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Stochastic backlog and delay bounds of generic rate-based AIMD congestion control scheme in cognitive radio sensor networks

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ABSTRACT

Performance guarantees for congestion control schemes in cognitive radio sensor networks (CRSNs) can be helpful in order to satisfy the quality of service (QoS) in different applications. Because of the high dynamicity of available bandwidth and network resources in CRSNs, it is more effective to use the stochastic guarantees. In this paper, the stochastic backlog and delay bounds of generic rate-based additive increase and multiplicative decrease (AIMD) congestion control scheme are modeled based on stochastic network calculus (SNC). Particularly, the probabilistic bounds are modeled through moment generating function (MGF)-based SNC with regard to the sending rate distribution of CR source sensors. The proposed stochastic bounds are verified through NS2-based simulations.

1. Introduction

Inefficient usage of spectrum in traditional wireless networks has lead to use of dynamic spectrum access (DSA) solutions. Cognitive radio (CR) technology is a capable tool to provide DSA and significantly improve performance and spectral efficiency in the next generation wireless networks [1]. A wireless network with CR-equipped nodes is called a cognitive radio network (CRN) [2]. A CR node senses the spectrum channels to find some vacant channels, i.e., the channels that are not occupied by primary users (PUs). Primary users in CRNs are the licensed users that have higher priority to use the licensed channels and CR users can only use the licensed channels in the absence of PUs. After spectrum sensing, the CR node selects an appropriate channel among the vacant channels in order to data transmission (spectrum decision) and if it is needed, a spectrum handoff is occurred (spectrum mobility). Since a CR node senses the channels periodically, if a PU enters into its licensed channel, the CR node detects the presence of PU and leave the channel immediately in order to minimize the interference on the transmission of PUs [2]. Cognitive radio is widely used in the different types of traditional wireless networks. Using of CR in traditional wireless sensor networks (WSNs) defines a new type of wireless networks called cognitive radio sensor networks (CRSNs) [3]. The DSA capability of CR sensors can reduce the collision, congestion and retransmission probabilities in the applications of WSNs with bursty traffic. Moreover, opportunistic spectrum access of CR sensors improves the transmission efficiency which leads to save and reduce the power consumption of resource-limited sensors in CRSNs [3].

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The dynamicity of available bandwidth in CRSNs because of PUs' activity and the operations of spectrum sensing and handoff, has crucial impacts on the performance of MAC, network and transport layer protocols. The main objective of CRSNs cannot be appropriately realized if the effects of unique features of CRSNs are not considered in the evaluation and the tunning of the parameters of different layers protocols. Hence, the performance evaluation of the protocols based on the CR-related parameters is critical in order to provide the quality of service (QoS) objectives in CRSNs. In this paper, we focus on the performance of congestion control schemes in CRSNs.

Providing the transport layer-based QoS can be important in various applications of CRSNs. The performance metrics of transport layer should be studied and modeled to satisfy various QoS guarantees in CRSNs. There are some studies [4–13] about the performance evaluation of transport layer in CRSNs and CRNs. Most of these papers evaluate the performance of transport layer protocols in CRNs and CRSNs based on simulations. In [14], the sending rate distribution of rate-based congestion control schemes is modeled in CRSNs. The [15] investigates the optimality of rate-based AIMD and AIAD congestion control schemes in CRSNs. However, there is no analytical modeling of rate-based congestion control schemes in the terms of stochastic backlog and delay bounds in CRSNs.

Stochastic network calculus (SNC) is a min–plus algebra based theory in order to model the probabilistic backlog and delay bounds of different network elements [16]. SNC is originated from its deterministic version as introduced by Cruz [17,18] and is developed in [19]. There are some SNC-based performance evaluation studies in CRNs [20–24]. However, there is no SNC-based study on the congestion control schemes in CRNs and CRSNs. Modeling the stochastic backlog and delay bounds of rate-based congestion control schemes based on the SNC can be used to provide QoS in various applications of CRSNs. To the best of our knowledge, there is no modeling of stochastic delay and backlog bounds of rate-based congestion control schemes for CRSNs based on SNC in the current literature. Among the rate-based schemes, we focus on the popular one, i.e., generic additive increase multiplicative decrease (AIMD) [25]. In this paper, the stochastic backlog and delay bounds of rate-based generic AIMD congestion control scheme are modeled in CRSNs. The stochastic bounds are modeled through moment generating function (MGF)-based SNC [26] based on our previous work on the modeling of the sending rate distribution of CR source sensors in CRSNs [14]. The proposed bounds are verified through various NS2-based simulations.

In the rest of paper, Section 2 explains the related work. The system model of CRSN is described in Section 3. Section 4 explains the sending rate distribution of CR source sensors. The stochastic backlog and delay bounds are modeled in Section 5. Analytical results and simulation-based verifications are presented in Section 6. Finally, we conclude the paper in Section 7.

2. Related work

To the best of our knowledge, there is no modeling of stochastic backlog and delay bounds of rate-based congestion control schemes for CRSNs and CRNs based on stochastic network calculus. In [4], the impacts of CR-related parameters on the performance of congestion control schemes are investigated in CRSNs. The challenges of real-time transport over CRSNs in various spectrum environments of smart grid applications are studied in [5]. The throughput and efficiency of TCP protocol in CRNs are investigated simulation-based in [6]. Authors in [7] study the impact of PU' activity, spectrum sensing time and the number of wireless channels on the TCP throughput. In [8], the behavior of TCP throughput, the size of congestion window and the value of round trip time (RTT) are studied with regard to the heterogeneity of spectrum channels, the spectrum sensing frequency, PU' traffic. In [9], the impact of spectrum sensing time and the changes of the available bandwidth of CR nodes on the behavior of TCP congestion control are studied. A study on the TCP performance degradation in CRNs with regard to the congestion window size, RTT behavior and retransmission timeout (RTO) is done in [10]. In [11], based on the PU' activity and the number of available wireless channels, the performance of TCP throughput is evaluated. An equation-based transport protocol for CRNs is introduced in [12]. Authors in [13] investigate on the TCP end-to-end delay, throughput and packet drop probability with regard to the packet size and various CR-related parameters. However, most of these studies investigates the performance evaluation of transport layer in CRNs and CRSNs based on simulation and there is no analytical modeling of rate-based congestion control schemes.

Some researchers study on the performance evaluation modeling based on stochastic network calculus in CRNs. In [20], the effects of spectrum sensing errors and various retransmission schemes in CRNs are investigated based stochastic network calculus. In this study, the backlog and delay bounds for primary and secondary users are modeled. The authors of [21] propose a stochastic arrival curve for spectrum sensing error process and a stochastic service curve for a Gilbert–Elliott fading wireless channel in CRNs. Based on the proposed arrival and service curves, the capacity limits of CRNs under wireless fading channel are modeled. The [22] proposes an SNC-based approach to find the capacity of CRNs under the period and Poisson traffic types with delay constraints. In [23,24], the delay bounds for cognitive radio users and primary users in CRNs with parallel Markov modulated On–Off channels are analyzed based on stochastic network calculus. However, there is no stochastic backlog and delay bounds modeling of rate-based congestion control schemes in CRSNs and CRNs.

In [14], the sending rate distribution of rate-based congestion control schemes in CRSNs is modeled based on a semi-Markov chain and the congestion probability of network. The congestion probability of network is calculated based on the proposed models of the queue length distribution and delay overhead of MAC layer. In [15], the optimality of rate-based congestion control schemes is investigated in CRSNs. In this study, the optimal rate-based congestion control schemes are obtained in order to maximize the new defined metric called Rate–Congestion Ratio (RCR). The maximization of the RCR leads to maximize the mean sending rate of congestion control scheme and minimize the congestion probability of network