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RELAY SELECTION-BASED ENERGY EFFICIENCY OF HYBRID DEVICE-TO-DEVICE-ENABLED 5G NETWORKS

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Abstract

Device to device (D2D) communication is one of the communication methods to be applied to the 5G mobile communication network to improve performance and energy efficiency. However, D2D communication is not effective when the link distance between two mobile devices is far away. Cooperative D2D is one of the solutions to maintain high network performance and increase energy efficiency to overcome this problem. Currently, the cooperative D2D network model focuses on multi-hop relay and multi-relay. Practically, a source can simultaneously transmit information over a multi-hop relay and multi-relay networks to be forwarded to a destination. In this paper, we introduce a hybrid relay network model for a 5G D2D network that uses relay selection strategies to improve energy efficiency. Then, we provide reactive and proactive relay selection procedures for the proposed hybrid relay network. The energy consumption and efficiency are mathematically analysed and simulated for several D2D network configuration models. All simulations are performed using MATLAB 2019a software. The simulation results show the energy consumption using the PRS strategy is smaller than that of using the RRS strategy. At a distance ratio of 0.5, the hybrid relay network using the PRS strategy can save energy by 0.05864 μJ/bit. Furthermore, the hybrid relay networks achieve higher energy efficiency compared to the multi-relay and multi-hop relay networks for both reactive and proactive cases. The proactive strategy achieves 5% higher energy efficiency than the reactive strategy for the hybrid relay networks at a distance ratio of 0.3. Furthermore, simulation results also show that the addition of SNR on the network does not have a significant impact on energy efficiency, although the proposed hybrid relay networks still have better efficiency. Thus, the proposed hybrid relay network using a relay selection strategy can improve the energy efficiency of 5G D2D networks.

Keywords: 5G network, Device-to-device, Energy efficiency, Hybrid relay network, Relay selection.

1. Introduction

5G technology is currently the latest generation of mobile communication systems. It promises to usher in the era of systems that can be connected to anything (everything), including device-to-device (D2D) and machine to machine (M2M) connections [1]. It is a new mobile communication standard that promises to enhance end-user experience through various applications and services, with speeds reaching Gbps, significant performance improvements, and high reliability. One of the main problems in systems such as D2D is multipath fading, which can affect the quality of the communication link [2]. The influence of fading and interference contributes to the energy consumption of mobile devices and base stations (BSs) [3]. Energy has become a global problem, especially in the field of communications technology. There are 4 million BSs serving mobile users globally, which consume a large amount of power, with the power consumption of 4.4 TWh by 2020 [4]. The number of BSs will continue to grow; hence, energy consumption will certainly continue to increase. This problem has motivated researchers to design and build low power communication systems.

Developments in communications technology design are no longer concentrated on optimizing performance metrics, such as increasing data rate and throughput and decreasing delay. Moreover, future technology development must pay attention to the economic and operational aspects in which communications technology affects the environment, especially in terms of energy efficiency. Energy efficiency is a key pillar in designing communication systems and networks [5]. Thus, the cooperative communication system has been studied as one of the communication methods for improving performance and reducing the energy consumption of communication networks [6]. This system has a diversity gain when a source sends information through another device to forward the information to the destination, and the destination combines the direct signal from the source and the relay.

Furthermore, D2D communication is one of the promising communication modes that will be adopted in 5G technology [7, 8]. D2D communication is also an energy-saving solution in communication systems, and it can reduce the need for network infrastructure by reducing the number of BSs required by the network. D2D communication forms a communication system between two mobile devices directly without connecting to the BS; hence, it can increase data rates due to the proximity of the communication devices [9]. The drawback of D2D systems is that the performance deteriorates when many users are connected to transmit information in the networks. In the conventional cellular network, communication between devices (D2D) is not usually close enough to have direct communication, which can also reduce network performance. Thus, the merging of cooperative communication systems with D2D communication is one of the challenges of 5G technology [10, 11]. The cooperative D2D system to support 5G (small cell) technology will lead to lower network energy consumption.

The energy efficiency of D2D communication systems is the focus of current research [12-14]. The energy efficiency of D2D communication was achieved through the power regulation of cellular networks [12]. D2D multi-hop network model can improve energy efficiency compared to direct communication among devices without going through the central BS [13]. The cooperative D2D multi-hop network model implemented through an optimal adaptive forwarding strategy can improve the network's energy efficiency [14]. However, the transmission model on this network is one-to-one, where information is forwarded from one hop to another; if the quality of one of the hops is in poor condition, the information will fail to send to the destination. Implementing a multi-relay network model through cooperative D2D communication can increase the capacity and quality of service of the system [15]. This network model on D2D communication affects the system's energy consumption and energy efficiency because the information is broadcasted to many nearby relays. Therefore, a hybrid cooperative D2D network model needs to be explicitly considered for cellular networks to improve energy efficiency and provide a flexible transmission mode. Practically, a source can transmit directly and through other devices (relays) in the form of multi-hop and multi-relay in a cellular network.

This paper proposes a hybrid relay cooperative model using relay selection strategies for cellular network-based D2D communication for 5G technology. A hybrid relay network can reduce power requirements on a source device and can increase transmission distance to a destination device. When the transmission path directly experiences deep fade, the hybrid relay network can provide spatial diversity gain because information can be forwarded to the destination device either via multi-relay or multi-hop relay. In the hybrid relay network model, two relay selection strategies are applied to improve energy efficiency, achieving results that provide an improvement over other cooperative D2D network models. The strategies include reactive relay selection (RRS) and proactive relay selection (PRS) [16, 17].

The application of relay selection strategies to D2D communication also increases end-to-end throughput and battery life [18]. Both relay selection strategies are applied to the proposed and conventional networks to obtain the best relay in the D2D networks with low power consumption and high energy efficiency. Then, we mathematically analyse the energy consumption and energy efficiency of each network. Subsequently, we performed computer simulation to validate the results, taking into account the parameters of the D2D network for 5G technology that affect the network energy efficiency. Generally, the latency in D2D communication is very low due to transmission over short distances [19].

A source can choose the best relay flexibly and good link quality in a proposed hybrid relay network, so the resulting latency is smaller than conventional D2D communication. Hence the effect of latency is not considered to determine energy efficiency in the network. The main contributions of this paper are as follows:

- We introduce a hybrid relay network model for cooperative D2D communication, where a source device sends information through multi-relays and multi-hop relays in a network to forward that information to the destination device.
- We apply relay selection strategies to hybrid relay networks in cooperative D2D communication by considering 5G technology. Then we provide the procedure for the reactive and proactive relay selections in the proposed network model.
- We analyse the consumption and energy efficiency of D2D hybrid relay networks and compare them with conventional network models.

2. System Model

Direct D2D communication was implemented in cellular networks by Qualcomm FlashLinQ [20] to meet the needs of 5G technology, especially spectral efficiency. Direct communication of two devices with a control link is carried out by the BS. Then, communication between devices can be done through relay devices. This paper considers several models of D2D communication systems both directly and through several relay methods in a network, as presented in Fig. 1. These models are as follows:

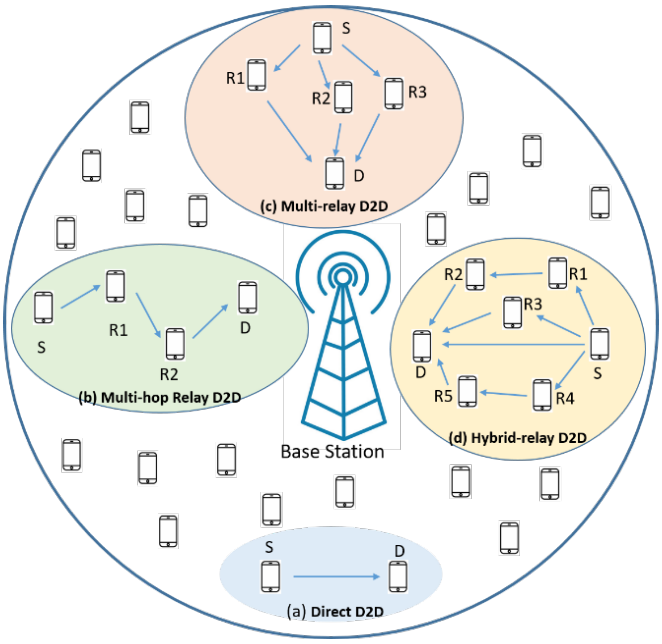

Fig. 1. System models for direct and cooperative D2D communications.

(a) Direct D2D: the source device (S) can communicate directly with the destination device (D) [7]. It allows two devices that are close together to communicate with each other in cellular networks with and without BS control. For direct transmission, the devices must discover each other. The D2D communication model is more suitable for short-range communication.

(b) D2D multi-hop relay: the source device (S) communicates through several relays in series (e.g., R1 and R2) to forward information to the destination device (D) [13, 14]. In the first phase of this network model, information signals are sent by the source device directly to the destination device and the relay. In the second phase, the signal received by the relay (R1) will be forwarded to the next relay (R2), and the last relay (Rk) forwards the information to its destination device. The signal sent through the direct network and multi-hop relay network will be combined at the destination device using the Maximum Ratio Combining (MRC) method.

(c) Multi-relay D2D: the source device (S) sends information to several relays (R1, R2,…, Rn) in parallel to be forwarded to the destination device (D) [15]. In the first stage, the source device sends information signals directly to the destination device, and several relays are arranged in parallel. In the second stage, the information signal received by some of the relays will be processed according to the protocol used and then forwarded to the destination device. At the destination device, the information signal received directly and from several relays will be combined using the MRC method.

(d) Hybrid D2D relay: it is a model proposed in this paper, where the source device (S) sends information directly to destinations as well as to several relays in the form of multi-hop relays as the model in (b) and multi-relay in (c), simultaneously, and then the relays forward the information to the destination device (D). In the first stage, the source broadcasts its information signal to all nearby relays in parallel. In the second stage, one or more relays forward the information signal directly to the destination. Then, one or more relays also forward information to other relays serially (hop by hop) to the destination. Finally, the destination will combine all the information signals from the relay using the MRC method.

In cooperative D2D communication, a relay protocol mechanism is vital in the system. For this reason, the relay protocol considered in this paper is amplify-and-forward (AF) because it is the simplest and easiest protocol to implement [21]. The AF protocol's working principle is that the source device's information signal to the relay will be strengthened first and then forwarded to the destination device. All cooperative D2D network models, as in Figs. 1 (b) - (d), use the AF relay protocol and the selection of relay strategies (RRS and PRS) to obtain a comparison of energy consumption and energy efficiency. The procedure for implementing relay selection strategies in the networks is described in the next chapter.

3. Relay Selection, Energy Efficiency Analysis, and Simulation

3.1. Reactive relay selection

In the RRS strategy, S sends information to n relays $(R_1 \ldots R_n)$, where n is the number of relay nodes near the source in the hybrid network. All nodes on the network are presumably able to hear for direct transmission. Then, the relay is selected if the direct transmission fails. In this hybrid-relay network, the relay nodes can be arranged in parallel (multi-relay) and several-hop links of relays in series (multi-hop), as shown in Fig. 1(d), to forward the information to the destination. Each relay node uses the amplify and forward (AF) protocol as a mechanism to forward information to the destination in which information received by the relay will be strengthened before forwarded to the destination. Then, the information received by the relays will be estimated at the SNR level and then sent back to the source. The quality of the SNR is considered when choosing the best relay to send information to the destination. In contrast, the other relays are silent. The procedure of RRS for the proposed hybrid-relay network is as follows.

1) In the first step, the source device sends information (x_s) directly to the destination and several relays in the network. The received signal via a direct link can be stated as follows [21]:

$$y_{S,D} = x_s h_{S,D} + n_{S,D}, \tag{1}$$

where $h_{S,D}$ is coefficient of channel fading at link source to destination and $n_{S,D}$ is AWGN at link source to destination.

2) The source device sends information in a broadcast to several nearby relays in the hybrid relay network. Information signals send to relays can be expressed as

$$y_{S,Ri} = x_s h_{S,Ri} + n_{S,Ri},\ i = 1,\ \dots,\ n. \tag{2}$$

For the multi-hop k-link in the network, information signals send to link S-R to another relay can be written as

$$y_{Rj,Rj+1} = y_{S,Ri} h_{Rj,Rj+1} + n_{Rj,Rj+1},\ \ j = 1,\dots,\ k, \tag{3}$$

where $h_{S,Ri}$ is coefficient of channel fading at link source to relay i, $n_{S,Ri}$ is AWGN at link source to relay i, $h_{Rj,Rj+1}$ is coefficient of channel fading at link relay to another relay j, and $n_{Rj,Rj+1}$ is AWGN at link relay to another relay j.

3) If information signals sent directly from source device to destination device fail, where $\mathrm{SNR}_{S,D} < \mathrm{SNR}_{\mathrm{threshold}}$ due to the influence of deep channel fading, which can cause an outage condition [22]. Then destination device transmits the bit training (x_{tr}) to several relays to obtain the SNR value between the relay and the destination device.

4) After the relay receives the training bit from the destination device, it will send feedback to the destination device.

5) All relays that receive information from the destination will be selected by the channel state information (CSI) method based on the best SNR value. Based on the concept in [17], the SNR value for the multi-relay (MH) network is determined as follows:

$$Rb_{MH} = \arg max\ \{\mathrm{SNR}_{Ri,D}\}. \tag{4}$$

In the multi-hop link, The SNR value is determined as follows:

$$Rb_{MR} = \arg max\ \{\mathrm{SNR}_{Rj}, \mathrm{SNR}_{Rj+1}\}. \tag{5}$$

Then, the SNR value for a hybrid relay network is determined as follows:

$$Rb_{H} = \arg max\ \{\mathrm{SNR}_{Rb_{MH}}, \mathrm{SNR}_{Rb_{MR}}\}. \tag{6}$$

6) Destination requests information on the selected relay (best relay). If no relay can be selected, the source will resend the information and follow steps 2) - 5).

7) The best relay will forward information to the destination device. Best relay uses an amplify and forward (AF) mechanism, where the received signal will be amplified first with the following coefficient [23]:

$$\beta = \sqrt{\frac{p_r}{|h_{S,Rb\_H}|^2 + p_s + n_0}}, \tag{7}$$

where p_s is average power at the source device, p_r is average power at the relay, h_{S,Rb_H} is the coefficient of channel fading at the link source device to best relay, and n_0 is the noise variance of the channel.

8) The information signals received by the destination device can be expressed as:

$$y_{Rb_H,D} = \beta x_s h_{Rb_H,D} + n_{Rb_H,D}, \tag{8}$$

where $h_{Rb_H,D}$ is coefficient of channel fading at link best relay to the destination device and $n_{Rb_H,D}$ is AWGN at link best relay to destination device.

3.2.3.2 Proactive relay selection

In the PRS strategy, the best relay is selected based on the maximum of the minimum SNR of the first hop and other hops in the hybrid-relay network. This strategy is also known as the "max-min" criterion [17]. Moreover, a relay selection process is done before the source transmission [16]. In the hybrid-relay network, The PRS strategy selects the best relay by estimating the SNR from n relays $(R_1, \dots, R_n)$ before the information is sent. The estimation is carried out by sending a small number of training bits before the original information is sent. Then, the source device sends information to the best relay to be forwarded to the destination device. Aforementioned, a relay also uses the AF protocol to forward the information to the destination. In the PRS strategy, the best relays are active while the other relays are idle. The procedure of PRS strategy for the proposed hybrid relay network can be described as follows.

1) The source device sends the bit training (x_{tr}) by broadcast to the destination and to several relays in the networks for estimating the SNR value.

2) Relays use the AF protocol to amplify the signal. The information signal that is forwarded to the destination device can be stated as

$$\hat{y}_{Ri\_tr} = \beta_{Ri} x_{tr} h_{Ri\_tr} + n_{Ri\_tr}, \tag{9}$$

and the amplification value for relay i [21] can be calculated as

$$\beta_{Ri} = \sqrt{\frac{p_r}{|h_{Ri}|^2 + p_s + n_0}}, \tag{10}$$

where $\hat{y}_{Ri\_tr}$ is bit training signals that are received by the relay i, h_{Ri_tr} is the coefficient of fading channel of the bit training transmission at the relay i, n_{Ri_tr} is the AWGN when broadcasting of bit training at the relay i, and h_{Ri} is the coefficient of channel fading at the link source device to relay i.

3) The destination device sends feedback to the source device in the form of SNR values of the source to relays and relays to the destination device.

4) Based on the feedback, the source device decides that the best relay has the largest SNR. Using the concept in [17], the SNR value for the k hops in the network can be stated as follows:

$$Rb_{MH} = \arg\max\{\min\{\text{SNR}_{S,Ri}, \text{SNR}_{Rj,Rj+1}, \text{SNR}_{Rk,D}\}\}. \tag{11}$$

The SNR value for the best relay in the form of multi-relay in the network can be stated as follows:

$$Rb_{MH} = \arg\max\{\min\{\text{SNR}_{S,Ri}, \text{SNR}_{Ri,D}\}\}. \tag{12}$$

Then SNR value for the hybrid relay network can be stated as follows:

$$Rb_H = \arg\max\{\min\{\text{SNR}_{Rb_{MH}}, \text{SNR}_{Rb_{MR}}\}\}. \tag{13}$$

5) The source device sends information(x_s)directly to the best relay, expressed as follows:

$$y_{S,Rb_H} = \beta x_s h_{S,Rb_H} + n_{S,Rb_H}, \quad (14)$$

where h_{S,Rb_H} is coefficient of channel fading at link source to the best relay, and n_{S,Rb_H} is AWGN at the link source device to the best relay.

6) The best relay forwards information to the destination device and stated as:

$$y_{Rb_H,D} = \beta_{Rb_H} x_s h_{Rb_H,D} + n_{Rb_H,D}. \quad (15)$$

3.3.3.3 Energy efficiency analysis

The energy efficiency of a cooperative D2D communication system can be calculated by comparing the total energy consumption per bit of transmitted information with the total energy consumption of transmitted information by the reference system (e.g., direct D2D). The energy efficiency of communication systems is influenced by several factors, including SNR, distance, and fading coefficient [24]. Based on the transmission stages in the cooperative communication system, the SNR can be calculated by considering the impact of the relay distance between the source, relay, and destination [25]:

$$\gamma_{S,D} = \frac{P_{S,D}}{d^{\propto}}, \quad (16)$$

$$\gamma_{S,R} = \frac{P_{S,R}}{{d_{S,R}}^{\propto}}, \quad (17)$$

$$\gamma_{R,R} = \frac{P_{R,R}}{{d_{R,R}}^{\propto}}, \quad (18)$$

$$\gamma_{R,D} = \frac{P_{R,D}}{{d_{R,D}}^{\propto}}, \quad (19)$$

where $\gamma_{S,D}$ is the SNR of the source to destination, $\gamma_{S,R}$ is the SNR from the source to the relay, $\gamma_{R,R}$ is the SNR from the relay to another relay in multi-hop, $\gamma_{R,D}$ is the SNR from the relay to the destination, d is the distance from the source to the destination, $d_{S,R}$ is the distance from the source to the relay, $d_{R,R}$ is the distance from the relay to the relay, $d_{R,D}$ is the distance from the relay to the destination, and $\propto$ is a coefficient channel. The SNR is also impacted by channel fading:

$$\gamma_{S,D} = P_{S,D}|h_{S,D}|^2, \quad (20)$$

$$\gamma_{S,R} = P_{S,R}|h_{S,R}|^2, \quad (21)$$

$$\gamma_{R,R} = P_{R,R}|h_{R,R}|^2, \quad (22)$$

$$\gamma_{R,D} = P_{R,D}|h_{R,D}|^2. \quad (23)$$

The total energy consumption of the direct D2D network not using a relay selection strategy can be calculated as follows:

$$E_D = \frac{P_{S,D}}{\mathcal{R}_{\mathcal{B}}}, \quad (24)$$

where $P_{S,D}$ is the power to send data bits from the source to the destination in Watt, and $\mathcal{R}_{\mathcal{B}}$ is the bit rate in bps.

The energy consumption of multi-relay (n relays) networks using the RRS and PRS strategies can be calculated as follows:

$$E_{MR\_RRS} = \frac{\sum_{i=1}^{n} P_{S,Ri} + P_{Rb,D} + P_{S,D} + P_{D_{tr},Rb} + \sum_{i=1}^{n} P_{R_i b,D}}{\mathcal{R}_{\mathcal{B}} + \mathcal{R}_{tr}}, \quad (25)$$

and

$$E_{MR\_PRS} = \frac{\sum_{i=1}^{n} P_{S_{tr},Ri} + \sum_{i=1}^{n} P_{R_{tr-i}b,D} + P_{D_{tr},S} + P_{S,Rb} + P_{Rb,D} + P_{S,D}}{\mathcal{R}_{\mathcal{B}} + \mathcal{R}_{tr}}, \quad (26)$$

where $P_{S,Ri}$ is the power consumption for sending data bits from the source to the relay to i and can be calculated as

$$P_{S,Ri} = \frac{P_s|h_{S,Ri}|^2}{d_{S,Ri}^{\propto} N}, \quad (27)$$

where P_s is the power at the source, $d_{S,Ri}$ is the distance between the source and relay i, $h_{S,Ri}$ is the fading coefficient between source and relay i, $\propto$ is the path-loss exponent, and N is the AWGN noise. $P_{Rb,D}$ is the power consumption for sending data bits from the best relay to the destination and expressed by

$$P_{Rb,D} = \frac{P_r|h_{Rb,D}|^2}{d_{Rb,D}^{\propto} N}, \quad (28)$$

where $d_{Rb,D}$ is the distance between the best relay and destination, and $h_{Rb,D}$ is the fading coefficient from the best relay to the destination. $P_{R_i b,D}$ is the power consumption for transmitting the training bits from relay i to the destination and can be calculated as

$$P_{R_i b,D} = \frac{P_{tr}|h_{R_i b,D}|^2}{d_{Ri,D}^{\propto} N}, \quad (29)$$

where P_{tr} is the power consumption for transmitting the training bits, and $h_{R_i b,D}$ is the fading coefficient from the best relay i to the destination. $P_{D_{tr},Rb}$ is the power consumption for transmitting the training bits from the destination to the best relay and can be calculated as

$$P_{D_{tr},Rb} = \frac{P_{tr}|h_{D_{tr},Rb}|^2}{d_{D,Rb}^{\propto} N}, \quad (30)$$

where $h_{D_{tr},Rb}$ is the fading coefficient from the destination to the best relay, and $d_{D,Rb}$ is the distance from the destination to the best relay. $P_{S_{tr},Ri}$ is the power consumption for transmitting the training bits from the source to relay i and is calculated as

$$P_{S_{tr},Ri} = \frac{P_{tr}|h_{S_{tr},Ri}|^2}{d_{S,Ri}^{\propto} N}, \quad (31)$$

where $h_{S_{tr},Ri}$ is the fading coefficient from the source to the relay i. $P_{S,Rb}$ is the power consumption for transmitting information from the source to the best relay and can be calculated as

$$P_{S,Rb} = \frac{P_S|h_{S,Rb}|^2}{d_{S,Rb}^{\propto}N}, \tag{32}$$

where $h_{S,Rb}$ is the fading coefficient from the source to the best relay, and $d_{S,Rb}$ is the distance from the source to the best relay. $P_{Rb,D}$ is the power consumption for transmitting information from the best relay to the destination and can be calculated as

$$P_{Rb,D} = \frac{P_S|h_{Rb},_D|^2}{d_{Rb,D}^{\propto}N}, \tag{33}$$

where $h_{Rb,D}$ is the fading coefficient from the best relay to the destination, and $d_{Rb,D}$ is the distance from the best relay to the destination. $\mathcal{R}_{tr}$ is the bit training rate. The energy consumption of the D2D multi-hop network is influenced by the distance between the hops (between relays). It can be calculated by applying the RRS and PRS strategies as follows:

$$E_{MH\_RRS} = \frac{\prod_{i=1}^{n} P_{S,Ri} + P_{Rb,D} + P_{S,D} + P_{D_{tr},S} + \prod_{i=1}^{n} P_{R_i b,D}}{\mathcal{R}_{\mathcal{B}} + \mathcal{R}_{tr}}, \tag{34}$$

and

$$E_{MH\_PRS} = \frac{\prod_{i=1}^{n} P_{Str,Ri} + P_{S,Rb} + P_{D_{tr},S} + P_{Rb,D} + P_{S,D}}{\mathcal{R}_{\mathcal{B}} + \mathcal{R}_{tr}}. \tag{35}$$

Then, the energy consumption of hybrid relay networks using the RRS and PRS strategies can be calculated as follows:

$$E_{H\_RRS} = \frac{\sum_{i}^{n} P_{S,Ri} + \prod_{j=1}^{m} P_{S,Rj} + P_{Rb,D} + P_{S,D} + P_{D_{tr},S} + \sum_{i=1}^{n} P_{R_i b,D}}{\mathcal{R}_{\mathcal{B}} + \mathcal{R}_{tr}}, \tag{36}$$

and

$$E_{H\_PRS} = \frac{\sum_{i}^{n} P_{Str,Ri} + \prod_{j=1}^{m} P_{Str,Rj} + \sum_{i=1}^{n} P_{R_{tr-i}b,D} + P_{D_{tr},S} + P_{S,Rb} + P_{Rb,D} + P_{S,D}}{\mathcal{R}_{\mathcal{B}} + \mathcal{R}_{tr}}. \tag{37}$$

Thus, the energy efficiency of multi-hop, multi-relay, and hybrid relay networks using the RRS or PRS (RRS/PRS) strategy can be calculated as follows:

$$EE_{MH\_RRS/PRS} = \frac{E_D - E_{MH\_RRS/PRS}}{E_D} \times 100\%. \tag{38}$$

$$EE_{MR\_RRS/PRS} = \frac{E_D - E_{MR\_RRS/PRS}}{E_D} \times 100\%. \tag{39}$$

$$EE_{H\_RRS/PRS} = \frac{E_D - E_{HR\_RRS/PRS}}{E_D} \times 100\%. \tag{40}$$

3.4.3.4 Simulation parameter

Computer simulations are conducted to calculate the energy consumption and energy efficiency of direct D2D, multi-relay, multi-hop relay, and proposed hybrid relay networks using the RRS and PRS strategies. Then, the network parameters need to be defined in the simulation, including the number of relays in the network, the relay distance ratio chosen by the RRS and PRS strategies, and the data rate in accordance with the 5G technology. We assume that the source-to-destination distance is normalized to a ratio of 1 [26]. The ratio of source to relay distance can be calculated by using $d_{S,R}$ / $d_{S,D}$ ratio. Thus, the distance for D2D is determined by the ratio of source to relay and relay to destination. The power at the source and relay is determined to be the same for all networks. All simulations are performed with MATLAB version 2019a software. The parameters used in the simulation are presented in Table 1.

Table 1. Simulation parameters.

Parameter	Remarks
Source node	1
Relay node	6
Destination node	1
Modulation type	16-QAM
Channel Model	Rayleigh Fading
Fading coefficient (∝)	3.0
Relay protocol	AF
Training bits	100
Data rate	1 Gbps
Relay distance ratio	0.1 - 0.9
Power at source (P_S)	0.5 W
Power at relay (P_R)	0.5 W
Total power for direct link (P_D)	1 W
SNR (dB)	0 - 14
Simulation Iteration	20

4. Results and Discussion

4.1. Energy consumption

A network's energy efficiency depends on the energy consumption of the network. Computer simulations have been carried out using Eqs. (24) to (26) and Eqs. (34) to (37) and the parameters in Table 1 to obtain each network's energy consumption using the RRS and PRS strategies. The first simulation was carried out to obtain the energy consumption on direct D2D, multi-relay, multi-hop relay, and hybrid relay networks using the RRS strategy. In some literatures, the SNR range commonly used in D2D communication is 0-30 dB [26] and 0 - 20 dB [27]. In this simulation, the SNR is fixed to 12 dB to ensure that the information signal can be received by the destination successfully (low error probability), whereas the best relay distance is varied in the ratio.

We consider the distance ratio of the source to the destination normalized to 1, as aforementioned. The best relay position is in the middle of the source and destination; the relay distance ratio is 0.5. Fundamentally, energy consumption will increase as the distance between the source and destination increases because the power required for signal transmission increases. Using RRS strategy, the simulation results presented in Fig. 2 reveal that the energy consumption of each network increases when the best relay distance is farther from the source.

The energy consumption difference between multi-relay and multi-hop relay networks is not significant, but it is still lower than that of direct D2D networks. At a relay distance ratio of 0.5, the energy consumptions for direct D2D, multi-relay, and multi-hop relay networks are 0.6522 μJ/bit, 0.1868 μJ/bit, and 0.168 μJ/bit, respectively. Here, the proposed hybrid relay has a lower energy consumption than other networks with an energy consumption of 0.1093 μJ/bit. The D2D network has a long distance between the source and the destination, so the network consumes much energy. While the hybrid relay network is more flexible in choosing the best relay closer to the destination than multi-relay and multi-hop relay networks, the energy consumption is the smallest because the effect of fading is getting smaller.

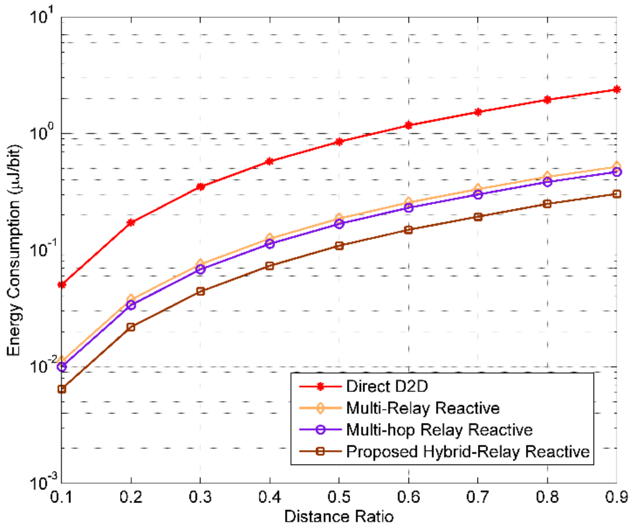

Fig. 2. Energy consumption versus distance ratio based on the RRS strategy.

The energy consumption of the same networks has been simulated using the PRS strategy. The simulation results are presented in Fig. 3. In general, the energy consumption of PRS strategy has characteristics similar to those of the RRS strategy in which the consumption increases with the increase of the best relay distance ratio. The energy consumption for direct D2D, multi-relay, and multi-hop relay networks at a relay distance ratio of 0.5 are 0.8431 μJ/bit, 0.1754 μJ/bit, and 0.0761 μJ/bit, respectively. The energy consumption of multi-hop relay networks is lower compared to that of multi-relay and direct D2D. The multi-hop relay network can choose the best relay among the many hop relays whose transmission distance is shorter than the best relay in a multi-relay network (dual-hop only) so that energy consumption can be lower. However, the energy consumption of the proposed hybrid relay network is still the lowest compared to those of other networks. At the same relay distance ratio, the energy consumption of the hybrid relay network is only 0.05034 μJ/bit. Theoretically, network energy consumption with the PRS strategy has the same characteristics as the RRS strategy, as previously described, where energy consumption is affected by link distance and network flexibility in choosing the best relay with proper link quality. Based on this, the proposed hybrid network can increase gain diversity and have the flexibility to select the best relay with lower power transmission.

A comparison of the energy consumption of the proposed hybrid relay networks with different selection strategies is presented in Fig. 4. The energy consumption using the PRS strategy is smaller than that of using the RRS strategy. At a distance ratio of 0.5, the hybrid relay network using the PRS strategy can save energy by 0.05864 μJ/bit. In the PRS strategy, after the best relay is selected, the other relays become idle. Thus, energy consumption can be minimized. Conversely, in the RRS strategy, all relays are still active even though the best relay has already been selected. Principally, the PRS strategy has better path diversity than the RRS strategy, so the PRS has higher energy efficiency. Furthermore, a hybrid relay network has more options in determining the best relay with short transmission distances and high SNRs on the path between relay and destination. It means that hybrid relay networks using the PRS strategy can improve the diversity gain and be an option for implementing cooperative D2D networks in 5G technology.

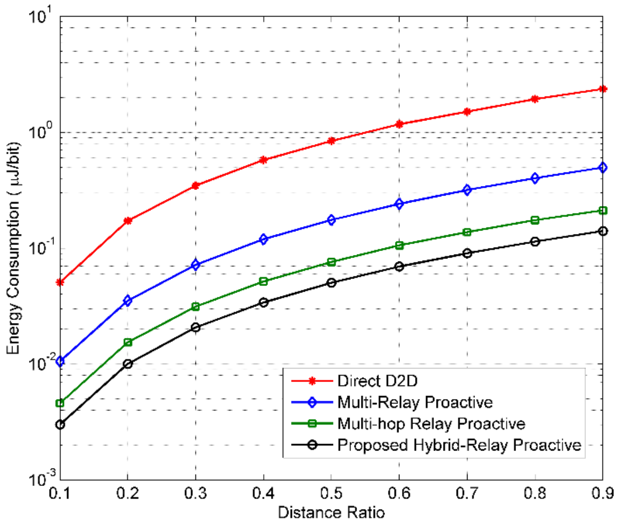

Fig. 3. Energy consumption versus distance ratio based on PRS.

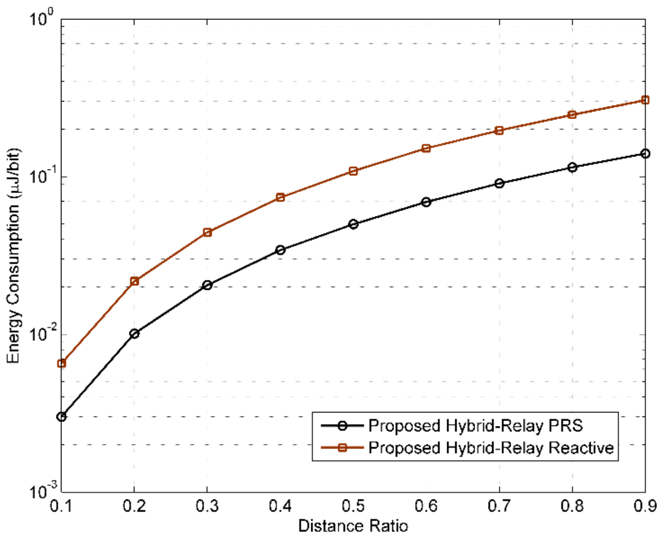

Fig. 4. Comparison of energy consumption versus distance ratio between the RRS and PRS strategies.

4.2. Energy efficiency

Based on energy consumption, the energy efficiency of each network can be calculated using Eqs. (38) to (40) and will be described in this section. The simulation results of energy efficiency using the RRS strategy are presented in Fig. 5. Energy efficiency decreases when the distance of the best relay to the source gets farther away because the energy consumption of the network is higher. The energy efficiency of the proposed hybrid relay network is still higher compared to those of other networks. For example, at a distance ratio of 0.3, the energy efficiencies of the multi-relay, multi-hop relay, and proposed hybrid relay networks are 22.7%, 24.68%, and 27.66%, respectively. The energy efficiency depends on the distance ratio, at the shortest distance ratio of 0.1 and the farthest distance to the distance ratio of 0.9, the energy efficiency achieved by the proposed hybrid network is 82.79% and 9.2%, respectively. These cooperative D2D networks have diversity gains with lower power transmission compared to conventional direct D2D. Using the RRS strategy, these cooperative networks only select one best relay from many candidates to minimize energy requirements while still maintaining the same order of diversity as conventional cooperatives without using a relay selection strategy. Based on the simulation results, the proposed hybrid relay networks have a higher diversity gain and energy efficiency compared to the other networks.

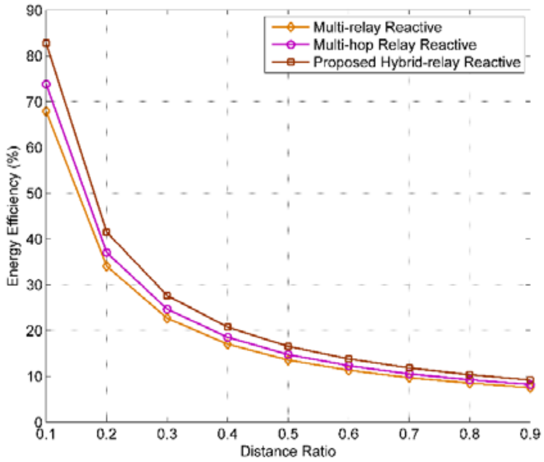

Fig. 5. Energy efficiency versus distance ratio based on RRS.

Using the same parameters and network models as the RRS strategy, the simulation result for the energy efficiency of the PRS strategy is presented in Fig. 6.

These results indicate that the energy efficiencies using the PRS strategy for multi-relay, multi-hop relay, and proposed hybrid relay networks are 22.46%, 27.24%, and 31.36% at a distance ratio of 0.3, respectively. The hybrid relay network has a better efficiency compared to the other two networks because they can choose the best relay from relay candidates in the serial or parallel mode that is close to the destination with the lowest transmit power. At the nearest distance ratio of 0.1, the energy efficiency of the proposed hybrid relay network is 94.08%, and the farthest distance ratio of 0.9 is 10.46%.

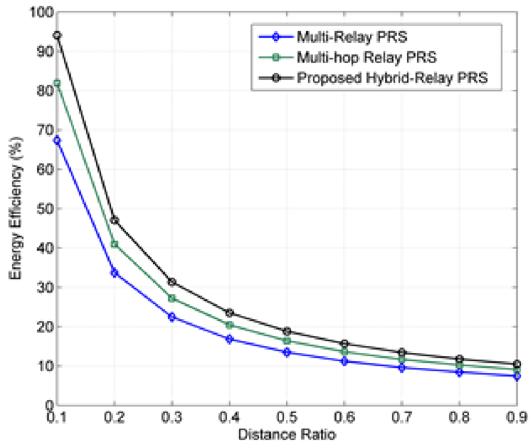

Fig. 6. Energy efficiency versus distance ratio based on PRS.

A comparison of the energy efficiencies of hybrid relay networks using the RRS and PRS strategies is presented in Fig. 7. The energy efficiency of networks using the PRS strategy is higher compared with the energy efficiency of networks using the RRS strategy. As an example, at a distance ratio of 0.3, the energy efficiency is 27.62% using the RRS strategy and 32.62% using the PRS strategy. It means that the hybrid relay networks can save energy by 5% using the PRS strategy. One of the drawbacks of the RRS strategy is that all relay candidates on the network receive information from the source. Thus, the energy consumption in the RRS strategy is higher than that of the PRS strategy. In contrast, PRS selects a relay before direct transmission, and relays that are not selected do not receive information from the source so that energy consumption can be lower. Based on this fact, the simulation results have confirmed that the energy efficiency of a hybrid relay network using PRS is higher than the RRS strategy.

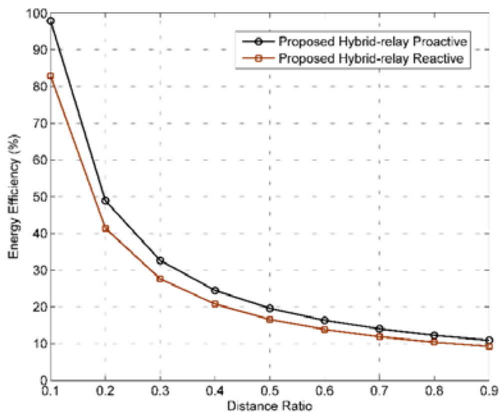

Fig. 7. Comparison of energy efficiency versus distance ratio between the RRS and PRS strategies.

Another factor that affects energy efficiency is the SNR in the network. The energy efficiency based on the SNR has also been simulated for both relay selection strategies at the same distance between source and destination. The simulation results of the energy efficiency of the networks using the RRS strategy are presented in Fig. 8. Then, the simulation results of the energy efficiency of the networks using the PRS strategy are presented in Fig. 9. Adding the SNR does not significantly affect the energy efficiency of each network. For example, when the SNR increases from 10 to 12 dB in hybrid relay networks, the efficiency gains for the RRS and PRS strategies are 0.0884% and 0.1917%, respectively. So, the distance of the best relay by the relay selection strategy significantly affects energy efficiency compared to the addition of the SNR value, as shown in Fig. 7. It is an advantage of the proposed hybrid relay network, which can choose the best relay close to a destination with a maximum SNR value using both the RRS and PRS strategies.

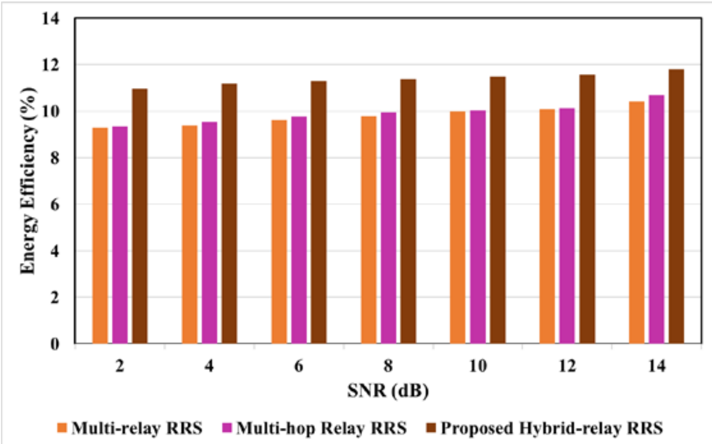

Fig. 8. Energy efficiency versus SNR based on RRS.

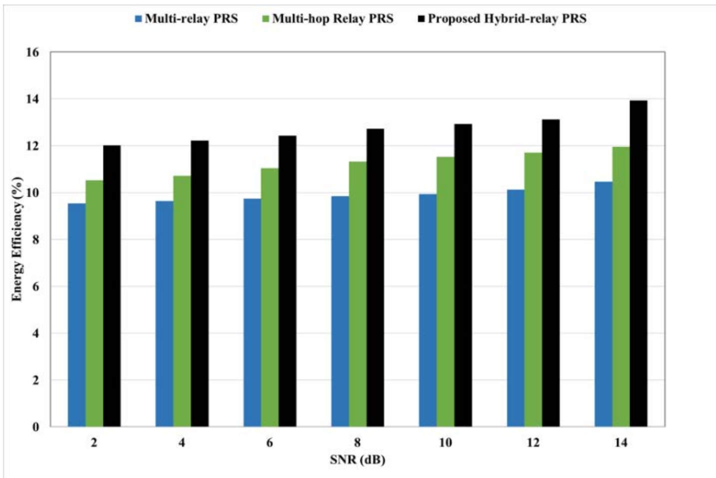

Fig. 9. Energy efficiency versus SNR based on PRS.

5. Conclusions

This paper has proposed a hybrid relay network model on the 5G D2D network using two relay selection strategies to improve energy efficiency, namely, RRS and PRS. The procedures of both relay selections have also been discussed in this paper. Moreover, the hybrid relay network model, energy consumption, and energy efficiency of the network have been presented and analysed mathematically. Furthermore, computer simulations have been carried out to obtain the energy consumption and energy efficiency of the proposed hybrid relay network and conventional networks, such as direct D2D, multi-relay, and multi-hop relay. Simulation results reveal that the network's energy consumption and energy efficiency increase and decrease, respectively, when the best relay is far from the source. The proposed hybrid relay network's energy efficiency is higher than that of multi-relay and multi-hop relay networks using both RRS and PRS strategies. However, the energy efficiency of hybrid relay networks using the PRS strategy is higher than those using the RRS strategy. Furthermore, energy efficiency based on the SNR in the networks has also been carried out, where the effect on the energy efficiency is not significant, but the hybrid relay network is still better than other conventional networks for D2D. Therefore, the proposed model with a relay selection strategy is a promising solution for energy-efficient cooperative D2D networks.

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Nomenclatures

d	Distance ratio
E	Energy consumption, $\mu\mathrm{J/bit}$
EE	Energy efficiency, %
h	Coefficient of channel fading
n	Additive white Gaussian noise
n_0	Noise variance of channel
Pr	Average power at relay, W
Ps	Average power at source, W
$\mathcal{R}_{\mathcal{B}}$	Bit rate, bps
$\mathcal{R}_{tr}$	Bit training rate, bps

Greek Symbols

$\propto$	Channel coefficient
β	Amplification factor at relay

Abbreviations

AF	Amplify and forward
AWGN	Additive white Gaussian noise
D2D	Device to device
H	Hybrid-relay
MH	Multi-hop

MR	Multi-relay
PRS	Proactive relay selection
RRS	Reactive relay selection
SNR	Signal to noise ratio

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