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Research article

Adaptive relay selection based on channel gain and link distance for cooperative out-band device-to-device networks

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ABSTRACT

Device-to-device (D2D) communication is one of the key enabling technologies for 5G to support many connections efficiently. In a cooperative out-band D2D communication network, relay nodes have an essential role in receiving and forwarding information signals from source (S) to destination (D), making the system more reliable and with higher energy efficiency. Therefore, the relay selection method is very important in determining the best relay among existing relays to achieve maximum performance. This paper proposes a new Adaptive Relay Selection (ARS) scheme for cooperative out-band D2D networks based on channel gain value and transmission link distance. Firstly, the best relay is adaptively selected among N available relays (R) based on the maximum channel gain values between S to R if the channel gain-based signal-to-noise ratio (SNR) is greater than the distance-based SNR. Otherwise, the best relay is selected based on the minimum distance between S to R. We also analyzed an exact closed-form throughput and the total energy consumption required for a cooperative out-band D2D communication system using the Quantization-and-Forward (QF) protocol. The numerical results show that the proposed ARS scheme has a higher throughput than the two previous schemes: maximum channel gain and minimum distance. Furthermore, the proposed ARS can reduce the total energy consumption, which indirectly impacts the resulting energy efficiency level. The proposed ARS scheme achieves higher energy efficiency than the previous schemes, either by link distance or power allocation. So, the proposed ARS scheme for an out-band D2D communication network is an appropriate solution for the next generation of cellular communications.

1. Introduction

The increasing number of mobile users in the last few decades has led to higher traffic in wireless communication systems such as cellular networks [1, 2]. Therefore, a wireless communication system must meet users' needs by providing high data rates and more reliability. The growing number of mobile users also requires cellular communication service providers to ensure each user's network services. A cellular network can provide the best service when the traffic is low or the number of users is low, as in suburban areas. However, there is a concern that the current condition of cellular networks will not be able to handle the high traffic communications where the mobile users are getting closer to each other, such as in urban areas [3]. This condition is one of the reasons for the emerging cooperative network concept. A cooperative network's main idea is that mobile users can become relay nodes for other mobile users in a network [4].

Cooperative networks have been widely applied in wireless communication systems [5]. Relay-assisted communication has been actively studied and has been considered in the process of standardizing mobile broadband communication systems, such as in the Third Generation Partnership Program (3GPP) Long-Term Evolution Advanced (LTE-Advanced), IEEE 802.16j and IEEE 802.16m [6, 7]. The cooperative communication networks use relaying protocols to expand communication access and to get better throughput performance [8], such as Quantize-and-Forward (QF), Decode-and-Forward (DF), and Amplify-and-Forward (AF) protocols [9, 10, 11]. Furthermore, cooperative communication is widely studied to improve the performance, capacity, and coverage area of 5th generation (5G) networks. One of the key enabling technologies for 5G is the capability of supporting a large

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number of connections efficiently, such as device-to-device (D2D) technology.

The D2D system is direct communication between two devices without going through the routing process to a base station (BS) [12]. D2D is one of the best communication systems to be applied to 5G technology, designed to increase data rates, reduce delays, and provide a better service quality [1]. Based on the frequency spectrum, the D2D system is categorized into two types; in-band and out-band [13, 14]. An In-band D2D system uses the same frequency spectrum as that of cellular users, whereas out-band D2D systems contrast the spectrum occupied by cellular users and use the unlicensed spectrum [15, 16, 17]. The Out-band D2D system itself is divided into two categories: control out-band and autonomous out-band communication [13, 15]. The cooperative network model can be applied to the D2D system to expand its access area of D2D communication systems. Many researchers have conducted research related to cooperative D2D systems [18, 19, 20]. The emergence of D2D and cooperative systems is an appropriate solution for the next generation of cellular communications. In cooperative D2D networks, the relay is used to forward information received from source (S) to destination (D) [7]. Every device in the vicinity of the S and D has the potential to become a relay. Therefore, the proposed relay selection method aims to select the best device, as a relay, to reduce energy consumption in the cooperative D2D network, therefore increasing the energy efficiency (EE) and throughput.

Cooperative communication systems use relaying protocols to improve performance and reduce the energy consumption levels. Nasaruddin et al. [21] compared the QF and AF protocols with Hamming channel coding to increase the EE of multi-relay cooperative networks. The simulation results show that the QF protocol achieved a better EE level than the AF protocol. Furthermore, the relay selection scheme for increasing the EE and performance on cooperative out-band D2D has also been carried out in several studies [22, 23, 24, 25]. Asadi et al. [22, 23] proposed the D2D opportunistic relay selection with quality of service (QoS) enforcement scheme, which can improve cellular downlink throughput by selecting one out-band D2D relay for each receiving end and specifying a delay constraint condition for D2D relay selection. Dang, et al. [24] also proposed several EE schemes, i.e., non-energy harvesting relaying (Non-EHR), energy harvesting relaying (EHR), and quantize-map-forward relaying (QMFR) for relay selection schemes in the D2D-NOMA communication system. For robust signal transmission to the cell-edge device, K decode-and-forward (DF) relaying nodes are required. The three schemes were proposed and a closed-form expression of the two D2D users' outage probability could decrease. The schemes could improve the outage performance. Zhang et al. [25] proposed an adaptive relay selection method-based model, known as SRSM (social--based D2D relay selection model), to determine the physical and social domains dealing with relay selection failures due to the diversity of users' willingness to cooperate. The SRSM adaptive relay selection using DF protocol increases the probability of relay selection success and reduces the cellular network's burden to improve system performance.

The relay selection scheme in the cooperative D2D communication system is the process of determining which devices will act as ‘intermediaries’ among N relays (R) to forward information from S to D [26]. In previous works, an adaptive relay selection for a cooperative D2D multi-relay network was proposed using DF relaying protocol [25]. In this paper, the information from S is received by the selected n-th relay (R_n) and will undergo a quantization process using the QF cooperative protocol. Its value limit will determine the quantized signal, or its value will be rounded off to the nearest integer value limit (discussed in section 2). Furthermore, the information signal that has been processed by the selected relay R_n is forwarded to D. An adaptive relay selection (ARS) scheme is proposed by considering the channel gain and the link distances between S to R_n as well as R_n to D. The cooperative out-band D2D communication system uses active devices as relays around the S and D. The relay assumes a mobile device in which an active device with a certain range can be a relay. Therefore, the relay selection process is important. In addition to determining the suitable relay, it also aims to increase throughput and save resources. To the best of author's knowledge, the adaptive relay selection method for the D2D cooperative communication system using the QF protocol has not been considered to date. Thus, this paper proposes an ARS scheme to improve throughput performance, reduce energy consumption levels in devices and increase EE.

The main contributions of this paper are as follows:

- A new adaptive relay selection (ARS) algorithm based on channel gains and link distances between S → R_n and R_n → D is proposed for cooperative out-band D2D communication networks using the QF protocol.
- An exact closed-form throughput for cooperative out-band D2D communication networks with the new proposed ARS algorithm is presented.
- Analysis of energy consumption and energy efficiency for the cooperative out-band D2D communication networks using the QF protocol based on the distance between S → R_n and R_n → D is provided.

The remainder of this paper is structured as follows. Section 2 describes the system model, while Section 3 outlines the proposed relay selection algorithm. The throughput and the EE analyses are investigated in Section 4 and Section 5, respectively. The numerical results of throughput performance and EE are presented in Section 6. Finally, a brief conclusion is provided in Section 7.

2. System model

This paper proposes a new ARS scheme by considering the channel gains and link distances between S to N-relay and N-relay to D for the cooperative out-band D2D communication system using the QF protocol. The network topology of multi-relay D2D communication is shown in Figure 1, in which the network components consist of one S node, N-relay nodes, and one D. The stages of the proposed ARS scheme for sending information data are divided into training, relay selection, and transmission. In the training stage, S sends a number of pilot bits to devices that have the potential to become an R or potential relay (PR). The device is assumed to be active and within a maximum distance of 500 m from S. The pilot bit signal from the S → PR received is:

$$y_{S-PR} = h_{s-pr}x_{pr} + n_{s-pr} \tag{1}$$

where x_{pr} is the information signal of the pilot bit from S → PR, h_{s-pr} is the channel gain between S→ PR, while n_{s-pr} is the additive white Gaussian noise (AWGN) on the PR node. After the relay candidate receives the pilot bit from the S, the relay will then quantify the pilot bit signal into y_{pRn} and calculate the signal-to-noise ratio (SNR) value from each link S → R_N. The signal received by node S at the training stage can be written as:

$$y_{pRn} = h_{pr-s}x_{pRn} + n_{pr-s} \tag{2}$$

where h_{pr-s} is the coefficient of fading channel between PR → S, x_{pRn} is the pilot relay signal, and n_{pr-s} is the AWGN component at node S.

The next step is N-relays to send back the pilot bit to the S with the SNR information between link S to N-relay. Then, the S performs the relay selection process based on the information received from PR, using the ARS method proposed in this paper. If the channel gain-based SNR value is greater than distance-based SNR, the best relay is selected based on the maximum gain channel values between S to N-relay. Otherwise, the best relay is determined based on the minimum distance between S to N-relay.

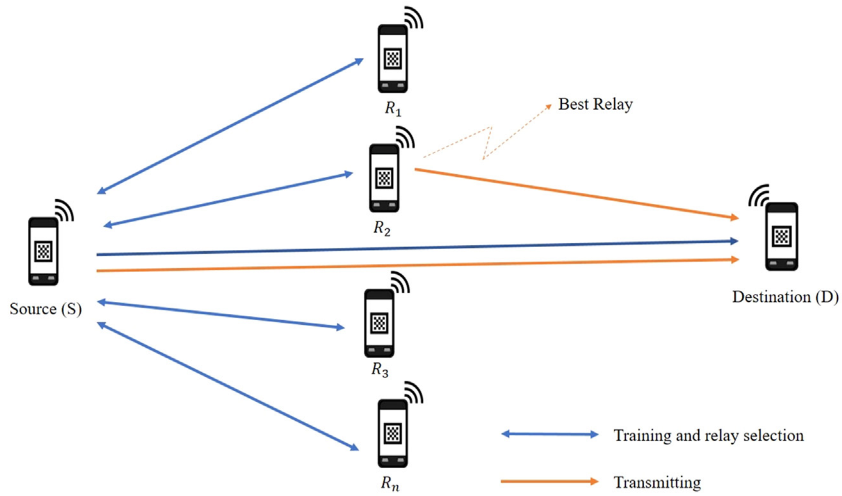

Figure 1. System model.

A. Signal Noise-to-Ratio (SNR)

Based on the approach to the transmission phase of cooperative communication systems, SNR is calculated in two ways: the first is based on the effect of distance between S → relay → D [27], and the second is based on the impact of fading [28]. Based on the effect of the distance between S to N-relay, the SNR calculation is as follows:

$$\gamma_{S,Rn} = \frac{P_S}{dS,R_n{}^{\propto}} \tag{3}$$

$$\gamma_{Rn,D} = \frac{P_S}{dR_{n,}D^{\propto}} \tag{4}$$

where γ_{S,R_n} is the distance-based SNR between S → Rn, P_S is the source's power, and $d_{S,Rn}$ is the link distance from S to the selected relay (R_n). The channel gain based SNR between S → R_n can be written as follows

$$\psi_{S,Rn} = \frac{P_s}{N_o}|h_{S,Rn}|^2 \tag{5}$$

$$\psi_{Rn,D} = \frac{P_{Rn}}{N_o}|h_{Rn,D}|^2 \tag{6}$$

where $\psi_{S,Rn}$ is the channel gain based SNR between S → R_n due to channel fading effect, $\psi_{Rn,D}$ is the channel gain based SNR between R_n → D and N_o is noise influence from S → R_n.

B. Link Distance Scenario

Link distance changes occur dynamically in the cooperative D2D communication system. Hence, distance is an important factor in wireless cooperative communication systems determining the amount of power consumption used for information transmission. The link distance can be explained [29], as in Figure 2.

The relay distance between the S and D is categorized into several scenarios; Rs are far from the S (scenario 1), some Rs are close to the S (scenario 2), some Rs are very close to the S, and Rs are close to the D (scenario 3). The maximum distance (d) in the cooperative D2D communication system is 500 m [12, 13, 30].

3. Proposed adaptive relay selection algorithm

This section introduces an ARS algorithm by considering the channel gain coefficient and the characteristics of the distance between S → R_n. Based on the proposed scheme in Figure 3, the S can select an appropriate R_n among N relays to forward the information signal to the D. The proposed ARS scheme aims to increase the throughput and reduce the level

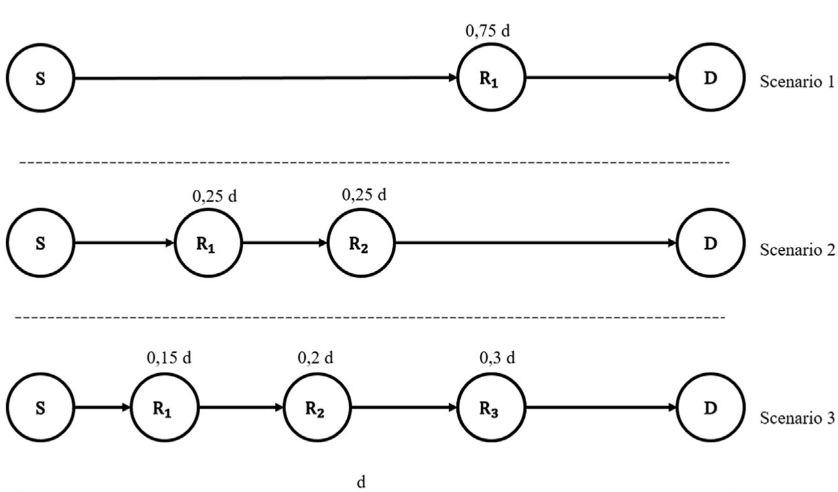

Figure 2. Link distance scenario.

of energy consumption in the mobile device compared to the previous schemes. The adaptive method is proposed for the cooperative out-band D2D communication system with a multi-relay network model. The simulation results of ARS schemes will also be compared to those of existing relay selection schemes: maximum channel gain [27] and minimum distance [28] schemes by using the QF cooperative protocol.

The ARS scheme is offered to select relays adaptively based on the channel gain and link distance between S → R_n. We assume that the communication between S, R, and D is half-duplex, and the stages of selecting relays using the ARS method are divided into two types; data training and data transmitting. The fading channel is considered as a Rayleigh flat fading channel, where h_{SD} , h_{SR} and h_{RD} are the independent, identically-distributed (i.i.d) fading channels from S → D, S → R_n, and R_n → D. $n_{S,Rn}$ and $n_{S,D}$ are AWGN at R_n and D. The input data is modulated using the binary phase-shift keying (BPSK) modulation scheme. The received input signal at R_n and D, respectively, can be written as:

$$y_{S,Rn} = h_{S,Rn}X_S + n_{S,Rn} \tag{7}$$

$$y_{S,D} = h_{S,D}X_S + n_{S,D} \tag{8}$$

The quantization stages using the QF protocol on information signals for the cooperative D2D communication system are as follows [31]:

$$\Delta = \left(y_{S,Rn\ maks} - y_{S,Rn\ min} \right) / L \tag{9}$$

$$L = 2^b \tag{10}$$

$$i = round\left(y_{S,Rn\ maks} - \frac{y_{S,\ Rn}}{\Delta} \right) \tag{11}$$

$$Y_{S,Rn} = y_{S,Rn\ \min} + i\,\Delta\ i = 0, 1, \ldots..L-1 \tag{12}$$

where Δ is the quantization level interval, L is the quantization level, b is the number of quantization bits, and $y_{S,Rn}$ is the quantized signal at R_n. In the proposed scheme, if the channel gain-based SNR value is greater than the distance-based SNR, the best relay is selected based on the maximum gain channel values between the S to N-relay. Otherwise, the best relay is selected based on the minimum distance between S to N-relay. The steps for selecting the best relay in the proposed ARS algorithm are as follows (Figure 3):

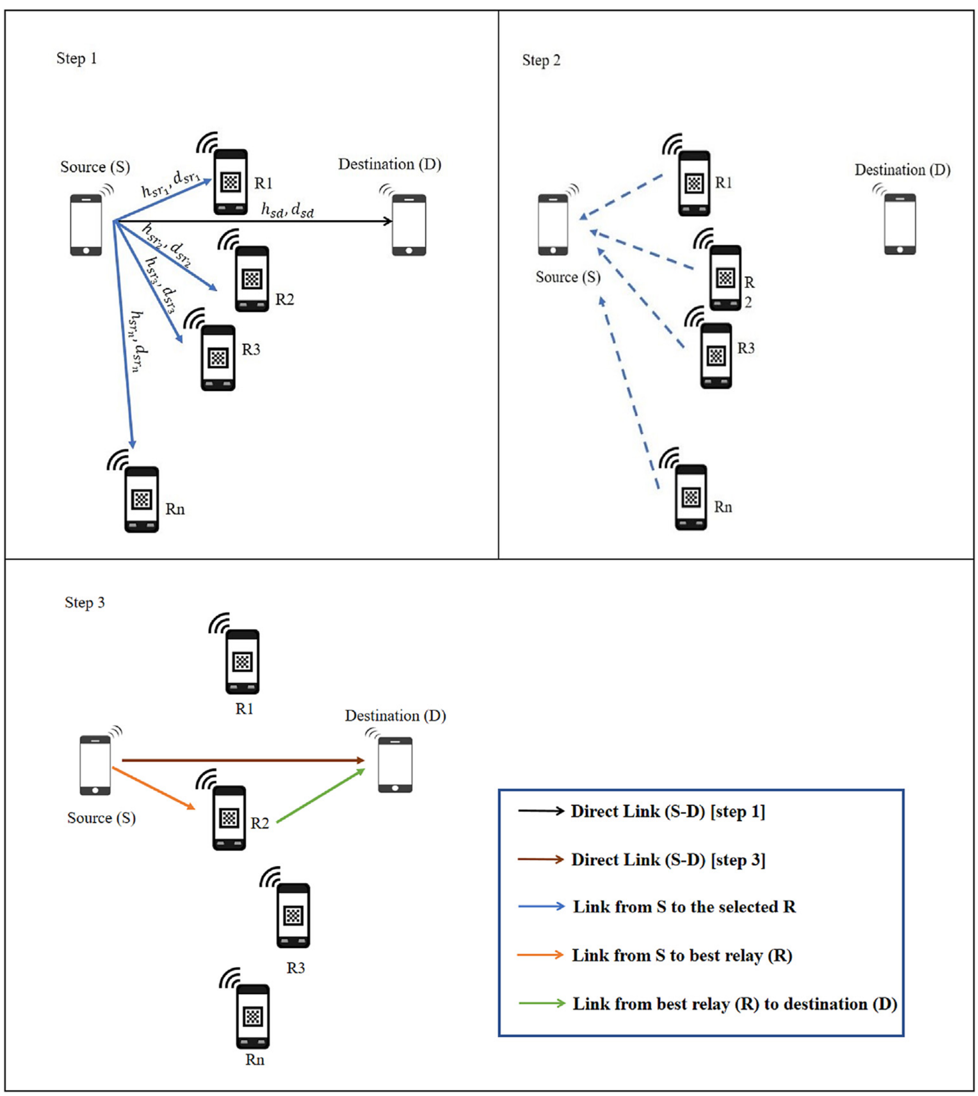

Figure 3. The proposed adaptive relay selection (ARS).

- Step 1: The S sends a pilot signal to the D and all PRs that are nearby; see Eqs. (1) and (2). The information signal received by the PRs is then processed according to the cooperative protocol used.
- Step 2: The PRs send back the pilot bit to the S, along with the information in the form of channel gain, SNR value information, and the distance information between S and N-relay. Then S calculates the SNR value of each R, as in Eqs. (3) and (5), as well as the maximum channel gain value and a minimum distance between the S to N-relay. One of the N-relay is chosen adaptively to be the best relay, by considering the maximum fading channel coefficient, if its SNR is the maximum, or the relay with the closest distance to the S, if the distance-based SNR conditions are at a maximum. The selected relay based on channel gain and link distance for the proposed ARS scheme, respectively, can be expressed as:

$$R_{channel\_gain} = \mathrm{argmax}\left\{\left[h_{SR_nD}\right]^2\right\}, n = 1, 2, ..., N \tag{13}$$

$$R_{distance} = \mathrm{argmin}\{d_{SR_nD}\}, n = 1, 2, ..., N \tag{14}$$

- Step 3: the process of sending the original information. The step is that the S sends an information signal directly to the D and the selected relay (R_n). The R_n processes the information using the QF protocol and then forwards it to the D, as follows:

$$y_{bestrelay(S-R)} = h_{S,Rb}X_s + n_{S,Rb} \tag{15}$$

$$y_{bestrelay(R-D)} = h_{Rb,D}X_r + n_{Rb,D} \tag{16}$$

The summary of the newly proposed ARS algorithm for QF protocol is given as follows:

Algorithm 1 Adaptive Relay Selection (ARS) Algorithm

initial N relay; $P_s =$; $d_{srd} =$;
for (each N relay) do
calculate $\gamma_{S,Rn}$ according to (3) and $\psi_{S,Rn}$ according to (5)
if $\gamma_{S,Rn} < \psi_{S,Rn}$, then
The best relay is $R_{channel\_gain} = \mathrm{argmax}\left\{\left[h_{SR_nD}\right]^2\right\}$ else
The best relay is $R_{distance} = \mathrm{argmin}\{d_{SR_nD}\}$ end
end

4. Throughput analysis

Throughput is the amount of information data that can be passed and received by D for each time unit. It can also be interpreted as the number of data packets that have been successfully sent to the destination from a number of attempts at sending information every second. Throughput can be calculated by considering the outage probability or the level of bit errors that can be tolerated at a certain threshold. If the outage exceeds the threshold value, the throughput performance for the cooperative D2D communication system becomes poor. Assuming that the error rate corresponds to the minimum SNR threshold value between S to R_n $(T_{S,Rn})$ and R_n to D $(T_{Rn,D})$ for the cooperative out-band D2D communication system. Outage probability (P_{out}) is the possibility of an outage on the system, which states the possibility of failure of information sent to a D. Therefore, the outage probability can be used to evaluate the cooperative out-band D2D communication system's performance. Mathematically, the outage probability from S to R_n and from R_n to D is presented in the following equations [24]:

$$P_{out\ S,D} = P_r(T_{S,D} < T_{th}) \tag{17}$$

$$P_{out\ S,Rn} = P_r(T_{S,Rn} < T_{th}) \tag{18}$$

$$P_{out\ Rn,D} = P_r(T_{Rn,D} < T_{th}) \tag{19}$$

The outage probability value for the cooperative out-band D2D communication system can be calculated using the equation:

$$P_{out\ Ars} = P_r(T_{Ars} < T_{th}) = P_r\left(1 + T_{S,D}(1) + T_{S,D}(2) + \frac{T_{S,Rn} + T_{Rn,D}}{T_{S,Rn} + T_{Rn,D}} < \gamma_{th}\right) \tag{20}$$

Throughput for the cooperative out-band D2D communication systems can be calculated based on the outage probability and threshold throughput (τ_{th}) using the formula:

$$\tau_{Ars} = (1 - P_{out\ Ars})\tau_{th} \tag{21}$$

5. Energy efficiency analysis

This section analyzes energy efficiency based on energy consumption for the cooperative out-band D2D communication system. The consumption rate for a multi-relay network is calculated by considering the number of relays between the S and D, as follows:

$$E_{MultirelayD2D} = \frac{\sum_{n=1}^{k} P_{s,Rn} + \sum_{n=1}^{k} P_{Rn,D} + P_{s,D}}{R_B}\ \mathrm{joule}/\mathrm{bit} \tag{22}$$

where $E_{multirelayD2D}$ is the energy consumption of the QF multi-relay wireless communication network, $P_{s,Rn}$ is the power consumption for sending data bits from S to R_n (W), $P_{Rn,D}$ is the power consumption to transmit the data bits from the R_n to the D (W), $P_{s,D}$ is the power consumption to transmit information bits directly from S to D (W), and R_B is the bit rate (bit/s).

$$P_{S,Rn} = \frac{P_s\left|h_{s,Rn}\right|^2}{d_{s,Rn}^{\propto}{}^{N}} \tag{23}$$

where P_S is the power consumption to transmit information from the S, $h_{S,Rn}$ is the effect of fading from S to R_n, $d_{S,Rn}$ is the distance from S to R_n, and N is the AWGN noise. The transmit power of information from R_n to D $(P_{Rn,D})$ is formulated as:

$$P_{Rn,D} = \frac{P_{Rn}\left|h_{Rn,D}\right|^2}{d_{Rn,D}^{\propto}{}^{N}} \tag{24}$$

where $P_{Rn,D}$ is the transmit power from R_n to D (W), $h_{Rn,D}$ is the fading effect from R_n to D, $d_{Rn,D}$ is the distance from R_n to D, and N is the AWGN noise. The energy consumption from S to D on the cooperative D2D multi-relay network is calculated as:

$$P_{S,D} = \frac{P_s\left|h_{s,D}\right|^2}{d_{s,D}^{\propto}{}^{N}} \tag{25}$$

where $P_{S,D}$ the power consumption to transmit information from S to D (W), $h_{s,D}$ is the effect of fading from S to D, while $d_{s,D}$ is the ratio of the distance from S to D, and N is the AWGN noise. Meanwhile, the total energy consumed in the maximum channel gain and minimum distance schemes are formulated, respectively, as [32]:

$$E_{channel\ gain} = \frac{\left(\sum_{n=1}^{k} P_{s,Rn} + P_{Rb,D} + P_{S,D}\right) + \left(\sum_{n=1}^{k} P_{bRn,D} + P_{bD,Rb} + P_{S,D}\right)}{R_B p + R_B}\ \mathrm{Joule}/\mathrm{bit} \tag{26}$$

$$E_{Distance} = \frac{\left(\sum_{n=1}^{k} P_{bS,Rn,} + \sum_{n=1}^{k} P_{bRn,D} + P_{bD,S} + P_{s,D}\right) + \left(P_{S,Rb} + P_{Rb,D} + P_{s,D}\right)}{R_B p + R_B} \text{Joule} \Big/ \text{bit} \tag{27}$$

Meanwhile, the energy consumption using the proposed ARS schemes can be written as:

$$E_{ARS} = \frac{\left(\sum_{n=1}^{k} P_{bS,Rn,}\right) + \left(P_{s,Rb} + P_{Rb,D} + P_{s,D}\right)}{R_B p + R_B} \text{joule}/\text{bit} \tag{28}$$

where $P_{s,Rb}$ is power consumption to transmit information from S to best relay (W), and $P_{Rb,D}$ is the power consumption to transmit information from R_n to D (W). Then the EE for the maximum channel gain and minimum distance schemes can be formulated, respectively, as [33]:

$$EE\ Channel\ Gain = \frac{E_{MultirelayD2D} - E_{channel\ gain}}{Emultirelay\ D2D} \times 100\% \tag{29}$$

$$EE\ Distance = \frac{E_{MultirelayD2D} - E_{Distance}}{Emultirelay\ D2D} \times 100\% \tag{30}$$

While the EE for the proposed ARS scheme is as follows:

$$EE\ ARS = \frac{E_{MultirelayD2D} - E_{ARS}}{Emultirelay\ D2D} \times 100\% \tag{31}$$

6. Numerical results

This section explains the simulation results of throughput, energy consumption, and the EE for the proposed ARS scheme in a cooperative out-band D2D communication system using QF protocol. The simulation results of the proposed ARS are compared to those of the conventional relay selection schemes of the maximum channel gain and minimum distance schemes. The simulation uses the MATLAB R2018a application with the Rayleigh fading channel and the BPSK modulation scheme. The proposed ARS power allocation is in the ratio of 0.1–1.0 for user devices to analyze changes in the value of throughput, energy consumption, and the resulting energy efficiency. The results are then compared with the relay selection algorithm, proposed previously. The number of bits of information used during the simulation is 10^6 bits with a total distance between S-D of 500 m and the distance between $S - R_n$, $R_n - D$ as modeled in the link distance scenario (section 2), assuming the threshold rate is 1 bit/s/Hz, and the threshold for throughput is 1 Gbps. In the simulation, the number of relays used was 1–3 relays. The detailed simulation setup is presented in Table 1.

Table 1. Simulation setup.

Parameter	Parameter Value
Power allocation ratio, P_r	0.1–1.0 W
Path-loss exponent, α	2
Thermal-noise power spectral density, N_o	1
Threshold rate, R_B	1 bit/s/Hz
Number of information bits	10^6 bits
Threshold throughput, τ_{th}	1Gbps
Distance between S to D, $d_{s,d}$	500 m
Modulation scheme	BPSK
Number of relays	1–3
SNR regime	0–30 dB

6.1. Throughput

Figure 4 shows the simulation results of link distance impact on the D2D cooperative communication system's throughput value. The threshold rate is assumed to be 1 bit/s/Hz, and the threshold for throughput is 1 Gbps. The number of relays varies from 1 to 3. Because the proposed ARS is based on channel gain and link distance, in our simulation, we also simulated the relay selection method based on channel gain or minimum link distance compared to our proposed scheme. Figure 4 shows the resulting throughput value simulation results based on the maximum channel gain value, minimum distance, and the proposed ARS. In this simulation, we consider the link distance as 500 m. The simulation results show the value of throughput to distance, with the proposed relay selection method ARS being 0.90 Gbps, much better than the previous relay selection methods (the maximum channel gain value and minimum distance). The throughput value generated by each relay selection is 0.78 Gbps, for the maximum channel gain value, and 0.80 Gbps, with the minimum distance. The proposed ARS scheme considers that the relay position is not fixed, and link conditions and distance can dynamically change in the cooperative out-band D2D multi-relay networks. The proposed ARS scheme has a higher throughput than the previous methods (maximum channel gain and minimum distance scheme) in the cooperative out-band D2D multi-relay networks.

The power allocation on the D2D network influences throughput performance. We simulated this factor with the allocation of information power varing from 0.1 W to 1.0 W for each relay selection method. The other simulation parameters are the same as the previous simulation in Figure 4. The simulation result of the power allocation's effect on throughput in the D2D cooperative communications is shown in Figure 5. The results showed that the effect of power allocation on throughput with the ARS method was better than the previous method, namely the maximum channel gain and minimum distance, as shown in Figure 5. At the power allocation of 0.5 W, it was found that the throughput value based on a maximum channel gain is 0.75 Gbps, the minimum distance is 0.78 Gbps, and the proposed ARS is 0.87 Gbps. These results indicate that, with the same power allocation, the proposed ARS could increase throughput by 16% and 11.5%, compared to the selection scheme of relay based on the maximum line gain and minimum connection distance, respectively. Since the proposed ARS can provide the dynamic conditions based on link distance or channel gain, it can improve the throughput.

6.2. Energy consumption

Figure 6 shows the simulation results of link distance impact on energy consumption in the D2D cooperative communication system. It shows the simulation results' energy consumption levels without using the relay selection method (conventional multi-relay network) and using the relay selection schemes. In the simulation, the link distance between S and D is 500 m. We can see that the level of energy consumption without the relay selection method is greater than using the relay selection. Based on the relay selection method used, at the link distance 250 m, the energy consumption levels based on the maximum channel gain, minimum distance, and the proposed ARS are 0.005028 J/bit, 0.003764 J/bit, and 0.002004 J/bit, respectively. So, the proposed ARS can save about 60.14% and 46.75% of the energy, compared to the maximum channel gain and minimum distance, respectively. This result

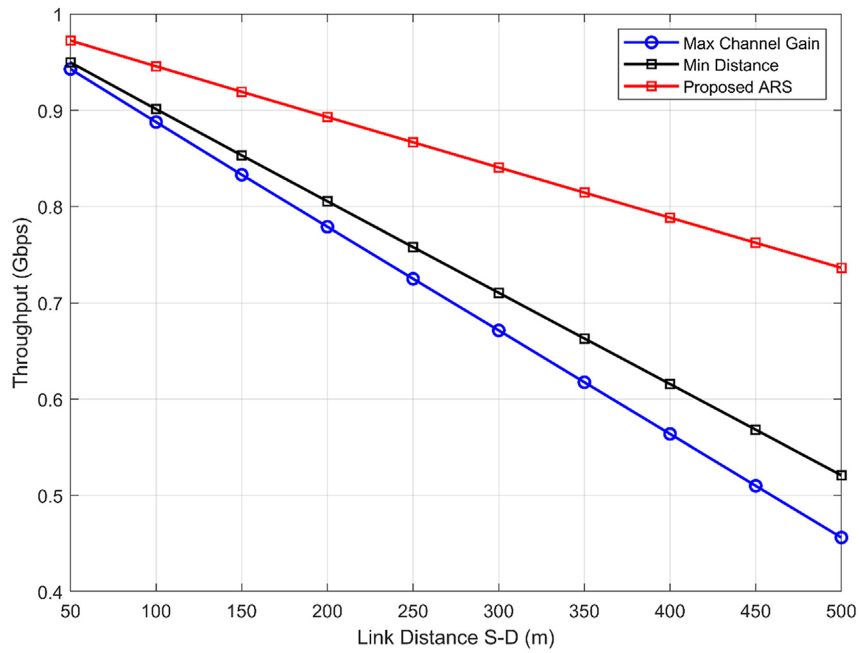

Figure 4. Throughput versus link distance based on the maximum channel gain value, minimum distance, and proposed ARS.

also shows that the minimum distance-based relay selection scheme is better than the maximum channel gain scheme.

The simulation results of power allocation to the energy consumption in the D2D cooperative communication system are presented in Figure 7. It can be seen that the energy consumption levels are increased with the increase of the power allocation for all relay selection schemes. However, the proposed ARS shows the lowest energy consumption among the schemes. For example, at the power allocation of 0.7 W, the energy consumption of the maximum channel gain, a minimum distance, and the proposed ARS are 0.00350 J/bit, 0.00181 J/bit, and 0.00112 J/ bit, respectively. It can be seen that the proposed ARS could save about 68% and 37.8% of the energy compared to the maximum channel gain and minimum distance schemes, respectively. Changes in link distance occur dynamically in the cooperative out-band D2D multi-relay networks. Therefore, distance is an important factor in a wireless cooperative communication system that determines the power consumption used for information transmission. With these considerations, the proposed ARS scheme has lower energy consumption than the maximum channel gain or minimum distance scheme in the cooperative out-band D2D multi-relay networks.

6.3. Energy efficiency

EE is a performance metric in D2D communication based on each of the aforementioned relay selection schemes, and it is simulated using Eqs. (29), (30), and (31). We also simulated the EE by considering the

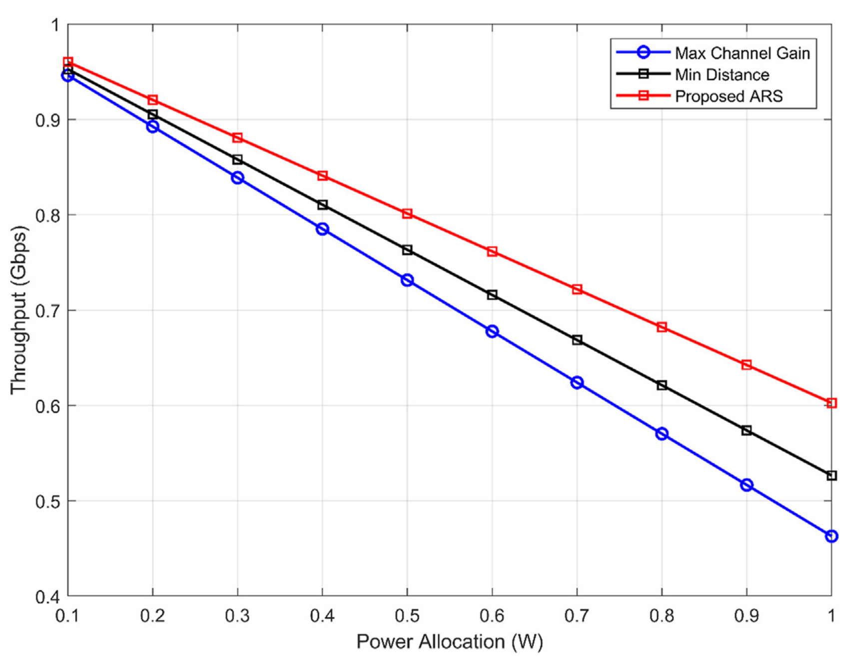

Figure 5. Throughput versus power allocation based on maximum channel gain, minimum distance and proposed ARS.

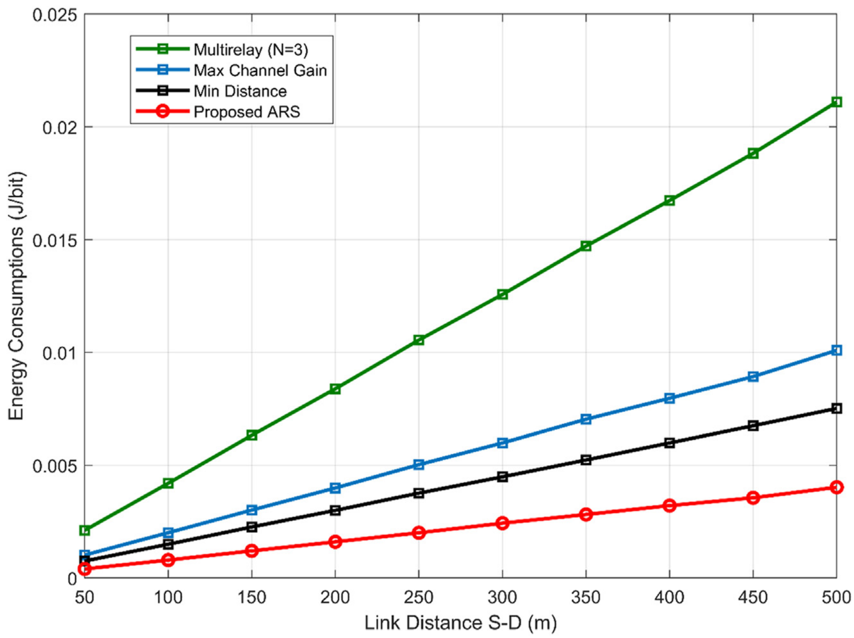

Figure 6. Energy consumption versus link distance for the maximum channel gain value, minimum distance, and proposed ARS.

impact of the link distance and power allocation in the system. Figure 8 shows the simulation results for the effect of link distance on the EE in the D2D cooperative communication system. In general, and for all schemes, EE will decrease as the link distance increases. However, the proposed ARS has the highest EE compared to the other schemes. For example, at a distance of 200 m, the proposed ARS has an EE of 22.64%. In contrast, the maximum channel gain and the minimum distance schemes are 14.31% and 16.67%, respectively.

The EE based on power allocation for the three relay selection schemes is also simulated. The simulation results of the EE are given in Figure 9. We can see that the proposed ARS could provide the highest EE compared to the maximum channel gain and minimum distance schemes. At a power allocation of 0.3 W, the EE for the maximum channel gain, the minimum distance, and the proposed ARS are 9.35%, 20.99%, and 25.73%, respectively. The proposed ARS considers the position of the relay and the channel conditions with the varying performance of the relays. Therefore, energy consumption in the proposed ARS scheme is lower than that of the maximum channel gain or minimum distance. The EE of the proposed ARS is more efficient than using the maximum channel gain and minimum distance selection method separately.

Table 2 describes the average simulation results of throughput, energy consumption, and EE for the ARS scheme proposed in the out-band cooperative D2D communication system using the QF protocol. The simulation results of the proposed method are compared with the previous relay selection methods: the maximum channel gain and minimum distance.

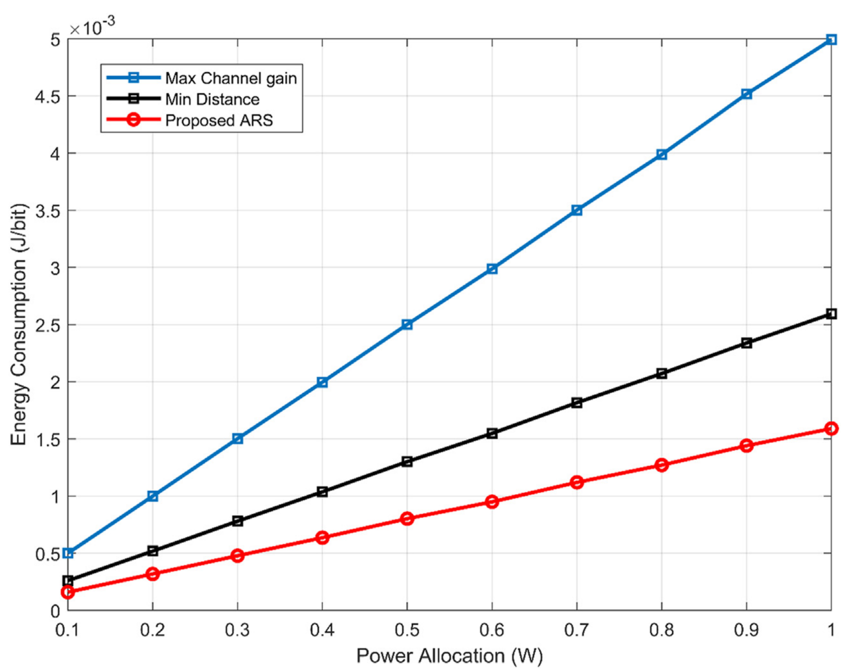

Figure 7. Energy consumption versus power allocation for the maximum channel gain value, minimum distance, and proposed ARS.

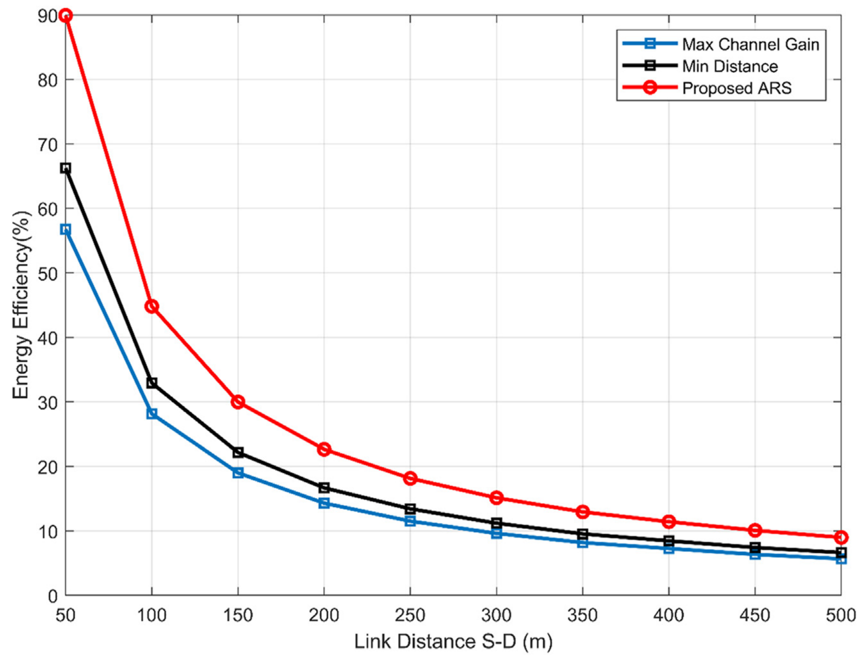

Figure 8. Energy Efficiency versus link distance for the maximum channel gain value, minimum distance, and proposed ARS.

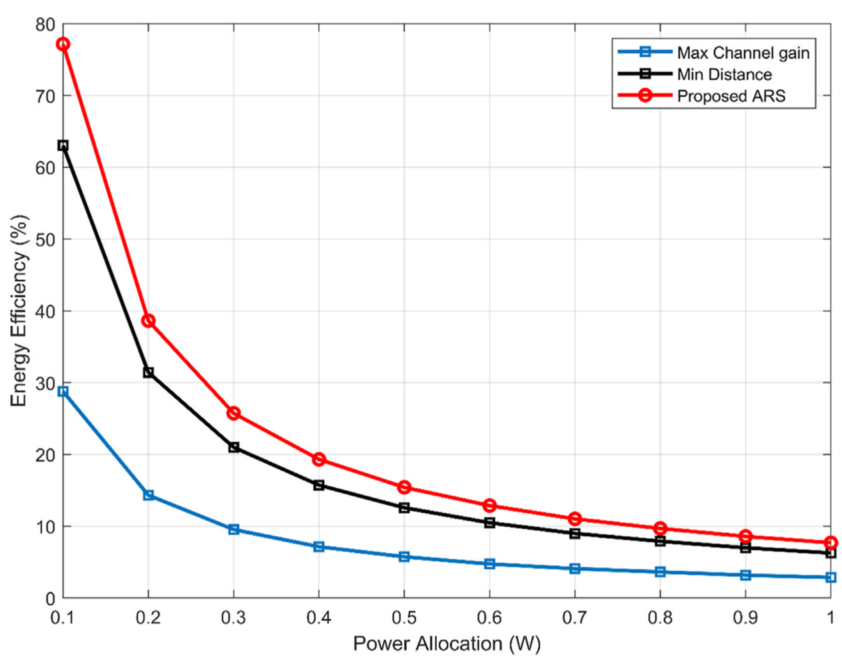

Figure 9. Energy efficiency versus power allocation based on the maximum channel gain value, minimum distance, and proposed ARS.

Table 2. The average comparison of throughput, energy consumption, and energy efficiency for different schemes.

Performance Parameters		Maximum Channel Gain	Minimum Distance	Proposed ARS
Throughput	Link Distance	0.70 Gbps	0.73 Gbps	0.85 Gbps
	Power Allocation	0.70 Gbps	0.74 Gbps	0.78 Gbps
Energy Consumption	Link Distance	0.0055 J/bit	0.0041 J/bit	0.0022 J/bit
	Power Allocation	0.0027 J/bit	0.0014 J/bit	0.0008 J/bit
Efficiency Energy	Link Distance	16.73%	19.50%	26.49%
	Power Allocation	8.37%	18.38%	22.60%

Furthermore, it can be concluded that the proposed ARS scheme can reduce energy consumption and increase throughput and energy efficiency in the cooperative out-band D2D using the QF protocol. Due to the complexity of the throughput analysis using M-QAM, we decided to only use BPSK modulation for the throughput performance in this work. It is better to consider M-QAM modulation for throughput analysis to improve cooperative D2D network performance for further research.

7. Conclusions

This paper proposed a new Adaptive Relay Selection (ARS) scheme, based on channel gain and link distance, for a cooperative out-band device-to-device (D2D) communication system. First, the system model and algorithm for the proposed scheme are presented, based on a multi-relay using QF protocol over Rayleigh fading channel. Then, exact closed-form throughput and energy efficiency expressions for the proposed scheme have been derived and simulated using Matlab programming. The numerical results obtained that the proposed ARS scheme has a higher throughput than the maximum channel gain and minimum distance. Furthermore, the proposed ARS can reduce the total energy consumption, which has direct impacts on the resulting energy efficiency level. The proposed ARS scheme achieves the highest energy efficiency, greater than the link distance or power allocation. Therefore, the proposed ARS scheme for out-band D2D communication networks is an appropriate solution for the next generation of cellular communications.

Declarations

Author contribution statement

Isyatur Raziah: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Yunida Yunida: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Yuwaldi Away, Rusdha Muharar & Nasaruddin Nasaruddin: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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