Resource Management in Device-to-Device Communications using Unlicensed Spectrum under Collision Constraints

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Abstract

In this paper, we propose a mechanism for D2D communication in unlicensed spectrum band considering the collision constraints. In our proposed model, D2D communication takes place along with WiFi network. Given collision probability of the WiFi system, the fraction of active time for the D2D communication is devised to guarantee minimum QoS for WiFi network. Then, we formulate an optimization problem to maximize utility for the D2D communication guaranteeing QoS to WiFi, considering collisions in WiFi. We use Lagrangian Relaxation to solve the optimization problem that decision for each D2D link. Our simulation results show that the proposed mechanism converges to an optimal solution.

1. Introduction

In the future wireless network, D2D communication enables mobiles devices to communicate directly with each other without access to the base station. Recently, the unlicensed channel has proposed to employ on the D2D communication to adopt the explosive growth of mobile devices and bandwidth-hungry applications [1], [8]. To deploy D2D-Unlicensed, some challenges should be addressed such as internet management and co-existence of the D2D and WiFi system.
Some existing works have studied to overcome the above challenges [1], [2]. In [1], a feasible duty cycle based protocol is proposed for the LTE-U and D2D-U users to utilize the unlicensed spectrum. An approximated model is elaborated to evaluate the interference to Wi-Fi networks introduced by LTE-U and D2D-U users. In [2], a coexistence for D2D/WiFi systems is proposed to decrease the number of users, which participate in the contention for accessing the unlicensed channel by grouping them with D2D communications. However, the resource allocation is not mentioned in [2] to optimize the unlicensed utilization in the D2D network.

Different from the previous works, in this paper, we investigate a D2D communication in unlicensed spectrum in which D2D communication requires assist and control from the central BS following the LBT mechanism. To cope with the above challenges, we first analyze the collision probability at the WiFi system. The success probability of the D2D network is elaborated to evaluate the active time for the D2D. Given the active time for the D2D communication, an optimization problem is formulated to maximize the total throughput of the D2D while guaranteeing the collision probability of the WiFi system. A distributed algorithm based on Lagrangian and Dual decomposition is devised to find an optimal solution the fraction of time for each D2D link.

2. System model.

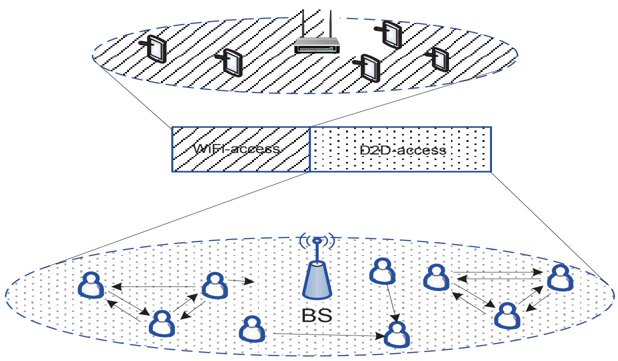

Figure 1: system model

We consider a D2D-Unlicensed network including N D2D links. The D2D network utilizes an unlicensed channel k from the Wi-Fi system, in which the channel access in the D2D is based on LTE-FDD standard. A base station manages resource allocation at the D2D links (BS). To access the unlicensed channel, the D2D's manager uses the LBT mechanism. On the contrary, the Wi-Fi stations work following the CSMA/CA mechanism and will back-off their transmission when they are sensing the channel busy. It is assumed that the D2D links have a higher priority than Wi-Fi station to access the unlicensed channel.

3. Problem formulation

3.1. Collision constraints analysis for the WiFi system

At the beginning of each time slot, from the WiFi perspective, the channel k is assumed to be busy if the D2D network activates this channel.
According to analysis in [4][5], the station probability that WiFi stations transmit a packet on unlicensed channel k can be written as

$$p_k^{\text{trans}} = \frac{2(1-2p_k^{\text{col}})}{(1-2p_k^{\text{col}})(W_{0,k}+1)+p_k^{\text{col}}W_{0,k}(1-(2p_k^{\text{col}})^{M_{0,k}})}, \quad (1)$$

In which $W_{0,k}$ is the minimum back-off window size, M_{0k} is the maximum contention stage. The collision probability is determined as follows:

$$p_k^{\text{col}} = 1-(1-p_k^{\text{trans}})^{N_k-1}(1-\theta_{k,\text{D2D}}^{\text{acc}}). \quad (2)$$

In (2), p_k^{trans} is the transmission probability of the WiFi user in WiFi k, N_k is the number of WiFi users.

Due to the D2D network transmission is adopted by the D2D manager, the successful transmission probability for the D2D network can be expressed as [ref]

$$\theta_k^{\text{succ}} = (1-\theta_k^{\text{busy}})(1-p_k^{\text{trans}})^{N_k}, \quad (3)$$

Where θ_k^{busy} is the access probability to unlicensed channel k based on the LBT. Hence, the duration time for the D2D transmission is addressed via the time fraction occupied by the D2D network, i.e., $t_{\text{D2D}}^k = \theta_k^{\text{succ}}$.
We can see that, on the one hand, given fixed variable t_{D2D}^k, the collision probability can be determined by (2). On the other hand, the collision probability can be controlled via the t_{D2D}^k parameter.
Given fixed parameter t_{D2D}^k, each D2D link can be achieved a data rate following LTE standard as follows [6]:

$$R_d^k(\beta_d^k) = t_{D2D}^k \beta_d^k B_k \log_2\left(1+\frac{h_d^k P_d^k}{t_{D2D}^k \beta_d^k B_k \delta_0}\right). \quad (4)$$

3.2. Optimization problem formulation for D2D-Unlicensed.

Given a fixed t_{D2D}^k, we formulate the resource problem for the D2D networks as follows:

$$\text{Max.} \quad \sum_{d=0}^{D}\left(R_d^k\left(\beta_d^k\right)\right) \quad (5)$$

$$\text{s.t.} \quad \sum_{d=1}^{D}\beta_d^k \le 1, \quad (6)$$

$$\beta_d^k \in [0,1], \qquad \forall d \in D. \quad (7)$$

The goal of the above optimization is to maximize the network utility that profits from all D2D links. The constraint (6) represents total the fraction of time for the D2D has to less than or equal to a preset threshold for protecting the WiFi system.

4. Optimal resource allocation for the D2D network

The above optimization problem is a convex optimization problem. To solve it, we use Dual Decomposition and sub-gradient methods [7].
The Lagrangian for problem (5) is

$$L(\beta,\lambda) = \sum_{d=0}^{D}\left(R_d^k\left(\beta_d^k\right)-(\lambda)\beta_d^k\right)+\lambda \quad (8)$$

Moreover, the dual function is

$$q(\beta,\lambda) = \sum_{d=0}^{D}\sup_{\beta_d^k\in[0,1]}\left(\left(R_d^k\left(\beta_d^k\right)\right)-(\lambda)\beta_d^k+\lambda\right) \quad (9)$$

Then, the dual problem of the problem (5) is

$$\min . q(\lambda) \quad (10)$$

With $\lambda \in R$.
We can see that the dual function can decompose into D sub-problems. Then, the optimal fraction of time can be determined as [7]

$$\beta_d^{k(t+1)} = \beta_d^{k(t)} - \frac{f(\beta_d^{k(t)})}{f'(\beta_d^{k(t)})}, \quad (11)$$

Where

$$f(\beta_d^{k(t)}) = t_{D2D}^k B_k \log_2\left(1+\frac{(\gamma_d^k/(t_{D2D}^k B_k))}{\beta_d^k}\right) - \frac{t_{D2D}^k B_k \gamma_d^k \beta_d^k}{t_{D2D}^k \beta_d^k B_k + \gamma_d^k} - \lambda,$$

$$f'(\beta_d^{k(t)}) = \frac{t_{D2D}^k B_k \gamma_d^k}{\left(t_{D2D}^k \beta_d^k B_k + \gamma_d^k\right)}\left(-t_{D2D}^k B_k - \frac{\gamma_d^k}{t_{D2D}^k \beta_d^k B_k + \gamma_d^k}\right),$$

$$\gamma_d^k = \frac{h_d^k P_d^k}{\delta_0}.$$

Based on the above analysis, we proposed a distributed algorithm to solve the problem (5) as follows:

Algorithm 1: Distributed resource allocation for the D2D Unlicensed.

1) Algorithm at the D2D transmitter of each link d:

Update $\beta_d^{k(t+1)} = \max(0, \min(\beta_d^{k(t)} - \frac{f(\beta_d^{k(t)})}{f'(\beta_d^{k(t)})}, t_{\text{D2D}}^k))$

2) Algorithm at the D2D manager

$$\lambda^{(t+1)} = \left[\lambda^{(t)} - \delta_k \left(\sum_{d=1}^{D} \beta_d^k - t_{D2D}^k \right) \right]^+$$

Until $\left| \lambda^{(t+1)} - \lambda^{(t)} \right| \leq \xi$ is satisfied.

5. Simulation results

In this section, we present our simulation using Python to evaluate the performance of our proposals. Besides, we use the Python-based Mininet software to simulate the WiFi system. Some parameters are installed as follows: M = 5 D2D links; $P_d^{\max}$ = 20dBm; σ^2 =-105dBm; B_k =20 MHz; N_k = 10 users. The channel gain is assumed to be i.i.d. Rayleigh random variables with mean value $h(d) = h_0(d/15)^{-4}$ where h_0 is a reference channel gain at a distance 15 m. The distance of receiver and transmitter of the D2D links respectively is 30, 45, 55, 65, and 75. Time fraction is to protect collision probability at the WiFi system is initiated of 0.4. The time is divided into each LTE system's supper frame with T = 10ms is considered to allocate for both WiFi and D2D links system.

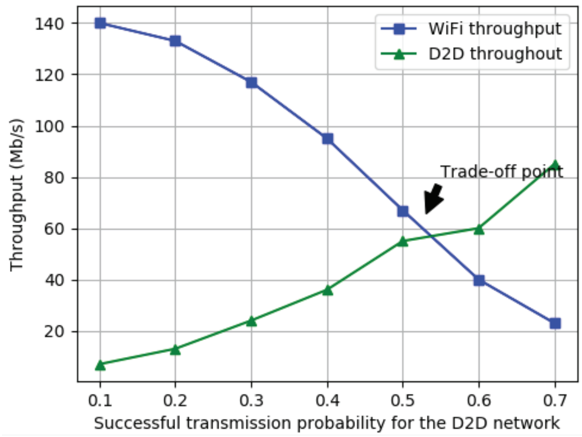

Figure 2. Networks throughput versus the successful transmission probability of D2D network.

In Figure 2, we show results of the proposed algorithm. To see that D2D unlicensed depending collision probability, we set probability values in the range [0, 1]. We can see that when increasing the collision probability, the WiFi throughput decreases meanwhile and D2D throughput creases. Hence, depending on the D2D demand, we can adjust the collision probability values to tradeoff WiFi and D2D throughput.

6. Conclusions

In this paper, we have studied a resource allocation for the D2D unlicensed spectrum. A collision probability is devised to protect the WiFi QoS. An optimization problem has formulated to maximize total network utility of the D2D network while guaranteeing WiFi system considering collision probability constraints. To solve this problem, we have used Lagrangian Relaxation to find an optimal decision on the time fraction for each D2D link. Simulation results show that our solution can convert to an optimal solution given a fixed collision probability.

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