

Medium Access Control Protocol Design, Analysis and Identification in Cognitive Radio Networks

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Abstract—Cognitive Radio (CR) is a promising technique to address the spectrum scarcity issue by enabling the unlicensed network users (SUs) to dynamic access the spectrum holes. This thesis designs Medium Access Control (MAC) protocols for SUs to utilize the unused spectrum without interfering the licensed network users' (PUs) transmissions; analyzes the MAC performance based on the queuing theories; and identifies the PU's and SU's MAC protocol types using machine learning techniques in order to implement smart cognitive radio.

Index Terms—MAC, Cognitive Radio, Machine Learning

I. INTRODUCTION

With the emergence of a large amount of new wireless communication systems such as digital video broadcasting (DVB) [1] [2] [3], wireless local area networks (WLANs) [4] [5], wireless metropolitan area networks (WMANs) [6], etc. and the explosive growth of currently network users, the demand for radio resources increases rapidly. As a result, the frequency spectrum has become a scarce resource for wireless systems. However, a large portion of the spectrum resources allocated to licensed network users, named primary users (PUs), are underutilized according to the actual measurement of federal communications commission (FCC). To address this spectrum scarcity issue, Joseph Mitola III first introduced the cognitive radio (CR) to enable effective frequency reuse to satisfy the increasing frequency spectrum requirements in 1999. In CR networks, the unlicensed network users, named CR users or secondary users (SUs), are able to dynamic access the spectrum holes which are defined as a frequency band that has been allocated to a licensed network users but is unutilized at a particular time [7]. Through this frequency reuse technique, the frequency spectrum utilization is improved in CR networks.

In this dissertation, we focus on the MAC protocol design, analysis and identification in CR networks. In section 2, we propose two Cog-MAC protocols for CR sharing a common TDMA network with primary users. Considering the different traffic model, independent packet arrival process (i.e., sensor network packets) or correlated packet arrival process (i.e., voice packets, image packets, and video packets), we provide a Cog-CSMA and a Cog-PRMA, in order to fit the specific traffic model and achieve a better network performance. In section 3, we investigate the tagged user analysis (TUA) for analyzing multiple medium access networks instead of traditional

Markov chain analysis in order to reduce the computational complexity. In this chapter, we consider slotted ALOHA as an multiple medium access control protocol example and investigate the network performance including network throughput, packet blocking probability, queue length, network delay, etc. in Additive White Gaussian Noise (AWGN) channel, Rayleigh fading channel, frequency selective fading channel. We then investigate slotted ALOHA in CR environment and its TUA analysis. In section 4, we investigate the MAC protocol identification based on machine learning techniques to detect and identify different types of MAC protocols in CR networks. Through the implementation of MAC protocol identification, a CR user is able to determine the existing MAC protocol types in air and adaptively configure its own transmission parameters in order to reduce/avoid the interference to primary users and achieve better CR network performance.

II. COG-MAC PROTOCOL FOR CR USERS

In this section, we consider that SUs attempt to share a common TDMA network with PUs and investigate medium access control protocols that support SUs to access the unused/idle TDMA time slots. Since network traffic can be independent (i.e., sensor network packets) or correlated (i.e., voice packets, image packets, and video packets), we consider both independent and correlated traffic scenarios for SUs which are described using a two-state Markov chain. The first scenario assumes that the packet arrivals of each SU are independent and follow a Bernoulli random process. We propose a cognitive carrier sensing multiple access (Cog-CSMA) protocol for this scenario which enables SUs to access a common TDMA channel. In Cog-CSMA, carrier sensing is used to sense the availability of each TDMA time slot and each time slot (of TDMA) is divided into sensing and transmission mini-slots, which helps to avoid the interference between PUs and SUs. The capture effect over a Rayleigh fading channel is considered in evaluating Cog-CSMA and the throughput is derived. In the second scenario, we assume that the secondary packet arrivals follow a correlated packet arrival process (bursty traffic model). In this traffic model, more consecutive packets will arrive after the first packet and therefore carrier sensing based MAC protocols lead to a lower bandwidth efficiency due to the serve contention of the consecutive packets. To achieve a better CR network performance, we propose a cognitive packet reservation multiple access (Cog-PRMA) protocol for this bursty traffic model. In Cog-PRMA,

TDMA time slots can be reserved by SUs for future utilization (consecutive packet transmissions) when the slots are not used by PUs. In Cog-PRMA, spectrum sensing is implemented at the beginning of each TDMA frame in order to determine the existence of PUs, which avoids the interference among PUs and SUs. The performance of PUs' transmissions is guaranteed by giving PUs higher network access priority in Cog-PRMA, which means that a SU should yield to a PU and pauses its transmissions when the PU is transmitting, and the SU resumes its transmission when the PU stops transmitting. To summarize, the Cog-CSMA is applied to independent packet arrival traffic scenario because it enables each secondary user randomly access the idle TDMA time slots through carrier sensing, while the Cog-PRMA is applied to correlated packet arrival (bursty) traffic scenario because it has an advantage that the time slot reservation mechanism improves the bandwidth utilization efficiency. They are two different MAC protocols proposed for two different traffic scenarios and applications. A CR network can choose either one of the proposed MAC protocols based on the SUs' traffic.

III. TAGGED USER ANALYSIS FOR CR NETWORKS

In modern realistic communication systems, there are only finite system users sharing the common communication channels at a given time. Meanwhile, most of them use a finite size buffer because of the recent proliferation of packet data transmission. Considering these kinds of finite-user and finite-buffer systems, Markovian analysis is an wildly used method to analyze the performances of multiple access systems. However, the potential large size and dimensions of its state space will result in exponentially increasing of computational complexity. To simplify the system performance analysis, a large amount of approximate system performance analysis methods have been applied.

In this section, we first investigate general wireless system performance analysis using TUA considering noisy channels and the multipath/frequency selective fading channels. We consider a homogeneous centralized slotted Aloha multiple access system. TUA is deployed in this chapter to analyze the system performance. Then we consider CR scenario and provide a cognitive slotted ALOHA protocol for secondary users. TUA is also used to analyze this proposed cognitive slotted ALOHA protocol considering noisy and Rayleigh fading channels [8] [9].

IV. MAC IDENTIFICATION

The emergence of new wireless communication systems, including digital video broadcasting (DVB), wireless local area networks (WLANs), wireless metropolitan area networks (WMANs), leads to significant increases in the demand for radio resources, resulting in spectrum shortage. However, according to the Federal Communications Commission (FCC) records, a large portions of the spectrum resources allocated to licensed network users (primary networks) are underutilized. Cognitive radio (CR) is thus implemented to improve the spectrum utilization by enabling CR users to access a spectrum

hole, which is defined as a frequency band that has been allocated to a licensed network users but is unused at a particular time.

CR is an intelligent radio that has the ability of reasoning and achieving the specific tasks in radio-related domains, which implies that CR users are able to learn from external radio environments and adaptively change their transmission protocols and parameters according to the learning results during their transmissions. This ability is characterized by observation and adaptability. The observation characteristic implies that the CR can observe the radio environment, i.e., spectrum sensing, channel estimation. The adaptability characteristic means that the cognitive radio is able to change its communication methods and parameters based on its observation results, i.e., channel allocation, modulation coding scheme (MCS) selection, waveform adaptation, to adapt to the radio environment. Notice that the radio environment observations discussed above relate to the physical layer of a communication networks, this paper explores the observation of the radio environment in terms of medium access control (MAC) protocols, which provides the potential benefits for CR network performance improvement.

In this section, we investigate the MAC protocol identification, identifying the primary network MAC protocol types and MAC layer parameters, considering primary time division multiple access (TDMA), carrier sense multiple access/ collision avoidance (CSMA/CA), slotted ALOHA and pure ALOHA networks. The received power and channel states features are extracted and used to perform MAC protocol identification. The support vector machines (SVMs) are used as the main method to finalize the identification result [10].

V. CONCLUSION

In this thesis, we investigate medium access control protocol design, analysis and identification in cognitive radio networks. In the MAC protocol design part, we consider the unused time slots in primary TDMA networks as spectrum holes which can be used for CR transmissions. Considering Bernoulli random secondary packet arrivals and bursty secondary packet arrivals scenarios, Cog-CSMA and Cog-PRMA are proposed respectively. In Cog-CSMA, carrier sensing is used to sense the availability of each TDMA time slot and each TDMA time slot is divided into sensing and transmission mini-slots in order to avoid the interference between PUs and SUs. In Cog-PRMA, TDMA time slots can be reserved by SUs for consecutive packet transmissions. Theoretical derivations for secondary throughput performance have been investigated in this part. The numerical results show that notable secondary transmissions were achieved in the proposed Cognitive MAC protocols, and meanwhile avoid the potential inference to the primary TDMA users. In the second part of this thesis, the TUA is investigated for cognitive MAC protocol performance analysis. The classic queuing model, G/G/1/K model, is used to modeling the queuing behaviors of the random access systems. We take the cognitive slotted ALOHA as an example to examine the performance of TUA. Compared with the traditional

Markov chain analysis, the numerical results show that the proposed TUA achieves similar perform but significantly reduces the computation complexity. In the identification part, MAC protocol identification based on machine learning is investigated. Four MAC protocols, ALOHA, slotted ALOHA, TDMA and CSMA are considered. A feature extraction scheme is proposed in this thesis, which is used to extract the power and channel states features from the received signal. SVMs has been used as the classifier to perform the one-versus-one and one-versus-all classification. The numerical results show that that MAC protocol classification is feasible and has a great potential to be used in the smart cognitive radio networks in the future.

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