International Review on Computers and Software (I.RE.CO.S.), Vol. 11, N. 10
ISSN 1828-6003
October 2016

Improving Routing Performance Using Cooperative Spectrum Sensing in Cognitive Radio Networks

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Abstract – *The traditional fixed spectrum assignment policy, in wireless networks, has led to significant underutilization (both spatially and temporally) of some licensed spectrum bands and crowdedness of unlicensed spectrum bands. These challenges gave birth to the new spectrum utilization paradigm called "Opportunistic Spectrum Access (OSA)". Networks that operate under this new paradigm are called Cognitive Radio Networks, named after the enabling technology of OSA. The new paradigm allows unlicensed wireless users, also called Secondary Users (SUs), to use licensed spectrum bands as long as they are not in use by their licensed users, also called Primary Users (PUs). One of the most important properties of CRNs is that channel availability changes over time depending on the activity of PUs. Therefore, SUs must be able to detect PU activity on licensed spectrum bands, in order to use those bands for data communication when they are not in use by their PUs.*

This nature affects many functions in the network including routing. Routing in CRNs is different from traditional network routing, since it requires spectrum availability awareness. Therefore in CRNs, all intermediate SUs must sense channels availability periodically. However, the overall sensing time over a selected route cannot be neglected. In fact, the overall transmission time for SUs along a route is reduced, due to the time spent on the required periodic sensing for these SUs. In this paper, we introduce a novel Cooperative Spectrum Sensing (CSS) strategy, in which SUs along a selected route cooperate with their neighboring SUs to monitor PUs' activities. In our proposed strategy, a SU along the route selects a neighboring SU, if exists, to conduct spectrum sensing on its behalf for a particular channel. This selection is based on the required channel sensing time, and the remaining available time of the candidate SU. Simulation results show that the proposed model improves routing performance such that it reduces the overall required sensing time along selected routes, and therefore, the available time that SUs can offer for data transmission is increased. Also, the end-to-end delay and the achieved bottleneck link rate are enhanced. ***Copyright © 2016 Praise Worthy Prize S.r.l. - All rights reserved.***

***Keywords**: Cognitive Radio Networks, Dynamic Spectrum Access, Cooperative Spectrum Sensing, Routing*

Nomenclature

CSS	Cooperative spectrum sensing
PU	Primary User
SU	Secondary Users
n	Number of SUs along the selected route
g	Set of SUs within the selected route
G	The set of neighbor SUs for a SU over the selected route
G^i	A SUi from the set of neighboring SUs for a SU over the selected route
SUr	A SU along the selected route
SUn	A neighboring SU for another SU along the selected route
T	The maximum remaining time for a SU in G SUs set
Tcyc	The monitoring cycle time
$T^i_{idle}(\%)$	SUi idle time percentage
T^i_{sen}	SUi channel sensing time
T^i_{sw}	SUi channel switching time
T^i_{busy}	SUi time utilized for other route transmission and sensing, if exist
T^i_x	SUi transmission time delay
L	Data segment size (Mb)
U_i	Utilized percentage of monitoring cycle that used only for data transmission by SUi
β	Bottleneck link rate in a selected route
R	Channel bandwidth (Mbps)
RTT	Round trip time

I. Introduction

Nowadays, the unlicensed spectrum bands became crowded, while the licensed spectrum bands generally is less crowded and temporally and spatially are

DOI: 10.15866/irecos.v11i10.10716

underutilized. The measurements of Federal Communications Commission (FCC) on spectrum utilization have shown that the utilization for some channel bands could be very low, and the overall spectrum utilization is less than 15% as reported in [1].

Therefore, a new spectrum access paradigm has been proposed, namely Cognitive Radio (CR), which dynamically allows unlicensed users to access the licensed spectrum, if available [2].

Cognitive radio technology allows the unlicensed wireless network users; also called Secondary Users (SUs), to adjust their transceivers frequencies depending on the availability of licensed frequency bands when they are not used by their licensees [3].

In this technology, SUs can dynamically and opportunistically share and access the unused licensed channels, in order to improve their performance metrics such as the End-to-End (E2E) delay, throughput, and service reliability. One important condition in opportunistic spectrum sharing is SUs must evacuate the licensed channels when their licensees, also called Primary Users (PUs), become active again.

Cognitive Radio Networks (CRNs) face many challenges such as spectrum sensing, management, mobility, allocation and sharing [4], [5], attacks [6], interference and collision [7]-[10], routing protection [11] due to dynamic channels availability, and channels assignment for SUs [12].

Spectrum sensing is very important for SUs in CRNs, because all SUs within the PU's surrounding interference area and currently using its licensed channel must evacuate when PU becomes active again, in order to avoid interference with the PU's transmission. Note that it is well known that each SU uses a PU's channel must check every some certain time, known as monitoring cycle in literature, whether the corresponding PU's channel becomes active again or not.

In this paper, we propose a Cooperative Spectrum Sensing (CSS) strategy between SUs along a given selected route and their neighbor SUs. In our proposed strategy, for any SU over a route, call it SUr, other SUs which are within the same geographic area of PU activity as SUr can be employed to sense the channel availability, and report sensing results to SUr.

Therefore, in every monitoring cycle, SUr does not need to sense the licensed channel availability.

Therefore, SUr can use the saved sensing time to transmit more data instead. Thus, the overall throughput over the selected route is increased, and the End-to-End delay is decreased. The rest of the paper is organized as follows: in Section II, the related work is presented. Section III explains preliminaries for our work. Section IV presents our motivation. Section V, we explained our proposed cooperative spectrum sensing model. Section VI, the end-to-end delay and throughput enhancement is discussed. Section VII shows our simulation results.

Finally, conclusions are presented in Section VIII. The abbreviations meaning that used in this work are shown in the nomenclature Table.

II. Related Work

Several studies addressed cooperative spectrum sensing in CRNs targeting different objectives.

Such objectives include increasing sensing accuracy and achieving energy efficiency or optimizing network throughput while maintaining a certain level of sensing accuracy. Next, we review some of these studies.

II.1. Cooperative Spectrum Sensing (CSS) for Accuracy

A cooperative spectrum sensing mechanism is proposed in [13] to overcome the multipath fading and shadowing effect. In their work sensing is constrained by a limited time and number of SUs which perform sensing. This work reduces the energy consumption caused by channels sensing, and computes the number of SUs that should participate in sensing.

Overcoming the effect of fading and shadowing by collaborative sensing is also studied in [4]. In [14], the authors investigated the detection performance of an energy detector used in cooperative spectrum sensing taking into consideration both multi-path fading and shadowing. Using data fusion, the problem is analyzed in four different scenarios to derive upper bounds on the detection probability. Using decision fusion, on the other hand, the exact detection and false alarm probabilities are derived. In [15], the problem optimizing the ability of detecting weak primary signals using cooperative spectrum sensing is investigated. An optimal linear cooperation framework that uses linear combination of local statistics from individual SUs is proposed. In [16], a clustering-based cooperative spectrum sensing method is proposed. SUs are divided into clusters based on users' diversity such that the node with the largest channel gain is selected as the cluster head. Cluster-heads send sensing results on behalf of cluster members.

The proposed method achieves significant improvement in the sensing performance by exploiting the diversity in user selection as reported in the paper.

II.2. Energy Efficient CSS

An energy efficient spectrum sensing method which depends on the combination of censoring and sleeping policies is proposed in [17]. It is based on given priori information about the activity of PUs, and the maximum allowable false alarm, their results show SUs energy consumption is reduced. In [18], the authors proposed the use of a sensor network dedicated for spectrum sensing in order to aid cognitive radio networks. The sensor nodes are divided into a set of clusters, and the optimal activation schedule of these clusters is calculated in order to minimize energy consumption while meeting necessary detection and false alarm thresholds.

The problem of energy-efficient spectrum sensing scheduling with satisfactory PU protection is also studied in [19].

A model that uses the signal-to-noise ratio (SNR) of the primary signal at various SUs is proposed, which helps to determine how long each SU must sense each of the channels, in order to achieve reliable energy efficient sensing performance. The length of the sensing period affects the total consumed energy of SUs due to sensing.

Therefore, the authors in [20] proposed a scheme in which the lengths of sensing periods of various channels are dynamically adjusted based on profiling PUs activities. An optimized energy and time schemes for CSS are proposed in [21]. SUs conduct a short sensing operation, which is sufficient when the SNR is high or when the intended PU is inactive. If this first stage is not sufficient, a second stage of fine spectrum sensing will be performed to increase the spectrum sensing accuracy.

Thus, the required sensing time and consumed energy are reduced.

II.3. CSS with Maximized Throughput

A CRN that consists of a single PU and multiple SUs is used in [22] to study the problem of exploiting cooperative spectrum sensing to maximize the total expected system throughput. A Bayesian decision rule based algorithm was proposed to solve the problem optimally with a constant time complexity.

A novel capacity-aware cooperative spectrum sensing method was proposed in [23]. The proposed optimization method computes the optimal cooperative sensing parameters like the number of sensed samples, the number of cooperating nodes, and the used bandwidth on control channel such that the secondary system capacity is maximized. In [24], the k-out-of-N fusion rule is used in cooperative sensing to determine the presence of the PU. The author studied the problem of finding the pair of sensing time and the value of k that maximize the SUs' throughput subject to sufficient protection to PUs.

III. Preliminaries

In this section, we give some preliminary definitions and highlight some of the assumptions we make in this work.

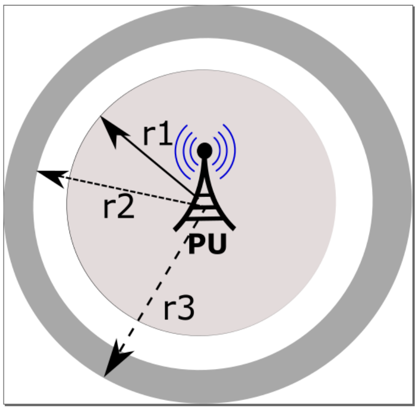

Fig. 1. Primary user transmission, sensing, and interference ranges with radii: r_1, r_2, r_3, respectively

Definition III.1: Sensing time is the amount of time required for a particular SU to sense the activity of PUs on a given spectrum channel. This amount may differ depending on the sensed channel as well as the hardware specifications of the SUs radio device [25].

Definition III.2: Monitoring Cycle is the amount of time that passes before the channel must be sensed.

Definition III.3: Secondary user available Time: the amount of time that is not dedicated for transmission on the current path (when the SU employed by other paths).

A PU is usually associated with different types of ranges (depicted in Figure 1) which are:

1. *The transmission range*: in which another PU can receive the transmitted data signal, shown with a radius of r1.
2. *The PU sensing range*: within this area SUs can sense the activity of PU with an acceptable accuracy, shown with a radius of r2.
3. *The PU's interference range*: in which SUs cannot transmit data if the PU is active, shown with a radius of r3, in order to avoid interference with PU transmission.

We assume in this work that when a SU wants to choose another SU for cooperative sensing on a specific channel, both SUs must be affected by the same group or set of PU(s) on that channel.

This condition guarantees that the sensing decisions made by both SUs are consistent and have the same meaning.

To explain this assumption, Fig. 2 shows an example scenario, assuming that all PUs operate on the same channel, only SU2 and SU7 can do cooperative sensing on each other's behalf, while other SUs pairs cannot, e.g.; SU3 cannot do cooperative sensing for SU2, since SU3 is affected by all PUs transmissions, while SU2 is affected only by PU2 transmission. Therefore, if SU2 sensed the channel to be busy or idle, then it is also busy or idle at SU7.

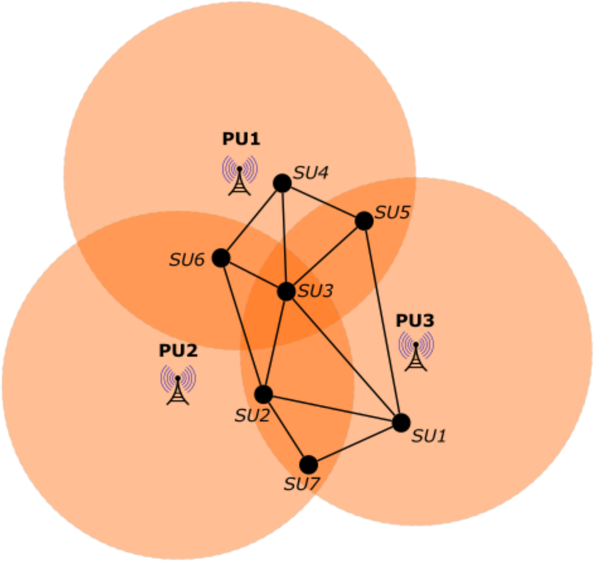

Fig. 2. Selection conditions for a cooperative spectrum sensing SU

IV. Motivation

For a given selected route in CRNs, SUs along this route may have some neighboring SUs which may have an idle time (where this idle time is enough to sense the currently used licensed channels, in order to decide whether their corresponding PUs become active again or not). In order to have a cooperative spectrum sensing between a SU along the route and its SU neighbor for a channel on each other's behalf (as explained in previous section using Fig. 2 network scenario), they must be within the sensing range of the same set of PUs operating on this channel.

Building on these two observations, we were motivated to propose the following:

1. For SUs along a given selected route, we propose to utilize their neighbor SUs' idle time, if exist, in order to perform cooperative channel sensing, while SUs along the route are busy with data transmission. As a result, the transmission time for SUs along the route is increased, and therefore, the throughput is increased.
2. SUs in a network may differ by their required sensing time which is required for spectrum sensing, since the needed sensing time is based on SUs channel conditions, and other factors [25]. Therefore, we are motivated to select a neighbor SU(s) which needs the least channel sensing time, and has largest idle time (such that this idle time is enough for the required sensing process). This selection factor is formulated in the objective function, equation (2), as explained in Section V.

Fig. 3 gives a motivational example. Assume that PU1, PU2, PU3, PU4, and PU5 are primary users which have the license to use channels: ch1, ch2, ch3, ch4, and ch2, respectively. Also, assume that at a given time, the common available channel between SU1 and SU2 is ch1, and between SU2 and SU3 is ch2, and between SU3 and SU4 is ch2, and between SU4 and SU5 is ch3.

The circles in this Figure represent the interference ranges of PUs. To choose a SU for cooperative sensing, it must be affected by the same set of PU(s).

For example in Fig. 3, SU3 may select SU_{C1}, because both are affected by PU2 and PU5 interference ranges, while SU_{C2} cannot be selected, since it is affected by PU2 only.

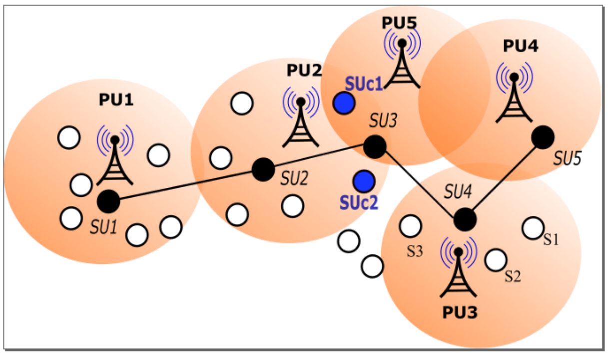

Fig. 3. An example of given selected route for SUs in CRNs

Notice that when SU3 wants to transmit to SU4 over ch2, both PU2 and PU5 must be idle, where SU_{C1} is the only neighbor SU which is capable to sense whether these two PUs is active or not, due to the aforementioned reason. Let's discuss another motivation, Fig. 3 shows SU4 has three neighboring SUs (that are affected by the same PU, called PU3) named S1, S2, and S3. Let's assume their available or remaining times are: 10%, 12%, and 15%, respectively, of the monitoring cycle time, also assume these SUs required sensing times for the licensed channel are: 50 ms, 50 ms, and 100 ms, respectively. Also, assume SUs monitoring cycle time = 1000 ms. In our proposed method, we choose the SU that has the maximum Remaining Time (RT) after conducting channel sensing, in order to balance the remaining idle times for other tasks in the network.

For S1, the RT = (1000×10% - 50) = 50 ms, and for S2, the RT = (1000×12% - 50) = 70 ms, and for S3, the RT = (1000 × 15% - 100) = 50 ms. Therefore, the maximum remaining time after sensing is 70 ms which corresponds to SU neighbor S2.

Therefore, S2 is selected to do sensing for the licensed channel, ch3 (which is used by SU4 to transmit data to SU5), in behalf of SU4 when it is busy with data transmission. It is worth mentioning that S3 is not chosen, although S3 has the maximum idle time.

However, S2 is selected based on our selection metric which is based on both factors: SU idle time and the required channel sensing time.

V. System Model

In cognitive radio networks, SUs must perform in-band sensing periodically in order to check whether the currently used PUs channel becomes active again or not [26]. This period of time is known in literature as monitoring cycle.

This monitoring cycle frame, T_{cyc}, for a SU includes, as shown in Fig. 4 and formulated in Eq. (1):

$$T_{cyc} = T_{tx} + T_{sw} + T_{sen} + T_{busy} + T_{idle} \qquad (1)$$

- *Data transmission time*, T_{tx}, the available time of a SU which can be used to transmit data.
- *Switching time*, T_{sw}, if needed (when the receiving and transmitting channels are different).
- *Sensing time*, T_{sen}, in order to check whether the PU becomes active again or not.
- *Busy time*, T_{busy}, SU time utilized for other route transmission and sensing, if exist.
- *Remaining (idle) time*, T_{idle}, SU is idle and this time is not utilized.

In this work, our goal is to reduce the overall sensing time for SUs over the selected route, in order to use this saved time for data transmission instead.

Therefore, the route E2E delay is decreased and throughput is increased, as explained in Section VI.

We assume SUs in the network have different sensing time, even to the same channel.

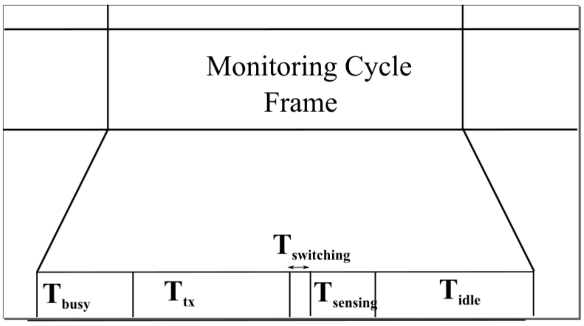

Fig. 4. A SU monitoring cycle time frame components

Also, SUs availability (idle) times are different, e.g.; if a SU idle time is 30% of monitoring cycle time, this means 30% of this SU time is not utilized, therefore, we are motivated to use this idle time for cooperative spectrum sensing.

Note that when SUs perform spectrum sensing, they may employ energy detection technique which usually needs about 1 ms, or employ feature detection technique, e.g.; cyclostationary, which usually needs more than 1 ms, e.g.; 150 ms, [26], [27]. In feature detection technique, SUs search for PUs features, e.g.; modulation scheme employed by PUs that distinguishes them from SUs transmission.

V.1. Reduction for the Overall Sensing Time Along the Given Selected Route

In the proposed model, we reduce the overall sensing time that performed by SUs along a selected route, if possible, using sensing cooperation. We propose to select for a SU along the selected route, a neighbor SU which has some available (idle) time, in order to conduct channel sensing. The neighbor SU required sensing time must be less or equal to its idle time, therefore, this neighbor SU can perform channel sensing.

The selection criteria of the cooperative SU is formulated in Eq. (2), where a SU is selected from neighbor SUs such that its remaining idle time, call it τ, is the maximum after performing the cooperative sensing. As Eq. (2) shows the available time for a neighbor SU is calculated by the multiplication of the monitoring cycle time and the SU neighbor idle time percentage, which must be greater or equal to the required sensing time by neighbor SU for the corresponding PU channel:

$$\tau = max\left(T_{cyc} \times T_{idle}^{i}\% - T_{sen}^{i}\right), \quad \forall i \in G^{i} \tag{2}$$

V.2. Our Proposed Co-Operative Sensing Protocol

In our proposed cooperative sensing strategy, these are the steps that are performed by each SU along the given selected routing path, in order to select the neighbor SU, if exist, to do a cooperative spectrum sensing.

Note that our proposed selection criteria is explained in the previous subsection.

- *Step 1*: Initially, each SU on the given selected routing path sends a control packet, call it "Hello" packet, to its neighbor SUs to ask them about: (a) - Their idle time percentage, (b) - Their required sensing times for PUs channels within their geographical area.
- *Step 2*: Neighbor SUs which receive the "Hello" packet and within one-hop reply by the requested information in step (1).
- *Step 3*: After that, each SU along the routing path when receives the requested information, uses the objective function formulated in equation (2), in order to select a neighbor SU that does channel sensing on its behalf.

Note that a neighbor SU, call it SUn, can perform a cooperative sensing for a SU along the selected route, call it SUr, if these conditions hold:

1. SUn geographical area is affected by the same PU(s) transmission and sensing ranges as SUr.
2. SUn is affected by the exact set of PUs which has the same licensed channel as SUr.
3. SUn available (idle) time is enough to perform sensing for PU licensed channel.

Also note that a SUn may have no idle time, since it is busy with other transmission or sensing for other currently working routes in the network, called T_{busy}.

After the cooperative SUs for spectrum sensing are selected, at the end of each monitoring cycle, SUs along the routing path communicate with their selected cooperative neighbor SUs, in order to exchange information about channels availabilities.

Exchanging control packets between a SUr and SUn is typically less than the required sensing time when the SU do spectrum sensing by itself. The exchange time that is represented by Round Trip Time (RTT) is much less than the required channel sensing time:

$$\begin{aligned} RTT &= (2\times\text{packet transmission time}) + \\ &+ (2 \times \text{propagation delay}) + \text{transceiver} \\ &\quad \text{processing delay} \end{aligned} \tag{3}$$

such that:

- Packet transmission time = (packet size/channel bandwidth),
- Propagation time = (distance/propagation speed),
- Propagation speed in wireless link = (3×10^{8}).

For example, say if the control packet size (which contains information whether the PUs channels are busy or not) = 60 bytes, bit rate = 1 Mbps, maximum distance between SUs = 1000 meters, and the processing delay (rounded within the SIFS) = 10 us [28]. By substituting these values to find RTT, as follows:

$$RTT = \frac{2\times60\times8}{1\times10^{6}} + \frac{2\times1000}{3\times10^{8}} + 10\times10^{-6} = 976.6\text{us}$$

RTT calculation above shows that it is about (1 ms), however, this time is still less than the required channel sensing time by a SU which is usually more than (1 ms) and up to (150 ms) [26], [27], in order to check the PUs activity over licensed channels.

VI. End-to-End Delay and Throughput Enhancement

In this section, we discuss how our proposed method reduces the E2E delay [30] for the selected route, since the sensing time which is needed for SUs along the selected route is reduced using the proposed cooperation scheme. Eq. (4) is used to find the E2E delay of SUs for a selected route:

$$E2E = \sum_{i=1}^{n} T_x^i = \sum_{i=1}^{n} \frac{L}{R \times U_i} \tag{4}$$

Let U_i denotes SUi utilization which represents the remaining percentage of monitoring cycle time that SUi can use for data transmission, Eq. (5).

U_i is increased by reducing sensing time. Therefore, when our proposed cooperative sensing method is employed, if possible, the sensing time becomes zero for SUi such that in-band channel sensing is performed by the selected cooperative neighbor SU:

$$U_i = \frac{T_{cyc} - T_{sen}^i - T_{sw}^i - T_{busy}^i}{T_{cyc}} \tag{5}$$

To find the bottleneck link that has the minimum rate for the set of SUs along the route, use Eq. (6):

$$\beta = min\left(U_i \times R\right), \quad \forall i \in g \tag{6}$$

when our proposed method is applied, the bottleneck throughput, β, is enhanced or increased, because the U_i for some SUs is most likely enhanced (increased).

Therefore, the E2E delay is decreased. Our simulation results in Section VII show the effectiveness of our proposed scheme.

VII. Simulation Results

In our simulation, PUs are distributed randomly in a square area between (0, 0) and (4000, 4000), such that the distances are in meters. SUs are distributed in a grid based such that the square side length = 500 m, so the total number of SUs is calculated as: (4000/500) * (4000/500) = 64. The interference range for the PU is 650 m (as this notion is explained in Fig. 1, Section 3, the transmission range of the SU is 500 m.

The simulation parameters are set as follows, unless mentioned otherwise: channel's sensing time by a SU is selected randomly between 1 ms and 150 ms, the message size delivered from the source SU to the destination SU over the selected route is (1 Mb), channel's data rate = (10 Mbps), number of PUs = 30 distributed randomly in the area, number of licensed channels in the network = 10, SU available time = 50%, channel switching delay = 1 ms per 10MHz [29], the SU monitoring cycle time = 1000 ms, probability of PU to be active = 0.60.

This simulation evaluates three performance metrics for the selected route:

1. The overall sensing time;
2. The E2E delay enhancement;
3. The improvement on the achievable bottleneck rate, β.

Fig. 5 shows the enhancement percentages for the E2E delay and the bottleneck, β, for different sensing time distributions.

For example, when the sensing range for SUs is [0 - 130], the E2E delay and bottleneck enhancements are 6.6% and 11%, respectively.

Clearly in Fig. 5, when the sensing time range is increased, the achieved enhancement is increased.

Fig. 6 shows the overall reduction percentages of the required SUs sensing time along the route with different SUs sensing time ranges.

Clearly, a novel improvement is achieved such that the overall required sensing time along the route is reduced by about 97% for SUs sensing ranges [0 - 40] to [0 - 190], while it is 78% for [0 - 10] sensing range. Note that sensing time for a channel by a SU ranges from 1 ms to about 200 ms based on employed detection technique, as explained in system model section V.

In Fig. 7, the E2E delay is reduced by about 7.5%. Also, this figure shows the achieved bottleneck rate improvement is increased from 9% (when number of PUs = 10) to 11.3% (when number of PUs = 60), this improvement demonstrates the necessity of employing our proposed CSS, when number of PUs increases in the network.

Fig. 8 shows an improvement for the route E2E delay when CCS is employed by about 7.6% when the SUs available time is randomly distributed between (0% and 40%) or more up to (0% and 90%).

Also in Fig. 8, it is shown the bottleneck throughput for the route is improved by 1.2% when SUs available time range [0 - 10], and improved by 12.5% when SUs available time range [0 - 60].

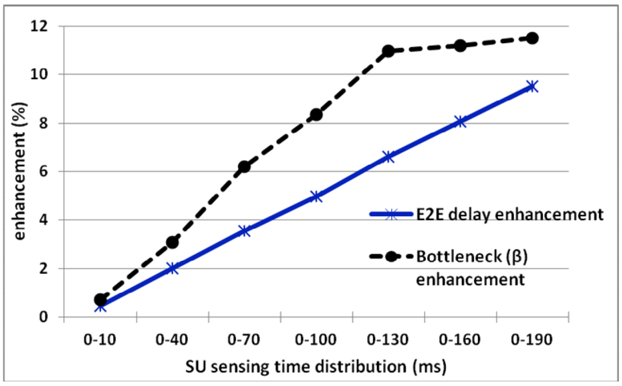

Fig. 5. E2E delay and bottleneck rate enhancement with different SUs sensing time ranges

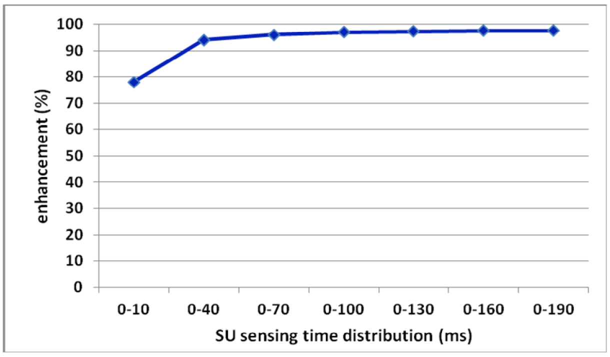

Fig. 6. Overall enhancement (reduction) percentages of the required sensing time for SUs along the route, with respect to different SUs sensing time ranges

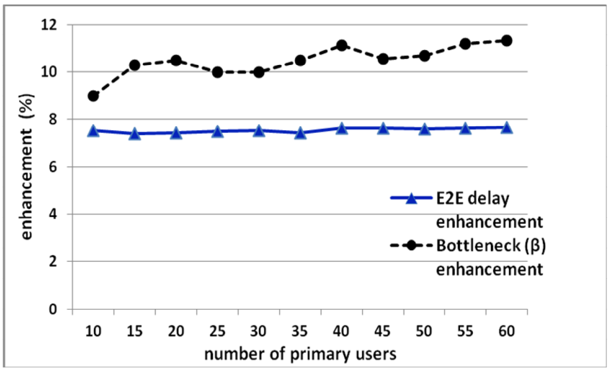

Fig. 7. E2E delay and bottleneck rate enhancement with different number of PUs

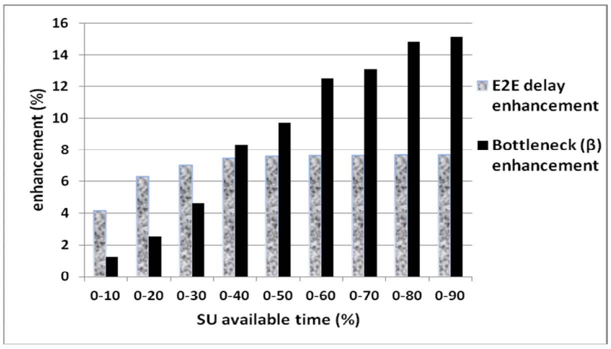

Fig. 8. E2E delay and bottleneck rate enhancement with different SUs available percentages

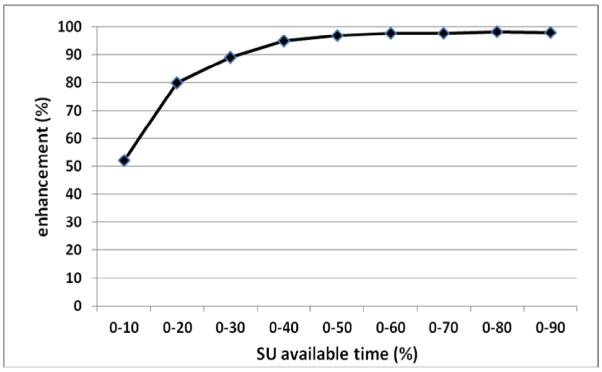

Fig. 9. Overall enhancement (reduction) percentages of the required sensing time for SUs along the route, with respect to SUs available time percentage

Fig. 9 shows the overall reduction percentages of the required sensing time for SUs along the route, with respect to different SUs available time percentage.

A big improvement is achieved when SUs available time range [0 - 30], the required overall sensing time is reduced by 90%.

VIII. Conclusion

In Cognitive Radio Networks (CRNs), routing is different from traditional network, because cognitive radio users, also known as Secondary Users (SUs), are required to have awareness about channels availability.

In this paper, we introduce a novel cooperative spectrum sensing strategy, in which SUs along a selected route cooperate with their neighboring SUs to monitor Primary Users (PUs) activities. In the proposed model, when a SU along a selected path wants to choose a neighbor SU for cooperative channel sensing, SU selection is based on: the required channel sensing time (different for SUs), and the remaining available time of the candidate SU. In our simulation, we study three routing performance metrics: the overall sensing time, the E2E delay enhancement, and the achieved enhancement on bottleneck link rate, β.

Our results show that the proposed model reduces the overall required channel sensing time along selected routes, the bottleneck link rate is enhanced such that the delivery rate is increased. Also, when SUs available time increases, the performance metrics are enhanced.

Some challenges for our proposed protocol:

(a)-A SU along a path may not have SU neighbors, in order to do cooperative sensing.

(b)-All neighbor SUs are busy and do not have enough time to do cooperative sensing.

(c)-There is no SU that satisfies the required cooperation condition, such that it must be affected by the same set of PUs as SU along the path.

As a future work, the case when there is no neighbor SU exists which is affected by the same set of PUs, we search for more than one neighbor SU which are affected by the same set of PUs, in order to improve sensing performance.

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