Cooperative Spectrum Sensing: A New Approach for Minimum Interference and Maximum Utilisation

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***Abstract*—Cooperative spectrum sensing is a widely studied topic in cognitive radio, which is capable of improving the detection accuracy of the primary channel activities. In cooperative spectrum sensing, secondary users' observations are sent to a common receiver, the Fusion Centre (FC), to obtain a better understanding and decision about the state of the primary channel. This work, however, investigates how these observations of the secondary users can efficiently be exploited in such a way that minimises the collision ratio between the secondary and the primary users and at the same time maximises the exploitation of the unused frequency spectrum. As a result, a simple yet efficient approach is proposed for cooperative spectrum sensing, which, to the best of the authors' knowledge, has not been covered in the literature. This approach outperforms the conventional approach of cooperative spectrum sensing for reducing the interference and increasing the utilisation of the unused frequency spectrum in cognitive radio systems.**

***Index Terms*—Cooperative spectrum sensing, cognitive radio, dynamic spectrum access, smart spectrum sharing.**

I. Introduction

In wireless communications, frequency spectrum is a precious limited resource that needs to be exploited wisely and efficiently. Many recent measurement campaigns have reported that frequency spectrum is underutilised due to the legacy spectrum management policies [1]. As a result, Dynamic Spectrum Access (DSA) [2] based on Cognitive Radio (CR) [3] technology has been proposed as a promising solution to maximise the utilisation efficiency of the frequency spectrum. In DSA/CR system, a Secondary User (SU) aims to utilise the licensed frequency spectrum of the Primary User (PU) in an opportunistic and non-interfering manner. To achieve this, secondary systems require to monitor the activity and inactivity patterns of the PUs by performing what is so called spectrum sensing. Spectrum sensing enables SUs to sense the status of the primary channels periodically with a constant sensing period of T_s. If the status of the channel is sensed as idle, then the SU can opportunistically access and utilise the primary channel. Otherwise, if the channel status is sensed as busy, SU needs to wait until the channel becomes idle again. From this, the accuracy of sensing PU's signal is a crucial factor in the performance of DSA/CR systems. If the Signal to Noise Ratio (SNR) of the detected signal from the PU is sufficiently high, Perfect Spectrum Sensing (PSS) can be assumed. However, in practice the impact of channel fading and noise is severe and low SNR primary signal is often observed at the secondary receivers. Therefore, Imperfect Spectrum Sensing (ISS) is a common scenario in DSA/CR systems. Under ISS, sensing errors could occur either as false alarms (when an idle state of the channel is sensed as a busy state) or as missed detections (when a busy state of the channel is sensed as an idle state). Reducing the impact of sensing errors in the spectrum sensing is one of the challenging aims in the recent studies of DSA/CR systems [4].

In this context, Cooperative Spectrum Sensing (CSS) [5] is one of the promising solutions that increases sensing reliability through taking advantage of spatial diversity of the performed spectrum sensing at different cooperating SUs. In CSS, SUs' local decisions are shared with a common receiver, the Fusion Centre (FC), to make a global decision about the presence/absence of a PU within a particular licensed channel. The global decision is made by the FC after combining the sensing data forwarded by the SUs. The combining methods in CSS are classified into two types: hard and soft combining. The hard combining approach is based on the binary local decisions of the SUs, while the soft combining approach is based on the detected signal energy itself at the SUs [6]. Regardless of which combining approach is used, CSS improves the accuracy of sensing PU's activity within a licensed channel by reducing the impact of sensing errors.

The majority of works in the literature regarding CSS (e.g., [5]–[8]) focus on exploiting SUs' observations to reduce the impact of sensing errors, thus producing more accurate decisions about the status of the primary channel. The main aim of reducing the impact of sensing errors is to avoid collision between SUs and PUs as well as to maintain high spectral utilisation. In this work we investigate a different approach of exploiting SUs' observations in CSS through considering not only the impact of sensing accuracy but also the impact of sensing resolution as well. The new proposed approach, to the best of the authors' knowledge, has not been presented in the literature, which outperforms the conventional approach for CSS for achieving minimum collision between secondary and primary users and maximum utilisation (i.e., minimum missed opportunities) of the frequency spectrum.

The rest of the paper is organised as follows. Section II and III define new metrics of collision ratio and missed-opportunity ratio, respectively, where an expression is derived for each of them. Then Section IV presents the conventional approach of CSS and evaluates its collision and missed-opportunity ratios. The new approach of CSS, on the other hand, is proposed in Section V where its collision and missed-opportunity ratios are also analysed. Finally, the simulation results of the proposed approach in comparison with the conventional one are evaluated in Section VI and then followed by the conclusion in Section VII.

II. Collision Ratio

Before we delve into pursuing the efficient way of utilising SUs' observations in cooperative spectrum sensing, we first define a new metric $\mathcal{C}$ to represent the collision ratio between a SU and a PU, which can be given by:

$$\mathcal{C} = \frac{T_c}{T_b}, \tag{1}$$

where T_c denotes the collision time between a SU and a PU, and T_b denotes the busy time of the PU as illustrated in Fig. 1. The collision ratio $\mathcal{C}$ represents the fraction of time that a PU transmission is under interference from a SU. Note that $\mathcal{C} = 1$ when the collision time T_c equals the busy time T_b, which means there is 100% interference between the SU and the PU (which could only happen when the probability of missed detection is $P_{md} = 1$), while $\mathcal{C} = 0$ when the collision time is $T_c = 0$, which means there is no interference at all between the SU and the PU (which could only happen when $P_{md} = 0$ and the sensing period is $T_s = 0$).

Under PSS, collision between a SU and a PU results from a late detection of the PU's busy periods, which depends on the resolution of the sensing period T_s. Therefore, collision time could vary uniformly between 0 and T_s (i.e., $T_c \sim \mathcal{U}(0, T_s)$) and its expectation is $\mathbb{E}(T_c) = T_s/2$. As a result, the total collision ratio for a given set $\{T_{b,n}\}_{n=1}^{N}$ of N busy periods under PSS can be found as:

$$\mathcal{C}_{pss} = \frac{\sum_{n=1}^{N} T_{c,n}}{\sum_{n=1}^{N} T_{b,n}} = \frac{N\frac{T_s}{2}}{N\mathbb{E}(T_b)} = \frac{T_s}{2\mathbb{E}(T_b)}, \tag{2}$$

where $\mathbb{E}(T_b)$ represents the mean of the busy periods.

On the other hand, under ISS, collision between a SU and a PU results from the resolution of the sensing period T_s as well as the missed detection errors. Every missed detection error increases the collision time by T_s, except when a missed detection occurs at the end edge of a busy period where it only increases the collision time by an average of $T_s/2$. Therefore, for N busy periods, collision time under ISS can be found as:

$$\sum_{n=1}^{N} T_{c,n} = N\frac{T_s}{2} + N_{md}T_s - NP_{md}\frac{T_s}{2}, \tag{3}$$

where N_{md} denotes the number of the missed detection errors within N busy periods, and it can be found from [9], [10]:

$$N_{md} = \frac{N\mathbb{E}(T_b)}{T_s} \cdot P_{md}. \tag{4}$$

Thus, (3) can be written as:

$$\sum_{n=1}^{N} T_{c,n} = N\frac{T_s}{2} + N\mathbb{E}(T_b)P_{md} - NP_{md}\frac{T_s}{2}. \tag{5}$$

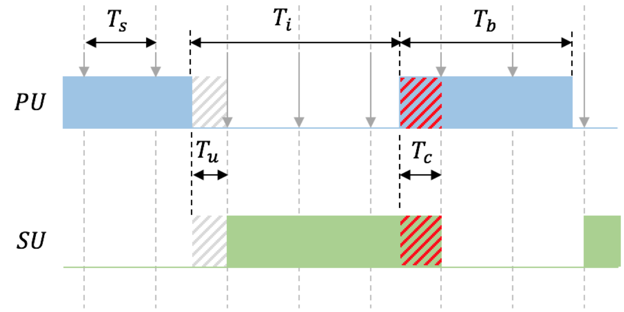

Fig. 1. Collision and missed opportunity in PU and SU coexistence.

Finally, the collision ratio $\mathcal{C}$ under ISS can be found as:

$$\begin{aligned}\mathcal{C} &= \frac{N\frac{T_s}{2} + N\mathbb{E}(T_b)P_{md} - NP_{md}\frac{T_s}{2}}{N\mathbb{E}(T_b)} \\ &= \frac{T_s}{2\mathbb{E}(T_b)} + P_{md} - \frac{P_{md}T_s}{2\mathbb{E}(T_b)} \\ &= \underbrace{\frac{T_s}{2\mathbb{E}(T_b)}}_{\text{Due to sensing period}} + \underbrace{P_{md}\left(1 - \frac{T_s}{2\mathbb{E}(T_b)}\right)}_{\text{Due to missed detections}}.\end{aligned} \tag{6}$$

Note that when $P_{md} = 0$ in expression (6), collision ratio $\mathcal{C}$ will be the same as (2) for PSS where only the sensing period has an impact. Therefore, in this work, (6) can be used as a general form expression for calculating the collision ratio $\mathcal{C}$. The correctness of the obtained collision ratio expression in (6) can be validated by means of simulations as discussed in Section VI.

III. Missed-Opportunity Ratio

We introduce another metric for calculating the utilisation of the available opportunities in a primary channel. Missed-opportunity ratio $\mathcal{M}$ is here used to represent the fraction of the opportunistic periods that has not been exploited or has been missed by the SUs. This fraction can be found as the ratio of the unexploited time to the available idle time in a primary channel as:

$$\mathcal{M} = \frac{T_u}{T_i}, \tag{7}$$

where T_u denotes the unexploited time by a SU and T_i denotes the idle time of the PU as illustrated in Fig. 1. Note that $\mathcal{M} = 1$ when the unexploited time T_u equals the idle time T_i, which means that SUs have not utilised any of the available opportunities in the primary channel and therefore they are 100% unexploited (which could only happen when the probability of false alarm is $P_{fa} = 1$), while $\mathcal{M} = 0$ when the unexploited time is $T_u = 0$, which means there is no missed opportunity at all or all the available opportunities have been exploited by the SUs (which could only happen when $P_{fa} = 0$ and $T_s = 0$). Also note that minimum missed-opportunity ratio $\mathcal{M}$ refers to maximum utilisation.

Under PSS, the available opportunities can be missed by a SU due to the late detection of the PU's idle periods, which depends on the resolution of the sensing period T_s. Therefore, the unexploited time could vary uniformly between 0 and T_s

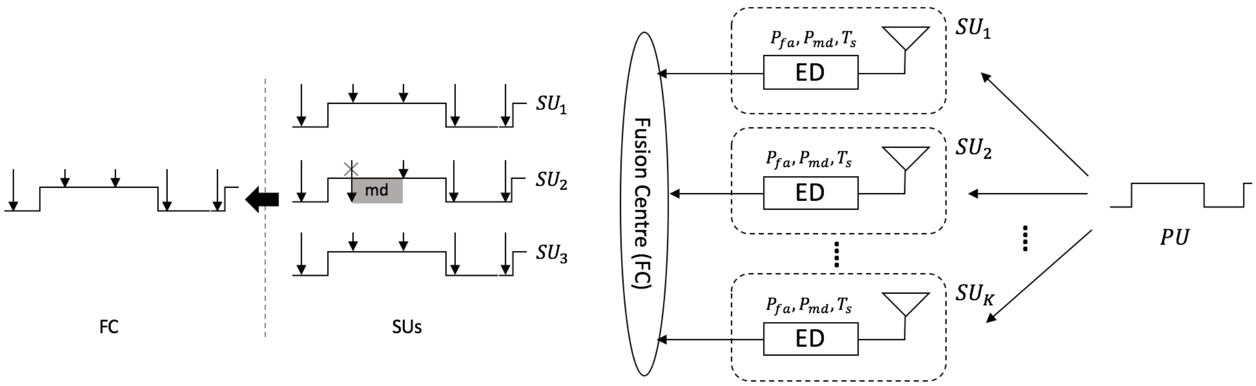

Fig. 2. Conventional cooperative spectrum sensing approach.

(i.e., $T_u \sim \mathcal{U}(0, T_s)$) and its expectation is $\mathbb{E}(T_u) = T_s/2$. On the other hand, under ISS, missed opportunities result from the resolution of the sensing period T_s as well as the false alarm errors. Every false alarm error increases the unexploited time by T_s, except when a false alarm occurs at the end edge of an idle period where it only increases the unexploited time by an average of $T_s/2$. As a result, the missed-opportunity ratio $\mathcal{M}$ can be found following the same analysis as for the collision ratio $\mathcal{C}$, by using P_{fa} and T_i parameters instead of P_{md} and T_b respectively, which yields:

$$\mathcal{M} = \underbrace{\frac{T_s}{2\mathbb{E}(T_i)}}_{\text{Due to sensing period}} + \underbrace{P_{fa}\left(1 - \frac{T_s}{2\mathbb{E}(T_i)}\right)}_{\text{Due to false alarms}}. \quad (8)$$

The correctness of the obtained missed-opportunity ratio expression in (8) can also be validated by means of simulations as discussed in Section VI.

One can understand from both (6) and (8) that the impact of the collision ratio $\mathcal{C}$ and the missed-opportunity ratio $\mathcal{M}$ in CR systems can be reduced by adjusting T_s, P_{md} and P_{fa} parameters, while $\mathbb{E}(T_b)$ and $\mathbb{E}(T_i)$ are non-adjustable since they depend on the PU activity within the primary channel, which is assumed to be unknown to the CR system.

Since the aim of this work is to investigate how SUs' observations in cooperative spectrum sensing can be exploited in such a way that minimum collision ratio and minimum missed-opportunity ratio (i.e., maximum utilisation) can be reached, we first introduce the conventional approach of CSS and analyse its collision ratio and missed-opportunity ratio.

IV. Conventional CSS Approach

A. Description

Consider a single primary channel which is occupied by a single PU. A group of K SUs on the other hand perform spectrum sensing to monitor the activity of the primary channel. Spectrum sensing using the Energy Detection (ED) [11] method can be applied at each SU based on a predefined probability of error (i.e., P_{fa} and P_{md}), which can be assumed to be the same for all K SUs. In addition, it is assumed that the performed sensing events at the SUs are synchronised with a periodic sensing interval T_s. In the centralized common receiver FC, the sensing data forwarded by the SUs are combined to make a global decision about the presence of the PU. Either hard or soft combining method can be applied to combine SUs observations. Both combining methods aim to increase the accuracy of the final decision taken by the FC about the presence of the PU. This approach (shown in Fig. 2) is the widely considered approach in the literature for CSS and for which the collision ratio $\mathcal{C}$ and the missed-opportunity ratio $\mathcal{M}$ will be analysed.

B. Analysis of $\mathcal{C}$ and $\mathcal{M}$ Ratios

In this work, we consider the hard combining method (using "n out of K" rule [12]) to anlyse the collision and missed-opportunity ratios (similar analysis can also be applied for soft combining method). In hard combining, each SU produces a binary decision about the status of the primary channel at each sensing event (where sensing events are synchronised for all SUs). Then a one-bit decision D_i for each sensing event is forwarded to the FC (where 1 stands for busy state and 0 for idle state of the PU). Since there are K SUs, FC will receive K one-bit decisions made for the same sensing event from different SUs. Based on which a global decision can be made as hypothesis $\mathcal{H}_1$ if at least n out of K are 1s and hypothesis $\mathcal{H}_0$ otherwise [12]:

$$Y = \sum_{i=1}^{K} D_i \begin{cases} \geq n, & \mathcal{H}_1 \\ < n, & \mathcal{H}_0 \end{cases} \quad (9)$$

The overall probability of false alarm Q_{fa} and missed detection Q_{md} of a cooperative spectrum sensing scheme using such rule is found as [12]:

$$Q_{fa} = \sum_{l=n}^{K} \binom{K}{l} P_{fa}^{l} (1 - P_{fa})^{K-l}, \quad (10)$$

$$Q_{md} = 1 - \sum_{l=n}^{K} \binom{K}{l} P_{d}^{l} (1 - P_{d})^{K-l}, \quad (11)$$

where $P_d = 1 - P_{md}$, and the optimum n is found as [12]:

$$n_{opt} = \left\lceil \frac{K}{1+\alpha} \right\rceil, \quad \text{where } \alpha = \frac{\ln \frac{P_{fa}}{1-P_{md}}}{\ln \frac{P_{md}}{1-P_{fa}}}. \quad (12)$$

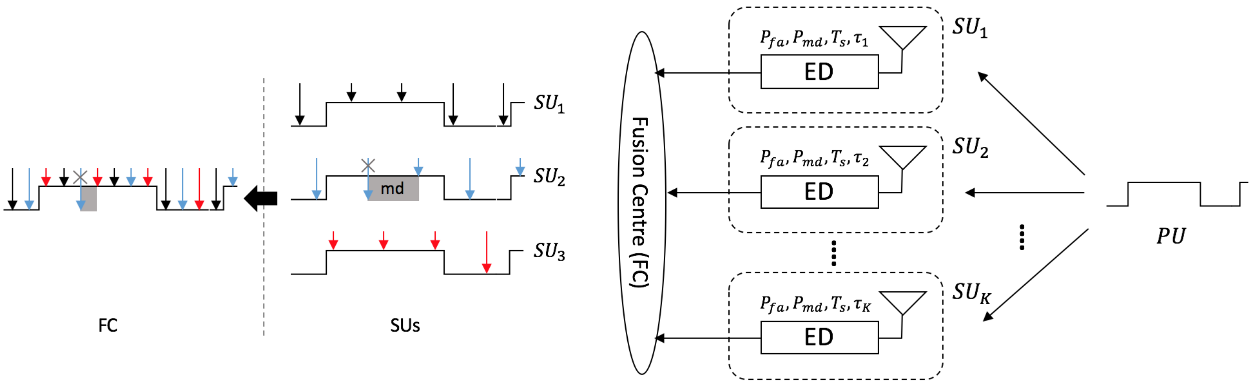

Fig. 3. Proposed cooperative spectrum sensing approach.

If $P_{fa} = P_{md}$, then $\alpha = 1$ and $n_{opt} = \lceil \frac{K}{2} \rceil$.

In comparison with P_{fa} and P_{md} predefined at each SU, the overall probabilities of false alarm and missed detection (i.e., Q_{fa} and Q_{md}) are significantly decreased as the number of the SUs (i.e., K) increases. As a result, the overall collision ratio $\mathcal{C}$ resulting from CSS using the conventional approach can be written based on (6) as:

$$\mathcal{C} = \frac{T_s}{2\mathbb{E}(T_b)} + Q_{md}\left(1 - \frac{T_s}{2\mathbb{E}(T_b)}\right), \qquad (13)$$

where $Q_{md} \ll P_{md}$ for $K \gg 1$ and as a result the collision ratio in (13) is lower than that in (6).

Similarly, the overall missed-opportunity ratio $\mathcal{M}$ resulting from CSS using the conventional approach can be written based on (8) as:

$$\mathcal{M} = \frac{T_s}{2\mathbb{E}(T_i)} + Q_{fa}\left(1 - \frac{T_s}{2\mathbb{E}(T_i)}\right), \qquad (14)$$

where $Q_{fa} \ll P_{fa}$ for $K \gg 1$ and as a result the missed-opportunity ratio in (14) is lower than that in (8).

V. Proposed CSS Approach

A. Description

As it can be noticed from (13) with reference to (6) and from (14) with reference to (8), CSS given by the conventional approach can only reduce the collision ratio $\mathcal{C}$ and the missed-opportunity ratio $\mathcal{M}$ by reducing the impact of sensing error (probability of missed detection in $\mathcal{C}$ and probability of false alarm in $\mathcal{M}$). As a result, the interest in the following two questions is motivated:

- Q1: Can CSS be exploited to reduce the collision ratio and the missed-opportunity ratio caused by the time resolution resulting from the employed sensing period T_s while keeping constant P_{fa}, P_{md} and T_s used at each SU? If so, what would be the method for such scheme?
- Q2: Which scheme would provide a lower collision ratio and a lower missed-opportunity ratio?

It is possible to reduce the impact of the collision ratio and the missed-opportunity ratio caused by the employed sensing period T_s (answer to Q1) by letting each SU to start sensing at a different time within T_s (i.e., unlike the previous approach, SUs' sensing events are not synchronised). A time difference of T_s/K can be allowed among the SUs' sensing time instants. In addition, a combining method will not be required at the FC since each received report from each SU represents a new sensing information about the presence of the PU at a different time instant, which also reduces the complexity and computational requirements of the FC. Fig. 3 shows the proposed approach of the CSS using asynchronous sensing events[1] at the SUs, which is capable of reducing the collision ratio and the missed-opportunity ratio caused by the employed sensing period T_s. Note that τ_i represents the relative sensing time instants across the SUs. If SU_1 starts sensing at time $\tau_1 = 0$, then SU_2 starts at $\tau_2 = T_s/K$ and SU_3 starts at $\tau_3 = 2T_s/K$, where $K = 3$ in this example.

B. Analysis of $\mathcal{C}$ and $\mathcal{M}$ Ratios

The proposed approach can reduce the overall resolution error of the sensing period T_s to T_s/K, which in turn will reduce the collision ratio $\mathcal{C}$ based on (6) to:

$$\mathcal{C} = \frac{T_s}{2K\mathbb{E}(T_b)} + P_{md}\left(1 - \frac{T_s}{2K\mathbb{E}(T_b)}\right), \qquad (15)$$

and also will reduce the missed-opportunity ratio $\mathcal{M}$ based on (8) to:

$$\mathcal{M} = \frac{T_s}{2K\mathbb{E}(T_i)} + P_{fa}\left(1 - \frac{T_s}{2K\mathbb{E}(T_i)}\right). \qquad (16)$$

As it can be noticed from (15) and (16), the proposed approach cannot decrease the impact of the sensing errors probabilities P_{md} and P_{fa} (opposite to the previous approach in (13) and (14) where P_{md} and P_{fa} were decreased to Q_{md} and Q_{fa}, respectively). This leads us to ask the second important question (Q2): which parameter is more significant to be decreased, sensing error or sensing resolution? The answer to this question is dependent on the values of T_s,

[1] Although synchronisation accuracy of the CSS is out of the scope of this work, it is worth mentioning that the conventional approach is more sensitive to the synchronisation error than the proposed one since its sensing events have to take place at the same time instant along with the other SUs.

P_{md} and P_{fa} themselves as well as the number of SUs K used in the CSS. An obvious example where the proposed approach outperforms the conventional approach is that when CR system operates under a sufficiently high SNR conditions (i.e., PSS). Under PSS scenario, the conventional approach fails to mitigate the collision and missed-opportunity ratios since the probabilities of sensing errors are already zero under PSS and cannot be further reduced by increasing the number K of cooperating SUs. Meanwhile increasing the number of cooperating users in such a case under the proposed approach would still reduce the collision and missed-opportunity ratios resulting from the time resolution imposed by the sensing period T_s. On the other hand, the conventional approach would perform better in some ISS scenarios as P_{md} and P_{fa} increase since their impact on the collision ratio and missed-opportunity ratio becomes more severe than the time resolution imposed by the sensing period T_s. However, a threshold can be obtained to decide which approach is more efficient to exploit SUs' observations in CSS in order to provide the lowest achievable collision ratio $\mathcal{C}$ and missed-opportunity ratio $\mathcal{M}$ (answer to Q2) as:

$$\mathcal{C}_c \underset{Conventional}{\overset{Proposed}{\gtrless}} \mathcal{C}_p, \tag{17}$$

$$\mathcal{M}_c \underset{Conventional}{\overset{Proposed}{\gtrless}} \mathcal{M}_p, \tag{18}$$

where $\mathcal{C}_c$ and $\mathcal{M}_c$ are the collision ratio and missed-opportunity ratio of the conventional approach based on (13) and (14), respectively, while $\mathcal{C}_p$ and $\mathcal{M}_p$ are the collision ratio and missed-opportunity ratio of the proposed approach based on (15) and (16), respectively. If $\mathcal{C}_c > \mathcal{C}_p$, the proposed approach should be selected. Otherwise, the conventional approach should be selected. The same rule applies when $\mathcal{M}_c > \mathcal{M}_p$.

VI. Simulation Results

First of all, the obtained expressions (6) and (8) for collision ratio $\mathcal{C}$ and missed-opportunity ratio $\mathcal{M}$, respectively, are validated by means of simulation. In order to calculate the collisions and the missed opportunities in simulation a large number (10^6) of idle/busy periods of a PU is generated. The duration of these periods are modeled to follow a Generalised Pareto (GP) distribution, which provides the best representation for PU periods according to the experimental measurements in [13]. The distribution parameters of GP are configured as: location $\mu = 10$ t.u. (time units), scale $\lambda = 30$ t.u., and shape $\alpha = 0.25$. This configuration results in a sequence of PU periods that have a busy mean period $\mathbb{E}(T_b) = 50$ t.u., an idle mean period of $\mathbb{E}(T_i) = 50$ t.u., a minimum busy period of $\mu_b = 10$ t.u. and a minimum idle period of $\mu_i = 10$ t.u.. Spectrum sensing can then be performed on the generated periods using a sensing period T_s in order to obtain the sensing decisions that would be observed by a SU. Based on these decisions, SU's accessing/waiting periods can be computed. Therefore, the collision between SU

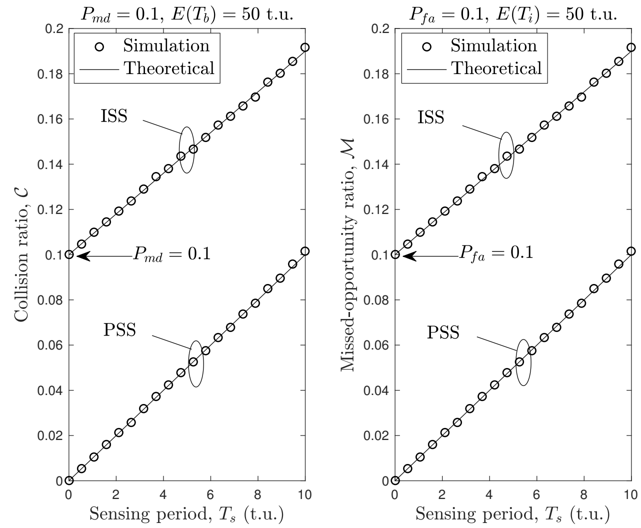

Fig. 4. Collision ratio (left) and missed-opportunity ratio (right) as a function of T_s under PSS and ISS.

(accessing/waiting periods) and PU (idle/busy periods) can be calculated in the simulation and compared with the theoretical expression obtained in (6). As shown in Fig. 4 (left), the calculated collision ratio $\mathcal{C}$ using (6) perfectly matches the simulation results (for both PSS and ISS) for different T_s values. In the same way, the missed-opportunity ratio $\mathcal{M}$ can be calculated from the simulation and compared with the theoretical expression obtained in (8) as shown in Fig. 4 (right), where a perfect match can also be observed, thus validating our analysis for $\mathcal{M}$ as well. Note that $\mathcal{C}$ and $\mathcal{M}$ in Fig. 4 show similar trends because the parameters P_{md} and $\mathbb{E}(T_b)$ (which control on the $\mathcal{C}$ ratio) are set similar to the ones P_{fa} and $\mathbb{E}(T_i)$ (which control on the $\mathcal{M}$ ratio), however, they are not necessarily to be the same in general.

On the other hand, to evaluate the collision ratio $\mathcal{C}$ and the missed-opportunity ratio $\mathcal{M}$ for the proposed approach of CSS with respect to the conventional approach, consider a CSS system with $K = 10$ SUs monitoring the idle/busy periods of the PU. The collision ratio $\mathcal{C}_c$ calculated in (13) based on the conventional approach, and the collision ratio $\mathcal{C}_p$ calculated in (15) based on the proposed approach can be evaluated and compared over different values of T_s and different values of P_{md} as shown in Fig. 5. It can be noticed that when P_{md} is low or approaching zero, the collision ratio is significantly lower for the proposed approach for all T_s values. In contrast, the conventional approach performs better when P_{md} increases. In addition, when P_{md} is somewhere in the middle (e.g., 0.05), the collision ratio will be lower for the proposed approach when T_s is high, and will be higher otherwise. It can also be noticed that the conventional approach is not useful at all under PSS (i.e., when $P_{md} = 0$) because P_{md} can not be reduced any further, whereas the impact of the sensing period T_s can still be reduced through the proposed approach. Similar trends can also be observed for the calculated missed-opportunity ratio $\mathcal{M}_c$ based on the conventional approach and the calculated missed-opportunity

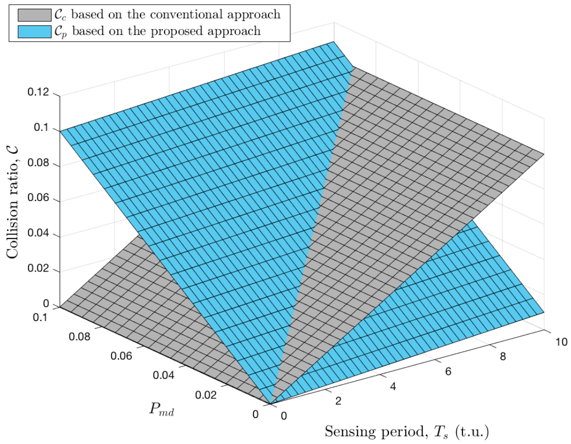

Fig. 5. Collision ratio as a function of T_s and P_{md}, when $K = 10, \mathbb{E}(T_b) = 50$ t.u. and $\mu_b = 10$ t.u..

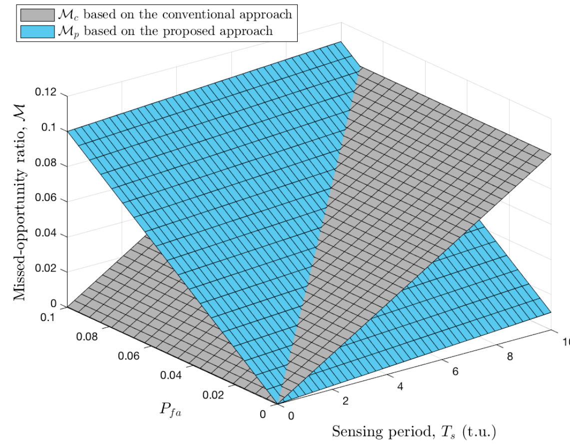

Fig. 6. Missed-opportunity ratio as a function of T_s and P_{fa}, when $K = 10, \mathbb{E}(T_i) = 50$ t.u. and $\mu_i = 10$ t.u..

ratio $\mathcal{M}_p$ based on the proposed approach over different values of T_s and different values of P_{fa} as shown in Fig. 6. It is worth mentioning that when P_{md} and P_{fa} are both low, the proposed approach can perform better in reducing both $\mathcal{C}$ and $\mathcal{M}$. In contrast, when P_{md} and P_{fa} are both high, the conventional approach would then perform better. In some scenarios, when P_{md} is low and P_{fa} is high (or vice versa), one approach would perform better than the other in reducing only one of the metrics ($\mathcal{C}$ or $\mathcal{M}$). As such, an approach can be selected based on what would be of most interest to a system to reduce (i.e., reducing $\mathcal{C}$ or $\mathcal{M}$). As a result, based on the parameters that are selected by the CSS (K, P_{md}, P_{fa} and T_s), it can easily be decided (using (17) and (18)) which approach is the most efficient one for mitigating the interference and maximising the utilisation of the spectrum in CR networks.

VII. Conclusion

Collision and spectral utilisation are the most challenging issues in cognitive radio networks. A SU could interfere with the busy periods of a PU or could miss utilising the idle periods of a PU due to the practical limitations of DSA/CR systems, which include the resolution of the employed sensing period and the presence of spectrum sensing errors. Cooperative spectrum sensing has been proposed to exploit SUs observations in order to reduce the impact of sensing errors and provide more reliable sensing data, which in turn will mitigate the interference between SUs and PUs. In this work, however, we have investigated a different approach for exploiting SUs observations such that minimum collision ratio and maximum utilisation can be achieved. As a result, a new approach has been proposed for cooperative spectrum sensing which can outperform the conventional approach by taking into account both the impact of sensing resolution and sensing error. In addition, a threshold has been found to select the most appropriate approach for cooperative spectrum sensing based on the given parameters of (K, P_{md}, P_{fa} and T_s). The dynamic approach proposed in this work can enable a more efficient coexistence between primary and secondary users with lower level of interference and higher utilisation.

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