# Joint Channel and User Selection for Transmission and Sensing in Cognitive Radio Networks

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***Abstract*—Cooperation among several secondary users for successful spectrum sensing defines an upper bound on the number of channels that can be sensed. Consequently, the maximum utilization is bounded by the number of sensing nodes rather than the availability of the channels. Hence, a subset of the channels should be selected based on the traffic requirements, and the secondary users should be assigned to those channels for the sensing task. In addition, secondary users experience different channel conditions due to interference, noise, and geographical location. Therefore, a secondary user should be assigned to a channel for which its sensing metrics are satisfactory. In this paper, we consider the problem of channel and user selection for cooperative sensing task. We model the mentioned channel selection and user assignment problem as a non-linear optimization problem and solve it using two alternative objectives to achieve increased throughput and number of satisfied users.**

## I. Introduction

Sensing is the most critical operation that enables the utilization of cognitive radio (CR). Sensing quality is usually measured by detection probability and false alarm probability. Cooperative sensing is shown to be more robust than individual sensing since it involves more sensors that are geographically apart and have different signal characteristics. On the other hand, the spectrum is large and sensing all available channels with limited number of secondary users (SUs) is impossible. Hence, a clever mechanism to select channels that can be sensed more accurately is needed together with the assignments of secondary users to those particular channels for sensing.

In addition, the transmission requirements of the SUs also affects the channel selection, and should be taken into account. If the channel capacities do not satisfy the user requirements, the utilization and throughput will be low, significantly affecting the performance.

Shen et al. study the optimization of cooperative spectrum sensing in cognitive radio [1]. They also try to maximize channel throughput by making use of cooperative sensing strategy [2]. They use energy detection for local sensing, and counting rule for cooperative decision. Their goal is to find the settings for sensing such that the channel throughput is maximized. Fan and Jiang try to find the ideal sensing setting for a multi-channel multi-user secondary network with cooperative sensing [3]. The sensing setting includes the time dedicated for the sensing task, and allocating that time to multiple channels. Zhang et al. use partially observable Markov decision process for scheduling of cooperative spectrum sensing [4]. They employ the myopic policy, which may not always be optimal. Moreover, they analyze the properties of the optimal policy for some simple cases. Zhang et al. also look at the cooperative sensing scheduling problem from an energy point of view [5]. They maximize the useful energy consumption, and use bisection search to find the optimal solution. Peh et al. optimize throughput by employing cooperative sensing [6]. They consider a single channel, and obtain the ideal values of sensing time and type of logic to be used for hard decision combining. They decompose the main problem into two subproblems and obtain a local optimum solution. Song et al. also study the single channel case and find the ideal number of seconday users for sensing, and also ideal durations for transmission and sensing [7].

These approaches do not differentiate between sensing quality of different SUs [1-7]. However, thanks to interference, noise and geographical location, an SU has different sensing quality for different channels. Moreover, they assume all channels can be sensed, which is not energy nor time efficient considering the spectrum and operating range of a typical cognitive radio network.

In this paper, we propose a system model together with its optimization model for channel selection for transmission and cooperative sensing that maximizes expected throughput of the system. Subsequently, we solve the problem using genetic algorithm along with CPLEX software, and evaluate its performance for different operational parameters.

The rest of the paper is organized as follows: In section II, we present the system model, define the decision variables and construct the optimization model. Section III discusses how non-linearity in the optimization problem is handled. The results of the performance analysis are given in Section IV. Finally, we conclude the paper and explore future research directions in section V.

## II. Joint Optimization of Channel and User Selection

In this section, we formulate and solve the cooperative sensing scheduling problem simultaneously with the transmission scheduling for infrastructure based CR networks.

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### A. System Model

In our system model, we assume that all channels operate according to the frame structure given in Figure 1. A frame starts with the revision of the transmission schedule for the current frame. After the transmission schedule is revised, it is announced to SUs by the secondary base station (BS). Secondary BS gathers the requests for the next frame subsequently. Then, data transmission begins. We assume a TDMA scheme with $T$ slots for all channels. During data transmission period, secondary BS works on the sensing and transmission schedule for the next frame. When transmission period ends, the sensing schedule is announced, which is followed by a quiet sensing period where the SUs sense the channels assigned to them. The secondary BS retrieves the sensing results from the SUs, and based on those results it revises the transmission schedule at the beginning of the next frame.

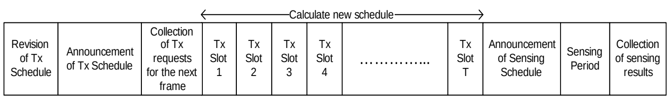


Fig. 1. Frame Structure

At request collection phase, each SU that requires a transmission opportunity for the next frame, informs the secondary BS about the number of bits it needs to send during the next frame. That is to say, the secondary BS knows all requirements of the SUs and it tries to allocate channels based on those requirements. However, in order to select the channels for allocation, a subset of all the candidate channels must be sensed. In this work, we are mainly focused on the joint scheduling of cooperative sensing and transmission.

We employ cooperative sensing mechanism with hard decision combining using majority logic since it is less error prone compared to individual sensing. Furthermore, a couple of criteria should be met in order to use a channel for transmission. Firstly, the result of the sensing procedure should indicate that the channel is not occupied by a PU. Secondly. the channel should be sensed accurately. Let $Q_m^D$ and $Q_m^F$ denote the cooperative detection and false alarm probabilities for channel $m$, respectively. If channel $m$ is to be employed for transmission, we require that $Q_m^D \geq {}_{th}Q^D$ and $Q_m^F \leq {}_{th}Q^F$ where ${}_{th}Q^D$ and ${}_{th}Q^F$ are threshold values for probability of detection and probability of false alarm, respectively. In our model, we assume that in order to successfully sense a channel $\delta$ SUs are needed. Moreover, we let individual detection and false alarm probabilities be different not only among SUs but also for different channels for each SU.

### B. Optimization Model

During the operation of the Cognitive Radio Network, we would like to sense as many channels as possible in order to obtain the maximum information about the status of the channels. Since there are many channels and the number of SUs is limited, sensing all channels is usually not an option. Moreover, we also have to keep the cooperative detection, and false alarm probabilities in compliance with their respective thresholds for the channels that are used for transmission. Hence we would like to successfully sense the channels that are more likely to be used for transmission by the SUs, and if there are still SUs unassigned for sensing, then sense other channels for updating our information about those channels.

The parameters for the system are given in Table I. In this table, the parameter $a_m$ deserves some explanation. It estimates the probability that channel $m$ is not occupied by a PU. The value of $a_m$ is calculated based on past data. To accommodate for trends such as peak hours of the day, an exponential smoothing procedure or a window based approach can be used. The former takes all of the past data into account whereas the latter takes only the last measurements within the window.

TABLE I
MODEL PARAMETERS

| | |
|---|---|
| $M$ | Number of channels |
| $N$ | Number of SUs |
| $T$ | Number of transmission slots in a frame |
| $a_m$ | Estimated probability that channel $m$ is available for transmission |
| $R_n$ | Number of bits for user $n$ that need to be sent at next frame |
| $C_m$ | Number of bits that can be sent in a slot using channel $m$ |
| $P_{mn}^D$ | Detection probability of user $n$ for channel $m$ |
| $P_{mn}^F$ | False alarm probability of user $n$ for channel $m$ |
| $Q_m^D$ | Cooperative detection probability for channel $m$ |
| $Q_m^F$ | Cooperative false alarm probability for channel $m$ |
| ${}_{th}Q^D$ | Threshold value for cooperative detection probability |
| ${}_{th}Q^F$ | Threshold value for cooperative false alarm probability |

After discussing the parameters, we give the decision variables for the optimization model. Let

$$y_{mnt} = \begin{cases} 1, \text{if channel } m \text{ is used for tx by } SU_n \text{ at slot } t \\ 0, \text{o/w} \end{cases},$$

$$r_{mnt} = \text{number of bits that will be sent by } SU_n \text{ using channel } m \text{ at slot } t \text{ in the next frame},$$

$$x_{mn} = \begin{cases} 1, \text{if channel } m \text{ is sensed by } SU_n \text{ in this frame} \\ 0, \text{o/w} \end{cases},$$

$$v_n = \begin{cases} 1, \text{if } SU_n \text{ transmits during next frame} \\ 0, \text{o/w} \end{cases},$$

$$u_m = \begin{cases} 1, \text{if channel } m \text{ is to be sensed in this frame} \\ 0, \text{o/w} \end{cases},$$

$$z_m = \begin{cases} 1, \text{if channel } m \text{ is used for tx in the next frame} \\ 0, \text{o/w} \end{cases}.$$

Then our problem becomes:

$$max\ w = \sum_{m=1}^{M} \sum_{n=1}^{N} \sum_{t=1}^{T} a_m r_{mnt} \tag{1}$$

subject to

$$\sum_{m=1}^{M} y_{mnt} \leq 1 \qquad \forall n, t \tag{2}$$

$$\sum_{n=1}^{N} y_{mnt} \leq 1 \qquad \forall m, t \tag{3}$$

$$\sum_{m=1}^{M}\sum_{t=1}^{T} y_{mnt} \leq \frac{R_n}{C_{min}} v_n \qquad \forall n \tag{4}$$

$$r_{mnt} \leq C_m y_{mnt} \qquad \forall m, n, t \tag{5}$$

$$\sum_{m=1}^{M}\sum_{t=1}^{T} r_{mnt} = R_n v_n \qquad \forall n \tag{6}$$

$$v_n \leq \frac{R_n}{R^+_{min}} \qquad \forall n \tag{7}$$

$$\sum_{m=1}^{M} x_{mn} \leq 1 \qquad \forall n \tag{8}$$

$$\sum_{n=1}^{N}\sum_{t=1}^{T} y_{mnt} \leq T z_m \qquad \forall m \tag{9}$$

$$z_m \leq u_m \qquad \forall m \tag{10}$$

$$\sum_{n=1}^{N} x_{mn} = \delta u_m \qquad \forall m \tag{11}$$

$$_{th}Q^D z_m \leq Q^D_m \qquad \forall m \tag{12}$$

$$Q^F_m \leq {}_{th}Q^F + (1 - z_m) \qquad \forall m \tag{13}$$

$$Q^D_m = \sum_{A \in H_\delta} \sum_{k=\lceil \delta/2 \rceil}^{\delta} \sum_{B \in A_k} [\prod_{i \in B} P^D_{mi} x_{mi} \prod_{j \in A \setminus B} (1 - P^D_{mj}) x_{mj}] \qquad \forall m \tag{14}$$

$$Q^F_m = \sum_{A \in H_\delta} \sum_{k=\lceil \delta/2 \rceil}^{\delta} \sum_{B \in A_k} [\prod_{i \in B} P^F_{mi} x_{mi} \prod_{j \in A \setminus B} (1 - P^F_{mj}) x_{mj}] \qquad \forall m \tag{15}$$

$$y_{mnt}, x_{mn}, v_n, u_m, z_m \in (0, 1) \qquad \forall m, n, t \tag{16}$$

$$r_{mnt} \geq 0. \tag{17}$$

The objective in (1) maximizes the expected throughput of the system for a frame by favoring channels with large $a_m$ values. Constraint (2) ensures that an SU can transmit in a single channel at any given slot since we assume that all SUs have single transceiver. Constraint (3) denotes that at most one SU can transmit in a channel at a given slot. Constraint (4) forces $v_n$ to be 1 if SU $n$ transmits at least once during next frame. In this constraint $C_{min}$ denotes the minimum of all $C_m$ values. Furthermore, this constraint also forces $y_{mnt}$ values of user $n$ to zero if $R_n$ is zero. Constraint (5) expresses that the number of bits sent over channel $m$ at slot $t$ should be less than or equal to the channel capacity. Constraint (6) makes sure that if a user transmits, its requirements are met. Constraint (7) forces $v_n$ to $0$ if $R_n = 0$. In this constraint, $R^+_{min}$ is defined as the minimum positive $R_n$ value. Constraint (8) guarantees that an SU can sense at most one channel. Constraint (9) forces $z_m$ to be $1$ if some SU transmits on that channel during the frame. Constraint (10) expresses that if a channel is to be used for transmission, it has to be sensed. We ensure that a channel is sensed by exactly $\delta$ users by constraint (11). Constraints (12) and (13) are used for forcing cooperative detection and false alarm probabilities meet the specified threshold criteria if a channel is used for transmission.

The mathematical definitions of $Q^D_m$ and $Q^F_m$ for majority logic are given in constraints (14) and (15), respectively. Let us focus on constraint (14). Let $H$ be the set $\{1, 2, \ldots, N\}$, and let $H_\delta$ denote the set of all the subsets of $H$ with $\delta$ elements. Similarly, $A_k$ denotes the set of all the subsets of $A$ with $k$ elements. In constraint (14), we select a set B from $A_k$ where $k$ ranges from $\lceil \delta/2 \rceil$ to $\delta$ for majority logic. The elements in B are the ones that correctly sense the channel (success), and contribute $P^D_{mi}$. The elements in $A \setminus B$ constitute the users that sense the channel incorrectly (failure), and contribute $(1 - P^D_{mj})$. We should state that in order for the product terms be different than zero, all $x_{mi}$ and $x_{mj}$ values should be 1. Hence, if we perform this task over all the subsets of $H$ with $\delta$ elements, we find the probability of successful detection of a given channel for the majority logic with the given set of SUs (with $x_{mn} = 1$). The same arguments also apply for constraint (15). Finally, constraints (16) and (17) merely define the types of variables.

We also propose another problem with the same set of constraints but with a different objective, $max\ w = \sum_{n=1}^{N} v_n$. This objective tries to maximize the number of transmitting SUs in a frame, that is to say it maximizes the number of satisfied users. In order to achieve this task, it favors SUs that has low $R_n$ values whereas our first objective favors SUs with high $R_n$ values to maximize throughput. For a given set of parameters, we solve both problems in order to compare the results.

The model given above is highly non-linear thanks to constraints (14) and (15) and cannot be solved to optimality by commercial solvers.

## III. Tackling Non-linearity in the Optimization Model

In the given optimization model, once $x_{mn}$ values are known, the problem becomes a standard binary linear problem that can be solved by commercial solvers. Knowing $x_{mn}$ values also enables us to know $u_m$ values. Furthermore, we can calculate corresponding $Q^D_m$ and $Q^F_m$ values easily. Based on those calculated $Q^D_m$ and $Q^F_m$ values, we set $z_m = 1$ if they satisfy the thresholds. Otherwise, $z_m = 0$, since that channel cannot be used for transmission. We employ a genetic algorithm to find the ideal $x_{mn}$ and $u_m$ values, and then solve for the other variables using CPLEX solver. We now discuss the details of the genetic algorithm.

### A. Encoding

Encoding defines how we represent a solution. To represent a solution we store the corresponding $x_{mn}$ values in matrix form and $u_m$ values in a vector form. As an example, with 4 channels, 5 SUs, and a $\delta$ value of 2, a possible solution is:

$$x = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 \end{bmatrix}, u = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \end{bmatrix}.$$

Since there are 5 users, at most 2 channels can be sensed. Hence, only two of the $u_m$ values are 1 in this case. That would not be the case if $\delta$ was 3.

### B. Fitness Function

We use the objective value of the optimization problem as the fitness value of an individual. As stated above, we employ CPLEX solver to find the optimal value for given $x$ and $u$.

### C. Initial Population

Before the algorithm starts, we find $r$, the number of channels that can be sensed, which is given by $\min \lfloor N/\delta \rfloor, M$. For each individual, we randomly select $r$ channels among $M$ channels, and construct the $u$ vector by assigning $u$ values to 1 for the selected channels. Then, for each channel to be sensed, that is $u_m = 1$, we randomly assign $\delta$ users from the set of unassigned ones for the sensing task and obtain $z_m$ values. Then, we calculate the fitness value for each individual.

### D. Crossover

Crossover operator produces offspring that will be added to the population for the next generation. In our algorithm, two parents are used for producing two children. We use roulette wheel selection together with 3-tournament strategy. In other words, for each parent three candidate individuals are inspected. The selection of candidates is done randomly, but candidates with better fitness values have more chance to be selected. Among the three candidates, the best one is selected as the parent.

After the parents are selected, the actual crossover procedure begins. We first select $r$ channels to be sensed among the channels sensed by either the first or the second parent. That is to say, we first form the $u$ vector. Then, for each $u_m = 1$ for the new child, we look at the $u_m$ value of the parents. There are two cases to consider:

- Only one of the parents have $u_m = 1$: We directly copy the $x_{mn}$ values of that parent at row $m$ to the child.
- Both parents have $u_m = 1$: This time, we randomly select a parent and perform the same procedure.

For instance, let $p_1$ and $p_2$ be two parents defined by $x_1$ and $u_1$, $x_2$ and $u_2$, respectively as follows:

$$x_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 \end{bmatrix}, u_1 = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \end{bmatrix};$$

$$x_2 = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}, u_2 = \begin{bmatrix} 1 \\ 0 \\ 1 \\ 0 \end{bmatrix}.$$

Then their children $c_3$ that is defined by $x_3$ and $u_3$, and $c_4$ that is defined by $x_4$ and $u_4$ may look like:

$$x_3 = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}, u_3 = \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \end{bmatrix};$$

$$x_4 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}, u_4 = \begin{bmatrix} 0 \\ 1 \\ 1 \\ 0 \end{bmatrix}.$$

We observe that $c_3$ is a feasible child whereas $c_4$ is not, since $SU_3$ needs to sense two channels at the same time. Let's now focus on how an infeasible child is transformed into a feasible one.

- Step 1: An SU may be assigned to 0, 1, or 2 channels for sensing. We find the SUs that are assigned to 2 channels and randomly reverse one of those assignments. Thus, after this step $c_4$ may look like:

$$x_4 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}, u_4 = \begin{bmatrix} 0 \\ 1 \\ 1 \\ 0 \end{bmatrix}.$$

- Step 2: Even though we solve the double assignment problem, this time there may be channels with less than $\delta$ users for sensing. To alleviate the problem, we randomly select from unassigned SUs and assign them to those channels until there are $\delta$ users for each channel that is to be sensed. After this step $c_4$ may look like:

$$x_4 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}, u_4 = \begin{bmatrix} 0 \\ 1 \\ 1 \\ 0 \end{bmatrix}.$$

After these two steps, a child is guaranteed to be feasible since each SU is assigned to at most one channel, and all channels to be sensed have $\delta$ users assigned to them.

### E. Mutation

When we generate offspring population, we perform mutation operation on each new member with some probability $p_m$. Mutation operation is defined as randomly exchanging two rows of the child. For instance, mutation operator applied to $c_4$ may result in:

$$x_4 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix}, u_4 = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 1 \end{bmatrix}.$$

### F. Replacement

We use the elitist strategy to perform replacement. We add all offspring to the current population and we discard the ones with worse fitness values such that the original population size is maintained in order to form the next generation. However; when adding an offspring to population, we check that if there is an individual with the same chromosome. If that is the case, we do not include that offspring in the population even if it has a good fitness value, to preserve the diversity.

The algorithm runs for a predefined number of iterations. The parameters that are used for the genetic algorithm are given in Table II.

TABLE II
PARAMETERS FOR THE GENETIC ALGORITHM

| | |
|---|---|
| Population Size | 100 |
| Number of Iterations | 100 |
| Offspring Population Size | 20 |
| $p_m$ | 0.1 |

## IV. EVALUATION OF THE METHOD

For performance evaluation of the proposed method, we assign a uniform random value between (0, 1) for $a_m$ values. $P^F_{mn}$ is also uniform random between (0.1, 0.4) for each channel-user pair. We assume a Rayleigh channel model with mean SNR, $\mu_{SNR}$. Then for each user and channel, we assign an exponential random SNR value. Based on that value and $P^F_{mn}$, we calculate the corresponding detection threshold ($\Delta$) and $P^D_{mn}$. Furthermore, we assign a random channel capacity ($C_m$) to each channel that is uniformly distributed between (0.125, 2) Mb. Each SU generates traffic for a given frame randomly based on an activity ratio, $\beta$. If the random number is smaller than $\beta$, we also assign a uniform random $R_n$ value between (0.125, 5) Mb. The same $R_n$, $C_m$, $a_m$, $P^F_{mn}$ values are used throughout the runs for consistency. In addition, the same SNR value is used for each channel-user pair for a given $\mu_{SNR}$. The other parameters are given in Table III. All values shown in the figures are the average of ten runs.

TABLE III
MODEL PARAMETERS

| | |
|---|---|
| M | 20 |
| N | 100 |
| T | 10 |
| $_{th}Q^D$ | 0.9 |
| $_{th}Q^F$ | 0.1 |
| $\delta$ | $\{5, 7, 9, 11, 13\}$ |
| $\beta$ | $\{0.2, 0.4, 0.6, 0.8, 1\}$ |
| $\mu_{SNR}$ | $\{4dB, 5dB, 6dB, 7dB, 8dB\}$ |

The effect of $\mu_{SNR}$ on expected throughput (ET) and transmitter count (TC) for different values of $\delta$ for throughput maximization (TPM) and transmitter maximization (TXM) is shown in Figures 2, and 3, respectively. For a given $P^F_{mn}$, higher SNR implies higher $P^D_{mn}$. Both performance metrics favor large $\delta$ values when $\mu_{SNR}$ is low. However, as $\mu_{SNR}$ increases both metrics increase for different $\delta$ values, the rate of increase for smaller $\delta$ being more significant. This is due to the fact that with higher $P^D_{mn}$, more channels can be sensed accurately when $\delta$ is low. For instance, for a $\mu_{SNR}$ of 4dB, taking $\delta = 5$ leads to zero ET since no channel is sensed with adequate accuracy. On the other hand, when $\mu_{SNR} = 8$dB, a $\delta$ value of 5 leads to the maximum ET. Thus, selection of the ideal $\delta$ value heavily depends on $\mu_{SNR}$. Another point to note is that, even though ET does not differ significantly for the two objectives, the same argument does not apply to TC, especially for low values of $\mu_{SNR}$.

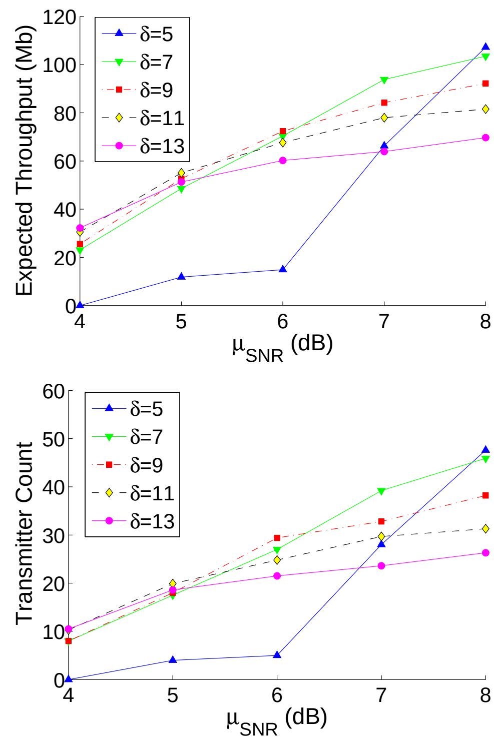


Fig. 2. Expected throughput and transmitter count for TPM ($N = 100$, $\beta = 0.6$)

The performance metrics for changing $\beta$ and $\delta$ values are given in Figures 4, and 5. As we can see from Figure 4(a), ET almost saturates after $\beta = 0.6$ for TPM. On the other hand, ET first increases then slightly decreases for increasing $\beta$ values for TXM as shown in Figure 5(a). This can be attributed to the fact that beyond a saturation point, increasing $\beta$ adds more users with small $R_n$ values. By favoring those users, although ET slightly decreases, TXM objective increases TC. This fact is also observed from Figure 5(b). It should be noted that for this case $\delta = 9$ always achieves the best performance.

## V. CONCLUSION

In this paper a joint transmission and sensing scheduling problem is defined in terms of its mathematical model together with two alternative objectives. Due to its non-linear nature, the optimization problem is solved by using genetic algorithm

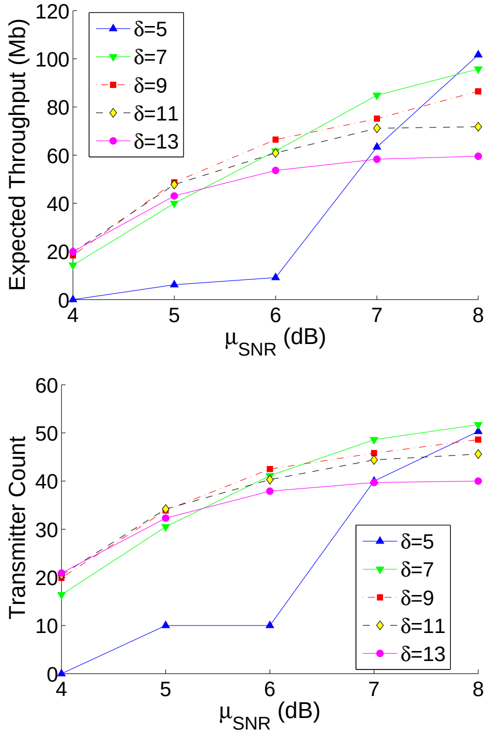


Fig. 3. Expected throughput and transmitter count for TXM ($N = 100$, $\beta = 0.6$)

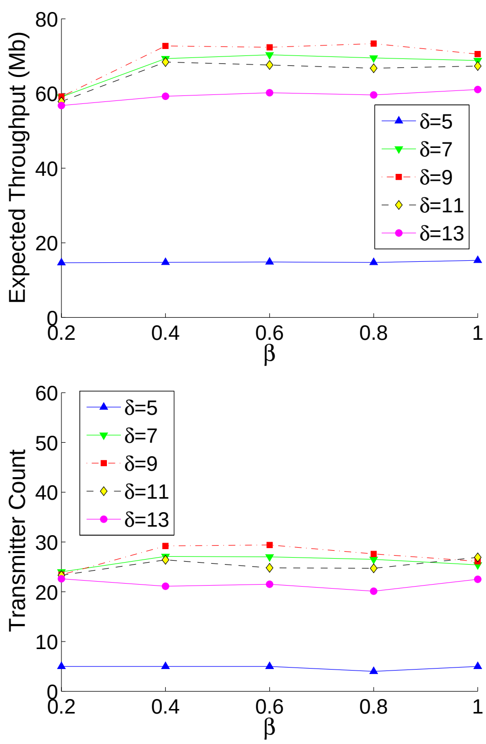


Fig. 4. Expected throughput and transmitter count for TPM ($N = 100$, $\mu_{SNR} = 6$dB)

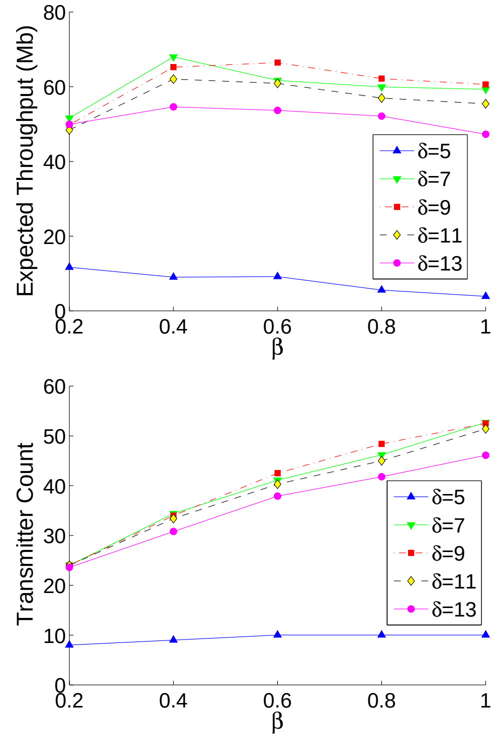


Fig. 5. Expected throughput and transmitter count for TXM ($N = 100$, $\mu_{SNR} = 6$dB)

together with CPLEX. For this task, building blocks of the genetic algorithm such as crossover and mutation strategy are defined. Then, both problems are solved for varying set of parameters.

For future work, we plan to model the same problem for a general case by incorporating $\delta$ and decision logic into the model. Hence, it will be possible to select the ideal $\delta$ and decision logic for each channel.

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