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A Performance Analysis on Inter-Cell Subcarrier Collisions Due To Random Access Based Upon SHARP Technique In Cognitive Radio Networks

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Abstract

Cognitive radio (CR) is an wireless technology of communication, in which transceiver can intelligently detect which communication channels are in usage and which channels are not, and instantly moves into vacant communication channels while leaving the occupied ones. CR optimizes the usage of the available radio frequency (RF) spectrum while minimizing the interference to the other users. This paper constitutes of an orthogonal frequency division multiplexing (OFDM) based CR spectrum sharing system that assumes an mechanism in which random access of primary network (PN) subcarriers or channels by secondary users (SUs) and the Spectrum Harvesting with ARQ Retransmission and Probing (SHARP) technique that performs sensing also. There are two varieties of spectrum sharing processes, which are conservative and aggressive SHARP methods. The SUs will randomly utilize the subcarriers of the PN and collides with the PU's subcarriers with a certain probability. Stochastic analyses of sensing as well as sharing the number of subcarrier collisions between the SU's and PU's subcarriers are consider.

Keywords: Cognitive radio, OFDM, Primary user, Primary network, Secondary user, SHARP.

Introduction

Wireless communication has become the fastest growing technology of the communication field in the last few years. As a result, wireless systems have several applications such as cellular telephony and wireless internet, and various devices working on it (e.g. laptops, mobiles, etc.). In addition, there are new applications like wireless sensor networks, automated factories, smart home appliances, remote telemedicine, and many more are also emerging from the research ideas to concrete systems. One of the emerging research fields is the Cognitive Radio.

With the incredible growth in the number of wireless systems and services, the availability of good quality wireless spectrum has become severely limited. Such that, real measurements carried out in several countries shows that most of the radio frequency spectrum is inefficiently utilized with spectrum utilization factor generally in the range of 5 to 50% [1]. Hence the real hurdle is not the spectrum scarcity but the inefficient spectrum management. This inefficiency results from static spectrum allocations, stiff regulations, fixed radio functions, and limited network coordination. *Cognitive radio* offers a novel solution to overcome these underutilization problems by allowing a timeserving usage of the spectrum resources. This shows us the proof from the definition of CR adopted by the Federal Communications Commission (FCC); Cognitive Radio: a radio or system that senses its operational electromagnetic environment and can dynamically, autonomously adjust its radio operating parameters to modify interference, facilitate interoperability, and access secondary markets[2].

Cognitive radio is a self learning mechanism which adapts according to the environment for sensing, reconfiguring, sharing, etc to provide unused spectrum to its secondary users, the centralized and distributed spectrum sharing approaches of CR. As shown in fig.1.

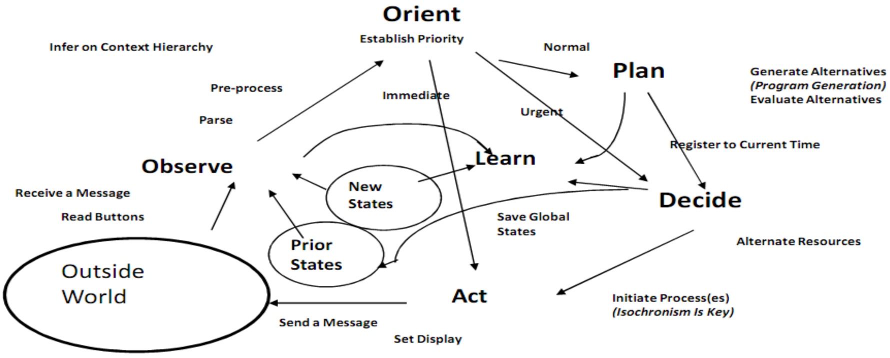

Figure 1: Cognitive Cycle

In cognitive radio terminology, a primary user (PU) is defined as a legacy user or a licensed user who has higher rights on particular band of spectrum. Examples of licensed technology are global system for mobile communications (GSM) [3], worldwide interoperability for microwave access (WiMAX), and long term evolution (LTE) while examples of legacy technology are microphone and wireless local area network (WLAN). On the other hand, unlicensed cognitive users with lower priority are defined as secondary users (SUs). A SU can access spectral resources of a PU when the PU is not using them. However the SU has to vacate the frequency band as soon as the PU becomes active so that negligible (or no) interference is caused to the

PU. Such an opportunistic access of the PU resources by the SUs is called as dynamic spectrum access.

Orthogonal frequency division multiplexing (OFDM) is a key technology for the present and the future broadband wireless communication systems. OFDM is a method of encoding digital data on multiple carrier frequencies. OFDM is a broadband multicarrier modulation method that offers the superior performance and giving many benefits over former techniques, more traditional single-carrier modulation methods because it is a better fit with today's high-speed data requirements and operation in the UHF and as well as in microwave spectrum.

System and Channel Model

A part of the RF bandwidth (spectrum) that occupies by a frequency channel allocated to the carrier and, therefore, may have a smaller information capacity, which is called as the subcarrier. A subcarrier is formally used for the signalling between the working stations on a wireless network. Spectrum measurements throughout the world have also revealed the fact that the available spectrum for wireless communication is under-utilized [1]. Hence, the efficient management of the spectrum (band width) represents a main hurdle in the wireless communications field [4]. The concept of cognitive radio (CR) is one of the most outstanding solutions to reveal with the under-utilization of spectrum [5]. There have been reported in many studies throughout the globe to investigate the performance of cognitive radio networks with spectrum sharing features, in which the SU capacity is mostly used as performance metric. The outage and also the ergodic capacities of spectrum sharing systems were studied in Rayleigh fading environments [7]. Assuming imperfect channel state information (CSI), [6], [8], [10], [11] conducted the capacity analysis as well as the power allocation studies. Besides the SU‘s average and peak transmit power constraints, in [12], the PU's outage loss is assumed as a constraint to maintain PU's QoS (Quality of Service) requirement. However, many studies require either knowledge of spectrum occupation by PU via the mechanism of spectrum sensing [9], [13] or knowledge of CSI between the PU-transmitter and PU-receiver to implement the interference level constraint for protecting the operation of PU.

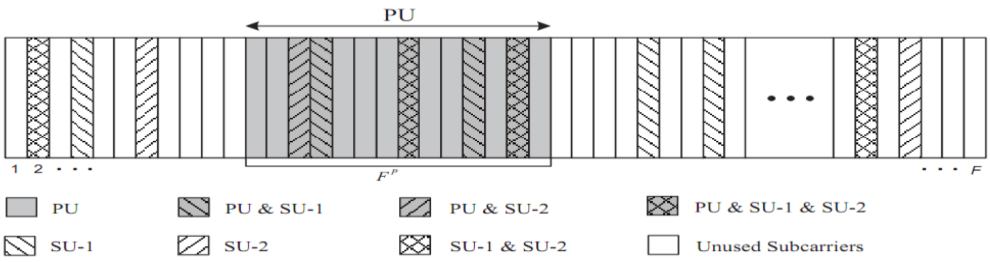

Figure 2: OFDM-based CR system for SUs in different secondary networks (cells) with subcarrier collisions with each other and PU due to the random access method. [22]

OFDM based CR system is illustrated in Fig.2, where a PU and SUs are assumed to be present in the primary and secondary networks, respectively, where each SU transmitter and receiver pair has belonged 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 can randomly access the available subcarriers set, F, in the primary network without having the access to the PU's channel occupancy information. Subcarrier collisions may occur when SUs have randomly employed subcarriers, which are in usage by the PU and/or other SU, and the probabilistic model for the number of subcarrier collisions will follow a hypergeometric distribution. Because of the random access (allocation) of subcarriers by SUs in different secondary cells, collisions can occur with a certain probability between the subcarriers of SUs and PU. In addition, inter- cell 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 categorized 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

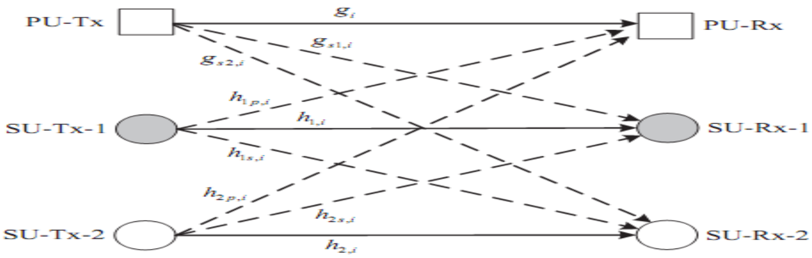

Figure 3: Channel model for the ith subcarrier, i ∈{1,...,F}, with SUs and PU-transmitter and receiver pairs, the performance of shaded SU pairs (SU-1) is of interest. [22]

In Fig.3, the channel model at the ith subcarrier (∈ {1,…,F }) is shown. The channel power gains from PU-Tx to PU-Rx, SU-Rx-1, and SU-Rx-2 are denoted by gi, gs1,i and gs2,i respectively. Similarly, h1,i , h1p,i and h1s,i represent the channel power gains from SU-Tx-1 to SU-Rx-1, PU-Rx, and SU-Rx-2, respectively. In addition, h2,i , h2s,i and h2p,i denote he channel power gains for the ith subcarrier from SU-Tx-2 to SU-Rx-2, SU-Rx-1 and PU-Rx, respectively [16]. The performance analysis of shaded SU (SU-1) is often interest in this work. To preserve the QoS requirement of PU, the interference power levels caused by the SU-transmitters at the PU-Rx must not be as larger than a pre-defined value for each subcarrier, taken as the interference temperature (power) constraint.

Statistical Analysis of The Number of Subcarrier Collisions

Throughout this entire section, the number of subcarriers needed by the PU and as well as SUs is assumed fixed. In order to properly assess the effect of the random access scheme on the subcarrier collisions are:

- Single Secondary Cell: Here, only a single SU (SU-1) is assumed to be available in the system. In the case of N PUs in the primary network, the SU-1 might experience subcarrier collisions with up to N PUs. In such a case, the resultant joint PMF of the number of subcarrier collisions will follows a modified multivariate hypergeometric distribution [14].
- Two Secondary Cells: In this scenario, due to the random access method, there can be inter-cell collisions between the subcarriers of SUs (belonging to the separate cells) in addition to those that collide with PU subcarriers. There are four such possible cases of the subcarrier collisions for the target SU (say SU-1):
  - ✓ Case 1: collisions between SU-1, PU and SU-2 subcarriers: k_{p12}.
  - ✓ Case 2: collisions only between SU-1 and PU subcarriers: $k_{p1}^{0} = k_{p1} - k_{p12}$
  - ✓ Case 3: collisions only between SU-1 and SU-2 subcarriers: $k_{12}^{0} = k_{12} - k_{p12}$
  - ✓ Case 4: collisions-free subcarriers of SU-1: $k_{f1} = F_1^s - k_{p1}^0 - k_{12}^0 - k_{p12}$
- *Hypergeometric Distribution* [15]: Suppose that an urn contains balls n, of which r are red and (n-r) are white. Let K denote the number of red balls drawn when taking m balls without replacement. Then, K is a hypergeometric random variable (RV) with parameters r, m and n, and its PMF is given by:

$$\mathrm{P_r}(K = k) = p(k) = \binom{r}{k}\binom{n-r}{m-k}\Big/\binom{n}{m}$$

Mathematical Analysis

The performance of the SU (SU-1) has been investigated by using the average capacity as a performance measure. In addition, the capacity (rate) loss of SU-1 due to the subcarrier collisions with the subcarriers of PU and SU-2 has been studied.

➢ *Average Capacity of SU:*

The expressions for the instantaneous and average capacity of SU-1 over an arbitrary channel fading model with a random access scheme are presented. [18], [19], [22]

Let $S_{p1,i}^{o}$, $S_{12,i}^{o}$ 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 1 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:

SINR level for ith subcarrier of SU1 for four cases are:

- Interference from PU only: $S_{p1,i}^{o} = \frac{h_{1,i}P_{1,i}}{g_{s1,i}P_i + \sigma^2}$

- Interference from SU-2: $S^{o}_{12,i} = \frac{h_{1,i}P_{1,i}}{h_{2s,i}P_{2,i}+\sigma^2}$
- Interference from both PU and SU-2: $S_{p12,i} = \frac{h_{1,i}P_{1,i}}{g_{s1,i}P_i+h_{2s,i}P_{2,i}+\sigma^2}$
- With no interference: $S_{f1,i} = \frac{h_{1,i}P_{1,i}}{\sigma^2}$

Where P_i , $P_{1,i}$ and $P_{2,i}$ represent the transmit powers of PU-Tx, SU-Tx-1 and SU-Tx-2 for the ith subcarrier, respectively. The thermal additive white Gaussian noise (AWGN) is assumed to have circularly symmetric complex Gaussian distribution with zero mean and variance σ^2.

Let, $S^{o}_{p1,i}$, $S^{o}_{12,i}$ 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.

Also $h_{1,i}$, $h_{1p,i}$ and $h_{1s,i}$ represent the channel power gains from SU-Tx-1 to SU-Rx-1, PU-Rx, and SU-Rx-2, respectively. Similarly, $h_{2,i}$, $h_{2s,i}$ 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.

Then, the instantaneous capacity of SU-1 with the random access method is expressed as Capacities of subcarriers for SU-1, SU-2 and PU. Where the expected values of capacities at the ith subcarrier for the four different cases, $C^{o}_{p1,i}$, $C^{o}_{12,i}$, $C_{p12,i}$ and $C_{f1,i}$ over the Rayleigh channel fading model.[20],[22]

$$C^{o}_{p1,i} = \sum_{i\epsilon K^{0}_{p1}} \log(1 + S^{o}_{p1,i})$$

$$C^{o}_{12,i} = \sum_{i\epsilon K^{0}_{12}} \log\left(1 + S^{o}_{12,i}\right)$$

$$C_{p12,i} = \sum_{i\epsilon K_{p12}} \log(1 + S_{p12,i})$$

$$C_{f1,i} = \sum_{i\epsilon K_{f1}} \log(1 + S_{f1,i})$$

Hence the instantaneous capacity is as:

$$C_{s1} = C^{o}_{p1,i} + C^{o}_{12,i} + C_{p12,i} + C_{f1,i}$$

- *Capacity Loss Due to Collisions:*

The upper bounds for the SU-1 instantaneous and average capacity loss due to subcarrier collisions are given by the following result.

The maximum capacity (rate) loss of SU-1 due to subcarrier collisions is upper-bounded by $\frac{1}{\sigma^2}\left[\sum_{i\epsilon K_{p1}} g_{s1,i}P_i + \sum_{i\epsilon K_{p12}} h_{2s,i}P_{2,i}\right]$. Mathematically,

$$\Delta C_{s1} = C_{s1}^{f} - C_{s1} \leq \frac{1}{\sigma^2}\left[\sum_{i\epsilon K_{p1}} g_{s1,i}P_i + \sum_{i\epsilon K_{p12}} h_{2s,i}P_{2,i}\right]$$

Where C_{s1}^{f} is the capacity of SU-1 when all of its subcarriers are collision-free, and is defined as

$$C_{s1}^{f} = \sum\nolimits_{i=1}^{f_1^s} \log\left(1 + \square_{1,i}P_{1,i}/\sigma^2\right)$$

Note that the expressions of the exact capacity loss can be obtained as

$E[\Delta C_{s1}]= E[C_{s1}]+ E\left[C_{s1}^{f}\right]$

➢ *Capacity over Rayleigh Channel Fading:*

The effect of a propagation environment on a radio signal, Rayleigh fading is a statistical model for it, such as that used by wireless devices. Rayleigh fading models assumes that the magnitude of a signal that has been passed through such a transmission medium (also called a communications channel) will vary randomly, or fade, Hence according to a Rayleigh distribution, the radial component of the sum of two uncorrelated Gaussian random variables. Rayleigh fading is a absolute model for ionospheric and tropospheric signal propagation as well as the effect of heavily built-up urban environments on radio signals.[1]

The average capacity expressions at the ith subcarrier for the four different collision cases, given in Section III, will be studied. Various methods have been proposed to protect the operation of the PU by maintaining the QoS requirements above some predefined threshold, and in this regard peak or average interference power constraints are the two well known methods [14], [17]. In this paper, to investigate the performance of the proposed random access scheme, the well known peak interference power constraint at each subcarrier is adapted. Peak transmit powers of SUs are the same for a tractable analysis P1 = P2 = Ps (assumed). So that, the transmit power of the SU-1 is altered to protect PU, and is given by: [21]

$$P_s^T = \begin{cases} P_s \text{ ,} \beta P_s \leq I \\ \frac{I}{\beta} \text{ ,} \beta P_s > I \end{cases} = \min\left\{P_s, \frac{I}{\beta}\right\}$$

Where $\beta = h_{1p} + h_{2p}$, and I is the interference power constraint. It is necessary 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. This condition assures that the QoS requirement of PU. Also notice that considering the above mentioned Rayleigh channel fading model, all the channel power gains are exponentially distributed with the unit mean.

Throughput Analysis

This paper proposes an method for the underlay cognitive radio , where the secondary pair listens to the primary ARQ feedback signals to get any information about the primary channel. The secondary transmitter channel may also take investigation about the channel by transmitting a packet and listening to the primary ARQ. Hence we are getting additional information about the comparative strength of the cross channel and as well as about primary channel. There are two varieties of spectrum sharing, that are conservative and aggressive SHARP introduced. Both methods avoids introducing any breakdown in the primary; their difference is that *conservative* SHARP will leave the primary operations completely unaffected, while *aggressive* SHARP may from time to time force the primary to use two instead of one transmission cycle for a packet, in order to get the better throughput for the secondary[23]. The conservative SHARP mainly 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 as well as the secondary. The conservative scheme precludes transmission in the secondary regions and leaves the primary alone.

Simulation Results

In this section, the simulation results of the above mentioned or proposed techniques are obtained and also have been discussed. The system model implementation has been done in MATLAB. The numerical and simulation results are presented to confirm the analytical results and investigate the impact of various system parameters on the performance of CR networks. Further, equal transmit powers of SUs are assumed to verify the simulation results with the numerical ones and the unit noise variance, $\sigma^2 = 1$, is used in all these plots. In this paper we have performed both sharing and sensing technique and also reduced the transmitted power from P=5dB to P=1dB. Thereafter, comparing the results with the simulation diagram has shown.

If we compare simulation result in fig.4 and fig.5, we can observe that the simulation result of fig.5 is better than fig.4. Similarly compare fig.6 and fig.7 than the simulation result of fig.7 is better.

In both comparison the capacities is better than previous cases and also requires less transmitted power.

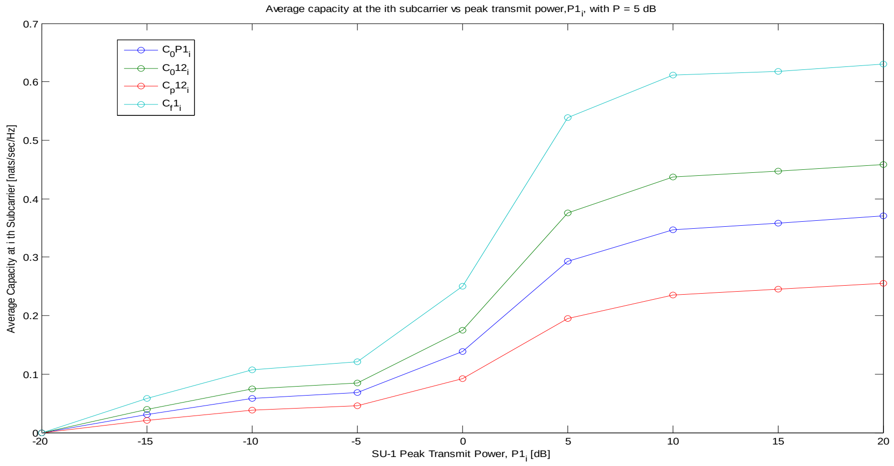

Figure 4: Average capacity at the ith subcarrier versus peak transmit power, Ps, in case of collision-free and interference from only PU, only SU-2 and both PU and SU-2 with P =5 dB and I =2 dB.

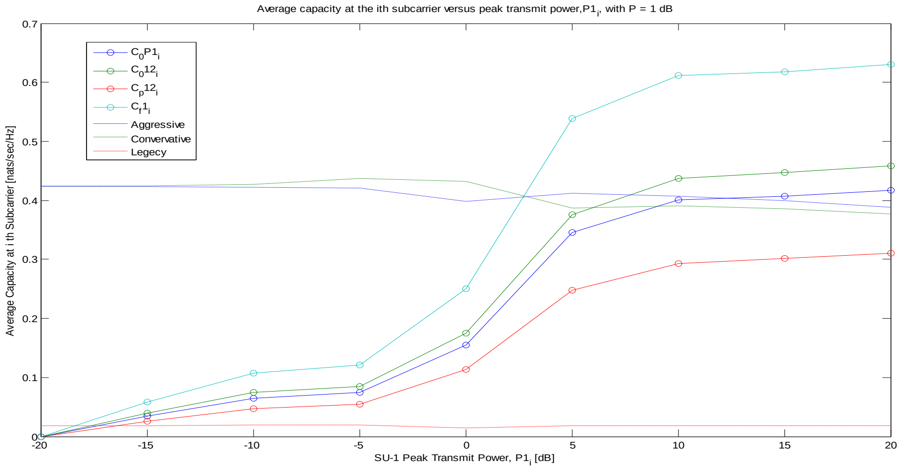

Figure 5: Compare to fig.4, it include SHARP and with P=1 dB

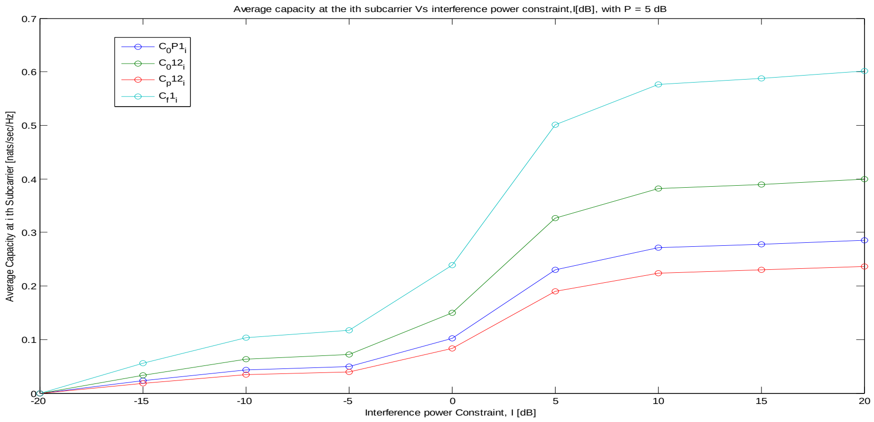

Figure 6: Average capacity at the ith subcarrier versus interference power constraint, I, in case of collision-free and interference from only PU, only SU-2 and both PU and SU-2 with P =5 dB and Ps =0 dB

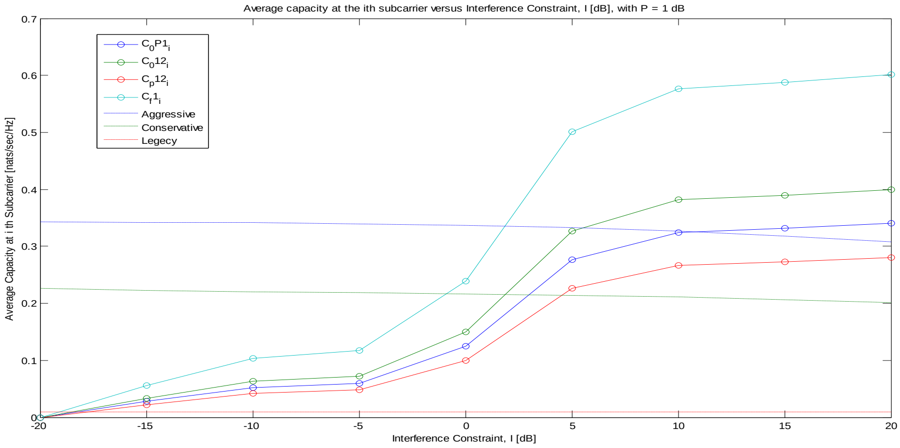

Figure 7: compare to fig.6, it include SHARP and with P=1 dB

Conclusion

The key contribution of this paper was about the research process is centered on the random subcarrier access scheme which is considered 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, Such that, the randomness of the access scheme and as well as the absence of cooperation between the SUs, there can be possibly inter-cell collisions between the SUs' subcarriers with a certain probability. The expressions for the PMFs and as well as the average of the number of subcarrier collisions, considering both fixed and random (to obtain the long term average) number of subcarriers utilized by PU and SUs, are derived. The performance of the random access scheme is analyzed by using the average capacity as a performance measure. To maintain the QoS of the PU, here we have also introduced the Spectrum Harvesting with ARQ Retransmission and Probing (SHARP) technique that also performs sensing in it. Therefore the collision between the PU and SUs will reduce and capacity will increase. In this paper we also reduced the transmitted power from P=5dB to P=1dB.

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