Interference-Aware Resource Allocation for Device-to-Device Communications in Cellular Networks

Xiaofan Wang[1], Xue Jun Li[2], Hnin Yu Shwe[1], Ming Yang[1], Peter Han Joo Chong[1]
[1]School of EEE, Nanyang Technological University, Singapore
{xwang8, hninyushwe, yangming, ehjchong}@ntu.edu.sg
[2]School of Engineering, Auckland University of Technology, New Zealand
xuejun.li@aut.ac.nz

***Abstract*—Device-to-device (D2D) communications was proposed underlying cellular networks to increase system capacity to support high-data-rate multimedia services. However, D2D communications unavoidably bring along co-channel interference to conventional cellular users. In this paper, we propose interference-aware resource allocation (IARA) scheme for cellular networks with underlying D2D communications. The proposed IARA scheme is based on two-way channel gain estimations and interference level measurements. Related works are revisited and the proposed IARA scheme is discussed. Its performance is investigated through extensive computer simulations. IARA scheme outperforms random allocation (RA) scheme. We further propose to use adaptive transmission power for D2D users to protect cellular users from severe co-channel interference. Simulation results show that this allows for longer link distance for D2D users, leading to better resources reuse.**

Keywords- Long Term Evolution, Device-to-Device, OFDMA, Resource Allocation, Channel Assignment, Bit Error Rate

I. INTRODUCTION

Telecommunication operators are under enormous pressure in order to accommodate that tremendous amount of traffic generated by the ever increasing number of mobile subscribers with their greedy request for high-data-rate multimedia services. Although recent deployment of fourth generation (4G) mobile networks in terms of Long Term Evolution (LTE) and its counterpart IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX) help mitigate the necessitous situation, there still exists a huge gap between the available system capacity and the required one in the near future. Subsequently, LTE-Advanced (LTE-A) [1] was proposed as a major enhancement of LTE standard with the following features: (i) relay node base stations (BSs), (ii) coordinated multipoint (CoMP) transmission and reception, (iii) Multiple Input and Multiple Output (MIMO), (iv) carrier aggregation and (v) cognitive radio. We expect large scale deployment of LTE-A will occur in the following few years.

In traditional cellular networks, communication links are established with BSs as an intermediate node, i.e., packets from one mobile station (MS) are routed through BSs towards its destination MS. Recently, this involvement of BS(s) in every pair of communicating MSs is unfortunately being viewed as a bottleneck of system capacity, and multihop cellular networks (MCNs) were introduced [2], for which the proposed MS-to-MS communications can be treated as device-to-device (D2D) communications. In particular, Dopper et al. proposed the concept of D2D as a form of underlay network consists of user equipment (UE) units that communicate directly without the aid of evolved NodeBs (eNBs) through D2D links [3]. As such, borrowing the concept of cognitive radio networks, it is important to properly manage the shared radio resources so that D2D communications can be accommodated as secondary users (peer-to-peer communication users) while minimizing their adverse effect to the primary users (conventional users with the aid of eNBs) of cellular networks. However, it should be pointed out that D2D communications are fundamentally different from cognitive radios because eNBs are still responsible to coordinate those UE units with D2D links [8]. Furthermore, all the users in D2D communications are also licensed users.

In general, radio resource management (RRM) [4] in cellular networks includes channel assignment, transmission power control, modulation/coding, and handover procedures. RRM can be classified as (i) static RRM in which resource allocation is rigid and irrespective of network traffic or channel conditions and (ii) dynamic RRM in which resource allocation is adaptive based on network traffic and/or channel conditions. Under dynamic RRM, dynamic channel assignment (DCA) can be grouped as centralized DCA and distributed DCA, where the latter is more suitable for cellular networks with D2D communications. Cheng and Chuang presented a performance evaluation of distributed DCA schemes in local wireless communications in [5]. Besides quasifixed frequency assignment [6] and threshold-based worst channel first algorithm [7], they studied the following algorithms: (i) Least Interference Algorithm (LIA); (ii) Least Interference below Threshold Algorithm (LTA); (iii) Highest Interference below Threshold Algorithm (HTA); (iv) Marginal Interference Algorithm (MIA) and (v) Lowest Frequency below threshold Algorithm (LFA). However, their study was limited to time-division multiple access (TDMA) systems. Lei et al presented a performance analysis of D2D communications with dynamic interference using stochastic Petri Nets [8] and studied the performance of D2D communications with Discrete Time Markov Chain (DTMC) model. However, the varying interference was modelled by the change of backlogged state of a link-level non-saturated buffer and no interaction between cellular network users and D2D users was considered.

In this paper, we propose interference-aware resource allocation (IARA) scheme, which is based on measurement-based DCA techniques and investigate the performance of

IARA through computer simulations. Our contributions are three-fold: (i) the detailed measurement-based resource allocation procedure to minimize co-channel interference; (ii) the simulation study using a practical three-tier 19 cell layout; and (iii) the introduction of adaptive transmission power levels for D2D users.

II. Related Work

D2D communications enable us to improve the spectrum efficiency provided that the following two requirements are substantially satisfied: (i) interference caused by D2D users to cellular users should be kept minimum; (ii) minimum quality-of-service for D2D users should be guaranteed [9]. In order to fulfil the two requirements, measurement-based resource allocation is considered as the most promising approach in such cellular networks operating in both cellular mode and D2D mode. Historically, distributed DCA, such as Autonomous Reuse Partitioning (ARP) is usually based on channel measurements [10]. Under ARP, all BSs simply scanned all channels in a certain order and select the first channel which met the CIR threshold requirement. The algorithm had proven itself able to effectively avoid interference and had better capability of handling traffic. Reuse partitioning was also achieved in such a way that the lower numbered channels were reused at shorter distances. Since ARP solely relied on the uplink interference measurement, its performance in downlink was not as good as that in uplink. Chuang showed that it was feasible to achieve a balanced two-way performance when BS and MS jointly made the allocation selection [11]. In such a proposed scheme, a BS first made the measurement and formed a list of candidate channels with low uplink interference, which was sent to a MS through downlink. The MS would scan and measure all the listed channels, and select one with the lowest downlink interference for its uplink transmission. Alternatively, the worst channel above a certain threshold could be selected first in order to improve the spectrum efficiency [7], and the simple aggressive LIA algorithm appeared to be one of the best choices in local wireless communication networks according to the comparison and study conducted in [5]. It outperformed all the other algorithms, yet without setting any threshold or constraint.

All the distributed DCA schemes discussed above were designed and investigated for conventional cellular networks. In [12] fractional frequency reuse (FFR) was proposed for cellular and D2D users by making use of different resource bands depending on their locations. However, it would be extremely difficult, if possible, to determine whether a UE resides in an inner region or an outer region. Janis et al. proposed an interference-aware resource allocation scheme and used an interference-to-noise (INR) target to perform transmission power control of D2D users [13] [14]. The simulation showed a 10% improvement over random allocation (RA) scheme. However, they assumed in every cell and subband there were only two simultaneous transmissions, one in D2D link and one in downlink, i.e., BS→MS link, which was certainly oversimplified. In addition, they only considered indoor environment with an area of 100m×100m. Auction-based resource allocation for D2D communications was proposed in [15] and game theoretic approach could also be applied [16]. However, they only considered single cell scenario and limited maximum D2D link distance to 5m and 20m in [15] and [16], respectively.

Most D2D communications in the literature is network-assisted, specifically, BSs will facilitate the initiation process of D2D links. However, relay-aided D2D communications were studied in [17], which provided the iterative Hungarian method to solve the joint relay selection and subchannel assignment problem for cellular networks with D2D communications. Furthermore, how to determine the proximity of D2D pairs is a non-trivial issue. An energy efficient D2D discovery method was proposed in [18], where the concept of proximity area was introduced and later Li et al. proposed social-aware resource allocation [19], where community detection algorithm was used to locate D2D communication pairs. Lin et al. studied how to select a suitable communication mode based relative velocities of mobile users [20], while Wu et al. studied the effect of mobility from the perspectives of energy and bandwidth efficiency [21].

III. Proposed IARA Scheme

Enlightened by the resource allocation schemes [11] [14] discussed in Section II, we propose IARA scheme for LTE-A networks with D2D communications operating in time-division duplex (TDD) mode, as depicted in Fig. 1. Each subcarrier is assumed to be a flat fading channel with no interference from other subcarriers, thus individual pilots can be used to estimate each subcarrier's channel gain. A set of adjacent subcarriers form a subband, which constitutes the basic resource unit. The BSs and/or MSs estimate the channel gain and measure the interference from surrounding cells for each subcarrier. The average value of estimated BER for subbands will be used as a decision metric for resource allocation.

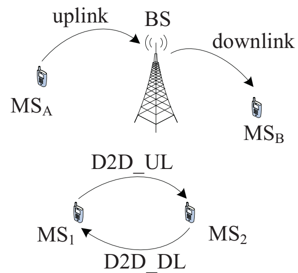

Fig. 1. Illustration of cellular networks with D2D communications.

The procedures of proposed IARA with D2D communications are described in Fig. 2(a), Fig. 2(b) and Fig. 2(c) for uplink (cellular users), downlink (cellular users), and D2D links, respectively. In this scheme, both uplink and downlink allocations use a two-way measurement-based algorithm to ensure no severe interference is caused to existing D2D users nearby. *In a D2D communication pair, there is no uplink or downlink transmission, but we deliberately consider the MS that initiates the D2D communication process is performing the uplink transmission (e.g., D2D_UL in Fig. 1), and the other MS is performing downlink transmission (e.g., D2D_DL in Fig. 1).* Notice that in D2D MSs do not perform two-way channel measurements because MS_1 and MS_2 are within each other's transmission range, which let us assume that they experience roughly the same level of interference.

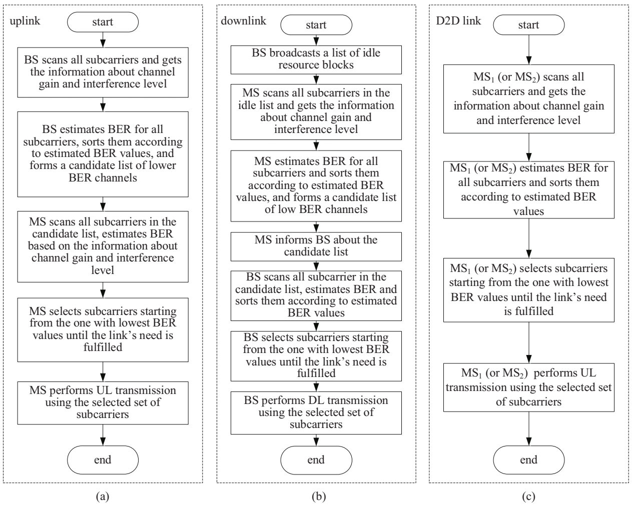

Fig. 2. Flowchart of IARA with D2D communications.

IV. PERFORMANCE EVALUATION

Monte Carlo MATLAB simulations are performed for three-tier cellular network of 19 cells. Results are collected from the central cell, with two-tier interferencing cells. Due to limited space, only downlink transmissions are considered. For each simulation run, positions of MSs are randomly generated. Cellular users have priority in utilizing the network services. Multipath power delay profile (PDP) is used with a statistical model, for which an exponentially decaying Rayleigh fading channel is adopted as a baseline channel model. The impulse response, h_i is a composition of complex samples with Rayleigh distributed magnitude with average power decaying exponentially, and uniformly distributed random phase,

$$h_i = N\left(0, \sigma_k^2/2\right) + jN\left(0, \sigma_k^2/2\right) \tag{1}$$

where $\sigma_k^2 = \sigma_0^2 e^{-kT_s/T_{RMS}}$, $\sigma_0^2 = 1 - e^{-T_s/T_{RMS}}$, $N(0,*)$ is a zero mean Gaussian random variable and $\sum \sigma_k^2 = 1$.

Table I summarizes the system configuration parameters, which include a modified PDP [22]. The transmitted signal-to-noise ratio (SNR) and subcarrier gain in the frequency domain are used to calculate the received SNR for every transmitted symbol. Then E_b/N_0 is calculated as $E_b/N_0 = SNR \times BW \times T_b$, and the BER is calculated as

$$BER = Q\left(\sqrt{2E_b/N_0}\right) \tag{2}$$

where $Q(x) = \left(1/\sqrt{2\pi}\right)\int_x^{\infty} e^{-u^2/2} du$.

TABLE I. SIMULATION SYSTEM CONFIGURATIONS

Number of cells	19
Cell radius	0.5 km
Total number of sub-carriers	1024
Total number of used sub-carriers	900
Sub-carrier spacing	15kHz
OFDMA symbol duration	66.667μs
Cyclic prefix period	4.6875μs
Number of RUs	75
Number of sub-carriers per RU	12
Number of slots per frame	8
Downlink modulation	QPSK
Noise power	-103.2057 dBm
Path loss exponent	3.5
Total BS downlink P_t	43dBm
Maximum downlink P_t per MS	2W
D2D P_t	variable
Power profile	[0, -3, -5.05, -12] dB
Delay profile	[0 260 521 681] ns
Radio frame length	10ms

We consider two levels of transmission power, P_t = 1W and P_t = 0.25W, and two inter-UE distance values, d = 100m and d = 200m, for D2D users. As such, four combinations of settings for D2D users are investigated.

As shown in Fig. 3, when the P_t of D2D users is high, the inter-UE distance d does not affect the average BER much. A drastic increase is noticed when the number of cellular users per cell is larger than 10, which is due to two factors: (i) Firstly, when there are few cellular users, it is highly likely that they use different resource blocks as compared to D2D users. As the number of cellular users increases, there is an increasing probability that both cellular users and D2D users share the same resource blocks, leading to rising co-channel interference; (ii) Secondly, the total P_t is limited in each cell. When there are more cellular users, the P_t for each cellular user decreases, and which makes cellular users more vulnerable to the co-channel interference caused by D2D communications.

When the P_t of D2D users is low, d has a prominent impact on the average BER. When d =100m, the performance of D2D communications is very promising. BER does not have an abrupt increase because the interference introduced by D2D communications is low. Nevertheless, the P_t is insufficient for D2D users to communicate over long distance.

As shown in Fig. 4, when P_t = 0.25W, the system achieves a high throughput for D2D pairs with d = 100m. However, the performance degrades when d =200m due to insufficient P_t. When P_t = 1W, d does not affect the throughput much. As the number of cellular users increases, P_t per cellular user decreases and more resource blocks have to be reused. As such, graceful increase in throughput is observed for larger number of cellular users due to the abrupt increase of average BER.

A higher P_t of D2D users might cause more severe interference to existing cellular users, but it allows for longer transmission distance; while a lower P_t achieves better system performance if the D2D users are near to each other. Although the scenario for (P_t = 0.25W, d = 100m) provides the best overall performance, it is rather limited and the performance cannot be sustainable if d increases. Furthermore, it is noticed the scenarios with P_t = 1W can achieve comparable system performance when the number of cellular users is small. The D2D users are using idle resource blocks that are not used by cellular users. Consequently, it is feasible to use a high P_t for D2D users in a sparsely populated cellular network. With the increased number of cellular users, more resource blocks have to be shared and P_t per cellular user decreases. In such situations, D2D communications with lower P_t is preferred so that the quality of cellular communication will not be compromised. We propose to use an adaptive P_t for D2D users such that it can allow D2D users farther apart to communicate in a sparse network, but will not be affected too much from the interference caused by increasing number of cellular users.

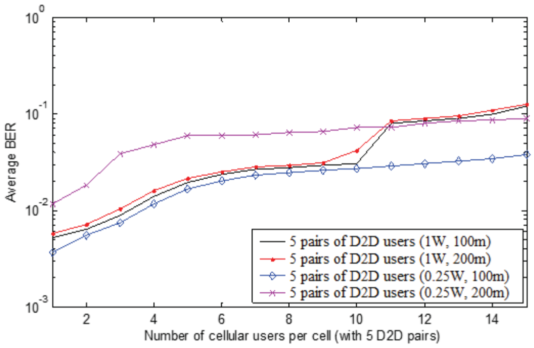

Fig. 3. Average BER of proposed IARA.

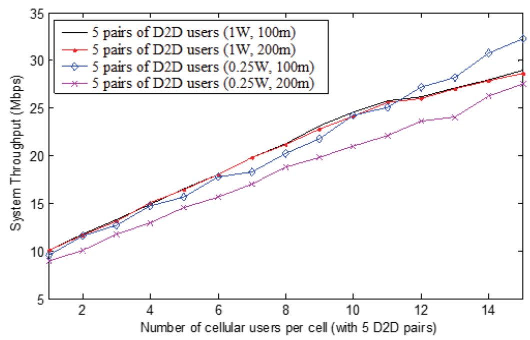

Fig. 4. Throughput of proposed IARA.

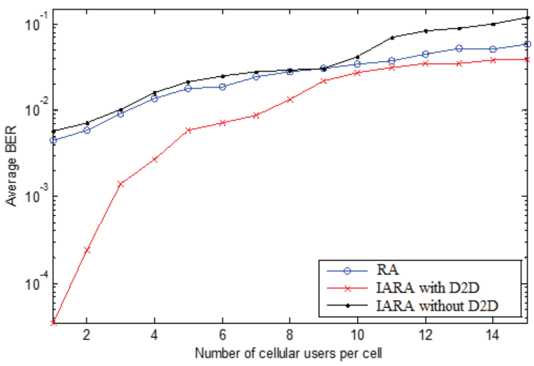

Fig. 5. Average BER comparison of IARA and RA schemes.

In the following simulations, an adaptive P_t is used for D2D users with d = 200m. Furthermore, P_t for the D2D users will always be half of that of cellular users. Therefore, cellular users are offered necessary protection against the interference caused by D2D users. Fig. 5 and Fig. 6 show the BER and throughput comparison between IARA and RA, respectively. With adaptive D2D P_t, the average BER is nearly the same as that of the scenario with high P_t for small number of cellular users. But as the cellular user number increases, it benefits from using decreased D2D P_t so that there is no abrupt increase in BER. Although the average BER is higher than the cellular network without D2D communications, the system throughput becomes much higher. Therefore, hierarchical cellular networks with D2D communications underlay outperform conventional cellular networks.

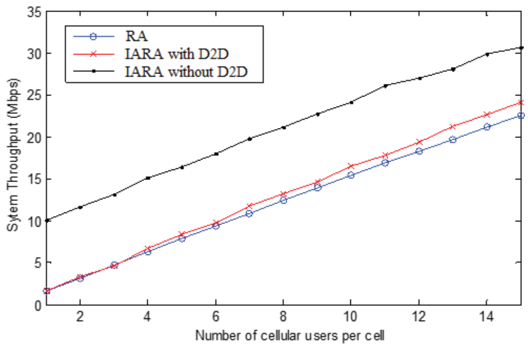

Fig. 6. Throughput comparison of IARA and RA schemes.

Finally, we study the following scenarios with different users added to the cellular network. In each scenario, it starts with 10 cellular users in each cell. Each pair of D2D communication users are within d= 200m and have an adaptive P_t as mentioned before. The results are presented in Fig. 7- Fig. 9. As each cell is able to accommodate 15 users on different subbands, the scenario without D2D communications prevents more users to share the network. The average BER remains the same but the blocking probability increases dramatically when the total number of users per cell exceeds 15. Nevertheless, the added D2D users are able to share the network resources under IARA scheme. Although the average BER keeps increasing, the blocking probability is kept at an acceptable level. The system throughput is thus much higher for IARA and it can accommodate more than 15 users per cell.

V. CONCLUSION

An interference-aware resource allocation (IARA) scheme is proposed, which minimizes the adverse effect of co-channel interference by sensing interference levels to efficiently and intelligently reuse radio resources. The proposal of using adaptive transmission power also enables maximum inter-user distance for D2D communications, enlarging the network coverage without compromising the quality of service of conventional cellular users. Simulation results have shown a significant improvement of IARA as compared to random allocation (RA) scheme on system throughput with relatively comparable average BER level. For a given level of system throughput, IARA is able to achieve a lower blocking probability. IARA maximize reuse of radio resources in a dynamic interference-conscious approach. More interference mitigation techniques for D2D communications under cellular networks can be explored in the future. Furthermore, it is also of interests to adapt an interruption mechanism of D2D communications, if necessary, so as to protect the quality of service for cellular users.

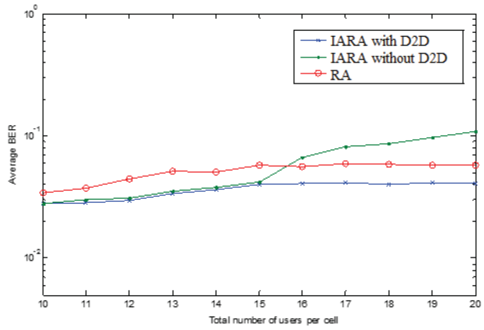

Fig. 7. Average BER of resource allocation schemes.

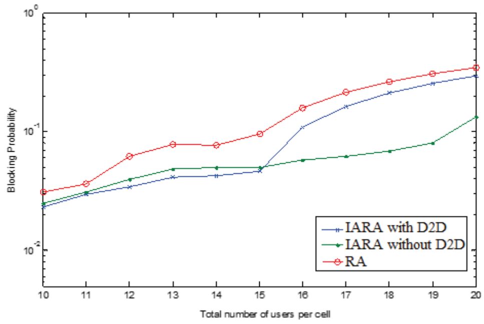

Fig. 8. Blocking probability of resource allocation schemes.

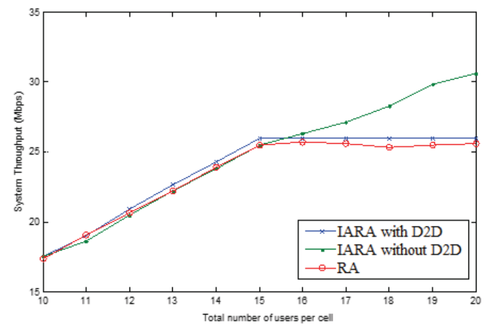

Fig. 9. System throughput of resource allocation schemes.

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