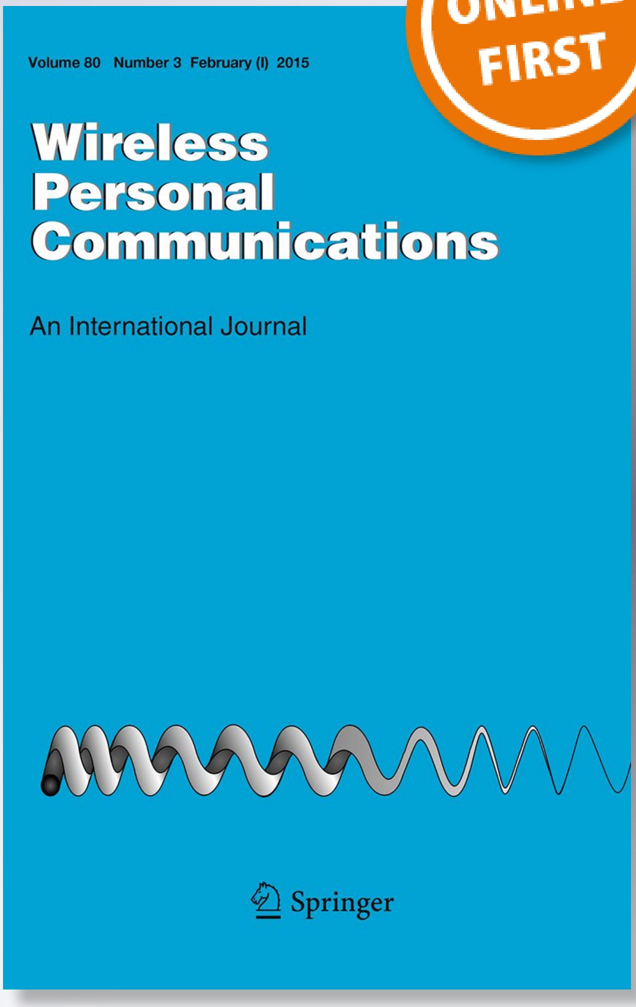
Power Beacon-Based Wireless Power Transfer in MISO/SISO: An Application in Device-to-Device Networks

Huu-Phuc Dang, Chi-Bao Le, Dinh-Thuan Do, Si-Phu Le, Hong-Nhu Nguyen & Miroslav Voznak

Wireless Personal Communications
An International Journal

ISSN 0929-6212

Wireless Pers Commun
DOI 10.1007/s11277-019-06733-z


Volume 80 Number 3 February (I) 2015

Wireless Personal Communications

An International Journal

Springer

Springer

Wireless Personal Communications
https://doi.org/10.1007/s11277-019-06733-z

Power Beacon-Based Wireless Power Transfer in MISO/SISO: An Application in Device-to-Device Networks

Huu-Phuc Dang[1] · **Chi-Bao Le**[2] · **Dinh-Thuan Do**[4] · **Si-Phu Le**[3] · **Hong-Nhu Nguyen**[3] · **Miroslav Voznak**[3]

Abstract

This paper considers device-to-device (D2D) together with single input single output and multiple input single output models in transmitting of nearby devices under help of wireless power transfer. To support more harvested energy, two modes are studied in which multiple-antenna/single antenna power beacons are proposed to robust D2D transmission network. Especially, enhanced successful communication is explored with short distance transmission. Accordingly, the alternative energy source can be used to maintain small devices which can operate at close position efficiently. In this paper, a model of radio frequency-assisted wireless energy transfer for D2D system with two realistic transmission schemes will be investigated, namely pure D2D and D2D with interference impact of conventional user equipment. As an important result, we derive analytical expressions for outage probability to achieve performance evaluation. This paper will analyze outage probability by matching Monte-Carlo and analytical simulations to corroborate the exactness of derived expressions.

Keywords Energy beamforming · Multiple input single output · D2D networks · Outage probability

1 Introduction

Because of the increasing speed of Internet of things and smart devices, investigating more energy and spectral effective energy consuming wireless technique becomes more important. Wireless Power Transfer (WPT) has a potential capability in energy transfer and becomes efficient in wireless devices which require less energy consuming, and hence makes it a promising research trend for green communications. Moreover, the leading advancement of energy harvesting protocols in wireless charging technology provide trusted evaluations for their applications in the near future [1–7]. In principle, it is obvious that RF signals can help in WPT [2, 3] to transmit energy to low power consuming devices for charging.

✉ Dinh-Thuan Do
dodinhthuan@tdtu.edu.vn

Extended author information available on the last page of the article

To extract the information and power from the same signal, WPT is proposed to adopt the power beacons (PBs) approach [4]. Considering on low cost PBs, backhaul links are not required. Such PBs are installed to deliver dedicated power transfer in wireless relaying and D2D networks. In wirelessly charge devices like smartphones in a home environment, a PB was designed by the Cota Tile and was showcased at the 2017 Consumer Electronics Show [5]. There are two crucial challenges in the deployment of PBs to wider networks. The first difficuty is the absence of tractable prototypes for analysis and design of such networks. Though computer simulations can be recycled in these concerns, exhaustive simulation of every possible situation of interest will be tremendously time-consuming and onerous. Hereafter, it need be explored tractable models for PB-assisted communications in wireless networks. The second challenge is the use of practical prototypes for WPT, which capture realistic aspects of WPT. For instance, WPT receivers (RXs) can only harvest power in case of the incident received power is enough high and it is greater than the power circuit activation threshold (typically approximate − 20 dBm [6]).

Besides that, a lot of attention has been paid to a promising area which is the simultaneously-carried possibility of both energy and information during transmission [2, 3]. Model of a perfect receiver—simultaneous wireless information and power transfer (SWIPT) can figure out the information and collect energy from the alike signal as described in [7]. In order to solve the problem of maximizing security speed in the SWIPT, the transmit beamforming without artificial noise and transmit beamforming with artificial noise have been investigated in [8]. However, because of the limited hardware, this supposition can not be used in actual environment [9]. To reduce this difficulty, many works presented Time switching (TS) and Power splitting (PS) as two different receivers in a MIMO system [10].

In other line of energy harvesting technique, most of the current studies in the RF-EH model concentrated on using RF signal transferred from the base station (BS). Nevertheless, in fact, the RF-EH capability is reduced partially as a result of the overall loss between base station (BS) and EH users. By introducing the Power beacon (PB) for wireless energy transfer, the authors in [11, 12] can adopt a effective power supply for RF-EH. Therefore, the relaying network can be considered as a solution to increase the coverage and operation time of RF-EH. Nevertheless, in such models, because the PB and BS are at the same cell, the Information-Decoding (ID) users near the PB can be prevented by the information transmitting of PB. The recent work presented derived exact expressions and asymptotic closed-form expressions of the secrecy outage probability by adopting the time-switching protocol at PB with regard to two transmission schemes under condition of the outdated channel state information (CSI) [11]. The other advantage of PB-assisted energy harvesting in which PB is attached with a lot of antennas. Therefore, when using the transmit beamforming with PB, the transmisison efficiency during transmission in realying model can be improved in case of multiple input multiple output (MIMO) or multiple input single output (MISO) systems is deployed with RF-EH. The interesting investigation in [12] shown two single antenna energy constraint devices can harvest energy from PB equipped multi-antenna and then transmit to each other with the helping relay. In addition, the authors in [13] have also applied the PB in the EH heterogeneous network to increase the efficiency of RF-EH and achieved a near-optimal rate energy region by maximizing the weighted sum of harvested energy and information rate. However, how to transmit the energy beamforming to remain optimal performance is still an open problem because the optimization problem has not been widely discovered.

Despite of considerable success achieved in the studies of SWIPT [14–20], these works also bring some undeniable drawbacks. The first downside is that the situations in which energy can be scavenged either from natural sources or RF signals by EH nodes are the major scopes of all these studies. Hence, the scenarios when energy from natural sources while others from RF signals can be harvested by several EH nodes are worth considering. Furthermore, it is proved that relay transmission may be less efficient compared to direct transmission, which there have been no studies on such situation previously, e.g, in [15]. Nonetheless, in practice, the efficient use of direct transmission or relay transmission should be considered, ie. in device-to-device (D2D) transmission. The next disadvantage is that the power splitting ratio is sometimes a constant value, e.g., in [15] it is allowed to take any value in the interval [0,1], but this parameter may take only discrete levels practically and should be optimized dynamically to maximize system performance [19, 20]. However, because of the random scavenged energy and there are some causes which negative affect it like weather, channel conditions, utilizing the amount of harvested energy effectively is essential to deal with some unpredictable events to lengthen network lifetime. Few works focused on optimal energy harvesting, for example in terms of energy causality and battery storage constraints, jointly design power control and transfer are proposed to maximize the sum rate over finite time duration [20].

In recent years, D2D network has attracted a lot of attention. It is considered as one of the modern technologies applied in 5th generation mobile networks for the purpose of improving spectral, energy efficiency and extend cellular coverage [21]. On the other hand, D2D devices are forced with energy, using RF wireless energy transmit can contribute to extend the endurance of D2D devices and broaden the scale of D2D network [22]. The D2D transmissions were initially mentioned in [23]. Presume that D2D transmitters have enough energy, in [24] the best power transfer of D2D transmitters was researched and inspected the [25] energy collecting in D2D communications by surround RF intervention from cellular users (CUs) and base stations (BS). However, the energy collected in [25] may not strong enough for D2D conversions because of the spacing problem, the transmit power of the CUs is insufficient and the signal power from the BSs is not strong enough.

In addition, D2D permits traffic offloading between devices with several advantages such as increases capacity, consumption of spectral resources, and depressing delay [26]. However, to consider impacts of interference in D2D network, transmit power constraints are strict forced on each device of D2D, which will affect on the quality and the throughput of the D2D network. In principle, after performing energy harvesting D2D nodes can spend the harvest to power their transmissions. However, the significant challenges are raised such as uncertainty energy harvesting and interference from other devices using co-channel. However, radio energy-gathering technique using radio frequency (RF) has been investigated in recent works [26, 27], which allows D2D nodes to improve their power consumption against to energy shortage [28–31]. Although the current achievement regarding harvesting circuit has limited capabilities, D2D devices just need low power with some applications in IoT field The traditional cellular users must limit their interference to decreasing impacts on performance of the main links in D2D. However, energy harvesting may be sufficient to information processing.

These recent works and interesting results in [32, 33] motivate us to find system performance of D2D with/without impacts of the nearby conventional user equipment (CUE) and how harvested energy amount from the PB affect on system performance. In this paper, there are difference concerns from the system model in [34] which has adopted the stochastic geometry while in the study wireless energy transfer is exploitted to support D2D communication,. In particular, we consider a PB-assisted wireless network under impact of interference of traditional cellular users in which the first device adopts the harvest-then-transmit protocol, i.e., they harvest energy from the aggregate RF signal transmitted by PBs and then use the harvested energy to transmit the information to the far device. It is worth noting that this work can be referred as an extended version of [35]. In particular, our work has also considered both the SISO and the MISO case, and make the performance comparisons between them. Furthermore, we develop a tractable analytical framework to investigate the outage probability. In the proposed framework, the outage probability is efficiently and accurately computed by numerical inversion using the closed-form expression. The novel contributions of this paper are shortened as follows:

- We adopt a realistic model of wirelessly powered by taking into consideration (i) the power splitting based relay is applied; (ii) power beacon with single antenna/multiple antennas for strong power transfer to satisfy required devices.
- For tractable analysis of the system performance, we intend to find exact outage probability to compare performance of four considered schemes, namely SISO/MISO pure D2D (SISO PDD vs. MISO PDD), SISO/MISO D2D with interference from conventional user (SISO CDD vs. MISO CDD).
- We investigate impacts of several parameters on outage performance of such schemes in D2D networks.
- Next, Monte Carlo simulations are presented the outage performance to corroborate our analysis and the impact of some significant parameters on proposed protocol in PB assisted networks are investigated.

The rest of the article is structured as follows: System model and related assumptions are designated in Sect. 2. Next, the outage probability analysis of power beacon (PB) assisted D2D system with two considered cases related to impact of interference from the CUE are presented. Simulation results are performed in Sect. 4. Section 5 concludes with important remarks for the paper.

Notation *Bold face vector x is matrix,* $E(.)$ *stands for expectation operation.* $f_Z(.)$ *and* $F_Z(.)$ *represent the probability distribution function (PDF) and the cumulative distribution function of random variables (RVs)*, Z, *respectively*. $\Pr(.)$ *is the outage probability function.*

2 System Model

The system model is described in Fig. 1, where the source D_1 connects with the destination D_2. We assume power splitting protocol for wireless power transfer to the self-power device because of its simplicity. Besides, it is also assumed that in MISO scheme only the BS equipped a lot of antennas while the near device and far device use only one antenna for reception, and all CSI are available at PB, which can be got by estimating the channel information. While one antenna is equipped at the PB in SISO circumstance. In case of device with energy shortage, to prolong lifetime of D2D transmission link, such device require the outside energy charging through wireless power transfer from a multi-antenna/single antenna PB. In particular, we provide a single antenna design for both D_1 and D_2, whereas N is positive integer number ($N \geq 1$) antennas are equipped in the PB.

The data transmissions in the system is done into two phases. In first phase, D_1 will collects energy from the energy-bearing signal which is sent from the PB, then D_1 will use harvested energy to send its own information to D_2. We call P is transmit power at the PB. We consider power splitting relaying protocol, i.e. during the first phase of duration εP, where $0 < \varepsilon < 1$ stands for power percentage for energy transfer, D_1 (i.e. energy harvesting-assisted device) collects energy from the PB and using such energy for direct communicate

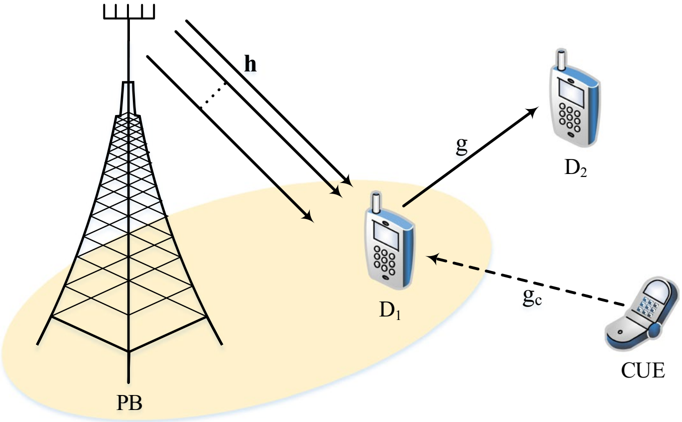


Fig. 1 System model for MISO D2D network

with D_2 which is also energy harvesting-aided device in MISO PDD or not in remaining schemes. In such model, the energy transfer occurs in dual hop from the PB to D_2. In this paper, we determine the system performance for direct communication where D_1 transfers information to D_2 and the study was conducted in two cases with the impact of interference and without impact of interference from the CUE.

The novel model of this work can be further described briefly as follows. In D2D networks, there are two basic system models. In the first case, two devices can communicated directly without help of the base station. In the second case, the base station operate as relay for forwarding signal from the device to the other device. In this paper, we examine the first mode to evaluation impacts of wireless power transfer. In next section, we consider two modes, namely pure D2D (PDD) and D2D with interference from CUE (CDD).

2.1 MISO PDD Mode

In this mode, we explore D2D transmission without impact of CUE. For the pure D2D case, during initial phase, i.e., the energy collecting phase, the harvested power at D_1 can be obtained via the channel $\mathbf{h}$ with supporting of transmit signal $\mathbf{x}_s$. We denote $\mathbf{x}_s$ is an $N \times 1$ signal vector. Besides, we also denote $\mathbf{h}$ is the Nakagami-m fading channel coefficients of the link $BS \to D_1$. Hence, the elements of $\mathbf{h} = \left[h_i\right], i = 1, \dots, N$, are considered to be independent and identically distributed (i.i.d.) with consistently allocated phase and the intensity, the random variable $x = \left[h_i\right]$ and $x \sim Nakagami(m, \Omega)$ with the probability density function (PDF) as follow

$$f(x; m, \Omega) = \frac{2}{\Gamma(m)} \left(\frac{m}{\Omega}\right)^m x^{2m-1} e^{\left(-\frac{m}{\Omega}\right)x^2}, \quad x \geq 0, \tag{1}$$

in which $\Gamma(\cdot)$ indicates the Gamma function, $m = \frac{E^2\left[x^2\right]}{\mathrm{var}\left[x^2\right]}$, $\Omega = E\left[x^2\right]$ and we set $\Omega = 1$.

Since many antennas are used, the energy transfer signal from PB to D_1 is shown as follows

$$\mathbf{x_s} = \mathbf{w s_e}, \tag{2}$$

where $\mathbf{w}$ is the beamforming vector with $||\mathbf{w}||^2 = 1$ and s_e is the signal that contains the power energy that needs to be transmitted.

Because PB is equipped with multiple antennas, PB can use either beamforming or randomly select antennas for signal transmission. Under the transmit beamforming, before transmitting as in (2) above, the transmitter will multiply the information signal with the optimal beamforming vector which is given by

$$\mathbf{w} = \frac{h^H}{||\mathbf{h}||}, \tag{3}$$

where the superscript "H" denotes the Hermitian transpose.

Therefore, the energy received in the initial phase can be considered as follows [3]

$$E_n = \eta\varepsilon||\mathbf{h}||^2 PT/2, \tag{4}$$

where $0 < \eta < 1$ is the energy conversion efficiency and T is block time. Then, the transmit power at D_1 can be expressed by

$$P_{D_1}^{MISO} = \eta\varepsilon||\mathbf{h}||^2 P. \tag{5}$$

In the second phase, thanks to the energy collected during the initial phase, D_1 will use this energy to transmit the signal to D_2. Thus, the received signal at D_2 is shown as follows

$$y_{D_2}^{MISO} = \sqrt{P_{D_1}^{MISO}}g\left(\sqrt{\alpha}s_{01} + \sqrt{(1-\alpha)}s_{02}\right) + n_{D_2}, \tag{6}$$

in which, $g \sim \mathcal{CN}(0, \lambda_g)$ denotes the Rayleigh fading channel coefficient of the link $D_1 \to D_2$, s_{01} is the signal that contains the data information while s_{02} serves as energy bearing signal to D_2, and $n_{D_2} \sim \mathcal{CN}(0, N_0)$, is the additive white Gaussian noise (AWGN). It is noted that power splitting factor for the first hop is ε while power splitting factor for the second hop is α.

Hence, the end-to-end signal to noise ratio (SNR) for can be calculated as

$$\gamma_{D_1-D_2}^{MISO} = \frac{\eta\varepsilon\alpha||\mathbf{h}||^2|g|^2 P}{\eta\varepsilon(1-\alpha)||\mathbf{h}||^2|g|^2 P + N_0}. \tag{7}$$

2.2 MISO CDD Mode

In such mode, we determine D2D transmission with impact of CUE. In such model, to satisfying high quality for the system performance, the D_1 device does not transmit energy to other device. In the existing work, we study the assumption that each D2D link with impact of at least one nearby CUE. In the existence of CUE, the received signal during first phase is given as

$$y_{D_1}^{MISO} = \sqrt{P}\mathbf{h}\mathbf{x}_\mathbf{s} + \sqrt{P_I}g_c s_c + n_{D_1}, \tag{8}$$

where P_I is the transmit power of the interferer (i.e. CUE), g_c is the interference channel coefficient, s_c is the transmit signal of the CUE. It can be calculated the transmit power at D_1 after processing energy harvesting at the first phase as follows

$$P_{D_{1I}} = \eta\varepsilon||\mathbf{h}||^2 P + \delta \approx \eta\varepsilon||\mathbf{h}||^2 P, \tag{9}$$

where δ denotes as energy collected from the CUE. Unfortunately, amount of such energy is very small compared with the power from the PB. Hence, in this model we eliminate impact of energy harvesting from the CUE. In the second phase, D_1 transmits the signal to D_2, the received signal at D_2 is given by

$$y_{D_2}^{MISO} = \sqrt{P_{D_1}^{MISO}}g\sqrt{\alpha}s_{01} + \sqrt{P_I}g_c s_c + n_{D_2}. \tag{10}$$

As a result, the end-to-end signal to interference plus noise ratio (SINR) can be calculated

$$\gamma_I^{MISO} = \frac{\eta\varepsilon|g|^2\alpha\|\mathbf{h}\|^2\frac{P}{N_0}}{1 + \frac{P_I|g_c|^2}{N_0}} = \frac{\eta\varepsilon|g|^2\alpha\frac{N_0}{P_I}\|\mathbf{h}\|^2\frac{P}{N_0}}{\frac{N_0}{P_I} + |g_c|^2}. \tag{11}$$

2.3 PDD and CDD Modes in SISO Case

In this scenario, the PB is only equipped by single antenna. Compared with MISO power transfer, less power can be furnished to the first device D_1 in D2D network. We denote $h \sim \mathcal{CN}(0, \lambda_h)$, $g \sim \mathcal{CN}(0, \lambda_g)$ and $g_c \sim \mathcal{CN}(0, \lambda_c)$ are the Rayleigh fading channel coefficients of the link $PB \to D_1$, $D_1 \to D_2$ and $CUE \to D_1$, respectively, in which λ_h, λ_g and λ_c are the channel average powers. Note that the PDF and the CDF of the channel $\mathbb{X}$ are $f_{\mathbb{X}}(x) = \frac{1}{\lambda_{\mathbb{X}}}e^{-\frac{x}{\lambda_{\mathbb{X}}}}$ and $F_{\mathbb{X}}(x) = 1 - e^{-\frac{x}{\lambda_{\mathbb{X}}}}$, respectively. In SISO scenario, the transmit power at D_1 can be expressed by

$$P_{D_1}^{SISO} = \eta\varepsilon|h|^2P. \tag{12}$$

With no interference from the CUE, to the end-to-end SNR in PDD SISO can be expressed as

$$\gamma_{\mathrm{PDD}}^{SISO} = \frac{\eta\varepsilon|h|^2|g|^2P}{N_0}. \tag{13}$$

With regard to the end-to-end SNR in CDD SISO, it can be computed as

$$\gamma_{CDD}^{SISO} = \frac{\eta\varepsilon|h|^2|g|^2P}{|g_c|^2P + N_0}. \tag{14}$$

3 Outage Performance Analysis

3.1 Outage Performance of MISO D2D Without Impact of CUE

We call $P_{out,PDD}^{MISO}$ as the outage probability. Such outage event can be defined as

$$P_{out,PDD}^{MISO} = \Pr(\gamma_{D_1-D_2}^{MISO} < \gamma_{th}), \tag{15}$$

where γ_{th} is the target SNR

Proposition 1 *Consider system performance, the outage probability of such D2D link at the target rate* R_0 *can be formulated as* [33]

$$P_{out,PDD}^{MISO} = 1 - \frac{2m^{\frac{Nm}{2}}}{\Gamma(Nm)}\left(\varphi_1\gamma_{th}\right)^{\frac{Nm}{2}} K_{Nm}\left(2\sqrt{m\varphi_1\gamma_{th}}\right), \tag{16}$$

where $\Gamma(x)$ is the Gamma function [[36], Eq. (8.310)], $K_n(.)$ is the modified Bessel function of the second kind [[36], Eq. (8.432)], $\varphi_1 = \frac{N_0}{\eta\varepsilon P\left(\alpha-\gamma_{th}+\alpha\gamma_{th}\right)}$, $\gamma_{th} = 2^{R_0} - 1$ is the threshold SNR and R_0 denotes the target rate of source.

Proof The system's outage probability can be described as follows

$$P_{out,PDD}^{MISO} = \Pr(\gamma_{D_1-D_2}^{MISO} < \gamma_{th}) = \Pr\left(\|\mathbf{h}\|^2|g|^2 < \varphi_1\gamma_{th}\right). \tag{17}$$

In such case, it is required the condition on power splitting factor as $\alpha > \gamma_{th}/\left(\gamma_{th}+1\right)$. It is worth noting that $\|\mathbf{h}\|^2$ is a Gamma random variable with PDF given by

$$f(x) = \frac{m^{\frac{Nm}{2}}}{\Gamma(Nm)}\left(\varphi_1\gamma_{th}\right)^{\frac{Nm-1}{2}} e^{-mx},\ for\ x \geq 0. \tag{18}$$

It is noted that the cumulative distribution function (CDF) of $\|\mathbf{h}\|^2|g|^2$ can be achieved by applying the following expression [33]

$$F(x|\|\mathbf{h}\|) = 1 - e^{-\frac{x}{\|\mathbf{h}\|}}. \tag{19}$$

To this end, averaging over $\|\mathbf{h}\|^2$, the absolute CDF of such function can be calculated as

$$F(x) = 1 - \frac{2mx^{\frac{Nm}{2}}}{\Gamma(Nm)} K_{Nm}\left(2\sqrt{xm}\right). \tag{20}$$

It will be obtained the expected result after simple manipulations is given in Proposition 1.

In the asymptotically large number of antennas regime, i.e., $N \to \infty$, it can be the approximate expression of outage probability as below.

Remark 1 In case the number of antennas is very large, i.e., $N \to \infty$, it can be approximate that $\|\mathbf{h}\| \approx N$.

Therefore, the system's outage probability in (17) can be computed in simple formula as

$$\begin{aligned} P_{out,PDD}^{MISO} &\approx \Pr\left(|g|^2 < \frac{\varphi_1\gamma_{th}}{N}\right) \\ &= 1 - \exp\left(-\frac{\varphi_1\gamma_{th}}{N}\right). \end{aligned} \tag{21}$$

3.2 Outage Performance of MISO D2D Under Impact of CUE

In the case of there is an interference affect D_1 due to the presence of a CUE which is transmitting information at a location close to D_1, the outage probability of system is calculated as Proposition 2.

Proposition 2 *We first denote* $\gamma_I^{MISO} = \frac{|g|^2}{|g_c|^2 + \Psi_1} \Psi_2 \|\mathbf{h}\|^2 \frac{P}{N_0}, \Psi_1 = \frac{N_0}{P_I}$ *and* $\Psi_2 = \eta \varepsilon \alpha \frac{N_0}{P_I}$, *the system's outage probability can be expressed as*

$$P_{out,CDD}^{MISO} = 1 - \frac{e^{-\Psi_1 (\gamma_{th} N_0 / (\Psi_2 NP))}}{1 + \gamma_{th} N_0 / \left(\Psi_2 NP \right)}. \tag{22}$$

Proof See in "Appendix" ☐

As important result, the Proposition 2 provides an accurate expression for the outage performance of the system, which may be applicable computed in practical design of D2D where require more energy from the PB for D2D transmission.

For delay limited transmission, the source transmits at a constant rate R_c, which may be subjected to outage due to fading. Hence, the average throughput can be evaluated as

$$\tau_{\psi}^{MISO} = \left(1 - P_{out,\psi}^{MISO} \right) R_c, \tag{23}$$

where $\psi = \{PDD, CDD\}$, denoted as outage probability corresponding with two considered schemes in (16) and (22).

Remark 2 Note that for the D2D networks with higher number of antenna equipped at PB, larger amount of harvested energy at the first device, but outage probability of such D2D becomes worse as observation from derived expression. On the other hand, for the D2D networks with smaller impact of nearby interference source, there is more noise terms contribute to expression of the obtained SNR, and hence outage performance also decreases. Therefore, there is a trade-off between the number of antenna at PB or interference levels and the outage probability. Since the outage probability is a function of the transmission power of the PB, there exists an optimal value which yields the maximum network throughput. It seems intractable to derive a closed-form expression for the maximum throughput.

3.3 Outage Performance of SISO D2D

In the previous sections, multiple antennas at the PB has been considered, and in this section, more sophisticated choices will be used. However, PB with various transmit antennas is costly deployment. Without loss of generality, we focus on the special case as the BS is assigned same role as PB. In cellular network, the BS controls signaling link and information processing for group of CUE and extra operation is that transmits power to devices which require wireless power transfer due to small size and simple signal processing. An important observation is that such case becomes the benchmark for MISO schemes. From the perspective of the system performance evaluation, we first derive SNR and corresponding outage performance.

In the SISO case, the PB is only equipped with an antenna and it can be assumed that there is without impact of the interference which caused by the CUE in PDD mode. Without loss of generality, it is assumed that $P_I = P$. It is worth noting that amount of harvested energy is smaller than MISO schemes, and hence D_1 only transmit information to D_2.

Next, we express the instantaneous rates at D_2 in SISO PDD mode and SISO CDD mode, respectively as

$$R_{PDD}^{SISO} = \frac{1}{2} \log_2 \left(1 + \gamma_{PDD}^{SISO} \right) = \frac{1}{2} \log_2 \left(1 + \frac{\eta \varepsilon |h|^2 |g|^2 P}{N_0} \right), \tag{24}$$

and

$$R_{CDD}^{SISO} = \frac{1}{2}\log_2\left(1 + \gamma_{CDD}^{SISO}\right) = \frac{1}{2}\log_2\left(1 + \frac{\eta\varepsilon|h|^2|g|^2P}{|g_c|^2P + N_0}\right). \tag{25}$$

The outage performance in PDD mode for SISO circumstance can be expressed by

$$P_{out,PDD}^{SISO} = \Pr\left\{\frac{\eta\varepsilon|h|^2|g|^2P}{N_0} \le \gamma_{th}\right\}. \tag{26}$$

So, the outage probability in PDD mode for SISO case that can be obtained from (26) as follows

$$\begin{aligned} P_{out,PDD}^{SISO} &= 1 - \Pr\left(|h|^2 > \frac{N_0\gamma_{th}}{\eta\varepsilon P|g|^2}\right) \\ &= 1 - \frac{1}{\lambda_g}\int_0^\infty \mathrm{e}^{-\frac{A}{\lambda_h x}} e^{-\frac{x}{\lambda_g}}\,dx, \end{aligned} \tag{27}$$

where $A = \frac{N_0\gamma_{th}}{\eta\varepsilon P}$. The outage probability in SISO case can be obtained by applying [[36], Eq. (3.324.1)] and it can be expressed as

$$P_{out,PDD}^{SISO} = 1 - 2\sqrt{\frac{A}{\lambda_h\lambda_g}}K_1\left(2\sqrt{\frac{A}{\lambda_h\lambda_g}}\right). \tag{28}$$

We denote $K_1(.)$ as the modified Bessel function of the second kind with first order.

Proposition 3 *The closed-form expression of CDD mode in SISO case can be formulated as*

$$P_{out,CDD}^{SISO} = 1 - \int_0^\infty 2\sqrt{\frac{B}{\lambda_h\lambda_g}}K_1\left(2\sqrt{\frac{B}{\lambda_h\lambda_g}}\right)\frac{1}{\lambda_c}e^{-y/\lambda_c}\,dy, \tag{29}$$

where $B = \frac{yP+N_0}{\eta\varepsilon P}\gamma_{th}$.

Proof See in "Appendix" □

4 Numerical and Simulation Results

Simulations are accomplished for system performance evaluation in MATLAB to obtain role of parameters which have an effect on D2D networks in analytical and simulation results. In this part, the results of Monte Carlo imitation are introduced to confirm the analytical expressions from the previous sections. The important data that support the simulation is shown in each illustration. Except for some special cases, the simulation parameters set as: $R_0 = 3(BPCU)$ so the target SNR is $\gamma_{th} = 2^{R_0} - 1 = 7$. The energy conversion

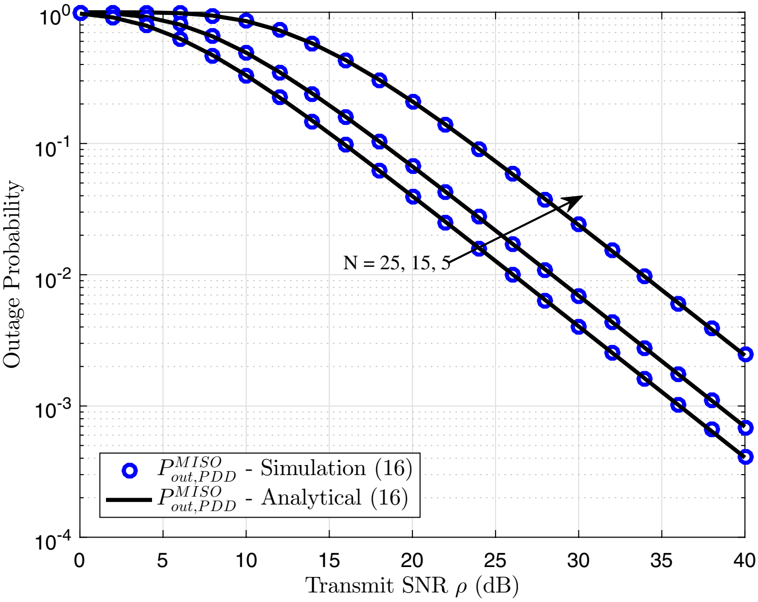


Fig. 2 System model for MISO D2D network

efficiency is set to be $\eta = 0.4$, power splitting factor in D2D link is $\alpha = 0.9$ and $\rho = P/N_0$ is denoted as transmit SNR, while the Nakagami-m parameter is set to be $m = 4$, which correlates to a Rician factor of $K = 3 + \sqrt{12}$. For simplicity, the distances between the PB and D_1, D_1 and D_2 are set to be unit.

The outage probability of D2D link that without interference from the CUE is shown in Fig. 2, when the PB uses a beamforming transmission strategy for transmitting information to the near device which use energy harvesting capability for D2D link transmission. It can be observed that the more antenna equipped at the PB outperforms the case which uses lower number of antenna in high SNR regime. Such performance gap related to the number of antenna can be seen clearly at high SNR value. In the case of SNR is low, energy for signal processing can not lead to large impacts on outage performance while more energy for better signal communication between two D2D users.

Figure 3 demonstrates the outage performance as varying power percentage of energy harvesting from the PB where can be enhanced quality of short distance transmission of D2D. It is noted that in this case we do not consider impact of the CUE's interference signal. As clear observation, it can be easily noticed that adding more energy to the PB can considerably enhance the achievable outage performance. Nonetheless, when the transmit power is low, the advantage of putting more antennas rapidly declines. This problem is quite normal, because growing the number of antennas can increase energy of beamforming, thus, the value of the collected energy is also enhanced, resulting in reduced the system's outage. Moreover, it is obvious that the analytical result maintains efficiently tight with Monte-Carlo simulation in various parameter of energy harvesting and the number of antenna.

In other observation with regard to impacts of the target rate, Fig. 4 validates the outage performance as varying the target rates where can be affected quality of transmission in D2D link. It is noted that in this case the higher requirement of the target rate must be

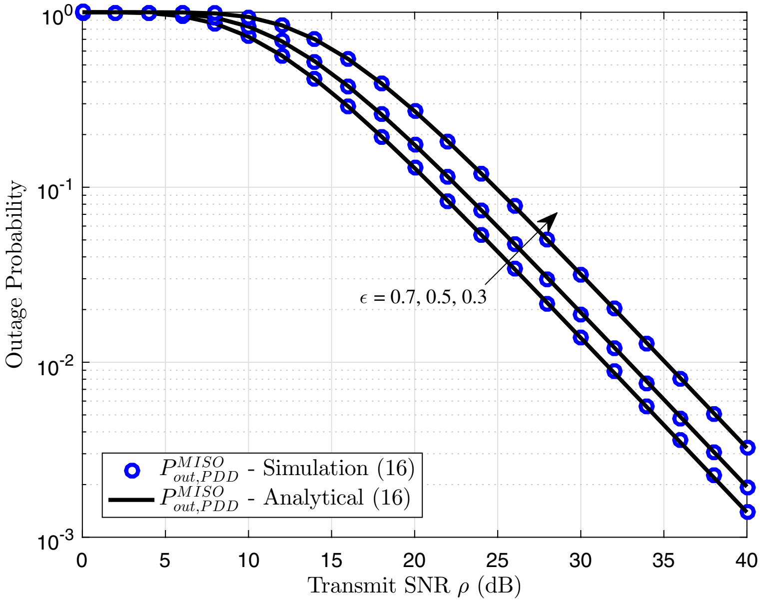


Fig. 3 The outage performance in PDD mode as varying harvested power percentage

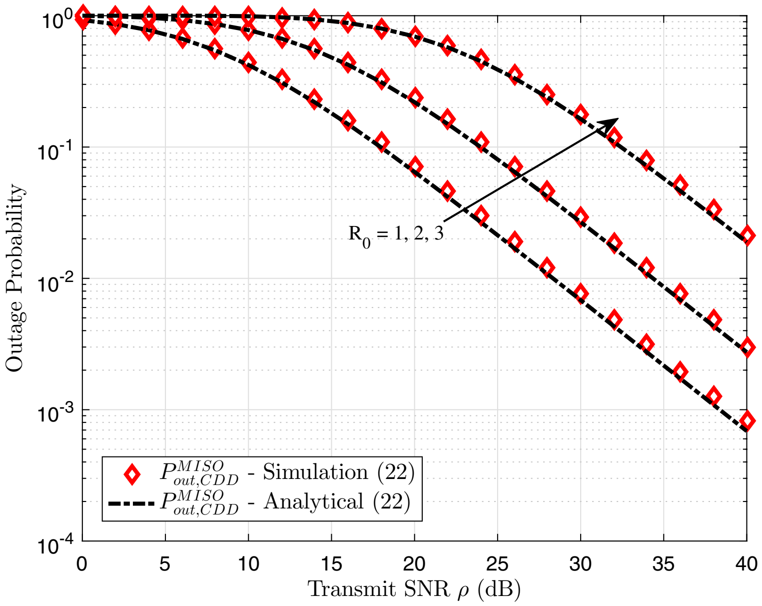


Fig. 4 The outage performance with different target rates in CDD mode

need higher harvested power and decrease outage performance. In practical design, one can clarify the number of outside interfere sources to evaluate system performance to satisfy requirement of such D2D network.

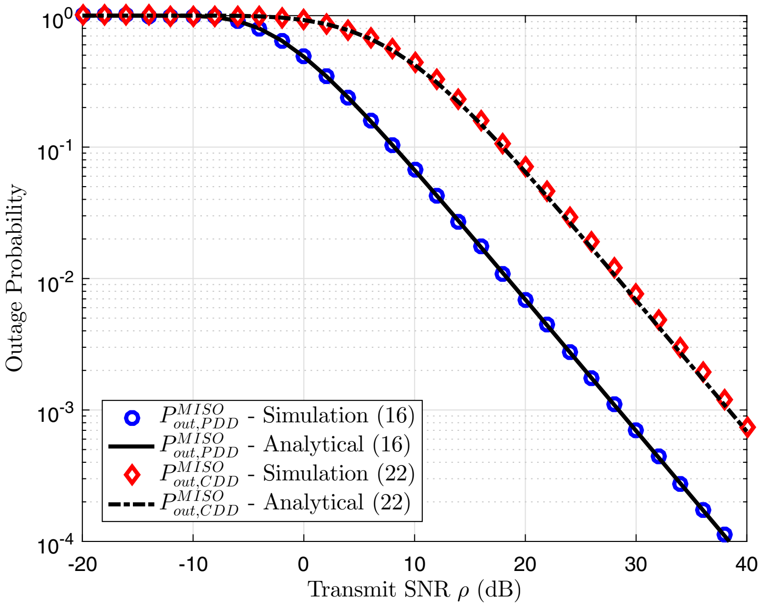


Fig. 5 The comparison study on the outage performance

Now Fig. 5 in this paper shows the outage probability results for the two cases related impact of the CUE on D2D link. Figure 5 demonstrates the outage probability comparison of the such D2D links, so-called MISO PDD and MISO CDD. It can be seen clearly that the CUE contributes to decreasing outage performance of D2D transmission although obtaining more energy beamforming from the PB.

As can be seen from Figs. 6 and 7 in this paper, the throughput results in delay-limited mode corresponding given outage probability for the two cases related existence of the CUE. It can be confirmed clearly that the more antennas equipped at the PB leads to improved throughput performance of D2D transmission. The reason is that throughput depends on the obtained outage performance in previous results.

The outage performance difference as varying the target rates in proposed SISO scheme is also illustrated in Figs. 8 and 9. The channel setup related to SISO PDD mode is $\lambda_h = \lambda_g = 1$ with regardless of distance of nodes in D2D and $\lambda_c = 0.03$ for SISO CDD case. It can be further investigated as put more parameters regarding distance in derived expression. However, it is minor variation in our result and we omit it here. When smallest target rate is required, the system outage scheme outperforms the remaining schemes, and this observation is consistent with MISO cases which shows that the reasonable selection of threshold SNR corresponding the target rates in these schemes achieves the minimal outage probability. When the CUE has be considered in achieved SNR, the lower SNR can be obtained and hence the corresponding outage performance will be worse than that in PDD mode. Furthermore, Figs. 8 and 9 also demonstrates that the users' targeted rates significantly affect the performance gap at high SNR regime. Particularly, as the difference target rates, the outage performance gap among outages enlarges accordingly. In addition, computer simulations also confirm the accuracy of the analytical results developed in previous propositions compared with Monte-Carlo simulation results.

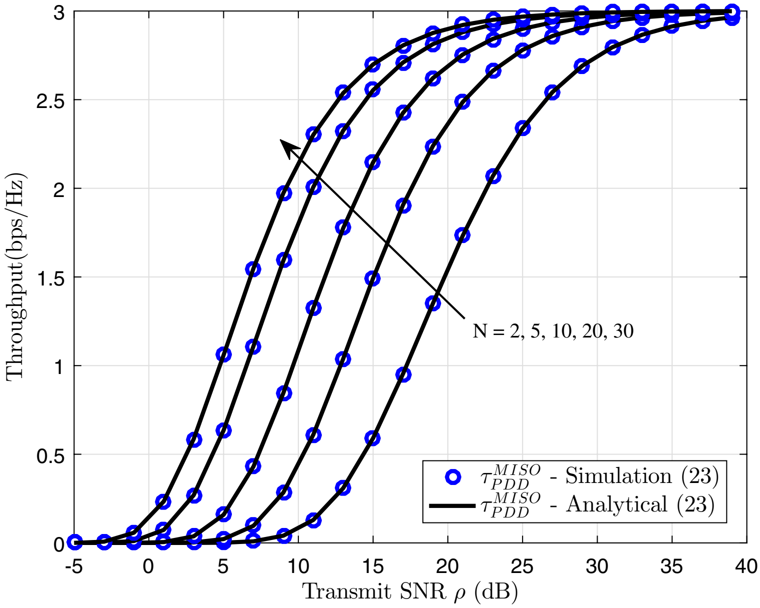


Fig. 6 The system's throughput MISO PDD mode varies with the number of antennas

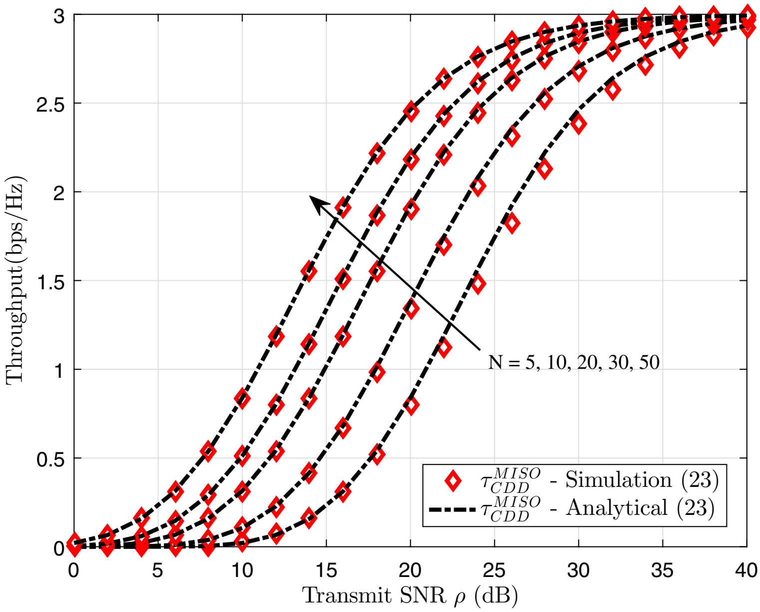


Fig. 7 The system's throughput MISO CDD mode varies with the number of antennas

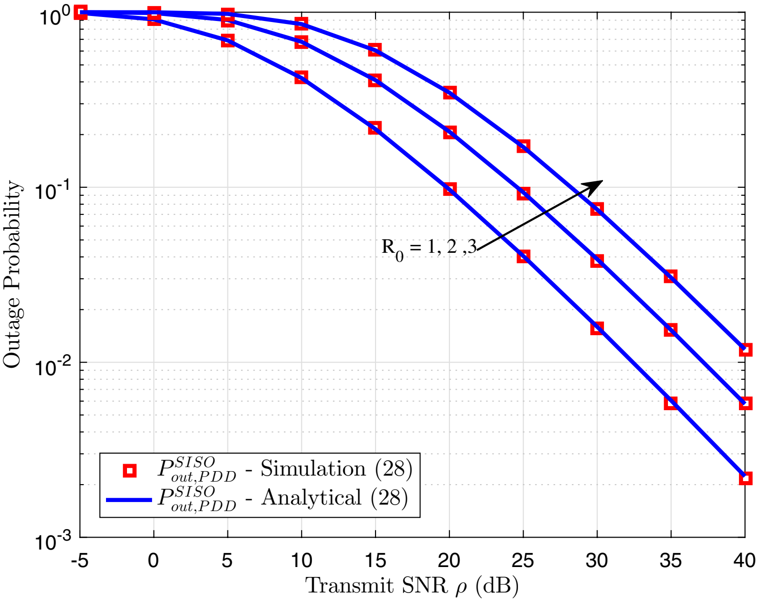


Fig. 8 SISO outage probability in case without impact of CUE varies with R_0

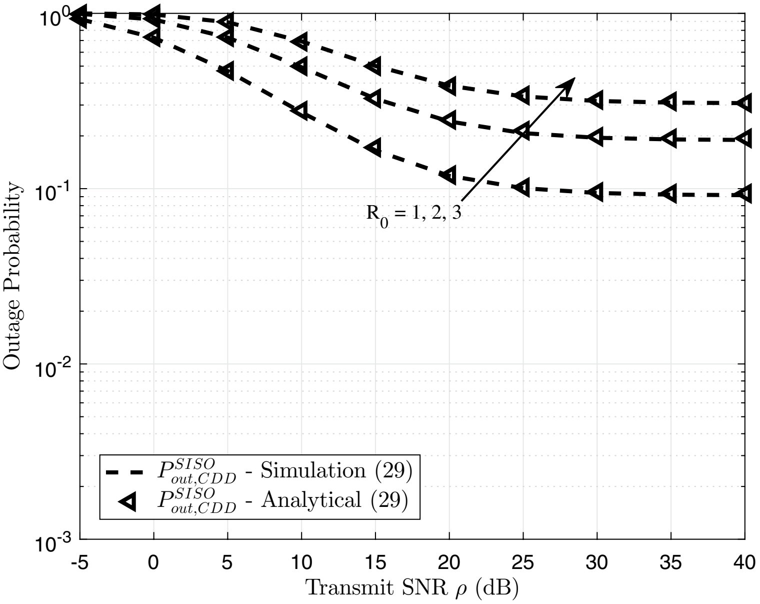


Fig. 9 SISO outage probability in case without impact of CUE varies with R_0

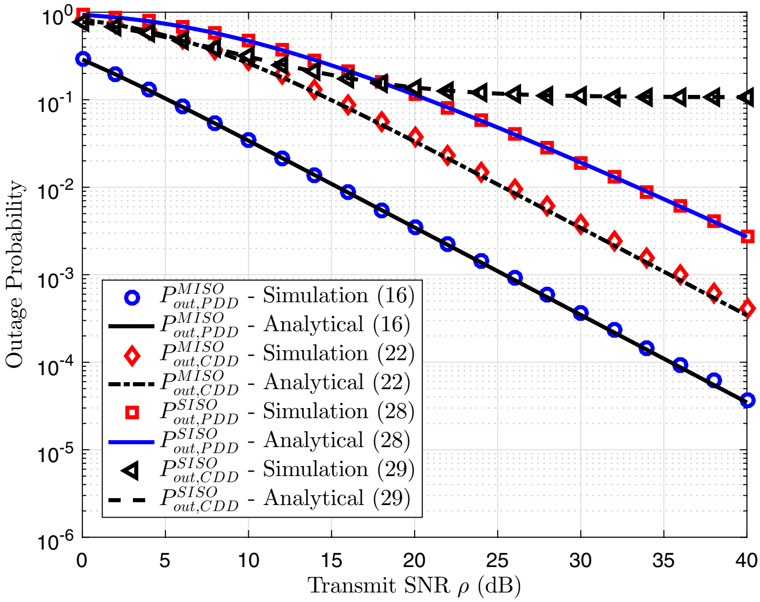


Fig. 10 Comparison on outage probability of 4 modes

From the above analysis results we observe in Fig. 10 that SISO CDD scenario can be regarded as a worst case of D2D considered in this paper. For the purposes of comparison, coefficients related MISO PB are $N = 10, \eta = 0.4, \varepsilon = 0.9$, target rate $R_0 = 1(BPCU)$ for all schemes. The interference related SISO CDD mode is $\lambda_c = 0.03$ due to such parameter contribute lower outage remarkably. The more antennas at the PB outperforms than the other cases due to more power used for information processing. In particular, one can observe that the outage performance of MISO PDD scenario is superior to the second scenario. This is due to the fact that non existence interference from CUE and strong harvested power at D_1 for transmit signal to D_2 in D2D transmission.

5 Conclusion

In this paper, two main schemes including single antenna and multi-antenna PB design that act as energy transmission station supporting D2D communication and its performance has been investigated. The outage probability of system is evaluated in two cases of D2D link under with/without impact of the interference from CUE. The results of the study are verified by simulation and it shows that the proposed PB regime obtained the reasonable performance to applied in wireless D2D network. In future, the proposed scheme will be extended to multiple antenna D2D users where can be able to signal transfer and harvest energy beamforming from the PB. We also can further investigate the other system performance such as the throughput of the concerned MISO D2D approach.

Appendix

***Proof of Proposition* 2** We denote two new variables $A = \frac{|g|^2}{|g_c|^2 + \Psi_1}$ and $B = ||\mathbf{h}||^2 \frac{P}{N_0}$. It can be shown the SINR as below

$$\gamma_I = \Psi_2 AB \tag{A.1}$$

We first examine the outage probability as following expression

$$F_A(x) = Pr\left(\frac{|g|^2}{|g_c|^2 + \Psi_1} \leq x \right) \tag{A.2}$$

It can be shown the outage probability as [36]

$$F_A\left(x \middle| |g_c|^2\right) = 1 - e^{-\Psi_1 x} e^{-|g_c|^2 x} \tag{A.3}$$

Such expression can be re-calculated as

$$F_A(x) = 1 - e^{-\Psi_1 x} \int_0^\infty e^{-(1+x)y} dy \tag{A.4}$$

And then we obtain new expression as

$$F_A(x) = 1 - \frac{e^{-\Psi_1 x}}{1 + x} \tag{A.5}$$

We only examine the special case of the PB where is equipped with large number of antenna which result in simple following result

$$F_A(x) = 1 - \frac{e^{-\Psi_1 (\gamma_{th} N_0 / (\Psi_2 NP))}}{1 + \gamma_{th} N_0 / \left(\Psi_2 NP\right)} \tag{A.6}$$

As a result, to clear evaluate outage performance, we can be obtain the closed-form expression as

$$P_{out,CDD}^{MISO} = 1 - \frac{e^{-\Psi_1 (\gamma_{th} N_0 / \boxed{(b_2} NP))}}{1 + \gamma_{th} N_0 / \left(\Psi_2 NP\right)} \tag{A.7}$$

This is end of proof. □

***Proof of Proposition* 3** Having a look on the outage probability in CDD SISO mode, it can be given by

$$P_{out,CDD}^{SISO} = \Pr\left\{ |h|^2|g|^2 \leq \frac{\left|g_c\right|^2 P + N_0}{\eta\varepsilon P}\gamma_{th} \right\} \tag{B.1}$$

We first define new variables as $x = |h|^2|g|^2, y = \left|g_c\right|^2$, conditioned on y, the outage probability can be computed as

$$P_{out,CDD}^{SISO} = \Pr\left\{ x \leq \frac{yP + N_0}{\eta\varepsilon P}\gamma_{th} \right\} \tag{B.2}$$

Utilizing the popular result in [1, 3], the CDF of x can be shown as

$$F_x(X) = 1 - 2\sqrt{\frac{X}{\lambda_h\lambda_g}}K_1\left(2\sqrt{\frac{X}{\lambda_h\lambda_g}}\right) \tag{B.3}$$

To this end, averaging over y, the desired result can be obtained as in Proposition 3.

This completes the proof. □

References

1. Do, D.-T., Nguyen, H.-S., Voznak, M., & Nguyen, T.-S. (2017). Wireless powered relaying networks under imperfect channel state information: System performance and optimal policy for instantaneous rate. *Radioengineering*, *26*(3), 869–877.
2. Do, D.-T., & Nguyen, H.-S., (2016). A tractable approach to analyzing the energy-aware two-way relaying networks in the presence of co-channel interference. *EURASIP Journal on Wireless Communications and Networking*, *271*(2016), 1–10.
3. Nguyen, H.-S., Bui, A.-H., Do, D.-T., & Voznak, M. (2016). Imperfect channel state information of AF and DF energy harvesting cooperative networks. *China Communications*, *13*(10), 11–19.
4. Le, N. P. (2018). Throughput analysis of power-beacon-assisted energy harvesting wireless systems over non-identical Nakagamim Fading channels. *IEEE Communications Letters*, *22*(4), 840–843.
5. CES 2017 Innovation Awards. Retrieved September 7, 2018 from http://www.ces.tech/Events-Experiences/Innovation-Awards-Program/Honorees.aspx
6. Lu, X., Wang, P., Niyato, D., Kim, D. I., & Han, Z. (2015). Wireless networks with RF energy harvesting: A contemporary survey. *IEEE Communications Surveys and Tutorials*, *17*(2), 757–789.
7. Nguyen, X.-X., & Do, D.-T. (2017) Optimal power allocation and throughput performance of full-duplex DF relaying networks with wireless power transfer-aware channel. *EURASIP Journal on Wireless Communications and Networking*.
8. Chu, Z., et al. (2016). Simultaneous wireless information power transfer for MISO secrecy channel. *IEEE Transaction on Vehicular Technology*, *65*(9), 6913–6925.
9. Zhou, X., Zhang, R., & Ho, C.K. (2012). Wireless information and power transfer: Architecture design and rate-energy tradeoff. In *Proceedings of the IEEE global communication conference (GLOBECOM)* (pp. 3982–3987).
10. Zhang, R., & Ho, C. K. (2013). MIMO broadcasting for simultaneous wireless information and power transfer. *IEEE Transactions on Wireless Communications*, *12*(5), 1989–2001.
11. Huang, Y., Zhang, P., Wang, J., & Wu, Q. (2017). Secure transmission in power beacon assisted wireless communication networks. In *Proceedings of 2017 IEEE 28th annual international symposium on personal, indoor, and mobile radio communications (PIMRC)* (pp. 1–6).

12. Liang, H., Zhong, C., Lin, H., Suraweera, H. A., Qu, F., & Zhang, Z. (2017). Optimization of power beacon assisted wireless powered two-way relaying systems under user fairness. In *IEEE global communications conference (GLOBECOM 2017)* (pp. 1–6).
13. Park, J.-H., et al. (2017). Energy beamforming for wireless power transfer in MISO heterogeneous network with power beacon. *IEEE Communications Letters*, *21*(5), 1163–1166.
14. Nguyen, T. D., Khan, J. Y., & Ngo, D. T. (2018). A distributed energy-harvesting-aware routing algorithm for heterogeneous IoT networks. *IEEE Transactions on Green Communications and Networking*, *2*(4), 1115–1127.
15. Nguyen, K. T., Do, D.-T., Nguyen, X. X., Nguyen, N. T., & Ha, D. H. (2015). Wireless information and power transfer for full duplex relaying networks: Performance analysis. In *Proceedings of recent advances in electrical engineering and related sciences (AETA 2015)* (pp. 53-62). Vietnam: HCMC.
16. Ying, L., Peilin, H., & Runzhou, L. (2018). Energy efficiency-delay tradeoff in energy harvesting-based D2D communication: An experimental learning approach. *IEEE Communications Letters*, *22*, 1704–1707.
17. Calvo-Fullana, M., Anton-Haro, C., Matamoros, J., & Ribeiro, A. R. (2018). Stochastic routing and scheduling policies for energy harvesting communication networks. *IEEE Transactions on Signal Processing*, *66*, 3363–3376.
18. Nguyen, X.-X., & Do, D.-T. (2017). Maximum harvested energy policy in full-duplex relaying networks with SWIPT. *International Journal of Communication Systems (Wiley)*, *30*(17), e3359.
19. Fan, R., Atapattu, S., Chen, W., Zhang, Y., & Evans, J. (2018). Throughput maximization for multi-hop decode-and-forward relay network with wireless energy harvesting. *IEEE Access*, *6*, 24582–24595.
20. Singh, K., Meng-Lin, K., Jia-Chin, L., & Ratnarajah, T. (2018). Toward optimal power control and transfer for energy harvesting amplify-and-forward relay networks. *IEEE Transactions on Wireless Communications*, *17*, 4971–4986.
21. Ma, Y., Chen, H., Lin, Z., Li, Y., & Vucetic, B. (2015). Distributed and optimal resource allocation for power beacon-assisted wireless powered communications. *IEEE Transactions on Communications*, *63*(10), 3569–3583.
22. Bi, S., & Zhang, R. (2016). Placement optimization of energy and information access points in wireless powered communication networks. *IEEE Transactions on Wireless Communications*, *15*(3), 2351–2364.
23. Asadi, A., Wang, Q., & Mancuso, V. (2014). A survey on device-to-device communication in cellular networks. *IEEE Communications Surveys and Tutorials*, *16*(4), 1801–1819.
24. Krikidis, I., Timotheou, S., Nikolaou, S., Zheng, G., Ng, D. W. K., & Schober, R. (2014). Simultaneous wireless information and power transfer in modern communication systems. *IEEE Communications Magazine*, *52*(11), 104–110.
25. Lin, Y. D., & Hsu, Y. C. (2000). Multihop cellular: A new architecture for wireless communications. *Proceedings of the IEEE INFOCOM*, *3*, 1273–1282.
26. Atat, R., Liu, L., Mastronarde, N., & Yi, Y. (2017). Energy harvesting-based D2D-assisted machine-type communications. *IEEE Transactions on Communications*, *65*(3), 1289–1302.
27. Atapattu, S., & Evans, J. (2016). Optimal energy harvesting protocols for wireless relay networks. *IEEE Transactions on Wireless Communications*, *15*(8), 5789–5803.
28. Jiang, L., et al. (2016). Social-aware energy harvesting device-to-device communications in 5G networks. *IEEE Wireless Communications*, *23*(4), 20–27.
29. Wijesiri, G. P., Chowdhury, S. S., & Li, F. Y. (2016). Energy harvesting-aware backoff algorithms for distributed device-to-device communication. In *Proceedings of the IEEE VTC* (pp. 1–5).
30. Zhou, Z., Ma, G., Xu, C., & Chang, Z. (2016). A game-theoretical approach for green power allocation in energy-harvesting device-to-device communications. In *Proceedings of the IEEE VTC* (pp. 1–5).
31. Darak, S. J., Zhang, H., Palicot, J., & Moy, C. (2015). An efficient policy for D2D communications and energy harvesting in cognitive radios: Go Bayesian! In *2015 23rd European signal processing conference (EUSIPCO)* (pp. 1231–1235). Nice: EUSIPCO.
32. Sun, H. Z. P., Shin, K. G., & He, L. (2017). Transmit power control for D2D-underlaid cellular networks based on statistical features. *IEEE Transactions on Vehicular Technology*, *66*(5), 4110–4119.
33. Zhong, C., Chen, X., Zhang, Z., & Karagiannidis, G. K. (2015). Wireless-powered communications: Performance analysis and optimization. *IEEE Transactions on Communications*, *63*(12), 5178–5190.
34. Shi, L., et al. (2018). Wireless energy transfer enabled D2D in underlaying cellular networks. *IEEE Transactions on Vehicular Technology*, *67*(2), 1845–1849.
35. Le, S.-P. et. al. (2018). Device-to-device network with MISO scheme for wireless power transfer: Outage performance analysis. In *Proceedings of the 41st international conference on telecommunications and signal processing (TSP)* (pp. 464–467).

36. Gradshteyn, I. S., & Ryzhik, I. M. (2007). *Table of integrals, series and products* (7th ed.). New York, NY: Academic Press.

Huu-Phuc Dang received the B.Sc. degree in Electrical-Electronics Engineering from HCMC University of Technology and Education, Vietnam (2004), and M.Sc. degree in Automation Control from HCMC University of Ho Chi Minh City University of Transport, Vietnam (2012). He is working at Tra Vinh University and is also Ph.D. student of Ho Chi Minh City University of Technology and Education, Vietnam. His research interest includes signal processing in wireless communications network, automation control.

Chi-Bao Le received the B.Sc. degree in Electrical-Electronics Engineering from Industrial University of Ho Chi Minh City, Vietnam (2018). He is working at WICOM lab. His research interest includes signal processing in wireless communications network, NOMA, relaying networks.

Dinh-Thuan Do received the B.S.degree, M.Eng. degree, and Ph.D. degree from Viet Nam National University (VNU-HCMC) in 2003, 2007, and 2013 respetively, all in Communications Engineering. He was a visiting Ph.D. student with Communications Engineering Institute, National Tsing Hua University, Taiwan from 2009 to 2010. Prior to joining Ton Duc Thang University, he was senior engineer at the Vina Phone Mobile Network from 2003 to 2009. Dr. Thuan was recipient of Golden Globe Award from Vietnam Ministry of Science and Technology in 2015. His research interest includes signal processing in wireless communications network, cooperative communications, full-duplex transmission and energy harvesting. His publications include 25 + SCI/SCIE journals and 50+ conference papers. He also serves as Associate Editor of Bulletin of Electrical Engineering and Informatics journal (SCOPUS).

Si-Phu Le was born in Da Nang city, Vietnam, on October 23, 1985. He graduated from Nha Trang University with Bachelor of engineering degree in 2010 and Master of Business Administration in 2013. He is working as lecturer at Van Lang University since 2009. In 2008, he joined IAESTE program at Manipal Institute of Technology-India, worked in Computer Network and Telecommunication. From 2009 to 2010, he attended Software Engineering course for SEGVN at Carnegie Mellon University-Pittsburgh. His research interest includes automation, wireless communication, computer network, energy harvesting, digital signal processing, embedded system and information system.

Hong-Nhu Nguyen was born in Tien Giang Province, Vietnam. He is currently working as lecturer at Sai Gon University. He is pursuing PhD degree at Technical University of Ostrava, Czech Republic. His research interest includes applied electronics, wireless communication, cognitive radio, energy harvesting.

Miroslav Voznak is a Full Professor with Department of Telecommunications, VSB–Technical University of Ostrava. He is currently with the VSB–Technical University of Ostrava and he was appointed as an associate professor in 2009. His professional knowledge covers generally Information and Communication technology, in his research, he deals with wireless networks, Voice over IP, security and optimization problems. He was IEEE Senior member and served as Chair of various international conferences.

Affiliations

Huu-Phuc Dang[1] · Chi-Bao Le[2] · Dinh-Thuan Do[4] · Si-Phu Le[3] · Hong-Nhu Nguyen[3] · Miroslav Voznak[3]

Huu-Phuc Dang
1627004@student.hcmute.edu.vn

Chi-Bao Le
lechibao@iuh.edu.vn

Si-Phu Le
lesiphu@gmail.com

Hong-Nhu Nguyen
hongnhuvsb@gmail.com

Miroslav Voznak
miroslav.voznak@vsb.cz

[1] Faculty of Electrical and Electronics Technology, Ho Chi Minh City University of Technology and Education, No.1, Vo Van Ngan Street, Linh Chieu Ward, Thu Duc Dist., Ho Chi Minh City, Vietnam

[2] Industrial University of Ho Chi Minh City (IUH), No.12, Nguyen Van Bao Street, Ward 4, Go Vap Ward, Ho Chi Minh City, Vietnam

[3] Faculty of Electrical Engineering and Computer Science, Technical University of Ostrava, 17. listopadu 15/2172, 708 33 Ostrava, Poruba, Czech Republic

[4] Wireless Communications Research Group, Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, 19 Nguyen Huu Tho Street, Ho Chi Minh City, Vietnam