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*Original Article*

# Performance Estimation and Validation of Spectrum Allocation for Multi User CRN

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***Abstract*** *- In this paper, an adhoc Cognitive Radio Network (CRN) having multiple Primary Users (PU) and multiple Secondary Users (SU) is proposed. The spectrum sensing and allocation for the SUs are performed on the Universal Software Radio Peripheral (USRP) test bed. The real-time environment signals are considered for the proposed CRN performance analysis. The CRN's participation of SUs in spectrum sensing and spectrum allocation has been analyzed using cooperative spectrum sharing and the Coalition Game Theoretic (CGT) approach. A CGT spectrum allocation technique for the proposed CRN with a primary and backup channel allocation scheme has been investigated. The result shows that the channel allocation scheme is realistic. It improves SUs participation in CRN functions. It gives high spectrum utilization efficiency and causes negligible interference to neighbouring SUs/PUs. The spectrum utilization is up to 92.85% for specific scenarios of SU coalitions.*

***Keywords*** *- Cognitive Radio Network (CRN) implementation, Coalition Game Theory (CGT), Dynamic Spectrum Allocation (DSA), Universal Software Radio Peripheral (USRP), Coalition Formation (CF).*

## 1. Introduction

Most of the research work in Cognitive Radio (CR) [1, 2] has been limited to the theoretical aspects or simulation-based analysis. Thinking beyond this, to implement the CR in a real-time environment, in this paper, the spectrum sensing and spectrum allocation are implemented on USRP [3, 4] 2943R testbed using Labview 2015.

This implementation is divided into four phases. In the first phase, spectrum sensing is implemented on the USRP test bed using the mean power detection spectrum sensing technique. In the second phase, the Adhoc multi user Cognitive Radio Network (CRN) is designed to improve its performance using real-time spectrum sensing results. Cooperative Spectrum Sensing and Coalition Game Theory have been utilized [5]. To improve the performance in spectrum utilization, all the SUs in the CRN must participate in the spectrum sensing and allocation. To enhance the participation of each SU in the spectrum sensing, Coalition Head Selection (CHS) and Coalition Formation (CF) techniques are utilized.

In the third phase, Spectrum Allocation on the USRP test bed is implemented successfully. The Dynamic Spectrum Allocation (DSA) is implemented in the fourth phase of the proposed CRN. This paper is based on the fourth phase of the CRN implementation. Here, the detailed analysis of a Coalition Game Theory (CGT) based DSA with primary and backup channel allocation scheme for the proposed multi-user CRN is executed.

## 2. Related Work

In [6], the concept of Dynamic Spectrum Access was explained in detail, where the authors indicated the harmful interference caused by device malfunction and by a malicious user. In [7], the authors proposed a Binary Particle Swarm Optimization (BPSO) algorithm to solve the channel assignment problem in CRN, where each SU kept the information about channel availability.

In [8], the convex optimization technique was proposed to resolve the spectrum allocation problem and reduce interference, but a detailed study of SU behaviour was not executed. In [9], the overview of the spectrum assignment problem and future directions are given. In [10], the Hidden Markov Model (HMM) was proposed to solve the DSA problem. However, the noise and the interference caused by SUs were unconsidered.

In [11], CF was performed based on the demand function, trust function and participation, where the authors have considered the agent-based CRN, which increases the memory requirement at each SU. This can be a time-consuming process. After studying these and many other research papers, it is concluded that, though many methods are available to resolve the problem of spectrum sensing and allocation, it is necessary to study it further for the practical implementation of CRN. As there is much difference in the realistic scenario and the simulation assumptions.

It has been observed that in previous research, the full behaviour of the SUs is unstudied, the region boundaries of SUs and PUs are not considered, and the interference level of each SU is ignored.

Considering these facts, in this research work, the problem statements are formulated as follows: (1) to Implement the mean power detection spectrum sensing on USRP, (2) to apply the real-time spectrum sensing results on the proposed multi-user CRN to improve its performance in terms of high Probability of Detection ($P_d$), developed cooperation among SUs, and (3) to develop and analyze a DSA technique using CGT to achieve high spectrum utilization efficiency with low interference to PU and other SUs in the proposed multi-user CRN.

This improves SUs participation in spectrum allocation. A detailed spectrum sensing and allocation study is executed [12, 13]. The paper is organized as follows: The first three implementation phases of the CRN are explained in brief in section 3.

The analysis of the CGT-based DSA technique (phase four) for multi-user CRN is given in section 4. The results are discussed in section 5, and the conclusion is made in section 6.

## 3. Spectrum Sensing and Allocation on USRP

### *3.1. Phase I*

In this spectrum sensing phase, the USRP testbed implements the CR. One USRP is tuned as a PU transmitter with a QPSK/BPSK modulation technique. To solve the hidden node and interference problem, the PU signals are transmitted through the Rayleigh fading profile.

The other USRP is tuned as an SU receiver, where the received signals are filtered, its FFT is measured, and the mean power of received samples is estimated. The mean power of the received signal is denoted by P(f). It is shown in Figure 1. The extensive observations of the PU data and noise signal reception at SU to measure the Threshold Value ($V_t$) are executed.

$$\left.\begin{aligned} P_n(f) &= mean(P(f) \mid H_0) \\ P_s(f) &= mean(P(f) \mid H_1) \\ V_t &= mean(P_n(f), P_s(f)) \end{aligned}\right\} \quad (1)$$

The $V_t$ is measured using (1). This $V_t$ measurement is known as predetermined $V_t$ prediction, where $P_n$(f)= mean of P(f) for PU signal is absent, $H_0$ = Hypothesis for PU signal absent, $P_s$(f)= mean of P(f) for PU signal present and $H_1$ = Hypothesis for PU signal present. The spectrum sensing decision is taken by comparing P(f) and $V_t$ at SU. If P(f) is greater, then SU decision is $H_1$ else $H_0$. $H_1$ indicates that PU is transmitting the signal and $H_0$ suggests it doesn't. This way, spectrum sensing is performed on USRP, also called local sensing.

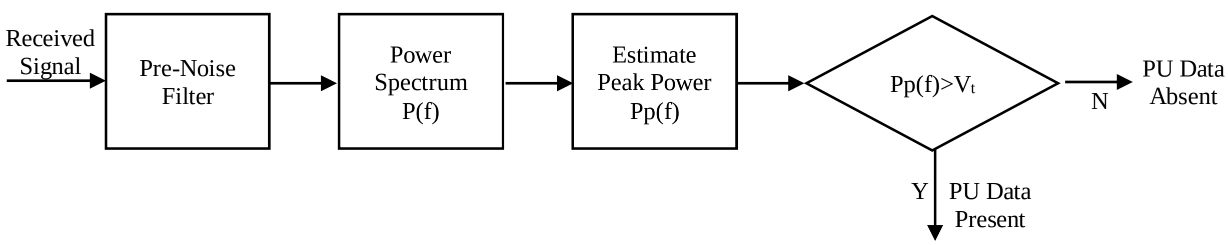


**Fig. 1 Spectrum sensing at Secondary User**

### *3.2. Phase II*

In this phase, a multi-user CRN is considered. Each SU is a transceiver equipped with USRPs. To establish cooperation among the SUs in the network, a CGT was executed on the CRN. The working of this network is explained in brief as follows:

1. Individual SUs and the result perform local sensing; whether PU is transmitting the signal is stored in SU itself.
2. All SUs are considered players; the SU near the networked centre location is declared a Base Station (BS). The BS decides the longest distance SU as a Coalition Head (CH) so that the maximum geographical area of the CRN is considered.
3. Then, each CH forms the coalitions. A coalition formation technique (Algorithm 1) [14] is used to achieve this. In this technique, the redundancy of the SU usage in more than one coalition is nearly zero. The speciality of this technique is that if any SU is out of the boundary region of all the PUs, it is declared a remote SU. The remote SU can form its coalition. The BS provides the sensing information to the remote coalition. Hence, they can participate in spectrum sensing and

allocation. This improves the participation of each SU in the CRN functions (The simulation of multi-user CRN is shown in Figure 3). As the participation of SUs improves, it is possible to allocate more white spaces to the SUs. Hence, spectrum allocation and spectrum utilization improve using CTG for the CRN.

### *3.3. Phase III*

Spectrum Allocation (SA) is implemented on the USRP test bed in this phase. For this SA, a small coalition is formed. In this coalition, three SUs are considered, out of which one is worked as CH, and the other two are served as Coalition Members. The block diagram of SA on the USRP testbed is shown in Figure 2.

In SA, the CH senses the free spectrum, for this spectrum sensing, the S-band (2 GHz to 4 GHz) was considered. The P (f) of the received signal was measured and compared with the predetermined $V_t$. The comparison result is either 1, indicating that PU is absent (i.e. $H_0$)* or 0, indicating that PU is present (i.e. $H_1$).

This result decides whether to allocate the PU frequency to the SU or not. If the result is 1, the same frequency is applied to the $SU_1$.

[* for the simplicity of the Labview code, we have reversed the notation of $H_0$ and $H_1$ results, actually $H_0$ = 0 and $H_1$ = 1.]

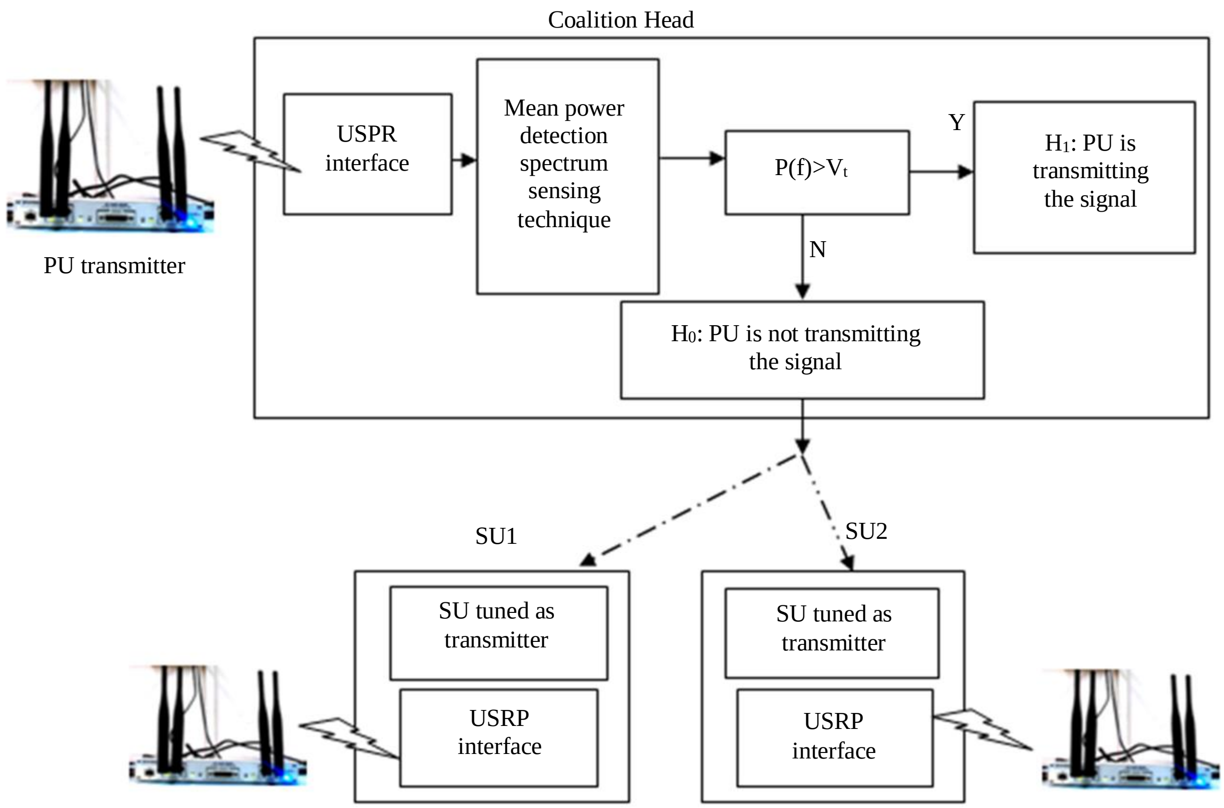


**Fig. 2 Coalition-based spectrum allocation on USRP testbed**

If $SU_2$ also needs the frequency, then PU frequency plus channel bandwidth (i.e. the nest free channel) can apply to the $SU_2$. In the implementation, USRP tuning and Labview coding are performed. The spectrum sensing and allocation phase is executed separately. SA for two devices performed successfully.

Implementing the full CRN with multiple PU and SU with the base station on USRP is challenging. Considering this, multi-user CRN with CGT is designed in MATLAB and analyzed its performance using the real-time received signals from the USRP testbed.

## 4. Coalition Game Theoretic-Based DSA for the Proposed CRN

The scenario of the proposed multi-user CRN is as follows:

1. PU operating frequency range: 2 GHz to 4 GHz.
2. PU/SU channel bandwidth: 130 MHz.
3. Local sensing: Power detection spectrum sensing.
4. Participation of SUs: High.
5. Spectrum allocation: CGT-based DSA with even and odd channel allocation schemes.

6. Metrics for allocation: demand by SU, region boundary, high $P_d$, low Probability of miss detection ($P_d$).
7. Back up channel: provided for each SU in advance.
8. SU transmission approach: Hybrid transmission approach.
9. Interference to the PUs: negligible.

The proposed multi CRN is shown in Figure 3. The Figure 3 shows the proposed CRN where three PUs and six SUs are considered. In experimentation, the $PU_1$, $PU_2$ and $PU_3$ transmit signals on frequencies of 2.5 GHz, 3.5 GHz and 2.2 GHz, respectively.

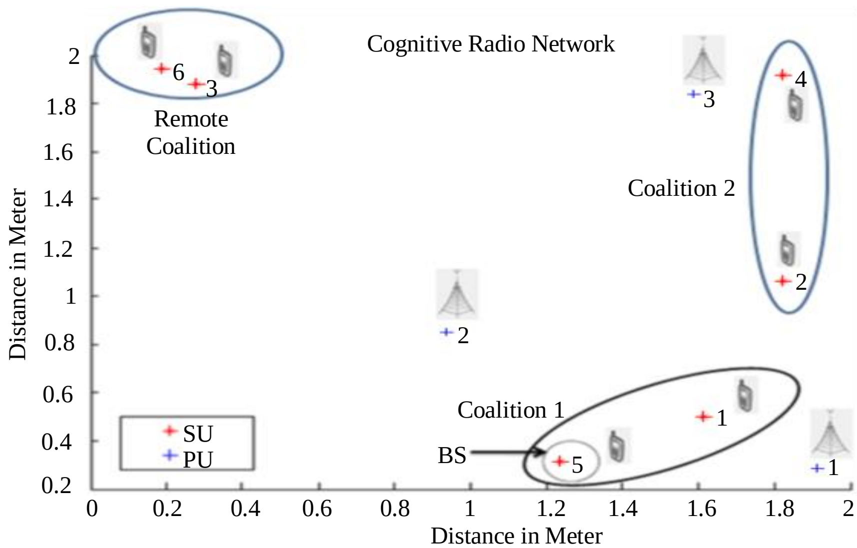


**Fig. 3 Adhoc multi user Cognitive Radio Network**

The circle at $SU_5$ indicates a BS. Three coalitions are formed using CF and CHS techniques. The third coalition is a remote collation, as the SUs in this coalition are out of the boundary region of all the PUs. The coalitions are as follows,

$C_1 = \{5, 1\}$, $C_2 = \{4, 2\}$, Remote $C_3 = \{6, 3\}$

Where C means coalition. All SU in the CRN performed the local spectrum sensing and report the result to the CHs. In this case, the CHs are {5, 4, 6}.

All CHs share the results and make Collaborative Decisions (CD) using the OR rule with the help of BS. The CD technique with its rules, actions and outcomes is given below:

Set of Rules for Collaborative Decision ($R_{CD}$):

$R_{CD1}$ : SUs can sense the PU signal if and only if the SU is in the Boundary region of any PU and reports its result to the CH.

$R_{CD2}$ : CH decision: Apply intra-coalition OR rule on each coalition member.

$R_{CD3}$ : BS decision: Apply inter-coalitions OR rule on CH decision.

Action Set for Collaborative Decision ($A_{CD}$):

$A_{CD1}$ : If (distance ($PU_j$, $SU_i$)≤) (region boundary of $PU_j$)
Then $SU_i$ can sense the $PU_j$ transmitted Signals
End

Where, i = 1 to number of SUs and j = number of PUs

$A_{CD2}$ : Collect the local sensing result of each coalition member and apply OR rule.

Local sensing Results of the SUs,

PUs ↓ SUs →

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \end{pmatrix}$$

Where 1 shows $H_1$ and 0 shows $H_0$. Zero in the first row indicates that $PU_1$is not transmitting the signal. i.e.: 1 in row 2, column 1 indicates $PU_2$ has sent the signal and $SU_1$ detected it correctly.

Intra-coalition OR rule for $C_1$ {5, 1}:

$$CH_{decision} = \begin{bmatrix} 0 & 0 \\ 1 & 1 \\ 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

Similarly, the OR rule is applied to each coalition.

$A_{CD3}$ : Then the OR rule is applied to the result of each inter-coalitions OR rule; this result gives the final collaborative BS Decision.

$$BS_{decision} = \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix}$$

Set of Outcomes for Collaborative Decision ($O_{CD}$):

$O_{CD1}$ : Due to the first rule condition ($R_{CD1}$), the $P_d$ of $PU_i$ Increases and the $P_m$ reduces. We have obtained the $P_d$ greater than 90% and $P_m$ less than 10% during experimentation.

$O_{CD2}$ : Due to the intra-coalition OR rule ($R_{CD2}$) the decision of each coalition can be reported to the CHs.

$O_{CD3}$ : Due to the inter-coalitions OR rule ($R_{CD1}$) the decision of each CH can be reported to the BS.

### *4.1. Advantages of OR Rule for CD*

1. In this collaborative decision, all CHs share individual results; hence, this CRN supports cooperative spectrum sensing.
2. The region boundaries of each PU and SU are considered for the spectrum sensing, so the accuracy of spectrum prediction increases.
3. The remote coalition OR rule result is zero, meaning this coalition does not know PU behaviour and $P_d$ of this coalition members is 0%. The BS provides the BS collaborative decision to the remote coalition; the remote coalition can also obtain information about the PU behaviour and demand the spectrum holes, which improves spectrum utilization efficiency.

After this CD, the BS understands the behavior of the PU transmission and operating frequencies. BS also has information regarding channel bandwidth and the total number of channels in the band; with this information, BS measures the unused channels/frequencies and allocates them to the SUs.

For the SA, a Coalition Game Theoretic DSA technique is used for the proposed multi-user CRN [16]. It is explained below:

Set of Rules for DSA (RDSA):

$R_{DSA1}$ : BS finds free channels.

$R_{DSA2}$ : Check the white spaces demand from CMs/SUs.

$R_{DSA3}$ : Consider a coalition member (SU). If it needs free spectrum, then allocate the odd unused frequency channel to that SU as the primary channel for communication.

$R_{DSA4}$ : Allocate the unused frequency channel to the same SU as a backup channel. Repeat the 3rd and 4th steps for all coalition members.

$R_{DSA5}$ : After allocation, the SU starts the transmission. The transmission power should be below the maximum allowed transmission for the SUs.

$R_{DSA6}$ : Find spectrum utilization efficiency (η).

Action Set of Players (ADSA):

$A_{DSA1}$ : $Free_{Chs}$ = ( total number of CHs - used CHs by PUs) where CHs = channels.

$A_{DSA2}$ : $SU_{demand}$ = rand(1, number of SUs)

$A_{DSA3}$ : $SU_j$ = coalition(i); $Free_{Chs, allocated} = 1$.

If $SU_{demand}$ ($SU_j$) = = 1

1. Main Channel: assign an odd number $Free_{Chs}$ to the $SU_j$,
2. Backup Channel: assign an even number $Free_{Chs}$ to the $SU_j$.
3. $Free_{Chs, allocated} = Free_{Chs, allocated} + 2$ ;

End

Where, i = 1 to number of coalitions,
j = 1 to number of SUs.

The SA for the $C_1$ is shown in Figure 4. The odd channel is the communication's main channel (M), and the even channel is the backup channel (B) for the SUs.

$A_{DSA4}$ : $SU_{pt} < PU_{pt}$

Where, $SU_{pt}$ = SU transmission power,
$PU_{pt}$ = mean $(P(f)_i)$, i = 1 to number of PUs

$A_{DSA5}$ : $\eta = (Free_{Chs, allocated} / \text{total no. of } Free_{Chs} * 100)$

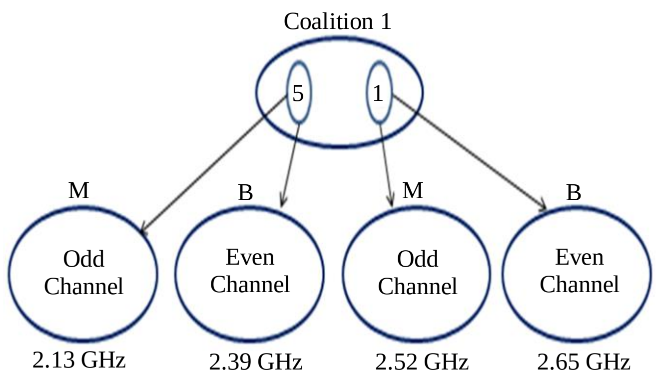


**Fig. 4 Free channel allocation to the SUs**

Set of Outcomes (ODSA):

$O_{DSA1}$: Obtained total unused frequencies in the given frequency band (i.e. S-band)

$O_{DSA2}$: BS understands the SUs demand.

$O_{DSA3}$: An SU can obtain the main channel and backup channel. If PU needs the channel back, SU can shift to the backup channel. The backup channel is available in advance; this strategy of spectrum mobility is called the Hybrid handoff strategy.

$O_{DSA4}$: Each SU transmission power is different, and below the PU transmission power so that the interference caused by SU to the PU, the intra-coalition and the inter-coalitions interference is negligible.

$O_{DSA5}$: Due to the high degree of SU's participation, central channel and backup channel allocation, the overall spectrum utilization efficiency increases.

### *4.2. Advantages of Coalition Game Theoretic DSA Technique*

1. Spectrum utilization improves.
2. Low interference communication within the CRN environment.
3. Backup channel is available for each SU.
4. Hybrid transmission approach: Opportunistic spectrum sensing and spectrum allocation with SU transmission power below the PU transmission power are proposed in this technique. It is a combination of overlay and underlay transmission approach that gives negligible interference between PU and SU.

The results of DSA for the proposed CRN are given in section 5.

## 5. Result

### *5.1. Phase I: Mean Power Detection Spectrum Sensing*

In phase I, the mean power detection spectrum sensing was implemented on the USRP testbed. Figure 5(a) and 5(b) show the spectrum sensing result for CH. Figure 5(a) shows $H_1$, i.e. PU is present. Whereas Figure 5(b) shows $H_0$ i.e. PU is absent.

### *5.2. Phase II: Modified CF and CHS Technique*

In phase II, the real-time spectrum sensing results were applied to the proposed CRN and improved the participation of SUs in the game using CF and CHS techniques. Figure 6 shows each SU's graph of and participation in the CRN.

The $P_d$ of $SU_1$ and $SU_5$ is 66.6% because it comes in the range of $PU_1$ and $PU_2$. The $P_d$ of $SU_2$ is 100% because it comes in the range of all PUs, and the $P_d$ for $SU_3$ and $SU_6$ is 0% because they have formed a remote coalition. The short height bars in the graph show each SU's participation in spectrum allocation.

Though the $SU_3$ and $SU_6$ $P_d$ are 0 %, improving their participation in the spectrum allocation is possible by providing white space information to them. CH does this task. This improves the spectrum utilization efficiency.

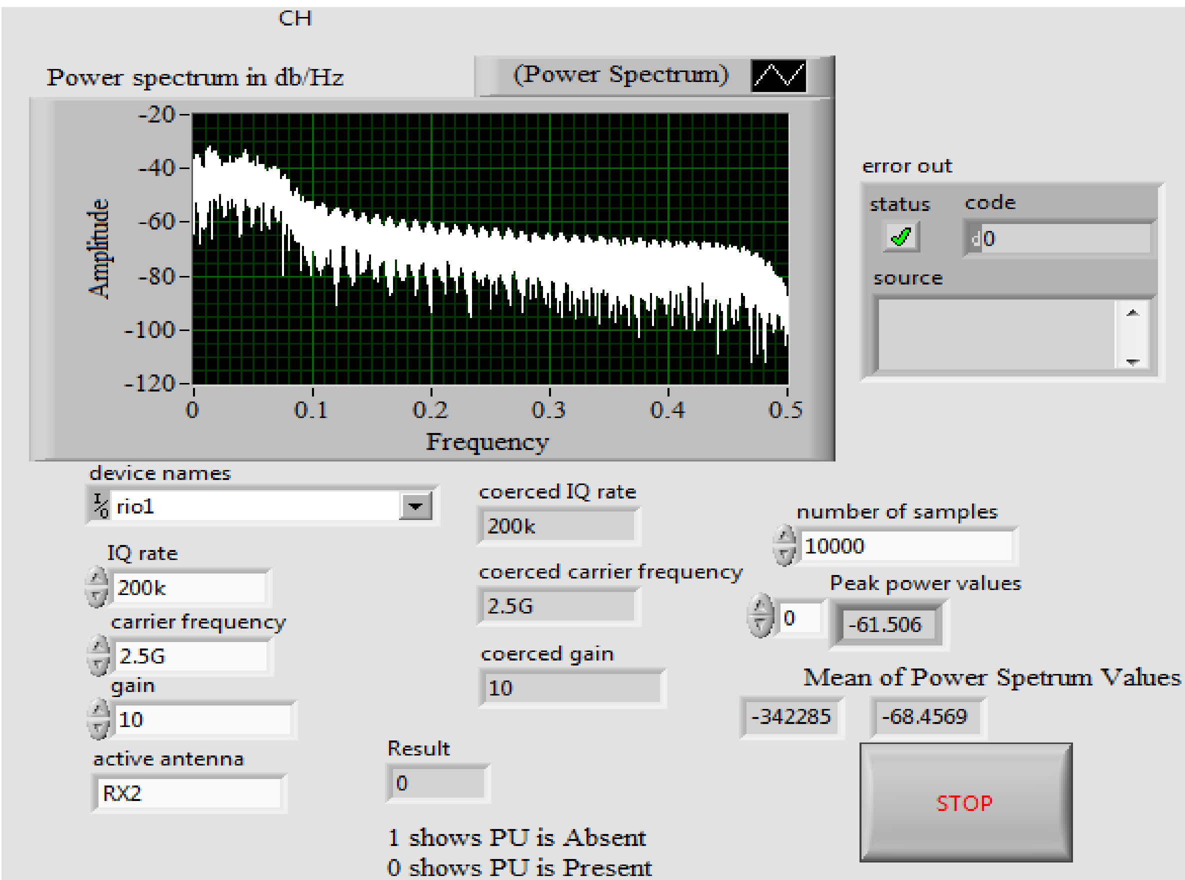


**Fig. 5(a) Coalition head spectrum sensing result-PU is present**

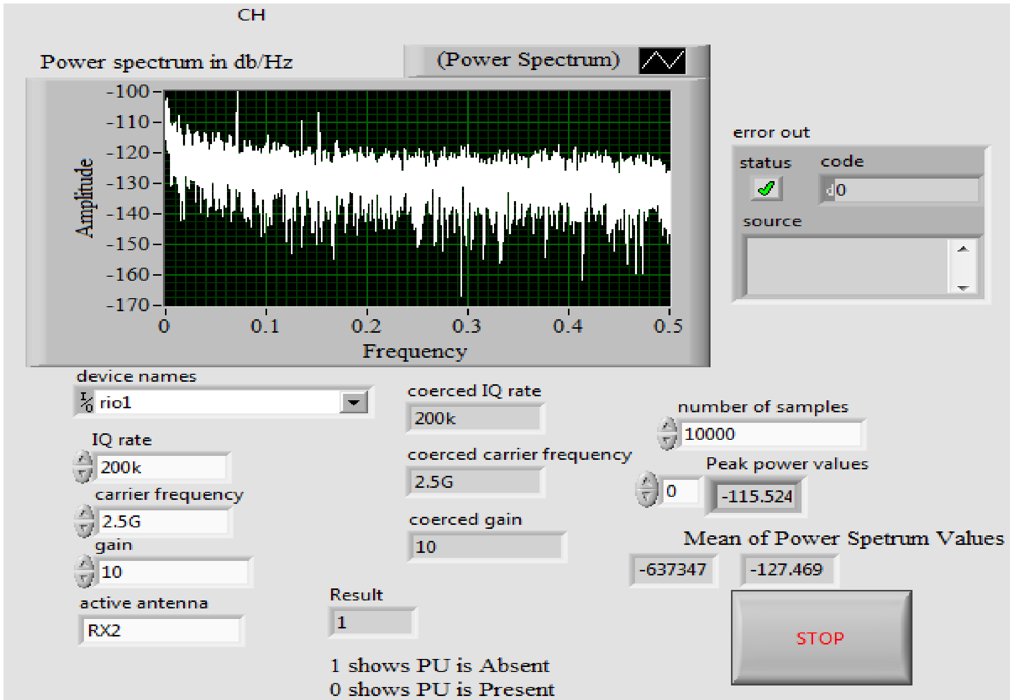


**Fig. 5(b) Coalition head spectrum sensing result-PU is absent**

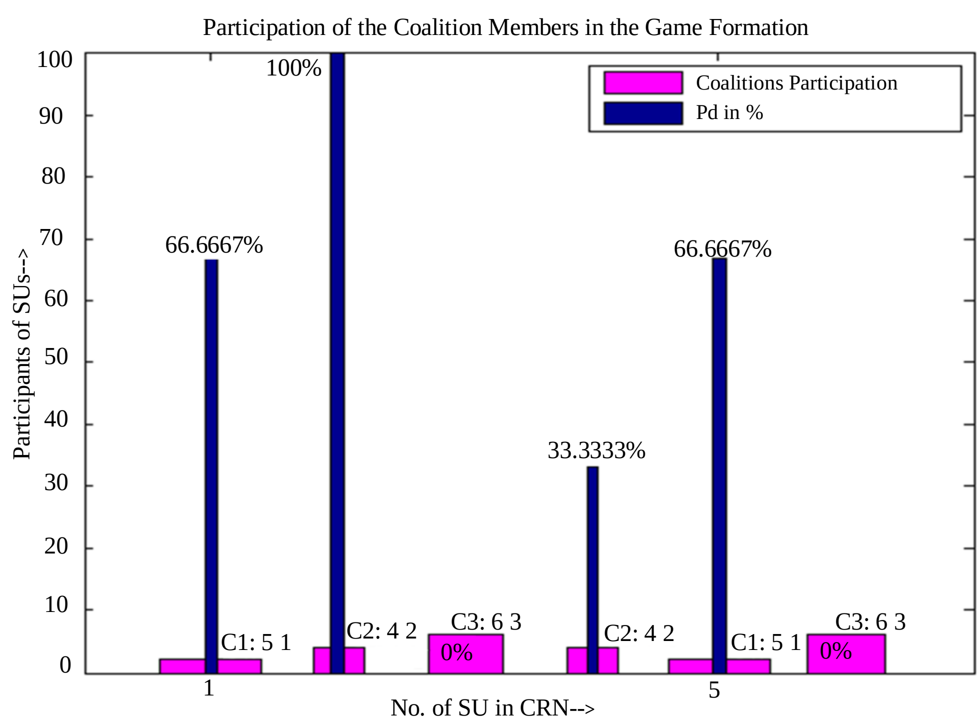


**Fig. 6 $P_d$ and participation of each SU in CRN functions**

### *5.3. Phase III Spectrum Allocation*

The CH performs the real-time SA on the USRP testbed in this phase. When the CH detects that PU is not transmitting the signal, it allocates the free channel to the SUs. The SA result is shown in Figure 7. On the carrier frequency 2.5 GHz, the PU was not transmitting, so the same frequency was allocated to the $SU_1$. The $SU_1$ was tuned as a transmitter with QPSK modulation.

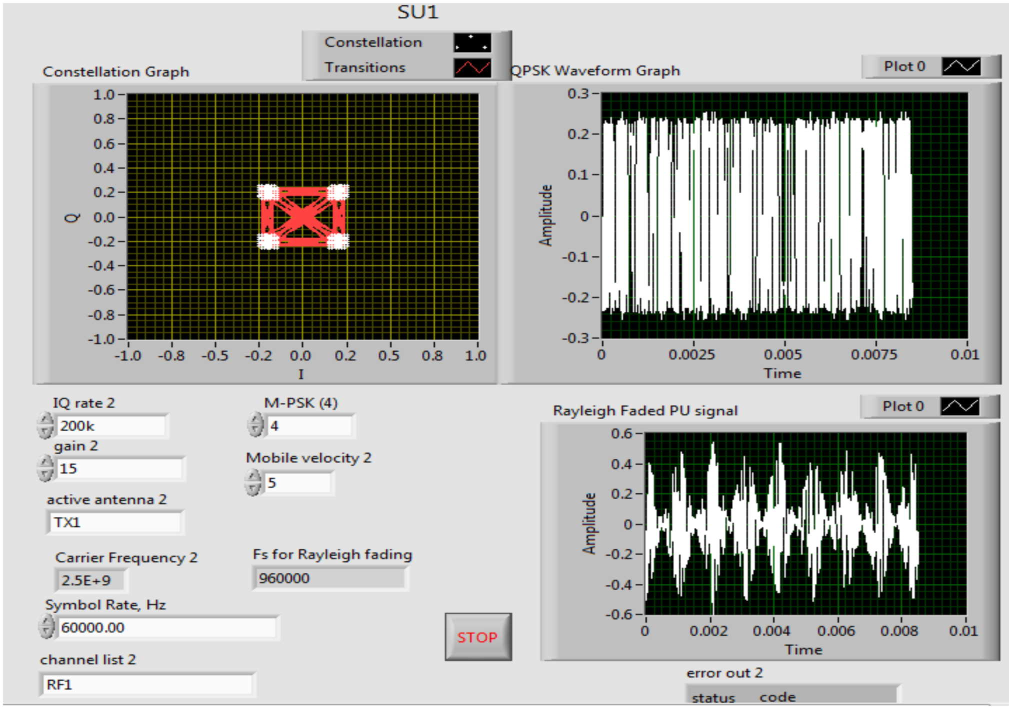


**Fig. 7 Spectrum allocation result (free spectrum allocated to SU)**

### *5.4. Phase IV: CGT-DSA Technique*

The real-time spectrum sensing results were applied to the proposed multi-user adhoc CRN in this phase. They improved the spectrum allocation efficiency using the Coalition Game Theoretic-based DSA technique. This technique supports the cooperation among SUs and supports the collaborative decision about the presence or absence of PU signal and performed the DSA with negligible interference. Figure 8 shows the DSA result for the CRN shown in Figure 3.

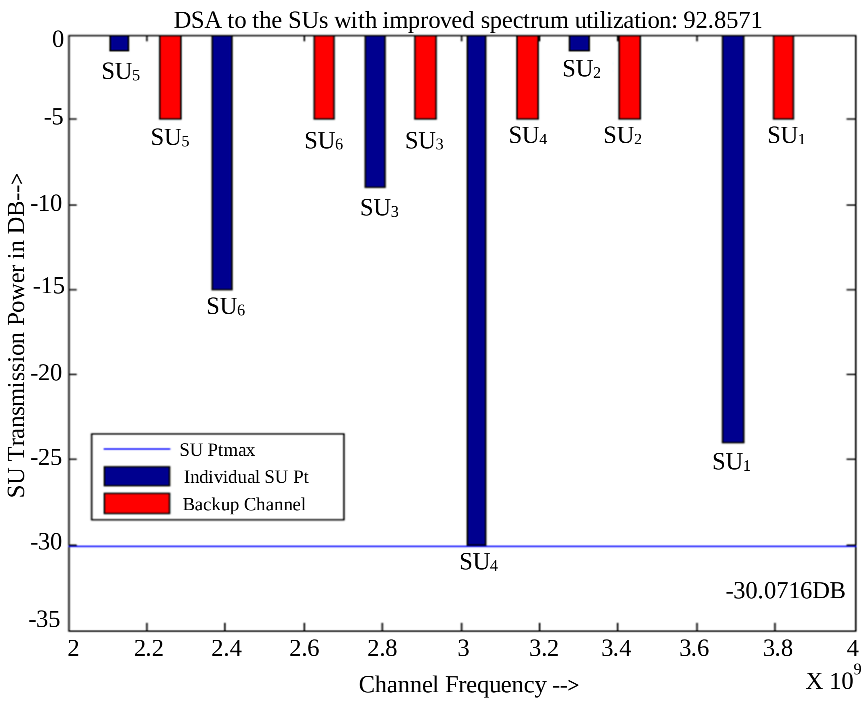


**Fig. 8 Dynamic Spectrum Allocation using Coalition Game Theory**

The graph shows that the two channels are allocated to a needed SU: the primary and backup channels. Each SU transmission power is different and below the maximum allowed transmission power (i.e. SU Ptmax = -30.07dbm). In the considered band were 14 channels present, out of which the $PU_1$ and $PU_2$ were transmitting on two channels. The rest of the 12 channels were possible to allocate to the SUs by using the DSA technique.

Hence, this CGT-DSA technique supports the hybrid transmission approach. Before DSA, the utilization of the S-band was 12.5% as $PU_1$ and $PU_2$ were using the channel; after free spectrum allocation, the spectrum utilization improved up to 92.85 %.

The comparison of the proposed DSA technique with previous work is discussed in Table 1.

**Table 1. Comparison of the proposed DSA technique with the previous work**

| Previous Work | Proposed DSA Technique |
|---|---|
| In [7], the BPSO algorithm was implemented for channel allocation, where each SU keeps the information about channel availability that increases the memory need. Here, the SU interaction was not done correctly. | In our technique, we have used BS to keep track of channel availability, so the memory of SU is saved. We have used the collaborative OR rule to interact with SUs. |
| In [15], a gradient projection algorithm is used for allocation, where the authors have not considered the backup channel and cooperation among SUs. | We have used the CGT-based DSA, where we have used backup channels, so SU transmission would not be affected in case of a handoff. Due to the CGT, achieving cooperation among SUs and improving the η is possible. |
| In [8, 10, 11], the spectrum allocation was done, but the real-time scenarios were not considered, and interference and SU behaviour were not studied much. | We have studied the behaviour of PU and SU well with region boundary limitations and proposed a DSA technique with a practical implementation approach so the results are more realistic. |

## 6. Conclusion

This paper proposes a multi-user Cognitive Radio Network with Coalition Game Theoretic approach. The spectrum sensing and allocation are implemented on the USRP testbed to obtain real-time results. In phase IV of the implementation, an analysis of the Dynamic Spectrum Allocation technique based on the Coalition Game Theory is performed. It supports the cooperation among SUs, takes collaborative spectrum sensing decisions, improves participation, and causes negligible interference to Primary Users. The results of the Dynamic Spectrum Allocation technique are tested for various scenarios of the proposed multi-user Cognitive Radio Network each time improvement in the spectrum utilization efficiency is recorded.

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