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Research Article

Rate Request Sequenced Bit Loading Secondary User Reallocation Algorithm for DMT Systems in Cognitive Radio

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A rate request sequenced bit loading reallocation algorithm is proposed. The spectral holes detected by spectrum sensing (SS) in cognitive radio (CR) are used by secondary users. This algorithm is applicable to Discrete Multitone (DMT) systems for secondary user reallocation. DMT systems support different modulation on different subchannels according to Signal-to-Noise Ratio (SNR). The maximum bits and power that can be allocated to each subband is determined depending on the channel state information (CSI) and secondary user modulation scheme. The spectral holes or free subbands are allocated to secondary users depending on the user rate request and subchannel capacity. A comparison is done between random rate request and sequenced rate request of secondary user for subchannel allocation. Through simulations it is observed that with sequenced rate request higher spectral efficiency is achieved with reduced complexity.

1. Introduction

Spectrum sensing is the central part of cognitive radio. The idea of cognitive radio is to allow secondary users (unlicensed) to utilize the spectra which are not occupied by primary users (licensed) [1]. A lot of research has been done to detect the spectral holes. The spectral efficiency is improved only when the detected spectral holes are reallocated to secondary users [2, 3]. Several allocation techniques have been proposed in literature for multiuser schemes. They are broadly classified as Margin Adaptive (MA) and Rate Adaptive (RA) [4]. In MA, the objective is to minimize overall transmit power given the constraint on user data rate and bit error rate (BER). The RA algorithm maximizes the user data rate with total transmit power constraint.

Multicarrier Modulation (MCM) is widely used in wireless communication as it offers high data rate, specifically in multimedia transmission. The transmission of data in MCM is done by splitting the data into different components and transmitting them over separate carrier signals. The common methods of MCM are Orthogonal Frequency Division Multiplexing (OFDM) and DMT. Both the methods divide the available bandwidth into orthogonal subchannels. The problem of Inter Symbol Interferences (ISI) due to multipath is also mitigated by these techniques. The advantage of DMT systems is that more bits can be assigned to subchannels with higher Signal-to-Noise Ratio (SNR). This improves the performance of the DMT systems as different bits and power are allocated to each subchannel depending on channel quality [5]. Different resource allocation strategies have been compared for OFDM in [6]. Also, for multiuser in OFDMA a fairness-aware resource allocation scheme that maximizes sum data rate using innovative priority scheduling is described in [7]. To reduce complexity suboptimal techniques can be used with adaptive algorithms [8].

The different resource allocation algorithms existing in literature are maximum rate solution for water pouring and flat energy power distribution by Leke and Cioffi [9], bit loading algorithms using Lagrange approach by Krongold et al. [10], Hughes-Hartogs algorithm [11], Chow's algorithm [12], and Fischer's algorithm [13]. If the data rate has to be maximized for a given transmit power, maximum rate loading algorithm becomes a better choice to determine the number of bits to be allocated to each subchannel. Some algorithms minimize the transmit power for a given data rate. DMT systems use maximum rate loading algorithm assigning more bits to a subchannel with highest SNR, unlike OFDM systems assigning same number of bits to each subchannel.

In this paper resource allocation for secondary users to occupy the spectral holes in cognitive radio is proposed. A DMT system was considered, for spectrum sensing and reallocation to secondary users. The total available bandwidth is divided into nonoverlapping subbands using filter banks and the spectral holes are determined using the conventional energy detection technique. The maximum number of bits that can be allocated to each subchannel is calculated using channel state information and the modulation scheme of secondary user. The main contribution of our paper is reallocation of free subchannels to secondary users with pooled and sequenced rate request algorithm. A comparison was done between random rate request and sequenced rate request algorithms for subchannel allocation with different modulation techniques. The paper is organized as follows: the system is described in Section 2; proposed method for subchannel allocation is explained in Section 3. Simulation and results are discussed in Section 4 followed by conclusion.

2. System Description

Multiband spectrum sensing techniques are used to sense the wideband spectrum to exploit spectral opportunities. In wideband spectrum sensing, the spectrum is divided into multiple narrow nonoverlapping subbands and sensed with filter bank techniques [14]. Matched filter, energy detection, and cyclostationarity based spectrum sensing are some of the common methods existing in literature [15]. Energy detection based methods are a common choice due to the simplicity in spectral detection. By computing the energy at the output of the individual subbands and comparing with a predetermined threshold the spectral holes can be detected [16]. Some work has been done on spectrum sensing using energy detection in different fading channels [17].

The signal to be sensed at the receiver is modeled as

$$y_k(n) = s_k(n) + v_k(n) \quad k = 0, 1, 2, \ldots, M-1, \tag{1}$$

where M is the total number of subbands in the filter bank, $s_k(n)$ the active signal, and $v_k(n)$ the additive white Gaussian noise with zero mean and variance σ_v^2. The energy is calculated at the output of each subband which is considered as test statistics for detection of active signal and is given as [16, 18–20]

$$Y_k = \frac{1}{L}\sum_{n=0}^{L-1} {y_k}^2(n), \tag{2}$$

where $L = N/M$ is the number of samples in each subband k. When the number of samples is increased, chi-square distribution approximates to a normal distribution from the central limit theorem. Then the binary hypothesis for energy detection with the Neyman Pearson test is given as [16, 21]

$y_k(n) \sim N(\sigma_v^2, (1/N)\sigma_v^4)$, for Hypothesis H_0;

$y_k(n) \sim N((\sigma_s^2+\sigma_v^2), (1/N)(\sigma_s^2+\sigma_v^2)^2)$, for Hypothesis H_1.

The presence of active signal in a specified subband is determined by comparing the energy in that subband with a predetermined threshold. The threshold is based on chi-square hypothesis test. The threshold λ is calculated with the knowledge of probability of false alarm P_{FA} and noise variance σ_v^2 of the received signal. Threshold value for M channel filter bank is calculated as [18]

$$\lambda = \left(Q^{-1}(P_{FA})\sqrt{\frac{1}{L}} + 1\right)\sigma_v^2. \tag{3}$$

The test statistics are compared with the predefined threshold and if the energy is below threshold the subband is detected as a free hole [20].

3. Proposed Method with Rate Request Sequenced Algorithm for Subchannel Allocation

Spectral efficiency is achieved only when the detected spectral holes are allocated to secondary users. In our paper we mainly focus on the spectrum reallocation algorithm. We propose a rate request sequenced algorithm considering the secondary user rate. The free subchannels are allocated to secondary users depending on the channel capacity and the user rate request. The bits to be allocated to each subchannel are determined based on channel quality and modulation scheme used by the secondary user. To increase the data rate of subchannel, the channel state information is considered and the subchannel with highest SNR is allocated to the secondary user with the highest data rate. The channel state information considers different fading channel conditions and additive white Gaussian noise in the channels.

The different multicarrier loading algorithms used for resource allocation are compared in [6]. Bit loading algorithm is suitable for Rate Adaptive DMT systems as optimal distribution of discrete bits is possible over different subcarriers [22]. They also adjust the number of bits per symbol in each subcarrier according to the channel conditions. The maximum number of bits that can be allocated in each subchannel is calculated with secondary user modulation scheme. The crucial part of loading algorithm is to determine the useable subchannels. Allocation of resources to subchannel other than a useable subchannel will increase the probability of error.

After spectrum sensing the spectral holes are detected and the number of free subchannels is calculated. Let N_{free} be the detected free subchannels, $n = 1, 2, \ldots, N_{\text{free}}$. The proposed method first determines the maximum number of bits that can be allocated to each free subchannel. The energy distribution of each subchannel is calculated using subchannel SNR and the water filling constant K:

$$\begin{aligned} \varepsilon_n &= K - \frac{\Gamma}{g_n}, \\ K &= \frac{1}{N_{\text{free}}}\left(\varepsilon + \Gamma\sum_{n=1}^{N_{\text{free}}}\frac{1}{g_n}\right), \end{aligned} \tag{4}$$

where ε_n represents the energy distributed in each subchannel; if ε is the total energy that can be distributed in the available bandwidth then $\varepsilon_n = \varepsilon/N_{\text{free}}$. The number of bits that can be allocated to each subchannel is obtained using the maximum rate loading algorithm [9]

$$b_n = \frac{1}{2}\log_2\left(1 + \frac{\varepsilon_n g_n}{\Gamma}\right). \quad (5)$$

The average bit rate is given as $b = (1/N_{\text{free}})\sum_{i=0}^{N_{\text{free}}-1} b_i$, and the subchannel SNR in each subband is $g_n = |H_n|^2/\sigma_n^2$. The SNR gap Γ refers to the additional amount of SNR required to transmit the bit rate equal to channel capacity. The value of SNR gap varies with the modulation scheme used by the secondary user and depends on the symbol error rate requirement. For PAM modulation, the symbols are real and SNR gap is calculated as in the following [23]:

$$\Gamma_{\text{PAM}} = \frac{1}{3}\left[Q^{-1}\left(\frac{\text{SER}_{\text{pam}}}{2\left(1-2^{-b}\right)}\right)\right]^2. \quad (6)$$

For QAM modulation the symbols are complex and SNR gap is calculated as

$$\Gamma_{\text{QAM}} = \frac{1}{3}\left[Q^{-1}\left(\frac{\text{SER}_{\text{qam}}}{4\left(1-2^{-b}\right)}\right)\right]^2, \quad (7)$$

where SER is the symbol error rate and b is the number of bits per symbol of the modulation scheme used by secondary user. When SNR gap increases symbol error decreases [23].

To increase the data rate of each subchannel maximum rate loading algorithm was chosen to determine the maximum number of bits that can be allocated to each subchannel. Subchannel gains are calculated and arranged in descending order to determine the useable subchannels for secondary user transmission. If noise variance is high, subchannel SNR reduces, and the energy in each subchannel becomes negative. The subchannel is declared as a bad channel, if $\varepsilon_n < 0$, and it is not suitable for secondary user transmission. Then the total number of usable subchannels reduces to $N^*_{\text{free}} = N_{\text{free}} - N_b$, where N_b is the number of subchannels with negative energy. Then the bit allocation is done only to the usable subchannels.

After determining the maximum number of bits that can be allocated to each subchannel, the available subchannels are allocated to the secondary users depending on the rate request. There are different ways to allocate subchannels to secondary user for efficient spectrum utilization. The spectrum utility is increased by pooling and sequencing the random rate requests from secondary users. The proposed algorithm is summarized below.

Step 1. Randomly generate L rate requests $R = [R_1, R_2, \ldots, R_L]$, $L > N_{\text{free}}$ of secondary users using Poisson distribution with mean μ and arrange them in descending order.

Step 2. Determine the maximum number of bits that can be allocated to each subchannel using bit loading algorithm as $B = [b_1, b_2, \ldots, b_{N_{\text{free}}}]$, where N_{free} is the number of free subbands.

Step 3. If $R_l \le b_n$, $l \in L$, $n \in N_{\text{free}}$, allocate nth subchannel to user request l; else discard that request.

Step 4. Each random user request searches for the suitable subchannel and that subchannel is allocated to that user.

The improvement in spectrum efficiency and reduction in computational complexity are achieved by pooling and sequencing the random rate requests R from secondary users and arranging B in descending order. By sequencing R, the first user request will occupy the subchannel with higher capacity. If the secondary user rate request is not satisfying the condition in Step 3, the request will be denied. This process is continued until all the subchannels are filled. The computational complexity is reduced as the sorting process is done only once at the beginning of the algorithm.

The proposed method was compared with random rate request without pooling and sequencing. In this case the users were allocated to subchannels in a first come first serve basis. The disadvantage of random allocation was that the user request with less data rate may occupy a subchannel of higher capacity. The last user with high data rate may be denied if subchannel is not free. The spectrum is not utilized efficiently and for each data request searching process takes place from the first subchannel excluding the filled subchannels. This also increases the computational complexity.

4. Simulation Results

The simulations were done in Matlab by generating primary user signals for evaluation of spectrum sensing and detection. Consider $N_{\text{free}} = 32$ free subchannels as spectral holes. The resource allocation to secondary users is done depending on secondary user rate request. The random rate requests are generated using Poisson distribution with different mean values. Different modulation schemes are considered for bit allocation. Figure 1 shows the bit allocation using QAM modulation with a SER of 10^{-7} and a SNR gap of 9.91 with mean $\mu = 6$ and Figure 2 shows the bit allocation using PAM modulation with a SER of 10^{-4} and a SNR gap of 5.05 using bit loading algorithm. The variation of total number of bits for different modulation with different SER is shown in Figure 3. From the figures it can be inferred that more number of bits can be allocated for QAM modulation. The simulation is done assuming the free subchannels are detected and the channel state information is known. The channel state information gives the subchannel SNR to determine the maximum number of bits that can be allocated in each subchannel.

In Figure 4, method 1 shows subchannel allocation using random rate request and method 2 shows pooled and sequenced rate request. By arranging the rate requests and bits per subchannel in descending order, spectrum is utilized efficiently. The proposed method was done for 100 Monte Carlo simulations and it was observed that method 2 has superior performance. A comparison was done between Hughes-Hartogs algorithm and bit loading algorithm and is shown in Figure 5. It is observed from Figure 5 that

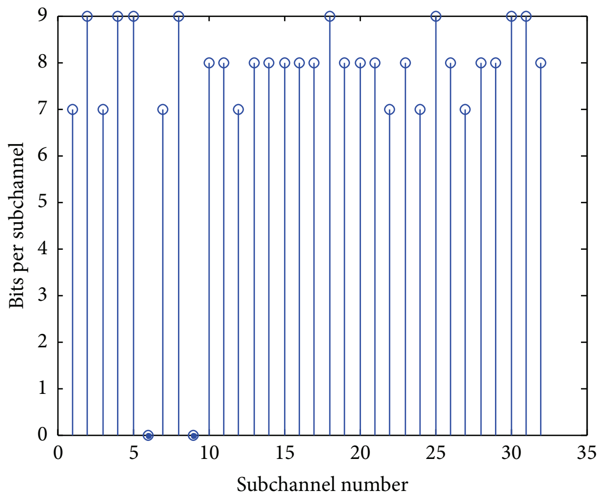

Figure 1: Bits distribution in each subchannel with QAM modulation for SER of 10^{-7} and a SNR gap of 9.91.

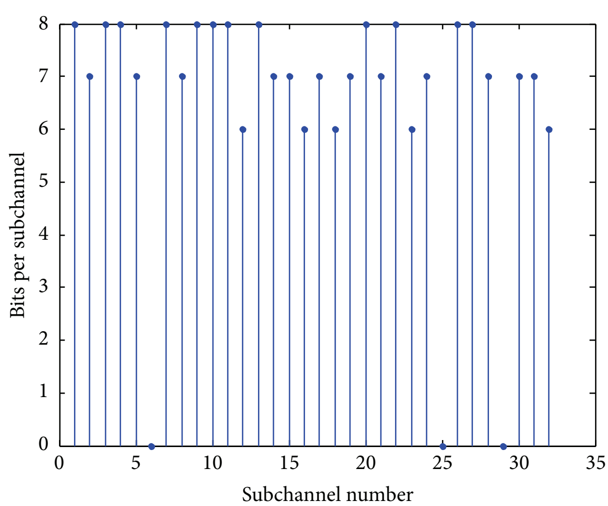

Figure 2: Bits distribution in each subchannel with PAM modulation SER of 10^{-4} and a SNR gap of 5.05.

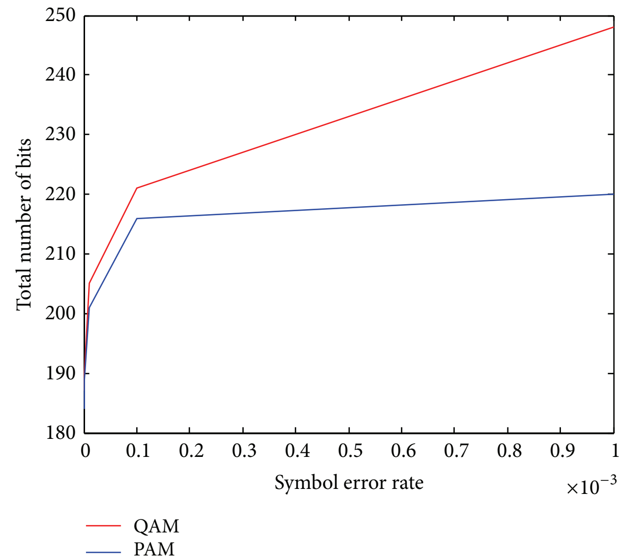

Figure 3: Comparison between PAM and QAM for total number of bits versus Symbol Error Rate (SER).

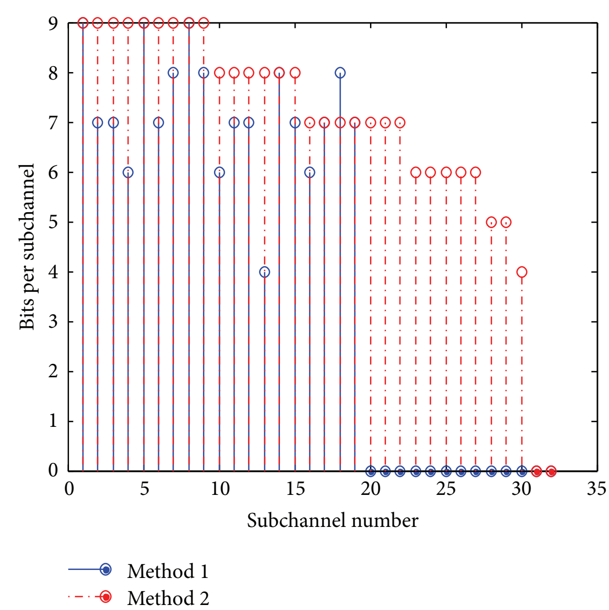

Figure 4: Subchannel allocation to secondary users with the two methods.

the request denial rate is less in both algorithms when rate requests are pooled and sequenced and higher capacity is achieved when compared to random allocation. For 35 rate requests, only 9 requests are denied using Method 2 whereas 16 requests are denied using Method 1. The request denial rate gradually increases with increase in number of rate requests.

5. Conclusion

In the paper the problem of allocating secondary users to spectral holes detected by cognitive radio was addressed. Bit loading algorithm is used to determine the maximum number of bits that can be allocated to each subchannel using the channel state information. For efficient spectrum utilization, a rate request sequenced algorithm was proposed to allocate spectral holes to the secondary users. Moreover the analysis shows that the algorithm has higher spectral utility and less complexity. A comparison was done between Hughes-Hartogs algorithm and bit loading algorithm and it is observed that the request denial rate is less in both algorithms when rate requests are pooled and sequenced and higher capacity is achieved when compared to random allocation.

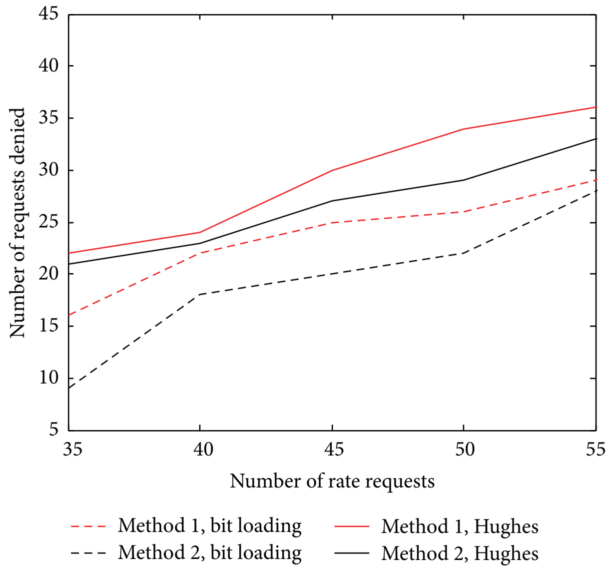

Figure 5: Comparison of spectrum utility using bit loading and Hughes methods.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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