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Article

Exploiting Symmetric Energy Harvesting Protocol in Wireless Sensor Networks with Outdated Channel State Information: Protocol Design and Performance Analysis

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Abstract: Wireless Powered Communication Networks (WPCN), which has attracted much attention of researchers, also been recently recommended in 5^{th} generation (5G) wireless networks. With the help of the WPCN, the reliability and battery life of wireless low-power devices can be improved. In this paper, we investigate throughput and ergodic capacity in WPCN-assisted amplify-and-forward (AF) relaying system, considering two transmission modes including delay-tolerant and delay-limited. As important achievement, we propose symmetric energy harvesting protocol, namely time power switching relaying (TPSR) in order to find maximal throughput. In particular, both time switching and power switching coefficients in this schemes are considered. Unlike most of the previous works, we further focus on impact of outdated channel state information (CSI) in this WPCN. In order to evaluate information processing efficiency, the performance can be substantially improved by optimally harvesting time and power coefficients of the received signal at relay node for energy and information extraction, and by deploying several scenarios. By deploying Monte Carlo simulation, it is confirmed that the system performance is more sensitive to CSI estimation error, noise variance, signal-to-noise ratio (SNR) and resulting in other reasonable computations of TPSR need be deployed to obtain QoS requirement.

Keywords: channel state information; energy harvesting; amplify-and-forward; time power switching relaying; throughput

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0. Introduction

Recently, the importance of harvested energy is widely recognized, when 5G cellular networks require high speed data and continuing operation. In [1], wireless powered communication network (WPCN) was presented the possibility of reliable data and wireless energy transfer technique in terms of interference channel. In principle, radio-frequency (RF) harvested energy is considered as a monotonous self-sustainability supply and it can use redundant power from ambient environment. In [2], the research results proved that the capacity can be enhanced even in the frequency-selective channels. Furthermore, in [1],[2] the receiver might encrypt the received signal and process energy collection in the same time slot. Unfortunately, the past works proved that it did not use to be applicable to receiver circuit technology, due to limitations of cheap capacitors.

In addition, thanks to recent advancements of circuit, it is confirmed that WPCN is feasible, since the capability extending coverage range of relaying wireless network and then it combines with RF-based energy harvesting to become key factors of next generations wireless systems [3]–[9]. In [3]–[4] proposed an energy pattern aided Simultaneous Wireless Information and Power Transfer

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(SWIPT) system and the optimal design for SWIPT in downlink multi-user of orthogonal frequency division multiplexing (OFDM) systems. In particular, such systems utilize signals received from a fixed access point (AP) to perform two duties, namely scavenging energy and decoding information. Meanwhile, it is proved that the reliability and security communication and the efficiency of wireless energy transfer can be provided effectively in a joint cooperative beam forming and energy signal scheme in [5]. To evaluate performance of wireless powered system, there was in [6]-[9] the various investigations conducted into the trade-off between the functions of information transfer and wireless power transfer. In particular, the authors in [9] introduced SWIPT in multi-relay scheme of two-hop relay system, in which by utilizing the idea of distributed space-time coding by multiple relay nodes at the same time, the transmission is positively assisted from source to destination. Regarding to Multiple-Input Multiple-Output (MIMO) systems, the work in [10] focused on a Multiple-Input Single-Output (MISO) system, in which the assistance of an access point (AP) that functions as a SWIPT for a user terminal (UT), which is not provided with external power supply. To obtain power consumption efficient evaluation of the system, Rate-Energy (R-E) region was revealed in [11], which features between the source-destination rate and the harvested energy at the relay by the optimal source and relay co-variance matrices. Furthermore, hardware impairment is evaluated the impact on throughput with energy harvesting-assisted relaying networks in [12], where impairment coefficients were computed carefully in order to maintain acceptable performance. Regarding to the authors in [13], in order to determine benefits of green communication in wireless sensor networks, the proposed novel energy harvesting scheme was introduce in different models for prolonging time sensor nodes.

In [14]-[17], some engaging results which illustrate that wireless energy transfer is the cause of lower transmission rate, due to shorter time used for data processing. The relay-assisted systems with power transfer ability has some existing major architectures in previous works. For example, the power from the radiated signal event applied in full-duplex transmission systems [14], while in [15] energy harvesting models were employed in cellular networks. Another example is that multi-hop power transfer scenarios, in which a relay or many relays transferred the energy to remote terminals [16],[17].

An important issue in energy harvesting models is that energy was calculated based on knowledge of channel state information (CSI). The authors in [18] took the performance of a cognitive relay network (CRN) into account under outdated channel state information (CSI), where a Decode-and-Forward (DF) relay was applied to secondary user (SU) networks. Meanwhile, it is shown in [19] that the imperfect CSI which impacts on the performance of relay selection (RS) networks and a RS scheme for full-duplex (FD) cooperative networks was proposed in an environment with less interference. In terms of the residual loop interference (RLI) at the relay, the performance of cooperative transmission linear decreases and relies on the interference coming from the direct link. In [21], there was an investigation conducted to evaluate transmit antenna selection (TAS) to the secrecy performances in MIMO secure cooperative relay systems with an adaptive DF relay over Nakagami-m fading channels. Another CRN was studied under outdated CSI where a SU transmits using a DF relay [22]- [23].

Motivated from previous works, there were only a few considerations in imperfect CSI, especially in energy harvesting at the relay, where outdated CSI affects the amplifying processing and output performance. In particular, we focus on throughput and outage performance in delay-limited transmission and the delay-tolerant transmission. In addition, three energy harvesting protocols are compared with throughput with respect to channel estimations error, SNR and time/power fraction of energy scavenging schemes. Our primary contributions in this study are summarized as below:

- The time power switching relaying (TPSR) protocol is first proposed for obtain optimal throughput.
- We investigate impact of CSI channel estimation errors on system performance in the considered energy harvesting protocol.

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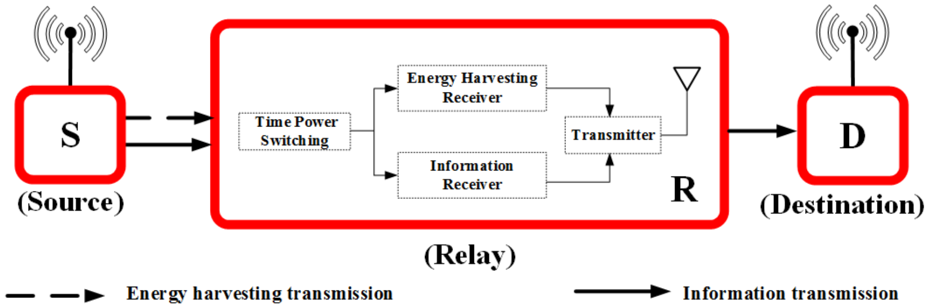

Figure 1. System model

- The closed-form analytical expressions of the throughput in terms of two transmission modes, including delay-limited and delay-tolerant are depicted.
- To obtain practical insights into design of WPCN, the values of CSI impairments are computed to satisfy acceptable outage performance.

The rest of the paper is organized as follows. The fundamental preliminaries and a system model of two-hop relaying networks with wireless energy transfer technique will be provided in section 2. Meanwhile, in section 3, the throughput and outage probability for different transmission modes will be considered. More importantly, the threshold values of channel estimations error can be predicted in practical requirements. This work continue with presenting numerical results with detailed analysis and comparisons in section 4. Finally, we will draw a conclusion in section 5.

1. Symmetric two-hop relaying model

The AF-based wireless communication system is considered, in which data is transferred from the source node (S) to the destination node (D) via a energy harvesting relay node (R). In this system model, we characterize channel estimation error as Δh corresponding with the channel link $S-R$ and Δg corresponding with the channel link $R-D$. It is assumed that quasi-static of Rayleigh fading channels for two-hop $S-R$ and $R-D$. It is noted that this is symmetric design of relaying wireless networks, i.e. two-hop with symmetric channel, symmetric time slot for data and energy processing. The first link $S-R$ is modeled which the fading channel of $\widehat{h}$ as $\widehat{h}=h+\Delta h$, while the second link $R-D$ transferred by channel of $\widehat{g}$ as $\widehat{g}=g+\Delta g$; h, g are denoted as estimated channel of two hops, and we thus have $h\sim CN\left(0,\Omega_h\right)$, $g\sim CN\left(0,\Omega_g\right)$, respectively. Δh, Δg are denoted channel estimation error of two hops, respectively, assumed as CSI noise denoted by $\Delta h\sim CN\left(0,\sigma_{\Delta h}^2\right)$, $\Delta g\sim CN\left(0,\sigma_{\Delta g}^2\right)$. The distance of two hops is denoted by l_1 and l_2. By utilizing energy harvesting in the first hop, the wireless power is equipped with a storage capacitor at relay node in order to supply power for information transmission in the next hop. It is assumed that the single antenna model is configured in source, relay and destination node. The detailed parameters are presented in Fig. 1.

Thanks to the implementation based on the algorithm of channel estimation in request-to-send/clear-to-send (RTS/CTS) procedure, the relay node in the WPCN can estimate CSI. However, the channel estimation error still exists in equalizer.

In each transmission frame as illustration in Fig. 2, the first time slot is designed for energy harvesting during γT, T stands for time block and the power of δP_S , the second time slot is used for information transmission corresponding with the first hop (S) to (R) and occupy $\left(1-\gamma\right)T/2$, the remaining time slot reserves for information transmission in the second hop (R) to (D) during $\left(1-\gamma\right)T/2$. In which γ is denoted as time switching coefficient, δ stands for power splitting fraction. It is noted that $0\leq\gamma\leq1, 0\leq\delta\leq1$. Moreover, the source are transmitted with power P_S.

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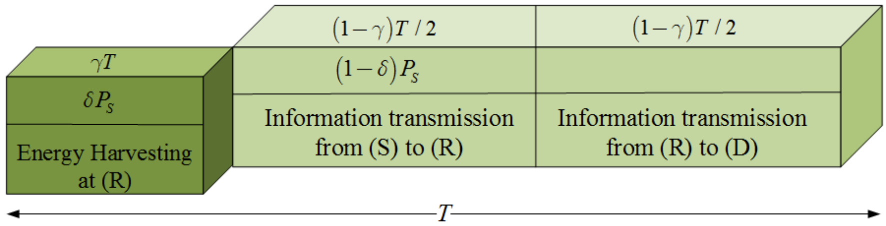

Figure 2. Energy harvesting protocol for relaying network

It is assumed that the received signal is added to the baseband additive white Gaussian noise (AWGN) at the relay node. We consider the received signal at time index t and then the received signal at (R), $y_r(t)$, is given by

$$y_r(t) = \sqrt{l_1^{-\alpha} P_S}(h + \Delta h)s(t) + n_r, \tag{1}$$

where information symbol is denoted by $s(t)$ with $E\{|s(t)|^2\} = 1$ ($E\{.\}$ is expectation operation), α is path loss factor, P_S represents transmitted power of the source node, n_r assumed as AWGN noise with $CN(0,\sigma_{n_r}^2)$.

In [20], the time switching-based relaying (TSR) protocol is proposed and harvested energy at (R) can be expressed as

$$E_h^{TSR} = l_1^{-\alpha} \eta P_S \left(|h|^2 + \sigma_{\Delta h}^2\right) \gamma T, \tag{2}$$

where $0 < \eta < 1$ is the power conversion efficiency that depends on the harvested power circuitry and rectification process.

In the power splitting-based relaying (PSR) protocol suggested in [20], the transmitted energy from source is divided into two components, δP_S used as harvested power function and $(1-\delta) P_S$ served for data processing. Therefore, the energy harvesting is given as

$$E_h^{PSR} = l_1^{-\alpha} \eta P_S \left(|h|^2 + \sigma_{\Delta h}^2\right) \delta T. \tag{3}$$

In this study, we derive the hybrid time and power harvesting protocols, namely TPSR that is calculated by

$$E_h^{TPSR} = l_1^{-\alpha} \eta P_S \left(|h|^2 + \sigma_{\Delta h}^2\right) \gamma \delta T. \tag{4}$$

The average energy harvesting over Rayleigh fading channels that is based on (4) is computed as

$$E_{avg}\left(E_h^{TPSR}\right) = l_1^{-\alpha} \eta P_S \gamma \delta \left(\Omega_h + \sigma_{\Delta h}^2\right). \tag{5}$$

Next, the transmitted power from (R) node, P_R is calculated by

$$P_R = \frac{E_h^{TPSR}}{(1-\gamma)T/2} = \varphi P_S \left(|h|^2 + \sigma_{\Delta h}^2\right), \tag{6}$$

where $\varphi = \frac{2 l_1^{-\alpha} \eta \gamma \delta}{(1-\gamma)}$.

In AF relaying network, the signal received at relay node (R) first amplifies and then forwards signal to destination node (D). After down sampling conversion, the received signal at (R) in the first hop at time index k is given by

$$y_r(k) = \sqrt{l_1^{-\alpha} (1-\delta) P_S}(h + \Delta h)s(k) + n_r, \tag{7}$$

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where n_r is denoted as AWGN with zero mean and variance of $\sigma^2_{n_r}$. In principle, the received signal is computed by $x_r(t) = G y_r(t)$ the transmitted signal at (R), where the amplification factor is calculated as

$$G^2 = \frac{l_1^\alpha P_R}{(1-\delta) P_S(|h|^2 + \sigma^2_{\Delta h}) + l_1^\alpha \sigma^2_{n_r}}. \tag{8}$$

The harvested energy at (R) node is produced transmitted power for remaining operation of the next hop , e.g, link $R - D$. As a consequence, the received signal at (D) node is computed by

$$y_d(k) = \sqrt{l_2^{-\alpha}} (g + \Delta g) x_r(k) + n_d. \tag{9}$$

Replacing (7) into (9), y_d can be rewritten by

$$\begin{aligned} y_d(k) = {} & \sqrt{l_2^{-\alpha}} \sqrt{l_1^{-\alpha} (1-\delta) P_S} G \underbrace{(hgs(k))}_{\text{Signal}} \\ & + \sqrt{l_2^{-\alpha}} \sqrt{l_1^{-\alpha} (1-\delta) P_S} G \left(\underbrace{g\Delta h + h\Delta g + \Delta h \Delta g}_{\textit{CSI Noise}} \right) s(k) \\ & + \sqrt{l_2^{-\alpha}} G \left(\underbrace{(g + \Delta g) n_r + n_d}_{\textit{AWGN Noise}} \right) \end{aligned} . \tag{10}$$

As a result, at destination, the end-to-end SNR can be written as

$$SNR = \frac{|signal|^2}{|overall\ noise|^2} = \frac{XY}{YQ_1 + XQ_2 + Q_3}, \tag{11}$$

where $Q_1 = \sigma^2_{\Delta h} + \frac{l_1^\alpha}{(1-\delta)P_S} \sigma^2_{n_r}$, $Q_2 = \sigma^2_{\Delta g}$, $Q_3 = \sigma^2_{\Delta g} \sigma^2_{\Delta h} + \frac{l_1^\alpha}{(1-\delta)P_S} \sigma^2_{\Delta g} \sigma^2_{n_r} + \frac{(1-\gamma) l_1^\alpha l_2^\alpha \sigma^2_{n_d}}{2\eta\gamma\delta P_S}$, and $X = |h|^2$, $Y = |g|^2$.

2. Outage Probability and Throughput Analysis

2.1. Delay-Limited Transmission:

In order to calculate throughput, we first compute outage probability. It is assumed that θ_{th} is SNR's threshold and then a fixed transmission rate, R_0 (bps/Hz) is computed by $R_0 = \log_2 (1 + \theta_{th})$. The outage probability is defined as probability for SNR less than threshold θ_{th}.

In the WPCN, the outage probability $P_{out} = \Pr (SNR < \theta_{th})$, can be given as

$$P_{out} = \Pr \left\{ \frac{XY}{YQ_1 + XQ_2 + Q_3} < \theta_{th} \right\}, \tag{12}$$

where $\theta_{th} = 2^{R_0} - 1$. In the Theorem 1, the analytical expression P_{out} can be extracted.

Theorem 1. *The outage probability of WPCN in case of imperfect CSI can be expressed as*

$$P_{out} = 1 - \exp \left(-\frac{Q_1 \theta_{th}}{\Omega_g} - \frac{\theta_{th} Q_2}{\Omega_h} \right) \Psi K_1 (\Psi), \tag{13}$$

where $\Psi = \sqrt{4 \frac{\theta_{th}(Q_3 + \theta_{th} Q_1 Q_2)}{\Omega_g \Omega_h}}$, the mean values of the exponential random variables X and Y are Ω_h, Ω_g, respectively, and $K_1(.)$ is the first order modified Bessel function of the second kind [24].

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Proof of Theorem 1. The cumulative distribution function (CDF) of X, Y which is the exponential random variable.

$$P_{out} \triangleq F(\theta_{th}) = \Pr\left\{\frac{XY}{YQ_1 + XQ_2 + Q_3} < \theta_{th}\right\}. \tag{14}$$

The outage probability, P_{out}, is given by

$$P_{out} = \int_0^{\theta_{th}Q_2} f_Y(\theta_{th})dy + \int_{\theta_{th}Q_2}^{\infty} f_Y(\theta_{th}) \times \Pr\left(X < \frac{\theta_{th}(yQ_1 + Q_3)}{y - Q_2\theta_{th}}\right)dy, \tag{15}$$

in which y is the integration variable, $f_Y(\theta_{th}) = \frac{1}{\Omega_g} e^{-\frac{\theta_{th}}{\Omega_g}}$ is the probability density function (PDF) of Y.

Thus, outage probability is calculated by

$$P_{out} = 1 - \frac{1}{\Omega_g} e^{\frac{\theta_{th}Q_1}{\Omega_g}} \int_{\theta_{th}Q_2}^{\infty} e^{-\left(\frac{y}{\Omega_h} + \frac{\theta_{th}(Q_3 + \theta_{th}Q_1Q_2)}{(y - \theta_{th}Q_2)\Omega_g}\right)} dy. \tag{16}$$

Therefore, the closed-form outage probability can be approximated as

$$\begin{aligned} P_{out} = 1 - e^{-\frac{Q_1\theta_{th}}{\Omega_g} - \frac{\theta_{th}Q_2}{\Omega_h}} & \sqrt{4\frac{\theta_{th}(Q_3 + \theta_{th}Q_1Q_2)}{\Omega_g\Omega_h}} \\ & \times K_1\left(\sqrt{4\frac{\theta_{th}(Q_3 + \theta_{th}Q_1Q_2)}{\Omega_g\Omega_h}}\right) \end{aligned}. \tag{17}$$

The aforementioned expression can be obtained thanks to utilizing, $\int_0^{\infty} e^{-\frac{u}{4x} - vx} dx = \sqrt{\frac{u}{v}} K_1\left(\sqrt{uv}\right)$, ([24], 3.324.1).
This ends the proof for Theorem 1. □

The throughput in delay-limited transmission mode, τ is defined as the effective communication time $(1 - \gamma)T/2$ which leads to the given fixed transmission rate R_0. The throughput at the destination is calculated relying on outage probability as below [20].

$$\tau = R_0(1 - P_{out})(1 - \gamma)/2, \tag{18}$$

where the throughput in (18), depends on $P_S, \eta, R_0, \gamma, l_1$, and $l_2, \sigma_{n_r}^2, \sigma_{n_d}^2$.

2.2. Delay-Tolerant Transmission:

In the delay-tolerant mode, the code length is assumed to be very enormous in comparison with the block time which contributes to possible realization of the channel can be seen during code-word timing. As a result, the ergodic capacity can be obtained by a rate equivalent with ergodic capacity, C,in condition of no knowledge of CSI at relay node and destination node.

The ergodic capacity C is computed by

$$C = \mathrm{E}_{X,Y}\left\{\frac{1}{2}\left(\log_2\left(1 + SNR\right)\right)\right\}, \tag{19}$$

where SNR relies on the random channel gains, X and Y.

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Theorem 2. *The ergodic capacity can be written as*

$$C \approx \int_0^{\infty} (M_1 + M_2) \times (\log_2 (1+x))\, dx, \tag{20}$$

where $M_1 = \frac{1}{\Omega_h \Omega_g} (\Omega_h Q_1 + \Omega_g Q_2) \times \exp\left(-\frac{Q_1 x}{\Omega_g} - \frac{x Q_2}{\Omega_h}\right) \Psi K_1 (\Psi)$ *and*
$M_2 = \frac{2(2Q_1 Q_2 x + Q_3)}{\Omega_h} \times \exp\left(-\frac{Q_1 x}{\Omega_g} - \frac{x Q_2}{\Omega_h}\right) K_0 (\Psi)$.

Proof of Theorem 2. In order to calculate the analytical expression for the capacity of ergodic, $f(x)$ is the probability density function (PDF) of SNR, which is evaluated first. The PDF can be obtained by the CDF, $F(x)$ that is illustrated in Theorem 1.

Next, the ergodic capacity is expressed as below

$$C = \int_0^{\infty} f(x) \log_2 (1+x)\, dx. \tag{21}$$

The PDF of SNR is given by

$$f(x) = \frac{\partial F(x)}{\partial x} = \frac{\partial \left[1 - \exp\left(-\frac{Q_1 x}{\Omega_g} - \frac{x Q_2}{\Omega_h}\right) \Psi K_1 (\Psi)\right]}{\partial x}. \tag{22}$$

Next, expression in (22) can be rewritten by

$$f(x) = \left(\begin{array}{l} \frac{1}{\Omega_h \Omega_g} (\Omega_h Q_1 + \Omega_g Q_2) \times \exp\left(-\frac{Q_1 x}{\Omega_g} - \frac{x Q_2}{\Omega_h}\right) \Psi K_1 (\Psi) \\ + \frac{2(2Q_1 Q_2 x + Q_3)}{\Omega_h} \times \exp\left(-\frac{Q_1 x}{\Omega_g} - \frac{x Q_2}{\Omega_h}\right) K_0 (\Psi) \end{array} \right). \tag{23}$$

Thus, the capacity of ergodic is rewritten by

$$C \approx \int_0^{\infty} \left(\begin{array}{l} \frac{1}{\Omega_h \Omega_g} (\Omega_h Q_1 + \Omega_g Q_2) \times \exp\left(-\frac{Q_1 x}{\Omega_g} - \frac{x Q_2}{\Omega_h}\right) \Psi K_1 (\Psi) \\ + \frac{2(2Q_1 Q_2 x + Q_3)}{\Omega_h} \times \exp\left(-\frac{Q_1 x}{\Omega_g} - \frac{x Q_2}{\Omega_h}\right) K_0 (\Psi) \end{array} \right). \tag{24}$$
$$\times (\log_2 (1+x))\, dx$$

This ends the proof for Theorem 2. □

The ergodic capacity C (bps/Hz) leads to the fact that the throughput at the (D) node is written as

$$\tau = \frac{(1-\gamma)T/2}{T} C = (1-\gamma) C/2. \tag{25}$$

2.3. Limitation of channel estimation error

It is assumed that the required outage probability must satisfy the least quality performance at the pre-set value of L

$$P_{out} = 1 - e^{-\frac{Q_1 \theta_{th}}{\Omega_g} - \frac{\theta_{th} Q_2}{\Omega_h}} \Psi K_1 (\Psi) = L, \tag{26}$$

in which $\Psi = 2\sqrt{\frac{\theta_{th}(Q_3 + \theta_{th} Q_1 Q_2)}{\Omega_g \Omega_h}}$.

In special case of high SNR $\Psi \to 0$ leads to $K_1(\Psi) \approx 1/\Psi$ and then resulting in $\Psi K_1 (\Psi) \approx 1$. We obtain new expression of the outage probability as

$$P_{out} = 1 - e^{-\frac{Q_1 \theta_{th}}{\Omega_g} - \frac{\theta_{th} Q_2}{\Omega_h}} = L. \tag{27}$$

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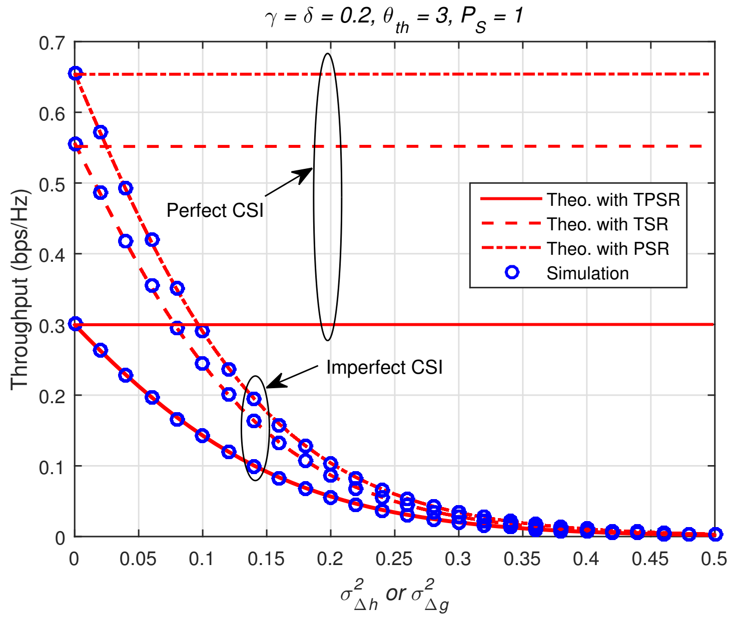

Figure 3. Comparison of throughput τ for imperfect CSI and perfect CSI in delay-limited transmission

For simplicity, in this analysis we assume that $\sigma^2_{\Delta g} = \sigma^2_{\Delta h} = \sigma^2_{\Delta}$, $\Omega_h = \Omega_g = \Omega$. It is noted $Q_1 = Q_2$ that at high SNR as $\frac{\sigma^2_{nr}}{P_S} \to 0$, we obtain limitation condition of the channel estimation error as below

$$\sigma^2_{\Delta} = \frac{-\Omega \ln(1-L)}{2\theta_{th}} \tag{28}$$

For low thresholds of outage probability, the performance for AF relaying is only slightly degraded by imperfect CSI impairments. The behavior is, however, very different as noise variance increases; the ideal CSI case gives a smooth convergence of outage probability towards 0 corresponding $L = 0$, while the practical case of CSI impairments experiences a slow convergence to the respective outage floors. The value of these wanted CSI errors were derived to obtain approximate outage probability. As can be seen that CSI error is more resilient to L, channel gain and the threshold SNR and it is very small as L is small.

3. Numerical Results and Discussion

In this part of the paper, the behavior of the outage probability and ergodic capacity in terms of transmission mode is illustrated by several samples. In particular, in both delay-tolerant and delay-limited transmission mode, the simulation for TPSR protocol is used. Furthermore, to confirm exactness of derived expression, the analytical throughput is evaluated and investigated.

In the delay-limited mode, the source transmission rate is set to $R = 2$ (bps/Hz), harvested energy conversion efficiency is $\eta = 1$, path loss exponent is $\alpha = 3$ and source transmission power is $P_S = 1$ (Joules/sec). The unit value remain unchanged from the first hop to the second hop. $\sigma^2_{n_r} = \sigma^2_{n_d} = \sigma^2 = 10^{-2}$ used to denote similar noise variances at (R) and (D) helps reduce the complexity. The values of the exponential random variables $|h|^2 = X$ and $|g|^2 = Y$, are set to 1. The averaging expressions along with end-to-end SNR and outage probability are computed by the experimental consequences and are run over 10^5 iterations that is the random realizations of Rayleigh fading channels g and h.

In Fig. 3 and Fig. 4, the impact of outdated CSI on delay-limited transmission and delay-tolerant transmission is depicted. It is obvious that there is a gradually decrease in the throughput for imperfect CSI. Besides that, we compared three energy harvesting protocol including TPSR, TSR,

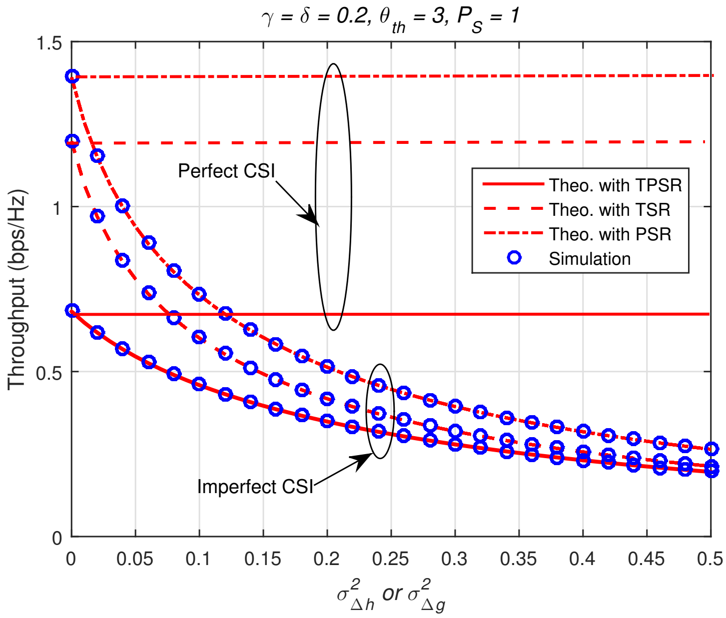

Figure 4. Comparison of throughput τ for imperfect CSI and perfect CSI in delay-tolerant transmission

PSR. In these scheme, the harvested receivers are designed with pre-set time/power splitting fraction corresponding with energy scavenging schemes, i.e. $\gamma = \delta = 0.2$ with TSR protocol $\gamma = 0.2$ and PSR protocol ($\delta = 0.2$).

In Fig. 5, it can be seen that there are upward trends when SNR increases. As observation, increasing SNR at source equivalent with increasing transmitted power at source brings significant throughput improvement as expected. The throughput in delay-tolerant transmission mode actually outperforms another in various cases of channel estimation error coefficients. In this illustration, these throughput increase remarkably as SNR greater than 15dB.

Fig. 6 and Fig. 7 investigate the performance of throughput versus the harvested power time coefficients and energy splitting coefficients, respectively. Analytical results of throughput are verified and examined by using Monte-Carlo simulations for both transmission modes in this case. Generally, the energy harvesting allows the relaying network remain the acceptable throughput with both ideal and imperfect CSI cases as if harvesting time and power coefficient are reasonable chosen. Importantly, the simulation and analytical results are match very well with all values of γ and δ as expected. As can be observed, the increasing harvesting time coefficient in range of 0.2 to 0.5 provides significant optimal throughput enhancement, compared to the worse case with harvesting time approximate equals to 0 or 1. In addition, this improvement is more prominent when the balance role of energy harvesting and information processing is satisfied. According to the Fig. 7, there is an increase in throughput when δ rises and approaching optimal throughput as δ belongs to (0.6, 0.8). The performance gap between perfect CSI and imperfect CSI can be seen clearly, especially in the optimal values of throughput.

In Fig. 8, the numerical results of ergodic capacity and harvesting energy trade-off are depicted. It is shown that results of ergodic increase as energy harvesting declines. Furthermore, energy harvesting is more sensitive to channel estimation error than ergodic capacity because of channel estimation error is linear with the level of transmitted of source's power.

In Fig. 9, outage probability performance can be determined in term of channel estimation error. In order to obtain pre-set of outage level, we can compute specific level of channel estimation error. This experiment compare outage probability of various scenarios. It can be confirmed that perfect CSI also bring the best performance in comparison with the others.

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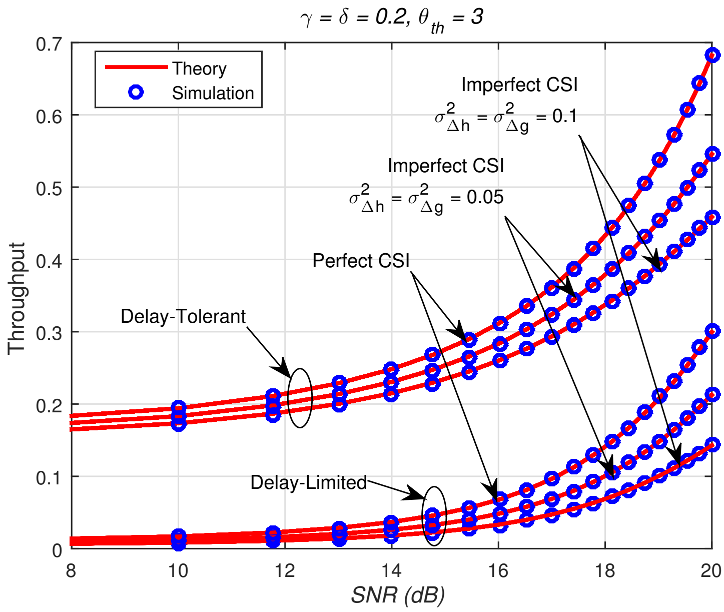

Figure 5. Throughput versus SNR for imperfect CSI $\sigma^2_{\Delta h} = \sigma^2_{\Delta g} = 0.1$ or $\sigma^2_{\Delta h} = \sigma^2_{\Delta g} = 0.05$

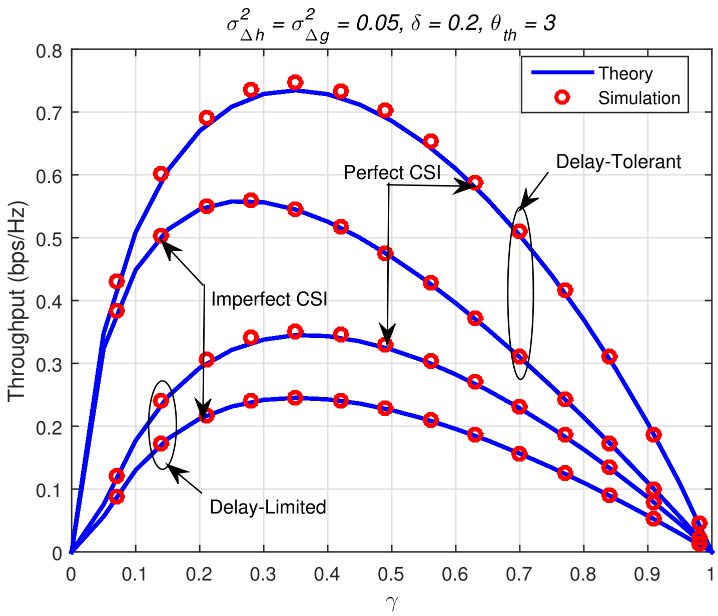

Figure 6. Throughput versus harvesting time coefficient

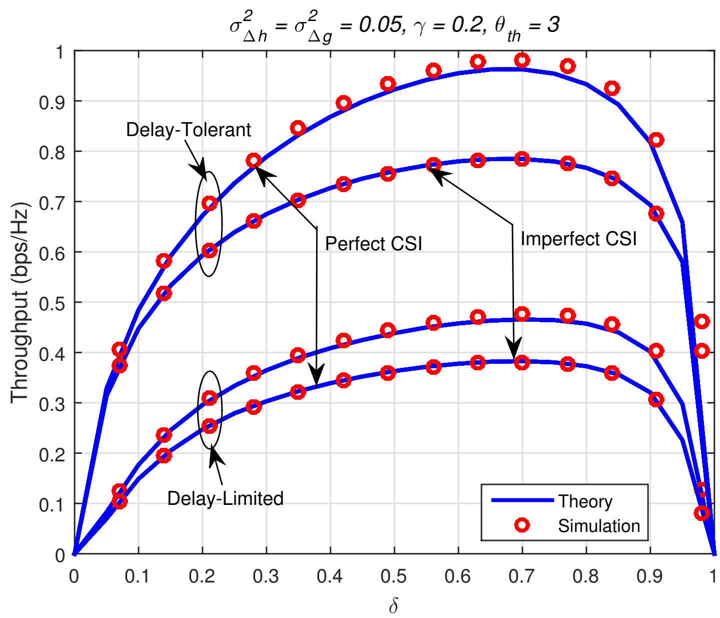

Figure 7. Throughput versus harvesting power coefficient

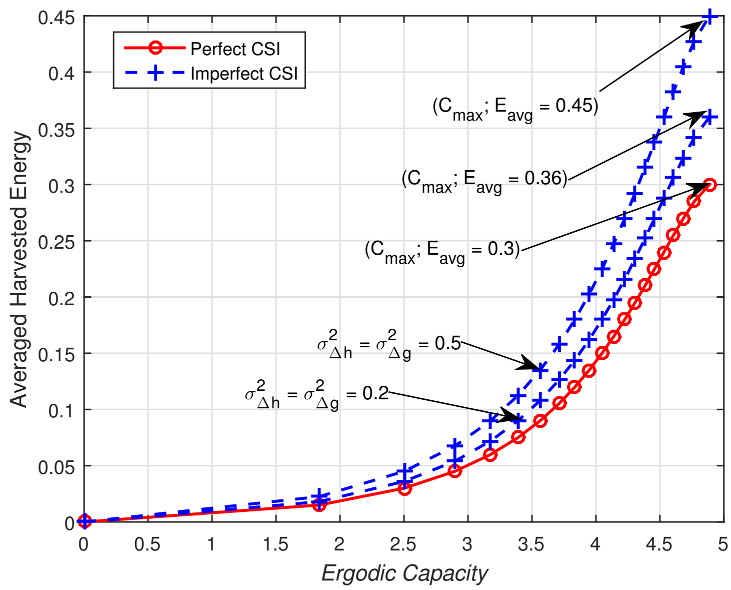

Figure 8. Averaged Harvested Energy for imperfect CSI with different $\sigma^2_{\Delta h} = \sigma^2_{\Delta g} = 0.5$ or $\sigma^2_{\Delta h} = \sigma^2_{\Delta g} = 0.2$ and Perfect CSI

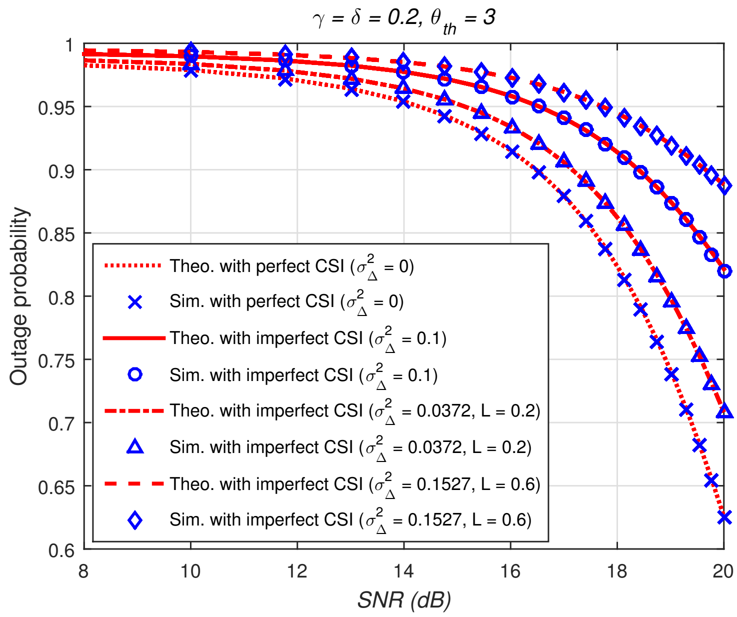

Figure 9. Outage probability vs. SNR with some limitations of CSI error

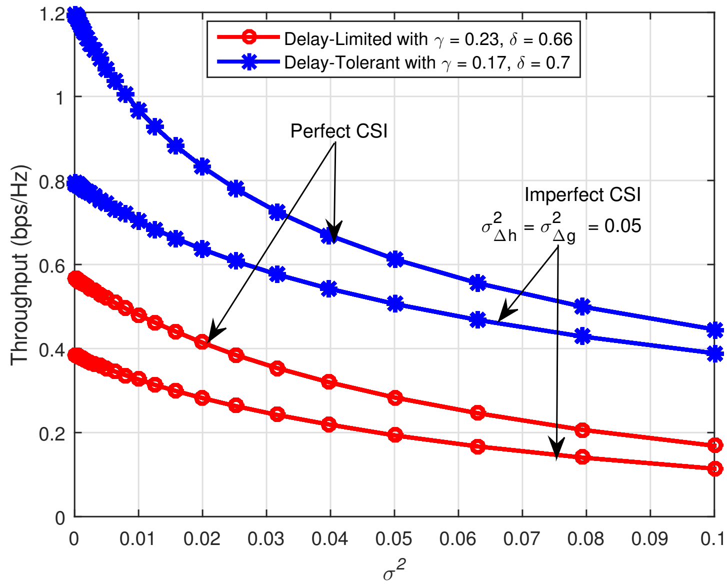

Figure 10. Throughput versus different of noise variance.

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As it is noted in some previous simulations that we can calculate optimal energy factors and time in the proposed TPSR protocol when throughput obtain maximum value (fixed $\gamma = 0.23$, $\delta = 0.66$ for delay-limited, and $\gamma = 0.17$, $\delta = 0.7$ for delay-tolerant). In Fig. 10, by investigating the impacts of noise on this result, we reveal optimal throughput in two modes for various values of noise variance σ^2. The performance of throughput gaps between two instances is considered as an appealing point, since it declines when noise variance rises.

4. Conclusion

In this paper, the new energy harvesting is proposed for optimal computation of the throughput and the impacts of imperfect CSI are considered. If the approximate harvesting time and power fractions of the proposed TPSR protocol are selected properly, the optimal performance of throughput can be obtained. In this investigation, we provide a tractable framework to characterize the performance of wireless energy and information transfer aided by AF relaying scheme network. Our analysis accounts for the key distinguishing features of WPCN systems. The simulated and analytical results illustrate that throughput in case of perfect CSI is remarkable higher than the imperfect CSI. However, the outage probability and throughput are remained, if CSI error value is careful computed.

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