Performance analysis of power beacon-assisted D2D communication networks in the presence of eavesdropper and co-channel interference

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ABSTRACT

Radiofrequency (RF) signals can provide both information and energy, which have excellent advantages (small dimensions, low cost, and independence concerning time and location in urban areas), can be considered as electrical sources for cooperative network devices. Performance analysis of power beacon-assisted D2D Communication Networks in the Presence of Eavesdropper and Co-channel Interference is presented is investigated. The outage probability and the intercept probability of the proposed system are analyzed and derived. The impact of the main system parameters on the system performance is investigated. The monte carlo simulation is used for verifying the correctness of the analytical section in this paper.

Keywords:
Energy harvesting
Half-duplex
Monte carlo simulation
Non-zero secrecy probability
Relaying network

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1. INTRODUCTION

Radiofrequency (RF) signals can provide both information and energy, which have excellent advantages (small dimensions, low cost, and independence concerning time and location in urban areas), can be considered as electrical sources for cooperative network devices [1]-[10]. In recent years, harvesting energy from radio frequency (RF) signals has drawn significant research interest as a promising solution to solve the energy problem. This energy collection method, referred to as RF energy harvesting, has clear advantages over other energy harvesting techniques due to its predictable, controllable, and stable nature. The research in RF energy harvesting mainly falls into two broad categories: Simultaneous wireless information and power transfer (SWIPT) and wireless powered communication network (WPCN) [10]-[18].

The main contributions of this paper are:
– Performance analysis of power beacon-assisted D2D communication networks in the presence of eavesdropper and co-channel interference is presented is investigated.
– The outage probability and the intercept probability of the proposed system are analyzed and derived.
– The impact of the main system parameters on the system performance is investigated.
– The monte carlo simulation is used for verifying the correctness of the analytical section.
2. SYSTEM MODEL

In this research, the proposed system model with the energy harvesting (EH) and information processing (IT) is illustrated as shown in [19]-[25]. The proposed system model is drawn in Figure 1 and the time switching protocol is presented in Figure 2.

![System model](image1.png)

**Figure 1. System model**

![Time switching protocol](image2.png)

**Figure 2. The EH and IT phases**

2.1. Energy harvesting phase

In this phase, the source S and R will receive the power from the power beacon. Hence, the average transmit power at S and R can be formulated by, respectively:

\[
P_S = \frac{E_S}{(1-\alpha)(T/2)} = \frac{2\eta \alpha TP_B |h_{SR}|^2}{(1-\alpha)T} = \mu P_B |h_{SR}|^2 \quad (1)
\]

\[
P_R = \frac{E_S}{(1-\alpha)(T/2)} = \frac{2\eta \alpha TP_R |h_{RS}|^2}{(1-\alpha)T} = \mu P_B |h_{RS}|^2 \quad (2)
\]

where \( P_B \) is the transmit power at the power beacon B, \( \mu = \frac{2\eta \alpha}{1-\alpha} \) and \( 0 < \eta \leq 1 \): energy conversion efficiency.

2.2. Information transmission phase

In the second time slot, the S transmits its signal to R, the corresponding received signal at the R can be expressed as,

\[
y_R = h_{SR}x_S + n_R \quad (3)
\]
where $x_s$ is the transmitted signal at the source $S$ and satisfied $\mathbb{E}\{|x_s|^2\} = P_s$, wherein $\mathbb{E}\{\cdot\}$ is expectation operator and $n_0$ is the additive white Gaussian noise (AWGN) with variance $N_0$.

In the third phase, the received signal at the destination $D$ can be given by:

$$ y_D = h_{rd}x_R + \sum_{n=1}^{M} x_n h_{n,d} + n_0 $$

(4)

where $x_R$ is the transmitted signal at the relay $R$ and must be satisfied $\mathbb{E}\{|x_R|^2\} = P_R$, $n_D$ is the AWGN with variance $N_0$, $h_{n,d}$ is the channel gain between $n^{th}$ interference source and destination.

To simplicity, we assume that all the interference sources have the same transmit power $P_I$, it means that $\mathbb{E}\{|x_n|^2\} = P_I$.

Next, the received signal at the Eavesdropper can be obtained by:

$$ y_E = h_{re}x_R + h_{se}x_s + \sum_{n=1}^{M} x_n h_{n,e} + n_E $$

(5)

where $h_{n,e}$ is the channel gain between $n^{th}$ interference source and eavesdropper and $n_E$ is also the AWGN with variance $N_0$.

From (3) and (4), the obtained signal-to-noise ratio (SNR) to successfully detect the data at $R$ and $D$ can be claimed as, respectively.

$$ \gamma_R = \frac{|h_{rs}|^2 P_s}{N_0} $$

$$ \gamma_D = \frac{|h_{rd}|^2 P_R}{P_I \sum_{n=1}^{M} |h_{n,d}|^2 + N_0} $$

(6)

By substituting (1) and (2) into (6), the (6) can be reformulated as

$$ \gamma_R = \frac{\Psi |h_{rs}|^2 |h_{bs}|^2 + \Psi Y}{\Delta \sum_{n=1}^{M} |h_{n,d}|^2 + 1} = \frac{\Psi X}{\Delta Z + 1} $$

(7)

where $\Psi = \frac{P_s}{N_0}$, $\Delta = \frac{P_I}{N_0}$, $X = |h_{bs}|^2 |h_{rs}|^2$, $Y = |h_{bs}|^2 |h_{sd}|^2$ and $Z = \sum_{n=1}^{M} |h_{n,d}|^2$

Similar to above, the obtained SNR at $E$ can be given by

$$ \gamma_E = \frac{\Psi |h_{re}|^2 |h_{se}|^2 + \Psi Y |h_{se}|^2 |h_{rs}|^2 + \Psi |h_{se}|^2 + \Psi |h_{se}|^2}{\Delta \sum_{n=1}^{M} |h_{n,e}|^2 + 1} = \frac{\Psi (T + U)}{\Delta Q + 1} $$

(8)

where $T = |h_{re}|^2 |h_{se}|^2$, $U = |h_{se}|^2 |h_{sd}|^2$ and $Q = \sum_{n=1}^{M} |h_{n,e}|^2$

**Remark 1:**
In [2], the probability density function (PDF) of the random variable (RV) Z and Q can be obtained as, respectively.

\[ f_Z(t) = \frac{(\lambda_{ID})^M}{(M-1)!} t^{M-1} \exp(-\lambda_{ID} t), \]

\[ f_Q(t) = \frac{(\lambda_{IE})^M}{(M-1)!} t^{M-1} \exp(-\lambda_{IE} t) \]

(9)

Where \( \lambda_{ID} \) and \( \lambda_{IE} \) are the mean of RV Z and Q, respectively.

3. SYSTEM PERFORMANCE ANALYSIS

3.1. Outage probability (OP)

The OP of the system can be computed as,

\[ OP = \Pr \left( \min \left( Y_R, Y_D \right) < Y_{th} \right) = \Pr \left[ \min \left( \frac{\mu P_X \Delta Z + 1}{\Delta Z + 1} \right) < Y_{th} \right] \]

\[ = 1 - \Pr \left( \frac{\mu P_X \Delta Z + 1}{\Delta Z + 1} \geq Y_{th} \right) \]

(10)

where \( Y_{th} = 2^{R_R} - 1 \) is the threshold of the system, and \( R \) is target rate.

From (10), \( P_1 \) can be calculated by:

\[ P_1 = 1 - \Pr \left( \frac{\mu P_X}{} < Y_{th} \right) = 1 - \Pr \left( h_{SR}^2 \left| h_{BS}^2 \right| < \frac{Z_{th}}{\mu P} \right) \]

\[ = 1 - \int_0^\infty f_{\mu P X} \left( \frac{Y_{th}}{\mu P X} \right) \times f_{\mu P X} \left( x \right) dx \]

\[ = 1 - \int_0^\infty \lambda_{SR} \left( 1 - \exp \left( -\frac{\lambda_{SR} Y_{th}}{\mu P X} \right) \right) \times \exp \left( -\lambda_{SR} x \right) dx \]

\[ = \int_0^\infty \lambda_{BS} \exp \left( -\frac{\lambda_{SR} Y_{th}}{\mu P X} - \lambda_{BS} x \right) dx \]

(11)

where \( \lambda_{SR} \) and \( \lambda_{BS} \) are the mean of RV \( \left| h_{SR} \right|^2 \) and \( \left| h_{BS} \right|^2 \).

Here, the equation (11) can be rewritten as,

\[ P_1 = 2 \sqrt{\frac{\lambda_{SR} \lambda_{BS} \mu \Delta Z}{\mu P}} \times K_1 \left( 2 \sqrt{\frac{\lambda_{SR} \lambda_{BS} \mu \Delta Z}{\mu P}} \right) \]

(12)

where \( K_1(\bullet) \) is the modified Bessel function of the second kind and \( v^{th} \) order.

Next, \( P_2 \) can be derived by:

\[ P_2 = 1 - \Pr \left( \frac{\bar{Y}}{\Delta Z + 1} < Y_{th} \right) = 1 - \int_0^\infty F_\bar{Y} \left( \frac{Y_{th}}{\Delta Z + 1} \right) \times f_\bar{Y}(t) dt \]

(13)

where \( \bar{Y} = \mu P Y \).

We apply the result from (12) and then substitute (9) into (13), \( P_2 \) can be obtained as,

\[ P_2 = 2 \left( \frac{\lambda_{ID}}{M-1} \right)^M \int_0^{\Delta Z + 1} \exp \left( -\lambda_{ID} t \right) \times \sqrt{\frac{\lambda_{RD} \lambda_{BS} \gamma_{th} \Delta Z + 1}{\mu P}} \times K_1 \left( 2 \sqrt{\frac{\lambda_{RD} \lambda_{BS} \gamma_{th} \Delta Z + 1}{\mu P}} \right) dt \]

(14)
Finally, substituting (12) and (14) into (10), the OP in the final form as,

\[
OP = 1 - \frac{\lambda_{ie}^M}{(M-1)!} \sqrt{\frac{\lambda_{se}^2 \beta_{se}^2}{\mu P}} \times K_i \left( 2 \sqrt{\frac{\lambda_{se}^2 \beta_{se}^2}{\mu P}} \right) \times \exp(-\lambda_{ie} t) \times \sqrt{\frac{\lambda_{se}^2 \beta_{se}^2 (\Delta t + 1)}{\mu P}} \times K_i \left( 2 \sqrt{\frac{\lambda_{se}^2 \beta_{se}^2 (\Delta t + 1)}{\mu P}} \right) dt
\]

\[\text{(15)}\]

3.2. Intercept probability (IP)

The IP can be defined as,

\[
IP = \text{Pr}(\gamma_x < \gamma_e) = 1 - \text{Pr}(\gamma_x > \gamma_e) = 1 - \int_{0}^{\infty} F_y \left( \frac{\mu P (T + U)}{\Delta Q + 1} < \gamma_e \right) = 1 - \int_{0}^{\infty} F_x (\gamma_e (\Delta x + 1)) \times f_y (x) dx
\]

where \( \Sigma = \mu P (T + U) \)

The CDF of \( \Sigma \) can be found as,

\[
F_y (y) = \text{Pr}(\Sigma < y) = \text{Pr}(\mu P (T + U) < y) = \int_{0}^{\infty} F_y (y) - t \times f_y (t) dt
\]

By using the result from (12) and formula \( \frac{d}{dx} \left( x' K_0 (x) \right) = -x' K_{-1} (x) \), the PDF of \( T \) can be computed by:

\[
f_y (t) = 2 \lambda_{se} \beta_{se} \times K_0 \left( 2 \sqrt{\lambda_{se} \beta_{se} t} \right)
\]

where \( \lambda_{se} \) and \( \beta_{se} \) are the mean of RV \( |h_{se}|^2 \) and \( |h_{rs}|^2 \), respectively.

And \( F_y \left( \frac{y}{\mu P} - t \right) = \left[ 1 - 2 \sqrt{\lambda_{se} \beta_{se} \left( \frac{y}{\mu P} - t \right)} \times K_0 \left( 2 \sqrt{\lambda_{se} \beta_{se} \left( \frac{y}{\mu P} - t \right)} \right) \right] \)

where \( \lambda_{se} \) and \( \beta_{se} \) are the mean of RV \( |h_{se}|^2 \) and \( |h_{rs}|^2 \), respectively.

Substituting (18), (19) into (17), and then into (16), the IP can be claimed by:

\[
IP = 1 - \frac{\lambda_{ie}^M}{(M-1)!} \int_{0}^{\infty} \left[ 1 - 2 \sqrt{\lambda_{se} \beta_{se} \left( \frac{y}{\mu P} - t \right)} \times K_0 \left( 2 \sqrt{\lambda_{se} \beta_{se} \left( \frac{y}{\mu P} - t \right)} \right) \right] \times \exp(-\lambda_{ie} x) \times K_0 \left( 2 \sqrt{\lambda_{se} \beta_{se} t} \right) dt
\]

\[\text{(20)}\]

4. NUMERICAL RESULTS AND DISCUSSION

Figure 4 draws the impact of \( \psi \) on the system OP with the main system parameters as \( \eta=0.8, \alpha=0.5, \) and \( \Delta=1 \) dB, respectively. The Figure shows that the OP falls in the rising direction of \( \psi \). Furthermore, the IP
is considered as the function of $\psi$, as shown in Figure 4. As shown in Figure 4, IP increases when $\psi$ rises. From Figures 3 and 4, we can see that the analytical and the simulation curves are the same as the analytical section.

![Figure 3. OP versus $\psi$](image1)

![Figure 4. IP versus $\psi$](image2)

Moreover, the system OP and IP versus $\alpha$ are considered in Figures 5 and 6, respectively. In these Figures, we set $\eta=0.8$, $\beta=0.5$, and $\psi=2$ dB. From Figures 5 and 6, we can state that the system OP has a massive increase and IP decreases with rising $\alpha$, respectively. In addition, the simulation and analytical values are the same.

![Figure 5. OP versus $\alpha$](image3)

![Figure 6. IP versus $\alpha$.](image4)

Finally, the system OP and IP versus $M$ are considered in Figures 7 and 8, respectively. In these Figures, we set $\eta=0.8$, $\beta=0.5$, and $\psi=2$ dB. From Figures 7 and 8, we can see that the system OP has a massive increase and IP decreases with rising $M$, respectively. And the simulation overlaps the analytical values.
5. CONCLUSION

Performance analysis of power beacon-assisted D2D communication networks in the presence of eavesdropper and co-channel interference is presented. The outage probability and the intercept probability of the proposed system are analyzed and derived. The impact of the main system parameters on the system performance is investigated. The Monte Carlo simulation is used for verifying the correctness of the analytical section.

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