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Performance Analysis Of Relay Aided On Device To Device Communications Underlay 5G Cellular Network

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ARTICLE INFORMATION

Received 26 July 2023
Revised 05 October 2003
Accepted 06 November 2003

Keywords :
5G Network
Device to Device
Iterative Algorithm
Load traffic
Relay Aided

ABSTRACT

The increasing development of today's technology specifically in the field of telecommunications triggers new problems associated with the increasing number of network connectivity users so that this makes the increased load of traffic on the Base Station (BS). To address traffic problems, a D2D technology is needed as a solution to enhance connectivity on 5G networks. In the use of D2D is still not optimal for dealing with the rapidly increasing load of traffic due to the large number of users. This research suggests the addition of devices in D2D communication, namely Relay Node. (RN). The results of the study showed that by using the relay aided communication scheme can improve the sumrate performance parameter is 1,970 × 107 bps and the spectral efficiency is 19,704 bpz/Hz, but less effective in the power efficiency parameter is 7,672 × 103 bps/mW due to the addition of relay devices that increase power consumption. Using iterative algorithms on relay aided communication schemes has been shown to improve performance parameters values more optimally than using full duplex and half duplex communications schemes. Therefore, the relay aided scheme is the most accurate communication scheme in dealing with transmission systems on D2D because by using the aided relay scheme, sumrate and spectral efficiency are improved by 55%.

1. Introduction

Today's technology is increasingly advanced and continues to evolve along with the needs of human beings who want ease in receiving and transmitting information. In the telecommunications industry, the increasing number of Cellular User Equipment (CUE) increases the need for network connectivity, which can trigger an increase in the load of traffic on the Base Station (BS). Traffic growth over the years can be highly fluctuating and can vary significantly between countries, depending on the local market dynamics. Globally, the growth of mobile data traffic per smartphone can be attributed to three main drivers: increased device capabilities, increased data-intensive content, and growth in data consumption due to continued improvements in deployed network performance (Ericsson, 2022).

Therefore, to address the traffic problem, a device-to-device (D2D) technology is needed as a solution to improve connectivity on the 5G network and it is expected that this D2D communication method will play an important role in responding to the demand for broadband communications services with high rates in the future (Sakti et al., 2019). A D2D communication system is a communication system that allows two users to communicate directly without passing through BS, the use of D3D can increase the data rate due to closer distances. This will increase spectral efficiency and reduce latency. Generally based on spectrum allocation for D2D communications, the two main modes of operations are the first underlay mode where the user uses the same frequency spectrum as the conventional cellular user at the same time and the second mode is the overlay mode in which the operator specifically allocates the source (channel or time slots) to the network. (R. Purnama, 2019)

This research uses the Decode and Forward (DF) RA-D2D technique in two directions in the underlay mode that is able to provide optimal power control in D2D communication by using relay-aided (RA) uplink communication, i.e., by adding relay devices between the D2C pairs. The process of obtaining optimal power allocation using iterative algorithms The optimum power allocation is then analyzed based on performance parameters in terms of sumrate, spectral efficiency, and power efficiency. D2D communications that use HD and FD transmission techniques are still not able to provide a high level of capacity, and the reach of the transmission system is not optimal, so the communication is not capable of providing an optimal service. (Yassine et al., 2020).

The relay aided scheme allows D2D users to communicate with each other through the relay nodes located between the D2C pairs. D2D communication with the help of relays that can provide efficient transmission processes to give me better communication capabilities D2D transmission is divided into two time slots, while the first time slot (TS) is DU1 and DU2 (RN). After the decoding process, the relay re-encodes the message and re-transmits it to the D2D terminals (DU1 and DU2) in the second time slot. (Thepsongkroh et al., 2017). The allocation of power is carried out in each D2D relay-aided communication scheme to obtain optimal power, so this research suggests an optimal solution. The optimal solution is obtained based on the optimum power allocation using the iterative algorithm that performs the repetition system to obtain the expected results so that the energy allocation on the relay and D2D is optimal (Rani et al., n.d.).

2. Method

The system model in this study consists of one pair of D2D (DU1 and DU2), and one base station (BS) and there is one cellular user (CU). When DU1 and DU2 communicate with each other using the uplink frequency and power allocation allocated to the CU (Akhyar et al., 2017). This causes interference between the cellular link with the D2D link as shown in Figure 1. When providing uplink resources, D2D communication interference will only affect the base station (BS).

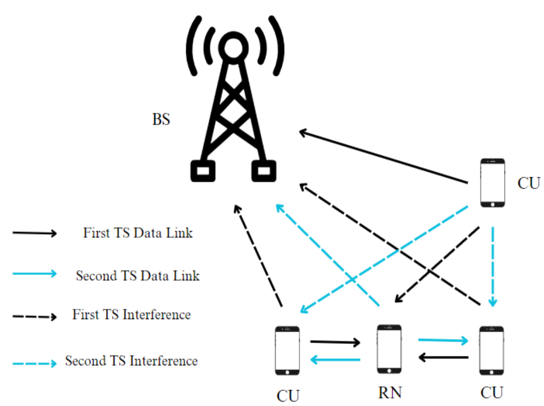

Figure 1 Relay Aided D2D Communication (Yassine et al., 2020)

The simulation in this study was carried out through several stages described on the flowchart found in Figure 2.

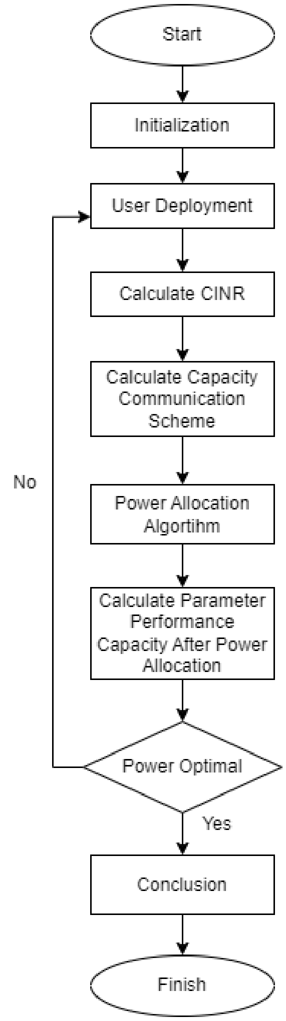

Figure 2 Simulatiom Flowchart

2.1 Initialization

Initialization is the first step in simulation. This step performs the determination of the number of devices used in this study, the devices used are CU, D2D pair, Relay, the radius of the blast BS, and the distance D2D to RN. The system model is described in Figure 1. After the initialization process, user distribution will continue.

2.2 User Deployment

This stage of the CU device, the D2D pair, and the Relay are distributed within the cell by calling the function that has been created. The relay is placed between D2D devices so that DU 1 communication with DU 2 must cross the RN to keep the quality of communication running properly.

2.3 Calculate CINR

The study carried out the calculation of the CINR against the scheme that will be used as a comparison analysis including the calculations of the CINR on the Half Duplex and Full Duplex schemes, as well as the computation of cinar on the Relay Aided.

2.4 Calculate CINR HD

The calculation of the CINR in the half duplex scheme can be done through the equations 1 and 2.

$$\gamma_c = \frac{g_{c,bs}}{P_d \cdot g_{d1,bs} + NW} \tag{1}$$

$$\gamma_d = \frac{g_{d1,d2}}{P_d \cdot g_{c,d2} + NW} \tag{2}$$

Where :

γ_c	= CINR at CU
γ_d	= CINR at DU
p_c	= Tansmit power at CU
p_d	= Transmit power at DU
$g_{c,bs}$	= Gain from CU to BS
$g_{d1,bs}$	= Gain from D1 to BS
$g_{d1,d2}$	= Gain from D1 to D2
$g_{c,d1}$	= Gain from CU to D1
N	= Noise
W	= Bandwidth

2.5 Calculate CINR FD

The CINR value of D2D in full duplex mode can be calculated on the equation 3.

$$\gamma_{di,dj} = \frac{g_{di,dj}}{P_c \cdot g_{ci,dj} + P_{di} + NW} \tag{3}$$

where (i,j) ∈ (1,2),(2,1). [5]

Where :

$\gamma_{di,dj}$	= CINR at D2D user
p_c	= Tansmit power at CU
p_d	= Tansmit power at DU
$g_{di,dj}$	= Gain from D1 to D2 or vice versa
$g_{ci,dj}$	= Gain from CU to DU
N	= Noise
W	= Bandwidth

The CINR value of CU can be calculated on the equation 4.

$$\gamma_c = \frac{g_{c,bs}}{P_{d1} \cdot g_{d1,bs} + P_{d2} \cdot g_{d2,bs} + NW} \tag{4}$$

Where :

γ_c	= CINR at CU
p_{d1}	= Tansmit power at D1
p_{d2}	= Tansmit power at D2
$g_{c,bs}$	= Gain fromCU to BS
$g_{d1,bs}$	= Gain from D1 to BS
$g_{d2,bs}$	= Gain from D1 to BS
N	= Noise
W	= Bandwidth

2.6 Calculate CINR RA

Calculation of the CINR on the relay assisted on the first TS with CINR DU1 to the releas and DU2 to the relays can be known using the equation 5.

$$\gamma_{di,r} = \frac{g_{di,r}}{P_c \cdot g_{c,r} + NW} \tag{5}$$

Where :

$\gamma_{di,r}$	= CINR DU to relay
p_c	= Tansmit power at CU
$g_{di,r}$	= Gain from DU to relay
$g_{c,r}$	= Gain from CU to relay
N	= Noise
W	= Bandwidth

The calculation of the CINR on the second TS, which is the relay to DU1 and the relays to DU2, can be known using the equation 6.

$$\gamma_{r,di} = \frac{g_{di,r}}{P_c \cdot g_{c,di} + NW} \tag{6}$$

Where :

$\gamma_{r,di}$	= CINR DU to relay
p_c	= Tansmit power at CU
$g_{di,r}$	= Gain from DU to relay
$g_{c,di}$	= Gain from CU to DU
N	= Noise
W	= Bandwidth

On the CU transmission, the CINR is calculated on TS 1 and TS 2 using the equations 7 and 8.

$$\gamma_c = \frac{g_{c,bs}}{P_{d1} \cdot g_{d1,bs} + P_{d2} \cdot g_{d2,bs} + NW} \; ; \; TS\ 1 \quad (7)$$

$$\gamma_{r,di} = \frac{g_{c,bs}}{P_r \cdot g_{r,bs} + NW} \; ; \; TS\ 2 \quad (8)$$

Where :

γ_c	= CINR at CU
$\gamma_{r,di}$	= CINR relay to DU
p_r	= Tansmit power at relay
p_{d1}	= Tansmit power at D1
p_{d2}	= Tansmit power at D2
$g_{c,bs}$	= Gain from CU to BS
$g_{d1,bs}$	= Gain from D1 to BS
$g_{d2,bs}$	= Gain from D2 to BS
$g_{r,bs}$	= Gain from relay to BS
N	= Noise
W	= Bandwidth

2.7 Calculation of capacity

In the simulation phase, the third capacity calculations were carried out in the half duplex, full duplex and relay aided communication schemes (Chour et al., 2018) .

2.7.1 Calculation of capacity HD

The calculation of half duplex capacity on DU and CU can be done with the equation:

$$R_c^{HD} = W\ log_2(1 + p_c \cdot \gamma_c) \quad (9)$$

$$R_d^{HD} = W\ log_2(1 + p_d \cdot \gamma_d) \quad (10)$$

Where:

R_c^{HD}	= Capacity of half duplex CU
R_d^{HD}	= Capacity of half duplex DU
W	= Bandwidth
p_c	= Tansmit power at CU
γ_c	= CINR at CU
p_d	= Transmit power at DU
γ_d	= CINR at DU

2.7.2 Calculation of capacity FD

The calculation of full duplex capacity on D2D and CU can be done with the equation 11.

$$R_i^{FD} = W\, log_2(1 + p_c \cdot \gamma_c) \tag{11}$$

Where :

R_i^{FD} = Capacity full duplex D2D and CU
W = Bandwidth
p_c = Tansmit power at CU
γ_c = CINR at CU

2.7.3 Calculation of capacity RA

Calculation of Relay Aided capacity against CU and D2D using the equation 12 and 13.

$$R_1^{RA} = W\, log_2(1 + min\,(p_{d_1} \cdot \gamma_{d_1,r}, p_{r_2} \cdot \gamma_{r,d_2})) \tag{12}$$

$$R_2^{RA} = W\, log_2(1 + min\,(p_{d_2} \cdot \gamma_{d_2,r}, p_{r_1} \cdot \gamma_{r,d_1})) \tag{13}$$

Where :

R_1^{RA} = Capacity relay to D1 and relay to D2
R_2^{RA} = Capacity D1 to relay dan relay to D1
W = Bandwidth
p_{d1} = Tansmit power at D1
p_{d2} = Transmit power at D2
p_r = Transmit power at relay
γ_d = CINR at DU

In this calculation, the capacity calculation is carried out against the minimum value between SINR D1 to relay and relay to D2. to calculate the capacity of the minimum value between the SINR value to the relay and the relay to D1. Then add up R1 and R2, then with this total the capacity value is obtained in the aided relay simulation scheme.

2.8 Algorithm of power allocation

The allocation of power is carried out in each D2D relay-aided communication scheme to obtain optimal power, so this research suggests an optimal solution. When doing allocation by taking capacity values to do power allocation on CU and D2D.

On the D2D communication scheme with the addition of relay devices can be performed power allocation on CU and D3D. Suboptimal solution is calculated using the D2D power present on the simulation parameter and entered in the equation at 14.

$$P_c' = \left(\frac{\mu}{g_{c,bs}} \cdot \left(max\left\{\left(P_d^{max} \cdot g_{d1,bs} + P_d^{max} \cdot g_{d2,bs}\right), 2P_d^{max} \cdot g_{r,bs}\right\} + NW\right)\right) \tag{14}$$

On the power allocation D2D and relay on the relay aided communication scheme is performed optimally according to the conditions of CINR values as follows (Yassine, 2020):

Case 1 : $(\gamma_{d_1,r} \leq \gamma_{r,d_2})$ and $(\gamma_{d_2,r} \leq \gamma_{r,d_1})$

$$P_{d_1} = P_d^{max} \text{ and } P_{d_2} = P_d^{max}$$
$$P_{r_2} = P_d^{max} \cdot \frac{\gamma_{d_1,r}}{\gamma_{r,d_2}} \text{ and } P_{r_1} = P_d^{max} \cdot \frac{\gamma_{d_2,r}}{\gamma_{r,d_1}} \quad (15)$$

Case 2 : $(\gamma_{d_1,r} \leq \gamma_{r,d_2})$ and $(\gamma_{d_2,r} \geq \gamma_{r,d_1})$

$$P_{d_1} = P_d^{max} \text{ and } P_{r_1} = P_d^{max}$$
$$P_{r_2} = P_d^{max} \cdot \frac{\gamma_{d_1,r}}{\gamma_{r,d_2}} \text{ and } P_{d_2} = P_d^{max} \cdot \frac{\gamma_{r,d_1}}{\gamma_{d_2,r}} \quad (16)$$

Case 3 : $(\gamma_{d_1,r} \geq \gamma_{r,d_2})$ and $(\gamma_{d_2,r} \leq \gamma_{r,d_1})$

$$P_{r_2} = P_d^{max} \text{ and } P_{d_2} = P_d^{max}$$
$$P_{d_1} = P_d^{max} \cdot \frac{\gamma_{r,d_2}}{\gamma_{d_1,r}} \text{ and } P_{r_1} = P_d^{max} \cdot \frac{\gamma_{d_2,r}}{\gamma_{r,d_1}} \quad (17)$$

Case 4 : $(\gamma_{d_1,r} \geq \gamma_{r,d_2})$ and $(\gamma_{d_2,r} \geq \gamma_{r,d_1})$

$$P_{r_2} = P_d^{max} \text{ and } P_{r_1} = P_d^{max}$$
$$P_{d_1} = P_d^{max} \cdot \frac{\gamma_{r,d_2}}{\gamma_{d_1,r}} \text{ and } P_{d_2} = P_d^{max} \cdot \frac{\gamma_{r,d_1}}{\gamma_{d_2,r}} \quad (18)$$

The optimal solution is obtained based on the optimum power allocation using the iterative algorithm that performs the repetition system to obtain the expected outcome so that the allocation of power on the relay and D2D is optimal. This is a pseudo code using the iterative algorithm used in the system. (Yassine, 2020).

Data : $\in =$ 0,1 mWatt, $P_{d_1} = P_{d_2} = P_{r_1} = P_{r_2} = P_d^{max}$

Output : $P_c = P_{d_1} = P_{d_2} = P_{r_1}$ and $= P_{r_2}$

1. Make a calculation on P_c
2. Get the optimal power ($P_{d_1} = P_{d_2} = P_{r_1} = P_{r_2}$) base on the case CINR 1-4
3. Repeat the calculation at P_c by subtitling the sub-optimal solution then obtaining the second step on the equation.
4. If ($P_c = P_c'$) $> \in$ then return to step 2
5. Else return $P_c = P_{d_1} = P_{d_2} = P_{r_1}$ and $= P_{r_2}$

3. Results and Speech

Here are the results of a simulation that analyzes the system by changing the variation of the distance between the D2D pairs. Variations start from distances of 200 m to 450 m, with the addition of distances every 5 m. This scenario will be analyzed based on sumrate, spectral efficiency, and power efficiency.

3.1 Sumrate

Sumrate is the number of bits transmitted in a second.

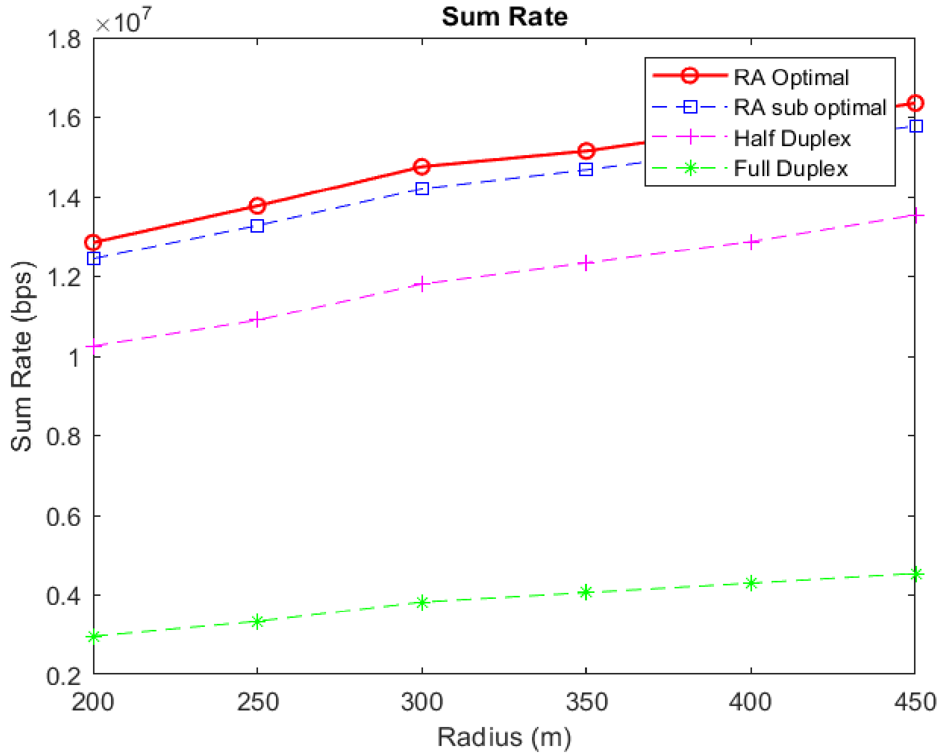

Figure 3 Results of Sumrate Simulation

Figure 3 shows that relay use has the highest sumrate value with an average of 1,970 × 107 bps compared to other schemes, with an optimal power allocation relay providing a solution to D2D systems in terms of sumrate. The full-duplex communication scheme has the lowest graphics. This is due to the existence of two-way communication, which resulted in this communication scheme undergoing a lot of interference and weakening power usage. On the other hand, the larger the user radius of D2D, the greater the sumrate obtained. This is because the distance between D2D users is constant, and each increase in user radius to BS results in a small amount of interference.

3.2 Spectral Efficiency

Spectral efficiency is the size of the data rate or efficiency of a system that can be transmitted within the bandwidth allocated within the system.

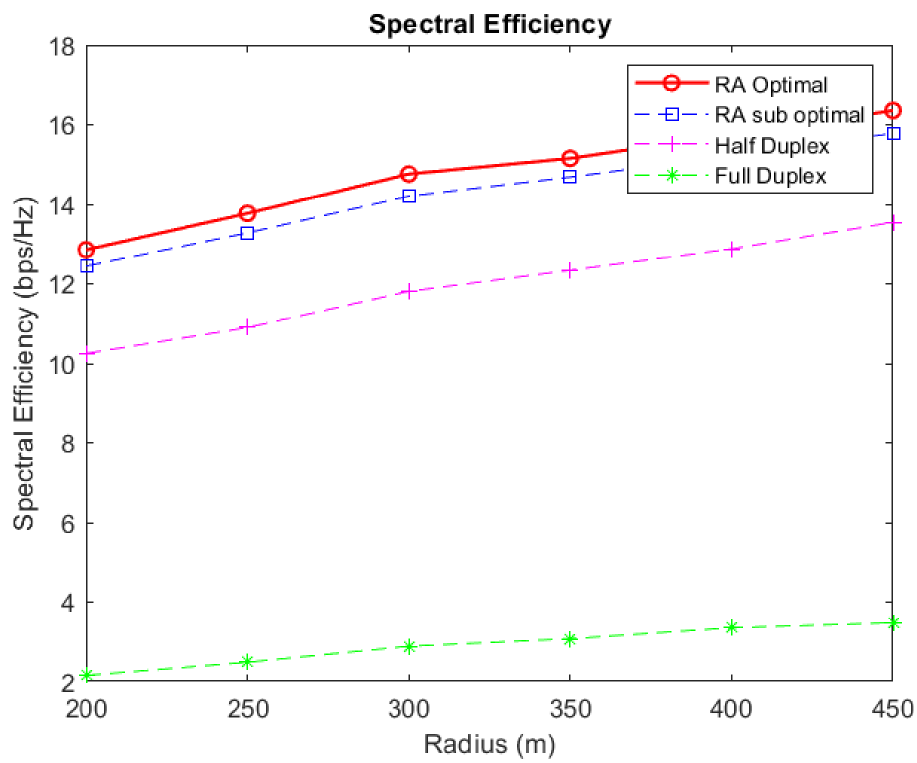

Figure 4 Results of Spectral Efficiency

Figure 4 shows that relay use has the highest spectral efficiency value with an average of 19,704 bps/Hz compared with other schemes, and the use of relays with optimal power allocation provides a solution to D2D systems in terms of spectrum efficiency. As for the full-duplex communication scheme, it has the lowest graph value with an average of 12,673 bps/Hz. This is due to the existence of two-way communication, which resulted in this communication scheme undergoing a lot of interference and weakening power usage. On the other hand, the larger the user radius of D2D, the greater the spectral efficiency obtained. This is because the radius between D2D users is constant, and each increase in user radius between BS and CU results in smaller and smaller interference.

3.3 Power Efficiency

Power efficiency is a parameter of the power transmitted by the number of bits per second.

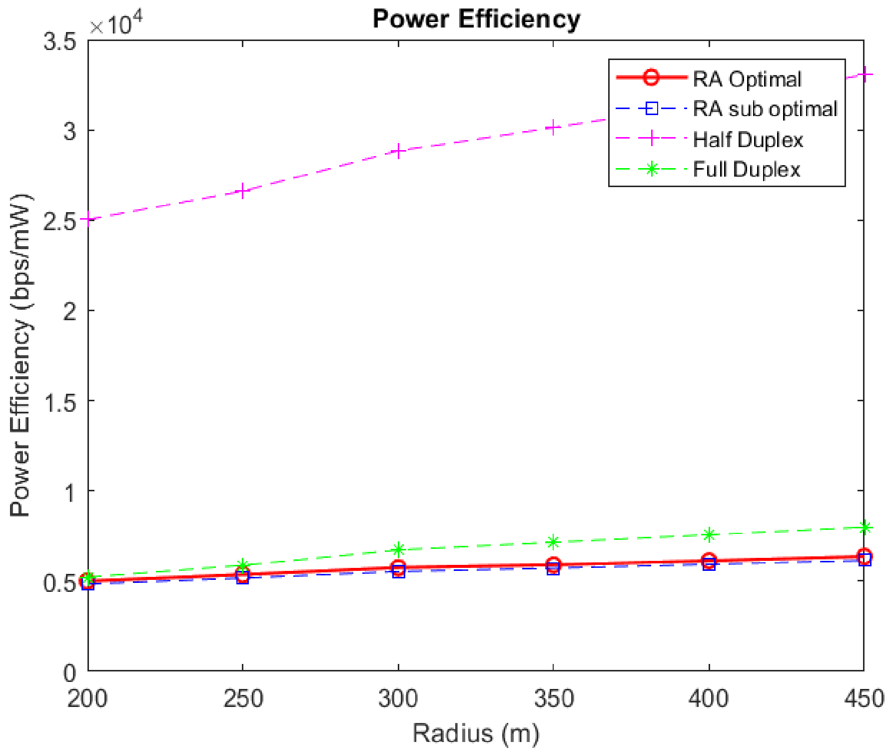

Figure 5 Results of Power Effiency

Figure 5 shows a graph comparing power efficiency to half-duplex communication schemes, full-duplex, relay-aided before power allocation, and relay-aided after power allocation based on the variation of the D2D pair distance. Power efficiency decreases when the distance from the sender device to the receiver device changes. The graph shows that the half-duplex communication scheme has optimal power efficiency; this occurs as a result of the fact that the half-duplex communication scheme only performs communication alternately, so that the interference and power used are low. The graph also shows that relay-aided and half-duplex communication schemes occupy the lowest position compared to half-duplex communication schemes. This occurs due to the use of relays, which can increase the amount of power used on these schemes, making them less efficient in terms of power usage.

Table 1 shows the results of the comparison of average values according to performance parameters based on half duplex, full duplex communication schemes, relay aided before power allocation, and relay assisted after power allocation.

Table 1 Comparison of performance parameters

Communication Scheme	**Parameter Performance**		
	Sum Rate (bps)	**Spectral Efficiency (bps/Hz)**	**Power Efficiency (bps/mW)**
Relay Aided Optimal	$1,970 \times 10^7$	$19,704$	$7,672 \times 10^3$
Relay Aided Sub Optimal	$1,826 \times 10^7$	$18,264$	$7,111 \times 10^3$
Full Duplex	$1,267 \times 10^7$	$12,673$	$3,093 \times 10^4$
Half Duplex	$2,827 \times 10^6$	$2,827$	$4,975 \times 10^3$

The results of the simulation stated that by using the relay-aided communication scheme, the sumrate parameter value has improved performance compared to the full duplex or half duplex communication schema, so it can be a solution in the D2D communication system. It is affected by the presence of relay devices between the D2D communication systems, so it can increase the SINR value. As for the value of spectral efficiency, it is also improved when using relay-aided communication schemes as a result of relay as a communication amplifier, so this scheme can increase sumrate and be compared directly with the increased spectrum efficiency; therefore, the scheme is very efficient in using the frequency on the D2D communication system. As for the influence of power allocation on the optimal relay-aided scheme, which also plays an important role in improving performance parameters, this is influenced by the used algorithm, i.e., the iterative algorithm that aims to perform repetitions to obtain optimal results so that it can allocate power on D2D and relay devices. Then for the performance parameters of the power efficiency scheme, half duplex is superior compared to other communication schemes because it is influenced by power consumption when communicating alternately less, so it is efficient in power use. If compared with a full-duplex communication scheme that performs two-way communication simultaneously using a lot of power, the relay-aided scheme also provides low power efficiency. This is due to the addition of power used by the relay device, so the power consumption increases. but this can be optimized by performing power allocation using the iterative algorithm on this scheme. Therefore, based on the analysis that has been done, it can be concluded that a relay-aided scheme can be a solution to the D2D communication problem.

4. Conclusion

The study dealt with relay-aided demonstrations on device-to-device communication underlay of the 5G cellular network. Using relay can improve performance parameters from the sumrate side and spectral efficiency. The results of the simulation showed that the performance parameters of the power efficiency relay-aided communication scheme provide less effective energy efficiency due to the addition of power to the relay device, which causes increased power consumption. The results of the simulation also showed that after power allocation with iterative algorithms on a relay-aided communication scheme, sumrate values of 1,970 × 107 bps, spectral efficiency of 19,704 bps/Hz, and power efficiencies of 7,672 × 103 bps/mmW and experienced an increase of 55%. The further distance between the D2D pair results in increased sumrate values, spectral efficiency, and power efficiency. This is caused by the increasing radius of the BS and CU, so that the interference is becoming smaller and smaller. Using iterative algorithms on relay-aided communication schemes can improve performance parameters compared to full-duplex and half-duplex communications schemes. The results of the research showed that relay-aided schemes are the most optimal communication schemes for dealing with transmission systems on D2D because, with the use of relay-aided schemes, the capacity and range of transmission systems are improved.

5. Acknowledgement

Appreciation for the lecturers of the Institute Technology Telkom Purwokerto, in particular Ms. Khoirun Ni’amah S.T., M.T. and Mr. Dr. Alfin Hikmaturokhman S.T., M.T. as a guide has given a lot of criticism and advice in completing this study.

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