Uplink Power Control Based on SINR for D2D Enabled in Cellular Communication Network

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Abstract. Device-to-device (D2D) communication is a promising technology for achieving the vision of next generation of cellular communication network in which D2D communication is known as one of candidates for fifth generation (5G) cellular network technology. By enabling D2D communication, it allows any two user equipment (UE) to communicate directly without going through enhance Node B (eNB) in Orthogonal Frequency Division Multiple Access (OFDMA) based cellular communication networks. However, with the presence of D2D-enabled UE (DUE) in the macrocell area of OFDMA based cellular network, the fundamental problem of interference arises due to radio resources sharing between conventional UE and DUE. This paper evaluates our two previous proposed power controls (namely, Power Control 1 (PC 1) and Power Control 2 (PC 2)) to reduce that interference effect in the uplink transmission of OFDMA based cellular network. The PC 1 and PC 2 methods were based on the estimated current Signal to Interference plus Noise Ratio (SINR) at the point of interest. Extensive simulation has been carried out to observe the effectiveness of the two power control methods compared to the system without power control. The collected performance parameters in the simulation is SINR and analyses its distribution. The simulation results show that both power control methods on the uplink transmissions outperform the system without power control.

1. Introduction

Device-to-device (D2D) communication is one of enabling technologies for the next generation cellular networks i.e. 5th generation (5G) of cellular network [1]. D2D communication provides proximity services in cellular communication networks. In addition, D2D communication offers the increases in capacity and network coverages [1]. By enabling D2D communication in cellular communication networks, it allows any two User Equipment (UE) to communicate each other without going through any controller node (enhanced node B/eNB). However, deploying D2D communication in existing cellular networks faces interference problems, since D2D communication shares the same frequency resources with the cellular networks where D2D communication are deployed. Hence, exploring the interference mitigation techniques is a crucial aspect to realize the success of D2D deployments. Certainly, there are many techniques to mitigate the interference effects available in the literature, there are radio resource allocation algorithms, interference cancellations, power control methods, etc. The survey for this topic is available in [2-3] just few to mention. In this paper, we focus on the power control method to reduce the interference effects in D2D communication deployed in OFDMA based cellular networks.

In [4-5], we proposed the power control methods for two tier femtocell-macrocell of cellular networks which was one of them called as Power Control Method 1 PC 1 we evaluated in this paper. In
[6], we proposed a power control method called as power control method 2, PC 2 and evaluated PC 1 and PC 2 for D2D communication deployed in cellular communication networks in downlink transmission. In this paper, we evaluate both power control methods PC 1 and PC 2 for D2D communication deployed in OFDMA based cellular communication network in uplink transmission which has not been evaluated in [6].

The rest of this paper is structured as the following. Following this introduction, the system model and power control methods PC 1 and PC 2 are described in Section 2. Section 3 explains the simulation setting, assumptions, results and its discussions. Finally, this paper is concluded in Section 4.

2. System Description
In this paper, we consider a single cell of Orthogonal Frequency Division Multiple Access (OFDMA)-based cellular network (macrocell) for the uplink transmission, i.e. transmission from Cellular User Equipment (CUE) to evolved Node B (eNB) with pair(s) of DUE deployed in the coverage of that macrocell. In this circumstance, two essential scenarios can be considered as depicted in Figure 1. Figure 1 (a) shows that one CUE (served CUE by eNB at the particular time) is transmitting his/her information to eNB and at the same time there are a number of DUEs transmitting to their corresponding DUE pairs. Meanwhile, Figure 1 (b) depicts that a number of CUEs is transmitting their information to eNB and at the same time there is one DUE pair in which one of them is transmitting to his/her pair. It is assumed that CUE and DUE share same sub-channel frequency resources. Therefore, there will be interferences at the receiver of DUE (RUE) caused by CUE and at eNB caused by Transmitter of DUE pair (TUE).

![Figure 1. System Model](image)

Figure 1. System Model (a) One CUE is transmitting to eNB and there are n TUEs transmitting to their corresponding RUEs and (b) One TUE is transmitting to his/her RUE pair and there are n CUEs transmitting to eNB

In Figure 1 (a), denote $P_{tx,CUE}$ as the CUE’s power transmit to eNB. The received power at eNB, $P_{rx,eNB,CUE}$, i.e. uplink condition, can be calculated as the following.

$$P_{tx,eNB,CUE}^{UL} = P_{tx,CUE} \cdot H_{CUE,eNB}$$

(1)

where:
For the path loss model of cellular link that is from CUE or TUE to eNB:

\[ H_{CUE \text{ or TUE, eNB}} = PL_{\text{Cellular Link}}(dB) = 128.1 + 37.6 \log_{10}(d(km)) \]  

(3)

For the path loss model of D2D link that is from TUE to RUE:

\[ H_{TUE, RUE} = PL_{D2D \text{ Link}}(dB) = 148 + 40 \log_{10}(d(km)) \]  

(4)

where:

- \( H_{CUE \text{ or TUE, eNB}} \): the channel gain between CUE or TUE to eNB
- \( H_{TUE, RUE} \): the channel gain between TUE to RUE
- \( PL_{\text{Cellular Link}} \): the path loss for the cellular link from CUE or TUE to eNB in dB
- \( PL_{D2D \text{ Link}} \): the path loss for the D2D link from TUE to RUE in dB
- \( d \): the distance in km.

The interferences at RUE for the intended TUE in Figure 1 (b) are caused by a number of CUEs transmitting to their corresponding eNB at the same sub-channel resources. Suppose there are \( n \) CUEs are transmitting to their corresponding eNB. Therefore, the Signal to Interference plus Noise Ratio (SINR) at the observed RUE can be calculated as follow.

\[ SINR_{RUE, k}^{UL} = \frac{r_{u}(k) P_{TUE, RUE, k} H_{TUE, RUE, k}}{\sum_{i=1}^{m} r_{u}(i) P_{TUE, RUE, i} H_{TUE, RUE, i} + N} \]  

(5)

where:

- \( SINR_{RUE, k}^{UL} \): SINR at the observed RUE \( k \)
- \( P_{TUE, RUE, k} \): the transmit power of TUE \( k \) to the observed RUE \( k \)
- \( H_{TUE, RUE, k} \): the channel gain between TUE \( k \) to the observed RUE \( k \)
2.1. Power Control Methods

We have proposed two power control methods in [6] for the downlink transmission in D2D communication underlaid cellular communication network in which one of them (PC 1) has been proposed for uplink [4] and downlink [5] of two-tier microcell-femtocell cellular networks. In this paper, we apply and evaluate those two power control methods for uplink transmission in D2D communication deployed in OFDMA based cellular network. In this section, we describe the two power control methods. This sub-section is overview of our power control methods described in [6]. The value of transmit power for the next frame transmission time is adjusted according to the following equation.

\[ P_{tx,CUE,eNB}(t_{i+1}) = P_{tx,CUE,eNB}(t_i) + k \gamma \]  \hspace{1cm} (6)

where \( k \) is an indicator value indicating whether the value of \( \gamma \) will increase the transmit power or decrease the transmit power or keep the same of transmit power for the next time of frame transmission \( (t_{i+1}) \) according to the algorithms for PC 1 or PC 2 described in the next sub-sections. The decision to the change of the transmit power at the next time of frame transmission is based on the estimated value of current time SINR \( (\text{SINR}_{est}(t_i)) \). SINR \( (\text{SINR}_{est}(t_i)) \) will be compared to the predetermined SINR \( \text{target} \). In short, the following equation determines whether the power transmit for the next frame transmission time will be increased or decreased or kept same as the transmit power of current transmission time.

\[ P_{tx,CUE}(t_{i+1}) = \begin{cases} \min(P_{tx,CUE}(t_{i+1}), P_{\text{max}}) & \text{if } \text{SINR}_{est}(t_i) < \text{SINR}_{target} \\ P_{tx,CUE}(t_{i+1}) & \text{if } \text{SINR}_{est}(t_i) = \text{SINR}_{target} \\ \max(P_{tx,CUE}(t_{i+1}), P_{\text{min}}) & \text{if } \text{SINR}_{est}(t_i) > \text{SINR}_{target} \end{cases} \]  \hspace{1cm} (7)

The function of \( \min(...) \) and \( \max(...) \) returns the minimum and maximum values of its arguments, respectively. \( P_{\text{max}} \) and \( P_{\text{min}} \) are the maximum and minimum transmit powers of CUE, respectively. Index of CUE in eq. (7) shows that the power in CUE, in case the power control applied at TUE, eq. (7) still applies by changes the index CUE to TUE.

2.1.1. Power Control Method 1 (PC 1). In Power Control Method 1 (PC 1), the multiplication of \( k \) and \( \gamma \) produces the fixed value. The value of \( \gamma \) is set to a constant value as a simulation parameter, meanwhile the value of \( k \) follows the condition in the expression below.

\[ k = \begin{cases} +1 & \text{if } \text{SINR}_{est}(t_i) < \text{SINR}_{target} \\ 0 & \text{if } \text{SINR}_{est}(t_i) = \text{SINR}_{target} \\ -1 & \text{if } \text{SINR}_{est}(t_i) > \text{SINR}_{target} \end{cases} \]  \hspace{1cm} (8)

2.1.2. Power Control Method 2 (PC 2). Power Control Method 2 (PC 2) uses the following equation for the value of \( k \).

\[ k = \begin{cases} +2 & \text{if } \text{SINR}_{est}(t_i) < \text{SINR}_{target} \\ 0 & \text{if } \text{SINR}_{est}(t_i) = \text{SINR}_{target} \\ -1 & \text{if } \text{SINR}_{est}(t_i) > \text{SINR}_{target} \end{cases} \]  \hspace{1cm} (9)
Meanwhile the value of $\gamma$ is determined based on the average value of $n$ estimated interferences received at the observed receiver node (eNB or RUE). eNB or RUE will inform this average value to the transmitter (CUE or TUE). The average value can be calculated using the equation below.

$$\bar{I} = \frac{1}{n} \sum_{j=1}^{n} I_n$$  \hspace{1cm} (10)

3. Simulation Setting, Results and Discussion

The simulation experiment has been done for the scenarios depicted in Figure 1 which was a single cell of cellular network considered. eNB was located in the center of the cell. The radius of macrocell (coverage of eNB) was set to 2000 meters. The system bandwidth was set to 20 MHz. The noise was thermal noise which was set to -174 dBm/Hz. The transmission radius of TUE to RUE was 1000 meters. We evaluated the systems without and with power control methods. The transmitting power for CUE and TUE for the system without power control method was set constant to 17 dBm. For the system with power control methods, the maximum and minimum transmitting powers for CUE and TUE were set to 23 dBm and -40 dBm, respectively [7]. In addition, for the system with power control, the initial transmitting powers for TUE and CUE were set to 17 dBm. The value of $\gamma$ for PC 1 was set to 2 dB.

There were two scenarios that were carried out. In Figure 1 (a), while one CUE is transmitting to eNB, there are $n$ TUEs transmitting to their corresponding RUEs. From our previous results in [6], we have shown that $n$ was equal to 100 enough to study the system for the downlink transmission. With the same reason, in this paper we determined that $n$ is equal to 100. This value of $n$ also was applied to the number of CUEs in Figure 1 (b).

The simulation was run for 10 times and SINR values were collected and averaged. Figure 2 shows the simulation results in terms of Cumulative Distribution Function (CDF) for SINR of Scenario 1 (Figure 2 (a)) and Scenario 2 (Figure 2 (b)). In general, the simulation results showed that the system with both power control methods PC 1 and PC 2 outperformed the system without power control. In Figure 2 (a), the evaluation has been done for one CUE transmitting to eNB with 100 TUEs transmitting to their corresponding RUEs. As shown in the Figure 1 (a), the systems with PC 1 shown to have the best performance compared to the systems with PC 1 and without power control methods. There was interesting the system with PC 2 behaved for the SINR values between -35 dB and -25 dB. In this range of SINR the system with PC 2 was worse than the system without power control. It was unstable due to the system with PC 2 controls its transmitting power based on the average of estimated interferences. However, after that SINR values, the system behaved stable and outperformed the system without power control. When we take the SINR value of 0 dB, the CDF of SINR for the system without power control took the value of 0.8 and the systems with power control took the values of 0.75 and 0.72 for the systems with PC 2 and PC 1, respectively. It can be said that the systems with PC 1 and PC 2 has improved the performance by 6.25% and 10%, respectively, compared to the system without power control.

For the simulation results of scenario 2 in Figure 2 (b), the similar trend as Figure 2 (a) was found. The systems with PC 1 and PC 2 outperformed the system without power control. The region where the system with PC 2 was worse than the system without power control was diminished. It almost cannot be seen. It can be said that both the systems with PC 1 and PC 2 outperformed the system without power control. For the SINR value of 0 dB, the system without power control took the value of CDF of SINR as big as 0.82, meanwhile both the systems with PC 1 and PC 2 took the value of 0.79. It is 3.66% improvement.

4. Conclusion

This paper has evaluated our previous proposed power control methods, PC 1 and PC 2, in the uplink transmission for D2D communication deployed in a single cell of cellular network. The power control method 1, PC 1, works based on the estimated current SINR value, meanwhile power control method 2, PC 2, works based on the average of estimated current interferences. The simulation experiments have been carried out in the single cell of OFDMA based cellular networks. Two scenarios were used to evaluate the power control methods. Those scenarios were observed at the side of eNB (scenario 1) and
at the receiver of D2D user equipment-RUE (scenario 2). The simulation results were collected in term of SINR which is the fundamental parameter for considering the Quality of Service (QoS) parameters for the communication networks. And then it was analyzed using PDF of SINR and compared to the system without power control. In generally, both the systems with PC 1 and PC 2 methods outperformed the system without power control method. When we consider the value of SINR at 0 dB, at the side of eNB, the systems with PC 1 and PC 2 has improved the performance by 6.25% and 10%, respectively, compared to the system without power control. At the RUE side, when we look at the value of SINR at 0 dB, both systems with PC 1 and PC 2 improve the system without power control by 3.66%.

![Figure 2. The Simulation Results (a) for Scenario 1 and (b) for Scenario 2](image)

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