Device-to-Device Communication Assisted Interference Mitigation for Next Generation Cellular Networks

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***Abstract*--Advanced interference management schemes have become crucial for achieving the required cell edge spectral efficiency targets and to provide ubiquity of user experience throughout the network, actively discussed for 4G and beyond 4G cellular standards. On the other hands, it requires the significant channel state information (CSI) feedback overhead on consumer units so as to promote the cell-edge performance. In this paper, we explore the interplay between interference management, device-to-device (D2D) communication, and CSI feedback. To show this, a novel interference management method, *D2D communication assisted interference alignment (DIA)* is proposed, which is inspired by subspace intersection property. We believe that the proposed technology can be well applied to consumer mobile communication devices over cellular networks such as smart phones, tablets, etc.**

I. INTRODUCTION

Inter-cell interference has become the major limiting factor in next generation cellular networks with frequency reuse factor one. A promising approach to mitigate the effects of inter-cell interference is cooperative communications between the neighboring cell sites, called coordinated multipoint transmission/reception (CoMP) [1]. On the other hands, it requires the significant channel state information (CSI) feedback overhead so as to promote the cell-edge performance.

Recently, device-to-device (D2D) communications underlying a cellular coverage has recently been proposed as a means of improving the user throughput. In general, collaboration levels of D2D links could be classified into two categories: received-signal forwarding and CSI sharing scenarios. Most prior works on D2D communication have considered the received signal forwarding cases, which act as a cooperative relay in various channel models such as broadcast channel [2], interference channel [3].

In this paper, we propose an advanced interference management scheme exploiting D2D link, operating in different frequency bands compared to cellular links. If D2D cooperation can be exploited to share the CSI among user terminals through the Wi-Fi Direct or Bluetooth networks, which is one scenario of promising future wireless network [1], the proposed interference mitigation scheme needs much smaller amount of channel feedback compared to the conventional schemes with global CSI available at the BS.

Our contribution in this paper is as follows. First, we newly introduce interference mitigation method via D2D links for the future cellular networks, called *D2D communication assisted interference alignment (DIA)*. Based on the numerical results, we demonstrate that the proposed DIA outperforms the conventional multi-user MIMO schemes on the cell outer area.

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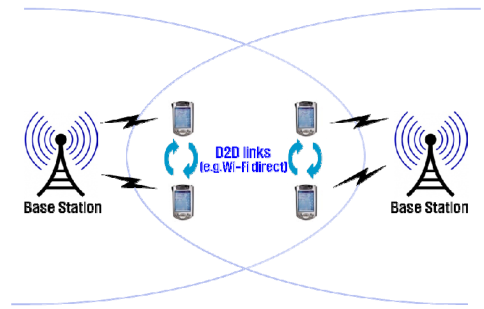

Fig1. D2D communication assisted next generation cellular networks

II. SYSTEM MODEL

Fig. 1 shows the system model of a cellular network assisted by D2D links. The system consists of two BSs with M antennas per BS and K users with N receive antennas per user in each cell, and we will cover general network topology in the full version of the paper. For notation convenience, we refer to the k-th user in the i-th cell as user $[k,i]$.

III. NEW INTERFERENCE MITIGATION WITH HELP OF D2D LINK

In this section, we introduce a new interference mitigation method for both inter-cell interference (ICI) and inter-user interference (IUI) caused by the broadcast nature of wireless medium in the two-cell two-user networks, i.e., $K=2$ with help of D2D connections, and investigate the benefits of exploiting of D2D links compared with existing schemes in terms of multiplexing gain and the amount of channel feedback.

A. Motivating example for (M,N,K)=(3,2,2)

To explain our DIA scheme and its benefits clearly, we start with a simple case of $(M,N,K)=(3,2,2)$ as shown in Fig. 2. The BS 1 wants to deliver two symbols, $s^{[1,1]}$ and $s^{[2,1]}$, to the user [1,1] and user [2,1] using the transmit beamforming vectors $\mathbf{v}^{[1,1]}$ and $\mathbf{v}^{[2,1]}$, respectively. In general, for given receive beamforming vectors, the minimum number of transmit antennas is 4 so that the transmit beamforming vectors cancel out all ICI and IUI. On the contrary, our proposed interference alignment scheme can remove both ICI and IUI with 3 transmit antennas by performing interference alignment. In the following four steps, we present our transmit and receive beamforming design method (i.e., DIA) without the need of global CSI.

Step 1: Sharing interfering channels among users

In order to share CSI between co-located cell-edge users, user terminals perform D2D communication using WPAN such as Wi-Fi Direct or Bluetooth. To be specific, the user [1,2] and the user [2,2] exchange CSI of interfering channels to cooperatively design receive beamforming vectors

Step 2: Designing the receive beamforming vectors

By using CSI of interfering channels acquired in the *step 1*, the user [1,2] and user [2,2] design the receive beamforming vectors $\mathbf{w}^{[1,2]}$ and $\mathbf{w}^{[2,2]}$, so that the effective ICI channels from the BS 1 are aligned with each other, which is

$$span\left(\mathbf{H}_1^{[1,2]\dagger}\mathbf{w}^{[1,2]}\right) = span\left(\mathbf{H}_1^{[2,2]\dagger}\mathbf{w}^{[2,2]}\right)$$

where span($\mathbf{A}$) and $\mathbf{A}^\dagger$ denotes the space spanned by the column vectors of a matrix $\mathbf{A}$ and the conjugate transpose matrix of $\mathbf{A}$, respectively. Note that the channel matrix $\mathbf{H}_j^{[k,i]}$ is the $N\times M$ matrix from the BS j to the user $[k,i]$. We can find out the intersection subspace satisfying the above condition by solving the following matrix equation,

$$\underbrace{\begin{bmatrix} \mathbf{I}_M & -\mathbf{H}_1^{[1,2]\dagger} & \mathbf{0} \\ \mathbf{I}_M & \mathbf{0} & -\mathbf{H}_1^{[2,2]\dagger} \end{bmatrix}}_{6\times 7} \begin{bmatrix} \mathbf{h}_1^{ICI} \\ \mathbf{w}^{[1,2]} \\ \mathbf{w}^{[2,2]} \end{bmatrix} = \mathbf{M}_1\mathbf{x}_1 = \mathbf{0}$$

where $\mathbf{h}_1^{ICI}$ implies the direction of aligned effective interference channels from the BS 1 to the user [1,2] and user [2,2] after applying the receiver beamforming vectors. Since the size of the matrix $\mathbf{M}_1$ is 6x7, it has one dimensional null space. Hence, the receive beamforming vectors for ICI channel alignment can be obtained explicitly with probability one.

Step 3: Feedback the effective channels to the BS

Each user feeds back equivalent channels after applying the receive beamforming vectors determined in the *step 2* instead of channels matrix itself through uplink feedback channels for the cellular networks to its corresponding BS. To be specific, the user [1,2] is required to feed back both the effective serving and interfering channel vectors after applying the receive beamforming vectors.

Step 4: Choosing the transmit beamfroming vectors

Since the effective ICI channels are aligned with each other, the BS 1 can consider two different ICI channel vectors as a one ICI channel vector which spans one dimensional subspace as shown in Fig. 2. Thus, the transmit beamforming vectors should be designed with the effective channel as follows:

$$\mathbf{v}^{[1,1]} \subset \text{null}\left(\left[\left(\mathbf{w}^{[2,1]\dagger}\mathbf{H}_1^{[2,1]}\right)^\dagger \quad \mathbf{h}_1^{ICI}\right]^\dagger\right)$$

$$\mathbf{v}^{[2,1]} \subset \text{null}\left(\left[\left(\mathbf{w}^{[1,1]\dagger}\mathbf{H}_1^{[1,1]}\right)^\dagger \quad \mathbf{h}_1^{ICI}\right]^\dagger\right)$$

where null($\mathbf{A}$) denotes a basis for the null space of a matrix.

IV. Simulation Results and Discussions

We consider a linear cell layout in which two BSs exist and the cooperating MS pair in each cell moves on the line connecting these two BSs. For comparison, we adopt typical multi-user MIMO schemes: block diagonalization (BD) and zero-forcing (ZF) beamforming. Based on the evaluation methodology of 3GPP [1], we choose the inter-BS distance of 500 m, BS transmission power of 43 dBm, and the distance-dependent pathloss L=128.1+37.6log10(R) [dB] where R is a distance in km. Fig. 3 shows the achievable sum rate as the cooperating MS pair moves from the middle of two BSs to its serving BS. As the MSs move into the inside of its serving cell

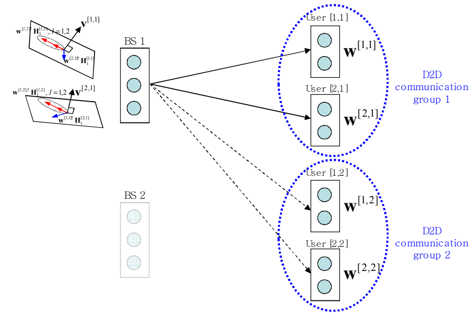

Fig. 2. The concept of the proposed IA scheme for two-cell scenarios

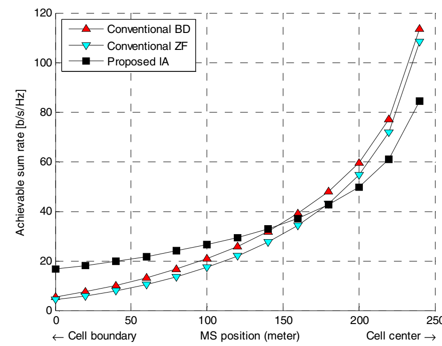

Fig. 3. Simulation results for linear cell layout as a function of MS position

(i.e., the MS position increases), the rate of all schemes is improved by the increase of SNR. Compared to the conventional BD and ZF, the proposed DIA shows better performance up to 150 m from the cell boundary, but shows worse performance as the MSs go to the cell center. This is because the per-cell multiplexing gain (i.e., the number of independent data streams transmitted simultaneously) of the proposed IA is two on the overall cell area, however that of the conventional schemes is three on the cell inside but approaches zero at the cell boundary since they are originally designed without respect to inter-cell interference. This leads us to conclude that the proposed DIA should be adaptively applied according to the level of inter-cell interference.

V. Conclusion

In this paper, we propose a novel cross-network cooperative protocol between D2D and cellular networks, one scenario of promising future wireless networks. Based on the shared CSI through D2D links, transmit and receive beamforming vectors can be jointly constructed so that every ICI and IUI is completely removed with lower CSI feedback overhead, thereby achieving much higher data rate for cell-edge users, such as smart phones, tablets.

Reference

[1] 3GPP TR 36.819 V2.0.0, "Technical specification group radio access network: coordinated multi-point operation for LTE physical layer aspects (Release 11)," Mar. 2010.

[2] R. Dabora and S. D. Servetto, "Multi-user MISO broadcast channel with user-cooperating decoder," IEEE Trans. Info. Theory, vol. 52, pp. 5438-5454, Dec. 2006.

[3] B. W. Khoueiry and M. R. Soleymani, "Destination cooperation in interference channel," *in Proc of IEEE ICCE*, Las Vegas, USA, Jan. 2012.