Location-aware Cognitive Sensing for Maximizing Network Capacity

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***Abstract*— We develop a closed-form optimal spectrum sensing threshold to maximize a cognitive network weighted sum capacity. In an one primary user and one cognitive user network, spatial location side information is used by the cognitive transmitter to adjust its sensing threshold accordingly. Numerical results show that, compared to another threshold based on minimizing a Bayesian risk function, the proposed threshold improves the network sum capacity significantly. The benefit of spatial location side information is also revealed in the sum capacity.**

I. Introduction

The increasing demand on the bandwidth of recent communication systems exerts extra loads on the already crowded spectrum allocation. However, it is found that the spectrum scarcity is mostly because of inflexible spectrum management rather than true natural resource shortage [3], [4]. Some licensed spectrum is under-utilized most of the time. Cognitive Radio, which has the ability to sense the spectrum [8] in order to utilize idle times of the licensed, primary link, is a promising candidate to solving the spectrum scarcity problem.

Another aspect of cognition is the use of side information. Side information can help the radios to adjust their transmission and coding schemes. For example, a two transmitter and two receiver cognitive channel model is considered in [5] with side information about primary user's signals. Without considering how to obtain the side information and the channel coefficients, achievable rate regions are deduced theoretically and simulated according to the different strategies of the cognitive radio based on the side information.

In spectrum sensing, detecting the primary user's transmission energy is a classical sensing method. Its performance can be improved by the use of side information on locations of the various transmitters and receivers. Intuited by this idea, the authors in [2] apply a model which characterizes interference and transmission power with distances. Further, they utilize spatial information to design optimal sensing thresholds based on a Bayesian criterion that minimizes a cognitive user's sensing cost. They reach the conclusion that spatial side information provides substantial advantage in reducing the sensing costs. However, they do not investigate the impact of spatial information on the network capacity.

Taking one step further, we reformulate the sensing cost in the threshold design and analyze the primary and cognitive link capacities in [7]. It is shown that the sensing cost must be carefully chosen for the side information to also be beneficial to the capacity of the cognitive user, while bringing little or no harm to the primary user's capacity.

In this paper, we formulate a new sensing threshold design problem to directly maximize the weighted sum capacities of the primary and cognitive users. The optimal thresholds are derived for different sets of location side information. The same sets of location information as in [7] are chosen for performance comparison. Numerical results show that the proposed threshold can dramatically improve the network capacity. The increase in the network sum capacity owes to improvement in the cognitive user's capacity, but comes at a drawback on the primary user capacity. Location side information is again found beneficial to the cognitive transmitter in setting its optimal sensing threshold to increase the network sum capacity. The impact of location information on the individual user's capacity depends on the weight in the network sum capacity objective. Interestingly, with equal weights, it is found that more location information to the cognitive users actually helps increase the primary user's capacity at some expense to the cognitive user's capacity.

Remainder of the paper is organized as follows. In Section II, we introduce the two-user network model and the channel model. In Section III, we introduce the network capacity formulation and the sensing objective. In Section IV, the optimal threshold aimed at maximizing the network weighted sum capacity with different sets of location information are derived. We discuss the numerical results in Section V. Finally, we provide our concluding remarks in Section VI.

II. Network and Channel Models

We consider the same network and channel models as in [7] as shown in Fig. 1. The network consists of one cognitive user and one primary user, each has a pair of randomly located transmitter and receiver. The location randomness can arise from mobility or from the random network access. Let the cognitive transmitter C_{tx} be the center of the network at the polar coordinates $(0, 0)$. The cognitive receiver C_{rx} is uniformly distributed within the disc centered at the origin with radius R_c. Let the impact radius of the cognitive transmitter be R_i such that any primary receiver falling within this radius will be noticeably interfered by the cognitive transmitter. The considered primary receiver P_{rx} lies uniformly within this radius R_i. Centered at P_{rx}, the primary transmitter P_{tx} is uniformly distributed within the disc with radius R_p. The radii R_c, R_i and R_p are known network parameters.

Furthermore, protection regions of radius ϵ centered at receiving nodes are assumed as shown in Fig. 1. Any active transmitter cannot be inside this region to exclude the possibility that the receive signal and interference power rises to infinity.

Let S_{pt} S_{pr} and S_{cr} respectively specify the locations of P_{tx}, P_{rx} and C_{rx} within the polar coordinates. Consider S_{cr}

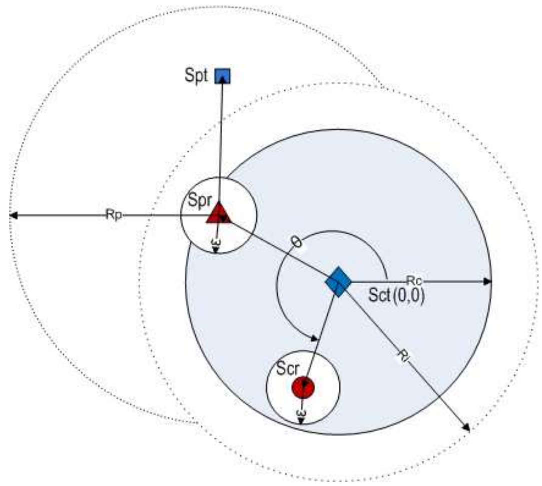

Fig. 1. Network model.

for example, and let r denotes its radius and θ denote its angle. For uniformly distributed C_{rx}, r has the density $f_r(r) = 2r/(R_c^2 - \epsilon^2)$ with $\epsilon \leq r \leq R_c$, and θ is uniform between 0 and 2π. The distributions for the radius and angles in S_{pr} and S_{pt} can be similarly derived.

The channel between any transmitter and receiver is modeled as $h = h_{PL} \cdot h_{FD}$, where free-space path loss $h_{PL} = \frac{A}{d^{\alpha/2}}$ with α as the pathloss exponent models the averaged power changing with distance and Rayleigh fading component h_{FD} models the small-scale variation. A is a constant dependent on the frequency and transmitter/receiver antenna gain, and $h_{FD} \sim \mathcal{CN}(0,1)$ is a complex circular Gaussian random variable with independent real and imaginary parts with equal variance.

To sense the primary transmission, the cognitive transmitter needs to perform a hypothesis testing to decide between the following two hypotheses:

$$\begin{aligned} \mathcal{H}_0 &: \quad y = z \\ \mathcal{H}_1 &: \quad y = x + z \end{aligned}$$

where y is the received samples at C_{tx}, x is the signal received at the cognitive transmitter from the P_{tx} after experiencing path loss and fading, and z is the thermal noise. Based on the studied channel model, the distributions of x and z are

$$x \sim \mathcal{CN}(0, \sigma_x^2) \ , \quad z \sim \mathcal{CN}(0, \sigma_z^2),$$

where $\sigma_x^2 = P h_{PL}^2$ with P as the primary transmit power, and the noise power σ_z^2 is constant.

III. Network Capacity Formulation and Sensing Objective

In the considered network, the cognitive transmitter performs the detection of the primary signal. Only when the cognitive transmitter detects that there is no primary transmission, it will begin its own transmission. In this paper, we consider the design of an optimal power sensing threshold to directly maximize the network weighted sum capacity. We will first formulate the capacity equations and then set up the capacity objective for designing the sensing threshold.

A. Capacity Formulation

Consider the capacity of the primary and the cognitive links, averaged over all radio locations. For the primary user, the capacity depends on its probability of transmission and the amount of interference, if any, from the cognitive user and thus, is a function of the miss-detection probability. For the cognitive user, the capacity depends on the opportunity to transmit and whether there is any interference from the primary user. Thus, the capacity of the cognitive user is a function of both the false-alarm and miss-detection probabilities. Specifically, these two capacities can be written as

$$\begin{aligned} C_p = E_{S_{pr},S_{cr},S_{pt}} \Bigg\{ & \Pr(H_1|H_1,\gamma)\lambda_1 E\left[\log_2\left(1+\frac{L_p}{\sigma_z^2}\right)\right] \\ & + \Pr(H_0|H_1,\gamma)\lambda_1 E\left[\log_2\left(1+\frac{L_p}{\sigma_z^2+I_{pc}}\right)\right]\Bigg\} \qquad (1) \\ C_c = E_{S_{pr},S_{cr},S_{pt}} \Bigg\{ & \Pr(H_0|H_0,\gamma)(1-\lambda_1) E\left[\log_2\left(1+\frac{L_c}{\sigma_z^2}\right)\right] \\ & + \Pr(H_0|H_1,\gamma)\lambda_1 E\left[\log_2\left(1+\frac{L_c}{\sigma_z^2+I_{cp}}\right)\right]\Bigg\} \qquad (2) \end{aligned}$$

where

- γ is the sensing threshold.
- λ_1 is the transmission probability of the primary user.
- $\Pr(H_0|H_1,\gamma)$ is the miss-detection probability, when the secondary transmitter makes a decision to transmit while the primary transmitter is also active. Denote

$$p = \Pr(H_1|H_1,\gamma) = 1 - \Pr(H_0|H_0,\gamma). \qquad (3)$$

- $\Pr(H_1|H_0,\gamma)$ is the false-alarm probability, when the secondary transmitter makes a decision not to transmit while the primary link is idle. Denote

$$q = \Pr(H_0|H_0,\gamma) = 1 - \Pr(H_1|H_0,\gamma). \qquad (4)$$

- L_p and L_c are the random received signal power of the primary and cognitive receiver,
- I_{pc} and I_{cp} are random interference power from the cognitive transmitter to the primary receiver, and from the primary transmitter to the cognitive receiver, respectively.

Since the locations of the radios are random, we are interested in the capacity averaged over all the random locations. Depending on the knowledge about any of the radio locations, the design of an optimal sensing threshold and the evaluation of the capacities will vary as subsequently analyzed.

B. Sensing Objective

Our objective here is to design a sensing threshold to directly maximize the weighted sum of primary and cognitive users' capacity as follows

$$\mathcal{C} = \mu C_p + (1-\mu) C_c = E_{S_{pt},S_{pr},S_{cr}}[ap + bq + c] \qquad (5)$$

where $0 < \mu < 1$ is the weight to emphasize either the primary or the cognitive link capacity importance, and p and q are given in (3) and (4). Here a captures the capacity terms associated with primary user transmitting, b with primary user not transmitting, and c captures the common capacity terms given as

$$a = \mu\lambda_1 E\left[log_2\left(1+\frac{L_p}{\sigma_z^2}\right)\right] - \mu\lambda_1 E\left[log_2\left(1+\frac{L_p}{\sigma_z^2+I_{pc}}\right)\right] - (1-\mu)\lambda_1 E\left[log_2\left(1+\frac{L_c}{\sigma_z^2+I_{cp}}\right)\right] \quad (6)$$

$$b = (1-\mu)(1-\lambda_1) E\left[log_2\left(1+\frac{L_c}{\sigma_z^2}\right)\right] \quad (7)$$

$$c = \mu\lambda_1 E\left[log_2\left(1+\frac{L_p}{\sigma_z^2+I_{pc}}\right)\right] + (1-\mu)\lambda_1 E\left[log_2\left(1+\frac{L_c}{\sigma_z^2+I_{cp}}\right)\right] \quad (8)$$

where $E\{.\}$ denotes the expectation with respect to channel fading.

Our goal is to design the cognitive sensing threshold to maximize this network weighted sum capacity $\mathcal{C}$. The optimal threshold design is aided with the information about location of other radios known to the cognitive transmitter. Based on the location information, the cognitive transmitter can adjust its sensing threshold to achieve a higher network capacity.

In deriving the optimal threshold, we investigate four different cases of location information (to be presented in Section IV). These cases have also been considered in [7] in designing a sensing threshold to minimize a Bayesian risk function, which is different from the capacity objective (5). As in [7], in all the four cases, we assume that σ_x^2 and σ_z^2 are known, but S_{ct} does not use σ_x^2 to infer the distance to the primary transmitter as it can alter the distribution of S_{cr}.

IV. Optimal Threshold

In this section, we derive in closed-form the optimal thresholds to maximize the weighted sum capacity (5). We provide detailed analysis for Case 1 with full location information, and then the extension for the other 3 cases.

A. Case 1: When S_{pr}, S_{cr} and S_{pt} are available

For Case 1, since the cognitive Tx knows the location of every radio, a, b, c are known for each network realization and can be regarded as constants. Maximizing the objective (5) is equivalent to maximizing $ap + bq + c$ for each realization of $\{S_{pt}, S_{pr}, S_{cr}\}$. Furthermore, the signal power received at the cognitive Tx from the primary Tx follows the two degree chi-square distribution in both cases of primary transmitting and non-transmitting with different variances. Thus, for each set of $\{S_{pt}, S_{pr}, S_{cr}\}$, we can express the objective function as

$$\begin{aligned} f(\gamma) &= ap + bq + c \\ &= a\int_\gamma^{+\infty}\frac{1}{(\sigma_z^2+\sigma_x^2)}e^{-\frac{\xi}{(\sigma_z^2+\sigma_x^2)}}d\xi + b\int_0^\gamma \frac{1}{\sigma_z^2}e^{-\frac{\xi}{\sigma_z^2}}d\xi + c \\ &= ae^{-\frac{\gamma}{(\sigma_z^2+\sigma_x^2)}} - be^{-\frac{\gamma}{\sigma_z^2}} + b + c \end{aligned} \quad (9)$$

Our goal is to find $\gamma \geq 0$ to maximize $f(\gamma)$. From (6) and (7) we observe that coefficient b is always positive, but a can be smaller or equal to zero in some locations under certain primary transmission probabilities. When $a \leqslant 0$, to maximize (9), the threshold should be set to infinity, which means the cognitive radio always transmit.

On the other hand, when $a > 0$, the first and the second derivatives of $f(\gamma)$ can be found as

$$f'(\gamma) = -\frac{a}{(\sigma_z^2+\sigma_x^2)}e^{-\frac{\gamma}{(\sigma_z^2+\sigma_x^2)}} + \frac{b}{\sigma_z^2}e^{-\frac{\gamma}{\sigma_z^2}}$$

$$f''(\gamma) = \frac{a}{(\sigma_z^2+\sigma_x^2)^2}e^{-\frac{\gamma}{(\sigma_z^2+\sigma_x^2)}} - \frac{b}{(\sigma_z^2)^2}e^{-\frac{\gamma}{\sigma_z^2}}$$

The second derivative is negative, $f''(\gamma) < 0$, when

$$\gamma < (\sigma_z^2+\sigma_x^2)\frac{\sigma_z^2}{\sigma_x^2}\ln\left(\left(\frac{\sigma_z^2+\sigma_x^2}{\sigma_z^2}\right)^2\frac{b}{a}\right) \quad (10)$$

Let the first derivative be equal to zero, $f'(\gamma) = 0$, we obtain an optimal threshold as

$$\gamma = (\sigma_z^2+\sigma_x^2)\frac{\sigma_z^2}{\sigma_x^2}\ln\left(\frac{\sigma_z^2+\sigma_x^2}{\sigma_z^2}\frac{b}{a}\right) \quad (11)$$

The optimal value (10) always satisfies condition (11), hence $f(\gamma)$ is maximized at this value. So the optimal threshold can be obtained as

$$\gamma_1 = \begin{cases} \infty, & \text{if } a \leqslant 0, \\ (\sigma_z^2+\sigma_x^2)\frac{\sigma_z^2}{\sigma_x^2}\ln\left(\frac{\sigma_z^2+\sigma_x^2}{\sigma_z^2}\frac{b}{a}\right) & \text{if } a > 0. \end{cases} \quad (12)$$

The network weighted sum capacity can be computed using this optimal threshold for each realization of $\{S_{cr}, S_{pr}, S_{pt}\}$, then averaged over all location realizations.

B. Case 2: When S_{pr} and S_{cr} are known

Since C_{tx} has no knowledge of S_{pt}, it should design the threshold based on the objective function averaged over S_{pt} for each pair of $\{S_{cr}, S_{pr}\}$. Maximizing (5) is equivalent to maximizing

$$\begin{aligned} f_2(\gamma) =& E_{S_{pt}}[a]\int_\gamma^{+\infty}\frac{1}{2(\sigma_z^2+\sigma_x^2)}e^{-\frac{\xi}{2(\sigma_z^2+\sigma_x^2)}}d\xi \\ &+ E_{S_{pt}}[b]\int_0^\gamma\frac{1}{2\sigma_z^2}e^{-\frac{\xi}{2\sigma_z^2}}d\xi + E_{S_{pt}}[c]. \end{aligned}$$

Similar to case 1, the optimal threshold for each pair of $\{S_{cr}, S_{pr}\}$ can be derived as

$$\gamma_2 = \begin{cases} \infty, & \text{if } E_{S_{pt}}[a] \leqslant 0, \\ (\sigma_z^2+\sigma_x^2)\frac{\sigma_z^2}{\sigma_x^2}\ln\left(\frac{\sigma_z^2+\sigma_x^2}{\sigma_z^2}\frac{E_{S_{pt}}[b]}{E_{S_{pt}}[a]}\right) & \text{if } E_{S_{pt}}[a] > 0. \end{cases} \quad (13)$$

In this new threshold, the capacity terms a and b are averaged over the unknown location S_{pt}. The respective capacities are calculated as follows.

$$\begin{aligned} C_p =& E_{S_{pr},S_{cr}}\Bigg[p\lambda_1 E_{S_{pt}}\left\{E\left[\log_2\left(1+\frac{L_p}{\sigma_z^2}\right)\right]\right\} \\ &+ (1-p)\lambda_1 E_{S_{pt}}\left\{E\left[\log_2\left(1+\frac{L_p}{\sigma_z^2+I_{pc}}\right)\right]\right\}\Bigg] \\ C_c =& E_{S_{pt},S_{pr},S_{cr}}\left[q(1-\lambda_1)E\left[\log_2\left(1+\frac{L_c}{\sigma_z^2}\right)\right]\right] \\ &+ E_{S_{pr},S_{cr}}\left[(1-p)\lambda_1 E_{S_{pt}}\left\{E\left[\log_2\left(1+\frac{L_c}{\sigma_z^2+I_{cp}}\right)\right]\right\}\right] \end{aligned}$$

The difference from Case 1 is that, for each pair of $\{S_{cr}, S_{pr}\}$, there is only one optimal threshold for all possible S_{pt}, and corresponding terms in the capacity expressions need to be averaged over S_{pt} while using this threshold.

C. Case 3: When only S_{cr} is known

Similar to Case 2, since C_{tx} does not know S_{pt} and S_{pr}, it should design the threshold by maximizing the objective function averaged over all $\{S_{pt}, S_{pr}\}$ for each given S_{cr}. The optimal threshold for each S_{cr} in this case is

- If $E_{S_{pt},S_{pr}}[a] \leqslant 0$, $\gamma_3 = \infty$
- If $E_{S_{pt},S_{pr}}[a] > 0$,

$$\gamma_3 = (\sigma_z^2 + \sigma_x^2)\frac{\sigma_z^2}{\sigma_x^2} \ln\left(\frac{\sigma_z^2 + \sigma_x^2}{\sigma_z^2} \frac{E_{S_{ptx},S_{prx}}[b]}{E_{S_{ptx},S_{prx}}[a]}\right) \quad (14)$$

The respective capacities should be calculated as follows.

$$C_p = E_{S_{cr}}\left[p\lambda_1 E_{S_{pt},S_{pr}}\left\{E\left[\log_2\left(1+\frac{L_p}{\sigma_z^2}\right)\right]\right\}\right.$$
$$\left. +(1-p)\lambda_1 E_{S_{pt},S_{pr}}\left\{E\left[\log_2\left(1+\frac{L_p}{\sigma_z^2 + I_{pc}}\right)\right]\right\}\right]$$
$$C_c = E_{S_{pt},S_{pr},S_{cr}}\left\{q(1-\lambda_1)E\left[\log_2\left(1+\frac{L_c}{\sigma_z^2}\right)\right]\right\}$$
$$+ E_{S_{cr}}\left[(1-p)\lambda_1 E_{S_{pt},S_{pr}}\left\{E\left[\log_2\left(1+\frac{L_c}{\sigma_z^2 + I_{cp}}\right)\right]\right\}\right]$$

D. Case 4: When no location information is available

As C_{tx} has no location information, the objective function should be averaged across all locations, resulting in only a single optimal threshold for all location realizations. This optimal threshold for all the location sets is given as follows.

- If $E_{S_{pt},S_{pr},S_{cr}}[a] \leqslant 0$, $\gamma_4 = \infty$,
- If $E_{S_{pt},S_{pr},S_{cr}}[a] > 0$,

$$\gamma_4 = (\sigma_z^2 + \sigma_x^2)\frac{\sigma_z^2}{\sigma_x^2} \ln\left(\frac{\sigma_z^2 + \sigma_x^2}{\sigma_z^2} \frac{E_{S_{pt},S_{pr},S_{cr}}[b]}{E_{S_{pt},S_{pr},S_{cr}}[a]}\right) \quad (15)$$

The respective capacities can be calculated according to (1) and (2) using a single threshold for all network realizations.

E. Generalization to multiple cognitive users

The proposed design can be generalized to a network with multiple cognitive users. Each cognitive transmitter needs to know only its respective location information, such as the locations of its own receiver and of the primary transmitter and receiver. Each cognitive user then independently senses the spectrum using the proposed threshold, which is designed to maximize the weighted sum of its own capacity and the primary user's capacity as in (5). In computing these capacities, the interference from other cognitive users can be treated as noise assuming a certain variance, so the effective impact of having multiple cognitive users is increasing the noise floor. The cognitive users can then choose to collaborate to fuse the sensing decisions. Since the sensing performance of each individual cognitive user is improved with this threshold design, as illustrated next, network performance should be improved as the whole.

V. Numerical Results

A. Simulation Settings

We use the model in Fig. 1 and set the network radii $R_c = R_p = R_i = 10$, the protection region $\epsilon = 1$ and the path loss parameter $\alpha = 2.1$. The primary and secondary transmit power and the thermal noise are set such that at the edge of a disc, the signal-to-noise ratio (SNR) is 0dB. For Case 1, we first generate 3000 sets of locations S_{pt}, S_{pr} and S_{cr}. For each set, 10000 Rayleigh fading channels are generated per link. We then compute the optimal threshold for each set of locations, perform detection and compute the capacities. The capacities are then averaged over fading and the different locations.

For Case 2, since S_{pt} is unknown, the same 3000 sets of S_{pr} and S_{cr} as in Case 1 are used. Then for each pair of $\{S_{pr}, S_{cr}\}$, another 3,000 S_{pt} are generated to compute the threshold (13) by averaging a and b over S_{pt} and fading. After obtaining the threshold for each set of locations, the same number of Rayleigh fading channels as in Case 1 are generated to perform the detection. Then the program computes the primary and cognitive capacities averaged over S_{pt} and fading, given the specific pair $\{S_{pr}, S_{cr}\}$. In the last step, these capacities are averaged over all $\{S_{pr}, S_{cr}\}$ pairs.

For Case 3, we use the same methodology and parameters as in Case 2. For Case 4, since the cognitive transmitter has no location information, the same locations of S_{pt}, S_{pr} and S_{cr} as Case 1 are used. And the threshold (15) is computed by averaging a and b over all three locations.

B. Results and Discussion

In Fig. 2, the weighted sum capacities (5) with different sets of location information are shown for $\mu = 0.5$. Furthermore, to compare with the performance of the previous threshold proposed in [7], the weighted sum capacity of [7] with full location information is also plotted. As the primary link transmission probability goes up, the network becomes more sensitive to miss detection, and the location information merit is better revealed. While more location information results in better capacity gain as expected, the comparatively modest gain with more location information is due to network parameters (the radii R_c, R_p, R_i). Specifically, a close inspection of the four log-terms in the capacity expressions a, b and c (6, 7, 8) reveals that, by setting the network parameters such that the average difference between the two terms without interference and the two with interference is larger, more capacity penalty will incur because of miss detection and false alarm. On the other hand, compared to the threshold in [7], which is designed to minimize a Bayesian sensing risk function, the capacity-optimal threshold (12) increases the network throughput significantly, with gain ranging from 5% to 36% depending on λ_1.

To investigate where this gain comes from, we decompose the objective function into separate primary link capacities and cognitive link capacities in Fig.3 and Fig.4. The corresponding capacities from [7] with full location information are also shown for comparison.

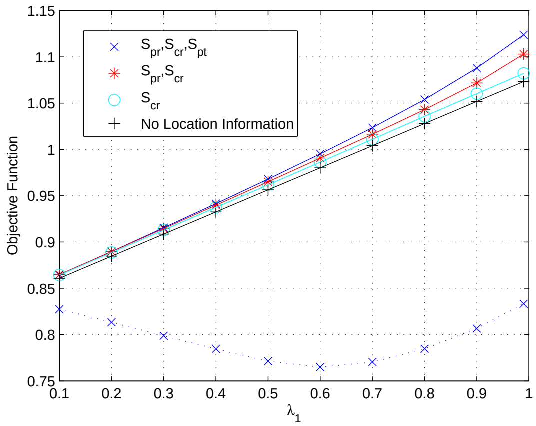

Fig. 2. Objective functions with different location information. The dotted line is plotted using threshold in [7]

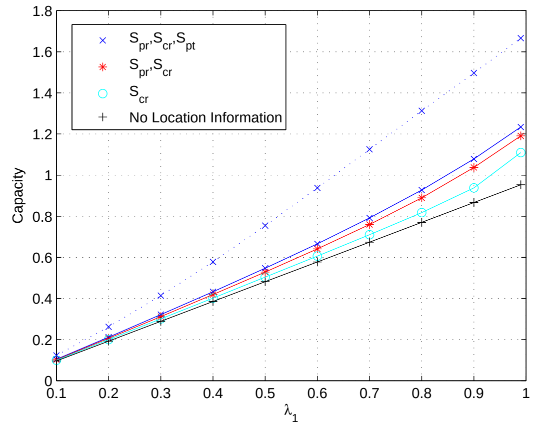

Fig. 4. Primary link capacity with different location information. The dotted line is plotted using threshold in [7]

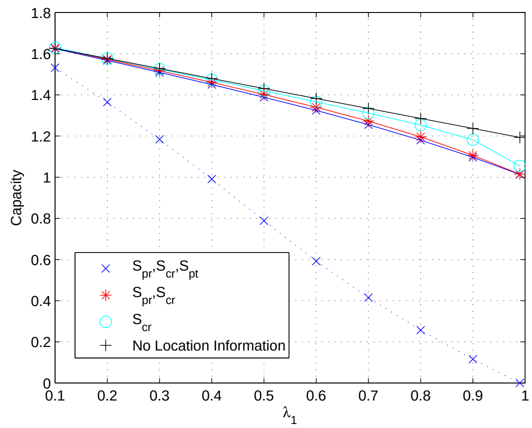

Fig. 3. Cognitive link capacity with different location information. The dotted line is plotted using threshold in [7]

From Fig.3, the cognitive link capacities are increased significantly compared to [7]. The gain is more pronounced as the primary user transmits more frequently (i.e., as λ_1 increases). In [7], when λ_1 approaches 1, the cognitive user's capacity drops to near zero, while with the new threshold (12), the cognitive user can still maintain a significant capacity.

However, in Fig.4, we discover that the network reaches its maximum weighted sum capacity by sacrificing the primary link's rate. As λ_1 increases, the primary user's capacity is decreased from its maximal value in [7] by up to 25%.

If we adjust the weight μ in (5) to be greater than 0.5, the gaps between the capacities using threshold (12) and the threshold in [7] in both Fig.3 and Fig.4 will be narrower.

Thus when designing a sensing threshold, the objective is important. The Bayesian risk objective in [7] does not result in maximum network capacity, but it affects the primary user's capacity little. The capacity objective (5) results in higher network sum capacity and higher cognitive user's capacity but at a penalty to the primary user's capacity. Using which design should depend on the preference of the network operator.

VI. Conclusion

In this work, we analytically derive an optimal sensing threshold which maximizes the weighted sum network capacity. Furthermore, we analyze the capacity with different sets of location side information. Simulation results show that, compared to another threshold designed to minimize a Bayesian sensing risk function [7], the proposed threshold can significantly improve the network sum capacity. The gain comes from higher cognitive user's capacity, but it is also at an, albeit smaller, penalty on the primary user's capacity. Moreover, location information is also helpful, for spatial side information is beneficial to the cognitive radio in making optimal sensing decision. However, unlike in [7], the capacity is not as sensitive to the location information as the Bayesian risk function. These results suggest that choosing the right objective is crucial in designing a sensing threshold.

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