CHANNEL QUALITY RANKING IN COGNITIVE RADIO NETWORKS

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Keywords: Cognitive Radio Networks, Cognitive Cycle, Spectrum Analysis, Quality of Service, Channel Quality Ranking.

Abstract

Cognitive radios have enabled the users to utilize licensed bands opportunistically without causing harmful interference to licensed users. Spectrum analysis is an important technique in cognitive radio networks. And it helps ranking available channels using spectrum sensing results. Appropriate channel assignment decisions will be made according to the ranking results and user requirements. Here we provide an overview of spectrum analysis in this paper. Some basic concepts of cognitive radio network and cognitive cycle are recalled in this paper first. Then, we introduce some traditional channel quality evaluation parameters. Finally, we provide our own ranking mechanism and describe it with the help of a flow diagram.

1 Introduction

Wireless spectrum is a valuable natural resource. Today, the wireless spectrum is mainly regulated by a fixed allocation strategy. Governmental agencies manage the spectrum resources and allocate the spectrum to authorized users. However, according to a report from Federal Communications Commission (FCC), temporal and geographical variations in the utilization of the authorized spectrum are from 15% to 85% [1]. Another research from National Radio Network Research Test-bed (NRNRT) shows that the average spectrum utilization below 3 GHz spectrum band is just 5.2%. It means that most of the authorized spectrum band is used by licensed users occasionally. At the same time, some of the non-licensed spectrum band is extremely crowded since the unauthorized users have no access to the licensed spectrum band. The waste of spectrum resources caused by the fixed allocation strategy did not draw enough attention to people in the past. Recent years, the dramatic increase of the need for wireless spectrum, limited available spectrum, and inefficient spectrum utilization necessitate a new communication mode to exploit the existing wireless spectrum opportunistically [2] [3]. This new networking mode is referred to as dynamic spectrum access (DSA) as well as cognitive radio networks (CRNs). In a CRN, unlicensed/secondary users (SUs) are allowed to exploit the free spectrum (also called “spectrum holes”) opportunistically when licensed/primary users (PUs) are not active.

The most important technology of CRNs is the cognitive radio (CR) which provides the capability to detect spectrum holes and share the spectrum in an opportunistic manner. DSA techniques enable the CR to select the best available spectrum to operate in. The main functions of CR in cognitive radio networks are introduced as follows [3]: (1) spectrum sensing: Detecting unused spectrum and sharing it without harmful interference to other users; (2) spectrum management: Selecting the best available spectrum to meet the quality of service (QoS) requirements of users. Spectrum management functions can be classified as spectrum analysis and spectrum decision; (3) spectrum sharing: Assigning the available spectrum fairly among CRN users; (4) spectrum mobility: Moving out of the current channel once conditions become worse or a PU is detected.

Cognitive capability is one of the most critical characteristics of the cognitive radio, which means the ability to obtain information from its radio environment and therefore select the best spectrum and the most appropriate operating parameters to adapt to the dynamic radio environment [4]. The steps for the adaptive operation are shown in Figure 1, namely cognitive cycle.

SUs detect the radio environment to identify the spectrum occupancy states of both PUs and other SUs in the spectrum sensing step. Then in the spectrum analysis step, the spectrum sensing results will be used to estimate the quality of available channels. The most appropriate channel assignment decisions will be made according to the spectrum quality and user requirements in the spectrum decision step [5]. Spectrum analysis is one of the most important components in the cognitive cycle.

This paper provides a brief introduction to spectrum analysis. The rest of this paper is organized as follows. In Section 2, we provide a brief overview of the conventional channel ranking methods. Our own channel ranking mechanism is generalized in Section 3, which will be explained in detail with a flow chart in Section 4. Section 5 concludes this paper.

Figure 1. The basic cognitive cycle [8] [9].
2 Conventional Channel Ranking Parameters

In CRNs, spectrum holes detected through spectrum sensing may be distributed in a wide range of both unauthorized and authorized frequency band. The properties of these spectrum holes may change with the time varying radio environment. Channel quality of different spectrum holes may also be different at the same time due to the spectrum band information such as the bandwidth and the operating frequency.

Since CR should be able to select the best available spectrum band to meet the QoS requirements of users [6] [7], it is essential to analysis the quality of the available channel after the spectrum sensing stage and sort the channel according to some certain criteria as well as the specific needs of users. The ranking result can be exploited to get the spectrum band appropriate to the user requirements [10]. Now we introduce some of the traditional channel quality evaluation parameters.

2.1 Signal-to-Noise Ratio (SNR or S/N)

Signal-to-noise ratio is a measure that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels [11]. Channel capacity, one of the most important measures for channel quality evaluation, can be derived from the SNR and the bandwidth that will be discussed below using the Shannon-Hartley theorem.

In CRNs, however, SNR at the receiver considers only local observations of secondary users, which is not enough to avoid inference to primary users. To solve this problem, we can derive the permissible transmission power of an SU from the amount of interference allowed at the primary receiver. The interference temperature model [12] can be used to achieve this derivation. A channel capacity estimation method considering such permissible transmission power has been proposed in [13].

2.2 Signal-to-Interference-Plus-Noise Ratio (SINR)

The concept of SINR is defined as the power of the signal divided by the sum of the interference power and the power of some background noise, which is widely used in wireless communication systems. If the power of interference term is zero, then the SINR reverts to the SNR which is discussed above. The interference power could be generated by all the other simultaneous transmission.

2.3 Bandwidth

Bandwidth which refers to analog signal bandwidth measured in hertz can be employed to calculate the maximum rate at which information can be transmitted over a communications channel in the presence of noise using Shannon-Hartley theorem.

In computer networking and computer science, bandwidth defines bit-rate of available, channel capacity or the maximum throughput of a logical or physical communication path in a digital communication system. The two terms can be connected with each other.

2.4 Delay

The delay of a channel indicates the time it takes for the data to transmit, which can be divided into several parts:

- **Processing delay**: The time it takes for routers to process the packet header in a network based on packet switching. The processing delay can be quite large in some application scenes when complex encryption algorithms have to be performed by the routers. Other forms of delay will be required more strictly under such security requirements.

- **Queueing delay**: The time a packet needs to wait in a queue until it can be transmitted. Multiple SUs may contend for spectrum usage, using random access, of available channels in a CRN. SUs’ queuing delay performance has been discussed in [14] [15].

- **Transmission delay**: Also known as store-and-forward delay or packetization delay. The time required to push all of the packet’s bits into the link. Transmission delay is a function of the packet’s length and the data-rate of the link, which has nothing to do with the distance between two nodes.

- **Propagation delay**: The time the head of the signal takes to travel from the sender to the receiver, which can be calculated as the link length divided by the propagation speed over the specific medium.

2.5 Packet Delay Variation (PDV)

The difference in end-to-end one-way delay between selected packets in a flow with any lost packets being ignored, sometimes called “jitter” [16]. For some certain applications, packet delay variation can be a serious trouble according to specific user requirements.

Some or all of the parameters mentioned above can be used to rank the available channel according to the QoS demands of different users.

3 Ranking Methods in CRNs

In this section, we briefly introduce our opinions on spectrum analysis in CRNs.

In a CRN, SUs are only allowed to opportunistically access the primary channels on a non-interference basis. Hence, naturally, the most important part of the channel ranking mechanism is the availability of the spectrum. The channel availability is given by the results of spectrum sensing, which has various kinds of techniques classified as transmitter detection, cooperative detection, and interference-based detection. The accuracy of spectrum sensing will definitely influence the quality of the channel. The channel availability duration, also called holding time, which is determined by the activities of primary users. The idle duration indicates how long the secondary user can employ a channel before a primary user appears.
Short duration time will lead to frequent spectrum handoff, which will obviously influence the performance of the channel. Moreover, if secondary users were caught during the utilization of licensed channels, they might be punished by primary users. Hence, the longer the idle duration is, the better the quality of a channel will be.

A channel quality prediction metric based on the predicted channel idle duration and the spectrum sensing accuracy has been proposed in [17]. They adopt the Non-Stationary HMM for spectrum detection and prediction to capture the busy/idle duration of channels.

However, ranking metric proposed in [17] which only consider the spectrum sensing accuracy and holding time is imperfect. These two points discussed above are the most important ranking parameters in CRNs. With the premise of those two parameters, conventional ranking methods mentioned in Section 2 should also be used to evaluate a channel. However, recent work on channel ranking only focuses on spectrum availability or capacity, which is not sufficient to characterize the spectrum band. A complete spectrum analysis model considering all characterization parameters described above has not been discussed. Our future research will involve the combination of the above parameters to evaluate the spectrum and rank the channel for different users to meet their own QoS needs for different types of applications.

In the next section, we will illustrate our channel quality ranking methods in detail with the help of a flow diagram.

4 Our Channel Quality Ranking Methods

There are two types of mechanisms for spectrum access: spectrum access based on random channel selection (SA-R) where each SU selects one channel to sense randomly and access a channel once it is identified to be idle; and spectrum access based on channel ranking (SA-CR) where SU sense and select a channel based on the channel ranking result. The performance of those two types of mechanisms has been compared in [17], too. The successful transmission rate and the time cost for each SU to sense and access an idle channel is verified to be significantly improved using ranking based spectrum access.

Except for the significant improvement of the access time to an idle channel, ranking based channel selection strategy will also bring benefits to varied user requirements. Some users may have strict requirements on the delay of the channel while others may have more stringent demands on the bit error rate, for example. They should sort and access the channel according to their own application scenarios.

Consider a practical example of Body Area Networks (BAN) [18]. We consider three different people wearing BANs. The first person has recently passed a surgery, the second person suffering from chronic diseases while the third one is quite healthy. Obviously, the first BAN has stricter QoS requirements in terms of the throughput and delay than others while the last BAN requires least in comparison. However, a clear channel ranking method under such application has not been proposed in [18], where the ranking result is thought to be already known. To the best of our knowledge, a complete channel sorting criterion considering all of the evaluation parameters and the variety user demands has never been discussed.

Currently, the channel state of the licensed spectrum band is mainly represented by an ON/OFF model. The result of spectrum sensing is compared with a pre-set threshold. The channel is considered to be idle if the detected power is lower than the threshold, otherwise it is thought to be occupied. However, such decision method cannot be utilized for ranking the channels. Moreover, the setting of the decision threshold will have significant impact on the quality of transmission of both primary and secondary users.

Hence, a new approach to analysis the spectrum, evaluate channel quality and allocate the channel according to specific application requirements need to be adopted. Instead of modelling the state of channel simply by a binary ON/OFF model, we will estimate the interference power of each channel to characterize the channel combining with other evaluation parameters discussed above.

We show a flow diagram of our channel ranking method in Figure 2.

The information of spectrum hole is given for spectrum analyzing after the spectrum sensing stage. The index of the idle channel will be known for the convenience of ranking. The wireless signal of the corresponding channel detected by spectrum sensing will be pre-processed first. Operations such as filtering, amplification or down-conversion will be done in this stage.

Then the multi-power interference of the channel will be estimated out of the processed signals, which will be used to estimate the available duration as well as evaluate the SINR. We use the hierarchical Dirichlet process to analysis and predict the possible channel state parameters and the hidden Markov model to describe the transition of states instead of the discrete ON/OFF model [3]. Other parameters such as bandwidth and delay mentioned in Section 2 may also be estimated depending on the QoS demands of different users.

The channel ranking results will be given to the secondary users based on the above-mentioned evaluations and their specific application requirements at last. The channel quality report will be given to the spectrum decision step to make an optimal spectrum assignment as discussed in Section 1. The signal transmission of users will change the radio environment and influence the sensing result of other users in turn to form the cognitive cycle as shown in Figure 1 eventually.

5 Conclusion

In this paper we give a brief introduction of spectrum analysis and provide our own channel ranking method in

Figure 2. The flow chart of our ranking method.
cognitive radio networks. We combine the evaluation of some conventional channel ranking parameters such as SNR, SINR, bandwidth and delay with idle duration to evaluate and rank the available channels. We will investigate our ranking mechanism in detail, show the performance of our method with simulations and improve it in our future work.

Acknowledgments

This work was supported by the National Natural Science Foundation of China under Grant No. 61201225, the Natural Science Foundation of Shanghai under Grant No. 12ZR1450800, and sponsored by Shanghai Pujiang Program under Grant No. 13PJD030. This paper was also supported by the Fundamental Research Funds for the Central Universities under Grant No. 20140767, the Program for Young Excellent Talents in Tongji University under Grant No. 2013KJ007, and “Chen Guang” project supported by Shanghai Municipal Education Commission and Shanghai Education Development Foundation under Grant No. 13CG18.

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