

Chapter 15

Channel State Prediction in Cognitive Radio

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ABSTRACT

Spectrum sensing is the cornerstone of cognitive radio, which detects the availability of a spectrum band for the current time. In theory, the result of spectrum sensing reflects the current channel state, which is the ideal case. However, according to the author's measurements, hardware platforms can introduce a non-negligible time delay on the signal path, which undermines the accuracy of spectrum sensing. To reduce the negative impact of the hardware platform time delay, channel state prediction in cognitive radio is proposed and presented in this chapter. As examples, channel state prediction algorithms based on a modified hidden Markov model (HMM) are given and tested using recorded real-world data. Moreover, as a second stage, cooperative channel state prediction is also proposed and experimentally evaluated. The experimental results approve that channel state prediction in cognitive radio indeed helps improve the accuracy of spectrum sensing in practical cases.

15.1 RESPONSE DELAYS IN HARDWARE PLATFORMS

As we know, a number of spectrum sensing techniques for cognitive radio have been proposed. In addition to tremendous efforts on theoretical investigation, work on hardware implementation

of spectrum sensing has been reported as well in (Chen, Guo, and Qiu, 2010; Mian, Zhou, Li, Hong, and Wu, 2009; Oh et al., 2009; Tkachenko, Cabric, and Brodersen, 2006). Experience gained in developing software defined radio (SDR) can benefit cognitive radio work, and existing SDR hardware platforms can be extended for developing cognitive radio transceivers. Implementing ef-

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fective spectrum sensing schemes is a fundamental part of the development effort toward a cognitive radio network testbed (Qiu et al., 2009; Qiu et al., 2010). It is worth noting that measurement can be critical in guiding implementation work and verifying algorithm performance. In implementing the algorithms in hardware platforms, we have found, however, time delay introduced by hardware platforms becomes non-negligible, though in theoretical investigations such a time delay is usually ignored. Accurately quantifying this delay is necessary since it is wise to take into account the measured results in algorithm design and implementation.

There have been some hardware platforms that can be used for cognitive radio, such as universal software radio peripheral (USRP), universal software radio peripheral 2 (USRP2) (Ettus Research LLC, 2010), SFF SDR DP (Lyrtech Incorporated, 2010), wireless open-access research platform (WARP) (Rice University WARP Project, 2010), and Sora (Tan et al., 2009). There exist a few reports on discussions of the time delay of the USRP platform. In (Nychis, Hottelier, Yang, Seshan, and Steenkiste, 2009), the time delay between the GNU Radio (GNU Radio, 2010) and the field programmable gate array (FPGA) is reported. The value ranges from 289 μ s to 9 ms. In (Valentin, von Malm, and Karl, 2006), an elapsed time is measured, where the elapsed time is the length from the start time of sending out a data link control (DLC) frame to the instance of completely receiving an acknowledgment DLC frame of the same size. The average of the time is 3.14 ms. In (Schmid, Sekkat, and Srivastava, 2007), the measured receive latency ranges from 1 ms to 30 ms, and the transmission latency ranges from 28.9 ms to 36.9 ms.

One of the reasons that the measured time delays of USRP differ greatly can be that different portions of the time delay are measured. We have not seen any reported measured time delays of USRP2 and SFF SDR DP.

In this section, the problem of the response delay is formulated and the minimum response delays of USRP2 and SFF SDR DP are measured.

15.1.1 Problem Formulation

A scenario of spectrum sensing is described as below. The time slot and the response delay are introduced.

15.1.1.1 Time Slot

Consider a scenario as shown in Figure 1, where a secondary user (SU) communicates with another SU or a secondary base station (SBS) through wireless channels, and both the uplink channel and the downlink channel are comprised of a sequence of time slots. Assume time slot level synchronization is performed and the length of the time slots is constant. Each time slot contains two phases: the spectrum sensing phase (the first phase) and the communication phase (the second phase). When in the spectrum sensing phase of a time slot, a potential SU sender or SBS sender senses the availability of the channel, it may start data transmission in the following communication phase if the sensed channel state is "idle."

In order to verify the sensed channel states, the actual channel states are required. The question is how SUs can get the actual channel states without the aid of primary users (PUs). Consider the following two cases: 1) The sensed channel state is "idle," so the SU sender can either (1a) send data in the next communication phase or (1b) hold on data transmission in the next communication phase. 2) The sensed channel state is "busy," so the SU sender holds on data transmission in the next communication phase. In (Hoang, Liang, Wong, Zhang, and Zeng, 2008), acknowledgment (ACK) and negative acknowledgment (NAK) messages are employed to indicate whether a transmission is successful or not. The same idea is borrowed here for case-1a verification. As shown in Figure 1, ACK or NAK mes-

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