Distributed Interference Channel Based Resource Allocation for Network-Assisted Device-to-Device Communications

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Abstract—**This paper proposes an advanced distributed resource allocation scheme for device-to-device (D2D) communication using loose network-assistance, namely distributed interference channel based resource allocation (DICRA). The MAC/PHY protocol of the proposed DICRA is described and the performance advantage over FlashLinQ is confirmed from computer simulation results.**

I. INTRODUCTION

Due to recent dramatic increase in data traffic with the proliferation of data services and smart phones, there has been a significant interest in device-to-device (D2D) communications. D2D communications, commonly refer to the technologies that enable devices to communicate directly without an infrastructure, hold the promise of three types of gains : *proximity gain*, *reuse gain* and *hop gain* [1][2]. The most widely used traditional D2D technologies so far, such as Bluetooth [3] and WiFi-Direct [4] operated without any network assistance, face the limitation in improving area spectral efficiency (ASE) of high density (HD) D2D communications, since RTS/CTS mechanism is in general, neither necessary nor sufficient [5]. Consequently, the network assistance functionality (e.g., node synchronization, connection control and resource allocation) in D2D communications becomes the vital condition for effectively solving the aforementioned drawbacks, although it takes some overhead (e.g., information exchange phase) [6].

In recent years, major efforts have been spent on the network-assisted D2D communication [7]-[11]. In [7]-[10] centralized resource allocation and power control algorithms are considered, where D2D communication is considered as an underlay to the cellular network. But, for these centralized approaches, the network is forced to obtain huge information (e.g., channel coefficients for all links) for full control of the D2D connection, including control and data plane functions (e.g., connection setup and resource allocation) as well as the cellular connections, which causes too much overhead.

To alleviate this network heavy load, distributed resource allocations (DRA) using a loose network assistance (synchronicity and control signal resource allocation only), including FlashLinQ [11], have been considered. The goal is to schedule a channel-state aware maximal set at any given time slot based on the current traffic and channel condition, and the scheduling algorithm leads to the ASE gain over the CSMA/CA system (IEEE 802.11g) [12] due to the additionally survived D2D pairs having sufficient signal to interference ratio (SIR). However, it can be further improved if the control signal overhead per pair is reduced and more aggressive interference handling schemes, such as the interference channel (IC) coding scheme [13].

In this paper, an advanced DRA scheme, namely distributed interference channel based resource allocation (DICRA), is proposed. In DICRA, two D2D links form a group by using a network assistance and share the same tone for control information exchange. After competition among groups, surviving groups use IC coding [13] to overcome the intra-group interference. Thus, the proposed DICRA is expected to improve the ASE over a DRA such as FlashLinQ [11]. The rest of this paper is organized as follows. Section II presents the proposed PHY/MAC architecture. Section III shows the advantage of the proposed scheme via computer simulation and Section IV gives concluding remark.

Regarding notation, we will use lowercase (uppercase) letters for scalars, lowercase (uppercase) boldface letters for vectors, and calligraphic letters for set. For example, we write X for scalar, $\mathbf{X}$ for a vector, and $\mathcal{X}$ for set.

II. PROPOSED DICRA

DICRA is designed to be an orthogonal frequency division multiplexing (OFDM)-based synchronous peer-to-peer system, in the same way as FlashLinQ, that enables distributed channel-aware spatial scheduling. The traffic slot (N_T) of the DICRA operation (see Fig. 1) consists of 4 parts: connection scheduling (N_C), rate scheduling (N_R), data (N_D) and ACK (N_A). Let N and N_{sym} be the FFT size and CP added OFDM symbol size, respectively. Also, T_s and $T_{sym}(= T_s \times N_{sym})$ denote the sampling time and symbol time duration, respectively. The scheduling operation occurs every $N_T \times T_{sym}$ msec in the traffic slot. Also, time synchronization, peer discovery and link management is done in every N_F OFDM symbols.

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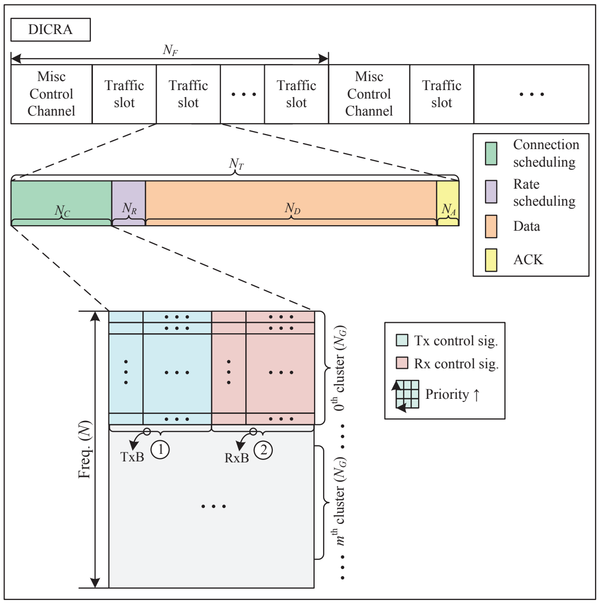

Fig. 1. The DICRA operation timeline

A. Connection scheduling phase

Assume that the network forms the groups where each group consists of neighboring 2 D2D pairs within its cluster using location information (e.g., using GPS). In each group, one D2D pair is randomly selected as the master and the other D2D pair as the slave. In the connection scheduling phase, each group's tone is assigned by pseudo-randomly determined priority (N_G parallel tones for each block as shown in Fig. 1), where the D2D pairs of each group simultaneously use the same tone for the control signal exchange. The frame structure for the connection phase is composed as Tx blocks (TxB) followed by Rx blocks (RxB) as shown in Fig. 1 using the following protocol.

1) Rx individual yielding : All Tx nodes (master and slave) transmit on the corresponding tones in TxB. Each Rx listens to TxB and determines its survival decision based on the ratio between the desired signal power (the sum power of the desired-link and the cross-link from the other D2D pair within same group) and the interference power from the other high priority groups.

2) Tx master yielding : All surviving Rx nodes respond by transmitting with the inverse-echo power. The master Tx node in each group determines the survival of its group when the sum of each desired signal power (the desired link and the cross link) is larger than the interference power from the other high priority groups by at least the Rx threshold.

Remark : If each D2D pair orthogonally use a single tone and individually communicate, DICRA is reduced to be FlashLinQ [11].

B. Rate scheduling phase

Let $\mathcal{G}$ and $\mathcal{I} = \{1, 2\}$ be the survival group index set and the D2D pair index set (1 for the master and 2 for the slave) within each group, respectively. Let $H_{ij}^{[g]}$ be the channel gain between the jth transmitter and the ith receiver in the gth group. Then, the rate scheduling is performed as follows.

1) Tx-1 transmits and Rx-1 and Rx-2 respectively obtain $H_{11}^{[g]}$ and $H_{21}^{[g]}$.

2) Tx-2 transmits and Rx-1 and Rx-2 respectively obtain $H_{12}^{[g]}$ and $H_{22}^{[g]}$.

3) Rx-1 transmits the channel quality indicators (CQI) of the quantized versions of $H_{11}^{[g]}$ and $H_{12}^{[g]}$, whereas Rx-2 transmits the CQIs of the quantized versions of $H_{21}^{[g]}$ and $H_{22}^{[g]}$.

Then, each Tx or Rx can aware the certain point having the maximum master D2D pair rate among the maximum sum-rate points in the achievable region via IC coding [13] and determines the private message signal to noise ratio (SNR) $\rho_{ii}^{[g]}$, codebook $\mathcal{C}_{ii}^{[g]}$, and the common message SNR $\rho_{i0}^{[g]}$, codebook $\mathcal{C}_{i0}^{[g]}$.

C. ASE during the Data exchange phase

Let $V_i^{[g]}$ be the message of the ith D2D pair in the gth group. Tx-i splits its message $V_i^{[g]}$ into the private message $V_{ii}^{[g]}$ and the common message $V_{i0}^{[g]}$, which respectively correspond to $\mathbf{C}_{ii}^{[g]} \in \mathcal{C}_{ii}^{[g]}$ and $\mathbf{C}_{i0}^{[g]} \in \mathcal{C}_{i0}^{[g]}$. Finally, the codewords are combined by using superposition coding as in [13]. At each Rx, the powerful joint decoder is used where Rx-i in gth group decodes $V_{i0}^{[g]}, V_{j0}^{[g]}$ and $V_{ii}^{[g]}$ simultaneously. Then, the sum-rate of the gth group and the ASE of the network are respectively given as

$$R^{[g]} = \sum_{i \in \mathcal{I}} \min\{R_{i3}^{[g]}, R_{i2}^{[g]} + R_{11}^{[g]} + R_{21}^{[g]}\}, \tag{1}$$

and

$$R = \frac{N_D \sum_{g \in \mathcal{G}} R^{[g]}}{N_T A^2} [\text{bps/Hz}/m^2], \tag{2}$$

where

$$\begin{aligned} R_{i1}^{[g]} &= \min\left\{ \log_2\left(1 + \frac{|H_{ii}^{[g]}|^2 \rho_{i0}^{[g]}}{1 + |H_{ij}^{[g]}|^2 \rho_{jj}^{[g]}}\right), \right. \\ &\qquad \left. \log_2\left(1 + \frac{|H_{ji}^{[g]}|^2 \rho_{i0}^{[g]}}{1 + |H_{ji}^{[g]}|^2 \rho_{ii}^{[g]}}\right) \right\}, \\ R_{i2}^{[g]} &= \log_2\left(1 + \frac{|H_{ii}^{[g]}|^2 \rho_{ii}^{[g]}}{1 + |H_{ij}^{[g]}|^2 \rho_{jj}^{[g]}}\right), \\ R_{i3}^{[g]} &= \log_2\left(1 + \frac{|H_{ii}^{[g]}|^2 (\rho_{i0}^{[g]} + \rho_{ii}^{[g]}) + |H_{ij}^{[g]}|^2 \rho_{j0}^{[g]}}{1 + |H_{ij}^{[g]}|^2 \rho_{jj}^{[g]}}\right), \end{aligned} \tag{3}$$

and A^2 is the network area.

III. SIMULATION RESULTS

The system operates over a 5MHz spectrum ($N = 512$) with 32 ($N_G = 32$) parallel tones per block and the duration of each traffic slot is 5ms ($N_T = 60$). Assume that the whole network size is $300m \times 300m$ square in which each cluster size is $100m \times 100m$ square. Tx nodes are assigned to be drawn from a homogenous 2-D Poisson point process (PPP) with intensity λ_s and Rx nodes are located from intended Tx nodes in a random direction and random distance among

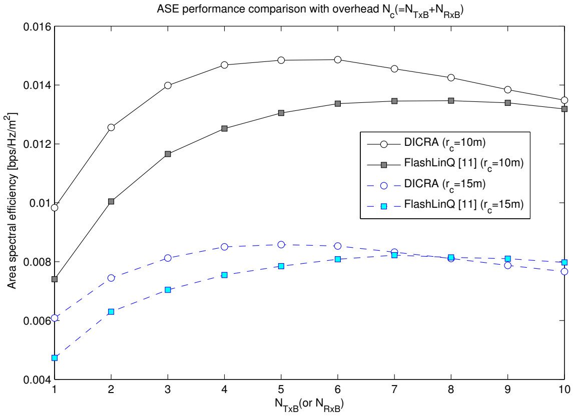

Fig. 2. ASE comparison in HD network with overhead N_C

$[0, r_c]$. Furthermore, pass-loss exponent is set to 4.5 and the average received SNR of the user at the edge of the D2D coverage ($\rho_{i0}^{[g]} + \rho_{ii}^{[g]}$) is set to 10dB. In DICRA, network forms the groups composed of neighboring 2 D2D pairs. To remove the boundary effect, we only consider the ASE gain at the center cluster. Also, the Tx thresholds and Rx thresholds for DICRA and those of FlashLinQ are set to obtain the optimal ASE by using intensive computer simulations.

Fig. 2 shows the ASE gain in HD network with the overhead constraint ($N_C = N_{\text{TxB}} + N_{\text{RxB}}$). Also, we plot the ASE performance in two cases when r_c is $10m$ (solid line) or $15m$ (dashed line). From the results, it is shown that the proposed DICRA has better performance than FlashLinQ. Also, the performance gap gets larger as less overhead is allowed, because the proposed DICRA is more efficient in terms of the control overhead so that the required overhead (N_C) for the optimal ASE in DICRA is smaller than that of FlashLinQ.

Fig. 3 shows the optimal ASE and the number of surviving D2D pairs when the optimal ASE is obtained in HD network according to the ratio (γ) between the D2D maximum coverage distance (r_c) and each network cluster size (r_{net}). The solid line and the dashed line respectively indicate the ASE performance and the number of surviving D2D pairs. From the results, it is shown that the performance gap increases as neighboring D2D pairs within each group are relatively close so that the aggressive interference handling of the proposed DICRA becomes more fruitful.

IV. CONCLUDING REMARK

In this paper, DICRA is proposed for a loose network-assisted D2D communications by grouping neighboring pairs to reduce control overhead and using IC coding to handle the intra-group interference. From simulation results, it is confirmed that the proposed DICRA improves ASE compared to FlashLinQ-like DRA.

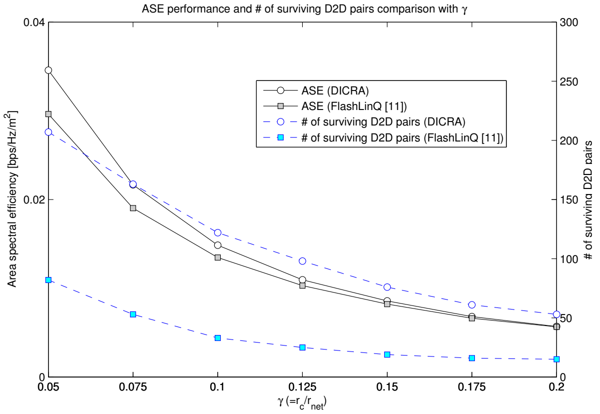

Fig. 3. ASE and the number of survived D2D pairs comparison with ρ

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