Joint relay selection and energy harvesting to improve performance of cooperative communication systems

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Abstract - This paper focuses on a combining relay selection with energy harvesting (EH), known as joint relay selection with EH (JRSEH), to improve performance in wireless cooperative communication systems. Previous research was examined performance improvement with relay selection (RS) techniques without combined with EH (RS non-EH). This study aims to improve the performance by applying EH and the RS in the cooperative communication system. In the system, a source selects the best relay from several relays that produce the highest SNR value at the destination. The selected best relay performs EH based on time switching. Then, the best relay with EH obtains the power to forward information to the destination using the Amplify and Forward (AF) relay scheme. The channel from source to relay is Rician fading, and from the relay to a destination is Rayleigh fading. The research method used is system modeling and analysis of computer simulations. The system performance is calculated based on the bit error rate (BER) and the throughput in a multi-relay cooperative system with EH and RS. The results show that the performance of the proposed JRSEH higher than that of RS non-EH, multi-relay EH, and multi-relay non-EH.

1. Introduction
The wireless cooperative communication system has become the focus of the current research as a reliable strategy in overcoming fading problems and increasing channel capacity. The concept of a wireless cooperative communication system is a system that uses one or more relays to transmit information from source to destination [1]. Before the information is forwarded to the destination, the relay must process the information with a specific protocol. The commonly used protocols in relays are the amplify-and-forward (AF) and decode-and-forward (DF) protocols. A cooperative communication system that utilizes multiple relays (multi-relay) has advantages in throughput but requires more energy than a single relay system. One of the techniques to overcome energy shortages but maintain throughput is by performing energy harvesting (EH) on relays and reducing the number of relays that will forward information to a destination [2].

Several previous studies have examined the increase of energy efficiency in systems with relay selection techniques. Previous work in [3] used a relay selection strategy by applying an adaptive mode to the relay in the cooperative system. One of the techniques used is adaptive relay transmit power to determine the energy consumption and system throughput compared to non-adaptive relay techniques. Research in [4] has discussed increasing power efficiency by applying relay selection based on the cooperative region and comparing it with the technique without using a cooperative region. Several studies combine relay selection and energy harvesting (EH) to increase network throughput, such as the research in [5] examined the combination of relay selection with EH to improve the performance of the system. The channel model in the research is Rayleigh fading. Then, the EH protocol used in relays is time switching (TS) and forward signals by using the DF protocol. The best relay is selected based on the energy stored in the relay. The relay with the highest EH is considered to have the best channel
between the source to the relay and is chosen to forward the information to the destination. Another research in [6] uses a relay selection strategy combined with EH with harvest-use-store power splitting techniques. EH on the relay is prioritized to charge the relay for further use in order to obtain a better network throughput.

This paper proposes joint energy harvesting (EH) and relay selection in a cooperative communication system. We consider the channel from source to relay is Rician fading, and from the relay to the destination is Rayleigh fading. The relay selection uses the opportunistic relay selection method as in [7]. The source selects the best relay that produces the highest SNR at the destination, and then the selected relay performs EH as the power to transmit information to the destination. The relay protocol is amplify and forward (AF), and the EH protocol is time switching. The performance parameters of the proposed system are bit error rate (BER) and throughput. Then, BER and throughput of the proposed method are compared with BER and throughput of relay selection systems without EH (RS non-EH), multi-relay EH, and multi-relay non-EH.

2. System Model
The system model of a multi-relay cooperative communication system of joint relay selection with the EH (JRSEH) can be seen in Figure 1, assuming the first relay is chosen as the best relay. The network component consists of several nodes, namely: source (S), relays ($R_1, R_2, \ldots, R_M$), and destination (D). Each node is equipped with one antenna. The source uses several relays to transmit information due to environmental conditions that make it impossible for the source to communicate directly with the destination. Source and destination are assumed to have unlimited energy, but relay has limited energy. The energy that can only be harvested by the relay that comes from the source. The relay has two circuits, namely a circuit for conducting EH and a circuit for transmitting information to the destination.

![Figure 1](image_url)

**Figure 1.** Joint relay selection with EH scheme and block time in cooperative communication systems.

In the model, the communication channel for the source-to-relay link is Rician fading with the fading coefficient is $h$. While the communication channel for the relay to the destination link is Rayleigh fading with the fading coefficient is $g$. Relay selection is carried out by opportunistic relay selection, where
the source selects one relay by estimating the channel quality using channel state information (CSI) from source to relay and relay to the destination to produce the highest SNR at the destination [8], [9]. Perfect CSI is applied in channel estimation, which is the node that performs the estimation to know the channel condition. Even though in real conditions, this estimation is not possible to calculate directly. Therefore, the relay selection scheme combined with EH in this paper can be one of the solutions for the estimation, as shown in Figure 1, by assuming the selected relay is the first relay.

The process of the proposed joint relay selection with energy harvesting (JRSEH) on a wireless cooperative communication system is as follow.

- The source broadcasts the pilot bit to all relays, and then each relay forwards to the destination to estimate the channel quality from source to relay and relay to destination.
- The destination estimates SNR value based on the pilot bits, which obtained from each relay is to determine the appropriate relay to be selected as the best relay.
- The destination chooses the best relay that produces the highest SNR in the destination using the following equation:

$$ R_b = \arg \max_{i \in M} (\gamma_{end_i}) $$  

where $\gamma_{end_i}$ is destination SNR through the relay $i^{th}$.

- The destination sends feedback to the source in the form of selected relay data.
- Based on the feedback obtained from the relay, the source sends the pilot bit to the selected relay to be active to the next stage, while the unselected relays are in an idle position (inactive).
- The source transmits energy with duration $\alpha T$ focused on the selected relay, and the selected relay performs EH during that duration. The path loss model used is the free space model [10], [11] is given by

$$ P_{L_{xy}} = G_t G_r \left( \frac{c}{4 \pi F d_{xy}} \right)^2 $$  

where $G_t$ is antenna gain at the transmitter, $G_r$ is antenna gain at receiver, $c = 3 \times 10^8$ m/s is the speed of light in a vacuum, $F$ is a carrier radio frequency, $d_{xy}$ is distance $x$ to $y$.

- The amount of energy saved by the selected relay at the time duration $\alpha T$ is calculated by [13]:

$$ E_H = \mu P_s |h|^2 \alpha T P_{LSR} $$  

where $P_s$ is the source power, $h$ is the channel gain from source to relay, $P_{LSR}$ is the free-space path loss model from source to relay, $\mu$ is the energy conversion efficiency value ($0 < \mu < 1$), $\alpha$ is EH time switching ratio, and $T$ is the time duration in one transmission.

- The source then transmits the information to the selected relay at the time duration $(1 - \alpha) \frac{T}{2}$ which is given by [12]:

$$ y_r(t) = \sqrt{P_s P_{LSR}} h x_s(t) + n_r(t) $$  

where $n_r$ is the noise in the relay, $x_s$ is the information signal sent by the source

- The selected relay then amplifies the information signal is given by [13]:

$$ \beta = \frac{P_r}{P_{LSR} |h|^2 d_{sr}^2 + N_1} $$
where \( d_{sr} \) is distance source to relay, where \( N_0 = N_1 = 1 \) is a variant noise.

- The selected relay uses all of the energy invested as the power to transmit information to the destination. The power of the relay is given by

\[
P_{EH} = \frac{E_H}{1 - \alpha} \frac{2 \mu_{p_s} |h|^2 \sigma_T P_{LSR}}{(1 - \alpha)}
\]  

where \( E_H \) is energy harvested by a relay.

- The relay transmits the information signal to the destination at a time duration \((1 - \alpha) T / 2\).

- The signal received by the destination through the best relay is formulated by the following equation:

\[
y_d(t) = \sqrt{P_{EH}P_{L_{RD}}} \beta \sqrt{P_s P_{L_{SR}}} h x_\alpha(t) + \sqrt{P_{EH}P_{L_{RD}}} \beta n_r(t) + n_d(t)
\]

where \( P_{L_{RD}} \) is a free-space path loss model relay to the destination, \( n_d \) is the noise at the destination.

- The amount of SNR received at the destination through the selected relay is given by

\[
\gamma_{EH} = \frac{P_s P_{EH} \beta^2 \beta^2 P_{L_{SR}} P_{L_{RD}}}{P_{EH} P_{L_{RD}} \beta^2 + N_0}
\]

where \( N_0 \) is a variant noise.

- The throughput at the destination is calculated as [13]

\[
\tau_{EH} = \frac{1}{2} (1 - \alpha) (1 + 2 \gamma_{EH}).
\]

where \( \gamma_{EH} \) is the SNR of the energy harvested at the best relay.

3. Setting and Simulation Parameters

This simulation is to calculate the bit error rate (BER) and throughput of joint relay selection and energy harvesting system. The relay selection method is opportunistic relay selection, which is then combined with energy harvesting. Joint relay selection with energy harvesting (JRSEH) system is expected to reach high throughput compared with non-EH, multi-relay non-EH relay systems, or multi-relay EH. In this paper, the computer simulation uses several parameters as in Table 1. The number of sent data bits is \( 10^5 \) bits, with 20 iterations. The Channel model source to relay is Rician fading, and the relay to the destination is Rayleigh fading. The unit of throughput is bits / Hz / sec, meaning the number of bits received at the destination in 1 Hz within 1 second. Throughput of JRSEH, RS non-EH, Multi relay non-EH, and Multi-relay EH systems are calculated using the same parameters in Table 1.

| Parameter        | Symbol | Information               |
|------------------|--------|---------------------------|
| Number of bits sent | \( N_{bits} \) | \( 10^5 \)               |
| Channel model    | \( h, g \) | Fading Rician, Rayleigh  |
| Resources        | \( P_s \) | 0.3 watt                  |
| Relay power non EH | \( P_r \) | 0.3 watt                  |
| Rician value     | \( k \) | 15 dB [9]                 |
| Amount of relays | \( M \) | 4                         |
| Energy conversion efficiency | \( \eta \) | 0.9                      |
| Time switching ratio | \( \alpha \) | 0.2                      |
4. Results and Discussions

4.1 Bit Error Rate (BER)

This section shows the bit error rate (BER) of a system with one relay, two relays, three relays, and four relays. Each relay performs EH during $\alpha T$. The BER is calculated using the parameters in Table 1. Figure 2 shows the simulation results for the BER of the multi-relay cooperative communication system with EH.

Figure 2 shows that BER decreases when the number of relays increases from 1 relay to 4 relays, which means that the system performance is getting better if more relays with EH are available in the system. Multi-relay systems have diversity gain when multiple relays forward information to a destination, where the destination combines all the information received by the relays. Thus, the more relays used in the system, the higher the diversity gain so that the performance is getting better.

The comparison of BER of the proposed and the other conventional system (RS non-EH, 4-relay EH, and 4-relay non-EH systems) are shown in Figure 3. The simulation results show that the cooperative system with RS non-EH has poor BER performance. Then, the BER performance of non-EH 4-relays is better than that of non-EH RS. However, the BER performance of the proposed and 4-relay with EH systems have the best performance compared to others. The BER performance of the proposed work is almost the same as the BER 4-relay with EH performance. Moreover, 4-relay with EH will consume higher energy because all relays are active. On the other hand, in the proposed system, only the best relay is active while the others are idle.

### Table 1

| Parameter                        | Value                        |
|----------------------------------|------------------------------|
| Source to destination distance   | $d_{sd}$, 10 – 400 m        |
| Source to relay distance         | $d_{sr}$, 0.2 $d_{sd}$; 0.4 $d_{sd}$; 0.6 $d_{sd}$; 0.8 $d_{sd}$ |
| Relay to destination distance    | $d_{rd}$, 247 m; 0.6 $d_{sd}$; 0.4 $d_{sd}$; 0.2 $d_{sd}$ |
| Antenna gain transmitter        | $G_t$, 23 dBi                |
| Antenna gain receiver            | $G_r$, 23 dBi                |
| Carrier frequency                | $F$, 450 MHz                |
| Efficiency spectral              | $\Delta$, 1 bit/Hz/Sec      |
| Energy harvesting protocol       | $TS$, Time Switching        |
| Relay protocol                   | $AF$, Amplify and Forward   |
| Variance noise                   | $N_0$, 1                     |

**Figure 2.** Bit Error Rate (BER) on a multi-relay system with EH.
4.2. Throughput

The simulation of this section is to calculate the throughput of joint relay selection with EH (JRSEH) system, multi-relay non-EH system, multi-relay EH system, and relay selection non-EH (RS non-EH) system. The throughput is calculated using equation (9) and the parameters in Table 1. The throughput of the proposed system is expected to be increased or the same as the RS without EH because reducing the transmission power of the proposed work does not reduce the throughput performance of the system. Thus, the proposed system can save power compared to other conventional systems. The emission of power from the source to the relay in the EH multi-relay system is focused on one particular relay with an energy conversion efficiency (\(\eta\)) value is 0.9.

Figure 4. Throughput comparison of the proposed with other systems.
Figure 4 shows the simulation results of the throughput of multi-relay non-EH, multi-relay EH, RS non-EH, and JRSEH (proposed) cooperative systems. From the figure, we see that the throughput of the proposed system is almost close to the throughput of the multi-relay EH system but exceeds the throughput of multi-relay non-EH and RS non-EH systems. So, one of the objectives of this paper is achieved where the proposed work can reduce the power consumption of relays by maintaining throughput performance.

5. Conclusions
This paper has proposed a joint relay selection with EH (JRSEH) to improved the performance of wireless cooperative communication systems using amplify and forward (AF) schemes. The EH protocol used time switching. The computer simulation has been conducted to calculate the bit error rate (BER) and throughput of the proposed system, the relay selection non-EH (RS non-EH), multi-relay non-EH, and multi-relay with EH. The results found that the joint relay selection with the energy harvesting (JRSEH) system could provide the good BER and throughput compared with the previous system, which are RS non-EH, multi-relay non-EH system, and multi-relay EH systems. Furthermore, the proposed JRSEH can reduce the power consumption of relays by maintaining throughput performance.

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