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# Performance Comparison of Random Subcarrier Access & Spectrum Harvesting with ARQ Retransmission and Probing Type of Cognitive Radio Networks

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**Abstract:** In cognitive radio (CR) systems, one of the main implementation issues is spectrum sensing. This paper considers an orthogonal frequency-division multiplexing (OFDM)- based CR spectrum sharing system that assumes random access of primary network subcarriers by secondary users (SUs) and absence of the PU's spectrum utilization information, i.e., no spectrum sensing is employed to acquire information about the PU's activity or availability of free subcarriers which is termed as Random Subcarrier Access (RSA) Scheme. This paper obtains the performance of the random access scheme in terms of capacity of the subcarrier collisions by assuming an interference power constraint at PUs to protect their operation. This paper also considers a method entitled Spectrum Harvesting with ARQ Retransmission and Probing (SHARP) which is based on spectrum sharing system where the secondary pair listens to the primary ARQ feedback to glean information about the primary channel. Two varieties of spectrum sharing, named conservative and aggressive SHARP, are introduced. The performance of RSA scheme and SHARP scheme is compared.

**Index Terms:** OFDM-based cognitive radio, random access, spectrum sharing, ARQ, average capacity.

## I. INTRODUCTION

SPECTRUM measurements around the globe have revealed the fact that the available spectrum is under-utilized. Hence, efficient utilization of the spectrum represents a crucial issue in the wireless communications field [1]. One of the most remarkable solutions to cope with the under-utilization of spectrum is the concept of cognitive radio (CR) [2]. CRs assume that the radio frequency (RF) spectrum can be utilized by secondary users (SUs) in addition to the legacy users also termed primary users (PUs) by complying with some predefined requirements imposed by PUs on SUs. Two of the most popular SU spectrum utilization methods are spectrum sharing and opportunistic access methods, which are also referred to as underlay and interweave CR networks, respectively. In the spectrum sharing method, a SU can concurrently use the same spectrum with a PU by regulating (adapting) its peak or average transmit power below a PU predefined interference temperature (IT) (power) constraint, so that the quality of service (QoS) requirement of PU is maintained. In the opportunistic access method, a SU can only access the spectrum when it is not occupied by PU. Combinations of the aforementioned methods are called hybrid CR networks [3].

One of the most challenging issues in the implementation of CR networks is the acquisition of information about the spectrum occupancy of PU(s) [4]. Deploying an efficient spectrum sensing mechanism is difficult because of the uncertainties present in the propagation channels at device and network-level, the hidden PU problem induced by severe fading conditions and the limited sensing duration. A survey of the major spectrum sensing algorithms including the design and implementation challenges are presented concisely in [5] and the references cited therein [4]. Tannious and Nosratinia [6] propose to use the ARQ feedback information to harvest excess mutual information in the channel when the primary has constant rate and power, while the channel gains fluctuate due to fading. The essence of the idea of [6] is that whenever the primary receiver sends a NACK, other nodes in the system (potentially) become aware that a second transmission will be underway. Because the first transmission has already provided some information to the primary receiver (albeit not enough), the second transmission now needs to provide less than a full amount of mutual information and can be more robust to interference.

This paper presents analysis of performance of RSA & SHARP type of cognitive radio networks. In the RSA scheme, two different SU transmitter and receiver pairs belonging to different cells are considered, and the performances in terms of capacity due to collisions (interference) between SUs in addition to that of PU are studied. The average capacity expressions of target SU's (SU-1) at the $i^{th}$ subcarrier are obtained for no interference case, and when there is interference from only SU-2, only PU, and both SU-2 and PU. In SHARP scheme, two different scenarios are considered: (a) each primary ARQ carries information about the channel gains in multiple time intervals (b) each secondary transmission creates interference on the primary, therefore the

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following ARQ carries further information back to the secondary regarding the relative strength of primary and cross channel coefficients. In effect, the latter source of information can be thought of as a probing of the primary channel by the secondary.

The rest of the paper is arranged as follows. In Section II, the system and channel models of random subcarrier access scheme are presented. The SU capacity analysis is investigated in Section III. Section IV introduces the Sharp scheme. In Section V two spectrum sharing schemes, namely aggressive and conservative SHARP which utilize the ACK/NAK feedback of the primary user, are analyzed. The throughput analysis of the considered scheme is given in Section VI. The simulation results are described in Section VII. Finally, concluding remarks are drawn in Section VIII, respectively.

## II. SYSTEM AND CHANNEL MODELS OF RSA SCHEME

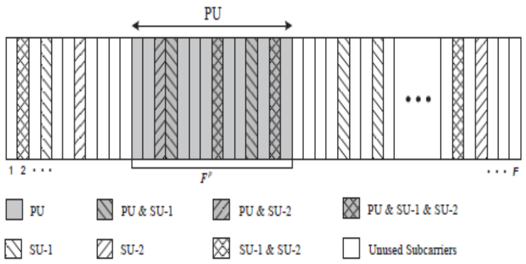


Figure1. OFDM-based CR system for SUs in different secondary networks (cells) with subcarrier collisions with SUs and PU due to the random access scheme.

The orthogonal frequency-division multiplexing (OFDM) - based CR system is illustrated in Figure 1, where a PU and SUs are assumed to be present in the primary and secondary networks, respectively with each SU transmitter and receiver pair belongs to separate cells. The total number of available subcarriers in the primary network is denoted by F and the number of PU's subcarriers is denoted by $F^P$.The number of subcarriers utilized by SU-1 and SU-2 are represented by $F_1^S$ and $F_2^S$ , respectively. SUs randomly access the available subcarriers set, $F$ in the primary network without having access to the PU's channel occupancy information. Subcarrier collisions occur when SUs randomly employ subcarriers, which are in use by PU and/or other SU, and the probabilistic model for the number of subcarrier collisions follows a hypergeometric distribution. Due to the random access (allocation) of subcarriers by SUs in different secondary cells, collisions occur with a certain probability between the subcarriers of SUs and PU. In addition, intercell collisions between the subcarriers of SUs might occur in addition to those that are utilized by PU. This set-up could be considered as the worst case scenario, where the collisions among the SUs subcarriers severely affect the performance due to the overall caused interference. One can observe from Figure 1 that the occurrence of collisions can be classified into different groups such as collisions between PU and SU-1, PU and SU-2, SU-1 and SU-2, and the worst case situation that assumes collisions among PU, SU-1 and SU-2. Notice that under the assumption of orthogonal allocation of subcarriers to the SUs in each secondary cell [4], subcarrier collision will only severely impact the performance of the SUs located at the cell-edge. It is assumed there is no cooperation between the cells (secondary base stations) or users (SUs) belonging different cells, therefore the collisions between the SUs belonging separate cells is probable due to random subcarrier access (allocation) scheme and it will degrade the performance of cell-edge SUs. Such an orthogonal subcarrier allocation scheme can be achieved in each cell by using our subcarrier allocation algorithm proposed in [4]. Notice that the algorithm, proposed in [4], still performs in a random manner. In random access scheme, due to the inherent nature of random access and the high number of available subcarriers available in practice, the probability of selecting (accessing) consecutive subcarriers by SUs will be considerably negligible [4]. Therefore, it is further assumed that there is no correlation among the subcarriers.

In Figure 2, the channel model at the ith subcarrier (i ϵ{1, . . ., F}) is shown. The *channel power gains* from PU-Tx to PU-Rx, SU-Rx-1, and SU-Rx-2 are denoted $g_i$ ,$g_{s1,i}$and $g_{s2,i}$, respectively. Similarly, $h_{1,i}$,$h_{1p,i}$and $h_{1s,i}$represent the channel power gains from SU-Tx-1 to SU-Rx-1, PU-Rx, and SU-Rx-2, respectively. In addition, $h_{2,i}$, $h_{2s,i}$ and $h_{2p,i}$denote the channel power gains for the ith subcarrier from SU-Tx-2 to SU-Rx-2, SU-Rx-1 and PU-Rx, respectively. The performance analysis of shaded SU (SU-1) is of interest in this work.

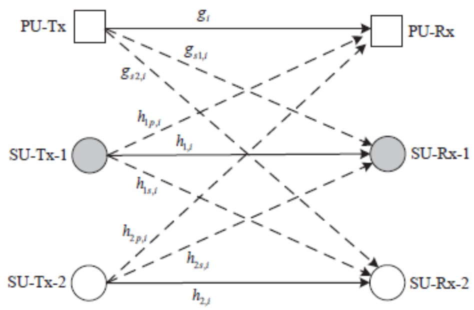


Figure 2. Channel model for the ith subcarrier, i ∈ {1, . . . ,F}, with SUs and PU-transmitter and receiver pairs, the performance of shaded SU pairs (SU-1) is of interest.

To preserve the QoS requirement of PU, the interference power levels caused by the SU-transmitters at the PU-Rx must not be larger than a predefined value for each subcarrier, referred to as the interference temperature (power) constraint. All the channel gains are assumed to be zero mean and unit variance independent and identically distributed (i.i.d.) flat Rayleigh fading channels. The channel *power* gains are hence exponentially distributed with unit mean [7]. In order for SUs to implement the transmit power adaptation and to have a tractable theoretical analysis, it is assumed that perfect information about the interference channels power gains, $h_{1p,i}$and $h_{2p,i}$, is available at SUs. The SUs can obtain this channel side information, through various means, e.g., from the channel reciprocity condition or from an entity called mediate band or CR network

 

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manager between the PU-Rx and SU-Tx [4]. For the sake of analysis simplicity, it is further assumed that the value of interference constraint is the same for all the subcarriers in the system, and the peak transmit power of each user is the same for all its subcarriers, i.e., $P_i = P$, $P_{1,i} = P_1$ and $P_{2,i} = P_2$, where $P_i$, $P_{1,i}$ and $P_{2,i}$ represent the transmit powers of PU-Tx, SU-Tx-1 and SUTx-2 for the ith subcarrier, respectively.

## III. PERFORMANCE ANALYSIS OF SECONDARY USER

In this section, the performance of the target SU (SU-1) is investigated by using the average capacity as performance measure. The sets of subcarriers are defined as follows. Let $K_{p1}^0$ be the set of collided subcarriers only between the SU-1 and PU, and $k_{p1}^0 = |K_{p1}^0|$ (fixed case) or $\hat{k}^0_{p1} = |K_{p1}^0|$ (random case), the cardinality of the set $_{p1}^{0}$.

### A. Average Capacity of SU

Various methods have been proposed to protect the operation of PU by maintaining the QoS requirements above some predefined threshold, and in this regard peak or average interference power constraints are two well-known methods. In this paper, to investigate the performance of the random access scheme, the well-known peak interference power constraint at each subcarrier is adapted. It is assumed that the peak transmit powers of SUs are the same for a tractable analysis P1 = $P_2$ = $P_s$. Therefore, the transmit power of the SU-1 is adapted to protect PU, and is given by 1 [8].

$$P_s^T = \begin{cases} P_S\,, & \beta P_s \le I \\ \frac{I}{\beta}\,, & \beta P_s > I \end{cases} = \min\left\{P_s, \frac{I}{\beta}\right\}, \qquad (1)$$

Where $\beta = h_{1p} + h_{2p}$ , and I is the interference constraint. It is worth to note that due to the random access scheme, the transmit power is adopted (regulated) considering the worst case scenario, as if there are collisions between both SUs and PU (interference from both SUs at PU-Rx, i.e., $(h_{1p}P_s + h_{2p}P_s)$. This condition assures the QoS of PU.

The expressions for the average capacity of SU-1 with a random access scheme are presented. Let $S_{p1,i}^0$, $S_{12,i}^0$ and $S_{p12,i}$ denote the signal-to-interference plus noise ratio (SINR) levels for the ith subcarrier of SU-1 with interference component coming only from PU, only from SU-2 and from both PU and SU-2, respectively. Similarly, let $S_{f1,i}$ stand for the signal-to-noise ratio (SNR) for the ith collision-free subcarrier of the SU-1. Mathematically, the SINRs and SNR are defined as and given by 2 [8].

$$\begin{aligned} S_{p1,i}^0 &= \frac{h_{1,i}P_{1,i}}{g_{s1,i}\,P_i + \sigma^2} \\ S_{12,i}^0 &= \frac{h_{1,i}P_{1,i}}{h_{2s,i}\,P_{2,i} + \sigma^2} \\ S_{p12,i} &= \frac{h_{1,i}P_{1,i}}{g_{s1,i}\,P_i + h_{2s,i}\,P_{2,i} + \sigma^2} \qquad (2) \\ S_{f1,i} &= \frac{h_{1,i}P_{1,i}}{\sigma^2} \end{aligned}$$

Then, the average capacity of SU-1 with the random access scheme is expressed and given by 3 [8].

$$C_{S1} = \sum_{i\in K_{p1}^0} C_{p1,i}^0 + \sum_{i\in K_{12}^0} C_{12,i}^0 + \sum_{i\in K_{p12}} C_{p12,i} + \sum_{i\in K_{f1}} C_{f1,i} \qquad 3$$

## IV. SHARP SCHEME

SHARP stands for Spectrum Harvesting with ARQ (Automatic Repeat Request) Retransmission and Probing which is implemented using cognitive radio as its technology. It is also a underlay cognitive radio where the secondary pair listens to the primary ARQ feedback to glean information about the primary channel. The secondary transmitter may also probe the channel by transmitting a packet and listening to the primary ARQ, thus getting additional information about the relative strength of the cross channel and primary channel. The method is entitled Spectrum Harvesting with ARQ Retransmission and Probing (SHARP).

The probing is done only infrequently to minimize its impact on the primary throughput. Two varieties of spectrum sharing, named conservative and aggressive SHARP are introduced, their difference is that conservative SHARP leaves the primary operations altogether unaffected, while aggressive SHARP may occasionally force the primary to use two instead of one transmission cycle for a packet, in order to harvest a better throughput for the secondary. The performance of the considered system is analyzed and it is shown that the secondary throughput can be significantly improved.

The transmission model is shown in Figure 3. The primary transmitter occupies the channel at all time; therefore the secondary can use the channel only through spectrum sharing. The channel gains are shown by $g_{ij}$ from transmitter $i$ to receiver $j$, where the subscript value 1 denotes the primary and 2 denotes the secondary. Channel gains obey the exponential distribution with mean $\lambda$. It considers a slow fading scenario, where the channel gain is assumed to be approximately constant over several transmission intervals.

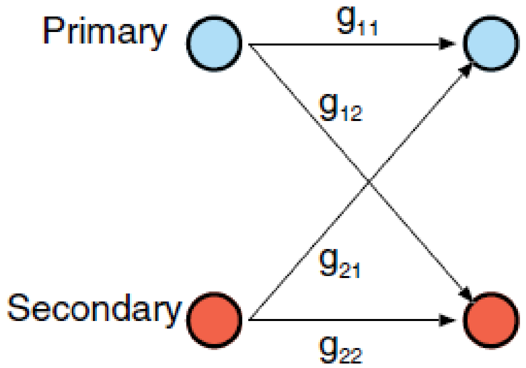


Fig.3.ARQ-based spectrum sharing without CSI at secondary transmitter.

The primary transmitter operates at a constant power $P_p$ and the nominal spectral efficiency of $R_p$ bits/sec/Hz. If the first transmission at this rate and power is not successful (indicated by a NACK from the primary receiver), the same packet is re-transmitted at the same power. The two packets are combined at the receiver. If after two transmissions still the packet cannot be decoded, the primary declares outage and moves on to the next packet. The ideas and the analysis directly extend to any number of ARQs. In this paper the analysis is to limited two ARQ rounds.

Whenever the secondary is activated, it has a peak power constraint of $P_s$ and transmits at a nominal spectral efficiency of $R_s$ bits/sec/Hz. The secondary receiver does not generate ARQ feedback.

## V. ARQ-BASED OPPORTUNISTIC SPECTRUM SHARING

The basic premise of this work is to allow a secondary to share the primary channel without explicit access to the primary channel-state-information (CSI). Partial channel state information is obtained via the ARQ from primary receiver. Furthermore, due to the persistence of channel state information (due to slow fading), the secondary is able to exploit opportunities that were not available. In particular, in our case not only retransmission rounds, but also the first transmission rounds are candidates for spectrum sharing.

The basic idea of SHARP is to exploit transmission opportunities for the secondary when possible, but also avoid driving the primary into outage (as a result of interference). The secondary can only observe the ACK/NACK from the primary receiver. The secondary also has knowledge of his own transmissions, therefore it can know whether the ACK/NACK of the primary was under the secondary interference or not. The opportunity for activating the secondary depends on the relative strength of the direct channel $g_{11}$ and the cross channel $g_{21}$. The plane $g_{11} - g_{21}$ is partitioned into six regions as shown in Figure 4. It is assumed unit transmit powers and noise, i.e., $P_p = P_s = N = 1$. We use the notations $\gamma_p \triangleq 2^{R_p} - 1$ and $\gamma_s \triangleq 2^{R_s} - 1$. The regions are characterized below.

a) The primary channel supports the rate in one transmission despite secondary interference. The condition under which this is true can be characterized and given by 4 [9].

$$\frac{P_p\, g_{11}}{P_s g_{21}+N} > \gamma_p \qquad (4)$$

Under this condition, the secondary should always transmit.

b) The primary channel can support its rate in one transmission if there is no interference, but needs two transmissions to succeed if there is interference. This is given by 5 [9].

$$\frac{\gamma_p}{2} < \frac{P_p g_{11}}{P_s g_{21}+N} < \gamma_p \qquad (5)$$
$$\frac{P_p g_{11}}{N} > \gamma_p$$

Under this condition, again the secondary can transmit at all times without pushing the primary into outage, but the throughput of the primary will be degraded.

c) The primary channel can support its rate in one transmission if there is no interference, but in the presence of interference it cannot succeed even with two transmissions. This is given by 6 [9].

$$\frac{P_p g_{11}}{P_s g_{21}+N} < \frac{\gamma_p}{2} \qquad (6)$$
$$\frac{P_p g_{11}}{N} > \gamma_p$$

Under this condition, the secondary can transmit every other time without causing outage for the primary, but the throughput of the primary will be degraded.

d) The primary channel can support its rate in two (but not one) interference-free transmissions; it can also succeed in two transmissions as long as only one of the two transmissions is subject to interference. Given by 7 [9].

$$\frac{P_p g_{11}}{N} + \frac{P_p g_{11}}{P_s g_{21}+N} > \gamma_p \qquad (7)$$
$$\frac{\gamma_p}{2} < \frac{P_p g_{11}}{N} < \gamma_p$$

Under this condition, the secondary should transmit only every other transmission interval without any effect on the primary.

e) The primary channel can support its rate in two (but not one) interference-free transmissions; it cannot support its rate with any interference (not even on one of its two transmissions). Given by 8 [9].

$$\frac{P_p g_{11}}{N} + \frac{P_p g_{11}}{P_s g_{21}+N} < \gamma_p \qquad (8)$$
$$\frac{P_p g_{11}}{N} > \frac{\gamma_p}{2}$$

Under this condition, the secondary should remain silent.

f) If $g_{11}$ is sufficiently small, the primary is doomed to outage even with retransmission and even in the absence of any interference. Given by 9 [9].

$$\frac{P_p g_{11}}{N} < \frac{\gamma_p}{2} \qquad (9)$$

Under this condition the secondary should transmit. These six operating regions are denoted $S_1$ - $S_6$ in Figure 4.

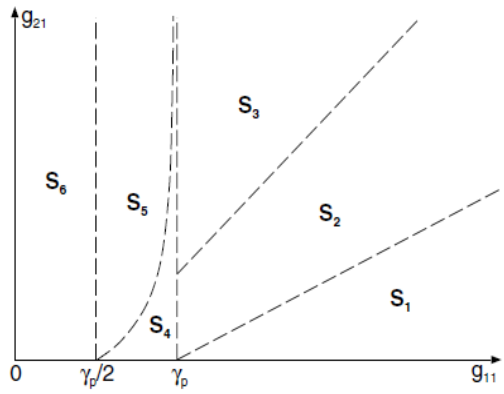


Fig. 4. The six regions for the operation of SHARP cognitive radio.

Based on these observations, two algorithms namely aggressive SHARP and conservative SHARP are devised. In the aggressive SHARP, the secondary will transmit whenever it is possible to do so without sending primary into outage, even if it will degrade the primary throughput. In the conservative SHARP, the secondary will only transmit when it has no effect on the primary. The probing of the system is characterized by the secondary transmission decisions. The following notations are used

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*Vol. 3, Issue 6, June 2014*

that combines the transmission modes of the primary and secondary.

$T_0$={Primary transmits new packet, secondary keeps silent}
$T_1$={primary repeats old packet; secondary keeps silent}
$T_2$={primary transmits new packet; secondary transmits}
$T_3$={primary repeats old packet; secondary transmits}.

Using the above notation, the discovery mechanism for the secondary is relatively simple, and is shown in the flowcharts in Figures 5 and 6. The algorithm starts from the root of the tree, and proceeds to a leaf. Throughout this process, the secondary makes transmission decisions and observes the ACK/NACK from the primary, until it can determine which of the six regions it is operating in. The probing and channel detection for each of the six operating regions is outlined.

($S_1$) is detected by receiving one ACK, probing the primary channel ($T_2$) and receiving another ACK. This indicates that primary channel supports the rate in one transmission despite any interference.

($S_2$) is detected by receiving the first ACK, then the secondary probing in two successive intervals ($T_2$ , $T_3$) and getting a NACK followed by an ACK. This indicates the primary channel supports its rate in one interference-free transmissions, but in the presence of interference needs two transmissions to succeed.

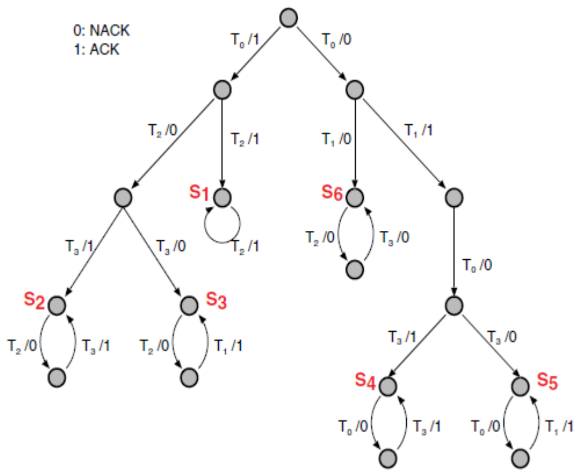


Fig.5. Flow chart for the aggressive SHARP.

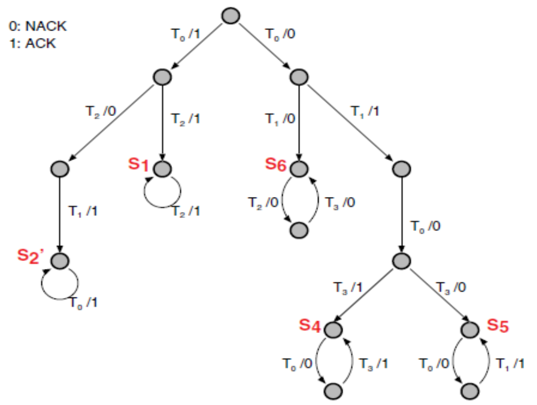


Fig. 6. Flow chart for the conservative SHARP.

($S_3$) is detected by receiving an ACK, then probing in two successive intervals ($T_2$ , $T_3$) and receiving two NACKs. This indicates the primary channel supports the rate in one interference-free transmissions, but in the presence of interference it is in outage even with retransmission.

($S_4$) is detected when the following sequence happens: receiving an initial NACK (which, recall, was under no interference), and the secondary staying silent and receiving a ACK (now we know the primary will get through in two transmissions if left alone). On the next transmission the secondary stays silent but hears a NACK (as expected), the next time the secondary transmits ( $T_3$) and hears an ACK. This indicates the primary channel supports the rate in two (but not one) interference-free transmissions; it can also succeed in two transmissions as long as only one of the transmissions is subject to interference.

($S_5$) is detected by going through the same sequence as the case above, however, in the last stage instead of an ACK a NACK is received, showing that despite all care the secondary cannot transmit. This indicates the primary channel supports the rate in two (but not one) interference-free transmissions, and that it cannot support its rate with interference (even on one of its two transmissions).

($S_6$) is detected by the secondary staying silent for two transmission intervals. When two successive NACKs are received, it is known that the primary is in outage even in the absence of secondary.

The detection of the operating region for aggressive SHARP can be implemented in a systematic way as shown in Figure 5. Starting from the root of the tree, the secondary stays silent for the first transmission and observes the primary ACK/NACK. Each of the six detection cases mentioned above traces a path from the root of the tree to one of the six leaves of the tree. The control diagram for conservative SHARP is shown in Figure 6. In the two regions $S_2$ , $S_3$, secondary transmission will reduce the primary throughput, therefore conservative SHARP refrains from transmitting in these two regions. Thus, the two outcomes $S_2$ , $S_3$ are merged into $S_2'$ for efficient representation.

## VI. THROUGHPUT ANALYSIS

In this section analytical results for SHARP scheme are provided.

***A. Throughput Analysis of aggressive and conservative SHARP schemes.***

In this subsection, the effective throughputs of the aggressive and conservative SHARP schemes are studied. As shown in Figure 5, the primary packet is sent by only one transmission cycle in Region $S_1$ and two cycles in the other SNR regions. Except in Region $S_6$, the packet is successfully decoded at the primary receiver. As a result, the throughput of the primary user for the aggressive SHARP is given by 10 [9].

$$G_p^A = R_p P\{S_1\} + \frac{R_p}{2} \sum_{i=2}^{5} P\{S_i\} \qquad (10)$$

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*Vol. 3, Issue 6, June 2014*

Where the superscript 'A' denotes the aggressive SHARP and $\frac{R_p}{2}$ is due to the two consecutive transmission cycles. Accordingly, the throughput of the secondary user in aggressive SHARP can be derived, following the flow chart in Figure 5, given by 11[9].

$$G_s^A = \Big(R_s(P\{s_1\} + P\{S_2\} + P\{S_6\}) \quad + \frac{R_s}{2}(P\{S_3\} + PS41 - PoS \qquad (11)$$

where the superscript OS indicates the 'outage for secondary' apart from exploiting the transmission opportunities in $S_1$ and $S_4$ which makes no harm to the primary system, the secondary user slows down the primary by forcing it to use two transmission cycles in Region $S_2$ and $S_3$

The conservative SHARP aims to avoid any negative effect on the primary user by allowing the secondary to transmit only when the channel is good enough to support simultaneous communication for both the primary and the secondary. The conservative scheme precludes transmission in the region $S_2'$ (i.e.,$S_2 \cup S_3$), and leaves the primary alone. Consequently, the throughput of the primary and the secondary in the conservative SHARP are given by12 and 13 [9].

$$G_p^C = R_p(P\{S_1\} + P\{S_2'\}) + \frac{R_p}{2}(P\{S_4\} + P\{S_5\}) \qquad (12)$$

$$G_s^C = \Big(R_s P\{S_1\} + \frac{R_s}{2} P\{S_4\} + R_s P\{S\}6\Big)\,(1 - POS \qquad (13)$$

## VII. SIMULATION RESULTS

In this section, the simulation results are presented. The average capacities (in nats per second per hertz) of the $i$th subcarrier, are shown versus the peak transmit power of SU, $P_s$, and interference constraint of PU, $I$, respectively. Due to the interference power constraint of PU, average capacities are saturated after a certain value of SUs' peak transmit powers. The channel power gains are assumed to be exponentially distributed with unit mean.

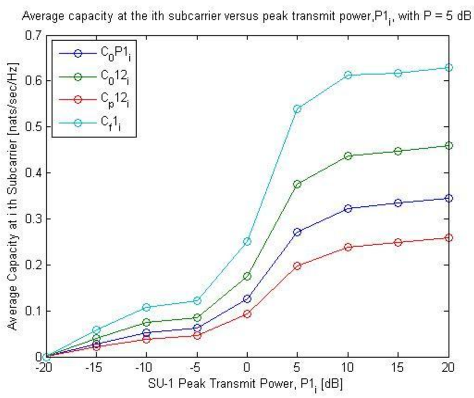


Figure.7 Average capacity at the $i$th subcarrier versus peak transmit power, *Ps*, in case of collision-free (no-interference) and interference from only PU, only SU-2 and both PU and SU-2 with $P$ = 5 dB and $I$ = 2 dB.

The average capacity is given in Figures 7, the best and the worst case performances belong to the collision-free case and collisions with both SU- 2 and PU, are given respectively. The average capacity in case of interference (collision) only from PU is lower than the average capacity in case of interference only from SU-2. This result is due to the fact that the SUs' transmit powers are equal and the low interference constraint. Therefore, SU-2 transmit power is also adapted, and the effect of interference on SU-1 capacity coming from SU-2 is lower than that of PU. We have studied the scenario with weak interference from the secondary transmitter to the primary receiver. The mean of the channel propagation gains are $\lambda 11$ = 4, $\lambda 21$ = 1, and $\lambda 22$ = 4. The rate thresholds are set to be *Rp* = 1 (bits/sec/Hz) and *Rs* = 0.5 (bits/sec/Hz) for the primary and secondary user, respectively. Figure 8 shows the achievable throughput of the primary and the secondary for various SHARP schemes.

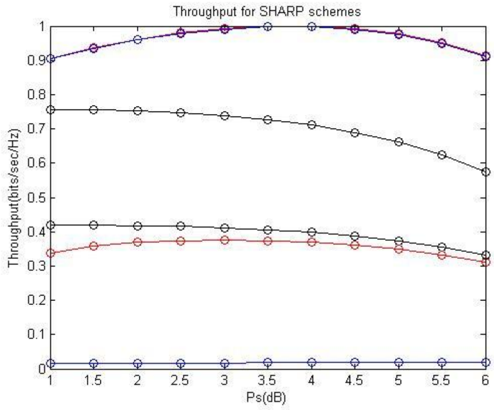


Figure.8. Throughput for SHARP schemes *Rp* = 1, *Rs* = 0.5, *Pp* = *N* = 1, $\lambda 11 = \lambda 22$ = 4, $\lambda 21$ = 1

Here in Figure 9 capacity of RSA scheme and SHARP scheme are compared. We have obtained that capacity of secondary user of RSA scheme is better compared to secondary user of Sharp scheme. Secondary user capacity for RSA scheme is 4.7nats/sec/Hz and for aggressive SHARP scheme is 3.9nats/se Hz and conservative SHARP scheme is 3.8nats/sec/Hz.

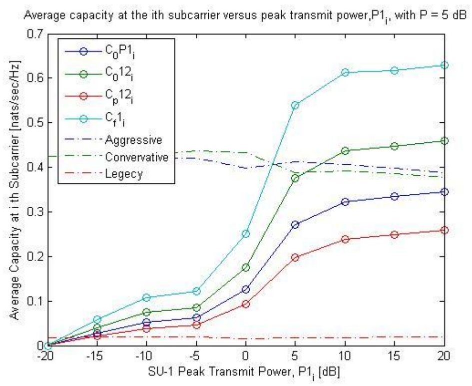


Figure.9. Comparison of Secondary user capacity of RSA scheme with SHARP scheme.

## VIII. CONCLUSION

In this paper, the random subcarrier access scheme is analyzed for an OFDM-based CR system with spectrum sharing features and two different secondary networks (cells). It is assumed that no spectrum sensing is performed, i.e., the information about the subcarrier occupation (utilization) by PU is not available at the SUs.

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It is shown that due to the randomness of the access scheme and the absence of cooperation between the SUs, there can be inter-cell collisions between the SUs' subcarriers with a certain probability. The performance of the random access scheme is analyzed by using the average capacity as performance measure. To maintain the QoS of the PU, the well known interference power constraint is applied to the SUs' transmit powers at their subcarriers. The expressions for the average capacity due to subcarrier collisions for the target SU are derived.

In this paper one more CR technique namely SHARP for the secondary user co-existing with an ARQ based primary system is considered. Based on the ACK/NAK message from the primary only, the considered SHARP schemes utilize several probing time slots to obtain a general picture about the primary channel condition. It was demonstrated that the aggressive SHARP achieves a better throughput than the conservative scheme with a small primary throughput loss. The conservative SHARP makes no negative effect on the primary system, and performs even better than the legacy system in terms of the primary user throughput. SHARP schemes are able to provide dramatic throughput gains to the secondary user without perfect CSI at the transmitter side.

The results reveals that RSA scheme efficient than SHARP scheme in terms of capacity of secondary user .

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