VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ACHIEVABLE DATA RATE FOR HYBRID MULTIBAND COGNITIVE RADIO NETWORKS WITH DIVERSITY RECEPTION

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ABSTRACT

Diversity techniques can be used in multiband cognitive radio networks to improve the achievable data rate of the receiver. Maximal Ratio Combining (MRC) technique is used in relay assisted network to provide better receiver performance. Power bidding and allocation algorithm together with diversity technique is used to improve the performance of a hybrid multiband cognitive radio network. The power is allocated to the secondary users (SUs) through an auction game conducted by the secondary relay (SR). The SUs compete for the transmit power of the relay. If the SU works in overlay mode, the relay allocates the power in proportion to its payment; for the SU works in spectrum underlay, the power is allocated in such a way that the quality of service (QoS) of the Primary User (PU) is maintained. After allocating optimum power to SUs diversity technique is implemented in receiver to enhance the achievable date rate.

Keywords: cognitive radio, auction game, power allocation, diversity reception, maximal ratio combining.

INTRODUCTION

With the rapid development in wireless communication services, scarcity of spectrum has become the bottle-neck of future wireless communication [1-3]. Therefore CR is introduced to utilize the spectrum efficiently. CR is an upcoming and promising technology to utilize the spectrum in an efficient manner. In a CR system, SUs senses the spectrum licensed by the PUs. The vacant spectrum holes in the spectrum are used by the SUs. In general there are three types of spectrum sharing approaches. (1) Spectrum overlay, in which the SU accesses a frequency band only when it is not used by the PU. (2) Spectrum underlay, where SU transmit along with the PU with power constraints to ensure the QoS of the PU. (3) Sensing based spectrum sharing, with which the SU first senses the status of PU and select an appropriate spectrum sharing mode based on the sensing result. If the PU is active, SU works in spectrum underlay and transmit with low power. Otherwise the SU works in spectrum overlay and transmit with maximum power budget. In such hybrid overlay/underlay scheme the throughput of the CR network is improved while maintaining a harmless interference to the PU [4].

A power bidding and allocation algorithm was proposed in [5], where the multiple SUs transmit with different power requirement according to its mode of operation. The SUs transmit with the help of a common relay and compete for the transmit power. Power bidding and allocation algorithm is used to allocate optimum power for the SUs. The SR organizes an auction for selling it's transmit power, whereas the SU acts as the player and bids for a maximum utility.

The next generation wireless systems are required to have high voice quality and high bit rate data services as compared to current wireless system. In other words, the next generation systems are supposed to have better quality, coverage and must be bandwidth efficient. Also the system must be reliable in different types of environment. When the signal is transmitted, different signal copies undergo different attenuation, distortion, delays and phase shifts and also the wireless communication channel suffers from much impairment such as (i) Thermal noise often modeled as Additive White Gaussian Noise (AWGN) (ii) The path loss in power as the radio signal propagates (iii) The shadowing due to the presence of fixed obstacles in the radio path (iv) The fading which combines the effect of multiple propagation paths. If these impairments are not overcome, the performance of the system is slowly degraded and hence the efficiency. The major problem in all these which makes reliable wireless transmission difficult is multipath fading. The fading can be avoided by introducing diversity technique at the receiver. In this paper we are applying the maximal ratio combining technique at the receiver to improve the achievable data rate of SU. MRC is applied at the receiver after allocating optimum power to the SUs.

The rest of this paper is organized as follows. In section II, system model is described. Section III gives details of diversity technique applied. Simulation results are presented in Section IV. Section V concludes the findings of the paper.

SYSTEM MODEL

Consider a CR system consisting of a primary network, which is divided into M no overlapping narrowband channels and the secondary network is composed of N $(N<M)$ secondary links. The primary network has a primary transmitter (PT) and a primary destination (PD). The secondary network has N STs, N secondary destinations (SDs), and a secondary relay (SR). The SR assists the transmission by decode and forward (DF) protocol. We had made the assumption that each channel of the primary network can be accessed by only one ST. The structure of the CR frame is shown in Figure-1. It consists of three slots namely sensing, auction and data transmission slot. In sensing slot the spectrum is sensed and channel is allocated. In the auction slot, the SR conducts an auction mechanism to sell its power. The STs

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

acts as players and bids for maximum utility. In the data transmission slot, STs began to transmit data with optimum power. The network model for both overlay mode and underlay mode is shown in Figure-2. In overlay mode PU is not transmitting any data. The ST transmits to SD through direct path and relay path, which is shown in Figure-2(a). In underlay mode both PU and SU is transmitting simultaneously over the same spectrum, as shown in Figure-2(b). Here, the solid lines indicate the intended communications, whereas dotted line represents the interference.

In spectrum overlay, the achievable data rate is given by

$$R_i^{oo} = \frac{1}{2} W log_2(1 + \Gamma_i^{oo}(1) + \Gamma_i^{oo}(2)) \quad (1)$$

where W is the signal bandwidth, $\Gamma_i^{00}(1)$ and $\Gamma_i^{00}(2)$ are the signal to noise ratio (SNR) in direct path and relay path of the *i*th user respectively[6]. In spectrum underlay, the achievable data rate is given by

$$R_i^{oo} = \frac{1}{2} W log_2(1 + \gamma_i^{10}(1) + \gamma_i^{10}(2)) \quad (2)$$

where $\gamma_i^{10}(1)$ and $\gamma_i^{10}(2)$ are the SNR in direct path and relay path of the *i*th user respectively.

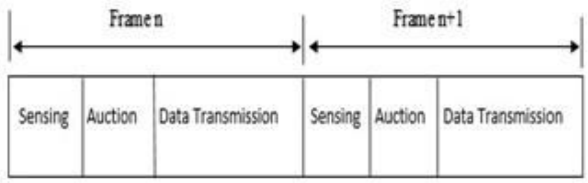

Figure-1. Structure of the CR frame.

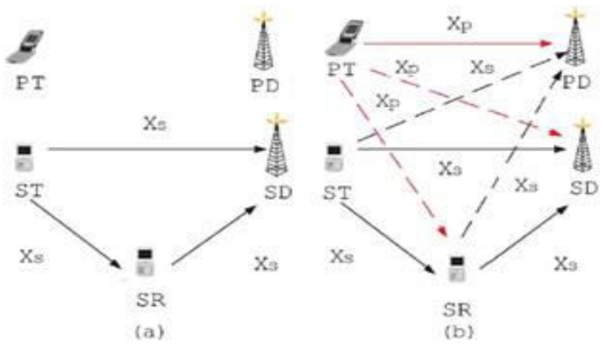

Figure-2. Network model for overlay and underlay.

The power bidding algorithm is given below. The SR decodes the signal transmitted by the STs. For the ST whose data are successfully decoded is allowed to participate in the current auction. If the signal of ST is not decoded correctly, the ST would not join in the current auction and can try in the next CR frame[7-8].

Algorithm: Power bidding and allocation algorithm [5]

Step 1. Request for cooperation
ST_i:sends a request to the relay for cooperation.
SR:responds the cooperation request of ST_i.
ST_i:transmits data in first phase.
SR:if the received signal is not decoded successfully, it informs ST_i of the failure; else it allows ST_i to participate in the auction and goes to step 2.
Step 2. Initialization
STi:initializes the required power $P_{r_i}(0)$ and original bid $f_i(0)$ and then submits these values to the relay.
Step 3. Power Allocation
SR:updates the allocated power $P_{r_i}(t + 1)$ and informthese values to each STs.
Step 4. Bid Update
STi:updates the bid value $f_i(t+1)$ and sends it back to the relay.
Step 5. Convergence
Repeat Step 3 and Step 4 untill the value of $f_i(t)$ no longer changes with additional iterations.

DIVERSITY TECHNIQUE

Diversity refers to transmitting and/or receiving the same information via different independent ways. In such a system, multiple copies of the same information signal are being transmitted to the receiver over two or more real or virtual communication channels. Thus the basic idea of diversity is repetition or redundancy of information. The diversity decisions are made by the receiver and are unknown to the transmitter. Thus, it provides wireless link improvement at a relatively low cost, power savings and increased system capacity. If diversity is not employed; the resulting efficiency would be very low [9]. Here we are applying maximal ratio combining (MRC) technique at the receiver, in which signal from each channel are added together. The MRC system for diversity reception is shown in Figure-3. The gain of each channel is made proportional to the rms signal level and inversely proportional to the mean square noise level in that channel. Different proportionality constants are used for each channel. MRC obtains the weights that maximizes the output SNR, i.e., it is optimal in terms of SNR [10].

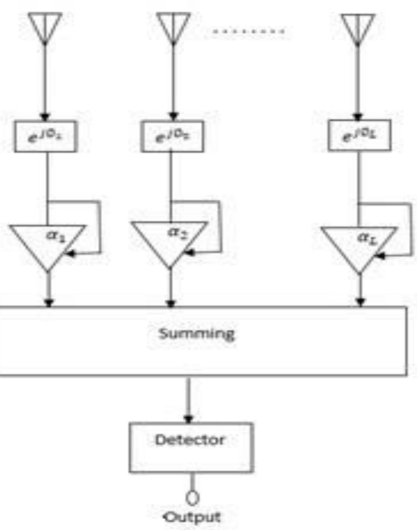

Figure-3. Maximal ratio combining system.

Writing the received signal at the array elements as a vector x(t), and the output signal as r(t)

$$x(t) = h(t)u(t) + n(t) \quad (3)$$

$$h = [h_0, h_1, \ldots, h_{L-1}]^T \quad (4)$$

$$n = [n_0, n_1, \ldots, n_{L-1}]^T \quad (5)$$

$$r(t) = \alpha^H x = \alpha^H h u(t) + \alpha^H n \quad (6)$$

where u(t) is the unit power signal transmitted, h represents the channel, n is the noise and x(t) is the received signal. The instantaneous output SNR is

$$\gamma = \frac{|\alpha^H h|^2}{E\{|\alpha^H n|^2\}} \quad (7)$$

Where α is the proportionality constant. The noise power in the denominator is given by

$$P_n = E\{|\alpha^H n|^2\} = \alpha^H E\{nn^H\}\alpha = \sigma^2 \alpha^H I_N \alpha = \sigma^2 \alpha^H \alpha = \sigma^2 \parallel \alpha \parallel^2 \quad (8)$$

where I_N represents an N×N identity matrix, σ^2 is the noise variance. Since constants do not matter, one could always scale α such that ‖ α ‖=1. The SNR is therefore given by $\gamma = \frac{|\alpha^H h|^2}{\sigma^2}$

By Cauchy-Schwarz inequality, this has a maximum when α is linearly proportional to h, i.e.,

$$\alpha = \mathbf{h} \quad (9)$$

$$\gamma = \frac{|h^H h|^2}{\sigma^2 h^H h} = \frac{h^H h}{\sigma^2} = \sum_{N=0}^{L-1} \frac{|h_n|^2}{\sigma^2} = \sum_{N=0}^{L-1} \gamma_n \quad (10)$$

where L is the total number of diversity branches. The output SNR is, therefore, the sum of the SNR of each element. In total the SNR improves by a factor of L.

SIMULATION RESULTS

Figure-4 shows the achievable data rates of the SU with different number of diversity branches. Here the graph is plotted between achievable data rate and average interference power at PD (Powerinter). The number of diversity branches used for simulation is L = 1, 3, 5 and 7. The peak transmit power of the ST, P_{max} = 20dBm and bit error probability, P_b=0.001. It is observed that the achievable data rate is improved when we increase the number of diversity branches.This is because the MRC technique applied at the receiver maximizes the Signal to noise ratio (SNR) of the received signal. The received signals are weighted with respect to their SNR and then summed. The resulting SNR yields $\sum_{L=1}^{N} SNR_L$, where SNR_L is the SNR of the received signal in the branch L. So as the number of diversity branches increases from 1 to 3, the achievable data rate will also increases due to increased SNR. This result is applicable for the cases L = 5 and L = 7.

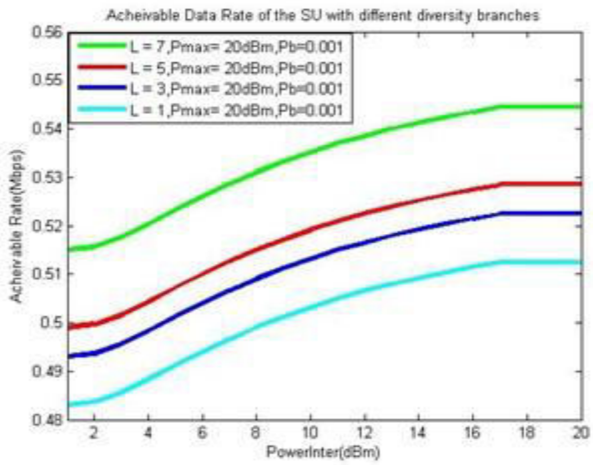

Figure-4. Achievable data rates of SU with different diversity branches.

Figure-5 represents the achievable data rate of the SU versus Primary power P_p under different BER requirements. For the simulation results we have taken four cases, First case corresponds to L = 3, P_{max} = 10dBm and P_b = 0.0001. For the remaining three cases the value of L and P_{max} remains the same and the value of P_b is taken as 0.001, 0.01, 0.1 respectively. It is clear that when the transmitting power of the PU increases, the SU has to reduce its transmit power for avoiding interference. So the achievable transmission rate of the SU decreases when we increase the transmit power of PU. The first case with P_b = 0.0001 has the highest data rate. For the remaining cases the data rate decreases when we increase the value of P_b.

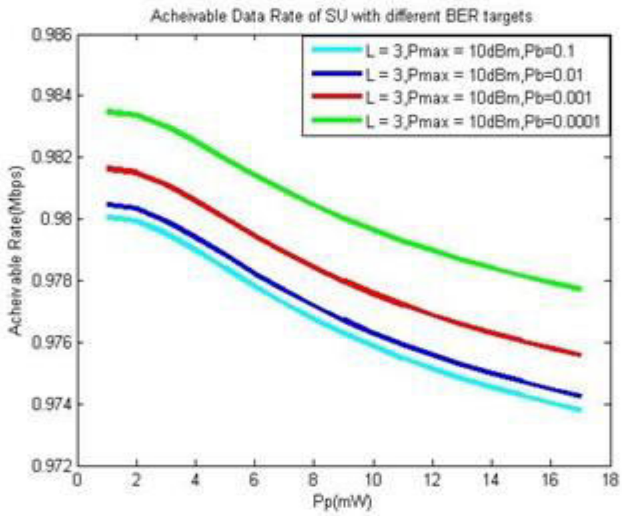

Figure-5. Achievable data rates of SU with different BER targets.

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CONCLUSIONS

In this paper, we have investigated the effect of diversity reception on the data rate of the secondary user in a hybrid multiband cognitive radio network. The power bidding and allocation algorithm is used together with diversity technique. Maximal ratio combining technique is used here for maximizing the diversity reception. In maximal ratio combining technique signals from different channels are added together to improve the SNR. As a result the achievable data rate is improved at the receiver. This work can be further improved by exploiting cognitive MIMO multiple access channel for multi-secondary users.

ACKNOWLEDGEMENTS

This work is supported by AICTE, Govt. of India through the project grant under Research promotion Scheme No.20/AICTE/RIFD/RPS (POLICY- 1)59/2013-14.

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