Multiple Time Blocks Energy Harvesting Relay Optimizing with Time-Switching Structure and Decoding Cost

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Abstract. Energy harvesting (EH) is of prime importance for enabling the Internet of Things (IoT) networks. Although, energy harvesting relays have been considered in the literature, most of the studies do not account for the processing costs, such as the decoding cost in a decode-and-forward (DF) relay. However, it is known that the decoding cost amounts to a significant fraction of the circuit power required for receiving a codeword. Hence, in this work, we are motivated to consider an EH-DF relay with the decoding cost and maximize the average number of bits relayed by it with a time-switching architecture. To achieve this, we first propose a *time-switching* frame structure consisting of three phases: (i) an energy harvesting phase, (ii) a reception phase and, (iii) a transmission phase. We obtain optimal length of each of the above phases and communication rates that maximize the average number of bits relayed. We consider the radio frequency (RF) energy to be harvested by the relay is from the dedicated transmitter and the multiple block case when energy is allowed from flow among the blocks, different from the single block case when energy is not allowed to flow among the blocks. By exploiting the convexity of the optimization problem, we derive analytical optimum solutions under the EH scenario. One of the optimal receiving rate for the relay is the same as in single block case. We also provide numerical simulations for verifying our theoretical analysis.

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1 Introduction

In recent years, communication technology has developed rapidly, and the resulting energy consumption problem has become more and more serious. Therefore, adding energy harvesting (EH) to the original communication system has become the preferred solution for researchers. The energy harvesting realizes its own data transmission and other functions by collecting external energy, which will effectively improve the energy utilization rate of the current communication system. Energy harvesting is widely used in communication systems. For example, the application of this technology in wireless sensor networks [4], cognitive radio [5], radio frequency communication [6], and car networking [7] can improve energy efficiency greatly. In the communication process, the point-to-point model, the relay model, and the collaboration model are common system models, and the packet loss rate [8], energy utilization [9], data throughput [10] and other indicators [1,2]. In [11], the point-to-point data transmission model is studied. The transmitter is an EH node. The collected energy is used to transmit the data packets transmitted to the transmitter to the receiver. The target achieves maximum throughput, and the overall process is implemented by the Q-learning algorithm. The two-hop relay communication model is studied in [12]. The transmitter and relay nodes are EH nodes, which can exchange causal knowledge. Therefore, the Markov decision model constructed in [11] is converted into the Markov game model. Construct a local action value function. In [13], a three-node relay transmission network consisting of a single source node, a single destination node, and multiple relay nodes using decoding and forwarding is proposed, and the target of minimum energy consumption is realized by the particle swarm optimization algorithm. Parallel multi-relay model is built in [14]. The model includes the transmitting node of the primary and secondary users, the receiving node and the parallel relay node inside the secondary user model. Both the relay and the secondary user (SU) are provided at the source. An energy harvesting device in which the relay collects radio frequency energy emitted from the transmitting source, and the transmitting source collects radio frequency energy emitted from the secondary re-transmission of the relay. In [15], the author proposes an energy-saving relay selection method (ESRS) based on the parallel relay model, which significantly reduces the power consumption.

In this paper, we study the problem of optimizing time fraction and receiving rate for an EH relay system for multiple block case whose energy comes from the dedicated transmitter for transferring more information from dedicated transmitter to destination. Both energy and data are allowed to flow among blocks. The frame structure is determined as three phase: harvesting, receiving information and transmitting information. The time fraction or ratio of these operations are to determined. The average transmitting rate for the relay is known, while the receiving rate related to the decoding energy is to be optimized. We have

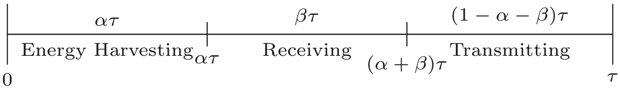

Fig. 1. The communication frame/block structure

the optimal solution in the single block case when energy and data are forbidden to flow among blocks. We consider the energy comes from dedicated receiver. We derive of the optimum time fraction for three operation phases and receiving rate and reach the conclusion that one of the optimal solutions is the same as that in single block case. Finally, numerical results are provided to validate the accuracy of the analysis. The main contributions of the paper are

- We formulate the information transferring and energy usage model for the energy harvesting relay considering the decoding cost.
- We give the solution for multiple block case where both energy and data are allowed to flow among blocks when energy is from dedicated transmitter by assumption and comparison.

2 System Model

We consider an end-to-end communication with an EH relay. The relay extracts the information contained in the signals sent by the transmitter, and then transmits it to the receiver in DF mode. We hope to transmit as most data as possible to the receiver. The energy source of the transmitter and receiver could be seen as infinite, while the energy of the relay is only from energy harvesting. Apparently, the bottle neck of the system is the EH relay which has limited harvested energy from the RF signals of the dedicated transmitter.

For purpose of simplicity and low cost, we design the structure of the relay as simple as possible. We consider a "Harvest-Receive-Transmit" time-switching architecture in this paper. The system consists of energy harvesting unit, decoding unit, transmitting unit, battery and data buffer. The energy harvesting unit harvest energy from RF signals of dedicated transmitter and ambient transmitters, and then store the energy in batteries for later transmitting or receiving freely. In the information receiving period, information is extracted from the received signals in the decoder unit using the energy drawn from the batteries. Then the information is stored in the buffer for later transmitting. In the information transmitting period, the information in the buffer is transmitted using the energy discharged from batteries.

We consider an average transmitting and receiving rate and channel condition when transferring information. So we could represent many parameters for the transmitting and receiving as constants during the block, such as the maximum signal power p_m, channel capacity C, the power gain of channel h, transmitting power p_t. A frame is divided into three parts as shown in Fig. 1. Assume the time length of a frame is τ.

- Over the time duration $[0, \alpha\tau), \alpha \in [0, 1]$, all the signals received are used for harvesting energy. To make the receiver harvest the largest amount of energy, the transmitter should always transmit the symbol with the largest energy. Denote $p_{\mathrm{m}} = \max_x p(x)$ where the maximum is over all possible values of $x \in \mathcal{X}$ and e is the energy harvested outside the bands used for transmission.
- Over the time duration $[\alpha\tau, (\alpha+\beta)\tau), \alpha+\beta \in [0, 1]$, switcher connects to the information extracting circuit. We assume that the decoder is the dominant source of energy consumption at the receiver. Generally, for a fixed channel capacity C [3], we assume the energy consumed for decoding per channel use is a non-decreasing convex function of $\theta = \frac{C}{C-R}$, denoted by $\mathcal{E}_{\mathrm{D}}(\theta)$. All other factors are 'hidden' in this function. $\mathcal{E}_D(0) = 0$. The bits that the relay could be decoded is $I_R = \beta\tau R$.
- Over the time duration $[(\alpha+\beta)\tau, \tau]$, switcher connects to the transmitting circuit and the information decoding is transmitted from the relay to the receiver. For transmission over an additive white Gaussian noise (AWGN) channel with power gain h, and unit received noise power spectral density, we consider the average rate as $Wlog(1 + hp_t)$ bits per channel symbol during the block.

  The may be several specific forms for characterizing the decoding energy consumption. For example, for LDPC codes on the binary erasure channel (BEC), [16] shows that for any $\theta > 0$, there exists a code with code rate of at least R, with complexity per input node per iteration scaling like $log\theta$, to make decoding iterations to converge. The iteration rounds scale like θ. So the total complexity of decoder per channel use scales like $\theta log\theta$ [17].

3 Transmission over a Single Block from Transmitter Only

For a single block transmission, the optimization problem to maximize the amount of information relayed can be formulated as

$$\begin{aligned}
&(\mathrm{P1}) \ \max_{\alpha, \beta, \gamma, R} I_R, \\
&\text{s.t.} \quad I_R \le I_T \\
&\qquad \beta\mathcal{E}_{\mathrm{D}}\left(\frac{C}{C-R}\right) + \gamma p_t + \le \alpha p_m \\
&\qquad 0 \le \alpha \le 1 \\
&\qquad 0 \le \beta \le 1 \\
&\qquad 0 \le \gamma \le 1 \\
&\qquad \alpha + \beta + \gamma = 1 \\
&\qquad 0 \le R \le C.
\end{aligned} \tag{1}$$

We assume that the average transmitting rate for the frame is known at the start of the frame, which is representing with a constant channel power gain and a fixed p_t, by optimizing R, α, β, γ. The second constraint follows because γ is time duration for transmission.

Theorem 1. *So there is a single optimal* R^*, $\alpha^*, \beta^*, \gamma*$ *for Problem of (P1).*

Proof. See Reference [17].

4 Transmission over Multiple Blocks: Energy Harvested from Transmitter Only

We now consider transmission over multiple blocks. We consider an average transmitting and receiving rate as not varying from block to block. So we represent the maximum signal power p_m, channel capacity C and the power gain of channel h as the same constraints for all blocks. The amount of harvested energy from ambient environment is different from block to block. Assume that there are N blocks. We use subscript i to denote the $i-th$ block. We consider the possibility that both energy and data flow to later blocks. The energy harvested from one block could be stored and used in the following blocks. Our goal is maximize the total information delivered to the destination through the relay by choosing proper parameters $\alpha_i\, \beta_i\, \gamma_i, R_i$. Assume p_t is known as the same for all the blocks. The problem could be formulated as (P2).

$$\begin{aligned}
\text{(P2)}\ & \max_{\boldsymbol{\alpha},\boldsymbol{\beta},\boldsymbol{\gamma},\mathbf{R}} \textstyle\sum_{i=1}^{N} IR_i = \sum_{i=1}^{N} \beta_i R_i \tau, \\
\text{s.t.}\ & \textstyle\sum_{j=1}^{i} IR_j \le \sum_{j=1}^{i} IT_j, \\
& \textstyle\sum_{j=1}^{i} IT_j = \sum_{j=1}^{i} log(1+hp_t)\gamma_j \tau, \\
& \textstyle\sum_{j=1}^{i} \alpha_j p_{\rm m} \ge \sum_{j=1}^{i} \left[p_t\gamma_j + \beta_j \mathcal{E}_{\rm D}\left(\frac{C}{C-R_j}\right)\right] \\
& 0 \le \alpha_i \le 1, 0 \le \beta_i \le 1, 0 \le \gamma_i \le 1, \\
& \alpha_i + \beta_i + \gamma_i = 1, 0 \le R_i \le C, \\
& \quad i = 1, \ldots, N.
\end{aligned} \tag{2}$$

where $\boldsymbol{\alpha} = \{\alpha_1, \ldots, \alpha_N\}$, $\boldsymbol{\beta} = \{\beta_1, \ldots, \beta_N\}$, $\boldsymbol{\gamma} = \{\gamma_1, \ldots, \gamma_N\}$ and $\mathbf{R} = \{R_1, \ldots, R_N\}$. Notice that Unfortunately, (2) is not a convex optimization problem. We construct another optimization problem (P3).

$$\begin{aligned}
\text{(P4)}\ & \max_{\boldsymbol{\alpha},\boldsymbol{\beta},\boldsymbol{\gamma},\mathbf{R}} \textstyle\sum_{i=1}^{N} IR_i = \sum_{i=1}^{N} \beta_i R_i \tau, \\
\text{s.t.}\ & \textstyle\sum_{j=1}^{i} IR_j \le \sum_{j=1}^{i} IT_j \\
& \textstyle\sum_{j=1}^{i} IT_j = \sum_{j=1}^{i} log(1+hp_t)\gamma_j \tau \\
& \textstyle\sum_{j=1}^{i} \alpha_j p_{\rm m} \ge \sum_{j=1}^{i} \left[p_t\gamma_j + \beta_j \mathcal{E}_{\rm D}\left(\frac{C}{C-R_j}\right)\right], \\
& 0 \le \alpha_i \le 1, 0 \le \beta_i \le 1, 0 \le \gamma_i \le 1, \\
& \alpha_i + \beta_i + \gamma_i = 1, 0 \le R_i \le C, \quad i = 1, \ldots, N. \\
& \alpha_1 = \alpha_2 = \cdots = \alpha_N,\ \beta_1 = \beta_2 = \cdots = \beta_N, \\
& \gamma_1 = \gamma_2 = \cdots = \gamma_N,\ R_1 = R_2 = \cdots = R_N.
\end{aligned} \tag{3}$$

Compared with (2), we see that (3) has more constraints to ensure that the fraction using for EH, receiving and transmission in each block are the same. The following lemma relates the optimization problem (3) with (1).

Lemma 1. *The optimal α_i, β_i, γ_i, R_i, $i = 1, \dots, N$, which maximize the objective function of (3) are $\alpha_1 = \cdots \alpha_N = \alpha^*$, $\beta_1 = \cdots \beta_N = \beta^*$, $\gamma_1 = \cdots \gamma_N = \gamma^*$, $R_1 = \cdots R_N = R^*$, where α^*, β^*, γ^* and R^* are optimal for (1).*

Proof. We argue that $\alpha_1 = \cdots \alpha_N = \alpha^*$, $\beta_1 = \cdots \beta_N = \beta^*$, $\gamma_1 = \cdots = \gamma_N = \gamma^*$, $R_1 = \cdots R_N = R^*$ satisfy the first set of constraints in (3), since

$$\begin{aligned} &\alpha^* p_{\mathrm{m}} = \beta^* \mathcal{E}_{\mathrm{D}}(\tfrac{C}{C-R^*}) + \gamma^* p_t \\ \Leftrightarrow &\textstyle\sum_{j=1}^{i} \alpha^* p_{\mathrm{m}} = \sum_{j=1}^{i} \beta^* \mathcal{E}_{\mathrm{D}}(\tfrac{C}{C-R^*}) + \gamma^* p_t, \\ \Rightarrow &\textstyle\sum_{j=1}^{i} \alpha^* p_{\mathrm{m}} \geq \sum_{j=1}^{i} \beta^* \mathcal{E}_{\mathrm{D}}(\tfrac{C}{C-R^*}) + \gamma^* p_t, \\ &\text{for } i = 1, 2, \cdots, N. \end{aligned} \tag{4}$$

$$\begin{aligned} &\beta^* R^* \tau = \gamma^* log(1 + hp_t) \\ \Leftrightarrow \quad &\textstyle\sum_{j=1}^{i} \beta^* R^* \tau = \sum_{j=1}^{i} \gamma^* log(1 + hp_t), \\ \Rightarrow \quad &\textstyle\sum_{j=1}^{i} \beta^* R^* \tau \geq \sum_{j=1}^{i} \gamma^* log(1 + hp_t), \\ &\text{for } i = 1, 2, \cdots, N. \end{aligned} \tag{5}$$

It is obvious that the last set of constraints are also satisfied. We will prove the optimality via contradiction. Define $\mathcal{O}_N(\alpha_1, \beta_1, \gamma_1, R_1 \dots, \alpha_N, \beta_N, \gamma_N, R_N) = \sum_{i=1}^{N} \beta_i R_i \tau$. Suppose there exist another $\hat{\alpha}$, $\hat{\beta}$, $\hat{\gamma}$ and $\hat{R}$ such that when $\alpha_1 = \cdots \alpha_N = \hat{\alpha}$, $\beta_1 = \cdots \beta_N = \hat{\beta}$, $\gamma_1 = \cdots \gamma_N = \hat{\gamma}$, $R_1 = \cdots R_N = \hat{R}$ and all the constraints of (3) are satisfied and we have $\mathcal{O}_N(\hat{\alpha}, \hat{\beta}, \hat{\gamma}, \hat{R} \dots, \hat{\alpha}, \hat{\beta}, \hat{\gamma}, \hat{R}) > \mathcal{O}_N(\alpha^*, \beta^*, \gamma^*, R^* \dots, \alpha^*, \beta^*, \gamma^*, R^*)$, i.e., $N\hat{\beta}\hat{R}\tau > N\beta^* R^* \tau$. Since it is always optimal to use up all the energy in the end, according to the constraints, we have

$$N\hat{\alpha}p_{\mathrm{m}} = N\hat{\gamma}p_t + N\hat{\beta}\mathcal{E}_{\mathrm{D}}\left(\frac{C}{C - \hat{R}}\right) \tag{6}$$

which means $\hat{\alpha}$, $\hat{\beta}$, $\hat{\gamma}$ and $\hat{R}$ also satisfy the constraints of (1). Since $\hat{\beta}\hat{R}\tau > \beta^* R^* \tau$, the results contradict the truth that α^*, β^*, R^* and γ^* are the optimal values for (1).

The following theorem relates the solution of (3) to the solution of (2).

Theorem 2. *One set of optimal values for α_i, β_i, γ_i, and R_i, $i = 1, \dots, N$, which maximize the objective function of (2) are $\alpha_1 = \cdots \alpha_N = \alpha^*$, $\beta_1 = \cdots \beta_N = \beta^*$, $\gamma_1 = \cdots \gamma_N = \gamma^*$, $R_1 = \cdots R_N = R^*$ where α^*, β^*, γ^* and R^* are optimal for (1).*

Proof. Since (3) has four more constraints than (2), assuming one set of optimal values for (2) are given as $\tilde{\alpha}_1, \tilde{\beta}_1, \tilde{\gamma}_1, \tilde{R}_1, \dots, \tilde{\alpha}_N, \tilde{\beta}_N, \tilde{\gamma}_N, \tilde{R}_N$, it is easy to obtain

$$\begin{aligned} &\mathcal{O}_N(\tilde{\alpha}_1, \tilde{\beta}_1, \tilde{\gamma}_1, \tilde{R}_1, \dots, \tilde{\alpha}_N, \tilde{\beta}_N, \tilde{\gamma}_N, \tilde{R}_N) \geq \\ &\qquad \mathcal{O}_N(\alpha^*, \beta^*, \gamma^*, R^*, \dots, \alpha^*, \beta^*, \gamma^*, R^*). \end{aligned} \tag{7}$$

Due to property of $\mathcal{E}_D(R)$, by using Jensen's inequality to code rate, we have

$$\sum\nolimits_{j=1}^{N} \frac{\tilde{\beta}_j}{\Phi} \mathcal{E}_{\mathrm{D}} \left(\frac{1}{1-\frac{\tilde{R}_j}{C}} \right) \geq \mathcal{E}_{\mathrm{D}} \left(\frac{1}{1-\sum\nolimits_{j=1}^{N} \frac{\tilde{\beta}_j}{\Phi} \tilde{R}_j / C} \right), \tag{8}$$

where $\Phi = \sum\nolimits_{k=1}^{N} \tilde{\beta}_k$. Hence, we can derive that

$$\begin{aligned} \sum_{j=1}^{N} \tilde{\alpha}_j p_{\mathrm{m}} &= \sum_{j=1}^{N} \tilde{\beta}_j \mathcal{E}_{\mathrm{D}} \left(\frac{1}{1-\frac{\tilde{R}_j}{C}} \right) + \sum_{j=1}^{N} \tilde{\gamma}_j p_t^j \\ &\geq \sum_{j=1}^{N} \tilde{\beta}_j \mathcal{E}_{\mathrm{D}} \left(\frac{1}{1-\frac{\sum_{k=1}^{N} \tilde{\beta}_k \tilde{R}_k}{\sum_{k=1}^{N} \tilde{\beta}_k C}} \right) + \sum_{j=1}^{N} \tilde{\gamma}_j p_t, \end{aligned} \tag{9}$$

So there exists an $R' \geq \frac{\sum_{k=1}^{N} \tilde{\beta}_k \tilde{R}_k}{\sum_{k=1}^{N} \tilde{\beta}_k}$ that makes $\sum\nolimits_{j=1}^{N} \tilde{\alpha}_j p_{\mathrm{m}} = \sum\nolimits_{j=1}^{N} \tilde{\beta}_j \mathcal{E}_{\mathrm{D}} \left(\frac{1}{1-\frac{R'}{C}} \right) + \sum\nolimits_{j=1}^{N} \tilde{\gamma}_j p_t$. Actually, $R' \geq \frac{\sum_{k=1}^{N} \tilde{\beta}_k \tilde{R}_k}{\sum_{k=1}^{N} \tilde{\beta}_k}$ means

$$\begin{aligned} &\mathcal{O}_N(\tilde{\alpha}_1, \tilde{\beta}_1, \tilde{\gamma}_1, R', \ldots, \tilde{\alpha}_N 1, \tilde{\beta}_N, \tilde{\gamma}_N, R') \geq \\ &\mathcal{O}_N(\tilde{\alpha}_1, \tilde{\beta}_1, \tilde{\gamma}_1, \tilde{R}_1, \ldots, \tilde{\alpha}_N, \tilde{\beta}_N, \tilde{\gamma}_N, \tilde{R}_N). \end{aligned} \tag{10}$$

However, this new R' together with $\tilde{\alpha}_1, \ldots, \tilde{\alpha}_N$, $\tilde{\beta}_1, \ldots, \tilde{\beta}_N$ and $\tilde{\gamma}_1, \ldots, \tilde{\gamma}_N$, may not satisfy the first group of constraints in (2), so we need to find feasible solutions. To solve it, we let $\beta' = \frac{\sum_{k=1}^{N} \tilde{\beta}_k}{N}$. Then we have

$$\begin{aligned} N\alpha' p_{\mathrm{m}} = \sum_{j=1}^{N} \tilde{\alpha}_j p_{\mathrm{m}} &= \sum_{j=1}^{N} \tilde{\beta}_j \mathcal{E}_{\mathrm{D}} \left(\frac{1}{1-\frac{R'}{C}} \right) + \tilde{\gamma} p_t \\ &= N\beta' \mathcal{E}_{\mathrm{D}} \left(\frac{1}{1-\frac{R'}{C}} \right) + \gamma' p_t, \end{aligned} \tag{11}$$

So we can show that the constraints are also satisfied according to the analysis similar to (4) and (5). In addition, we also have

$$\begin{aligned} &\mathcal{O}_N(\alpha', \beta', \gamma', R', \ldots, \alpha', \beta', \gamma', R') = \\ &\mathcal{O}_N(\tilde{\alpha}_1, \tilde{\beta}_1, \tilde{\gamma}_1, R', \ldots, \tilde{\alpha}_N, \tilde{\beta}_N, \tilde{\gamma_N}, R'). \end{aligned} \tag{12}$$

Noticing that $\alpha', \beta', \gamma', R', \ldots, \alpha', \beta', \gamma', R'$ also satisfy all the constraints in optimization problem (3), we can obtain that

$$\begin{aligned} &\mathcal{O}_N(\alpha', \beta', \gamma', R', \ldots, \alpha', \beta', \gamma', R') \leq \\ &\mathcal{O}_N(\alpha^*, \beta^*, \gamma^*, R^* \ldots, \alpha^*, \beta^*, \gamma^*, R^*). \end{aligned} \tag{13}$$

Combining (7), (10), (12) and (13), we can easily obtain the fact that $\mathcal{O}_N(\alpha^*, \beta^*, \gamma^*, R^*, \ldots, \alpha^*, \beta^*, \gamma^*, R^*) = \mathcal{O}_N(\tilde{\alpha}_1, \tilde{\beta}_1, \tilde{\gamma}_1, \tilde{R}_1, \ldots, \tilde{\alpha}_N, \tilde{\beta}_N, \tilde{\gamma}_N, \tilde{R}_N)$.

Comparing Lemma 1 and Theorem 2, we find that the relaxation of constraints that the fraction and code rate in each block are the same can not improve the performance.

Notice that $\{\alpha^*, \beta^*, \gamma^*, R^*\}$ is only one solution for (2). There may be other solutions that have different fractions and R. To be optimal, the code rates in all blocks should be equal due to (9).

5 Numerical Results

Firstly, we focus on the optimization results in single block case. Because the multiple block case solution in each block is the same with the single block case, so the simulation result also reflects multiple block case results. In order to follow the representation in the paper, we adopt energy unit as mW and bit rate unit as Mbits/s.

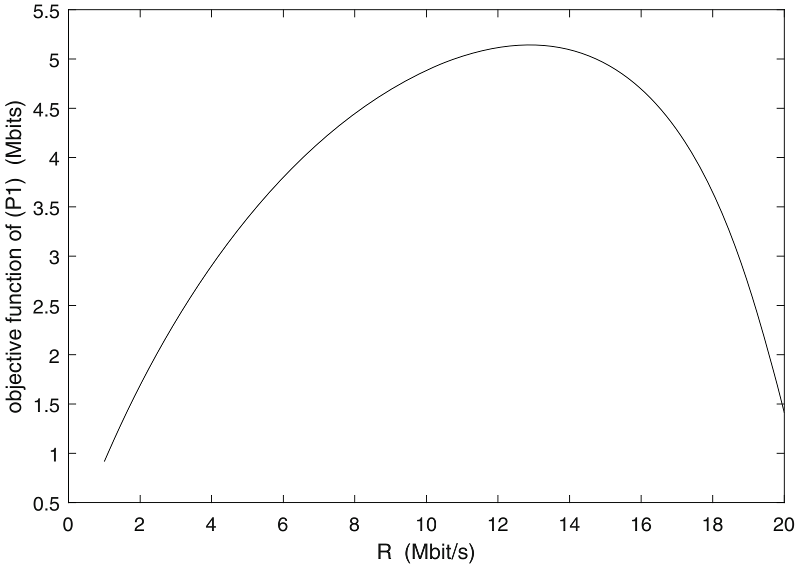

Fig. 2. The objective function value of (P1) versus R

We originally assume that $\mathcal{E}_D(\theta) = 10^{-3} \times \theta log_2\theta$W, $T(p_t) = Blog_2(1+p_t h')$ bit/s, $B = 10^6$ Hz, $C = 21$ Mbit/s, $N_0 = 10^{-15}$ W/Hz, $\tau = 1s$, $h' = \frac{1}{N_0 W} = 10^9$. As the coefficients at the front in $T(p_t)$ and $\mathcal{E}_D(\theta)$ do not affect the convexity property of the functions, Theorem 1 still holds.

In the following simulation, we adopt energy unit as mW and bit rate unit as Mbit/s. Then we have $\mathcal{E}_D(\theta) = \frac{C}{C-R} log_2\left(\frac{C}{C-R}\right)$ mW, $T(p_t) = log_2(1 + p_t h)$ Mbit/s, where p_t represent x energy unit, $h = 10^6$, C, R and $T(P_t)$ are bit rate with unit Mbit/s.

We assume $C = 21$ Mbit/s, According to $P_1(R^*) = 0$, the numerical result for optimum R^* could be obtained at 18.66 Mbit/s.

In order to verify we plot the objective function of (P1) versus R in Fig. 2. We could easily get the optimum $R^* = 18.66$ Mbit/s. When $p_m = 8$ mW, $p_t = 7$ mW, we could give the optimum $\alpha = 0.6755$, $\beta = 0.2072$ and $\gamma = 0.1173$.

We also give the analysis for α, β and γ which are all varying versus P_t and p_m in Fig. 3, Fig. 4, and Fig. 5. We can observe that when p_m, the average power of the best symbol for EH increases, α decreases, while β and γ increase. It is a correct trend as α, the time duration for EH, could be shorter than before, as a result of the increase of p_m. When the forwarding power p_t increases, γ decreases. It is a correct trend because γ, the time duration for forwarding the same amount of data will decrease, and α, the time duration for EH phase will increase because the forwarding power is less efficient in power as the forwarding data bits I_T is a log function of p_t. For the same reason, β will decrease too, leading to a lower throughput of the relay network.

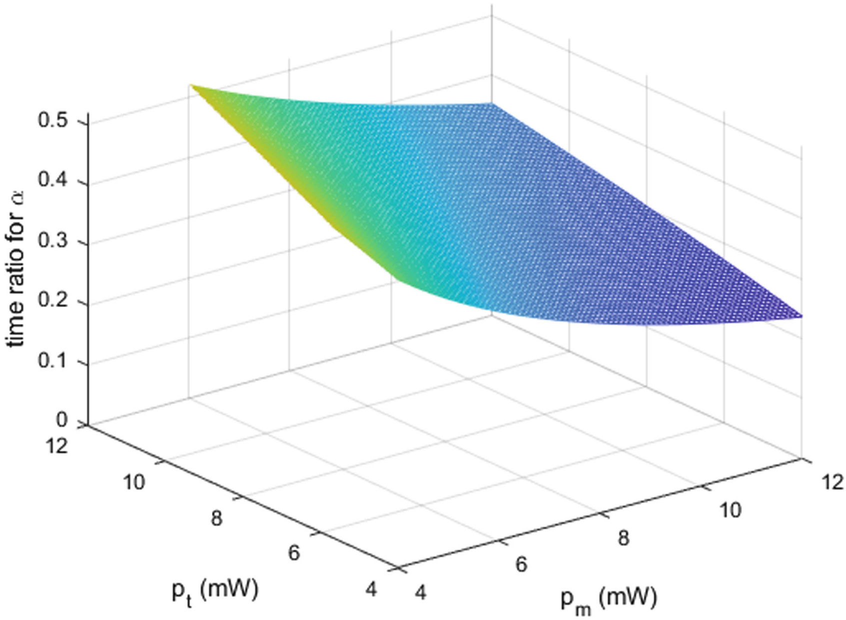

Fig. 3. α versus p_t and p_m

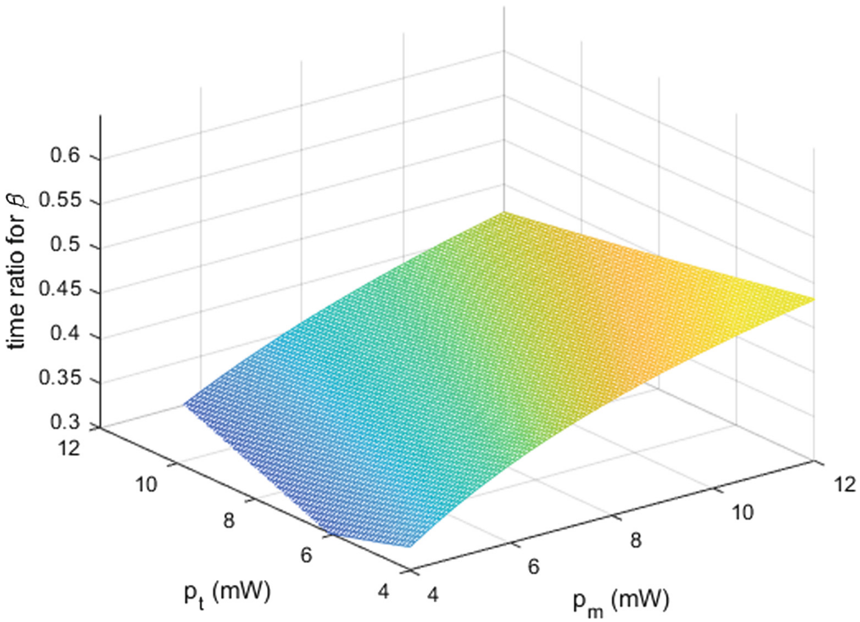

Fig. 4. β versus p_t and p_m

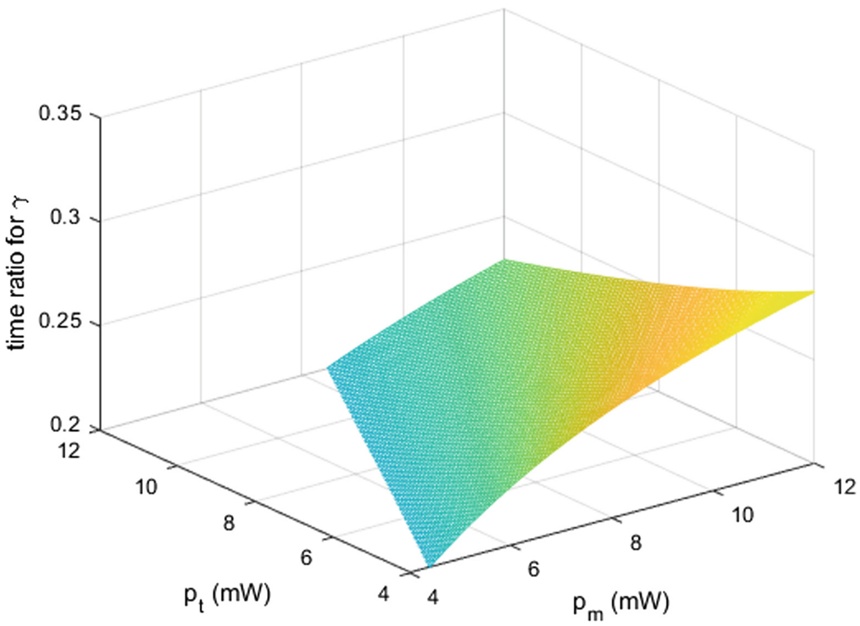

Fig. 5. γ versus p_t and p_m

6 Conclusion

The paper studies maximizing relay information using an energy constrained relay which harvests energy from the dedicated transmitter with a time-switching structure. The energy is allowed to flow among blocks. Given the optimal solution for a single block case, one of the optimal solution for multiple block case is derived. Simulation are done to give the numerical results to verify the correctness of the theoretical analysis.

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