Resource Allocation for Interference Management in D2D underlying Wireless Cellular Networks

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Abstract

The proliferation of novel network access devices and demand for high quality of service by the end users are proving to be insufficient and are straining the existing wireless cellular network capacity. An economic and promising alternate to enhance the spectral efficiency and network throughput is device to device (D2D) communication. However, enabling D2D communication poses significant challenges pertaining to the interference management. In this paper, we address the resource allocation problem for underlay D2D pairs. First, we formulate the resource allocation optimization problem with an objective to maximize the throughput of all D2D pairs by imposing interference constraints for protecting the cellular users. Second, to solve the underlying mixed-integer resource allocation problem, we propose a stable, self-organizing and distributed solution using duality based. Finally, we simulate our proposition to validate the convergence, cellular user protection, and network throughput gains achieved by the proposal. Simulation results reveal that D2D pairs can achieve significant throughput gains (i.e., up to 45-91%) while protecting the cellular users compared to the scenario in which no D2D pairs exist.

I. Introduction

The introduction of bandwidth hungry devices i.e., tablets, smart phones and bandwidth hungry applications i.e., on-line gaming, video conferencing, rich multimedia local services have strained the existing cellular network's capacity. To satisfy this ever increasing demands of the end users, many efforts focus on improving the wireless resource capacity by exploring new coding schemes, installing multiple antennas, and deploying small cells in the existing cellular networks. Although these technologies are successful for increasing the resource capacity, they do not solve the network capacity problem due to many reasons: a) wireless resource capacity has physical limitations, b) additional cost is involved in new hardware installations and c) traffic growth is faster compared to technology advancements [1]. As an alternative, device to device (D2D) communication underlying the existing cellular network has been proposed for long term evolution (LTE) advanced [1]. This technology is envisioned to be very successful especially for the network capacity congestion issues.

One of the most critical challenge is the interference problem which is caused by the reuse of cellular resources [1][2][3][4]. Thus, in order to utilize the cellular resources efficiently, an efficient interference coordination scheme guarantee a target performance threshold of the cellular communication. We in this work focus on downlink transmission of the cellular system in which BS transmits to the cellular users (CUs) and a D2D transmitter transmits to a D2D receiver using the same resource as shown in Fig 1. There exist two cases, in which interference takes place in the network, shown by red dotted line in Fig 1. In the first case, the interference occurs at the CU when a D2D pair transmits using the same resource. The second case is at the D2D receiver, when the BS transmits to its CU. In either case, interference will degrade the system's performance.

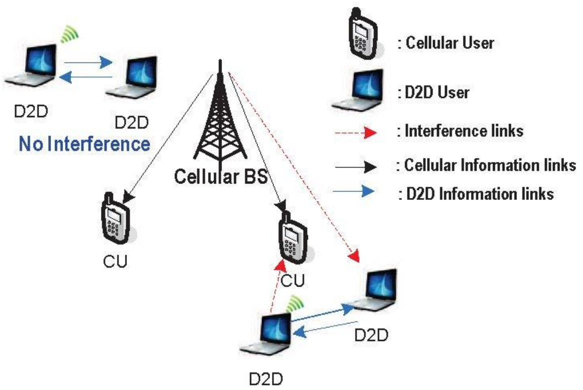

Fig.1. System model

In this work, our objective is to optimize the throughput of D2D pairs underlaid in a cellular network while protecting the cellular users (co-channel interference avoidance). In order to practical implementations and network scalability, we aim to develop a decentralized and self organizing resource allocation scheme in which D2D pairs and BS can interact and make resource allocation decisions based on local information without relying on central coordinator for coordination.

II. System model and Optimization Problem

Consider a cellular network with a set $\mathcal{K} = \{1, 2, ..., K\}$ representing D2D pairs, located within the coverage of one cellular base station (BS) as shown in Fig.1. The set of cellular users (CUs) are denoted by $\mathcal{C} = \{1, 2, ..., C\}$. The BS and D2D pairs use the same set of resource blocks (RBs) $\mathcal{R} = \{1, 2, ..., R\}$. One resource block can correspond to one sub-carrier of the OFDM-based LTE network. However, for any given RB $r \in \mathcal{R}$, a predefined interference threshold $I_{\max^r}$ must be maintained for protecting the CUs. Finally, note that D2D pairs and CUs only differ in their modes of communicating with each other, i.e., direct transmission or via BS.

The D2D pairs at each time slot need to determine which RB is feasible in order to maximize the utility of the system while protecting CUs. For RB allocation optimization, we introduce binary variables, as follows:

$$x_k^r = \begin{cases} 1, & \text{if D2D pair } k \text{ is assigned RB } r, \\ 0, & \text{otherwise.} \end{cases} \quad (1)$$

The received SINR pertaining to the transmission of D2D pair *k* over RB *r* with transmit power P_k^r is:

$$\gamma_k^r = \frac{P_k^r g_k^r}{P_M^r g_{M,k}^r + \sigma^2}, \quad (2)$$

where P_M^r represent the transmit powers of the BS. The RB gain between D2D pair *k* is g_k^r whereas $g_{M,k}^r$ is the RB gain from the BS to D2D pair *k*. The noise power is assumed to be σ^2.

Our goal is to maximize the sum rate of the D2D pairs by reusing the RBs already occupied by CUs. It should be noted that a D2D pair can only use a RB if the interference level is less than the predefined interference threshold $I_{\max^r}$ set by the BS. Moreover, the interference experienced by CU *c* on RB *r* is given by $I_k^r = x_k^r P_k^r g_{k,c}^r$, where $g_{k,c}^r$ is the RB gain between D2D pair *k* and CU *c*, on RB *r*. The considered RB allocation problem can be stated as follows:

$$\textbf{P1}: \quad \underset{x_k^r \in \mathcal{X}}{\text{maximize}}: \sum_{r \in \mathcal{R}} \sum_{k \in \mathcal{K}} W^r x_k^r \log(1 + \gamma_k^r) \quad (3)$$

$$\text{subject to: } I_k^r \le I_{\max^r}, \forall r \in R, \quad (4)$$

$$\sum_{k \in K} x_k^r \le 1, \forall r \in R, \quad (5)$$

$$\sum_{r \in R} x_k^r \le 1, \forall k \in K, \quad (6)$$

$$x_k^r \in \{0, 1\}, \forall k \in K, \forall r \in R. \quad (7)$$

In **P1**, constraint (4) is to ensure the protection of CU by keeping interference produced by D2D transmitter below a predefined threshold. This allows the re-usability of a RB *r* to increase the RB efficiency, if the interference constraint can be maintained. Constraint (5) ensures that each RB can be allocated to at most one D2D transmitter. Additionally, constraint (6) ensures that each D2D transmitter can be allocated one RB only. The binary RB allocation indicator variable is represented by the last constraint (7).

III. The Resource Allocation Algorithm

In this section we propose a distributed algorithm based on the duality solution to solve the problem **P1**

Algorithm 1: The Resource Allocation Algorithm:

1: **Initialization**: $t = 0$, $\alpha_k^r(0) \ge 0$, step size $\kappa_k^r(0) > 0$

2: **Repeat**

3: $t \leftarrow t + 1$

4: **Each D2D pair update** $x_k^{r(t)}$ **and** $\alpha_k^{r(t)}$ **as follows**

$$x_k^{r(t+1)} = \begin{cases} 1, & \text{if } r = r^*, \\ 0, & \text{otherwise} \end{cases}$$

$$r^* = \arg\max_r \Big(\sum_{r \in \mathcal{R}} \sum_{k \in \mathcal{K}} W^r \log(1 + \gamma_k^r) - \alpha_k^{r(t)} P_k^r g_{k,c}^r\Big),$$

$$\alpha_k^{r(t+1)} = \alpha_k^{r(t)} - \kappa_k^{r(t)} \Big(\sum_{n=1}^{N_j} x_k^{r(t)} g_{k,c}^r P_{k,c}^r - I_{\max}^k\Big),$$

5: **Until** $|\alpha_k^{r(t+1)} - \alpha_k^{r(t)}| \le \epsilon$

IV. Numerical Results.

The network topology for our simulations contains an BS, with an number of CUs and D2D pairs which are randomly located inside circles of radius of $r_1 = 500\ \text{m}$ and the communication radius of each D2D pair is randomly chosen to be within the range of $(20 - 40)\ \text{m}$. We consider a network with 10 D2D pairs, with 10 RBs, and 10 CUs using these RBs unless stated otherwise. The RB gain is given by $g_{m,n} = 10^{(-PL(d_{m,n}))/10}$, where function $PL(d_{m,n})$ represents path loss and $d_{m,n}$ (in meters) is the distance between D2D pair and CU connected to BS *n*. We assume that $L(d_{M,k}) = 16.62 + 37.6\log_{10}(d_{M,k})$ for the RB gain from the BS to CU *k* and $L(d_k) = 37 + 32\log_{10}(d_k)$ for the RB gain between the D2D pair *k*. Finally, the maximum BS transmission power is fixed to 43 dBm which is uniformly dived among the available RBs whereas all the D2D pairs transmit with a varying power over simulation runs ranging from 20 to 24 dBm.

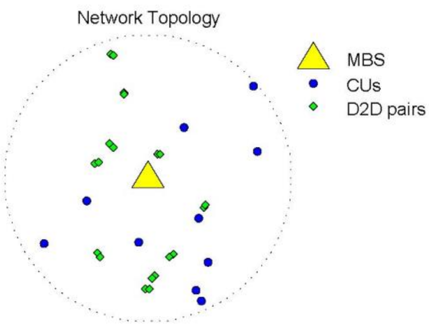

Fig. 3. Network topology

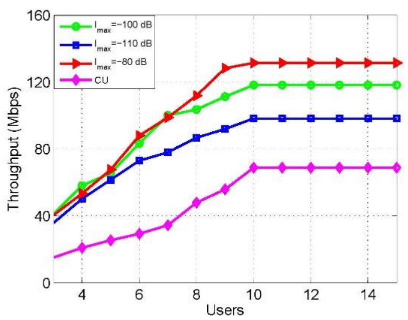

Fig. 4. Throughput with different interference threshold

In Fig. 4, the achievable throughput by D2D pairs are shown with respect to three different maximum interference tolerance thresholds set by the cellular tier i.e. $I_{\max} = -110, -100, -80\, dB$. In this simulation, we increased the number of users (both D2D and CU) and observed that the average throughput increases with more users under all scenarios, which, however, saturates as the number of users becomes sufficiently large. This is because of the limited number of RBs ($r = 10$) available and both users are only allowed to use one RB each.

Fig.5 presents cumulative distribution of the interference produced on all RBs by D2D pairs reuse under three maximum interference tolerance threshold scenarios $I_{\max} = -110, -100, -80\, dB$. It can be seen that in all the cases, the interfering power is always less than the predetermined maximum threshold for cellular tier protection.

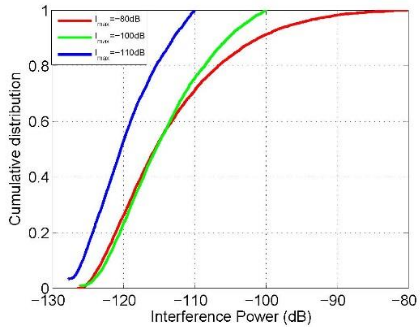

Fig. 5. Interference threshold distribution

V. Conclusions

In this paper, we have proposed a RB allocation algorithms for the underlying D2D pairs. We used the duality theory to solve the RB allocation problem and propose a stable, and decentralized solution while protecting the cellular users. We also discuss the distributed implementation of this algorithms in detail. Numerical studies have shown that the proposed algorithm can provide interference protection and significantly enhance the network throughput.

Acknowledgement

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