A comparison of power allocation mechanisms for 5G D2D mobile communication networks

Dimitris Georgiadis
Department of Informatics and Telematics
Harokopio University
Athens, Greece
dgeorgiadis@hua.gr

Elena Politi
Department of Informatics and Telematics
Harokopio University
Athens, Greece
politie@hua.gr

George Dimitrakopoulos
Department of Informatics and Telematics
Harokopio University
Athens, Greece
gdimitra@hua.gr

***Abstract*—The ever-increasing demands for higher data transmission speeds, channel reliability and less energy consumption push the scientific community to discover new methods to manage resources of modern networks, without degrading the quality of communications. Modern cellular systems of the fifth generation (5G) are internationally recognized for their excellent performance and for the innovative technologies that they apply. The Device-to-Device (D2D) protocol has been established among the technologies of 5G, for the fast and secure direct connections between terminals and the overall capabilities that it provides. The protocol is able to offload the network and reorganize connections in order to save system resources, while also supporting decentralized communications. The present work aims to highlight the importance of D2D communications in 5G cellular networks by assessing the performance of four well known energy resource allocation mechanisms in scenarios with environmental constraints. Results of our simulations showcase that D2D Communication technologies can improve the energy efficiency and increase the total throughput output of existing cellular networks.**

***Index Terms*—D2D communications, Energy efficiency**

I. INTRODUCTION

With the advent of intelligent devices and the Internet of Things, current cellular networks are witnessing an increasing demand for higher data transmission speeds, channel reliability and less energy consumption. Additionally the rise of the population density, particularly in urban areas has increased dramatically the number of mobile users creating new communication opportunities. To meet aforementioned demands, the arrival of the 5th Generation network is a promising solution for improving the capacity and optimizing the resource allocation of current cellular networks. One of the key technologies of 5G, the D2D has emerged as a defining contributor for enabling exponentially higher traffic demands. D2D allows the direct communication between two devices with minimal involvement of the Base Station (BS), thus improving the communication quality of existing networks [1]. D2D can coexist with traditional cellular networks bringing many advantages such as increasing QoS, improving system throughput, reducing equipment energy consumption and end-to-end delays, while it can enhance blind spot coverage and improve the spatial multiplexing of the spectrum by reusing the wireless resources [2].

In this work we assess the performance of four well known power allocation models introduced in [3], [4] for a 5G network supporting D2D connections with respect to energy efficiency and path loss. To enhance the accuracy of our results we test the models in two diverse simulation scenarios with the presence of environmental constraints and obstacles. In addition, the Gale-Shapley algorithm [5] is implemented in order to generate the best possible D2D and cellular user pair in terms of the aforementioned criteria.

The main contributions are as follows:

- A comparison of the four power allocation mechanisms with respect to energy efficiency and path loss.
- An introduction of a well established stable matching algorithm, namely the Gale-Shapley for assessing the performance of the proposed power allocation mechanisms by generating the best possible pairs.
- An experimental validation of the aforementioned trials in a 5G millimeter Wave setup with environmental constraints for more realistic conditions.

In Section 2 that follows we summarize the main research areas related to the problems that we study. Section 3 provides details on the simulation environment, as well as the description of the algorithms that we employ for the simulation of the D2D communication. Section 4 demonstrates the results from the experimental evaluation of our approach, in the direction of comparing the efficiency of the proposed power allocation. Finally, Section 5 provides a discussion on the results achieved so far and describes our next steps.

II. RELATED WORK

Existing cellular networks have obvious shortcomings in terms of spectrum utilization, coverage, expansion of communication services, and power consumption. Moreover they cannot sustain the communication demands of D2D networks. 5G cellular systems can address those needs with efficient energy consumption that will reduce the overall costs for maintaining the network, while improving their functionality. In recent years a number of interesting studies have explored the establishment of power management methods in 5G cellular systems. Authors in [6] presented a network model design to extend the range of information transmitted and improve the energy efficiency of a D2D network through energy harvesting technology. By taking into consideration the hypothesis that satisfying the minimum rate of D2D users can maximize energy efficiency, they divided the optimization problem into two sub-problems: RS problem and time optimization problem.

Another interesting work in [7] presented a two-tier cellular network to allow re-transmissions for D2D communications supporting traditional Uplink (UL) connections. The authors created an optimization problem aiming to maximize the Energy Efficiency (EE) of the Relay-Assisted D2D (RA-D2D) channel, while satisfying the minimum transmission rate required to hold such a connection. In a similar work proposed in [8], the application of the ANFIS (Adaptive Neuro-Fuzzy Interference System) methodology was introduced in the RA-D2D concept. In this work, the Power Allocation (PA) technique was based on the PSO (Particle Swarm Optimization) [9] algorithm and it was applied to the source and the distinguished relay device, increasing the overall energy efficiency of the whole system. In [10] an Uplink scenario was depicted for direct communications from a cellular network using the *Single Carrier-Frequency Division Multiple Access (SC-FDMA)* technique. The system was implemented according to a mathematical model of mixed strategy game theory and specifically the energy distribution is modeled with a non-cooperative mixed game strategy. Therefore, every user inside the cell was able to transmit with the appropriate power level so as to satisfy the Signal-to-Interference plus Noise Ratio (SINR) requirements for reliable signal quality. In [11] a network of direct communications for vehicles is displayed. The article proposes resource management based on shadowing effects and statistical information which are extracted from each channel. For the ideal distribution of energy resources, a method was produced that maximizes the productive capacity for specified CUE (Cellular User Equipment)-DUE (D2D User Equipment) pair, ensuring connection reliability for the D2D device. Once the best power levels are calculated for the two terminals, the process of removing the CUE-DUE combinations that do not support the minimum QoS requirements begins.

An interesting approach is conversed about in paper [4], where the system model presented, considers an Underlay D2D communication environment, in which cellular terminals and the D2D users coexist within a single cell network. Focusing on UL connections, the BS allocates network resources, in a manner to maximize system's capacity, meaning that CUE and the D2D pair's throughput is the maximum achievable. The paper addresses four different allocation methods regarding network's resources and the total available transmission power of the system. The authors introduce the implementation of the Gale-Shapley (GS) algorithm for stable matching between the cellular users and D2D pairs, in order to maximize the capacity of the whole system. They partner the GS along with an Optimized Power allocation (OPA) method, simplifying the MINLP (Mixed-Integer Nonlinear Programming) optimization problem. This throughput-based power allocation indicates that the maximum feasible system power to be allocated is greatly affected by each link's channel gain and thermal noise. Afterwards the system appoints the appropriate power resource to all the affected devices, respecting the capacity level that can be achieved for every channel. Comparing this combination to random allocation of resources and power, proved the superiority of the GS integration and the increased system capacity, when the OPA mechanism took place.

In [3] three distinct power allocation mechanisms were provided, the equal, random and path-loss based power allocation. Network is described as a single cell UL cellular network containing cellular users and D2D pairs, operating under the underlay protocol. This permits these pairs of continuously accessing the licensed spectrum. As all communications are occurring at the same time, one of the aforementioned power allocation schemes for the D2D pairs, was applied at each simulation as it will improve the interference effects as well as the QoS at the cellular network, enhancing the overall performance of the system. The authors derived the closed form expressions for performance metrics, such as outage probability and they presented the behavior of that probability in regards to total transmit power of the D2D network. The simulation and numerical results showcased that the path-loss based scheme achieved the highest performance, with respect to sum-rate, with the equal power allocation following and the random allocation having the lowest results.

An honorable mention has to be given to [12]. This paper is not concerned with the energy efficiency or power allocation of a network. More specifically, in this paper a novel mechanism is proposed which enables the D2D devices to complete transmissions using the micro-Wave (μW) or the millimeter-Wave (mmW) band. They propose a distributed link detection mechanism that categorizes the connection as a Line-of-Sight (LoS) or Non-Line-of-Sight (NLoS). Considering a D2D underlay cellular network, accommodating rectangular shaped blockages, the D2D devices are capable of using both frequency bands. Nonetheless for the mmW transmissions the link constructed must be a LoS link, otherwise the μW band is selected. The proposed model enables D2D devices to defect LoS links and to perform proper beam alignment, by utilizing discovery of peers and by comparison of the arriving signal's angle, from their intended peer, over subsequent time slots. Through a geometrical stochastic approach the authors built a complete framework to assess the performance of the suggested scheme, in relation to SINR coverage probability. Finally the issued simulation results show considerable performance gain over single band communications.

Our work focuses on testing the capabilities of the four power allocation models discussed in [3], [4] in a 5G network supporting D2D connections, with respect to energy efficiency and path loss. These four allocation schemes are then paired with the capabilities that the Gale-Shapley algorithm can provide to test the performance of those algorithms in regards to system throughput. Then we compared the results to a system that utilizes these four allocation algorithms, without the use of the Gale-Shapley model. To enhance the variability of our results, our simulations are executed in two distinct

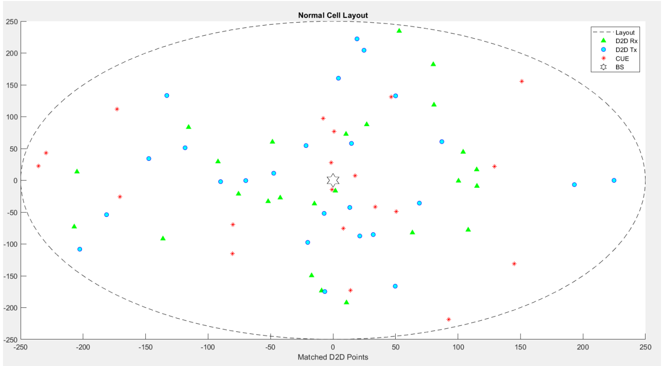

Fig. 1. A full representation of the first environment. The BS is located at the center (star), the D2D Rxs are represented with the triangles, the D2D Txs with the circles and the CUE with the asterisks. Radius R is set to 250m.

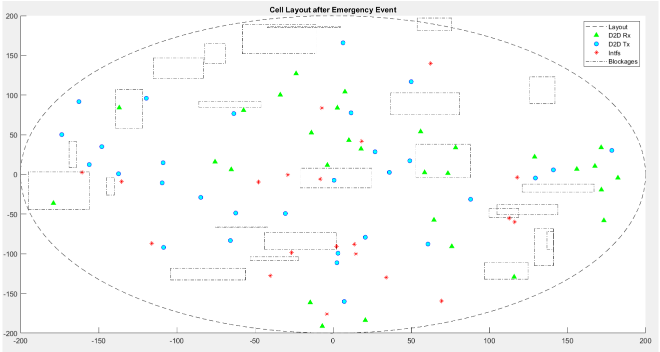

Fig. 2. A full representation of the second environment. There is no BS at the system, also the points located inside the obstacles, will be removed from the simulation.

scenarios: a common underlay cellular network occupying D2D pairs using the 5G protocol and a cellular network underlaying D2D communications using the 5G mmW band where the environment contains rectangular-shaped blockages randomly distributed, as inspired by [12].

III. System Model

A. Simulation environment

For the simulation, in the current paper, consider a general uplink 5G cellular network with the ability to support D2D communications. Specifically for the purpose of testing the distinct power allocation mechanisms that will be covered, two separate systems have been constructed. In each case the network accommodates D2D transceivers and receivers, cellular users and a central base station. The disk-shaped cell has a radius of *250m* for the first case and *200m* for the second.

For the first environment of simulation as shown in Fig. 1, the system aims to reduce the energy consumed from the devices while prolonging the reliability of communications between terminals. The network is a basic 5G cellular network with a base station at the center of the cell (positioned in axis origin) and it accommodates *N* D2D Receivers (D2D Rxs) and D2D Txs with *M* cellular users, where *N is set to 30* pairs and *M is set to 20* devices. Our experiment in this case comprises of two tests, one that utilizes the matching algorithm and one that does not. Devices exploit the Microwave Band (μW), specifically the frequency at *2GHz*, a basic carrier frequency for in-band underlay 5G systems. The bandwidth is adjusted to *100KHz* the common Bandwidth (BW) for such frequencies. However when the matching algorithm is applied the BW is settled at *500KHz* as suggested by the paper in [4].

In the second experiment we examine a more realistic scenario where various environmental constraints exist in the space. This creates obstacles in the cell coverage and therefore traditional communications are no longer supported. A system facing this type of situation relies exclusively on D2D communications, with the base station still relative, helping with the set up of these connections. In this context, the bare minimum of functions for the BS would be device discovery and distribution of the available energy to the appropriate devices. The rest operations are up to the devices to bring to pass. As shown in Fig. 2, the center of the cell does not incorporate a BS, as it is not taken into account because of its dysfunctional behaviour. The obstacles are randomly generated based on the Poisson Point Process (PPP) distribution, with a mean number of blockages equal to 35. System manipulates the Millimeter Wave (mmW) spectrum, individually the *28GHz* and anticipates that the points included into the communications will be outside of the blockages [12]. Those connections will then be categorized as LoS or NLoS and will have different path loss models applied for each type.

The points in every scenario, which will eventually be linked, are processed by the program, in order to create pairs with the minimum distance possible. The link's distance greatly affects system parameters, such as path loss, channel gain and energy distribution. Once the points have been generated, the program builds an array using recursion to store every pair and the minimum distance of it. Thus, it is reasonable to assume that in the beginning of the table, the pairs indeed are characterized by the short distances, but as the pairs are reaching the maximum number of pairs, N_{max} set to 25, distances are increasing and may exceed the value of radius. Surpassing the radius is an issue especially in the second scenario, where mmW frequencies, at the time of writing this paper, can only function with distances less of 200m. The alteration of the radius from 250m to 200m and forming pairs based on shortest distance, ensure that the link in the second scenario, will be successfully built.

Having both D2D connections and traditional communications linking CUE with the BS, will ultimately produce interference between devices. Respectively, a D2D receiver is affected by all the operational CUE-BS channels. Conversely the BS is influenced by the transmission signals from the D2D Txs. Literature references that in basic cellular systems following the aforementioned structure, the D2D Rx will also suffer interference signals from other D2D pairs. In spite of that the simulations presented in this paper do not include the last type of interference, which becomes clear from the SINR equations for the D2D Rx.

Every simulation executes 50 repetitions (epochs) with each one containing 35 *Monte Carlo (MC)* reiterations. The generation of points follows the uniform distribution and the coordinates produced for D2D Tx and CUE, change with every MC iteration. As for the D2D Rx and the obstacles generated in the second environment, those alternate with every epoch.

We clarify that simulations were implemented using the MATLAB R2020 platform and the code was strongly affected by [4], [12].

B. Description of Algorithms

Calculating the SINR is crucial when trying to determine the quality of a channel and identify the throughput of a link or for the whole system [4], [12]:

SINR for First Scenario

$$\gamma_{K_k} = \frac{P_{i_k} h_{i_k,K_k}}{No + I_{K_k}^{\mu W}}, \tag{1}$$

$K \in \{Rx, BS\}$, $i \in \{Tx, CUE\}$, $k \in \{1, \ldots, N\}$ when $i = Tx$ and $k \in \{1, \ldots, M\}$ when $i = CUE$.

SINR for Second Scenario

$$\gamma_{K_k} = \frac{P_{i_k} h_{i_k,K_k} Ge_{D2D_k} PL_{D2D_k}(d_{D2D_k})}{No + I_{K_k}^{mmW}} \tag{2}$$

$K = Rx$ as BS is disregarded for communications, $i = Tx$ and $k \in \{1, \ldots, N\}$. In the equations, *P* symbolizes the power for each transmitter, *h* is the channel gain calculated from the channel coefficient based on path loss. *I* is the interference for the distinct cases, *Ge* is the antenna gain calculated based on the angle of transmission (for the D2D links, D2D Tx transmits directly to the receiver, but the angle of transmission is random for the interfering devices), *PL* is the distance-based path loss parameter and lastly *No* represents the AWGN (Additive White Gaussian Noise) calculated by the equation:

$$No = -174 + 10\log(BW) + NF, \tag{3}$$

where *BW* is the bandwidth used for every transmission frequency and *NF* is a variable called Noise Figure, representing the degradation of signal to noise ratio and is utilized in combination with radio receiver sensitivity. In our simulation we use the following three equations to extract the three distinct power allocation mechanisms as described in [3], where the multitude of D2D devices amounts to *N*.

i) Equal Power Allocation (equ)

$$P_{Tx_k}^{equ} = \frac{P_{tot}}{N}, k \in \{1, \ldots, N\} \tag{4}$$

ii) Random Power Allocation (ran)

$$P_{Tx_k}^{ran} = \nu_k P_{tot}, k \in \{1, \ldots, N\} \tag{5}$$

iii) Path-Loss Power Allocation (pl)

$$P_{Tx_k}^{pl} = \frac{PL_{dr_k,dt_k}}{\sum_{i=1}^{N} PL_{dr_i,dt_i}} P_{tot}, k \in \{1, \ldots, N\} \tag{6}$$

In these equations P_{tot} amounts to the total energy that the system is capable of providing, ν_k is a random generated variable, where $\nu_k \in \{0, 1\}$, $\forall k$ and $\sum_{k=1}^{N} \nu_k = 1$ and *PL* is the path loss value for each link. Once the power allocation completes, the SINR calculations begin. The next step is the determination of throughput for which the Shannon's Capacity Theorem is enlisted as used in [13]:

Capacity for each link

$$C = BW^{freq} \log_2(1 + \gamma_{K_k}), \tag{7}$$

where *C* is the throughput for each link, *BW* is the bandwidth, freq is a parameter that belongs in $freq \in \{\mu W, mmW\}$ and γ is the SINR depending on the receiver.

A notable mention for our program is the path loss models. Path loss greatly affects the transmitted signal as it describes the conditions which constitute the medium of dissemination. When mmW band is the transmission frequency, the aggregation of path loss is much higher, decreasing the reliability of the signal. In this presented paper each system derives its particular path loss models based on distance and frequency for the first environment and based on least square fits of intercept and slope in the measured distances for the second, to successfully delineate the effects of path loss.

IV. RESULTS

In this section we showcase the results of our simulations, taking into consideration the conditions of each environment. Simulation is executed 1750 times, for each power allocation model in each use-case scenario. The presented figures are classified based on the effect of the power allocation mechanisms on system throughput and the energy that is provided during the simulation to each D2D pair. Each figure compares the results of the 4 PA algorithms for the first environment when the matching algorithm is utilized and when it isn't, as well as the results of the 3 PA (excluding throughput PA) in the second environment.

A. First Environment of Simulation

The simulation process of the first environment is divided in two executions: *i) without the utilization of the matching algorithm and ii) with the use of the matching algorithm*. Fig 3. depicts the system throughput when Gale-Shapley is *not* affecting the simulation. The Equal PA and the Random PA seem to be the most unstable modes which face difficulties when trying to produce high data rates. The number of pairs created remains fixed on *N = 25 pairs* during the simulation, which means that the channels are successfully formed. The capability of the program to identify and create the shortest distance D2D pairs certainly has an impact on the Path Loss PA, as the mechanism assembles the higher data rates during this execution. The Throughput PA algorithm is build around the matching model that the Gale-Shapley algorithm offers, yet it reaches the data rate values of the remaining PA models without the use of its counter-part. But, as manifested in Fig. 4, the Throughput PA will always put together the best performance when the matching algorithm is active.

As illustrated in Fig. 4 the total system throughput has been reduced approximately *40-80Mbps* but the Throughput

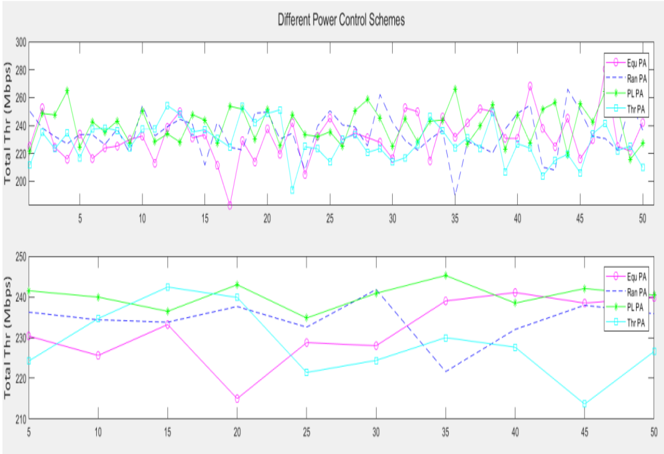

Fig. 3. Active system throughput for the first environment, without using the Gale-Shapley matching algorithm. The first diagram shows the throughput for every execution, while the second groups the results into groups of 5 repetitions.

PA algorithm is impressively better than the rest of the PA algorithms. The mechanism generates a balanced data rate between the D2D pair and the CUE which aggravates the performance of an algorithm that doesn't take into consideration the data rate of the CUE-BS channel. All in all, based on the two simulations the worst discharge originates from the Equal PA and the Random PA. The fact remains that the maximum and minimum deviation is the greatest in these two among the PA models. Nonetheless, the application of the matching algorithm for all the PA modes of energy distribution implies comparatively more stability on the performance and a consistency which occurs after multiple executions. So the deviations may be minimized for all the models.

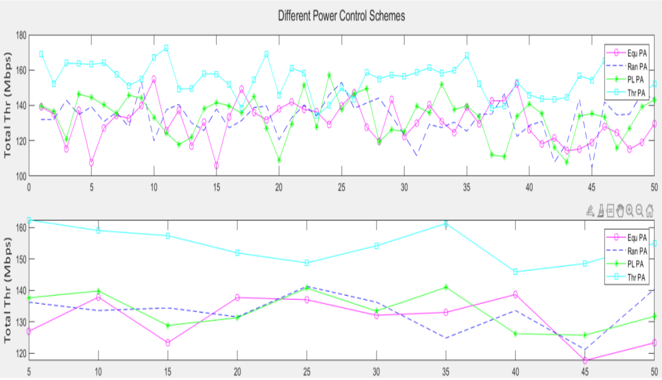

Fig. 4. Active system throughput for the first environment, with the utilization of the Gale-Shapley matching algorithm.

Fig. 5 indicates the mean energy which is provided by the system to each one of the *25* pairs during the first and last repetition of the simulation. It is imperative to note that, once again the number of pairs for the first environment remains stable at 25 pairs. Firstly, the Equal PA successfully fulfils its purpose since in all executions carried out during the experimental stage, the energy for each pair is equal to *0.1265W* when the total system energy is set to $P_{tot} = 35dBm$.

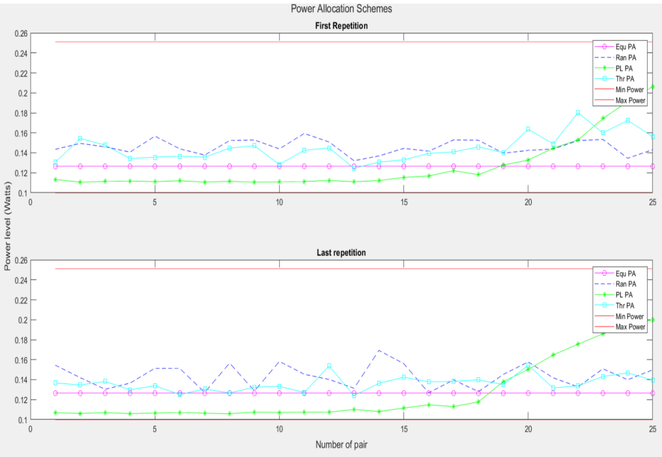

Fig. 5. Energy Distribution with the four PA models during the execution of the simulation.

In Random PA the randomness of the ν factor means that at an unspecified moment in time pairs may demand the maximum power that the system is able to give out to each one. The increase of devices using the network will cause a reduction in the provided energy, of course in the case that total system energy remains constant. The Path Loss PA algorithm manages to capture our interest with its diverse graphic depiction. Since the D2D pairs are formed with the shortest distance in mind, the beginning positions of the array holding the pairs, contain the closest pairs and towards the end, distance grows. This fact is fully aligned with the energy distribution of PL PA at Fig. 5, for the initial pairs as energy will be proportional to the smaller amount of distance and will increase the bigger the distance. Thus the gradual lifting of the PL PA mechanism is justified.

B. Second Environment of Simulation

Considering that the BS is dysfunctional, results in computationally intensive procedures to not be carried out. That's the case with the Throughput PA and matching algorithm which are not taken into account for this environment. Immediately after noticing Fig. 6 the Path Loss PA clearly produces the best total data rates for the network, but even so, throughput is recorded to be less by approximately $\sim 100Mbps$. Notifier of difference is the created pairs factor. In this scenario of simulation when a point is generated inside an obstacle it is removed from the available devices, thus decreasing the number of pairs which are successfully linked. Consequently, after creating the shortest-distance pairs, N is 25 and after that if some points are inside obstacles, program excludes them from the network along with their partner. Fig. 7 shows the instability of pairs that were formed during an execution with an average multitude of $20 - 21 pairs$.

Fig. 6. Total system throughput for the second environment of simulation.

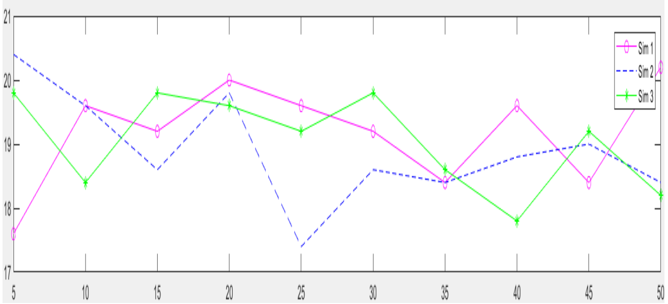

Fig. 7. Pairs successfully matched during execution

Path Loss PA is favored by the path loss calculation models applied especially for mmW environments, which keep relatively low the path loss values ($\sim 180dB$) and it is still benefiting from the short-distance pairs, allocating higher amounts of energy to the edges of links with greater distance. The deviations for the most part relate to the number of pairs created, although there is a systemic consistency in the results of the distribution modes. In the instance when there are no available points to be processed, the simulation will fail to manufacture any connections, leaving the data rate equal to zero. It is worth mentioning the advantage of the PL PA algorithm, which is that the nearby interferences that affect a single D2D receiver will be possessed by smaller power levels. Consciously the power control algorithm reduces the interferences for close interactions while for the far interferences the dedicated higher amount of energy is balanced by long distances and intense path loss values.

Lastly, Fig. 8 showcases the mean energy allocated to each pair during the first and last execution of the simulation. With an average of $20-21 pairs$ created in the second environment, means that all energy distribution for pairs after this upper limit will collapse because none of executions has enough pairs produced during several sessions. Throughout the period of experimental tests for the last D2D pairs the average energy level turns out to be equal to zero. Paradoxical is the fact that in the first environment the PL PA method gave the highest possible values in the last pairs whereas in the second, the last couples are not even included in the system. The immediate consequence is that while the results of the PL PA algorithm may not seem as clear as in the first environment, the method actively operates in the same way, benefiting higher distances, reducing the effect of interference from the CUE in the process. Overall our simulations showcase that the PL PA algorithm outperforms the Throughput algorithm by achieving the best balance of high total throughput and energy distribution based on distance, in all simulations. However in case that the matching algorithm is applied to the system, the Throughput PA algorithm exhibits better performance in comparison to the rest of the power allocation methods.

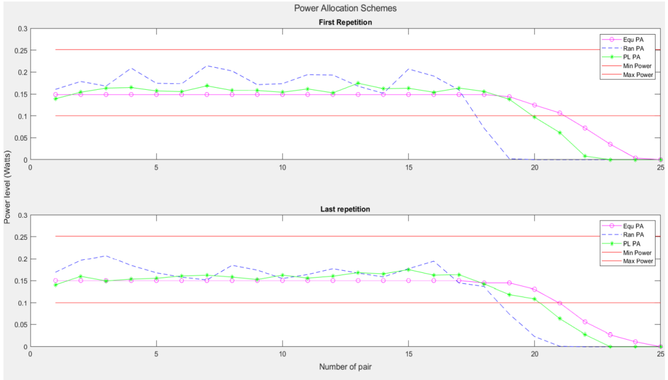

Fig. 8. Power allocation for each pair in the second environment of simulation

V. CONCLUSIONS

In this work we explore the effect of selected power allocation mechanisms on throughput and energy for a 5G cellular network that utilizes D2D communications. Results of our simulations showcase that our proposed models can improve the energy efficiency and increase the total throughput output of the system. The combination of the Gale-Shapley mechanism along with each distinct power allocation scheme shows that the path-loss based and throughput-based models excel performance-wise. The path-loss based power allocation also improves the overall performance of the mmW scenario, outperforming the equal allocation with the random allocation producing the lowest values. We also show that D2D communication technology can be a promising solution to meet the demands of increased number of users and limited channel resources of future cellular networks. As future enhancements, we aim to explore the capabilities of our D2D communication model and challenge its efficiency in real applications, such as the case of the Unmanned Aerial Vehicles (UAVs) and their communication networks. Lastly we want to explore the idea of applying the power control mechanisms alongside the Gale-Shapley model, in wireless UAV-assisted cellular networks or Flying Ad-hoc networks.

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