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A Survey on Spectrum Utilization: Measurement and Prediction

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Abstract
Cognitive Radio (CR) is believed to be an innovative approach to improve the spectrum utilization and alleviate the spectrum scarcity. Thus, having a full understanding of the dynamic usage of spectrum is crucial to the future development of cognitive radio. The measurement and prediction of spectrum utilization have already been studied by some research groups. In the paper, we reviewed and analyzed the existing methods for the measurement and prediction of spectrum utilization.

Keywords
Cognitive radio, Spectrum measurement, Spectrum prediction

I. Introduction

Radio spectrum is a scarce, natural and precious resource. With the development and emergence of new technologies and applications, the shortage of radio spectrum resource has drawn increasingly attention. Cognitive radio, which implements spectrum sharing by utilizing the spectrum holes (i.e. the idle periods of licensed bands), can effectively alleviate the shortage of radio spectrum[1]. In order to better exploit the spectrum holes, it is important to have a full understanding of spectrum occupancy. By long-term measurement of spectrum occupancy, it is helpful to understand the activity of primary user and optimize the strategy of spectrum sensing and access.

II. Spectrum measurement

In order to detect the spectral holes, it is necessary to make a long-term spectral measurement. Through this way, we can understand the primary users' activities. Since 2002 a large number of broadband spectrum measurements have been carried out over the world. The research conducted by the US Federal Commission and Austria spectrum sharing company is one of the representative researches. From the January 2004 to the August 2005, they surveyed the spectrum utilization in the frequency bands ranging from 30MHz to 3000MHz in US. The result showed that the average utilization rate of the frequency band was only 5.2%[2],[3]. In Germany[4], Spain[5], South Africa[6], etc, spectrum measurement activities have also been carried out, and the results showed that the spectrum utilization rate of each region was very low. Furthermore, the spectrum utilization rate shows the dynamic nature of time and space, different place at different time has different utilization rate[7].

In addition, the researchers have also studied the correlation of spectrum usage. During the 2006 Football World Cup in Germany, a spectrum measurement was carried out in Kaiserslautern and Dortmund and the researchers found that the change of spectrum usage was clearly related to specific events[8]. Later in 2009 another measurement was conducted in China in the frequency band from 20MHz to 3.6GHz. Beijing University of Posts and Telecommunications conducted a one-week measurement at four locations (two urban and two suburban)in Guangdong province in China[9]. The authors analyzed the statistics of the collected data and found the channel vacancy duration follow an exponential-like distribution. Meanwhile, they analyzed the service congestion rate and other indices. Their results have showed that there was temporal, spatial and spectral correlation among channels of the same service.

III. Spectrum prediction

Prediction of spectrum utilization is very important to design efficient spectrum sensing algorithm and optimize the spectrum access strategy. In general, prediction of spectrum occupancy is done by measuring the received signal strength and estimating the status of primary users. In [10], the authors employed the AR-2 (2-order autoregressive model) to model the received signal strength of channel. An ARMA (auto-regressive and moving average model) could be also used to predict the received signal strength of television services channel[11]. The methods mentioned above were used to handle stationary time series. For non-stationary time series, it is meaningful to apply the ARIMA (integrated ARMA model) [12], because this method could transform the non-stationary received signal strength into the stationary and periodic time series.

In addition to the prediction of the received signal strength of the channel, many studies have focused on the prediction the state of the channel whether it is occupied at the next time. The researchers always transform the received signal strength into a binary time series reflecting the channel state through data processing. Most of the research work was assumed that a Markov model exists in this binary sequence, and the HMM (Hidden Markov Model) is used for modeling and forecasting. However, in [13], the authors noted that nearly 45% of the channels are not suitable for applying Markov model when predicting the occupancy state of the channel. For the other channels, 1st-order Markov method could achieve obvious improvement. In order to further improve the forecasting accuracy, the authors [14],[15] proposed a channel state prediction method based on a multilayer neural network. The researchers took the historical moment of the occupancy status of a single channel as the input of BP(back propagation) neural network. Through training data, it is easy to conduct a neural network model to predict. With the wide application of data mining and machine learning, a method based on frequent pattern mining [9] and its improved version were proposed to predict the spectrum occupancy of channels. These methods first mined the historical sequence of spectrum occupancy status, and then predicted the following spectrum occupancy status. Their method was reported to achieve a higher prediction accuracy.

IV. Conclusion

In this paper, we reviewed the existing spectrum measurement and prediction carried out by different research groups. For spectrum measurement, the utilization of spectrum rates is quite low, and they showed temporal, spatial and spectral correlation among different channels. For spectrum prediction, the prevalent methods are based on integrated moving averaging auto-regression, hidden

Markov model, back propagation neural network and frequent pattern mining. Although those methods have improved the prediction accuracy of spectrum utilization, there are still many difficulties and challenges for the prediction method, which will be the direction of our future research.

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