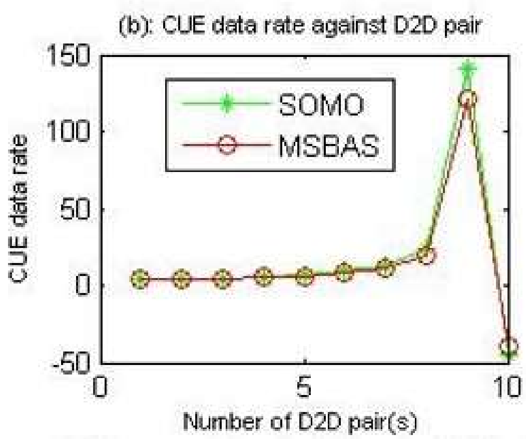

Fig. 11: CUE data rates with increasing D2D pairs.

The plot indicates that the MS-BAS CUE data rate and that of SOMO were the same within the range of 1 – 4 D2D pairs in the D2D network. However, at 5 – 8 D2D pairs, SOMO performed slightly better than the MS-BAS. At 9 D2D pairs, the performance of SOMO CUE data rate was better when compared with that of MS-BAS by 14.28 %, while MS-BAS performed better at 10 D2D pairs when compared to SOMO by 16.68 %.

Fig. 12 is performance of all UEs in the network as the number of D2D pairs increased.

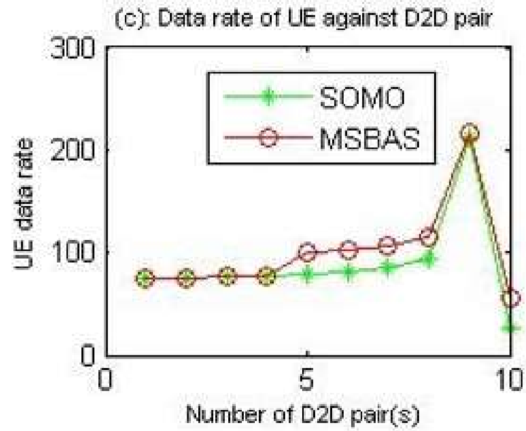

Fig. 12: UE data rate with increasing D2D pairs

The plot presents the data rate performance of all the UEs in the network. At each DUE distance, the data rate of DUEs and CUEs were summed up and plotted. The graphs show that the total UE data rate of SOMO and MS-BAS within range of 1 - 4 D2D pairs, were the same. However, from 5 – 10 D2D pairs MS-BAS data rate outperformed that of SOMO by 22.52 %, 21.82 %, 20.57 %, 17.72 %, 1.67%, and 53.93 % respectively. This outperformance results directly from the additional 10% bandwidth dynamically assigned to DUEs once the condition $N_{D2D} \geq N_{CUE}$ was met, from the formation of 5 D2D pairs upwards.

Fig. 13 is the average UE performance for both schemes

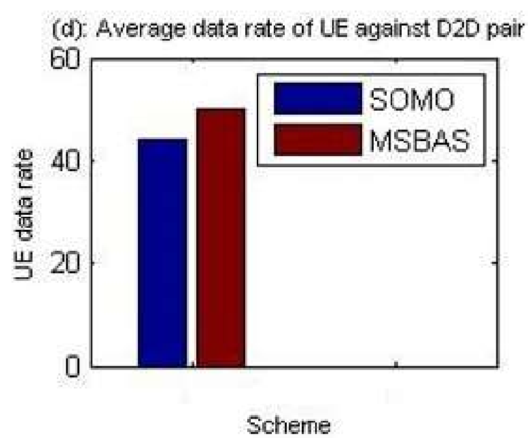

Fig. 13: Average UE data rates with increasing D2D pairs.

The plot shows the average of the entire UE (DUE and CUE) data rate, when number of D2D pairs increased from 1 – 10 and the DUE distance was kept constant. The average data rate of SOMO and MS-BAS stood at 44.08 Mbps and 50.17 Mbps respectively. The MS-BAS average data rate outperformed that of SOMO when compared by 12.14 %.

CONCLUSION

In this work, mode selection and bandwidth allocation techniques were integrated to mitigate cross-tier interference in a macro-D2D network. The mode selection sub-scheme focused on the UE separation distance and the receiver's SINR to assign communication mode to UEs, while the bandwidth allocation sub-scheme allocated a fixed fraction of 60% to CUEs (being the primary users of the network), and 30% for D2D connections, while dynamically allocating the remainder 10% to deserving communication tier based on the number of UEs in that mode, to maximize data rate (throughput), and limit spectrum wastage, which is an inherent problem with overlay architecture.

The integration of the Mode Selection and Bandwidth Allocation Schemes (MS-BAS) lead to the attainment of better system performance against previous works. Therefore, the MS-BAS addresses the problem of cross-tier interference, while improving system throughput and avoiding spectrum redundancy.

REFERENCES

Adejo, A., Asaka, O., Bello-Salau, H., & Alenoghena, C. (2020). New framework for interference and energy analysis of soft frequency reuse in 5g networks. Bulletin of Electrical Engineering and Informatics, 9(5), 1941–1949. https://doi.org/10.11591/eei.v9i5.2536.

Alquhali, A. H., Roslee, M., Alias, M. Y., & Mohamed, K. S. (2020). D2D communication for spectral efficiency improvement and interference reduction: A survey. *Bulletin of Electrical Engineering and Informatics, 9(3), 1085–1094. https://doi.org/10.11591/eei.v9i3.2171*

Alzubaidi, O.T.H.; Hindia, M.N.; Dimyati, K.; Noordin, K.A.; Wahab, A.N.A.; Qamar, F.; Hassan, R. (2022) Interference Challenges and Management in B5G Network Design: A Comprehensive Review. *Electronics, 11, 2842. https:// doi. org/10.3390/electronics11182842.*

Asadi, A, Wang Q, and Mancuso V, (2014). A survey on device-to-device communication in cellular networks, *IEEE Communications Surveys & Tutorials*, vol. 16, no. 4, pp. 1801–1819.

Barik P.K., Shukla A, Datta R., and Singhal C., (2020). A Resource Sharing Scheme for Intercell D2D Communication in Cellular Networks: A Repeated Game Theoretic Approach. *IEEE Transactions on Vehicular Technology*. Volume: 69, Issue: 7, Page(s): 7806 – 7820. DOI 10. 1109/TVT.2020.2991476.

Chen, H., Deng, X., Gao, M., Yang, L., Guo, L., & Chi, M. (2018). Location Related Communication Mode Selection and Spectrum Sharing for D2D Communications in Cellular Networks. *International Conference on Intelligent Transportation, Big Data & Smart City* pp. 169-173. *doi:10.1109/icitbs.2018.00051*.

Cho B, Koufos K, and Jantti J, (2013) Interference control in cognitive wireless networks by tuning the carrier sensing threshold, *IEEE International Conference on Cognitive Radio Oriented Networks*, pp. 282-287.

Gao, X.; Yang, K.; Yang, N.; Wu, J. (2019) Energy-efficient resource block assignment and power control for underlay Device-to-Device communications in multi-cell networks. *Computer Networks*, 149, 240–251.

Hassan, T. U., & Gao, F. (2019). An Active Power Control Technique for Downlink Interference Management in a Two-Tier Macro–Femto Network. *Journal of Sensors*, 19(9), 504 - 528.

Hassan, T. U., Gao, F., Jalal, B., & Arif, S. (2018). Interference Management in Femtocells by

the Adaptive Network Sensing Power Control Technique. *Journal of Future Internet*, 10(3), 2015 - 2028.

Jiale, Z., Shuangzhi, L., Dan, M., & Xiaomin, M. (2018). Research on Joint Mode Selection and Resource Allocation Scheme in D2D Networks. *International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery,* 429 – 432.

Junjie Tan, Ying-Chang Liang, & Gang Feng (2021). Deep Reinforcement Learning for Joint Channel Selection and Power Control in D2D Networks. *IEEE Transactions on Wireless Communications,* (20)2, 1363 – 1378.

Koushik, M. & Shahedur, R. (2021); Multi-cell Interference Management in In-band D2D communication under LTE-A Network. *4th International Conference on Computing, Electronics and Communications Engineering*, pp 16-17 Aug 2021, University of Essex, Southend, UK.

Li, Y, Song, W. Su, Z, Huang, L, Gao, Z, (2018) A distributed mode selection approach based on evolutionary gam for Device-to-Device communications. *IEEE Access 2018, 6, 60045–60058.*

Li, M. (2019). Soft Frequency Reuse-Based Resource Allocation for D2D Communications Using Both Licensed and Unlicensed Bands. *International Conference on Ubiquitous and Future Networks, 384–386. https://doi.org/10.1109/ICUFN.2019.8806044.*

Librino, F., & Quer, G. (2018). Distributed Mode and Power Selection for Non-Orthogonal D2D Communications: A Stochastic Approach. *IEEE Transactions on Cognitive Communications and Networking, 4(2), 232–243. doi:10.1109/tccn. 2018.2809721.*

Nasser, A., Muta, O., Elsabrouty, M., & Gacanin, H. (2019). Interference Mitigation and Power Allocation Scheme for Downlink MIMO-NOMA HetNet. *IEEE Transactions on Vehicular Technology, 1–1. doi:10.1109/tvt.2019.2918336.*

Noura M and Nordin R (2016). A Survey on Interference Management for Device-to-Device (D2D) Communication and its Challenges in 5G Networks, *Journal of Network and Computer Applications, Volume 71, Pages 130-150.* http://dx.doi.org/10.1016/j.jnca.2016.04.021

Onu, C., Bala. S., & Abolarinwa J. (2018). Enhanced Fractional Frequency Reuse in LTE A Heterogeneous OFDMA Network. *ATBU, Journal of Science, Technology & Education (JOSTE),* 6 (2), 18 – 27.

Rana, Z.A., Abdul, R.J., Shakir, M., Mohammad, Z.K., Abdulfattah, N. & Muhammad, R. (2021). Interference Mitigation in D2D Communication Underlying Cellular Networks: Towards Green Energy. *Computers,* *Materials & Continua, 68(1), 45 – 58.*

Rehman, S. U., Hussain, A., Hussain, F., & Mannan, M.A. (2020). A Comprehensive Study: 5G Wireless Networks and Emerging Technologies. *International Electrical Engineering Conference (IEEC 2020), 5, 25-32.*

Safaei, B, Mahdi, A, Monazzahy, H, Milad B and Ejlali, A., *(2017*). Reliability Side-Effects in Internet of Things Application Layer Protocols. *International Conference on System Reliability and Safety; At: Milan, Italy.*

Shami T.M, Grace D., Burr1 A., and Vardakas J.S. (2019). Load balancing and control with interference mitigation in 5G heterogeneous networks. *EURASIP Journal on Wireless Communications and Networking:177 https://doi.org/10.1186/s13638-019-1487-0*.

Song, X., Han, X., Ni, Y., Dong, L., & Qin, L. (2019). Joint uplink and downlink resource allocation for D2D communications system. *Future Internet, 11(1), 1–6. https://doi.org/10.3390/fi11010012*

Swetha, G.D., & Murthy, G.R. (2017). Selective Overlay Mode Operation for D2D communication in dense 5G cellular networks. *IEEE Symposium on Computers and Communications. doi:10.1109/iscc.2017.8024610*

Xiaoqin, L., Yang, X. (2018). Mode Selection and Resource Allocation Algorithm Based on Interference Control for D2D Communication. *International Conference on Communications, Circuits and Systems,* 10(1), 286 – 290.

Yang, C. Li, J, Semasinghe, P, Hossain, E, Perlaza, S.M, Han, Z, (2017) Distributed interference and energy-aware power control for ultra-dense D2D networks: A mean field game. *IEEE Trans. Wireless Communication*.16, 1205–1217.

Zhai, D Sheng, M. Wang, X. Sun, Z. Xu, C. Li, J. (2017) Energy-saving resource management for D2D and cellular coexisting networks enhanced by hybrid multiple access technologies. IEEE Trans. *Wireless Communication*. 16, 1.

Zhao, J., Li, S., Dan, M., & Xiaomin, M. (2018). Research on Joint Mode Selection and Resource Allocation Scheme in D2D Networks. *International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery. 429 – 432.*