Scheduling in LTE-Unlicensed: A Self-organization Solution

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Abstract

LTE-Unlicensed was proposed to enable mobile cellular services on unlicensed channels. The mobile network operators can readily access the unlicensed channels without any licensing fees. Thus, the mobile network operators can provide high quality service to the customers at low operating costs. We investigate the scheduling in LTE-Unlicensed and design a self-organization algorithm which can adapt rapidly with the dynamically changing environment.

1. Introduction

Cisco forecast shows that monthly IP traffic is projected to grow exponentially [1]. In order to meet the projected traffic growth, the capacity and efficiency of the Radio Access Networks (RANs) must be increased. This requires adopting new access schemes and solving new network optimization problems for RANs. Recently, LTE-Unlicensed (LTE-U) has been proposed to enable mobile cellular services on the unlicensed 5 GHz band [2]. The Small-cell Base Stations (SBSs) are one of the key enablers for 1000 times capacity increase in fifth generation (5G) communication networks. However, at present, SBSs operate on the licensed spectrum which the mobile network operators have to leased or purchased licensed for the government regulation agencies. This impedes the mobile network operators from providing high quality service at low operating cost. In LTE-U, the mobile network operators can readily access the spectrum without any licensing fees. Thus, the mobile network operators can provide high quality service to the customers at low operating costs [3]. Furthermore, LTE-U enables channel bonding / carrier aggregation methods which can utilize both licensed and unlicensed spectrum simultaneously leading to higher efficiency.

The most challenging issue in enabling LTE-U is the coexistence between LTE/WiFi systems which has different PHY and MAC layer specifications. LTE system adopts a centralized MAC protocol whereas the WiFi system adopts the Distributed Coordination Function (DCF) which is based on carrier sense multiple access with collision avoidance (CSMA/CA) [3]. In addition to different MAC protocols, the two systems have different physical layer features as shown in Table 1.

Table 1. Different MAC/PHY features of LTE and WiFi Systems

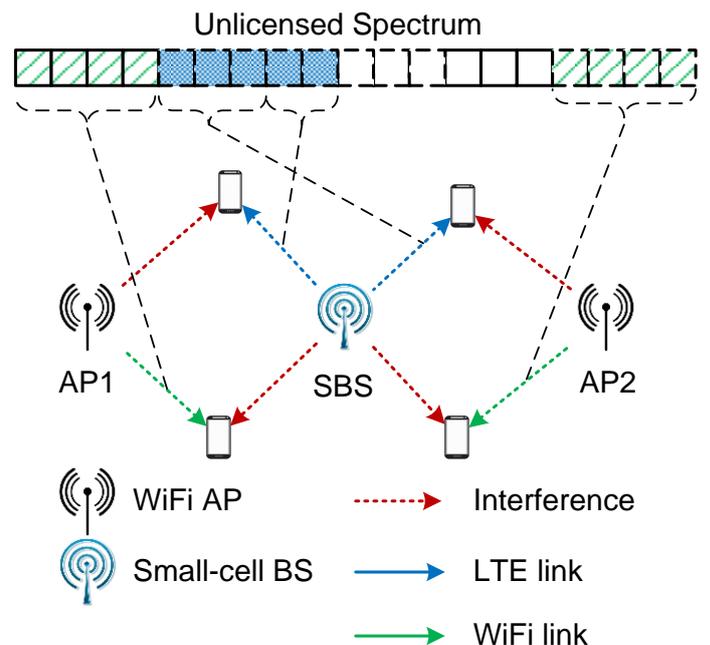|	LTE	WiFi
MAC	Centralized	Distributed
PHY	OFDMA	OFDM
Symbol duration	71.4 µs	4 µs
Subcarrier bandwidth	15 kHz	312.5 kHz
System bandwidth	1.4-20 MHz	20/40/80 MHz

Fig. 1: Network Model

Hence, we propose to isolate the interfering links between LTE/WiFi via orthogonal allocation of channels

as shown in Figure 1. We focus on scheduling of the LTE−U system where the network optimization problem addresses joint sub−problems of user association, resource allocation and interference mitigation.

2. System Model

There are M LTE small−cell base stations (SBSs) and N WiFi access points (APs) deployed over an area. Let **A** and **B** denote the sets of APs and SBSs, respectively. We assume all APs and SBSs are connected to a high speed back haul with negligible delay. Let $\mathbf{S_L}$ and $\mathbf{S_U}$ denote the set of available physical resource blocks (PRBs) for the SBSs on licensed and unlicensed channels, respectively. $\mathbf{S_U}$ is updated every 10 ms frame for LTE system to avoid interfering the WiFi APs and $\mathbf{S} = \mathbf{S_L} \cup \mathbf{S_U}$.

If the subcarrier bandwidth of LTE is W, then, signal−to−interference−plus−noise (SINR) from SBS m to user i on PRB k is given by:

$$\Gamma_{mi}^k = \frac{h_{mi}^k P_{mi}^k}{\sum_{n \in \mathbf{B} \setminus \{m\}} h_{ni}^k P_{ni}^k + W N_0}, \tag{1}$$

where $P_{mi}^k \in [P_1, P_2, \ldots, P_J]$ is the transmit power of BS m, h_{mi}^k is the path loss between SBS m and user i, and N_0 is the thermal noise for 1 Hz at 20 degree C. Accordingly, the downlink data rate from SBS m to user i on PRB k can be calculated as:

$$R_{mi}^k = W \log_2(1 + \Gamma_{mi}^k), \tag{2}$$

Then, the instantaneous data rate from SBS m to user i can be calculated as:

$$R_i = \sum_{m \in \mathbf{B}} x_i^m \sum_{k \in \mathbf{S}} y_{mi}^k R_{mi}^k, \qquad x_i^m, y_{mi}^k \in \{0,1\}, \tag{3}$$

where x_i^m and y_{mi}^k are user association and resource allocation variables, respectively.

3. Problem Formulation

Unique association constraint: each user can associate with at most one SBS, i.e.,

$$\sum_{m \in \mathbf{B}} x_i^m \leq 1, \ \forall i \in \mathbf{U}. \tag{4}$$

SLA constraint: the SBS must allocate enough resource to each user to satisfy its demand, i.e.,

$$\psi_i \leq R_i, \ \forall i \in \mathbf{U}. \tag{5}$$

Resource constraint: the SBS must not exceeds it available resource budget, i.e.,

$$\sum_{k \in \mathbf{S}} y_{mi}^k \leq |\mathbf{S}|, \ \forall m \in \mathbf{B}. \tag{6}$$

Spectrum interference constraints: First, given a SINR threshold, Γ_{th}, we define the BS conflict and reuse sets as follows:

$$\mathbf{B}_{\text{conflict}} := \{(m,n) \mid \min \{\Gamma_{mi}^k, \Gamma_{nj}^k\} \leq \Gamma_{th}\}, \tag{7}$$

$$\mathbf{B}_{\text{reuse}} := \{(m,n) \mid \min \{\Gamma_{mi}^k, \Gamma_{nj}^k\} > \Gamma_{th}\}. \tag{8}$$

(7) states that SBSs m and n cause high interference to each other. Thus, when both links are active, they conflict with each other. On the other hand, (8) states that SBSs m and n cause low interference to each other and can be active on same PRB k. Based on the link conflict and reuse set, we have the following spectrum interference constraints: $\forall m \in \mathbf{B}, \forall i \in \mathbf{U}$

$$y_0^k + y_{mi}^k \leq 1, \ \forall k \in \mathbf{S_U}. \tag{9}$$

$$y_{mi}^k + y_{nj}^k \leq 1, \ \forall (m,n) \in \mathbf{B}_{\text{conflict}}, \ \forall k \in \mathbf{S}. \tag{10}$$

where y_0^k is the sensing result. **Error! Reference source not found.** ensures that no WiFi AP occupied channel is allocated to LTE system. (10) ensures that high interference links are not allocated to the same PRB. On the other hand, low interference links are allocated to the same PRB.

Objective function: we define the objective function as sum rate minus total cost, i.e.,

$$u_i(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{P}) = R_i - \lambda \sum_{m \in \mathbf{B}} x_i^m \sum_{k \in \mathbf{S}} y_{mi}^k P_{mi}^k. \tag{11}$$

$$U(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{P}) = \sum_{i \in \mathbf{U}} u_i(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{P}), \tag{12}$$

where λ is the unit price for transmit power. The *optimization problem* is to maximize the utility of the LTE−U system via user association, resource allocation and power control. Our objective is to maximize social welfare, i.e. maximize sum rate and minimize total cost.

$$\begin{aligned} \text{maximize:} \quad & U(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}) \\ \text{subject to:} \quad & (4), (5), (6), (9), (10). \end{aligned} \tag{13}$$

(13) is a combinatorial problem and NP−hard.

4. Markov Approximation

We use Markov approximation framework [4] to solve (13). Let $f = \{\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{P}\}, f \in \boldsymbol{F}$ be a network configuration where $\boldsymbol{F}$ is the set of all feasible configurations which satisfy the constraints (4), (5), (6), (9), (10). Further, for ease of presentation, let $U_f = U(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{P})$. Then, by [4],

$$\max_{f \in \boldsymbol{F}} U_f \quad \Rightarrow \quad \begin{aligned} \max_{\boldsymbol{p} \geq 0} \quad & \sum_{f \in \boldsymbol{F}} p_f U_f \\ \text{s.t.} \quad & \sum_{f \in \boldsymbol{F}} p_f = 1 \end{aligned} \tag{14}$$

We then apply log−sum−exponential approximation to (14 with the following differentiable function [4], [5]:

$$\max_{f \in \boldsymbol{F}} U_f \approx g_\beta(U_f) \triangleq \frac{1}{\beta} \log \left[\sum_{f \in \boldsymbol{F}} \exp(\beta U_f) \right] \tag{15}$$

The upper bound of the approximation gap is $\frac{1}{\beta} \log |\boldsymbol{F}|$ [5]. (15) is the same as the optimal value of the following problem:

$$\max_{\boldsymbol{p} \geq 0} \quad \sum_{f \in \boldsymbol{F}} p_f U_f - \frac{1}{\beta} \sum_{f \in \boldsymbol{F}} p_f \log p_f \qquad (16)$$
$$\text{s.t.} \quad \sum_{f \in \boldsymbol{F}} p_f = 1$$

where p_f is the proportion of time the configuration f is in use and β is a positive constant. By solving the Karush-Kuhn-Tucker (KKT) conditions [5] of (16),

$$p_f^*(U_f) = \frac{\exp(\beta U_f)}{\sum_{f' \in \boldsymbol{F}} \exp(\beta U_{f'})}, \quad \forall f \in \boldsymbol{F}. \qquad (17)$$

5. Algorithm Design via Markov Chain

Let each configuration $f \in \boldsymbol{F}$ be the states of a time-reversible ergodic Markov chain with stationary distribution $p_f^*(U_f)$ in (17) [4]. Let $q_{f \to f'}$ be the nonnegative transition rate from state f to state f'. Then the two following conditions are sufficient to allow a large degree of freedom in algorithm design [4]:

1) Any two states are reachable from each other,
2) $p_f^*(U_f) q_{f \to f'} = p_{f'}^*(U_f) q_{f' \to f}$.

Furthermore, if we let $\exp(-\alpha)(q_{f \to f'} + q_{f' \to f}) = 1$, we obtain the following symmetric transition rates as:

$$q_{f \to f'} = \exp(-\alpha)(1 + \exp[\beta(U_f - U_{f'})])^{-1} \qquad (18)$$
$$q_{f' \to f} = \exp(-\alpha)(1 + \exp[\beta(U_{f'} - U_f)])^{-1} \qquad (19)$$

where α is a constant. Based on (18) and (19), we designed a self-organization algorithm.

6. Performance Evaluation

We performed experiments to test convergence of the proposed self-organization algorithm. We create a random trace of user arrivals and departures with varying workloads following a binomial distribution. Fig. 2 shows the total data rate achieved for the LTE-U system. Fig. 2 shows that in every time slot, the user demand is met and the sub-optimal solution is close to the optimal. Fig. 3 shows the normalized performance gap of the proposed self-organization system which is within 20 % of the optimal 95 % of the time.

7. Conclusion

In this paper, we study scheduling in LTE-Unlicensed network. First, we propose a mechanism for coexistence between LTE/WiFi via orthogonal allocation of resources. We formulate scheduling for LTE-Y system as an optimization problem. Second, we apply Markov approximation framework to arrive at a self-organization algorithm. Finally, we evaluate the performance of our proposal.
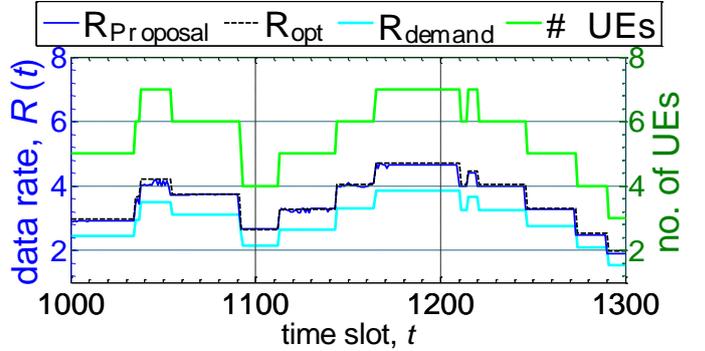
Acknowledgement

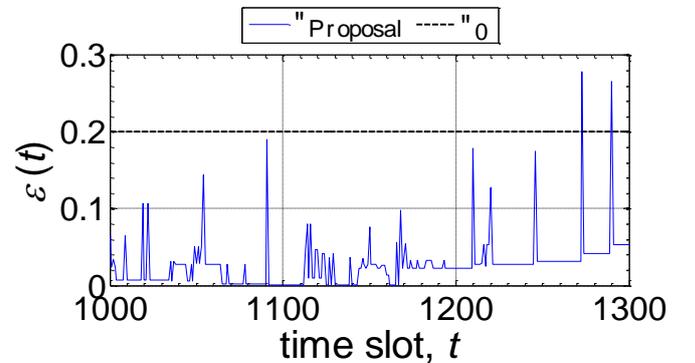Fig. 2: Total flow rate versus iterations

Fig. 3: Total incurred cost versus iterations.

References

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