Relay Position considering Interference from Other Sub-Channels in D2D Group-casting Systems

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Abstract – Device-to-device (D2D) communication is a way to communicate directly between devices without going through the base station or other infrastructure. In many D2D communication systems, orthogonal frequency division multiple access (OFDMA) is used in order to maintain the similarity with the mobile communication systems and to secure a sufficient transmission distance. In OFDMA systems, sub-channels, consisting of multiple subcarriers, are used to concurrently support multiple users. Although sub-channels in OFDMA systems are theoretically orthogonal, there is non-negligible interference from other sub-channels due to in-band emission. This paper considers a D2D group-casting system with a relay focusing on the effect of the interference from other sub-channels, and calculates the outage probabilities according to the relay position.

Keywords - D2D, OFDMA, Relay, Groupcasting, Interference, In-band emission

I. INTRODUCTION

Device-to-device (D2D) communication is a method to exchange direct traffic between devices without going through the infrastructure such as a base station or an access point [1-3]. Compared to the traditional communication methods through the infrastructure, D2D communication technology has the advantage of increasing the resource efficiency, improving the system capacity, decreasing the delay and power consumption due to the proximity. In many D2D communication systems, orthogonal frequency division multiple access (OFDMA) is used in order to maintain the similarity with mobile communication systems and to secure a sufficient communication distance. In OFDMA systems, sub-channels, consisting of a group of subcarriers, are used to concurrently support multiple users. In theory, if time and frequency synchronization is perfect, different sub-channels in OFDMA systems are orthogonal and not interfered with each other. However, in real systems, even with perfect time and frequency synchronization, there can be non-negligible interference from other sub-channels due to in-band emission [4-8].

One of popular transmission configurations of D2D communication systems is group-casting with multiple receivers. In group-casting, especially when the transmitter is located near or at the edge of the group, a single transmission from the transmitter may not achieve the required success rate at the receivers. In this case, a relay can be used to reduce the outage probability for the receivers. The use of a relay in a D2D communication system has also some other advantages [9-10]. For example, the transmission power of the D2D transmitter can be reduced due to the short transmission distance. Although there are many studies to consider relays in D2D group-casting systems, most of them do not consider the interference from other sub-channels.

This paper focuses on the interference from other sub-channels with ignoring other effects such as fading or co-channel interference, and considers relay positions in a group to minimize the outage probability due to interference from other sub-channels. When a transmitter sends data to multiple receivers in a group, the error probabilities may not be small for some receivers, especially those far away from the transmitter or close to other sub-channel interferers. To overcome these problems, we consider a repetitive transmission through a relay in addition to the direct transmission between the transmitter and the receivers. In this paper, we calculate outage probabilities considering the interference from other sub-channels and find the position of a relay producing the lowest outage probability. This paper is organized as follows. In Section II, we address the system model considered in this paper and calculate the outage probability. In Section III, we show the performance according to relay positions through simulation results and conclusions are presented in Section IV.

II. OPTIMAL RELAY POSITION FOR GROUP-CASTING

A. System Model

In this paper, we consider a D2D group-casting system with focusing on the interference from other sub-channels ignoring other effects such as fading, insufficient signal power, co-channel interference, and intra-group collisions. We assume that there is sufficient diversity and the power of received signal is sufficiently larger than noise. We also assume that the collisions in the same group and the interference between groups in the same channel can be carefully handled by smart resource management techniques. Hence, we only consider interference from other sub-channels for the cause of reception failures. Although the interference from other sub-channels is very weak and thus only receivers nearby interferers are affected, the interference from other sub-channels cannot be ignored, especially when the number of sub-channels is large. In order to reduce the outage probability due to the interference, a relay can be used. Fig. 1 shows the system model used in this paper. The transmitter (source) sends data to the receivers (destinations) in the group and the relay repeatedly transmits the data to the receivers if the relay successfully received the data.

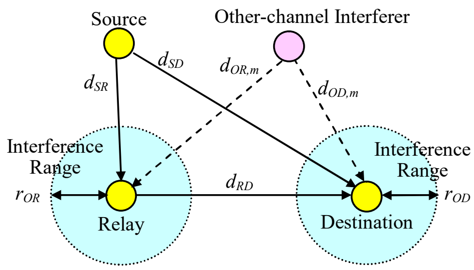

Fig. 1. System model

B. Outage Probability

Suppose that there are M sub-channels in a circular cell with radius R, and there is one D2D group per sub-channel. If we consider the transmission on the n^{th} sub-channel, the other $M-1$ sub-channels produce other-channel interference. Let the interference effect from the m^{th} sub-channel to the n^{th} sub-channel be $\lambda_{m,n}$, where $\lambda_{m,n}=1$ if $m=n$ and $0<\lambda_{m,n}<<1$ otherwise. We consider a source, a destination, and a relay in the n^{th} sub-channel and an interferer in the m^{th} sub-channel, as shown in Fig. 1. d_{SD} represents the distance between the source and the destination, d_{SR} represents the distance between the source and the relay, d_{RD} is the distance between the relay and the destination, $d_{OR,m}$ represents the distance between the m^{th}-channel interferer and the relay, and $d_{OD,m}$ is the distance between the m^{th}-channel interferer and the destination. P_S^{TX} is the transmitting power of the source, P_O^{TX} is the transmitting power of the interferer, and P_R^{TX} is the transmitting power of the relay. The received signal power at the destination can be expressed as $K_1 P_S^{TX} d_{SD}^{\;-\alpha}$, where α is the path-loss exponent parameter between two devices and K_1 is a constant. The received interference power at the destination from the interferer is denoted as $K_1 \lambda_{m,n} P_O^{TX} d_{OD,m}^{\;-\alpha}$. Therefore, The signal-to-interference ratio (SIR) at the destination, denoted as SIR_{SD}, can be defined as follows.

$$SIR_{SD} = \frac{P_S^{TX} d_{SD}^{\;-\alpha}}{\lambda_{m,n} P_O^{TX} d_{OD,m}^{\;-\alpha}} \tag{1}$$

The interference range at the destination, expressed as r_{OD}, can be defined as the minimum distance between the other-channel interferer to the destination that satisfies $SIR_{SD}=\Gamma_D$, where Γ_D is the required SIR value at the destination.

$$r_{OD} = d_{SD}\left(\frac{\Gamma_D \lambda_{m,n} P_O^{TX}}{P_S^{TX}}\right)^{1/\alpha} \tag{2}$$

The outage probability can be approximately calculated by the ratio of the area affected by the other-channel interferer ($r_{OD}^{\;2}\pi$) to the cell area ($R^2\pi$) assuming that interferers are uniformly distributed.

$$P_{SD,m}^{Outage} \approx \min\left(1, \frac{r_{OD}^{\;2}}{R^2}\right) \tag{3}$$

Considering the $M-1$ interferers on the $M-1$ sub-channels, the outage probability of the direct transmission from the source to the destination can be written as follows.

$$\begin{aligned} P_{SD}^{Outage} &= 1 - \prod_{m=1,m\neq n}^{M}\left(1 - P_{SD,m}^{Outage}\right) \\ &\approx 1 - \prod_{m=1,m\neq n}^{M}\left(1 - \min\left\{1, \frac{d_{SD}^{\;2}}{R^2}\left(\frac{\Gamma_D \lambda_{m,n} P_O^{TX}}{P_S^{TX}}\right)^{2/\alpha}\right\}\right) \end{aligned} \tag{4}$$

The outage probability can be reduced by repeated transmission through the relay. In this case, we need to consider two transmissions: from the source to the relay and from the relay to the destination. Let Γ_R be the required SIR at the relay. Similar to Eq. (4), the outage probabilities of the transmission from the source to the relay and from the relay to the destination can be expressed as follows.

$$P_{SR}^{Outage} \approx 1 - \prod_{m=1,m\neq n}^{M}\left(1 - \min\left\{1, \frac{d_{SR}^{\;2}}{R^2}\left(\frac{\Gamma_R \lambda_{m,n} P_O^{TX}}{P_S^{TX}}\right)^{2/\alpha}\right\}\right) \tag{5}$$

$$P_{RD}^{Outage} \approx 1 - \prod_{m=1,m\neq n}^{M}\left(1 - \min\left\{1, \frac{d_{RD}^{\;2}}{R^2}\left(\frac{\Gamma_D \lambda_{m,n} P_O^{TX}}{P_R^{TX}}\right)^{2/\alpha}\right\}\right) \tag{6}$$

The reception process at the destination is successful if the direct transmission from the source is successful or the transmission through the relay is successful. Hence, the outage probability at the receiver can be written as follows.

$$\begin{aligned} P_{Outage} &= 1 - \left\{\left(1 - P_{SD}^{Outage}\right) + P_{SD}^{Outage}\left(1 - P_{SR}^{Outage}\right)\left(1 - P_{RD}^{Outage}\right)\right\} \\ &= P_{SD}^{Outage} P_{RD}^{Outage} + P_{SD}^{Outage} P_{SR}^{Outage} - P_{SD}^{Outage} P_{SR}^{Outage} P_{RD}^{Outage} \end{aligned} \tag{7}$$

Considering all receivers in the group, the outage probability for the group can be calculated using the integration over the group area A, written as

$$P_{Outage}^{Group} = \frac{1}{|A|}\iint_A P_{Outage}\,dxdy \tag{8}$$

assuming the destination is uniformly distributed over the group area.

III. Simulation Results

In order to verify the equations, the outage performance is measured with simulation. In the simulation, there are 25 sub-channels. In each sub-channel, there is one D2D group having a circular area of radius 30m, and 30 receivers are uniformly distributed in each group. The central position of the considered group is (0,0). The source is located from -30m to 0m, and the relay is placed from -30m to 30m on the X axis. We also assume that the transmission powers of the source, relay, and interferers are all same. The detailed simulation parameters are shown in Table 1.

TABLE I. SIMULATION PARAMETERS

Parameters	Values
Cell radius (R)	100m
Group radius	30m
Path loss exponent between two devices (α)	4
The number of sub-channels	25
The number of devices in a group	30
Target SIR at the relay (Γ_R)	10dB
Target SIR at the destination (Γ_D)	10dB
Interference effect to other sub-channels ($\lambda_{m,n}$)	0.001
The position of the source	(30~0 m, 0 m)
The position of the relay	(-30~30 m, 0 m)

Fig. 2 shows the outage probability according to the relay position with various source positions in the group. The solid lines represent the simulation results and the dotted lines show the analytical results. While the analysis considers only the nearest interferer, receivers are affected by the interference from all interferers in the simulation. Hence, an outage probability produced from the simulation is always larger than the corresponding outage probability using the analysis. Fig. 3 shows the optimal relay positions according to the source positions. Note that that the optimal relay position is not the center of a group especially when the source is in the edge of the group since the link between the source and the relay needs to be also reliable.

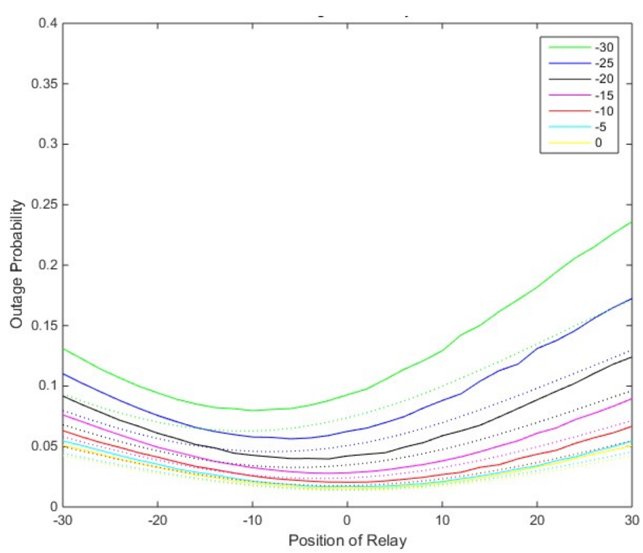

Fig. 2. Outage probability

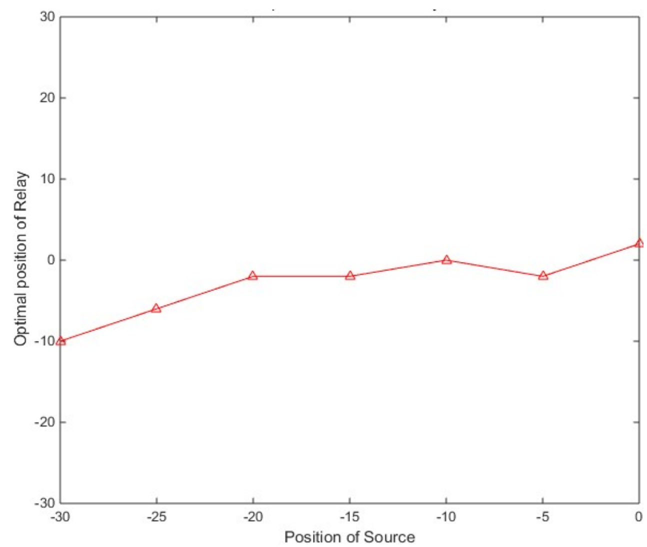

Fig. 3. Optimal relay position

IV. CONCLUSION

In this paper, we have discussed D2D relays for OFDMA-based D2D group-casting systems considering the interference from other sub-channels. We obtained the outage probability according to the relay position through the analysis and simulation. The analytical and simulation results show that the optimal relay position can be determined according to the source position. In this paper, we focused on the interference from other sub-channels and could not consider other causes for the outage such as fading, co-channel interference and intra-group collisions. Further analysis and accurate simulations are required with assumptions that are more practical.

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