AN ANALYTICAL MODEL TO CALCULATE BLOCKING PROBABILITY OF SECONDARY USER IN COGNITIVE RADIO SENSOR NETWORKS

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Abstract: The new trend in telecommunication is to use underutilized spectrum by dynamic spectrum access (DMA) using cognitive radio technology. A node (secondary user, SU) in cognitive radio network (CRN) exploits a spectrum channel in the absence of the spectrum owner (primary user, PU). The SU must evacuate the spectrum when the PU appears to use the channel. This significantly reduces the TCP throughput which works based on the assumptions that each packet loss is due to the congestion that inherently exist in wired networks. The PU presence in the channel causes a secondary units (SUs) blocking loss (SBL). In this paper, two main factors of SBL, is identified and the probability of them are modelled by a discrete-time Markov chain (DTMC). Through this analytical model, packet loss that happens due to the actual congestion can be distinguished from the packet loss induced by cognitive radio sensor network CRSN channel including, spectrum sensing, spectrum mobility and etc. The proposed model analytically captures effect of primary user's behaviours on the performance of the CRSN TCP. The SBL probability estimation helps network to avoid TCP performance degradation by differing between actual and wrong congestion situations. Performance of TCP protocol in term of throughput metric in CRSN is discussed. To the best of our knowledge, this is the first work to segregate SBL from the congestion in the buffers.

Key words: TCP, cognitive radio sensor network, SBL, primary user, secondary user

1. INTRODUCTION

With the current wireless network spectrum allocation policy, almost all the available spectrums are statically allocated to the licensed users. Inefficient spectrum for various communications, technology development and increasing use of wireless networks for different services, caused spectrum shortage. Many licenced users cannot utilize their spectrum efficiently as indicated by the federal communications commission (FCC) report [2]. Dynamic spectrum access (DSA) is a solution to this problem by letting spectrum sharing between licenced and unlicensed users. Cognitive Radio Network (CRN), is a wireless network that its nodes have Cognitive Radio (CR) capabilities [4] to implement DSA and have operations of spectrum sensing, decision and spectrum handoff [3]. Components of CRN architecture can be divided into two categories called: primary and secondary networks. Primary network is a traditional wireless network which has license to use some spectrum bands while the secondary network wants to access the same bands does without having any licence. There are two kinds of users: primary users (PUs) are the licensed nodes of primary network that have a higher priority than secondary unlicensed users (SUs). The SU's can use the licensed band during the absence of PUs and must immediately evacuate the channel otherwise and find an alternative channel or wait until the channel is set free by the PU. Such a sudden change in the system throughput can affect the performance of the network protocols (such as TCP) that are designed earlier without considering such variable channels. TCP is the most commonly used protocol of the transport layer that is initially developed for wired networks that regulated the traffic based on controlling congestion, the only cause of packet loss in such networks. Many applications use TCP as a reliable and connection oriented transport layer protocol so that about 90% of the frames containing TCP segments [4]. In wireless networks, there are other causes of packet loss that mislead TCP to wrongly shape the traffic and reduces the throughput rather than optimizing it. When a PU occupies the channel, the SU leaves the channel (spectrum handoff), and as a result the route is broken and some packet is lost. TCP, according to its nature, assumes that each packet loss is a sign of congestion and hence it invokes congestion avoidance algorithm and decreases its transmission rates by reducing TCP congestion window. In this paper a new type of packet loss called secondary user blocking loss (SBL) is introduced. The SBL is a part of the total packet loss in CRSN that is caused by PUs activities. The delay that is happened during the SUs' channel handoff causes RTO timer in TCP to expire. Actually secondary user's communication may be blocked due to:

1- Presence of primary user in the channel and no alternative channel found
2- There is no free channel

In this paper, two main causes of SBL is identified and the probability of SBL is modelled by a discrete-time Markov chain (DTMC). Through this model, the packet loss from congestion is segregated from packet loss from CR operation (spectrum sensing, spectrum mobility and etc.). This paper has following sections. First section comprehensibly explains TCP challenges in CRSN. Section 2 outlines the research works to overcome TCP performance degradation. The CRSN architecture is investigates in section3 and the proposed analytical model is described in section 4. Consequently, section five concludes our paper.

2. RELATED WORKS

TCP in the cognitive radio networks originally encounters more difficulties than in the traditional wireless networks. Primary user's activities and CRN inherent channel characteristics play significant role in occurrence of these problems. Some researches reveal the TCP challenges over CRN and some other concentrate on the improvement of TCP performance over the CRN and the CRSN.

Papers in [5, 6, 7, 8, 9] analysed CRN environments using Markov models by considering a limited number of CRN characteristics and therefore, cannot give realistic results. In general, researches focused on studying the TCP in cognitive radio sensor network in the following areas.

Performance evaluation of TCP over CRSN using the analytical model is conducted in [10, 11]. The authors investigated impact of CRSN specific characteristics such as spectrum sensing and spectrum mobility and primary user activities, on the TCP performance. Their main aim is to investigate the impact of CRSN environment on the TCP performance without considering the physical layer and MAC sub-layer performance.

Understanding the problems that TCP encounters in CRSN is useful to design optimized or near optimized transport layer protocol for CRSN. In [12], the impact of variable channel capacity of dynamic spectrum access and the probability of false alarm as a parameter of PUs activities are investigated on the throughput of TCP. Simulation based performance evaluation shows that sensing time has significant effect on TCP throughput. TCP performance is investigated over cognitive radio ad-hoc network (CRAHN) in [13] using an extension of NS2 to evaluate their CRAHN model that supports SUs spectrum management operations. By assuming a specific model for PU activities, it proves PU activities and SU sensing spectrum scheme plays significant roles in degrading TCP throughput. The research in [5] demonstrated that how traditional TCP variations are not suitable for CRNs. They presented an analytical model for calculation of TCP throughput. Using a continuous Markov chains, [14] presented an analytical model to estimate SUs performance in a term of throughput under the variable PUs traffic. Impact of primary/secondary user's traffic, the number of channel on the TCP performance of secondary users are analysed.

The cross-layer designs based on the CR-related operations (such as spectrum sensing, decision, and handoff) is considered by many researchers [15, 16, 17, 18, 19, 20, 21 and 22] to enhance transport layer performance in the term of throughput and delay. Researchers believe that instead of changing TCP and using alternative transport layer protocols, wireless networks must be optimized to enhance TCP performance.

Some studies have designed new transport layer protocol instead of TCP in CRSN [23, 24, 26, 26, and 27] in view of the belief that the CRSN requires its own transport layer protocol to avoid violation of the CRSN objectives. The proposed transport layer protocols are mostly enhanced TCP protocol.

3. CRSN ARCHITECTURE

Figure 1 shows a typical CRSN network with various types of CR sensor nodes that transmit data toward a sink node by multi-hop links. Spectrum sensing is a part of CR sensor nodes activity. If a vacant channel is found, these nodes opportunistically send data to the next available nodes and eventually sink node as its ultimate destination. It is assumed that sink node is equipped by unlimited power and more than one transceiver to send and receive data simultaneously. The CRSN node has a radio transceiver unit that enables to sense spectrum and dynamically adapt its parameters such as transmission power, carrier frequency and modulation [28].

It is expected that TCP faces serious problems from multi-hop communication, self-organization, having no centralized entity and dynamic topology to prepare end to end communications when compared to single hop environments. Furthermore, TCP performance can severely degrade because of some inherent characteristics of CRSN such as high probability of routing failure due to the PU arrival.

CRSN node cannot concurrently send/receive packet at the spectrum sensing time because of half-duplex communication ability. In this state, source node does not know the status of intermediary nodes, therefore it sends data packets. Many of these packets have to be saved in the buffer of sensor nodes (Figure 2). Packet loss due to buffer overflow and sending many data packet to the next hop are other results of long sensing duration which will mostly degrade TCP performance in the term of throughput in CRSN.

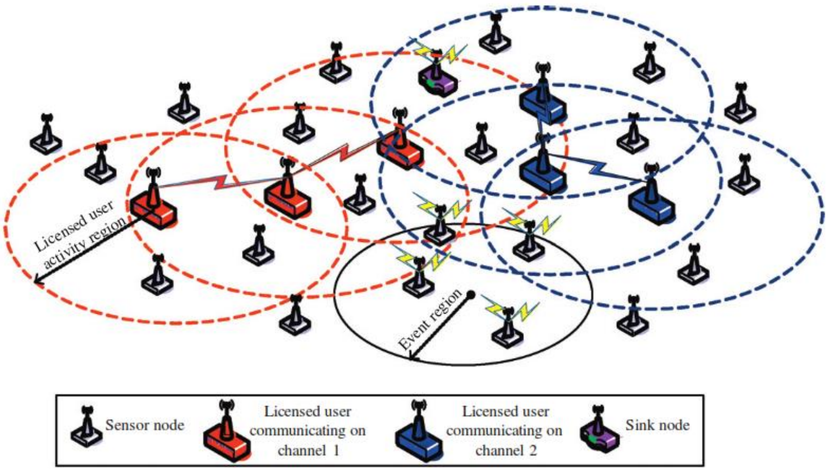

Fig. 1. A typical CRSN network architecture [28]

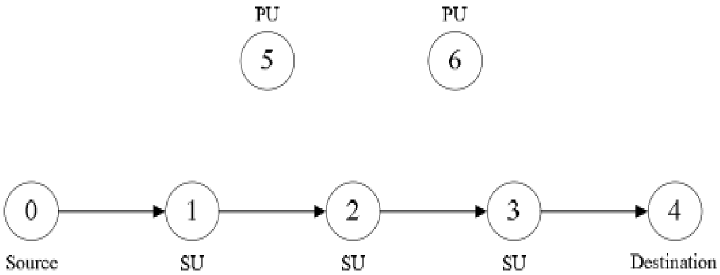

Fig. 2. CRSN multi-hop communications

4. TCP PROBLEMS IN CRSN

The main deficiency of TCP is that it cannot identify the source of error to adjust the transmission rate accordingly. Furthermore, it cannot effectively and efficiently monitor multiple network conditions that results in data transmission discontinuity. For instance, in the spectrum sensing period, the SU halts data communication or SU's radio modules work on half-duplex mode to cover upstream and downstream data flow. As a result, TCP experiences low performance and hence it is essential to be modified or replaced with new protocols.

In this section, an analytical model is developed to determine the SUs behaviour. Furthermore, blocking probability of SUs (P_{block}) is calculated in CRSN. The N channels are available and there is one PU per each channel. PU traffic is modelled by two states ON-OFF Markovian states with the arrival rate of β and departure rate of α. P_{ON} is the probability of PU operation on the channel and P_{OFF} is the probability that channel is not occupied by PU [28]. The SU activities divide into sensing and operating time. It senses the channel to determine whether channel is idle or busy by a PU in the sensing time. If a free channel is found, the SU can transmit data over it during the operating time. It is assumed that there is no error in PU detection in the channel.

The network of the current paper is a classic wireless sensor network with cognitive radio ability. We assume that for each cognitive radio channel there is at least one primary user. Sending data packet by SUs is blocked either when there is no free channel after sensing or by primary user presence on the channel. Accordingly, the secondary user must find an alternative vacant channel. If there is no free channel, it must wait until primary evacuate channel.

PUs and SUs Poisson arrival rates is assumed to be λ_p and λ_s. Also, the service rates are μ_p *and* μ_s. Each state has been denoted as (*i, j*) where *i* and *j* represents the number of active PUs and SUs in the CRSN respectively. For example, (*3,1*) denotes a model with 4 available channel, and there are 3 secondary users and one primary user where occupy 4 channels in *CRSN*.

P_{block} is a state that the secondary user is blocked due to primary user activities or there is no free channel. $P_{i,j}$ is the steady state probability of state (*i, j*). The probability that *i* SUs and *j* PUs are active and occupy *i+j* channels. $P_{block\ i,n-i}$ denotes the steady state probability of state ($block_{i,n-i}$). It is the blocking probability due to:

1-One PU returns to the channel and want to send packets.

2-All of N channels are occupied and there are no vacant channels.

For example, in 3 channels model in Figure 3, one channel is allocated to one SU and two channels are owned by two PUs.

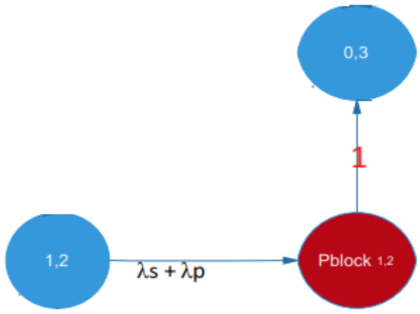

Fig. 3. Transition from common state to blocking state

While all 3 channels are occupied by one SU and two PUs, state (*1,2*), when the second PU returns to its channel with the rate of λ_p the SU must leave the channel. The event transition is shown by moving from state *(1,2)* to state $P_{block\ 1,2}$. Consequently the channel is allocated to the newly arrived PU. This event transition is denoted by moving from state ($P_{block\ 1,2}$) to state (0, 3) in the Markov model. On the other hands, when all of 3 channels are filled by one SU and two PUs, state *(1,2)*, if a SU, if a PU want to transmit on a channel with the rate of λ_s, because of all channels are occupied then SU traffic locates in the block situation. This event transition is denoted by moving from state *(1, 2)* to state ($P_{block\ 1,2}$).

Whole blocking probability of SUs is given by the sum of all blocking probability which is:

$$P\ block_{Total} = \sum_{i=0}^{n} P_{i,n-i} \quad (1)$$

For example, whole blocking probability is calculate according to following equation in 3 channels model:

$$P\ block_{Total} = Pblock_{0,3} + Pblock_{1,2} + Pblock_{2,1} + Pblock_{3,0} \quad (2)$$

The proposed Markov chain and transition matrix are shown by Figure 4, for 3 channels model.

$$\begin{pmatrix}
0 & \lambda_p & 0 & 0 & \lambda_s & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mu_p & 0 & \lambda_p & 0 & 0 & \lambda_s & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 2\mu_p & 0 & \lambda_p & 0 & 0 & \lambda_s & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 3\mu_p & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda_s & 0 & 0 & 0 \\
\mu_s & 0 & 0 & 0 & 0 & \lambda_p & 0 & \lambda_s & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \mu_s & 0 & 0 & \mu_p & 0 & \lambda_p & 0 & \lambda_s & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \mu_s & 0 & 0 & 2\mu_p & 0 & 0 & 0 & 0 & 0 & \lambda_s + \lambda_p & 0 & 0 \\
0 & 0 & 0 & 0 & 2\mu_s & 0 & 0 & 0 & \lambda_p & \lambda_s & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 2\mu_s & 0 & \mu_p & 0 & 0 & 0 & 0 & \lambda_s + \lambda_p & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 3\mu_s & 0 & 0 & \lambda_p & 0 & 0 & \lambda_p \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0
\end{pmatrix}$$

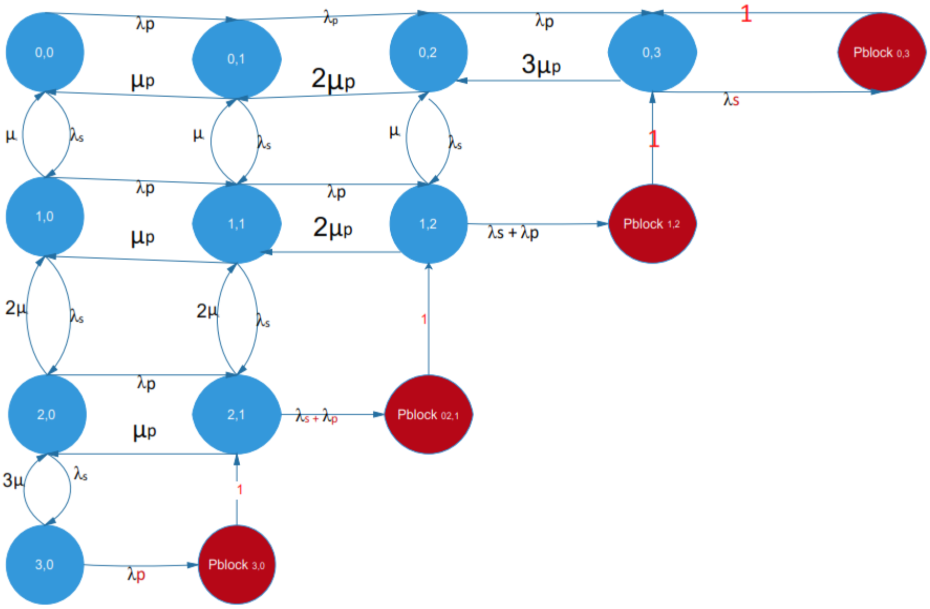

Fig. 4. 3 channels Markov model and transition matrix

5. ANALYSIS THE BLOCKING PROBABILITY

In this section Blocking is calculated based on transition matrix. Furthermore, influence of it is investigated on network performance. Figure 5, shows the variation of $P_{blocking}$ as a function of λ_p.

Figure 5, Shows the blocking probability is increased with the increase of primary user arrival rate (λ_p). With the increasing the PUs arrival rate, the amount of traffic and PU's activity can be increased in each channel, hence more SUs transmission is not completed and they are located in the blocking state.

It is observed that by increasing number of channels the SU blocking probability rate is decreased in each curve. This reduction is due to the fact that by increasing number of channels, SU's chance to occupy the channel and transmission of data is increases. Consequently, with the less SU's transmission intrupt, there will be less blocking probability.

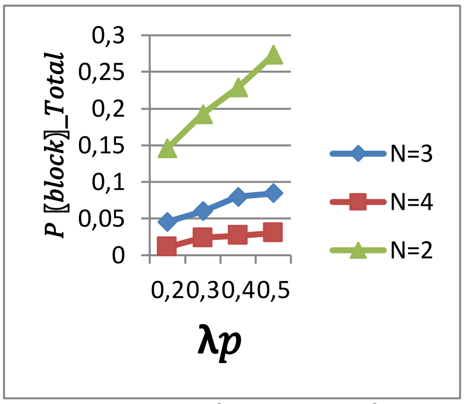

Fig. 5. Variation of P $_{blocking}$ as a function of λ_p

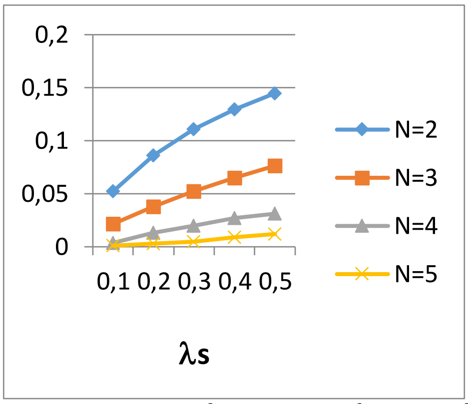

Fig. 6. Variation of $P_{blocking}$ as a function of λ_s

Figure 6, shows SU Blocking probability variation as a function of secondary user arrival rate (Λ_s) for 2, 3, 4 and f channels model.

By increasing secondary user arrival rates, $P_{blocking}$ is increased per each N channels model. Intuitively, when SU's traffic are increased, the compeition between SUs to access the vacant channel is increased too, hence more SUs are blocked. With the smaller number of channels, there will be more channel is blocking. As results, increasing the $P_{blocking}$ will be faster. With the increasing number of channels, the secondary users chance is oppotunitically enhanced to access channel dynamically, therefore the blocking probabilty of SU is reduced.

The $P_{blocking}$ variations as a function of primary user service rate for N channels models are shown by Figure 7.

Figure 7, obviously shows that by increasing μ_p, secondary user blocking probability is decreased. By increasingμ_p, channel access time of primary users are decreased, therefore chance of channel allocation is increased by each secondary user. Furthermore they can occupy channels more times and blocking probabilty rate is decreased. Eventually, Figure 8, Shows $P_{blocking}$ varation according to secondary users service rate (μ_s).

Decreasing amount of P_{blocking} with the increase of μ_s due to this fact that faster secondary users service rate causes faster SU transmission completion and more chance of other secondary users to find vacant channels.

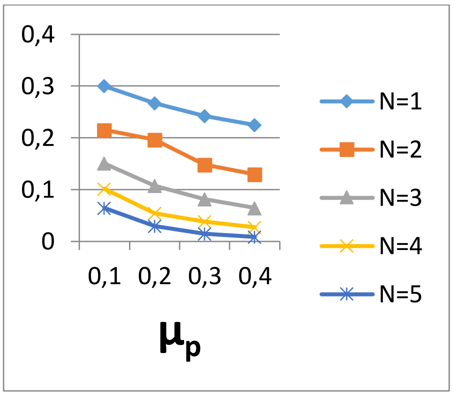

Fig. 7. Variation of P $_{blocking}$ as a function of μ_p

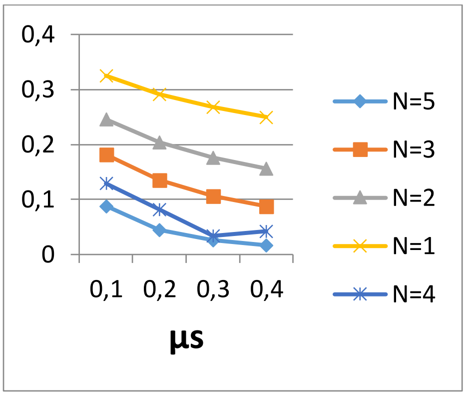

Fig. 8. Variation of $P_{blocking}$ as a function of μ_s

4. CONCLUSION

In this paper, we investigated TCP behaviour as a well-known transport protocol on CRSN. Many reasons are discussed for CRSN performance degradation as a term of throughput parameter. We introduced SBL as a new type of packet loss. 2 main factors are caused this kind of packet loss. Primary user's activities play main role to occur secondary user handoff because of prioritized primary system. During the secondary user transmission, if a primary user is detected, it connection is blocked. Packet loss that is happened because of this condition is wrongly guessed congestion. For distinguish between SBL and packet loss due to congestion, The Sus dynamic spectrum access is modelled by the discrete-time Markov chain (DTMC). With the investigation of this Markov model, the blocking probability of the secondary users are computed this model help us to calculate secondary user blocking probability. The proposed analytical model considers effects of Pus and Sus arrival and service rates in estimating secondary user blocking probability.

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