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A Spectrum Sensing Method for TDM based Cognitive Radio Networks

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Abstract

The usage of mobile radio devices has been increased exponentially for the last few years and the radio spectrum is being exhausted every day. Hence, there is huge demand for new methods and technologies for solving the radio spectrum scarcity. On this line, the researchers invented a new technology called Cognitive Radio Networks (CRN). There are two phases associated with the CRN. The first phase handles the spectrum hole detection and the second phase allocates the spectrum hole. In this paper, we propose a new method for spectrum hole detection in time division multiplexing (TDM) based communications systems. The simulation work shows that the proposed method is useful for solving the spectrum scarcity problems in TDM based systems.

Keywords: *Radio Spectrum; Cognitive radio networks; Spectrum detection; Spectrum allocation; Time division multiplexing.*

1. Introduction

The increase in the demand of wireless applications has put many constraints on the usage of available radio spectrum, which is precious and limited resource in the current situation. The whole spectrum is classified into various frequency bands. Each frequency range has a band assigned and each range of frequencies function differently and performs specific tasks. For communications purposes, the usable frequency spectrum now extends from about 3Hz to about 300GHz. The laser communication is taking place at about 100THz. The range from 3Hz to 300GHz has been split into regions. The fair thing about the radio frequency is that once the range has been split, it remains in the same way and becomes standard. Frequency band standard is defined in International Telecommunications Union radio regulations. The complete electromagnetic spectrum can be broadly divided into two spectrum bands, radio spectrum and optical spectrum [1], as shown in Figure 1. Government, Civil, and military users of all nations according to International Telecommunications Union (ITU) radio regulations share the frequency spectrum. On the other side, a fixed spectrum band assignment has led to underutilization of spectrum, as most of the times the licensed spectrum is not effectively utilized. One of the promising technology used to solve this effective utilization of radio is the cognitive radio [2-5]. The cognitive radio networking process has two stages. In the first stage, the spectrum hole detection is done. The second stage is responsible to allocate the spectrum holes of the Primary Users (PU) to the Secondary Users (SU). Here, we focus on the first stage of CRN. In the literature, there are many methods proposed for spectrum hole detection [6-8]. A well-known spectrum sensing method called energy detection [9-13], which depends on the energy wave exists in each channel of the given spectrum. This method is simple and useful for the frequency division multiplexing (FDM) based communication systems. However, it is complex to use for the TDM based communication systems.
In this work, a new energy detection method proposed, which works for the TDM based systems.

The remaining of this paper is organized as follows. The section 2 describes the basic information needed for this paper followed by the literature review. The section 3 describes the proposed method and the algorithm used for this method. In section 4, we provide the simulation and the results. Finally, we conclude the paper in the section 5.

2. Related Work

The usage of mobile devices and their applications is increased significantly in the recent years, which in turn demands huge radio spectrum. However, a fixed spectrum assignment has led to underutilization of the spectrum, as a great portion of licensed spectrum is not effectively utilized. Hence, a promising technology that provides effective utilization of available electromagnetic spectrum is required. The cognitive radio networks are served for such purpose.
Cognitive Radio (CR) is a smart wireless communication system that senses its surrounding environment, learns from the environment, and records internal states and statistical values for managing the radio frequency spectrum in the real time [2-5]. The main objective of the cognitive radio is to provide highly reliable communications whenever and wherever needed and to efficiently utilize the radio spectrum. In other words, the cognitive radio is to use the natural resources efficiently including frequency, time, and transmitted energy. Cognitive radio networks can be used for lower priority secondary users that improve spectral efficiency by sensing the environment for unused licensed spectrum. The unused frequencies kept in the spectrum pool from which the frequencies can be allocated to secondary users. The secondary users can also directly use the frequencies discovered are free to use without gathering into the spectrum pool. In addition, CR techniques can be used internally within a licensed network to improve the efficiency of spectrum use.

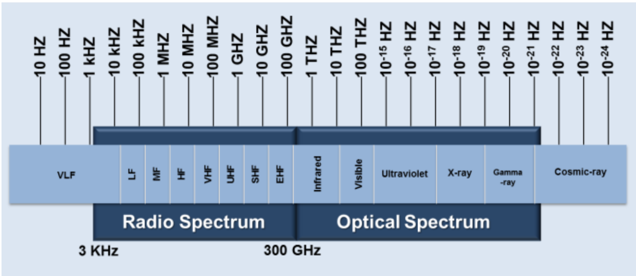

Fig. 1: Spectrum Divisions

The spectrum sensing research is still an active area because it is still under development. In the literature, various methods are proposed for identifying the spectrum holes. In some methods, the criterion of sensing spectrum is based on signal characteristics and some are based on signal types [6-8].
The matched filter method [14,15] is well known spectral sensing method, which works well when the signal information is known. The matched filter is a coherent detector which maximizes the SNR. This method correlates the wave form with the time shifting version. However, the matched filter method is said to be weak if the information about the signal is not known.
The Neyman-pearson criterion [16] is from the radar system for finding the spectrum holes. This method depends on the false alarm probability, which can increase the probability of detecting the spectrum holes. There is trade-off between false alarm probability and the detection probability. However, the high detection probability may decrease the overall system performance. Even if the detection time is increased to reduce the false alarm probability, the system throughput would be degraded. A collaborative approach is required to balance the system performance and decrease the signal processing complexity.
A cyclostationary feature detection method is used as spectrum sensing method [17,18]. A signal is said to be cyclostationary if its autocorrelation and the mean are periodic functions. This method can distinguish the primary user signal from the noise; hence, it can be used at low SNR by attaching the information about the primary users. The disadvantage of this method is the complexity associated with the method.
In the noise environment, a DTV pilot tone signal is detected by using Fast Fourier Transform (FFT) output of received signal. Later it finds the power peak in the average output by discretising the Fourier transform, and followed by applying the adjustment parameter to adjust the received signal power. This method helps in finding the presence or absence of DTV pilot tone [19,20].
Another popular spectrum sensing method is the energy detection method [9-13]. In this method, the radiometer detects the presence or absence of signal in the channel. Here, to identify the signal, a threshold value is fixed based on the noise associated with the channel. Compare to the other methods, it is simple to implement, whereas the matched filter and cyclostationary detection methods require the prior knowledge of primary users, which is sometimes hard to detect when the primary users vary.
In the energy detection method, it is comfortable that the primary users are given the channels on FDM based systems. However, it has not described clearly any method, which can handle TDM based systems. In the next section, we propose a new method for finding the spectrum holes in the TDM based communication systems.

3. Proposed Method

The cognitive radio networks are used to efficiently utilize the predefined radio spectrum governed by the government regulatory authorities [2-5]. There are two major tasks associated in cognitive radio networks; spectrum detection and spectrum allocation. In this section, we describe a new method to detect the unused licensed spectrum. In other words, we will find a method to detect the spectrum holes of primary users and allocate them to the secondary users.
The base idea of the proposed method is observed from energy detection method [9-13]. The energy detection method works well for the frequency division multiplexing based system. It is complex to use for the TDM based systems. The proposed method uses the energy identification procedure [10-12] to discover the presence or absence of signal in the channel. In this method, the number of users are divided over time. For example, the Figure 2 shows the four primary users. Each user is given the full bandwidth for a specific period. This period is called time quantum Δ_x.

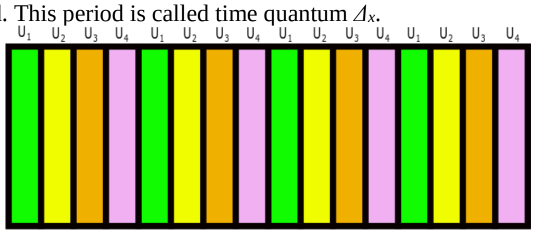

Fig. 2: Four Primary User System

Each user uses the entire spectrum and the energy detector is used to check whether the spectrum is free or not for a quantum period of time Δ_x. Observing the presence and absence of the primary users by detecting the SNR in the channel to see if the SNR is more than the threshold value then it leads to the presence of the PU, else the absence of PU.
The algorithm for the proposed method is as follows:
Let the number of users be '*n*'. The running time on threshold be T_{thresh}. The Δ_x is the time quantum for each user in the TDM based system.

Algorithms:
Step1: Collect the information about the number of primary users. Let '*n*' be the number of users.
Step2: $\forall i \in n$, initialize U_i.occ = free, and define the parameters Δ_x, T_{thresh}, SNR_{thresh}, and K.
Step3: $\forall i \in n$, U_i is given spectrum slot on the TDM based system at a given time t_{init}. Each user U_i gets the time slot at $t_i, t_{i+n}, t_{i+2n}, t_{i+3n}$ etc.
Step 4: Do the following process for each user U_i during its quantum time.

```
if (SNR ≥ SNRthresh)
 {
    Ui.occ = busy;
 }
else
{
    No-op;
}
```

Step5: For each user, repeat the *step 4* at every $n*\Delta_x$ time. Each user U_i gets the time slot at $t_i, t_{i+n}, t_{i+2n}, t_{i+3n}$ etc.
Step6: The repeating process of *step 4* and *step 5* is continued until the time is less than or equal to the T_{thresh}.
Step7: After exceeding the T_{thresh}, check each user U_i to see for $U_i.occ=free$. If it's so, declare the channel for user U_i is unused and can be used for secondary users.
In this algorithm, initially, the information about the primary users is collected at *step 1*. Each user gets the full bandwidth for a quantum period of time Δ_x, as shown in the Figure 2. In the algorithm, we assume the spectrum is free for each user at the initial stage. For each user, we check the presence of a signal in the spectrum at every iteration. We say the presence of a signal in the spectrum if the *SNR* is greater than or equal to SNR_{thresh}. Here the number of iterations are restricted with the total time of $(K*n*\Delta_x)$, where the K is the maximum number of iterations allowed. The K value depends on the T_{thresh}.
The process of checking the signal in the spectrum is stopped once the total time exceeds $(K*n*\Delta_x)$. After all the iterations are finished,

the algorithm checks to see the $U_i.occ$ value. If the value is busy then we declare the channel is used. If its value is free then we declare the channel is unused, hence declared the spectrum hole.
The accuracy of the spectrum hole detection depends on the number of iterations. If the number of iterations is high, then the accuracy of the method increases. However, there is a trade-off between the efficiency of the method and the number of iterations. The more iterations lead to high latency and hence the performance degrades.

4. Simulation and Results

The simulation work has been carried out to see the performance of the algorithm. We have considered various number of primary users for the simulation; 5, 10, 15, and 20 users. Each user gets a quantum time of 20ms as Δ_x. We have considered various spectrum bands for the TDM based system depending on the number of primary users. These are 3.915MHz, 7.83MHz, 11.745MHz, and 15.66MHz for the 5, 10, 15, and 20 users respectively. The SNR_{thresh} value for the simulation considered is 20 dB. The T_{thresh} value considered as 250 ms. We have used the random process in the simulator for transmission of data by the primary users.

In the simulation, we have calculated the spectrum holes for various numbers of users. The Figure 3 shows the average number of spectrum holes found for 5, 10, 15, and 20 primary users. For this, we have considered 10 simulations for each set of primary users. The graph shows that the number of holes increase with the number of primary users

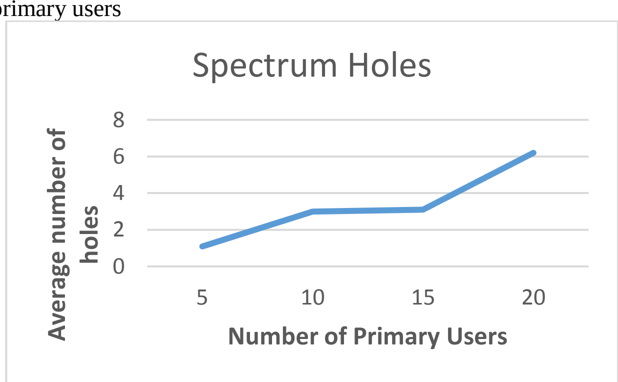

Fig. 3: The average number of spectrum holes

In the next experiment, we have calculated the maximum number of holes among the 10 simulations done for each set of primary users, see the Figure 4.

In the third experiment, we have calculated the minimum of holes for various number of primary users as shown in the Figure 5.

5. Conclusion

The radio spectrum has various ranges in the space defined by ITU. The people use specific band for special purposes. There are many spectrum bands underutilized. Hence, need to use the CRN. Many methods discovered for spectrum holes in CRN. In this paper, we proposed a new method to detect the spectrum hole in TDM based communication systems. The simulation results have been carried out and analysed to see the performance of the method.

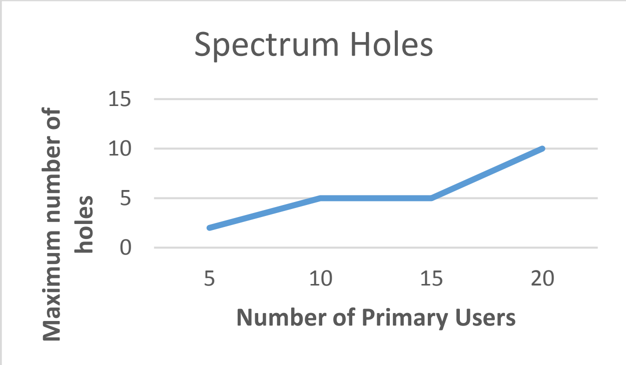

Fig. 4: The maximum number of spectrum holes

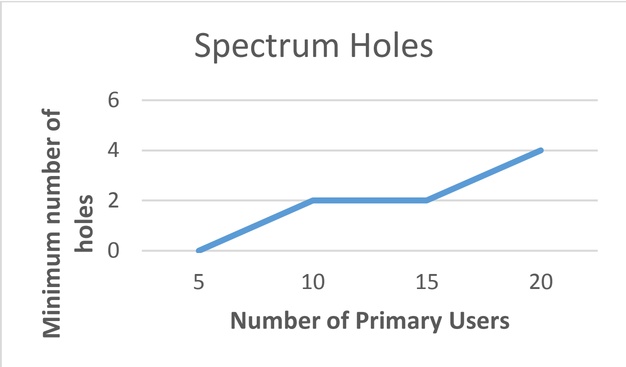

Fig. 5: The minimum number of spectrum holes

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