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RESEARCH ARTICLE

A New Adaptive Power Control Based on LEACH Clustering Protocol for Interference Management in Cooperative D2D Systems

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ABSTRACT The cooperative device-to-device (D2D) system is becoming one of the most popular communication models in wireless 5G technology that combines the D2D system with cooperative communication to extend coverage and increase system performance. However, interference is one of the factors of decreasing service quality in cooperative D2D systems because of adjacent users/clusters and excessive power usage, which also causes interference to the receiver. Interference management, such as power control, can overcome interference problems in the cooperative D2D communication system. Therefore, this paper proposes a new form of adaptive power control (APC) based on the low-energy adaptive clustering hierarchy (LEACH) protocol for interference management systems in cooperative D2D systems that other studies have not considered. For a fair comparison, this paper also modifies the conventional fixed power control (FPC) method using the LEACH protocol and the modified fixed power control (MFPC) used in the previous study and then considers the system without power control. The simulation results show that the proposed APC can significantly reduce interference in cooperative D2D communication compared to the MFPC and without power control. Moreover, the simulation results also show that concerning the signal-to-interference and noise ratio (SINR) to the outage probability and throughput, the proposed APC performs better than the MFPC and without power control. Thus, the proposed APC can effectively reduce interference in cooperative D2D systems.

INDEX TERMS Adaptive power control, LEACH clustering protocol, interference management, cooperative D2D.

I. INTRODUCTION

Information and communication technology development is improving [1], especially in cellular telecommunications, which has rapidly grown as a popular communication mode [2]. The result of this technology cannot be separated from the increasing number of cellular users and services. It encourages service providers to increase customer satisfaction as well as improve service quality [3]. Based on research by Jakubowski [4], the number of internet users worldwide by 2021 will significantly increase, reaching 53.6%. The research also states that the number of users will continue to grow in the following years. Of course, it will be a big challenge for telecommunication service providers to improve their performance and capacity. The increasing number of cellular service users increases traffic density for base transceiver station (BTS) or evolved Node B (eNB) services, demanding service providers to increase the capacity and quality of their services. Efforts to do so continue to be carried out by various related parties, both the industry as service providers and academics as providers of existing technological innovations. One of the technologies

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developed is device-to-device (D2D) communication technology [4], [5], [6].

D2D communication is a feature in user equipment (UE) units that allow two of them to communicate directly without going through eNB [7]. D2D communication technology aims to reduce the traffic load in eNB coverage. When cellular service is unavailable, this technology allows two UE units to communicate over a certain distance [8]. However, a cluster is covered by eNB services, so there are two types of communication simultaneously in that condition. This condition results in inter-cell interference or interference with each other [9] because of the same frequency or short-range and transmit power provided by each UE [10]. This can cause the degradation of system performance. One solution is to regulate the power using the power control method. It can reduce interference and increase system capacity and wireless communication quality. In other conditions, user interference can coincide in the same or different clusters on the same channel. This interference is caused by each user's disproportionate use of transmit power. Interference can also occur between one cluster with another (intra-cluster interference) and among cluster members (inter-cluster interference), thus worsening system performance. Therefore, it is necessary to have a power control system applied on the user side to minimize intra-cluster and inter-cluster interference. The power control method aims to ensure that the transmitter power reaches a level high enough to be detected by the receiver but low enough to avoid interference with other users.

Research on the low-energy adaptive clustering hierarchy (LEACH) protocol has been considered for use in wireless sensor networks (WSNs) for clustering and routing systems, as in Tyagi and Kumar [11]. LEACH is a popular protocol used in WSNs based on adaptive clustering techniques; in research conducted by Tyagi, various models of cluster selection based on LEACH are shown and aim to increase network lifetime, reduce energy consumption, and improve system performance. Meanwhile, Xiangning and Yulin [12] conducted a study related to the LEACH protocol. As a result, two scenario models of the LEACH protocol are introduced—energy LEACH and multi-hop LEACH. The two proposed methods have different schemes for selecting cluster heads (CHs). According to Xiangning et al., the energy LEACH model performs better than the multi-hop LEACH model.

Cooperative communication systems have been introduced to improve system performance and to extend network coverage [13], [14], [15]. A cooperative D2D system is a communication model in the D2D system in which one or more devices serve as relays in transmitting the information to the destination. Interference management is crucial to reduce the impact of interference and increase the reliability of the cooperative D2D system. However, to the best of the authors' knowledge, the literature on interference management for cooperative D2D systems is scant. Several studies have also been carried out for D2D [16], [17], [18] and cooperative D2D systems [19], [20]. Such research [16], [17], [18] focuses on interference management in D2D systems. First, Doumiati et al. [16] proposed the interference network model as a connected graph, turning the clustering problem into a graph partitioning problem. To solve this, we based our method on the relaxation of the semi-definite problem (SDP) of the maximum truncation algorithm while calculating the maximum number of devices allowed within a multiple-input multiple-output (MIMO) cluster environment. Then Doumiati et al. [17] proposed joint clustering and topological interference management (TIM) for the D2D system. Finally, Kasi et al. [18] proposed a new decentralized interference management methodology for dense LTE-A-based in-band D2D underlay. The proposed interference management scheme can separate the interference in the network into cross-cluster and intra-cluster interference, and then the interference is handled separately. In contrast, other studies [19], [20] focused on interference management in the cooperative D2D communication system. Ghallab and Shokair [19] proposed an amplify-and-forward (AF) strategy method with maximum ratio combining (MRC) to reduce interference and cancellation in the cooperative D2D communication system. Based on their proposed method, it can increase throughput and improve the bit error rate (BER) as well as the effect of the number of D2D pairs on the outage value. Meanwhile, Bakhsh et al. [20] proposed a new relay selection (RS) method with cooperative beamforming (CBF) techniques to increase the signal-to-interference and noise ratio (SINR) at the receiver for a cooperative D2D communication system in the cognitive radio network.

This research was motivated by the importance of interference management to support the reliability of cooperative D2D systems. Thus, we propose a new form of adaptive power control (APC) using the LEACH protocol for interference management in a cooperative D2D system, which has not been considered in previous studies. We have implemented a clustering model using the LEACH protocol for cooperative D2D systems [21]. However, the LEACH protocol in the previous work was used as a CH selection method based on the number of nodes available in the cooperative D2D system. Also, our previous work only focused on calculating energy consumption. The proposed LEACH protocol has shown that it can increase network life and reduce energy consumption in cooperative D2D communication systems. As a result, this research was conducted by combining the power control method proven to reduce the level of interference with the LEACH protocol for CH selection.

This paper proposes a new form of APC based on the LEACH clustering protocol for a cooperative D2D system to reduce the level of interference. In this paper, the CH is considered not to send information to all cluster members but only to active members. So in addition, the system can reduce the level of energy consumption and the level of interference. In managing the existing interference, the proposed APC is used to improve the quality of existing services. The transmitted power in wireless communication is a crucial factor in determining the quality of service. The greater the power provided, the wider the communication coverage area. However, the excessive use of power will cause interference between the receiver and transmitter, including interference to adjacent transceivers. The proposed APC manages interference by adjusting the power control used by a transceiver device. This paper also modifies the conventional power control method based on the LEACH clustering protocol, called modified fixed power control (MFPC), and also with systems without power control to compare the effectiveness of the proposed APC to reduce interference. MFPC is a power control method used in previous studies. However, it has been modified using the LEACH protocol in this study. The main contributions of this paper are as follows:

- We propose a new form of APC that can reduce the transmit power at a predetermined distance and the interfering device power when the interference values are the same among devices in the system.
- Using the LEACH cluster clustering protocol, we derive a mathematical analysis of the proposed APC for the uplink and downlink of D2D cooperative communication systems.
- We provide closed-form outage probability and throughput analysis for the proposed APC in a cooperative D2D communication system.

II. SYSTEM MODEL

This paper proposes a new APC method to reduce interference in D2D cooperative systems by controlling the power emitted by the device user equipment (DUE) and cellular user equipment (CUE). In the system model, we consider a number of DUE and CUE grouped into clusters using the LEACH protocol. Each cluster has two communication modes: cooperative D2D and cellular communication. We assumed that DUE and CUE operate in the half-duplex mode so that the communication process is divided into two phases: uplink and downlink. The uplink phase where CUE communicates with DUE can be seen in Figure 1. On the other hand, the downlink phase where DUE communicates with CUE can be seen in Figure 2. The cooperative D2D communication system utilizes cluster members as relays to forward information. The cooperative protocol used in this research is decode-and-forward (DF) and a number of relays.

In the first phase, DUE plays the role of source (S) in both clusters and transmits the information signal to the CUE relay (R) and DUE destination (D) simultaneously. The information signals received at D and R in the uplink phase, respectively, can be written as follows:

$$ysd_{ul} = h_{s,d(ul)}x_{s,d(ul)} + n_{d(ul)} \tag{1}$$

$$ysr_{ul} = h_{s,r(ul)}x_{s,r(ul)} + n_{r(ul)} \tag{2}$$

where ysd_{ul} and ysr_{ul}, respectively, are the information signals sent from the source (S) to the destination (D) and from S to the relay (R) in the uplink phase (CUE to DUE), $h_{s,d(ul)}$ and $h_{s,r(ul)}$, respectively, are the fading channel coefficients from S to D and from S to R in the uplink phase, where both

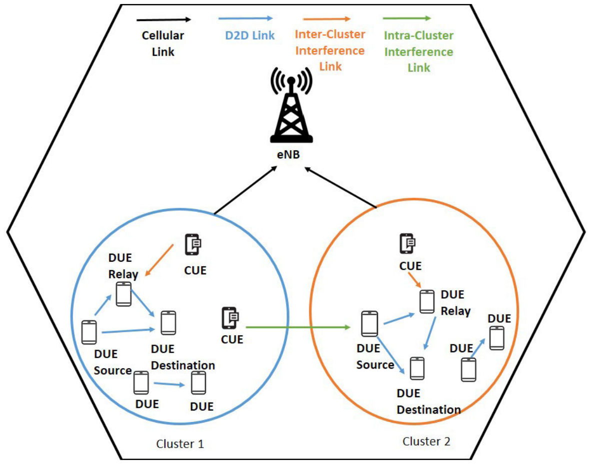

FIGURE 1. System model uplink phase (CUE to DUE).

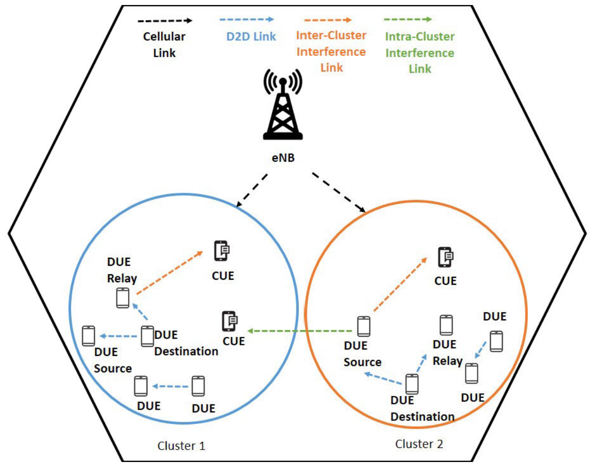

FIGURE 2. System model downlink phase (DUE to CUE).

of them are considered as a Rayleigh flat fading channel that is independent and identically distributed (i.i.d.), $x_{s,d(ul)}$ and $x_{s,r(ul)}$, respectively, are the information signals from S to D and from S to R at the uplink phase, and $n_{d(ul)}$ and $n_{r(ul)}$, respectively, are the Gaussian noises at D and R in the uplink phase (CUE to DUE).

The received information at the relay is then processed using the DF protocol, where the information will be decoded and encoded before being sent to the destination. The information sent by the relay is as follows:

$$yrd_{ul} = h_{r,d(ul)}x_{r,d(ul)} + n_{r(ul)} \tag{3}$$

where yrd_{ul} is the information signal sent from R to D using the DF protocol in the uplink phase, $h_{r,d(ul)}$ is the Rayleigh fading channel coefficient from R to D, and $x_{r,d(ul)}$ is the information signal from R to D. Meanwhile, the received information signal at the downlink phase can be written as follows:

$$yds_{dl} = h_{d,s(dl)}x_{d,s(dl)} + n_{s(dl)} \tag{4}$$

$$ydr_{dl} = h_{d,r(dl)}x_{d,r(dl)} + n_{r(dl)} \tag{5}$$

where yds_{dl} is the information signal sent from D to S at the downlink phase (DUE to CUE) and ydr_{dl} is the information signal sent from D to R at the downlink period (DUE to CUE).

$h_{d,s(dl)}$ and $h_{d,r(dl)}$, respectively, are independent fading channels at the downlink phase from D to S and D to R. $x_{d,s(dl)}$ and $x_{d,r(dl)}$, respectively, are the information signals from D to S and from D to R at the downlink phase. $n_{s(dl)}n_{r(dl)}$ are the Gaussian noises in both D and S at the downlink phase and in both D and R at the downlink phase. It is assumed that interference is due to two types of devices in a cluster and the large transmit power used for signal transmission [22].

This paper uses the LEACH protocol to select the CH, in which the main features of LEACH are coordination and localized control for random data transfer, self-configuration and adaptive clustering, low energy media access, and data processing, such as data aggregation to reduce global communications [23], [24], [25]. The LEACH operation is divided into the setup and the steady-state stages. The setup stage is for cluster formation; each node initially decides whether to be the CH or not for the current round. The node makes this decision by randomly selecting a number between 0 and 1. In contrast, the steady-state stage is for data transfer, where the device sends its data to the selected CH to be forwarded to each cluster member device [23]. In the setup stage, the device selected as the CH is based on the residual energy level at the time interval. Each random device can potentially become a CH if the requirements are met. Otherwise, the device will become a cluster member. CH threshold conditions are calculated using the following formula [21]:

$$T(n) = \begin{cases} \dfrac{P_{opt}}{1 - P_{opt}\left[r mod \left(\frac{1}{P_{opt}}\right)\right]} & \text{, if node } n \in G \\ 0, & \end{cases} \quad (6)$$

where P_{opt} is the ideal level of group heads, r is the current round, and G is the arrangement of hubs that have not become bunch heads at the last round $1/P_{opt}$. The number of possibilities for the device to become a CH (p_{ch}) is calculated using the following formula:

$$p_{ch}(x) = \frac{\gamma^x e^{-\gamma}}{x!}, \quad x = 1, 2, \ldots, 100 \quad (7)$$

where γ is the calculated average of events over a certain period and e is Napier's constant of 2.71828.

A single macro-cell is modeled in the simulation, including CUE and DUE. Simulation scenarios are carried out on the downlink and uplink sides by considering interference among cluster members (inter-cluster interference) and with other cluster members (cross-cluster interference). Two analysis methods were applied in each scenario: the analysis with and without the power control methods. Referring to Figure 1, eNB transmits a broadcast signal to CUE, and then the CUE device transmits an uplink to eNB. Meanwhile, cooperative D2D users communicate directly and use the relay. It has CUE and several D2D pair devices, each D2D pair communicating in a macro-cell network. In this condition, interference occurs between CUE and DUE, which are in the same or different clusters. All paired D2D devices use the same frequency resource as in CUE. The cellular network devices such as eNB are generated automatically at coordinates (x, a), and CUE and DUE are generated randomly. The coordinates of the DUE device generation are determined as follows [26]:

$$Co - DUEx = Radius\ x \cos(a) \quad (8)$$

$$Co - DUEx = Radius\ x \sin(a) \quad (9)$$

where x is the coverage area of the macro-cell (kilometers), while a is worth 0 to 360 degrees.

III. PROPOSED ADAPTIVE POWER CONTROL

The proposed APC reduces the transmit power at a predetermined distance, and the interference value is the same when using the LEACH clustering protocol in the D2D cooperative communication system. The proposed APC regulates the amount of power emitted by the eNB that will be transmitted by the CUE, which can affect other nearby devices, such as D2D. The LEACH clustering protocol is used in groups DUE and CUE. The proposed APC is used on the uplink side to regulate the transmission power from both CUE and DUE so that the interference effect is reduced and the SINR will meet a specific value according to user needs by considering the distances among CUE, DUE, and eNB.

In our proposed APC, we focus on the performance analysis and implementation of the LEACH protocol to reduce the level of interference in the cooperative D2D system. Then we provide closed-form outage probability and throughput analysis for the proposed APC in a cooperative D2D system. Therefore, the proposed system has no focus on stability analysis.

The proposed APC assumes the eNB radius for CUE devices is 100–800 m and the DUE radius is 500–800 m. The distance between CUE and DUE is limited because we used a single relay in this study, so the maximum distance between CUE and DUE is 800 m. Therefore, after generating a DUE device, the next step is calculating the distances among DUE, CUE, and eNB. Then the broadcast signal received by the DUE and CUE devices is estimated. Furthermore, the distance from DUE and CUE to eNB can be calculated as follows [27]:

$$D_{CUE-eNB} = \sqrt{(d_{eNBx} - d_{CUEy})^2 + (d_{CUEx} - d_{eNBy})^2} \quad (10)$$

$$D_{DUE-eNB} = \sqrt{(d_{eNBx} - d_{DUEy})^2 + (d_{DUEx} - d_{eNBy})^2} \quad (11)$$

$$D_{DUE-CUE} = \sqrt{(d_{DUEx} - d_{CUEy})^2 + (d_{CUEx} - d_{DUEy})^2} \quad (12)$$

where $D_{CUE-eNB}$ is the distance between CUE and eNB, $D_{DUE-eNB}$ is the distance from DUE to eNB and $D_{DUE-CUE}$ is the range from DUE and CUE, d_{eNBx} is the distance from eNB when sending information, d_{eNBy} is the distance from eNB when receiving information, $d_{CUEx}$is the distance from CUE when sending information, d_{CUEy} is the distance from CUE when receiving information, d_{DUEx} is the distance from DUE when sending information, and d_{DUEy} is the distance from DUE when receiving information.

The propagation scenario is modeled by Equation (6) for the path loss in the CUE and eNB cases, while the path loss in the DUE and CUE cases uses Equation (7). The path loss is the reduced received power influenced by the earth's contours, the propagation medium, and the distance between the transmitter and the receiver. The longer the distances among the eNB, CUE, and DUE, the more the occurrences of signal path loss along the transmission line, which will affect the quality of the signal at the receiver. Hence, it is necessary to calculate the path loss to design and analyze the system performance. The path losses among eNB, CUE, and DUE are calculated as follows [27], [28], [29]:

$$PL_{CUE-eNB} = 128.1 + 37.6(\log(d1)) \tag{13}$$
$$PL_{DUE-CUE} = 148 + 40(\log(d2)) \tag{14}$$

where $PL_{CUE-eNB}$ is the path loss on CUE and eNB, $PL_{CUE-DUE}$ is the path loss on DUE and CUE, and d is the distance between two devices whose path loss is calculated in kilometers, $d1 = D_{CUE-eNB}$ and $d2 = D_{DUE-CUE}$. Then the power values on the receiving device ($R_{CUE-DUE}$) for both CUE and DUE are calculated as

$$R_{CUE-DUE}\,(dBm) = P_{CUE-DUE}\,(dBm) - PL_{CUE-DUE} \tag{15}$$

where $P_{RCUE-DUE}$ is

$$P_{RCUE-DUE} = P_{CUE-DUE}\, d_{CUE-DUE}\, S_{CUE-DUE}\, h_{CUE-DUE} \tag{16}$$

where $P_{RCUE-DUE}$ is the received power by the receiving device (R), $P_{CUE-DUE}$ is the power transmitted by the sending device (CUE), $d_{CUE-DUE}$ is the distance from CUE to DUE, $S_{CUE-DUE}$ is shadowing, which is the attenuation caused by obstructions in the propagation path from CUE to DUE, and $h_{CUE-DUE}$ is the fading channel coefficient between CUE and DUE devices. The SINRs for the uplink and downlink are calculated using the following equations [26]:

$$SINR^{DL}_{CUEk} = S_{eNB,CUE} \Big/ \sum\nolimits_1^k \left(I_{DUET_k,CUE}\right) + N \tag{17}$$
$$SINR^{UL}_{CUEk} = S_{CUE,eNB} \Big/ \sum\nolimits_1^k \left(I_{DUER_k,CUE}\right) + N \tag{18}$$

where $SINR^{DL}_{CUEk}$ is the SINR at CUE in the downlink period, $SINR^{UL}_{CUEk}$ is the SINR at CUE in the uplink period, $I_{DUER_k,CUE}$ is the interference power in watts, and N is the noise power in watts. The proposed APC works by adjusting the value of the transmit power, which depends on $P_{RCUE-DUE}$. In a condition when D2D devices share resources on the downlink and uplink channel with CUE, the SINR of DUE- k can be calculated by the following equation [29]:

$$SINR^{DL}_{DUEk} = \frac{P_{eNB,DUE_k} G_{eNB,DUE_k}}{rd\,(k)\, P_{TUE_k} CUE_k G_{TUE_k} CUE_k} + N \tag{19}$$

$$SINR^{UL}_{DUEk} = \frac{P_{CUE_k,eNB} G_{CUE_k,eNB}}{rd\,(k)\, P_{TUE_k} CUE_k G_{TUE_k} CUE_k} + N \tag{20}$$

where $SINR^{DL}_{DUEk}$ is the SINR at DUE in the downlink period, $SINR^{UL}_{DUEk}$ is the SINR at DUE in the uplink period, P_{eNB,DUE_k} is the transmitted power from eNB to DUE, G_{eNB,DUE_k} is the channel gain from eNB to DUE, P_{RDUE_k,CUE_k} is the received power from DUE to CUE, and $G_{DUE_k CUE_k}$, is the channel gain from DUE to CUE. P_{RCUE_k,DUE_k} is the received power from CUE to DUE, $G_{DUE_k CUE_k}$ is the channel gain from CUE to DUE, $rd\,(k)$ is the indicator for equality of using the downlink resources (1 if the resources used are the same and 0 if the resources used are different), and ru (k) is the indicator for equality of using the uplink resources (1 if the resources used are the same and 0 if the resources used are different).

The SINR value on the D2D user transmitter (TUE) and receiver (RUE) on a k-channel resource is obtained as follows:

$$SINR^{DL}_{RUEk} = rd(k) P_{TUE_k} RUE_k \big/ P_{eNB,RUE_k} G_{eNB,RUE_k} + N \tag{21}$$

where P_{RDUE_k,CUE_k} is the received power from DUE to CUE, P_{eNB,CUE_k} is the transmitted power from eNB to CUE, and G_{eNB,CUE_k} is the channel gain from the link eNB to CUE. The condition when a D2D device pair shares resources with mobile users on an uplink channel by multiple uplink resources is calculated as follows:

$$SINR^{UL}_{k} = \frac{ru(k) P_{CUE_k} RUE_k GTUE_k RUE_k}{P_{CUE_k} RUE_k G_{CUE_k} RUE_k} + N \tag{22}$$

where P_{DUE,CUE_k} is the transmitted power from DUE to CUE, $G_{DUE,CUEk}$ is the channel gain from DUE to CUE, and PR_{DUE,CUE_k} is the received power by the link DUE to CUE. The SINR value for interference that occurs between fellow cluster members (inter-cluster) and with other clusters (intra-cluster) can be calculated using the following equations [30]:

$$I_{inter-cluster} = \sum\nolimits_{i=1}^{m} SINR_{i\_CUE-DUE} \tag{23}$$
$$I_{intra-cluster} = \sum\nolimits_{j=1}^{n} SINR_{j\_CUE-DUE} \tag{24}$$

where $SINR_{i\_CUE-DUE}$ is the SINR for the interference from the *i-th* inter-cluster and $SINR_{j\_CUE-DUE}$ is the SINR for the *j-th* intra-cluster interference, while m is the total inter-cluster interference that occurs ($i = 1, 2, 3, \ldots, m$) and n is the total interference intra-cluster that occurs ($j = 1, 2, 3, \ldots, n$). So the total SINR is as follows:

$$SINR_{total} = PR_{CUE-DUE} \big/ I_{inter-cluster} + I_{intra-cluster} + Noise \tag{25}$$

where $PR_{CUE-DUE}$ is the received power by the base station from the UE, both CUE and DUE, $I_{inter-cluster}$ is the total inter-cluster interference power, and $I_{intra-cluster}$ is the total intra-cluster interference power.

This paper also modifies the fixed power control (FPC) as a more objective comparison for the proposed APC using the LEACH protocol. The FPC has been introduced in previous studies, but this paper modifies it using the LEACH clustering protocol MFPC. The procedure for the MPFC method is the same as for the proposed APC, but it reduces the interference transmit power if the interference values are the same. While the path loss is calculated using Equations (13) and (14), the acceptability is calculated by Equation (16), and the SINR value on the uplink and downlink sides of the CUE is obtained based on Equations (17) and (18). Meanwhile, the SINR value during the downlink and uplink DUE phases are estimated using Equations (19) and (20).

IV. PERFORMANCE ANALYSIS

This section will analyze the performance of outage probability and throughput. The BER can be tolerated at a certain threshold, but if the error rate exceeds the specified threshold value, it will result in poor system performance assuming the error rate is set according to the minimum SINR value, namely, the SINR threshold limit on the system. Outage probability is a poor condition in the system where the system fails to send the destination information. The probability of blackout is one of the parameters to determine the excellent or poor performance of the wireless network system. Therefore, the channel outage probability can be used to evaluate the performance of the wireless relay network system. The outage probability in the uplink for inter- and intra-clustering can be calculated as follows:

$$P_{out-inter-cl(ul)} = P_{RCUE-DUE}\{\gamma_{inter-cl-ul} \leq \gamma_{th-ul}\} \quad (26)$$
$$P_{out-intra-cl(ul)} = P_{RCUE-DUE}\{\gamma_{intra-cl-ul} \leq \gamma_{th-ul}\} \quad (27)$$

where $P_{out-inter-cl(ul)}$ is the outage probability among cluster members on the uplink phase, $P_{out-intra-cl(ul)}$is the outage probability between cluster members and other clusters on the uplink side, $\gamma_{inter-cl-ul}$ is the SINR at $inter - cl$ during the uplink phase, $\gamma_{intra-cl-ul}$ is the SINR at $intra - cl$ at the uplink phase, and γ_{th} is the SINR threshold at the uplink phase. For the downlink, the outage probability for inter- and intra-clustering is as follows:

$$P_{out-inter-cl(dl)} = P_{RDUE-CUE}\{\gamma_{inter-cl-dl} \leq \gamma_{th-dl}\} \quad (28)$$
$$P_{out-intra-cl(dl)} = P_{RDUE-CUE}\{\gamma_{intra-cl-dl} \leq \gamma_{th-dl}\} \quad (29)$$

where $P_{out-inter-cl(dl)}$ is the outage probability among cluster members on the downlink phase, $P_{out-intra-cl(dl)}$ is the outage probability between cluster members and other clusters on the downlink phase, $\gamma_{inter-cl-dl}$ is the SINR at the inter-cluster during the downlink phase,$\gamma_{intra-cl-dl}$ is the SINR at the intra-cluster at the downlink phase, and γ_{th-dl} is the SINR threshold at the downlink phase.

The throughput is the amount of data information that can be passed and received by the destination for each unit of time, which can also be interpreted as the number of data packets that have been successfully sent to the destination from a number of attempts to send information every second. The throughput can be calculated by considering the outage probability or SINR. Then the throughput can be calculated using the following equation [31]:

$$\tau_{inter-cl-ul} = (1 - P_{out-inter-cl(ul)})\tau_{th} \quad (30)$$
$$\tau_{intra-cl-ul} = (1 - P_{out-intra-cl(ul)})\tau_{th} \quad (31)$$

where $\tau_{inter-cl-ul}$ is the throughput among cluster members on the uplink phase, $\tau_{intra-cl-ul}$is the throughput between cluster members and other clusters on the uplink side, and τ_{th} is the throughput threshold at the uplink. The throughput in the downlink phase for inter- and intra-clusters are as follows:

$$\tau_{inter-cl-dl} = (1 - P_{out-inter-cluster-dl})\tau_{th} \quad (32)$$
$$\tau_{intra-cl-dl} = (1 - P_{out-intra-cluster-dl})\tau_{th} \quad (33)$$

where $\tau_{inter-cl-dl}$is the throughput among cluster members on the downlink phase, $\tau_{intra-cl-dl}$is the throughput between cluster members and other clusters on the downlink side, and τ_{th} is the throughput threshold at the downlink.

V. NUMERICAL RESULT

This section presents the simulation results of outage probability and throughput of the proposed APC for interference management in cooperative D2D with LEACH clustering. The computer simulation has been conducted using MATLAB R2018a programming. First, the Rayleigh fading channel and the BPSK modulation are considered in the cooperative D2D system. Then the proposed APC simulation results are compared to those without power control and MFPC. Moreover, in the simulation, the radius of the macro-cell is 1 km, while the maximum distance between cooperative D2D devices is 100 m, the distance between CUE and eNB is 100 to 500 m, and the distance between D2D and eNB is 500 to 900 m. The maximum transmission from eNB is 23 dB, the maximum transmission from CUE is 23 dB, and the thermal noise is −174 dBm/Hz. The detailed simulation setup is presented in Table 1.

Before performance analysis in the form of outage probability and throughput, mapping is done to determine the number of users in a macro-cell network. Figure 3 shows a simulation result of available devices in a macro-cell network, where red represents unavailable devices, green means active cellular devices, blue represents D2D devices, and the asterisk (∗) denotes devices that are CHs for both CUE and DUE.

In addition to facilitating clustering and selecting CHs by determining the number of active and inactive devices on a network, the possibility of interference between CUE and DUE can be identified. The more active the CUE and DUE devices, the higher the possibility of interference. Then the outage probability and throughput analysis are obtained by determining which devices are involved in the network.

TABLE 1. Simulations parameters [27], [28], [29].

Parameter	Value
Number of devices	80 DUE and 20 CUE
Radius macro-cell	1 km
Max. distance between cooperative D2D devices (S-R-D)	100 m
Max. transmission (eNB)	46 dB
Max. transmission (CUE)	23 dB
Thermal noise	−174 dBm/Hz
CUE–eNB distance	100−500 m
D2D–eNB distance	500−900 m

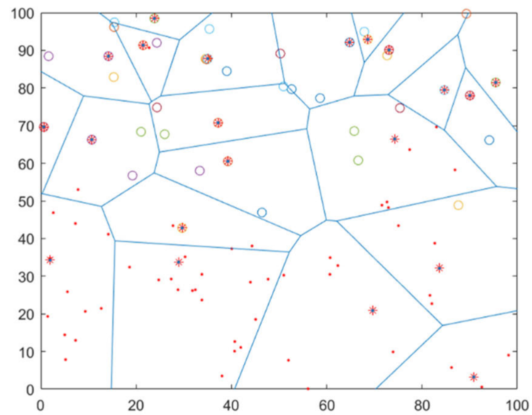

FIGURE 3. Simulation results of D2D device and cellular device on macro-cell network.

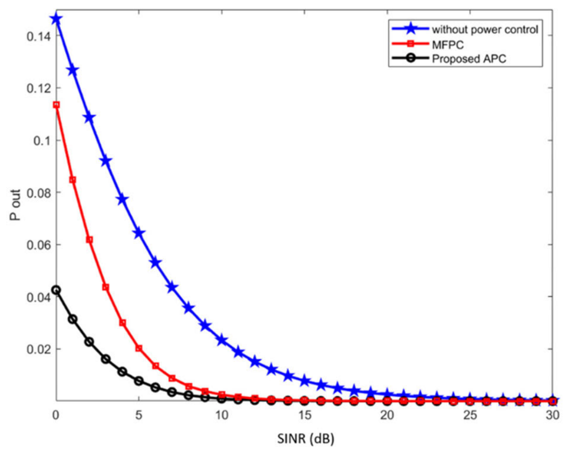

FIGURE 4. Outage probability and SINR for uplink inter-cluster communication on the cooperative D2D communication system.

A. OUTAGE PROBABILITY

This section analyzes the outage probability and SINR for communication among clusters on a cooperative D2D communication system in the uplink and downlink phases. Figure 4 shows the simulation results of SINR impact on the cooperative D2D communication system's outage probability at the uplink for the inter-cluster. The proposed APC works by reducing the interference transmission power when the distance is less than 500 m from the CUE device and less than 800 m from the DUE device. All interferences are reduced transmission power. Reducing the interference power will affect the received interference power by CUE. Furthermore, using the path loss value obtained previously, the receiver and interference power are calculated. Then the SINR value is calculated against the outage probability. The FPC has the condition that the transmitter that reduces its transmission power is the interference if the interference values are the same. For example, at a 5 dB SINR, the outage probability without power control is 0.063, using the MFPC is 0.021, and the proposed APC produces 0.014. The simulation results show that the proposed APC can reduce interference significantly compared to the two conventional APC methods.

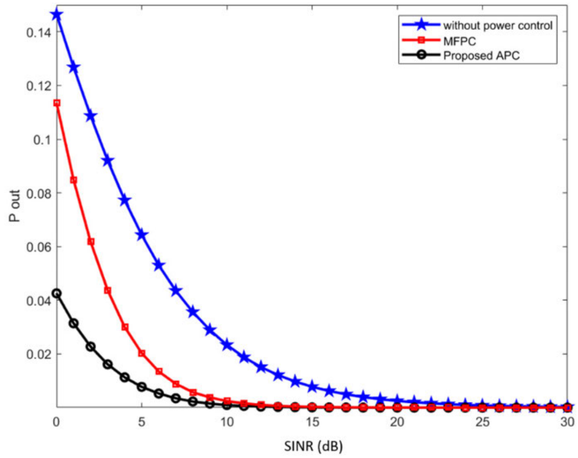

FIGURE 5. Outage probability and SINR for uplink intra-cluster communication on the cooperative D2D communication system.

Fig. 5 shows the simulation result of the SINR's impact on the D2D cooperative communication system's outage probability at the uplink for the intra-cluster. The simulation results generally show that the outage probability decreases with the increase in SINR. For example, the outage probability value at a 5 dB SINR without using the power control method is 0.063, the MFPC method at the same SINR is 0.015, and the proposed APC is 0.012. Based on the simulation result, the proposed APC could reduce outage probability in the uplink inter-cluster and intra-cluster on the cooperative D2D communication system.

Figure 6 shows the SINR and outage probability simulation results on the downlink network's inter-cluster D2D cooperative communication system. The results are also compared with those of the proposed APC with MFPC and without power control, in which the simulation process and parameters are the same as the results in Figures 4 and 5. The results in Figure 6 show that the outage probability of the proposed APC is lower than that without power control and MFPC. For example, the outage probability value at a 5 dB SINR without the power control method is 0.062, using the MFPC method

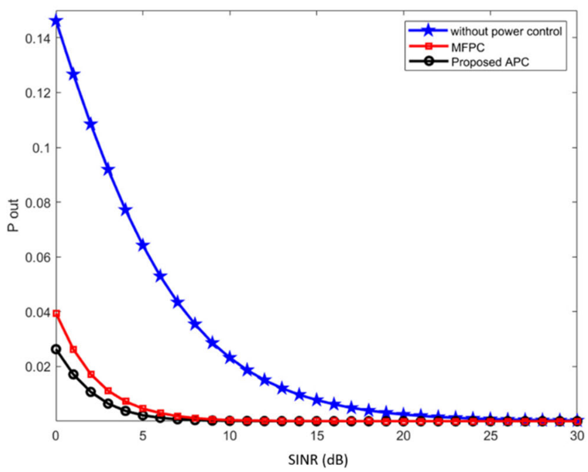

FIGURE 6. Outage probability and SINR for downlink inter-cluster communication on the cooperative D2D communication system.

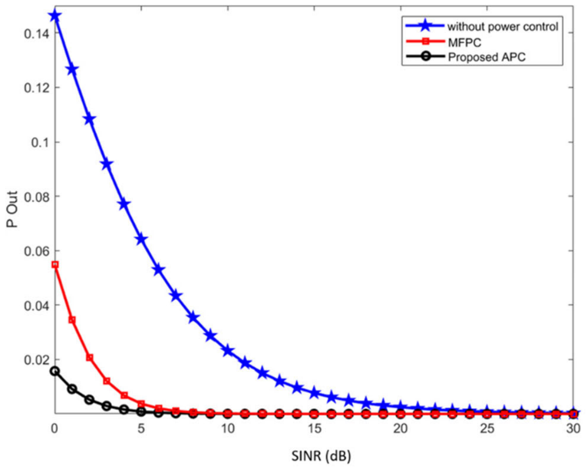

FIGURE 7. Outage probability and SINR for downlink intra-cluster communication on the cooperative D2D communication system.

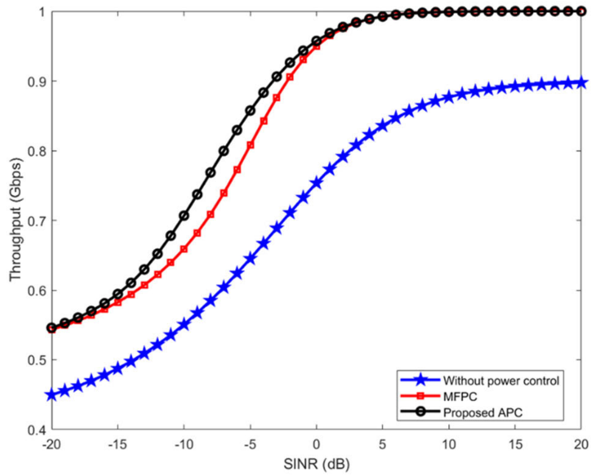

FIGURE 8. Throughput and SINR for uplink inter-cluster communication on the cooperative D2D communication system.

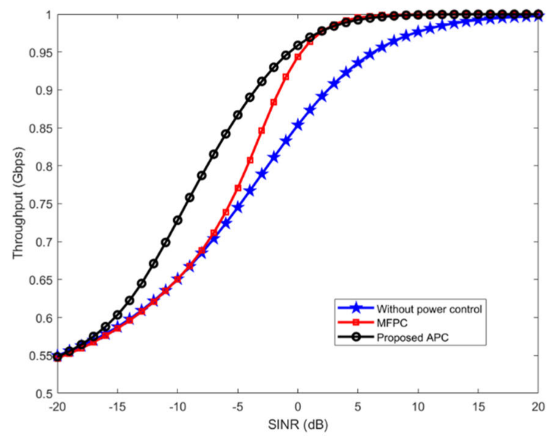

FIGURE 9. Throughput and SINR for uplink intra-cluster communication on the cooperative D2D communication system.

at the same SINR is 0.016, and using the proposed APC is 0.012. This means that the proposed APC could minimize the impact interference in the downlink phase and produces high performance with a lower outage probability.

The simulation results for the SINR and outage probability on the downlink network's intra-cluster D2D cooperative communication system are shown in Figure 7. The simulation was conducted similar to that in Figure 6, and the results between them were compared. As shown in Figure 7, the outage probability of the proposed APC in this study resulted in a lower outage probability than without power control and MFPC. The proposed APC produces the lowest outage value among all the power control methods. Meanwhile, without power control, it produces the worst blackout in the system. For example, the outage probability at a 5 dB SINR without the power control method is 0.061, the MFPC is 0.015, and the proposed APC is 0.011.

B. THROUGHPUT

This section analyzes the throughput and SINR for communication among clusters on a cooperative D2D communication system on the uplink and downlink phases. Figures 8 and 9 show the simulation results of the impact of the SINR on the throughput for uplink inter-cluster and intra-cluster D2D cooperative communication systems. The threshold rate, in this case, is assumed to be 1 bit/s/Hz, and the threshold for the throughput is 1 Gbps. Devices in this paper are supposed to be ordinary cellular users (CUE) and D2D users (DUE). Interference between the two devices can be inter-cluster or intra-cluster. The results of the average throughput values for each (inter-cluster and intra-cluster) are shown in Figures 8 and 9, in which the system with the proposed APC produces the best throughput compared to others (inter-cluster and intra-cluster).

The simulation results of the impact of the SINR on the throughput for downlink inter-cluster and intra-cluster D2D cooperative communication systems are shown in Figures 10 and 11. In the simulation, the radius of the macrocell is 1 km, the distance between CUE and eNB is a maximum of 500 m, and the distance between DUE and eNB is 900 m. The average throughput results for the inter-cluster and intra-cluster are shown in Figures 10 and 11. The proposed APC also produces the best throughput value (inter-cluster and intra-cluster). Thus, the throughput gener-

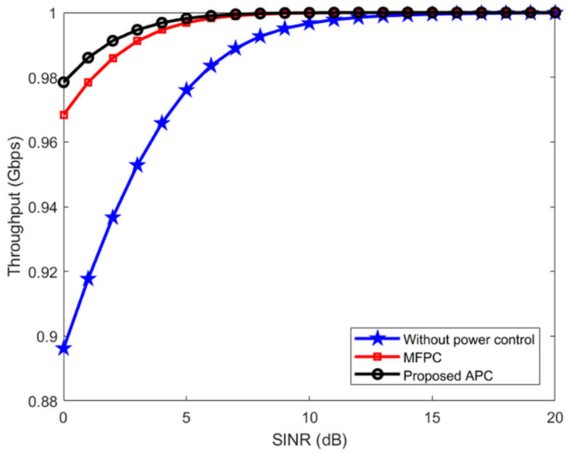

FIGURE 10. Throughput and SINR for downlink inter-cluster communication on the cooperative D2D communication system.

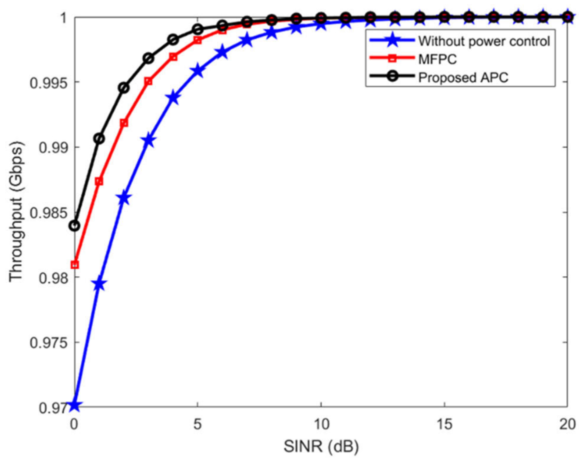

FIGURE 11. Throughput and SINR for downlink intra-cluster communication on the cooperative D2D communication system.

ated by the proposed APC is the highest compared to the others for downlink and uplink on a cooperative D2D system. So the proposed APC can reduce the influence of interference, provide excellent outage probability performance, and have high throughput in the cooperative D2D communication system.

VI. CONCLUSION

This paper has proposed a new APC based on the LEACH clustering protocol to manage interference in cooperative D2D systems. The system model and closed-form performance analysis consider the proposed APC in the cooperative D2D. This paper considered inter-cluster and intra-cluster interferences, where a macro-cell network has active and communicating CUE and DUE users. The computer simulation was conducted to analyze the outage probability and throughput of the proposed APC and its comparison with the conventional methods (without power control and MFPC) from previous research. The MFPC was a modified version of conventional FPC using LEACH clustering in this paper. Based on the simulation results, the proposed APC produces a lower outage probability than the MFPC and without power control in both inter-cluster and intra-cluster interferences. Moreover, the cooperative D2D system with the proposed APC has produced a better throughput than MFPC and without power control. Thus, the proposed APC can effectively reduce interference in cooperative D2D systems to support wireless 5G technology.

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