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Energy Efficient Resource Allocation in Cognitive Radio using LabVIEW

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***Abstract*—Resource allocation is used for complete utilization of frequency spectrum in cognitive radio networks. To maximize energy-efficiency is current research problem because of the many practical limitations such as transmission power, interference threshold of primary users and traffic demands of secondary users. Orthogonal frequency division multiplexing is an efficient technique used for achieving downlink resource allocation in communication systems. Margin adaptive approach is used to minimize amount of transmit power whereas rate adaptive approach is used to maximize data rate, it will give energy efficiency of system. For resource allocation process, subcarrier and power allocation is done sequentially to reduce the complexity of system with single user as well as multi-user. The communication setup includes two host computers, communicating through two USRP boards over the range of 400 MHz to 4.4 GHz with software tool of LabVIEW. By evaluating the performance of single user and multi-user greedy algorithm, it has been found that energy efficiency for single user is nearly 185bits/Joule whereas for multiuser has 150bits/Joule using 20dB minimum power gain as the date rate is distributed. The result of resource allocation gives complete utilization of spectrum bandwidth with minimum power along with maximum data rate .**

***Keywords—Cognitive radio networks, OFDM, energy efficiency, resource allocation*.**

I. Introduction

The increasing number of wireless users and services lead to a major increase in the demand for higher user data rates and network capacity in wireless networks. Most of the spectral resources which are available have already been licensed from regulatory spectrum allocation policy but some radio spectrum is unutilized. The spectrum utilization scheme has been introduce due to lack of radio spectrum and inefficiency of the spectrum usage, which recognized as resource allocation. The highly promising technique, cognitive radio (CR) allows the unlicensed secondary user (SU) to sense the environment of radio spectrum and access the spectrum by keeping the transmission parameters under the tolerable interference of licensed primary user (PU).

Resource allocation in cognitive radio is the concept of distribution of resources such as power, channel availability, frequency and so on. Spectrum resource allocation for cognitive radio networks (CRNs) presents many unique challenges in which the mutual interference between Primary Users (PUs) and Cognitive Radio (CR) users. Resource allocation must maximize the efficiency of the spectral resources utilization and minimize the risk of overlapping the coverage of CRNs with adjacent primary networks. Resource allocation is of two types, dynamic and adaptive resource allocation.

The energy efficient resource allocation in cognitive radio was developed in [1] using efficient barrier method to work out optimal solutions. In heterogeneous wireless networks with femtocells, issue of interference is consider between femtocells and macro cells [2] and energy efficiency aspect of spectrum sharing and resource allocation had explained in heterogeneous wireless networks with femtocells and cognitive radios. A low-complexity Max-Min algorithm has been proposed in [3] for allocating resources in an OFDM-based CR system in Mat lab.

This paper is organized as follows. Section II shows the energy efficient resource allocation scheme in cognitive radio using OFDM technology. Section III includes the system design of resource allocation in cognitive radio networks. Section IV gives detail analysis of results of single and multiuser greedy algorithm use for resource allocation. Further sections conclude the paper and provide future scope for enhancement of the system.

II. ENERGY EFFICIENT RESOURCE ALLOCATION

For energy efficient resource allocation, an efficient algorithm is developed by jointly considering the transmission power budget of the CR system and the interference constraints of the PUs, which achieves a good tradeoff between capacity performance and complexity. The resource allocation schemes can be classified into two categories: margin-adaptive (MA) and rate-adaptive (RA). Margin adaptive allocation schemes is formulated by minimizing the total transmit power while providing each user with its required quality of service in terms of data rate and BER. The rate adaptive objective is to maximize the total data rate of the system with the constraint on the total transmit power. OFDM technology is used in resource allocation.

A. OFDM System

Orthogonal frequency division multiplexing (OFDM) is a promising technique for implementation of resource allocation which provides high performance of physical layer. In OFDM, available bandwidth is divided into N orthogonal sub channels. Multicarrier transmission is done in OFDM system. The high rate data stream is then split into N sub streams of lower data rate which are modulated into N OFDM symbols and transmitted on N orthogonal subcarriers simultaneously. OFDM provides spectral efficiency, which is most required for CR system. This is because the subcarriers are overlapping and are very closely spaced, with zero interference. Figure 1 shows block diagram of OFDM system which includes transmitter and receiver. Advantage of OFDM is that it is very flexible and adaptive. OFDM can be easily implemented using the Fast Fourier Transform (FFT), which can be done by digital signal processing using software.

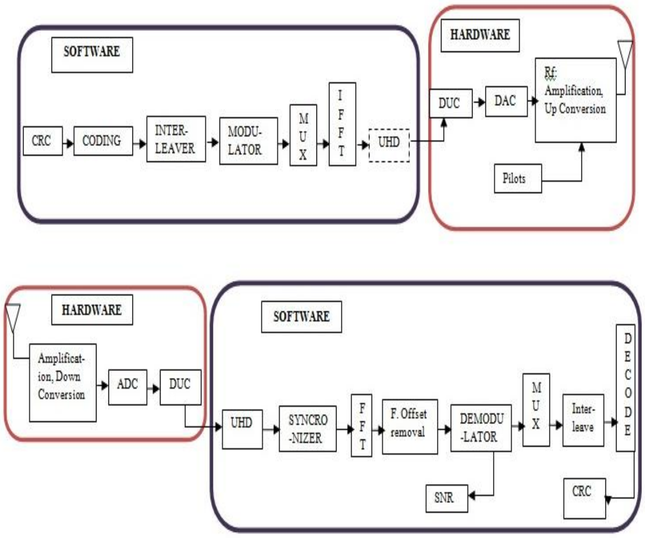

Figure 1: Block diagram of OFDM system

B. *Spectrum sensing*

Spectrum sensing is done using energy detection method, in which it scans various frequencies with different channel. Calculate its power spectral density of 1000 1iterations and take summation of magnitude of first 1000 iterations and compare with the threshold (noise floor). Threshold is calculated by receiving signal value in absence of primary transmitter. If the signal is greater than threshold then channel is considered as busy. If signal is less then threshold than channel is free. So following are the results of scanning the channel one by one.

C. *Energy Efficient Greedy Algorithm*

Greedy algorithm is user for single user and multiple user cognitive radio system which reduces the complexity of system. There are two stages of resource allocation greedy algorithm as shown in figure 2. In the first stage, the number of subcarriers to be allocated to each user is first determined before the actual subcarrier assignments are chosen, whereas the second one is concerned with subsequent power allocation. For subcarrier allocation, modulation bit rate should be calculated for different modulation scheme like BPSK, QPSK, 8PSK and16 QAM and 64QAM. The signal to noise ratio is calculated using noise density and bandwidth. The transmitter and receiver should know the channel state information between the channels. In power allocation, power is calculated for the same subcarrier. Then energy efficiency is calculated by taking the ratio of maximum rate to transmitted power.

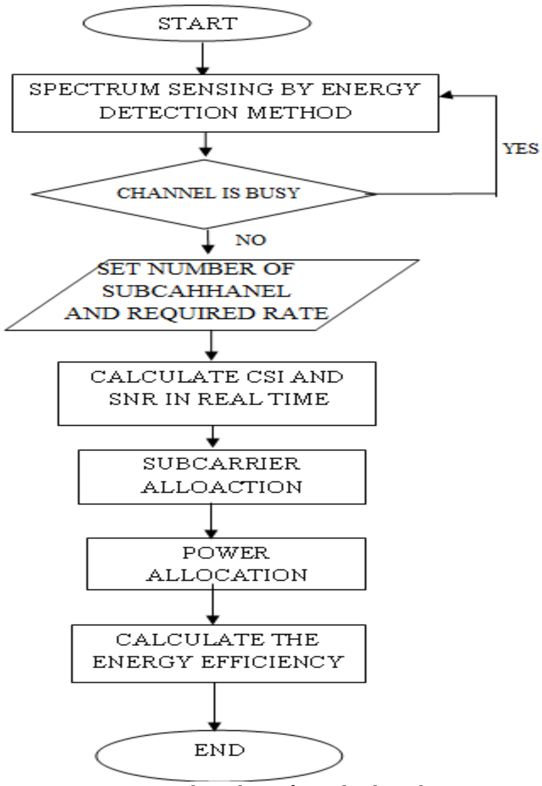

Figure 2: Flow chart of greedy algorithm

III. System Design

Consider the OFDM-based cognitive radio system with K SUs, denoted by K= {1, 2, ... , K}, along with the existing of L PUs in a licensed system. The spectrum registered by the PUs are allowed to access the radio by SUs. The whole available bandwidth W is divided into N sub channels in the cognitive radio system, denoted by N ={1,2,...,N}.The bandwidth of the n^{th} sub channel spans from $f_0+(n-1)B$ to f_0+nB, where f_0 is the starting frequency and B=W/N. Throughout this paper, we assume that CR system has the perfect knowledge of the channel state information (CSI) between the transmitter of the active PUs and the receivers of the SUs, as well as perfect CSI between the transmitter of SU and the receivers of the SU. The CSI can be predicted in practical environment by using the statistical information of channel gains. We consider instantaneous energy efficiency with perfect CSI in this paper. Therefore the results obtained by our proposed system includes achievable EE with errors in channel estimation. The interference introduced to PU's is having tolerable range to disallow the unacceptable performance degradation of the PUs.NI USRP-2922 board used as hardware and LabVIEW 2012 version software tool is used for implementation of resource allocation scheme.

Consider general OFDM system[1] having l^{th} PU's nominal band ranges from f_l to $f_l + B_l$, where f_l and B_l are the l^{th} PU's starting frequency and bandwidth respectively, the interference generated by the l^{th} PU into the nth sub channel used by the k^{th} SU is

$$I^{PS}_{k,n,l} = \int_{fl-fo-(n-1/2)B}^{fl+Bl-fo-(n-1/2)B} g^{P,S}_{k,n,l}\, \phi_l(f) \qquad (1)$$

where $\varphi_l(f)$ is the PSD of the l^{th} PU's signal and $g^{P,S}_{k,n,l}$ is the power gain from the l^{th} PU's transmitter to the receiver of the k^{th} SU over the n^{th} sub channel [1].

Let $r_{k,n}$ denote the rate of transmission of the n[th] sub channel used by the k[th] SU, we have

$$r_{k.n} = \log\left(1+\frac{p_{k,n}|h_{k,n}|^2}{\tau(N_0B+\sum_{l=1}^{L} I_{k,n,l}^{P,S})}\right) \qquad (2)$$

where $p_{k,n}$ is the power allocated to the n[th] sub channel used by the k[th] SU and $h_{k,n}$ is the channel gain from the transmitter to the k[th] SU's receiver over the n[th] sub channel. N_0 is the PSD of additive white Gaussian noise which is equal to 10^{-11} W and τ is the SNR gap. For an uncoded MQAM, τ is related to a given bit-error-rate (BER) requirement with τ = −ln (5BER)/1.5 derived in [13]. The interference caused by the PUs' signals on the n[th] sub channel used by the k[th] SU can be calculated by $I_{k,n,l}^{P,S}$ using (2), or regarded as noise and measured by the receiver of the k[th] SU .

The signal-to-noise ratio (SNR) of the n[th] sub channel used by the k[th] SU with unit power is given by,

$$H_{k,n} = \frac{|h_{k,n}|^2}{\tau(N_0B+\sum_{l=1}^{L} I_{k,n,l}^{P,S})} \qquad (3)$$

The data rate of the k[th] SU is

$$R_k = \sum_{n=1}^{N} \rho_{k,n} \log\left(1+p_{k,n}H_{k,n}\right) \qquad (4)$$

where $\rho_{k,n}$ can either be 1 or 0 informing whether the n[th] sub channel is occupied by the k[th] SU or not. The signal to noise ratio is calculated in real time using equation (3)[1]. The transmission power of the k[th] SU is

$$P_k = \sum_{n=1}^{N} \rho_{k,n}\, p_{k,n} \qquad (5)$$

Besides the transmission power, the energy consumption includes circuit energy consumption in the active mode of transmitter, incurred by signal processing, active circuit blocks, etc.[1] Without loss of generality, the associated circuit energy consumption is generally modeled as a constant P_c.

Adequate energy efficiency is defined as the system throughput for unit-energy consumption. Both the transmission power and the circuit energy consumption should be taken into consideration for energy-efficient communication. Thus, the EE in bits/Joule of the CR system[1] is given by

$$\eta_{EE} = \frac{\sum_{k=1}^{K} R_k}{\sum_{k=1}^{K} P_k + P_c} \qquad (6)$$

we aim to maximize the downlink EE of the CR system under the transmission power budget. When the interference of SU is strictly less than PU threshold.

IV. SIMULATION RESULTS

A. *OFDM Transmitter*

OFDM transmitter VI is shown in Figure 3 which works on 500KHz sampling frequency and carrier frequency of 2.4GHz. Frequency is used between 2.4 to 3.4GHz. The USRP device address is set in LabVIEW code which seen in USRP utility. Figure 3 shows the 4 QAM constellation diagram, interleaved output array and output bit stream. The size of symbols is 1600 and number of bits transmitted is 1250

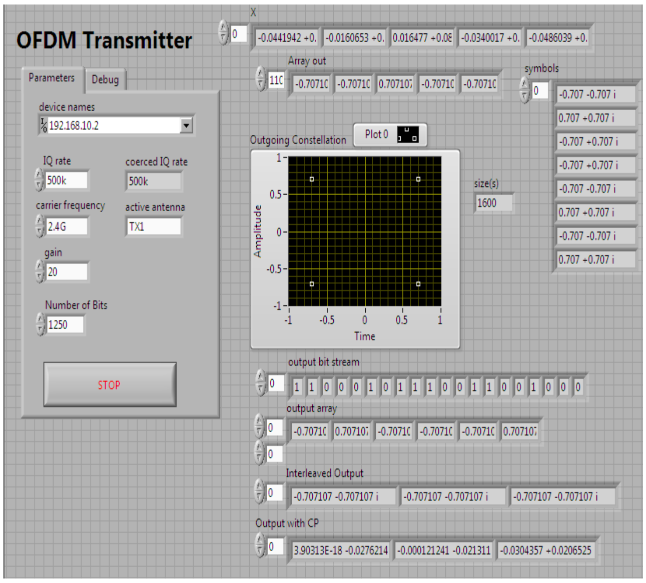

Figure 3: Block diagram of OFDM transmitter VI

B. *Single User Resource Allocation*

The single secondary user system scenario is shown in figure 4 having two USRP boards with one antenna each. NI USRP-2922 is used for communication setup. Here, implemented system includes one antenna at transmitter side and other antenna works as transceiver. The USRP boards are connected to host PC's using Ethernet cable. There are four sub channel as there are four frequency scanned.

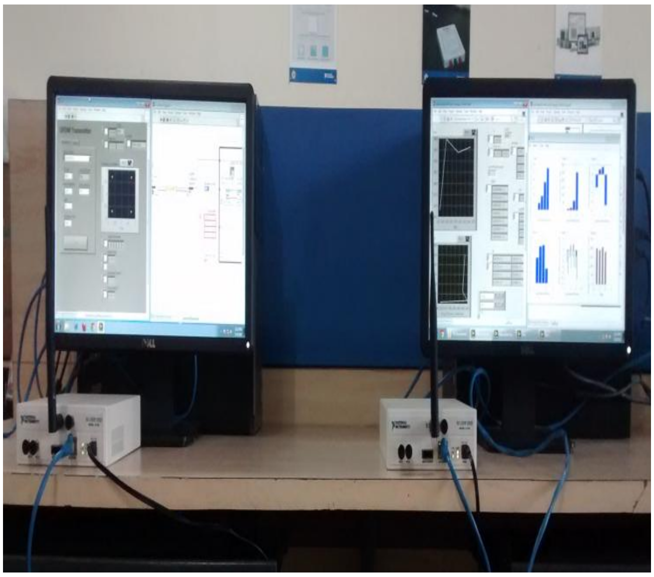

Figure 4: Single user system scenario

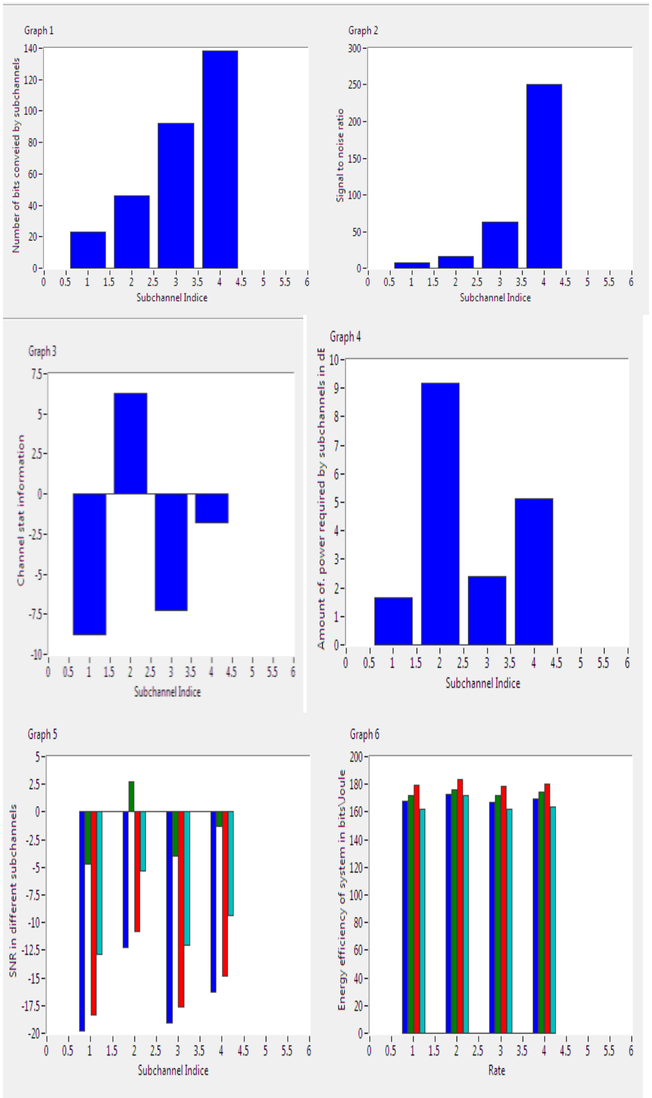

Figure 5: Graphs of Single User System (Greedy algorithm)

Results of single user greedy algorithm are shown in figure 5. First graph shows the sub channel indices (number of sub channel) Vs numbers of bits allotted to the sub channel according to different modulation schemes. In real time, there are 4 sub channel are found. The second graph shows signal to noise ratio at that same number of sub channel in dB which indicates that increasing values of SNR. The third graph shows the channel state information which indicates the noise between transmitter and receiver for four sub channel. The channel state information of every channel changes in every iteration. The fourth graph shows amount of power allotted to the same sub channel in dB. The fifth graphs shows signal to noise ratio at different sub channel other than these four sub channel so there values are negative. Finally sixth graph of figure 5 indicates the energy efficiency of system in bits\joule Vs the data rate for sub channel. The different color shows different modulation scheme like BPSK, QPSK, 8PSK and16 QAM and 64QAM on 4 sub channel . The EE of system got nearly 185bits\Joule by transmitting minimum power to get maximum rate.

C. Multi-User Resource Allocation

Multiple Users system includes one transmitter and two transceiver (SIMO system). Two USRP transceiver are connected through MIMO cable as shown in figure 6. All frequencies are scan by all SU simultaneously and if it is idle then same frequency used by two users so there are two number of sub channel.

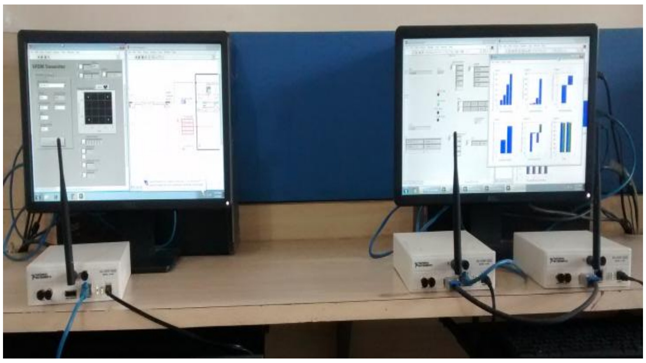
Figure 6: Multiple user system scenario

Figure 7 indicates multiple user greedy algorithm results, in first graph, the sub channel indices (number of sub channel) Vs numbers of bits allotted to the sub channel according to different modulation schemes. For multiuser system,the setup founds 2 sub channel. The second graph shows signal to noise ratio at that same number of sub channel in dB which indicates that increasing values of SNR. The third graph shows the channel state information which indicates the noise between transmitter and receiver for two sub channel. The fourth graph shows amount of power allotted to the same sub channel in dB. The fifth graph shows signal to noise ratio at different sub channel other than these two sub channel. Finally sixth graph of figure 7 indicates the energy efficiency of system in bits\joule Vs the data rate for sub channel. The different color shows different modulation scheme. The EE of system got nearly 150bits\Joule by transmitting minimum power to get maximum rate. The energy efficiency is decreases as the data rate is distributed among the number of SU.

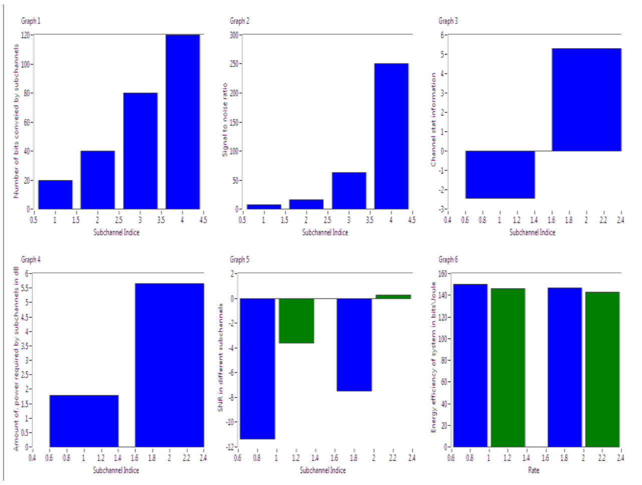
Figure 7: Graphs of Multiple Users System

V. CONCLUSION

In this paper, we developed the energy-efficient resource allocation for a single user and multiuser cognitive radio network in the presence of primary networks. The proposed algorithm maximizes the system data rate while maintaining the interference leakage to the primary users below a threshold, the data rate for each secondary user is above a required data rate and the total transmission power at the secondary cognitive network is below a power budget decided. In addition, several hardware limitations of CR users are considered in the proposed frame-work. Based on the performance evaluation results presented in this work, the proposed framework improves the utilization of spectrum. Resource allocation algorithm is formulated into mathematical framework using OFDM system with known channel state information. The communication setup is done between OFDM transmitter and receiver using hardware as USRP board with LabVIEW in host PC. Greedy algorithm is implemented in single and multiple users system for subcarrier and power allocation which results in resource allocation. It is observed that single user OFDM system has energy efficiency of 185bits/Joule. In multiuser system, as data rate is distributed, so energy efficiency is 150bits/Joule using minimum power which is less than single user system. Comparatively single user gave better results than multiple user system. Energy efficient system is achieved by reducing the transmitted power to maximum data rate which is required for green communication.

FUTURE SCOPE

The next step of work is to extend the algorithm for the case when imperfect knowledge of channel state information is available to the secondary network base station. The system is proposed for single primary and two secondary users due to limitations of hardware, but focus on designing the multi secondary users with more efficiency.

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