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# A Joint Relay Selection and Energy Harvesting Approach to Improve The Performance of IoT Networks

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*Abstract*— **In the fifth generation of cellular networks, many users are included in a broad network known as the Internet of Things (IoT). Relay selection and energy harvesting are among the topics of interest to researchers in the field of IoT. In this paper, a method for relay selection with energy harvesting in IoT networks is investigated. In the proposed method, several relays with the best channel to the receiver are selected to transmit to the destination, and the detection is carried out by the MRC method. To increase the network lifetime, relay nodes harvest part of the received signal from the source in the form of energy. The outage probability of the system for different harvesting coefficients, different densities of relay distribution, and different network dimensions are studied and compared with previous methods. The proposed method demonstrates impressive improvements and succeeds to considerably reduce the outage probability, compared to previous methods.**

***Keywords: Internet of Things, Energy Harvesting, Relay Selection, Channel State Information, Outage Probability***

## I. Introduction

Smart sensors connected through cellular networks for various applications including industrial automation, environmental monitoring, infrastructure management, energy management, home automation and transportation, are called Internet of Things (IoT) [1]–[3]. The industry on IoT is expected to experience more growth, especially after 5G kicks off in 2020 [4]. With the arrival of the 5G, resource energy allocation has become a major challenge [5], [6], [7]. Due to the small dimensions of the smart sensors, it is impossible to employ multiple antennas (MIMO). However, if the sender does not have a reliable connection to the receiver, the relay can cooperate to improve the performance [8]. The relay selection method becomes one of the challenges faced by researchers in the IoT. Device-centric architecture is one of the fifth-generation communications aspects, which directly connects devices and equipment to the base station (BS) with minimal dependence [9]. When the devices go beyond the threshold of direct forwarding, they detect relays that are in their vicinity and use relays to retransmit data to the receiver. Important factors in the choice of relays include signal-to-noise ratio, remaining energy in the relay battery, buffer space and greater reliability.

Suppose a relay set is located in the vicinity of a transmitter, and each relay can communicate individually with the receiver. In [10] a relay selection method is proposed, where a relay is selected that has the least interference with the communications of other devices. The source broadcasts the information. The relays receive information and calculate the energy needed between themselves and the transmitter and between themselves and the receiver for successful transmission. Candidate relays are the ones received the correct information. From this set, a relay is selected that has the least effect of interference.

Another recommended way of selecting a relay is based on the outdated channel state information [11]. By the help of outdated channel state information, an estimate of the channel is obtained, based on this estimate, a relay that is expected to have the best signal-to-noise ratio is selected. Instead of receiving information or distributing them from the receiver via feedback, the previously used slot data are used to select the relay.

The choice of relay with a large-scale energy harvest is suitable for IoT. If the relay holds the instantaneous data of the channel, the Diversity is equal to the number of relays available. Getting accurate channel information instantaneously requires significant power consumption that is not suitable for IoT applications. In [12], a method is proposed which applies energy harvesting. This method is discussed in details in Section 2

In this paper, a system modeled with a Poisson point process is considered. The relays work in amplify and forward (AF) mode. The source first sends the data and the relay receives information from the source and, with the help of the approximate channel information, receives an estimate of the outage probability and reports it to the source. The receiver selects the relay with the least estimated outage probability.

The main contributions of this article can be listed as follows:

- Selection of several relays combined with energy harvesting to send simultaneously and utilize the space diversity in the receiver, which improves system performance and reduces the outage probability

- Presenting extensive simulation results to compare the performance of the proposed system and previous schemes, for different energy harvesting coefficients and the different density of relay distribution.

The rest of this paper is organized as follows. Section 2 introduces the system model. In Section 3, the proposed method is discussed. In Sections 4 simulation results and discussions are provided. Section 5 concludes this paper.

## II. SYSTEM MODEL

### A. Network Model

The system model is similar to the one presented in [12] and consists of a transmitter, a receiver, and a number of relays in Euclidean two-dimensional M × M space. This two-dimensional space is modeled by a static Poisson point process. In the static Poisson point process, the average number of relays that are used (K) is equal to the product of the area and the density of the spatial distribution (represented by $\lambda$). The system model is shown in Fig. 1. The closest relay to destination is labeled as number one, the second nearest relay in the vicinity of the destination is labeled as number two, and so on. Channels between transmitter and relay, as well as between relay and receiver, are Rayleigh block fading. The noise term is considered with mixed Gaussian distribution with mean zero and unit variance. This is a small-scale fading. Also, a large-scale fading is considered to be due to a path loss. Parameter β represents the path loss factor, which is often considered to be between 2 and 4. In the proposed system, the path loss factor is considered equal to 2. Signal transmission is carried out in two steps. In the first step, the sender sends the signal and all the relays receive the information. In the second step, several relays are simultaneously candidates for sending received information to the receiver. The relay knows channel information between itself and the sender.

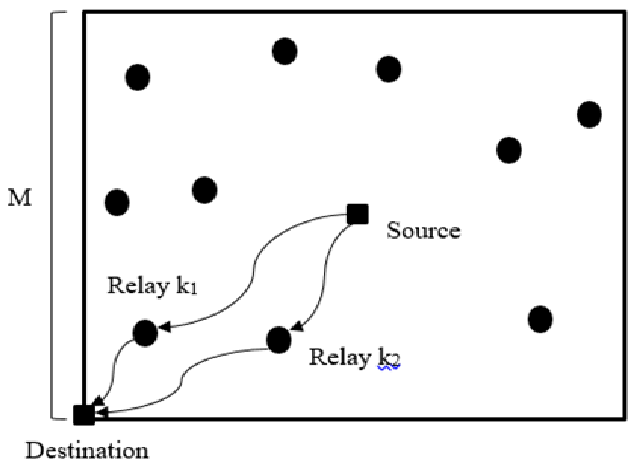


Figure 1. The proposed system model.

### B. Energy Arrival Model

The energy received is a statistical process in time, and the amount taken as energy depends on the position of the relays and time. The energy harvested with parameter E is formulated in (1). At each time slot, each relay saves its battery by using an effective energy harvesting coefficient as a coefficient of the time signal received by the receiver, and the rest of the energy is consumed in that time slot for sending information. Therefore, the energy harvested at each time slot is as follows.

$$E = \rho P_s * T_s \quad (1)$$

We propose to select multiple relays, so that part of the battery power of each relay is consumed. Suppose $N_k$ is the number of time slots that the *K*th relay is transmitting. The energy supplied when *n* relays transmit simultaneously is:

$$E_{kopt,i} \triangleq \frac{N_{kopt,i}}{n} \times \rho E_s \ ; \quad \text{for} \quad i = 1{:}n \quad (2)$$

## III. PROPOSED RELAY SELECTION METHOD

Our goal is to reduce the outage probability of the radio link. Therefore, the analyses of this section focus on the calculation and optimization of this component. It was assumed that in each relay the distribution of the channel fading coefficient and the corresponding distance to the receiver are available. The outage probability of a radio link is expressed as follows [12]:

$$P_o^k = P_r\left[\frac{\log_2\left(1+\Gamma_{AF}^k\right)}{2} < R\right] = P_r\left[\Gamma_{AF}^k < 2^{2R} - 1\right] \quad (3)$$

By considering the relay information that contains the information between itself and the transmitter in full, we may write:

$$P_o^k = \begin{cases} P_r\left[\Gamma_{kD} < \dfrac{a(1+\Gamma_{Sk})}{\Gamma_{Sk} - a}\right], & (\Gamma_{Sk} > a), \\ P_r\left[\Gamma_{kD} < \dfrac{a(1+\Gamma_{Sk})}{a - \Gamma_{Sk}}\right], & (\Gamma_{Sk} < a), \end{cases} \quad (4)$$

Where in (4), parameter *a* is the threshold value of the signal ratio to the definite noise of the radio link from the sender to the receiver.

We also have the following distributions:

$$|h_{kD}|^2 \sim f(x) \triangleq e^{-x} \quad (5)$$

$$1 + r_{kD}^2 \sim g(y; k, \lambda) \triangleq \frac{(\pi\lambda)^k (y-1)^{k-1}}{\Gamma(k)} e^{-\pi\lambda(y-1)} \quad (6)$$

The outage probability of a radio link for each relay based on the number assigned to that relay is calculated as follows [12]:

$$P_o^k \approx 1 - \exp[-\frac{\Gamma_t(1+\Gamma_{Sk})}{P_k(\Gamma_{Sk} - \Gamma_t)} \frac{(\pi\lambda + k)^3}{[(\pi\lambda + k)^2 + k]\pi\lambda}] \quad (7)$$

The decision-making center in each loop has a set of error probabilities with the number of relay members. The proposed method is to select multiple relays instead of a relay and utilize the Maximal Ration Combining (MRC) in the receiver.

The mathematical expression of how to select a relay for a K-member is as follows:

$$k_{opt,1} = \arg \min_{k\epsilon\{1,2,\ldots,K\}} P_o^k(\Gamma_t|\Gamma_{Sk}, P_k, k) \quad (8)$$

$$k_{opt,2} = \arg \min_{k\epsilon\{1,2,\ldots,K\}-\{k_{opt,1}\}} P_o^k(\Gamma_t|\Gamma_{Sk}, P_k, k) \quad (9)$$

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$$k_{opt,n} = \arg \min_{k\epsilon\{1,\ldots,K\}-\{k_{used}\}} P_o^k(\Gamma_t|\Gamma_{Sk}, P_k, k) \quad (10)$$

The use of multiple relays simultaneously allows us to use the diversity gain. The outage probability in this case is expressed as follows:

$$P_{out}^{n-select} = P_r(\Gamma_{AF}^{k_{opt,1}} + \cdots + \Gamma_{AF}^{k_{opt,n}} < 2^{2R} - 1) \quad (11)$$

In the next section, by presenting the simulation results, we examine the performance of the proposed method.

## IV. SIMULATION RESULTS

In this section, Monte-Carlo simulations are applied to illustrate the performance of the proposed relay selection system with energy harvesting. The data transmission rate is normalized to R = 1. Without loss of generality, the density of the white AWGN is considered to be $N_0 = 1$. ρ is the energy harvesting coefficient, λ is the relay distribution density per unit area, and M is the system dimension. A direct link between sender and receiver does not exist.

In Figure 2, the performance of the system when employing two relays is investigated for the different energy harvesting coefficients. The performance of the system has been degraded by reducing the effective efficiency of energy harvesting. For example, in the outage probability of 0.0001, the system performance with an energy harvesting coefficient of 0.8, compared to the system with an energy harvesting coefficient of 0.4, shows a 3.5dB improvement and compared to the system with energy harvesting coefficient of 0.1, shows a 8dB improvement. This reduction in the efficiency of harvesting energy with a lower coefficient is due to the use of the relay in a mode of amplification and forward. With reduced energy harvesting, there is not enough power to amplify and resend the signal, which is why the performance of the system has clearly dropped.

In Figure 3, the performance of the system is investigated when three relays are simultaneously selected for transmission. The performance of the system has been reduced by reducing the energy harvesting coefficient. For example, in the probability of outage of 0.0001, the system performance with an energy harvesting coefficient of 0.8 shows a 2.5dB improvement in comparison to the system with energy harvesting coefficient of 0.4, and 7.5dB improved in comparison to the system with effective coefficient of 0.1.

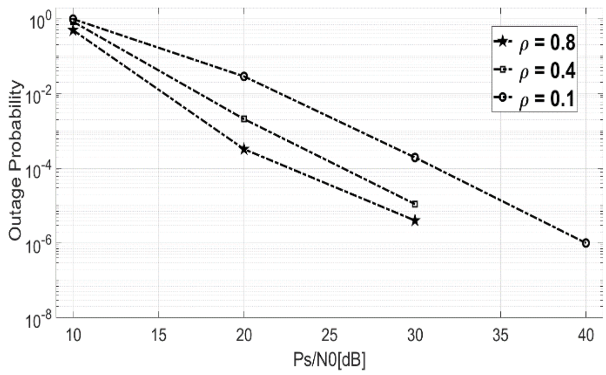


Figure 2. Outage probability of the proposed method with two relays, density λ = 1 and a square space with side scales M = 10

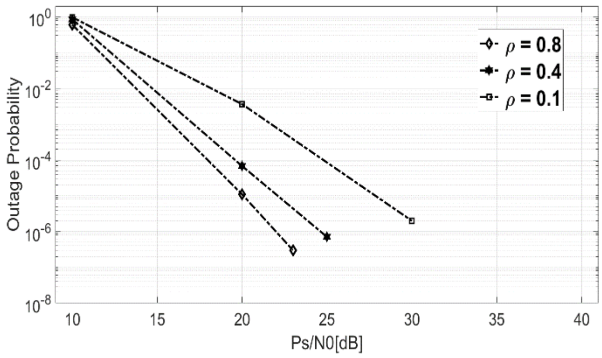


Figure 3. Results for selecting three relays and sending simultaneously for density λ = 1 and a square space with side scales M = 10

In Figures 4 and 5, a comparison between the system proposed in the paper [12], which applies a single relay, is carried out with the proposed system of this paper. Effect of energy efficiency coefficient on system performance with increasing number of relays has been investigated. As observed in Figure 4, for the single-relay selection scheme proposed in literature, the outage probability is relatively large. However, using two and three relays simultaneously, impressively improves the performance. As observed in Fig. 5, by increasing the energy harvesting coefficient, the performance of all three systems improves. This is expected, because the more power is available to the amplify-and-forward relay, the relay will send a stronger signal to the receiver, and consequently the likelihood of an outage event will be reduced.

In Figure 6, performance of the proposed system by changing the number of selected relays is investigated. It is observed that the performance improvement continues as long as up to 4 relays are selected. However, Fig. 6 suggests that the gain achieved by increasing the number of selected relays beyond the value of 4, is perhaps negligible.

## V. Concluding Remarks

A joint relay selection and energy harvesting scheme was proposed to reduce the outage probability in IoT networks. Extensive simulation results were provided to compare the performance of the proposed scheme with existing schemes and demonstrate its superiority. Considering other combining methods (such as EGC), and studying other system parameters (such as Symbol Error Rate) are amongst interesting directions to take for future research.

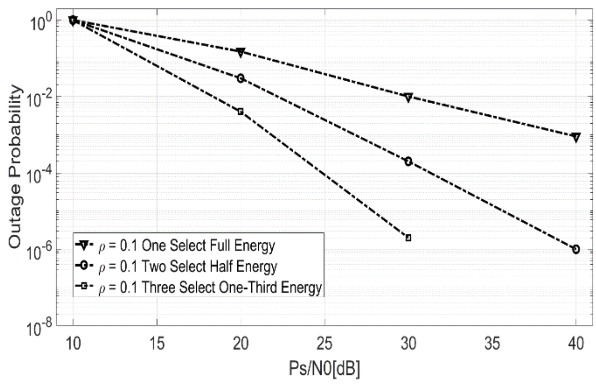


Figure 4. Comparison of the system performance in the transmission using [12], with the proposed system applying two, and three relays, for ρ = 0.1

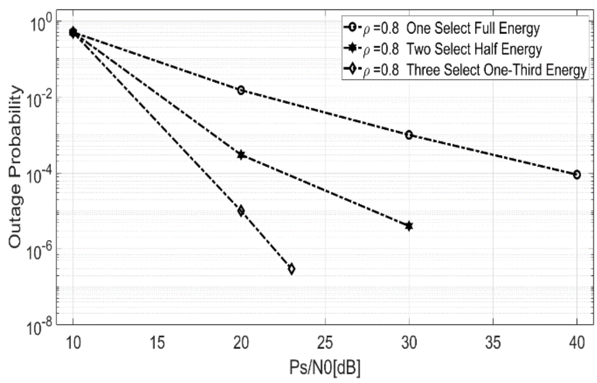


Figure 5. Comparison of the system performance in the transmission using [12], with the proposed system with 2 and 3 relays and ρ = 0.8

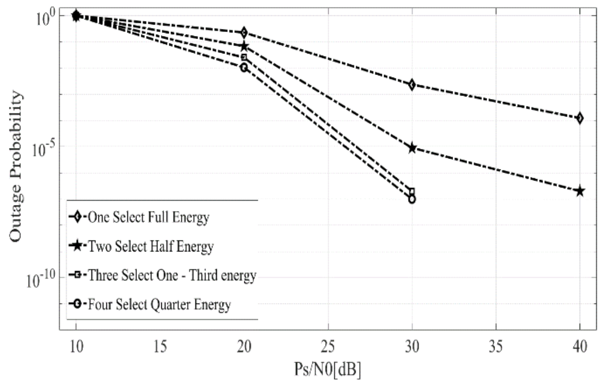


Figure 6. Comparison of proposed system performance for different number of selected relays. ρ = 0.5, λ = 0.5 and M = 50

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