A SINR Improvement Algorithm for D2D Communication Underlaying Cellular Networks

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Abstract. In this paper, we study the interference scenario where multiple Device-to-Device (D2D) pairs and one cellular user share the same spectrum resources, and propose a novel D2D signal-to-interference-plus-noise ratio (SINR) improvement algorithm called DSIA from the perspective of precoding and decoding. Numerical results show that in comparison with the traditional spectrum orthogonal scheme, the DSIA will enable D2D to achieve significant SINR gains.

Keywords: D2D, cellular networks, precoding, decoding, SINR.

1 Introduction

Recently, Device-to-Device (D2D) communication underlaying cellular networks has been considered as a promising technology to improve the network spectrum utilization, reduce the network loading, increase the cellular coverage, and decrease the battery consumption of users [1]. Hence, D2D is becoming a research hotspot.

To guarantee the performance of D2D communication, one of important issues is to control the interference. In this paper, we investigate the interference scenario where multiple D2D pairs reuse the same resources allocated to the cellular user, and thus the mutual interference between D2D pairs and the cellular interference to D2D are both involved. According to this consideration, we try to handle the interference problem from the perspective of precoding and decoding, and based on that, a signal-to-interference-plus-noise ratio (SINR) improvement algorithm called DSIA is proposed for D2D. Based on the D2D system with the introducing of a green AF relay, we first formulate the interference control problem as an optimization problem with multiple variables to maximize the SINR of each D2D receiver. Then, the DSIA is proposed to work out this problem and obtain the optimized precoding and decoding vectors which make the SINR of each D2D receiver being maximized which achieves the goal of controlling interference.

In order to verify the performance of the proposed novel algorithm, we execute Monte Carlo simulations for it. Numerical results show that in comparison with the
traditional spectrum orthogonal scheme [2, 3] and the case without interference control, the DSIA will enable D2D involved to obtain significant performance gains in terms of SINR.

2 System Model and Problem Formulation

Here we consider a single cell interference scenario, there exist one base-station, one cellular user \((C)\), one green AF relay \((R)\), and \(M\) D2D pairs involving the transmitter \((S_i)\) with its corresponding receiver \((D_i)\), where \(i \in \Omega\) and \(\Omega = \{1, \ldots, M\}\). The optimization problem to maximize the SINR of each D2D receiver is described in the rest of this section.

First, the signals received by \(D_i\) in two time slots are expressed in vector form as

\[
\mathbf{y}_{D_i} = \begin{bmatrix} \mathbf{y}^{(1)}_{D_i} \\ \mathbf{y}^{(2)}_{D_i} \end{bmatrix} = \begin{bmatrix} h_{S_i D_i}^{(1)} s_i + \sum_{j=1}^{\Omega \setminus i} h_{S_j D_i}^{(1)} x_{S_j}^{(1)} + h_{C D_i}^{(1)} x_{C}^{(1)} + n_{D_i}^{(1)} \\ h_{S_i D_i}^{(2)} s_i + \sum_{j=1}^{\Omega \setminus i} h_{S_j D_i}^{(2)} x_{S_j}^{(2)} + h_{C D_i}^{(2)} x_{C}^{(2)} + n_{D_i}^{(2)} + \beta n_{R D_i}^{(2)} \end{bmatrix}
\]

(1)

where \(\mathbf{y}^{(1)}_{D_i}\) denotes the received signal at \(D_i\) through the direct link in time slot 1, \(\mathbf{y}^{(2)}_{D_i}\) denotes that at \(D_i\) through the relay link and direct link in time slot 2, and \(n_{R D_i}^{(2)}\) denotes the received signal at \(R\). Besides, \(h_{A B}^{(t)}\) denote the channel gains between user \(A (A \in \{S_i, S_j, R, C\})\) and \(B (B \in \{D_i, R\})\) in time slot \(t (t \in \{1, 2\})\), which are assumed to be known at all users and modeled as

\[
h_{A B}^{(t)} = c_{A B}^{(t)} \sqrt{d_{A B}^{(t)}}\alpha, \quad d_{A B}^{(t)} \text{ are the distances of A-to-B links, } c_{A B}^{(t)} \text{ are the channel fading coefficients of these links, and } \alpha \text{ is the path loss exponent.}
\]

Then, defining \(\mathbf{x}_{S_i} = \begin{bmatrix} x_{S_i}^{(1)} \quad x_{S_i}^{(2)} \end{bmatrix}^{T} = v_i s_i\), where \(s_i\) is the data symbol transmitted by \(S_i\) with the expectation \(P_{S_i}\) (the transmit power of \(S_i\)), and \(v_i\) is the \(2 \times 1\) precoding vector of \(S_i\) with the power constraint \(v_i^{H} v_i = 1\). Besides, defining \(\mathbf{x}_C = \begin{bmatrix} x_{C}^{(1)} \quad x_{C}^{(2)} \end{bmatrix}^{T}\), where \(x_{C}^{(1)}\) and \(x_{C}^{(2)}\) are independent, and their expectations is equal to \(P_c\) (the transmit power of \(C\)). By the above definitions, (1) can be rewritten as

\[
\mathbf{y}_{D_i} = \mathbf{H}_{S_i D_i} x_{S_i} + \sum_{j=1}^{\Omega \setminus i} \mathbf{H}_{S_j D_i} x_{S_j} + \mathbf{H}_{C D_i} x_{C} + n_{D_i}
\]

(2)
where $H_{2D1} = \begin{bmatrix} h_{1}^{(1)} & 0 \\ h_{2}^{(1)} & h_{2}^{(2)} \\ \end{bmatrix}$ and $n_{D1} = \begin{bmatrix} n_{D1}^{(1)} \\ n_{D1}^{(2)} + \beta h_{2}^{(2)} n_{D1}^{(1)} \\ \end{bmatrix}$.

Finally, defining $u_i$ as the corresponding 2×1 decoding vector of $D_i$, and the decoded signal at $D_i$ can be obtained via multiplying (2) by $u_i^H$. Based on this, the SINR of each D2D receiver can be obtained, and thus the optimization problem can be formulated as

$$\begin{align*}
\max & \quad \text{SINR}_i(v_1, \ldots, v_M, u_i) \\
\text{s.t.} & \quad v_i^H v_k = 1, \quad \forall k \in \Omega
\end{align*}$$

where $\text{SINR}_i(v_1, \ldots, v_M, u_i) = \frac{P_i u_i^H H_{S,D_i} v_i v_i^H H_{S,D_i}^H u_i}{u_i^H \sum_{j \in \Omega, j 
eq i} P_j H_{S,D_i} v_j v_j^H H_{S,D_j}^H + P_c H_{C,D_i} H_{C,D_i}^H + N_i} u_i$

$$N_i = \begin{bmatrix} \sigma^2 & 0 \\
0 & \sigma^2(1 + \beta^2 [h_{2D1}^{(2)}]^2) \end{bmatrix}.$$ 

3 The SINR Improvement Algorithm for D2D Communication

Apparently, it is difficult to work out the optimization problem (3) directly because multiple optimized variables exist. Therefore, we first simplify the object function of the optimization problem according to the generalized Rayleigh quotient and Rayleigh-Ritz theorem [4], which is expressed as

$$\begin{align*}
\max & \quad v_i^H H_{S,D_i}^H K_i^{-1} H_{S,D_i} v_i \\
\text{s.t.} & \quad v_i^H v_k = 1, \quad \forall k \in \Omega
\end{align*}$$

where $K_i = \sum_{j \in \Omega, j 
eq i} P_j H_{S,D_i} v_j v_j^H H_{S,D_j}^H + P_c H_{C,D_i} H_{C,D_i}^H + N_i$. Then, we can find out the relationship between the optimized variables in accordance with the simplified results, i.e., when $u_i = e_{\text{max}}[M_i]$ and $v_i = e_{\text{max}}[Q_i]$ (where $e_{\text{max}}[\ ]$ denotes the maximal eigenvector, $M_i = P_i K_i^{-1} H_{S,D_i} v_i v_i^H H_{S,D_i}^H$ and $Q_i = H_{S,D_i}^H K_i^{-1} H_{S,D_i}$), the objective function in (4) can achieve the maximal eigenvalue $\lambda_{\text{max}}[Q_i]$, by which the original optimization problem can be transformed to one of solving the nonlinear equations which is expressed as

$$\begin{align*}
v_1 &= e_{\text{max}}[Q_1] \\
\vdots \\
v_M &= e_{\text{max}}[Q_M]
\end{align*}$$
Finally, we combine the idea of Simulated Annealing (SA) metaheuristic [5] with the relationship between variables to propose the D2D SINR improvement algorithm (i.e., DSIA) solving (5), which is shown in Fig. 1.

**Algorithm: DSIA**

Initializing the precoding vector of each D2D transmitter as arbitrary $\mathbf{v}_k^{(0)} (\forall k \in \Omega)$ with the power constraint $\left[\mathbf{v}_k^{(0)}\right]^H \mathbf{v}_k^{(0)} = 1$, and $\text{temp} = T_0$ ($T_0$ denotes the initial temperature).

while $\text{temp} > T_{\text{min}}$ ($T_{\text{min}}$ denotes the lower limit of temperature)

for $l = 1$ to $\delta$ ($\delta$ denotes the amount of inner loop)

Calculating $\mathbf{v}_k^{(l)} = \mathbf{e}_{\max} \left[ \mathbf{Q}_k^{(l-1)} \right]$ and $\Delta_k = \lambda_{\max} \left[ \mathbf{Q}_k^{(l)} \right] - \lambda_{\max} \left[ \mathbf{Q}_k^{(l-1)} \right]$.

if $\Delta_k \geq 0$

Updating $\mathbf{v}_k^{(l)} \leftarrow \mathbf{v}_k^{(l-1)}$

else

Updating $\mathbf{v}_k^{(l)} \leftarrow \mathbf{v}_k^{(l-1)}$ with the probability $\exp(\Delta_k \cdot \text{temp}^{-1})$

end if

$l = l + 1$

end for

Resetting $\mathbf{v}_k^{(0)} = \mathbf{v}_k^{(\delta)}$

Annealing as $\text{temp} = r \cdot \text{temp}$ ($r$ denotes the annealing control parameter)

end while

Outputting the optimized results as $\{\mathbf{v}_1^{\text{opt}}, \ldots, \mathbf{v}_M^{\text{opt}}\}$ and calculating $\mathbf{u}_k = \mathbf{e}_{\max} \left[ \mathbf{M}_k \left( \mathbf{v}_1^{\text{opt}}, \ldots, \mathbf{v}_M^{\text{opt}} \right) \right]$.

Fig. 1. The D2D SINR improvement algorithm: DSIA

4 Numerical Results

In this section, we present several simulations and numerical results to verify the performance of the proposed algorithm. Here we assume that $h_{AB}^{(i)} \sim \text{XN} (0,1)$, $M = 2$, $P_{S_1} + P_{S_2} + P_R = P_S$ ($P_R$ is the transmit power of $R$, $P_S = \hat{P}_{S_1} + \hat{P}_{S_2}$ is the total transmit power of $S_1$ and $S_2$ in the scenario without the introducing of the relay).

For simplicity, we set $P_{S_1} = P_{S_2}$ and $\hat{P}_{S_1} = \hat{P}_{S_2}$. Furthermore, $T_0 = 1$, $T_{\text{min}} = 10^{-5}$, $r = 0.8$ and $\delta = 10$ are set in the DSIA according to [6]. Other key simulation parameters are given below: $\alpha = 2$, $d_{S_1D_1} = d_{S_2D_2} = 10m$, $d_{CD_1} = d_{CD_2} = 50m$, $d_{R} = d_{S_1R} = 10m$, $d_{RD_1} = d_{RD_2} = 10m$ and $\mathbf{v}_k^{(0)} = \left[ \sqrt{2}/2, \sqrt{2}/2 \right]$ ($\forall k \in \Omega$).
Fig. 2 shows the SINR of both D2D receivers with different values of $\frac{P_k}{\sigma^2}$, where $P_c = P_c$ and $P_c/P_k = 1/5$. From this figure, we can see that the DSIA will enable D2D to obtain obvious performance gains in terms of SINR. For example, when $P_c/\sigma^2 = 20$ dB, D2D using the DSIA can achieve SINR gains of 27.64% and 32.01% over that using the spectrum orthogonal scheme and the case with no interference control, respectively.

![Fig. 2. SINR of D2D receivers with various D2D transmit SNR](image)

5 Conclusion

In this paper, we propose a novel D2D SINR improvement algorithm (DSIA) in the interference scenario where multiple D2D pairs and one cellular user coexist. Numerical results show that D2D using the DSIA will make all D2D receivers obtain the same SINR performance, while compared with that using the traditional schemes, significant SINR gains can be achieved as the D2D transmit power increase.

References