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Performance analysis of CSMA-based opportunistic medium access protocol in cognitive radio sensor networks

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ABSTRACT

Given the highly variable physical layer characteristics in cognitive radio sensor networks (CRSN), it is indispensable to provide the performance analysis for cognitive radio users for smooth operations of the higher layer protocols. Taking into account the dynamic spectrum access, this paper formulates the two fundamental performance metrics in CRSN; bandwidth and delay. The performance is analyzed for a CSMA-based medium access control protocol that uses a common control channel for secondary users (SUs) to negotiate the wideband data traffic channel. The two performance metrics are derived based on the fact that SUs can exploit the cognitive radio to simultaneously access distinct traffic channels in the common interference region. This feature has not been exploited in previous studies in estimating the achievable throughput and delay in cognitive radio networks. Performance analysis reveals that dedicating a common control channel for SUs enhances their aggregated bandwidth approximately five times through the possibility of concurrent transmissions on different traffic channels and reduces the packet delay significantly.

1. Introduction

In the recent past, cognitive radio network (CRN) has gained overwhelming recognition in a great deal of wireless networks, which are not limited to the envisioned infrastructure based networks but also infrastructureless ad hoc networks. This is mainly realized due to the challenges faced by the pervasive wireless networks, which are primarily the spectrum scarcity and hostile propagation environment. Wireless sensor networks (WSNs), which are supposed to operate in the saturated free ISM bands and deployed in usually harsh environment, are the potential candidates to benefit from the dynamic spectrum access technique devised in CRN, thus effectively presenting WSNs as cognitive radio sensor networks (CRSN) [2].

Cognitive radio exploits the temporally unused spectrum defined as the spectrum hole or white space of the licensed users, known as primary users (PU) [1]. If the cognitive radio, or secondary user (SU), encounters the primary user at the licensed spectrum band, it performs spectrum handoff or stays in the same band without interfering with the licensed user by adapting its communication parameters such as transmission power or modulation scheme. As for the unlicensed spectrum bands in which the PUs cannot exist and all users have the same priority to access the spectrum, dynamic spectrum access allows the user to utilize the spectrum more efficiently. Hence, the cognitive radio technology enables the users to opportunistically access the available licensed or unlicensed spectrum bands.

Due to the lack of dedicated spectrum bands in CRSN, the opportunity of accessing the spectrum is always sensed dynamically that prohibits the SUs to stipulate performance guarantees. Thus, due to the continuously changing physical layer characteristics, estimating the performance of the cognitive radio user is of paramount importance since the performance of the overlying protocols depends

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on some close estimate of the realized bandwidth and delay. For example, if the flow admission control at the transport or routing layer allows the large number of flows based on spontaneous increase in bandwidth that diminishes soon, QoS might be deteriorated awfully. Hence, it is indispensable to provide throughput and delay estimation of SUs that persists over the long period of time to maintain the performance of communication protocols, eventually mitigating the shortcoming of dynamic spectrum access.

Performance analysis has been conducted in terms of the delay estimation [13–17] and also the throughput [4,8,9]. However, it has not been fairly investigated so far with little attention on the potential capacity of cognitive radio operated through common control channel. Generally, the existing studies [6,7] investigate the bandwidth by means of spectrum sensing efficiency, which does not reflect the bandwidth practically achievable by the SUs. Similarly throughput is analyzed for a single channel access in the common interference region where the potential of cognitive radio can be exploited to utilize multiple channels. Hence, this is the first study that investigates the performance of dynamic spectrum access for CRSN in terms of both metrics bandwidth and delay by incorporating multiple channels access.

In this paper, we conduct performance analysis of secondary users in terms of the two fundamental metrics bandwidth and delay under the given PU traffic model and investigate its relationship with different factors, such as, PU idle time, PU access time, number of PUs and also the number of traffic channels that cause variations dynamically. We employ a CSMA based MAC protocol that uses a dedicated control channel to negotiate the use of a traffic channel between a pair of SU sender and receiver. The two performance metrics are derived based on the fact that SUs can exploit the cognitive radio to simultaneously access distinct traffic channels in the common interference region. The delay estimation is based on the priority queuing model M/G/C in which PUs belong to a high priority queue while SUs are grouped into a low priority queue. The queues are served through C servers or channels such that the low priority queue is served only if the number of PUs in the queue are lesser than the number of channels. It is shown that, though, the bandwidth of a SU is limited due to the PU traffic, the aggregated throughput can be enhanced significantly up to five times by enabling concurrent transmissions of SUs through distributed coordination incorporated with the CSMA scheme and the delay is also minimized significantly.

The remainder of the paper is organized as follows. The existing work on performance analysis of cognitive radio network is reviewed in Section 2. In Section 3, we describe the PU and SU network model. Section 4 provides an overview of the CSMA based MAC protocol along with the bandwidth formulation for SUs. Numerical results are provided in Section 5 and finally the paper is summarized in Section 6.

2. Related work

Performance of MAC protocols for cognitive radio network has been investigated in the literature, where some consider delay as the performance metric [13–17] while other perform throughput analysis. These studies generally model the PUs and SUs as priority queues giving PUs the highest priority. Recently, a performance analysis of CSMA MAC is also provided for ad hoc networks [3] but it does not incorporate dynamic channel access in CRSN. In [13], a M/G/1 system containing one primary user and multiple secondary users is modeled to analyze the delay and throughput on a single channel or server at a time with the function of traffic and channel conditions. Based on the analysis, the secondary user is considered to act as a relaying terminal to assist the primary communication by adopting an amplify-and-forward TDMA protocol. This analysis does not apply to CRSN in which nodes can experience interference from many PUs and also the TDMA is hard to implement in CRSN. Authors in [14] also investigate the packet delay of SUs through queueing analysis with PUs getting higher priority queue than SUs. In [15], authors conduct performance analysis by considering both spectrum sensing and retransmission. Stochastic network calculus is employed to analyze performance distribution bounds for both primary users and secondary users under different retransmission schemes. Then performance analysis is conducted based on stochastic network calculus, where expressions for backlog and delay bounds are derived. These studies are based on the phenomenon that only a single queue can be served at any given time ignoring the potential of accessing multiple channels simultaneously in a common interference region. Delay of SUs is also investigated in [16] using fluid queue theory in which steady state queue length is analyzed for SUs. The delay analysis is based on two cognitive radio interfaces employed by the SUs which does not apply to CRSN due to the size and cost of nodes.

Performance is also analyzed in terms of secondary users throughput. Some medium access control algorithms analyse the throughput specific to their design approach. In [4], bandwidth is restrained by an active pair of users and the availability of multiple idle channels is not realized simultaneously to obtain the potential bandwidth of cognitive radio users. A power and rate adaptive CSMA based protocol [8] analyses the potential bandwidth with the aim of transmitting simultaneously with the PU, yet the simultaneous access of channels is not explored for aggregated bandwidth. SU performance is also analyzed in [9] that models channels as preemptive queuing server allowing PUs to preempt the channel from SUs, thus modeling only the delay incurred in SU transmission and do not investigate the bandwidth. Hence, the existing schemes do not provide performance analysis of SUs in more rigorous way to facilitate the operations of higher layer protocols and this is the first study to investigate the problem for CRSN.

3. System model

In this section, we describe the basic assumptions about the cognitive radio sensor network for analyzing performance. In cognitive radio sensor networks, primary users are more privileged users of the spectrum unlike the