# Stochastic Optimization for Fair Spectrum Allocation in LTE-U

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**Abstract**

In order to solve the problem of spectrum scarcity, LTE-unlicensed (LTE-U) is proposed where spectrum from unlicensed band can be utilized in cellular networks. This results in a coexistence issue among LTE-U and the pertaining unlicensed technologies e.g. WiFi. WiFi system performance is suffered by the collisions happening in WiFi as well as the channel allocation to LTE-U. We propose a scheme to allocate the channel to LTE-U based on the collisions happening in WiFi system so that sufficient throughput of WiFi can be maintained. This paper proposed a stochastic optimization based solution to provide fair spectrum allocation in LTE-U. Chance constraint is used to provide sufficient fairness to WiFi system. Simulation results show that our proposed scheme dynamically allocates the resources to LTE-U to provide fairness to WiFi system.

## I. Introduction

As a result of various high-demand applications in future mobile networks, data rate demands are increasing exponentially. Various 5G applications including Hetnets, device-to-device(d2d) [1], NOMA, and uRLLC have been developed to meet these demands.

LTE-Unlicensed (LTE-U) is one of these various approaches proposed to meet such requirements. LTE-U basically extends the spectrum in cellular networks to unlicensed band in order to solve the problem of spectrum scarcity.

Along the benefits of solving the problem of spectrum scarcity using LTE-U, there comes the challenges of coexistence of LTE-U with the pertaining technologies operating in unlicensed spectrum e.g. WiFi.

It is observed that the operation of LTE-U in unlicensed band can severely cause interference to the WiFi system in the form of long delays and less throughput. To meet such challenges, a fair coexistence mechanism is required in LTE-U for fair spectrum allocation among LTE-U and WiFi.

Various approaches have been proposed in the literature to solve this coexistence problem of LTE-U/WiFi [2], [3]. A ruin theory based approach is proposed in [2]. [3] proposed an approach to ensure the QoS requirements of cellular and WiFi users to maximize the sum-rate of both LTE-U and WiFi. Similar approaches are proposed for the fairness of WiFi in [4] and [5].

It is observed in the literature that developing a spectrum allocation mechanism for the coexistence of LTE-U and Wifi is not easy due to the discrepancies in both of the coexisting technologies in terms of spectrum access. LTE-U uses a centralized approach to allocate the spectral resources to its users in contrast to distributed approach of WiFi system. Such differences in channel access mechanisms in both LTE-U and WiFi make the coexistence problem more difficult.

WiFi system uses the contention-based approach to access the channel and the nodes choose random back-off timer after collision. As a result, WiFi system behaves as a stochastic system. To deal with the randomness in WiFi system due to the collisions and back-offs, an appropriate stochastic model is required.

This paper proposed a stochastic optimization based duty-cycle allocation to provide fairness to WiFi system. Chance constraint is developed to guarantee the sufficient performance of WiFi. Duty cycle allocation of the channel is done based on the random collisions in WiFi system. These collisions are modeled using the chance constraint optimization. The goal of this paper is to develop a dynamic resource allocation scheme for spectrum sharing among WiFi/LTE-U while maintaining sufficient throughput level for WiFi system. The randomness of WiFi system due to unpredicted collisions is also addressed properly and the redundant resources are allocated to LTE-U dynamically.

The paper is organized as follows. Section II discusses the

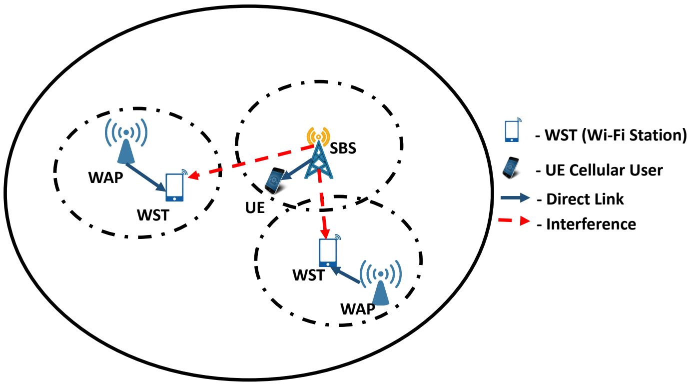


Fig. 1. LTE-U system model

system model and Section III formulates the problem using stochastic optimization. Section IV explains the technique to solve the problem. Simulation results are drawn in Section V. Finally, Section VI concludes the paper.

## II. System Model

The system model consists of a cellular small-cell base station (SBS) and corresponding cellular user set $\mathcal{U}$ of $U$ users coexisting with WiFi system containing $W$ number of wiFi access points (WAPs) and corresponding set $\mathcal{S}_w$ of $S_w$ WiFi stations (WSTs) with each WAP $w \in \mathcal{W}$. All the SBS and WAPs are operating on unlicensed band having a set $\mathcal{K}$ of $K$ channels. It can be seen from Fig. 2 that SBS transmission can cause interference to existing WiFi system transmission.

Each channel $k \in \mathcal{K}$ can be divided among WiFi and LTE-U based on throughput of WiFi system. The throughput of WiFi system is dependent on the WiFi collisions and the proportion of channel allocation to LTE-U. The more allocation to LTE-U will give less chance to WiFi system to access the channel. We propose to allocate the channel to LTE-U based on the random collisions in WiFi system. Fig. 2 shows the duty-cycle division among WiFi and LTE-U.

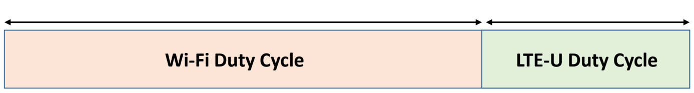


Fig. 2. Duty-cycle distribution among WiFi and LTE-U

The duty-cycle among WiFi/LTE-U is dynamically adjusted for each channel $k \in \mathcal{K}$. To adjust and control the duty-cycle, we propose a chance constraint based optimization problem. Our aim is to adjust the duty-cycle so as to reduce the interference for WiFi system and improve the spectral efficiency of unlicensed spectrum.

## III. Stochastic Optimization

To capture the randomness in the throughput of WiFi system and allocating the duty-cycle to LTE-U for each channel from unlicensed spectrum, we utilize the stochastic optimization. Stochastic optimization is a strong tool to deal the randomness problems while meeting the objective.

Let us consider that there are random collisions $X_t$ happening in WiFi system which can be modeled as Poisson process with parameter $\lambda$. In order to guarantee sufficient throughput to WiFi, we will ensure that the probability of collision time $X_t$ and LTE-U duty-cylce $\beta_k$ is under a threshold $\zeta$. This can be summarized in the chance constraint given as:

$$P[(X_t + \beta_k T) \leq \zeta] \geq \vartheta \tag{1}$$

We can use this chance constraint to formulate the optimization problem for maximizing the rate of LTE-U. LTE-U duty-cycle proportion for each channel $k \in K$ can be represented by $\beta_k$. This proportion of LTE-U duty-cycle is allocated uniformly to each cellular user of LTE-U. SNR of each cellular user can be represented as $\gamma_i$ where $i \in \mathcal{U}$. The chance constraint based optimization problem is formulated as follows:

$$\max_{\boldsymbol{\beta}} \sum_{k\in\mathcal{K}} \sum_{i\in\mathcal{U}} \beta_k \log(1+\gamma_i), \tag{2}$$

$$\text{s.t.} \quad P[(X_t + \beta_k T) \leq \zeta] \geq \vartheta, \quad \forall k \in \mathcal{K}, \tag{2a}$$

$$\beta_k \in [0,1], \quad \forall k \in \mathcal{K}, \tag{2b}$$

here, the objective of the problem in (2) is to maximize the LTE-U rate for cellular users. The constraint (2a) provides the bound for the LTE-U allocation duty-cycle $\beta_k$. This constraint provides the fairness to WiFi system by limiting LTE-U duty-cycle under a threshold. Constraint (2b) gives the range of decision variable.

We can see that the problem is difficult to solve using the typical optimization solvers due to randomness in the chance constraint. We can solve this problem using the stochastic optimization technique given in next section.

## IV. Proposed Solution

To solve the above problem, we use the stochastic optimization to convert the chance constraint into deterministic constraint. This can be done as follows:

Rearranging (1), we get:

$$P[(X_t) \leq \beta_k T + \zeta] \geq \vartheta \tag{3}$$

where, $P[(X_t) \leq \beta_k T + \zeta]$ can be considered as CDF of Poisson distribution and replaced as $F_{X_t}(\beta_k T + \zeta)$. So we get:

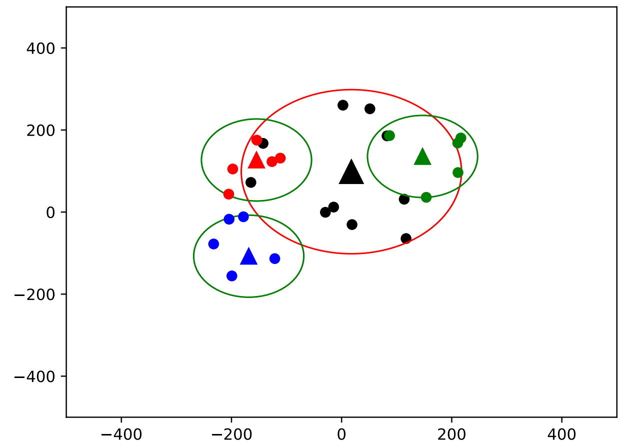


Fig. 3. System model topology

$$F_{X_t}(\beta_k T + \zeta) \geq \vartheta \tag{4}$$

From here, we can easily get the following expression for $\beta_k$

$$\beta_k T \leq \zeta - \mathcal{F}_{X_t}^{-1}(\vartheta) \tag{5}$$

We can replace the Eq. (5) with Eq. (1) to formulate the following optimization problem.

$$\max_{\boldsymbol{\beta}} \sum_{k\in\mathcal{K}} \sum_{i\in\mathcal{U}} \beta_k \log(1+\gamma_i), \tag{6}$$

$$\text{s.t.} \quad \beta_k T \leq \zeta - \mathcal{F}_{X_t}^{-1}(\vartheta), \quad \forall k \in \mathcal{K}, \tag{6a}$$

$$\beta_k \in [0,1], \quad \forall k \in \mathcal{K}, \tag{6b}$$

This problem is easy to solve and can be solved using the KKT conditions.

## V. Simulation

To draw the simulation results, we built the system model of 1 SBS coexisting with 3 WAPs. Cellular users and WiFi stations are uniformly deployed in their respective cells. Fig. 3 shows the topology of the system model built in python. The black triangle represents the SBS while other triangles are representing WAPs. The corresponding users of SBS and WAPs are displayed in the same color dots.

Fig. 4 shows the plot of number of collisions happening in WiFi system verses the LTE-U duty-cycle. It can be seen that the proportion of LTE-U duty-cycle is reduces as the number of WiFi collisions are increased. This dynamic allocation of duty-cycle provides fairness to WiFi system and WiFi is given more chance to cover the loss caused by extra collisions.

## VI. Conclusion

In this paper, we proposed a stochastic optimization based solution for the problem of coexistence among LTE-U and WiFi. Sufficient duty cycle access to WiFi system is provided using the chance constraint. Dynamic duty cycle proportion is allocated to LTE-U according to the random performance of WiFi system. Simulation results reveal that such dynamic allocation provides better fairness to WiFi system as compared to other fairness schemes.

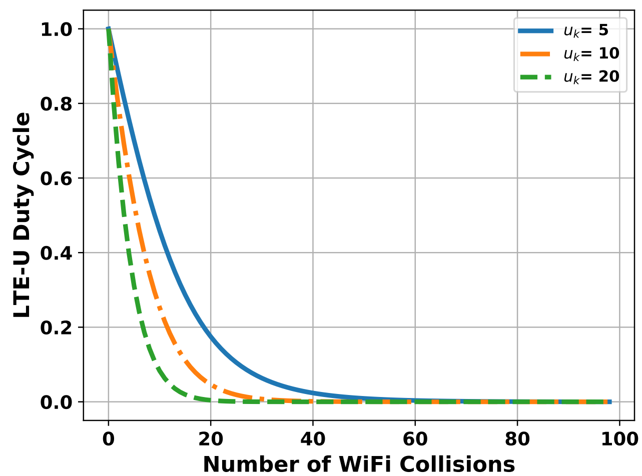


Fig. 4. Plot of WiFi collisions vs. LTE-U duty-cycle

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