A New Power Control Algorithm in MMSE Receiver for D2D Underlying Massive MIMO System

Faezeh Heydari
Department of Electrical Engineering, College of Technical and Engineering, Saveh Branch, Islamic Azad University, Saveh, Iran.
heydari@stu.iau_saveh.ac.ir
Saeed Ghazi-Maghrebi*
Department of Communication, College of Electrical Engineering, Yadegar-e-Imam Khomeini (RAH) Shahre Rey Branch, Islamic Azad University, Tehran, Iran.
s_ghazi2002@yahoo.com
Ali Shahzadi
Department of Telecommunications, Semnan University, Semnan, Iran.
shahzadi@semnan.ac.ir
Mohammad Jalal Rastegar Fatemi
Department of Electrical Engineering, College of Technical and Engineering, Saveh Branch, Islamic Azad University, Saveh, Iran.
j_rastegar@iau-saveh.ac.ir

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Abstract

Device to device (D2D) underlying massive MIMO cellular network is a robust deployment which enables network to enhance its throughput. It also improves services and applications for the proximity-based wireless communication. However, an important challenge in such deployment is mutual interference. Interference, in the uplink spectrum, reusing the same resource with cellular user, is caused by D2D users. In this paper, we study a distributed power control (DPC) algorithm, using minimum mean square error (MMSE) filter in receiver, to mitigate the produced interference in this deployment scenario. For the DPC algorithm, employing the coverage probability of D2D links, an optimal power control approach is proposed, which maximizes the spectral efficiency of D2D links. Using this modeling approach, it is possible to derive closed-form analytical expressions for the coverage probabilities and ergodic spectral efficiency, which give insight into how the various network parameters interact and affect the link. Also, the DPC algorithm is modeled by stochastic geometry and receiver filter is designed by estimation theory that a new structure in this robust network is an approach to improve spectral efficiency. Simulation results illustrate enhancing coverage probability performance of D2D links in term of the target (signal to interference ratio) SIR with respect to different receiver filter and other parameters which are existing in D2D links.

Keywords: Device to Device; Massive MIMO; Power Control; Spectral Eefficiency.

1- Introduction

A. Background

Based on the fifth generation public private partnership (5G-PPP), power consumption is a key performance indicator (KPI) in 5G wireless mobile network. This is declined by many preparations, such as power control (PC) scheme and received filter designed, which result in power efficiency and spectral efficiency enhancement [2]. The power efficiency and spectral efficiency play key role in the 5G structure. In this manner, emerging massive multi input multi output (MIMO) and device to device (D2D) is as a tight key to derive the 5G target such as mobile multimedia, fast mobile internet service, drop data traffic and low latency [3].

In massive MIMO deployment, each base station (BS) is equipped with a significantly great array antennas. As a result, the number of antennas at the BS is much greater than the number of users. Therefore, the link between user and BS will be orthogonal and the process performance in this link becomes simple. It means that in the presence of interference, the system is the same as matched filter [4],[5].

The D2D, without aid of central core and BS, is proximity-based communication in direct transmission [6]. D2D underlying massive MIMO cellular network, with many opportunities and advantages, is a potentially enabled wireless network to improve quality of network performance and to guarantee quality of service (QoS) [7]. However, a main challenge of the mutual interference model is caused by cellular links when sharing the same resource with D2D links. In this paper, we present some methods to alleviate the irritating interference.

The first method is applied to MMSE filter in the receiver with a special structure to boost the desired signal, and also to cancel the interfering signal which influences

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* Corresponding Author

the intended signal. It was confirmed that single-stream transmission is favored with respect to multi-stream, when the optimal linear processing strategy, as the MMSE receiver, is employed [8]. Authors in [9] indicated that network throughput can be accelerated linearly with the number of the received antennas, even if a single transmit antenna is merely used at each node. This gain is important specially, to use only linear receive processing such as MMSE and partial zero forcing (PZF). Further, the linear gain is achieved by the usage of maintaining grade of freedom in order to restrain interference and to increase the power of the desired signal simultaneously. Authors in [10], using PZF, studied the spectral efficiency as a metric for D2D underlying massive MIMO communication deployment with perfect and imperfect channel state information (CSI) at receivers.

Next, using an aspect of resource management means PC approach, leads to handle network interference. We investigate the D2D coverage probability $\bar{\mathrm{P}}$ by using the SINR of the uplink for D2D user. In addition, probability should be greater than a minimum SINR such as β. It leads to a good connection in uplink. Then, applying the stochastic geometry tools, the coverage probability is derived [11].

Authors in [11-20], in order to handle the interference and to manage the power resource of network, focused on the D2D underlying cellular networks. To decrease the D2D-to-cellular interference in co-existence networks, in [12] a dynamic PC model was proposed. In [13], for power saving during the transmission, and in the case of the transmit power of D2D users' equipment (DUEs) and cellular users' equipment (CUEs) are greater than a specific value, the powers of these links are matched, since the sum rate of this system is constant. In [14], a centralized PC model, as a solution for managing resource, is proposed for D2D-enable two-tier cellular network. Authors in [15], to decrease the cross-tier interference between the DUEs and CUEs in the uplink communication, studied nominating PC schemes. In this paper, using centralized PC algorithm, two schemes are proposed, and then we use off-on PC algorithm. A centralized PC scheme requires global channel state information, whereas the distributed PC (DPC) scheme requires only direct link information. In [16], a PC algorithm, considering a distributed resource allocation, was verified. Also, using the game theory in uplink system with D2D communication underlying MIMO cellular network, the problem in this model was solved. In [17], for a system with one cell, one D2D pair and multiple CUE, an optimization approach was evaluated to minimize the transmit power.

The authors in [18], to maximize the sum rate in downlink D2D communication with cellular network, introduced a PC solution. It is obvious that PC usually needs the channel state information (CSI). It is difficult in D2D, to set cellular network together in the system. The CSI between links of D2D and cellular communication is a big challenge. This subject was studied in [16-18]. In [19], to obtain the coverage probability and average rate for channel allocation, a D2D overlaid cellular system was studied. The open-loop PC, using a reference certain value as allocated power, was adopted to control CUE transmit power and DUE transmit power [20]. In [21] and [22], to decrease interference in D2D underlying cellular communication, a channel allocation scheme has been studied together with three kinds of PC schemes. The main aspects of these schemes are managing interference, compensating large scale path loss, increasing the sum rate and providing sufficient probability and also, to model this random network to present PC schemes, stochastic geometry as a mathematical technique to describe a system model via special spatial design of user location and to analyze the system interference, was used. Authors in [28] proposed an interference alignment algorithm to reduce the interference of DUE to CUE according to MMSE criterion to derive the received precoding matrix based on the initialized transmitted precoding matrix and then power allocation matrix is derived by using Lagrange duality based PC. Authors in [29] considered pilot-based CSI estimation in which known training sequences are transmitted and used for estimation proposed. During the training phase, different orthogonal set of pilots are used for CUEs and DUEs. Also, the BS uses linear MMSE estimator for the channel estimation. The authors in [30] derived a closed-form spectral efficiency lower bound for the CUE and DUE under impact CSI with maximum-ratio and zero-forcing processing. Also, they used several data PC problems using SE expressions and then, using convex optimization, they solved them. The data PC of CUE and DUE are jointly optimized to guarantee max-min fairness for the cellular and D2D communications. In paper [31], the authors constructed a framework for the joint pilot and data PC for the sum SE maximization in uplink cellular Massive MIMO systems with a variable number of active users. This is a non-convex problem to overcome the inherent non-convexity, an equivalent problem with element-wise convex structure was derived. An alternating optimization algorithm was proposed to find a stationary point.

A channel allocation scheme together with a set of PC schemes in [32] was used to adequately control interference levels under various static and dynamic conditions. The authors used distance-based path-loss parameters (with error margin), varying target SINR in a D2D underlaid cellular system modeled as a random network.

B. Contributions and Outcomes

The main contributions of this paper are summarized as follows. We considered a hybrid network model consist of two kind of ad hoc nodes infrastructure for cellular system and D2D communication. In uplink cellular, users communicate with the BS, while D2D users communicate together with a sufficient distance. The spatial position of D2D and cellular transmitters are modeled by Poisson point process (PPP) with different densities. Such random model, using the stochastic geometry, is used to introduce irregular spatial build of user location. The main challenge of this network is interference between cellular and D2D links. In this paper, to avoid the interference, using MMSE receiver filter before receiver signal and PC algorithm, two approaches are applied. In such network, we propose a PC algorithm which is named distributed algorithm. The main idea of the distributed PC algorithm is to use the CSI knowledge in direct link between transmitter and its corresponding receiver. We derived the coverage probability of D2D links by applying a simple analytic of SINR. Firstly, we compute an approximate expression of ergodic spectral efficiency (ESE) for a typical D2D link. For this purpose, we consider coverage probability of the D2D link. Then, we are able to derive the maximum spectral efficiency of D2D links by achieving the optimal transmission probability. The spectral efficiency of the D2D links is in terms of the density of D2D links and the path loss exponent. In D2D scenario, we suppose that the distance of D2D transmitter to D2D receiver is fixed. However, coverage probability of the cellular link is a function of the distance of CUE from BS. In cellular scenario, the distance of CUE (as transmitter) to BS is variable. Therefore, the optimal transmit power of the CUE will be derived in many different way with respect to distance to the BS.

The remainder of this paper is organized as follows. Section 2 introduces system model with underling massive MIMO in cellular system with designing receiver filter to compute SINR. We present a DPC scheme as an impressive way to decrease the interference in Section 3. The proposed coverage probability to find PC is given in Section 4. In section 5, the spectral efficiency of D2D links is derived by explaining ESE according to DPC scheme. Finally, numerical results and conclusions are shown in Sections 6 and 7 respectively.

2- System Model

In a system model, as shown in Fig. 1, we consider a network uplink which includes a cell with multiple users with one BS in the center of each cell. Also, this BS is equipped with massive MIMO technique and D2D communication underlying. There are two types of users in this system, CUE and DUE which means massive MIMO and underlying D2D respectively. The CUEs and DUEs share the same resource. We assume that the location of the cellular users are modeled as the two dimensions plane according to a homogeneous PPP ϕ_C with density of λ_C. Also, the spatial PPP is based on a uniform distribution of users in the network. The location of D2D transmitter are distributed in homogeneous PPP ϕ_D with density λ_D [25]. We present this system in accordance with single input multi output (SIMO) structure, i.e., a transmitter (either cellular or D2D) applied to an antenna in transmitter. In this case, all receivers have many antennas i.e. the BS has M antennas and D2D receiver has N antennas. If the cell has K cellular users, it should not be bigger than the M. It means that M should be M>>K. In the downlink transmission, the CUE receives signal from the BS and suffers interference from the D2D transmitter caused by sharing the same resource. Also, the D2D receiver suffers the BS interference. Since the power of BS is greater than the D2D receiver, its interference is very annoying. We study network uplink to find a good condition for QoS.

In this system, by proposing the DPC, we follow the scheme to reduce the interference. This model is more considerable than other models, because it only required the CSI of the approach nodes in the direct link. It depends on the distance between the transmitter and receiver. A supportive adaptive way for DPC is proposed, because it supports its link when the SINR reduces from β, then compensates the SINR.

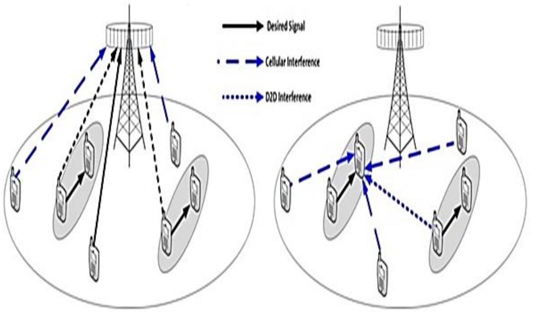

Fig. 1. A signal cell D2D underlying massive MIMO cellular network involving cellular link and D2D links.

The received signals at the BS from typical CUE are as bellow:

$$y_k^{(c)} = \sum_{k \in \phi_M} \sqrt{P_c} \left\| x_k^{(c)} \right\|^{-\alpha_c/2} h_k^{(c)} u_k^{(c)} + \sum_{i \in \phi_D} \sqrt{P_d} \left\| x_i^{(d)} \right\|^{-\alpha_c/2} h_i^{(d)} u_i^{(d)} + n^{(c)} \qquad (1)$$

Where $x_k^{(c)}$ and $x_i^{(d)}$ denote the distance of cellular transmitter *k* to the BS and the distance of D2D transmitter *i* to the BS, respectively. $\alpha_c > 2$ is the path loss exponent of CUE_BS link. $\boldsymbol{h}_k^{(c)} \in C^{M \times 1}$ and $\boldsymbol{h}_i^{(d)} \in C^{M \times 1}$ are the fading channels from cellular transmitter *k* to the BS and D2D transmitter *i* to the BS, respectively. They are independently distributed with zero mean and unit variance. $u_k^{(c)}$ and $u_i^{(d)}$ represent the transmit symbols of cellular transmitter *k* to the BS and D2D transmitter *i* to the BS, respectively. $y_K^{(C)}$ denotes received signal at the BS. $\boldsymbol{n}^{(c)}$ denotes additive white Gaussian noise. Also, $\mathbf{P}_c = [P_{c.0}, \dots P_{c.i}, \dots, P_{c.k}]^T$ expresses the profile vector of cellular transmit power with $P_{c.i}$ with the transmit power of the *i*th CUE, and $\mathbf{P}_d = [P_{d.0}, \dots P_{d.j}, \dots, P_{d.l}]^T$ expresses the profile vector of D2D transmit power with $P_{d.j}$ as the transmit power of the *j*th DUE transmitter. The transmit power constraints are $P_{c.i} \leq P_{max_c}$. $P_{d,i} \leq P_{max_d}$ for all links.

In this research, we compute and proof the SINR for typical cellular uplink with the MMSE filter as bellow:

$$SINR_{k.MMSE}^{c} \tag{2}$$
$$= \frac{P_{k.c}|x_k|^{-\alpha_c}\boldsymbol{h}_k^H\boldsymbol{h}_k}{I_1 + I_2 \ + \sigma^2}$$
$$I_1 = \sum\nolimits_{i \,\in\, \phi_M} P_{i.c}|x_i|^{-\alpha_c}\boldsymbol{h}_i\boldsymbol{h}_i^H$$
$$I_2 = \sum\nolimits_{j \,\in\, \phi_D} P_{j.d}\beta\left|x_j\right|^{-\alpha_c}\boldsymbol{h}_j\boldsymbol{h}_j^H$$

Proof. See Appendix A

Where the numerator represents the desired signal power of CUE K and its denominator represents the summation of interfering signal power of cellular links and D2D links and noise power.

The received signals at D2D receiver from typical DUE are given as

$$\boldsymbol{y}_\ell^{(d)} = \sum_{\ell \,\in\, \phi_D} \sqrt{\mathbf{P}_d}\, \left\|x_\ell^{(d)}\right\|^{-\alpha_d/_2}\, \boldsymbol{g}_\ell^{(d)}\, u_\ell^{(d)} + \sum_{j \,\in\, \phi_M} \sqrt{\mathbf{P}_c}\, \left\|x_j^{(c)}\right\|^{-\alpha_d/_2}\, \boldsymbol{g}_j^{(c)}\, u_j^{(c)} + \boldsymbol{n}_\ell^{(d)} \tag{3}$$

Where $x_\ell^{(d)}$ and $x_j^{(c)}$ denote the distance of D2D transmitter ℓ to the typical D2D receiver and the distance of cellular transmitter *j* to the typical D2D receiver, respectively. $\alpha_d > 2$ is the path loss exponent of D2D transmitter__ D2D receiver link. $\boldsymbol{g}_\ell^{(d)}$ and $\boldsymbol{g}_j^{(c)}$ are the fading channel from D2D transmitter ℓ to the typical receiver and cellular transmitter *j* to the typical D2D receiver, respectively. $u_\ell^{(d)}$ and $u_j^{(c)}$ represent the transmit symbol of D2D transmitter ℓ to the typical D2D receiver, cellular transmitter *j* to the typical D2D receiver, respectively. $y_\ell^{(d)}$ denotes the received signal at the typical receiver. $\boldsymbol{n}_\ell^{(d)}$ denotes additive white Gaussian noise.

The SINR of typical D2D uplink with MMSE filter is given by

$$SINR_{l.MMSE}^{(d)} \tag{4}$$
$$= \frac{P_{l.d}|d_{l.l}|^{-\alpha_d}\boldsymbol{g}_l^H\boldsymbol{g}_l}{\sum_{i \,\in\, \phi_M} P_{i.c}|d_{l.i}|^{-\alpha_d}\boldsymbol{g}_i\boldsymbol{g}_i^H \ + \sum_{j \,\in\, \phi_D} P_{j.d}\left|d_{l.j}\right|^{-\alpha_d}\boldsymbol{g}_j\boldsymbol{g}_j^H + \sigma^2}$$

Where its numerator represents the desired signal power of D2D transceiver pair l and the denominator represents the interfering signal power of cellular links and other D2D links and noise power. In D2D link, we perform the same way as accomplished in cellular link.

3- Distributed Power Control (DPC)

In this section, we present a DPC scheme as an impressive way to decrease the interference. The DPC scheme needs the CSI of direct link between transceiver D2D pair. This scheme needs no transmitter coordinate, since each transmitter can choose transmitter power to maximize its rate from its receiver. It is disregarding any interference and possibly influences its link. This scheme, according to the direct link channel information, chooses power transmitted from the organized set $\{0, P_{max}\}$. P_{max} is assigned to transmitter D2D when the quality of its link is good, i.e. $|\ \boldsymbol{g}_l\boldsymbol{g}_l^H|\ {d_{l.l}}^{-\alpha_d} > \Gamma_{min}$ and 0 assigned in other states. It is formulated as bellow:

$$P_k = \begin{Bmatrix} P_{max,d} & with\ P_s \\ 0 & with\ \overline{P_s} \end{Bmatrix} \tag{5}$$

Where P_s is transmission probability and it is explained as bellow

$$P_s = \left[\mathbb{P}\left[|\ \boldsymbol{g}_l\boldsymbol{g}_l^H|\ {d_{l.l}}^{-\alpha_d} > \Gamma_{min}\right]\right] \tag{6}$$
$$= \exp(-\Gamma_{min}E[{d_{l.l}}^{\alpha_d}])$$

In the DPC scheme, each D2D transmitter is chosen its power based on some factors such as gain of its channel $\boldsymbol{g}_l\boldsymbol{g}_l^H$, distance with path loss ${d_{l.l}}^{-\alpha_d}$ and threshold criterion of Γ_{min} . To obtain sufficient PC scheme, we must select a suitable threshold for Γ_{min} . The $\Gamma_{min}(\ P_s)$ plays key role in coverage property and sum rate performance. If Γ_{min} is chosen very big, compare to gain and distance, the transmit probability P_s will be reduced and the interference will be decreased. Decreasing interference leads to decrease the number of active D2D transmitter. These conditions are motivated us to optimize the $\Gamma_{min}(\ P_s)$. Then, we enhance the D2D efficiency in order to optimize the $\Gamma_{min}(\ P_s)$.

Therefore, the appropriate choice for threshold Γ_{min} and consequently P_s can be good modifier for this comparison. So, to culminate the sum rate in this structure, we should optimize the coverage probability.

4- Coverage Probability to Find Power Control

In this section, coverage probability of the D2D link, using stochastic geometry, is computed by concept of mathematical coverage probability. Finally, considering the transmit power limit, an optimal PC algorithm is proposed. In this case, it is assumed that each D2D transmitted power is independent and power distributed function are $F_D(.)$ [34]. However, this algorithm only requires the information in direct link i.e. it is not efficient for cellular communications. So, it does not guarantee the reliability of the whole cellular links. The coverage probability of the cellular links behaves different ways according to the location of the cellular user. It means that the impact of the distance of the uplink user from BS is a key factor to derive the coverage probability [15]. So, the DPC approach is not enough to guarantee reliable cellar links. In this research, we compute and proof the coverage probability of D2D link as bellow

$$\overline{\overline{P}}_{\mathrm{cov}}^{(\mathrm{d})} = \mathbb{P}\left(SINR_{l.MMSE}^{(d)} \geq \beta\right) \tag{7}$$

$$= exp\left(-\frac{\pi\lambda_C(M^{-1}\beta)^{2/\alpha_d}}{\sin c\left(\frac{2}{\alpha_d}\right)} {P_{i.c}}^{2/\alpha_d} P_{l.d}^{-2/\alpha} {d_{l.l}}^2 - \frac{\pi\lambda_D(M^{-1}\beta)^{2/\alpha_d}}{\sin\left(\frac{2}{\alpha_d}\right)} P_{j.d}^{2/\alpha_d} P_{l.d}^{-2/\alpha_d} {d_{l.l}}^2\right)$$

Proof. See Appendix B

5- Spectral Efficiency of D2D Links

The interference of D2D links, that affects *l*-th D2D receiver, is $\sum_{j\in\phi_D} P_{j.d}\beta\left|d_{l.j}\right|^{-\alpha_d}\boldsymbol{g}_j\boldsymbol{g}_j^H$, where $j \in \{1.2.\ldots.|\ A|\ \}$. Also, $|\ A|$ is the number of active D2D links that is used in DPC algorithm, i.e.,

$$|\ A|\ =\lambda\mathbb{P}\left[|\ \boldsymbol{g}_l\boldsymbol{g}_l^H|\ {d_{l.l}}^{-\alpha_d} > \Gamma_{min}\right]\pi R^2 = \tilde{\lambda}\pi R^2 \tag{8}$$

For more explanation, signal transmission from all active link are assumed be Gaussian signal. Therefore, the signals of interference are also Gaussian. The variance of the noise is assumed that $\sigma^2 = 0$, which means SINR is converted to SIR (signal to interference ratio). Consequently, this expression is sufficient to explain ergodic spectral efficiency according to DPC scheme. The spectral efficiency of D2D links is given as bellow

$$R^{(D)} = A \times E[log_2(1 + SIR_l)] \tag{9}$$

$$= A \times \bar{R}_{D2D}$$

$$= \widetilde{\lambda_D}\pi R^2 \times \bar{R}_{D2D}$$

We compute an approximate expression of ESE for a typical D2D link. For this purpose, we consider SIR and coverage probability of the D2D link as bellow

$$\overline{\mathrm{R}}_{\mathrm{D2D}} = \int_0^\infty \log_2(1 + \mathrm{x})\left[\mathbb{P}[\mathrm{SIR}_\mathrm{l} \geq \mathrm{x}]\right]\mathrm{dx} \tag{10}$$

$$\approx \int_0^\infty \frac{1}{1+\mathrm{x}}\ \overline{\overline{\mathrm{P}}}_{\mathrm{cov}}^{(\mathrm{d})}(\mathrm{x})\mathrm{dx}$$

by substituting (7) in (10), we will have

$$= \int_0^\infty \log_2\mathrm{C}\cdot\exp(\mathrm{A} + \mathrm{B})\ \mathrm{dx}$$

Where A, B and C are defined as bellow

$$\mathrm{A} = -\frac{\pi\lambda_\mathrm{C}(\mathrm{M}^{-1}\beta)^{2/\alpha_\mathrm{d}}}{\sin \mathrm{c}\left(\frac{2}{\alpha_\mathrm{d}}\right)}{\mathrm{P}_{\mathrm{i.c}}}^{2/\alpha_\mathrm{d}}\mathrm{P}_{\mathrm{l.d}}^{-2/\alpha}{\mathrm{d}_{\mathrm{l.l}}}^2$$

$$\mathrm{B} = -\frac{\pi\lambda_\mathrm{D}(\mathrm{M}^{-1}\beta)^{2/\alpha_\mathrm{d}}}{\sin\left(\frac{2}{\alpha_\mathrm{d}}\right)}\mathrm{P}_{\mathrm{j.d}}^{2/\alpha_\mathrm{d}}\mathrm{P}_{\mathrm{l.d}}^{-2/\alpha_\mathrm{d}}{\mathrm{d}_{\mathrm{l.l}}}^2$$

$$\mathrm{C} = (1 + \mathrm{x})$$

Analytical expression of the typical D2D ESE is obtained by the Laplace transform of link interfering and approximated expression of the uplink interference. However, this is valid for any DPC, when the transmit power is independent from another D2D links. The approximated spectral efficiency of D2D links is given as $R^{(D)}$ that we can maximize it and then we optimize the D2D threshold Γ_{min} , as bellow

$$\mathrm{R}^{(\mathrm{D})} = \widetilde{\lambda_\mathrm{D}}\ \pi\ \mathrm{R}^2 \log_2(1 +\ \beta)\left[\mathbb{P}[\mathrm{SIR}_\mathrm{l} \geq \beta]\right] \tag{11}$$

$$= \lambda_\mathrm{D}\mathrm{P}_\mathrm{S}\ \pi\ \mathrm{R}^2\log_2(1 +\ \beta)\exp(\mathrm{A} + \mathrm{B})$$

We calculate the optimal transmit power probability, using the optimization problem theory, as bellow.

$$\max \mathrm{R}^{(\mathrm{D})}\ (\beta) \qquad subject\ to\ \ 0 < P_S < 1 \tag{12}$$

To achieve the optimal transmission probability, we must differentiate even though the objective function is not concave.

$$\frac{\mathrm{d\ R}^{(\mathrm{D})}\ (\beta)}{\mathrm{d\ P_s}} = 0$$

$$1 - \frac{\pi\ \lambda_D\ (M^{-1}\beta)^{2/\alpha_d}}{sinc\ (2/\alpha_d)}\ \ P_{j\ .\ d}^{2/\alpha_d}\ \ P_{l\ .d}^{-2/\alpha_d}\ {d_{l.l}}^2\ P_S = 0 \tag{13}$$

To determine the P_s is maximum or minimum, we must use the second order differentiation as bellow

$$\frac{\mathrm{d^2\ R}^{(\mathrm{D})}\ (\beta)}{\mathrm{d\ P_s}} < 0 \tag{14}$$

$$-\frac{\pi\ \lambda_\mathrm{D}\left(\mathrm{M}\ \beta^{2/\alpha_\mathrm{d}}\right)}{\mathrm{sinc}\ (2/\alpha_\mathrm{d})}\ \ \mathrm{P}_{\mathrm{j\ .\ D}}^{2/\alpha_\mathrm{d}}\ \ \mathrm{P}_{\mathrm{l\ .d}}^{-2/\alpha_\mathrm{d}}\,{\mathrm{d}_{\mathrm{l.l}}}^2 < 0$$

$$P_s = \frac{\sin c\left(\frac{2}{\alpha_d}\right)}{{d_{l.l}}^2\pi\lambda_D(M^{-1}\beta)^{2/\alpha_d}}$$

Then, we have $P_s^* = \min\left\{\frac{\sin c\left(\frac{2}{\alpha_d}\right)}{{d_{l.l}}^2\pi\lambda_D(M^{-1}\beta)^{2/\alpha_d}}\ ,\ 1\right\}$. Now, considering $d_{l.l} = d_0$, the spectral efficiency of D2D links can formulate as bellow

$$\mathrm{R}_{(\beta)}^{(\mathrm{D})} = \begin{cases} \pi\lambda_\mathrm{D}\mathrm{R}^2\mathrm{F} \times \mathrm{E} & \text{for } \beta < \bar{\beta} \\ \mathrm{H} \times \mathrm{G} & \text{for } \beta > \bar{\beta} \end{cases} \tag{15}$$

Where F, E, H and G are defined based on definition of P as bellow:

$$\mathrm{P} = \log_2(1 + \beta) \tag{16}$$

$$\mathrm{F} = \mathrm{P} \times \exp\left(-\frac{\pi\lambda_\mathrm{C}(\mathrm{M}^{-1}\beta)^{\frac{2}{\alpha_\mathrm{d}}}}{\sin \mathrm{c}\left(\frac{2}{\alpha_\mathrm{d}}\right)}\left(\frac{\mathrm{P_i,c}}{\mathrm{P_l,d}}\right)^{\frac{2}{\alpha_\mathrm{d}}}\mathrm{d}_0^2\right) \tag{17}$$

$$\mathrm{E} = \exp\left(-\frac{\pi\lambda_\mathrm{D}(\mathrm{M}^{-1}\beta)^{\frac{2}{\alpha_\mathrm{d}}}}{\sin \mathrm{c}\left(\frac{2}{\alpha_\mathrm{d}}\right)}\mathrm{d}_0^2\right) \tag{18}$$

$$\mathrm{H} = \frac{\mathrm{R}^2\sin \mathrm{c}\left(\frac{2}{\alpha_\mathrm{d}}\right)}{{\mathrm{d}_0}^2(\mathrm{M}^{-1}\mathrm{B})^{\frac{2}{\alpha_\mathrm{d}}}} \tag{19}$$

$$G = P \times \exp\left(-\frac{\pi\lambda_C(M^{-1}\beta)^{\frac{2}{\alpha_d}}\, d_0^2}{\sin c\left(\frac{2}{\alpha_d}\right)}\left(\frac{P_{i},c}{P_{l},d}\right)^{\frac{2}{\alpha_d}}\right) \tag{20}$$

Where $\bar{\beta} = \left(\frac{\operatorname{sinc}\left({}^{2}/_{\alpha_d}\right)}{\pi\ \lambda_D\left(M^{-1}\ \beta^{2/\alpha_d}\right)}\right)^{\alpha_d/2}$.

The spectral efficiency of D2D links is depended on some factors. For example, in the case of $\beta < \bar{\beta}$, the spectral efficiency is derived based on the target SIR value β and density of D2D links λ_D. In the second case, the spectral efficiency is independent of the D2D density and the effect of *M* is lower than the first case. In this research, we compute and proof the spectral efficiency of D2D links by integrating of the spectral efficiency of D2D links in (15) with respect to β. Then, the spectral efficiency of D2D links can be given as

$$\bar{R}^{(D)}_{(\beta)} = U+V \tag{21}$$

Where U and V are defined as

$$U = \int_0^{\bar{\beta}} U_1 dx \tag{22}$$

$$U_1 = \frac{R^2 \sin c\left(\frac{2}{\alpha_d}\right)}{\exp(-1) {d_0}^2 \left(\frac{x}{M}\right)^{\frac{2}{\alpha_d}}} \frac{1}{(1+x)} \exp\left(-\frac{\pi\lambda_C\left(\frac{x}{M}\right)^{\frac{2}{\alpha_d}} d_0^2}{\sin c\left(\frac{2}{\alpha_d}\right)} \left(\widetilde{P}\right)^{\frac{2}{\alpha_d}}\right)$$

$$V = \int_{\bar{\beta}}^{\infty} V_1 dx \tag{23}$$

$$V_1 = \lambda_D \pi R^2 \exp\left(-\frac{\pi\lambda_C\left(\frac{x}{M}\right)^{\frac{2}{\alpha_d}}}{\sin c\left(\frac{2}{\alpha_d}\right)} \left(\widetilde{P}\right)^{\frac{2}{\alpha_d}} d_{0)}^2\right) \exp\left(-\frac{\pi\lambda_D\left(\frac{x}{M}\right)^{\frac{2}{\alpha_d}}}{\sin c\left(\frac{2}{\alpha_d}\right)} d_0^2\right) \frac{1}{(1+x)}$$

It is assumed that distance between transmitter and D2D receiver is fixed and also, DPC scheme in this network operates at maximum power.

6- Numerical Result

In this section, to evaluate the proposed algorithm, numerical results are presented. In this research, the BS is located at the center of the cell with radius of R_c in R^2 plane. The D2D transmitters are distributed according to PPP with density of λ_D. Also, the distance between the transceiver pairs of D2D is *d*. We suppose that the average number of D2D links in the cell equals to $\lambda_D \pi R^2$.

The cellular transmitters have PPP distribution. We applied these results for D2D communication underlying cellular system equipped with two structure, i.e. MMSE filter and PC method. We show how MMSE filter and distributed PC method affect the coverage probability performance gain. Analytical coverage probability performance gain curves for D2D in terms of SIR are achieved. Parameters of the simulated network are shown in Table 1. In this research, we prepared two scenarios. In the first scenario, we compare effects of two filters in present of the DPC on performance gain. In the second scenario, the coverage probability in term of SIR, with MMSE filter and different parameters in D2D links, is derived.

Table 1. Simulation/ Numerical Parameter

Parameter	Value
BS radius of coverage R_c	500m
length of D2D link d	20m
quantity of cellular UEs k	20 to 80
D2D UEs density λ_D	0.00002 and 0.00005
BS antennas quantity M	500
UE Rx antennas quantity N	1and 8
Cellular max Tx power P_c	100mW
D2D max Tx power P_d	0.1mW
Path-Loss exponent of UE-BS $\propto_c$	3.5
Path-Loss exponent of UE-UE $\propto_d$	4

In the first scenario, the coverage probability performance gain of the equipped MMSE filter together with PC algorithm is compared to the case of with PZF filter that the result are shown in Fig. 2. The coverage probability have high amount in lower SIR than higher ones. Also, in the case of using MMSE, performance gain will be enhanced, especially when the target SIR is low. This implies that the desired signal is robust and overcomes the interference. Using MMSE filter in receiver leads to receive the desired signal and overcomes undesired signal. However, the coverage probability of with PZF filter is about 0.2 bps/Hz l less than MMSE filter.

In the second scenario, we compute coverage probability performance with respect to different parameters. Figure 3 illustrates the effects of SIR with variation the number of D2D antennas on the coverage probability of D2D link. As a result, two curves have decreased trend in high *SIR* while the number of antenna is 4 with respect to 8, the coverage probability gain will be increased. The antenna quantity affects the MMSE filter deployment as well as PC case. It is notable, the coverage probability performance gain gradually decreases when the SIR goes up. This is because the SIR is implied interference, so the system interference will be increased as shown in two curves of this figure.

Figure 4 illustrates the effect of SIR with variation of distance between transceiver D2D pair on coverage probability of D2D link. It shows when distance of D2D pair is low, the coverage probability gain in PC algorithm is better than the case of the distance D2D pair is great. For instance, in *SIR*=6 the coverage probability is about 1.99, 1.95, 1.88 in *d*=20, *d*=50, *d*=80 respectively. The significant reason is that maximum power is allocated to transmitter which is at the least distance to its receiver.

Figure 5 shows the effects of SIR with PC and without PC on the coverage probability of D2D links. The coverage probability performance gain is increased by using PC algorithm compared to the case of without PC. Applying PC algorithm leads to mitigate intra D2D interfering and cross-tier D2D and cellular interfering. In the SIR=19, the coverage probability with PC is about 1.82. However, in this SIR we derive coverage probability without PC nearly 1.80.

Figure 6 illustrates the effects of SIR with variation of D2D pair density on the coverage probability of D2D links. This figure demonstrate the analytical result of coverage probability gain and the result of Monte Carlo simulation with the increased rang of SIR and two kind of D2D deployment density. We observe that the analytical performance gain is matched with Monte Carlo simulation. These curves show that D2D coverage probability is improved in high D2D density region in the proposed PC method.

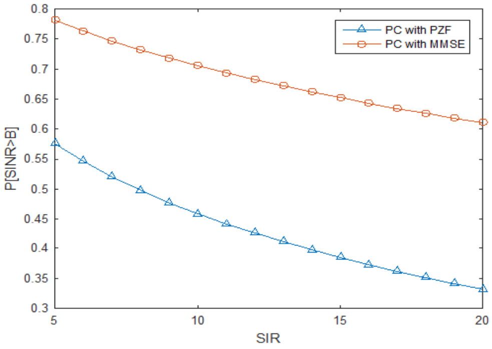

Fig. 2. Coverage probability performance gain of D2D communication with distributed PC algorithm with PZF filter and MMSE filter.

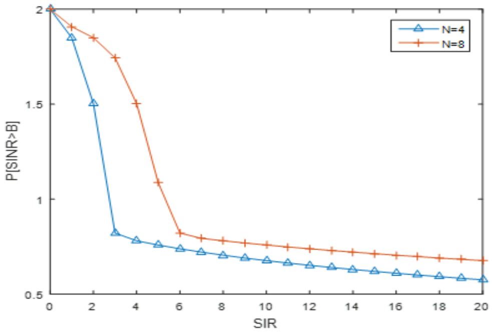

Fig. 3. Coverage probability performance gain of D2D communication with distributed PC algorithm with different number of antenna on D2D transmitter.

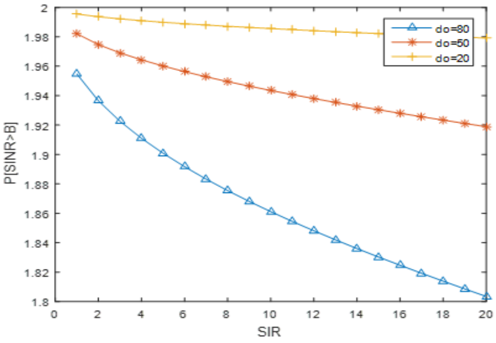

Fig. 4. Coverage probability performance gain of D2D communication with distributed PC algorithm for different distances between transmitter and D2D receiver.

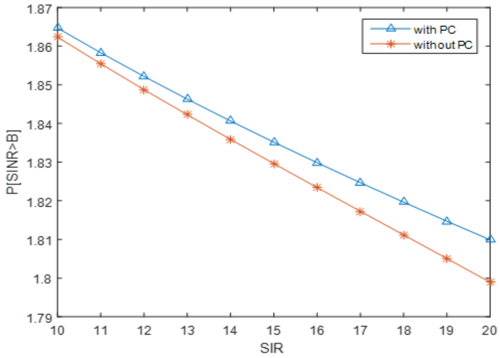

Fig. 5. Coverage probability performance gain of D2D communication according to PC algorithm and the case of without PC.

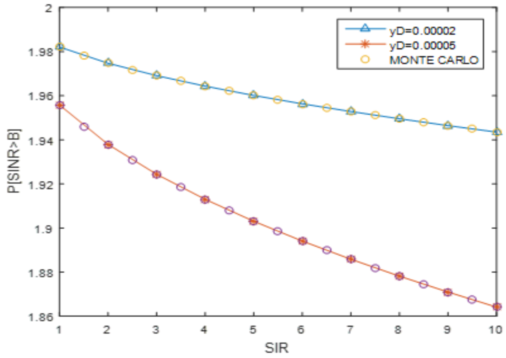

Fig. 6. Coverage probability performance gain of D2D communication with distributed PC algorithm with different densities D2D.

Authors in [20] evaluated spectral efficiency and energy efficiency of the hybrid structure using the power control model. In this research, our final simulation is a comparison between the performances of our proposed method and the used scenario in the article [20]. Figure 7 shows the effects of D2D user density on two scenarios, i.e. the first with the proposed power control model along with the effect of MMSE receiver filter, and the second without using the filter. In our proposed method, the receiver filter model has been added to the proposed system model and we considered power control method. By applying MMSE receiver filter, spectral efficiency calculations with power control and receiver filter are about 4bps / Hz more than spectral efficiency with power control method without receiver filter as considered in [20]. Since we want to show the presence of the receiver filter along with the power control method to improve the simulation curve, we introduced the density of D2D users with very small changes in the surface of a circular cell with radius of 1×10^4m. Thus for both scenarios, without filter as well as with filter the spectral efficiencies are constant curves. Therefore, applying a filter receiver with a special structure in the hybrid network along with the power control model increases the spectral efficiency compared to a mechanism with the same structure without a filter.

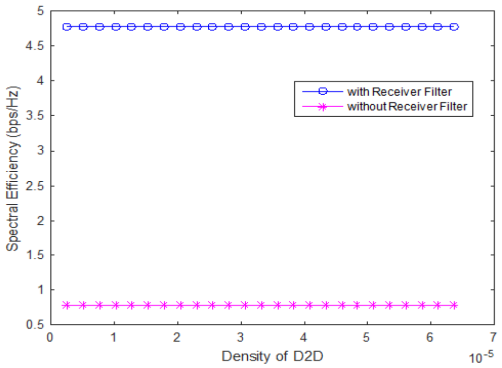

Fig. 7. The effect of D2D users density with receiver filter and without receiver filter on spectral efficiency.

7- Conclusion

We cross check the model consisting of D2D underlying massive MIMO. The network with such deployment deals with challenging interference. Mitigating of interference is the result of enhancing an important metrics such as spectral efficiency.

We followed two way to achieve high spectral efficiency, utilizing MMSE filter after output of channel gain and applying the PC scheme (as a way for managing power resource). They are important approaches to improve network performances. As a result, both of these approaches enable the network to reduce interference. Since MMSE is based on the estimation theory and the model of PC is according to stochastic geometry. We derived the coverage probability of D2D links in the network, eventually spectral efficiency of D2D links has been calculated according to ESE. Also, the spectral efficiencies of D2D links are significantly affect the receiver filter. So, the MMSE filter is the reason of boosting the power of the intended signal and suppressing the interferences. Also, the D2D DPC algorithm is more accommodating to guarantee rate of its links. The DPC method, the optimal PC way is considered, which maximizes the spectral efficiency of D2D links.

APPENDIX

A. Proof of Proposition

The MMSE filter is derived based on the estimation theory, If $s_0$and $\{ s_1 s_2, \dots, s_N\}$ are favored signal and set of interfering signals, respectively. Each signal is iid zero-mean process with magnitude variance a^2 . As where $g_0 = \boldsymbol{w}^H \boldsymbol{h}_0$ and $g_n = \boldsymbol{w}^H \boldsymbol{h}_n$ are the desired signal gain and the nth interfering signal gain, respectively, Also $\hat{s}$ is a random signal that is estimated by the desired signal s_0 , and s_n the nth interfering signal. $\boldsymbol{h}_1 \boldsymbol{h}_2, \dots, \boldsymbol{h}_N$ are the M × 1 channel vectors and Each vectors is independent zero-mean unit variance complex Gaussian random variable. η_0 is an M × 1 noise vector that is an independent zero-mean complex Gaussian random vector with $\sigma^2 \boldsymbol{I}$ variance. $\boldsymbol{w}^H$ is the M × 1 vector of MMSE filter. the favored signal is estimated by

$$\hat{s}_0 = g_0 s_0 + \sum_{n=1}^{L} g_n s_n + \eta_0 \tag{24}$$

Where $g_0 = \boldsymbol{w}^H \boldsymbol{h}_0$ and $g_n = \boldsymbol{w}^H \boldsymbol{h}_n$ are the desired signal gain and the nth interfering signal gain, respectively, Also $\hat{s}$ is a random signal that is estimated by the desired signal s_0 and s_n the nth interfering signal [23],[24].

MMSE filter in the receiver leads to minimum mean square error between the desired signal and the output of the receiver, so the SINR will be maximized.

$$\in = E[| \hat{s}_0 - s_0| ^2] \tag{25}$$

$$\in = a^2 (W^H A W - W^H h_0 - h_0^H W + 1)$$

$$W = \arg\min E\,[\hat{s} - s1] \tag{26}$$

Where each signal $\{s_0 . s_1 . \dots . s_L\}$ has zero-mean and a^2 variance. Also,

$$A = (h_0 h_0^H + \sum_{n=1}^{L} h_n h_n^H + \frac{\delta^2}{a^2} I) \tag{27}$$

$$\sum = \sum_{n=1}^{L} h_n h_n^H + \frac{\delta^2}{a^2} I \tag{28}$$

Where $Aw = h_0 \, . W = A^{-1} h_0$

$$\begin{aligned} &\in = a^2 (1 - h_0^H w) \\ &\quad \in = a^2 (1 - g_0^*) \end{aligned} \tag{29}$$

after some algebra manipulation, the MSE is derived as

$$= a^2 (1 - \boldsymbol{h}_0^H \Sigma^{-1} \boldsymbol{h}_0)^{-1} \tag{30}$$

Based on minimum MSE criterion, the SINR according the MMSE filter is given as bellow

$$\begin{aligned} SINR &= \frac{E[| g_0 s_0 | ^2]}{E[| \sum_{n=1}^{L} g_n s_n + \eta_0 | ^2]} \\ SINR &= \boldsymbol{h}_0^H \sum^{-1} \boldsymbol{h}_0 \end{aligned} \tag{31}$$

B. Proof of Theorem

$$\overline{\overline{P}}_{\text{cov}}^{(\mathrm{d})} = \mathbb{P}\left(SINR_{l.MMSE}^{(d)} \geq \beta\right) \tag{32}$$

$$= \mathbb{P}\left(1 \geq \beta \left(\sum_{i \in \phi_M} P_{i.c} |d_{l.i}|^{-\alpha_d} g_i g_i^H + \sum_{j \in \phi_D} P_{j.d} \beta |d_{l.j}|^{-\alpha_d} g_j g_j^H + \sigma^2 \right) P_{l.d}^{-1} {d_{l.l}}^{\alpha_d} (\boldsymbol{g}_l^H \boldsymbol{g}_l)^{-1} \right)$$

It is assumed that x is exponentially distributed with unit mean and unit variance. Then, we will have $\mathbb{P}(\mathrm{X} \geq C) = \exp(-C)$.

$$= E\left(exp\left(-\beta P_{l.d}^{-1} {d_{l.l}}^{\alpha_d} (\boldsymbol{g}_l^H \boldsymbol{g}_l)^{-1} \left(\sum_{i\,\in\,\phi_M} P_{i.c}|d_{l.i}|^{-\alpha_d} \boldsymbol{g}_i \boldsymbol{g}_i^H + \sum_{j\,\in\,\phi_D} P_{j.d}\beta\left|d_{l.j}\right|^{-\alpha_d} \boldsymbol{g}_j \boldsymbol{g}_j^H \,\sigma^2\right)\right)\right) \tag{33}$$

By definition, ${g_l}^H g_l$ is the square norm of $||g_l||^2$ and also it is defined a χ_{2s}^2 random variable [29].

$$\mathrm{g}_\mathrm{l}^\mathrm{H}\mathrm{g}_\mathrm{l} = ||\mathrm{g}_\mathrm{l}||^2 \sim \chi_{2\mathrm{M}}^2 \tag{34}$$

Therefore, $g_i g_i^H$ is a linear combination of complex Gaussian random variables that equals G_i and thus G_i is iid unit mean exponential. It follow that

$$\mathrm{g}_\mathrm{i}\mathrm{g}_\mathrm{i}^\mathrm{H} \sim \mathrm{Exp}(1) \tag{35}$$

Using Eq. (33) we obtain as below

$$= \mathrm{E}\left(\exp\left(-\gamma\left(\sum_{\mathrm{i}\,\in\,\phi_\mathrm{M}} \mathrm{P}_{\mathrm{i.c}}|\mathrm{d}_{\mathrm{l.i}}|^{-\alpha_\mathrm{d}} + \sum_{\mathrm{j}\,\in\,\phi_\mathrm{D}} \mathrm{P}_{\mathrm{j.d}}\beta\left|\mathrm{d}_{\mathrm{l.j}}\right|^{-\alpha_\mathrm{d}} + \sigma^2\right)\right)\right) \tag{36}$$

$$\gamma = \beta P_{l.d}^{-1} {d_{l.l}}^{\alpha_d} M^{-1}$$

Conditioning with respect to transmit power and distance yields as follow

$$\begin{aligned} &= E_{P_{l.d}^{-1} {d_0}^{\alpha_d}}\left(exp(-\gamma\sigma^2)\right) \\ &\times E_{P_{l.d}^{-1} {d_{l.l}}^{\alpha_d}}\left(exp\left(-\gamma \sum_{i\,\in\,\phi_M} P_{i.c}|d_{l.i}|^{-\alpha_d}\right)\right) \\ &\times E_{P_{l.d}^{-1} {d_{l.l}}^{\alpha_d}}\left(exp\left(-\gamma \sum_{j\,\in\,\phi_D} P_{j.d}\beta\left|d_{l.j}\right|^{-\alpha_d}\right)\right) \end{aligned} \tag{37}$$

Using Laplace transform yields

$$\mathrm{E}\Big(\exp\big(-\mathrm{s}\big(\textstyle\sum_{\mathrm{i}\,\in\,\phi_\mathrm{M}} \mathrm{P}_{\mathrm{i.c}}|\mathrm{d}_{\mathrm{l.i}}|^{-\alpha_\mathrm{d}}\big)\big)\Big) = \exp\left(-\frac{\pi}{\sin \mathrm{c}\left(\frac{2}{\alpha_\mathrm{d}}\right)} \mathrm{E}\left({\mathrm{P}_{\mathrm{i.c}}}^{2/\alpha_\mathrm{d}}\right) \lambda_\mathrm{C}(\mathrm{s})^{2/\alpha_\mathrm{d}}\right) \tag{38}$$

Applying Laplace transform we can obtain

$$\begin{aligned} &= E_{P_{l.d}^{-1} {d_{l.l}}^{\alpha_d}}\left(exp(-\gamma\sigma^2)\right) \\ &+ exp\left(-\frac{\pi}{\sin c\left(\frac{2}{\alpha_d}\right)} E\left({P_{i.c}}^{2/\alpha_d}\right) \lambda_C(\gamma)^{2/\alpha_d}\right) \\ &+ exp\left(-\frac{\pi}{\sin c\left(\frac{2}{\alpha_d}\right)} E\left({P_{j.d}}^{2/\alpha_d}\right) \lambda_D(\gamma)^{2/\alpha_d}\right) \end{aligned} \tag{39}$$

Deconditioning with corresponding to transmit power and distance yields the coverage probability as follow

$$= exp\left(-\frac{\pi}{\sin c\left(\frac{2}{\alpha_d}\right)} E\left({P_{i.c}}^{2/\alpha_d}\right) \lambda_C(\gamma)^{2/\alpha_d} - \frac{\pi}{\sin c\left(\frac{2}{\alpha_d}\right)} E\left({P_{j.d}}^{2/\alpha_d}\right) \lambda_D(\gamma)^{2/\alpha_d}\right) \tag{40}$$

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Faezeh Heydari received the B.S. degree in Physic from Azad University, Tehran North Branch, Iran in 2004, and M.S. degree in Telecommunication from Azad University, Tehran South Branch, Iran, in 2010. she has received Ph.D degree from Azad University, Saveh Branch, Iran in 2021. Her research interests include Massive MIMO Antennas, Device to Device Networks, Power Control.

Saeed Ghazi-Maghrebi was born in Iran in 1963. He received the B.S. degree in electrical engineering from Kerman University, Iran, in 1988, and the M.S. degree from the Khajeh Nasir-edin- Toosi University of technology, Iran, in 1995. He received the PhD degree in digital communications from Islamic Azad University, Iran in 2010. He is associate professor in communication systems engineering. He has published six books. He has received the grade of the second degree of 30th Khwarizmi International Award (KIA) on Feb. 2017. He is designer of Iranian national data centre. He is a dean of Azad University, Yadegar-e-Imam Khomeini (RAH) Share Rey Branch, Tehran, Iran. His current research interests are digital communication, signal processing and adaptive filtering.

Ali Shahzadi is a full-time Associate-Professor of Electerical and Computer Engineering in the Faculty of engineering at Semnan University, Semnan University, Semnan, Iran. He is conducting research activities in the areas of Wireless Communications Networks, Cognitive Radio, Cooperative Communications.

Mohammad Jalal Rastegar Fatemi works as full-assistant professor in the Faculty of Engineering at Azad University, Saveh Branch, Iran.