Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2019) 27: 2081 – 2092
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doi:10.3906/elk-1706-292

Impact of the primary user on the secondary user blocking probability in cognitive radio sensor networks

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Received: 23.06.2017 • **Accepted/Published Online:** 06.11.2018 • **Final Version:** 15.05.2019

Abstract: With the increasing usage of wireless sensor network technologies, their unlicensed bands become overcrowded. To address this challenge, cognitive radio technology with the dynamic spectrum access policy has merged with Wireless Sensor Network to overcome spectrum underutilization. The Cognitive Radio Sensor Network (CRSN) has emerged as a promising solution to overcome spectrum scarcity in a resource-constrained wireless sensor network. In CRSN, TCP has to cope with a new type of packet loss due to the primary users (PU) arrival, known here as a secondary user (SU) blocking loss. In this paper SU blocking loss is modelled by a discrete-time Markov chain. The experimental results are verified using the NS2.

Key words: Transport protocol, cognitive radio network, wireless sensor network, secondary user blocking probability, discrete-time Markov chain.

1. Introduction

With the traditional spectrum assignment policy, almost all the available spectra are statically allocated to the licensed users [1]. Furthermore, many licensed users cannot utilize their spectrum efficiently, as indicated by the federal communications commission (FCC) report. Dynamic spectrum access (DSA) is a key enabling technology to solve these problems by sharing the spectrum among licensed and unlicensed users. Cognitive Radio Network (CRN) is a wireless network, where its unlicensed users, referred as the secondary users (SUs) are equipped with a CR transceiver to sense the spectrum and to exploit the vacant channel opportunistically [2]. Wireless Sensor Networks (WSNs) exclusively operate over unlicensed bands so the bands become overcrowded. Cognitive radio technology aims WSN to utilize the spectrum effectively [3].

A Cognitive Radio Sensor Network (CRSN) is a distributed network of wireless cognitive radio sensor nodes, in which the sensor nodes sense an event signal. Furthermore, they collaboratively communicate their readings over available spectrum bands in a multihop manner. The CR sensor nodes can use the vacant channel during the absence of primary users (PUs) and evacuate the channel upon the arrival of a PU. The CRSN can improve the energy efficiency and increase the communication reliability of wireless sensor networks [4]. In this paper, we have concentrated on the performance of TCP in CRSN. TCP is the most commonly used protocol of the transport layer that is initially developed for wired networks. It regulates the traffic based on controlling congestion. The congestion is the only cause of packet loss in such networks, however, in wireless networks, there are other challenges to cause packet loss, i.e. noisy wireless channels in wireless networks, variable channel bandwidth, and random bit error rate, which could mislead TCP to shape the traffic and reduce the throughput.

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In addition, TCP throughput worsens in CRSN due to DSA activities, i.e. spectrum sensing, spectrum handoff, and mobility.

When a PU occupies the channel, the SU has to leave the channel (spectrum handoff). As a result, the route is broken and some packets are lost. According to its nature, TCP assumes that each packet loss is a sign of congestion and hence it invokes the congestion avoidance algorithm and decreases its transmission rates by reducing the TCP congestion window.

In this paper, a new type of packet loss, namely SU blocking loss (SBL) is introduced. Actually, SU's communication may be blocked due to:

- Presence of PU in the channel and no alternative channel found
- Lack of free channel

As a result of these features, the TCP connection of the SU may be ceased and they have to find a vacant channel. The long delay to find an idle channel, as well as lack of channel bandwidth may invoke a retransmission timeout (RTO). These features would cause a large amount of packet loss, which TCP mistakenly categorizes as a congestion loss. Accordingly, it starts a congestion control, which will largely affect TCP throughput. In this paper, two main factors of SBL are identified. Meanwhile, the probability of SBL is modelled by a discrete-time Markov chain (DTMC). Through this model, the congestion loss is segregated from packet loss due to CR activities. The SBL probability is used to propose new congestion algorithm in [5]. Section 2 reviews the related works. The system model of the CRSN architecture is investigated in Section 3. In Section 4, the new proposed analytical model for calculating SBL probability by a Markov chain is described. In Section 5, the experimental results verifications are presented. Finally, in Section 6, the conclusions are reviewed.

2. Related works

To the best of our knowledge, there has been no modelling of SU blocking probability for CRSN by a Markov model. The existing transport protocols are classified into two main categories, layered and cross-layered approaches. Layering is the traditional methodology in communication protocol stack, but it does not support exchange of information between nonadjacent layers. Cross-layer approach performs better in DSA-dominated networking because of supporting communications between layers. Furthermore, TCP copes with other serious problems such as insufficient infrastructure, multi-hop network, and lack of centralized network management.

In [6], the challenges for reliable data delivery in cognitive radio sensor networks are investigated. The experimental results show that the traditional transport protocols like TCP and UDP are not suitable for cognitive radio sensor networks because of lacking differentiation between packet loss happening due to congestion and PU activity. In [7], the first layered equation-based transport protocol, called TFRC-CR, is proposed. It is a sender-based approach which permits quick changes in the transmission rates according to the spectrum changes in the CRAHN environment. TFRC-CR uses FCC mandated spectrum database for recognizing PU activity. But in the case of spectrum hand-off, it will take a long time to adjust the rate to the newly available channel.

In [7], the optimally of generic rate-based AIMD and AIAD congestion control scheme is investigated in cognitive radio sensor network. In [8], the throughput of TCP over cognitive radio network is analysed.

Some studies have designed new transport layer protocols instead of TCP in CRAHN [9–13]. They believe that the CRAHN requires its own transport layer protocol to avoid violating of the CRAHN objectives. In [9], authors proposed a new cross-layer window-based transport protocol for cognitive radio ad hoc network called TP-CRAHN. The authors believe that the activity of CR users and bandwidth variation between channels are the key challenges in CRAHN. TP-CRAHN is proposed, which distinguishes between these events by a combination of explicit feedback from the immediate nodes and the destination. They modelled the transport protocol as a six-state FSM machine. Furthermore, TP-CRAHN employs the ECN mechanism to determine the loss cause. In [10], a cross-layer approach to maximize TCP throughput is presented over the CRN. The simulation results illustrate that the lower layer design parameters have a great impact on the TCP throughput. Actually, the optimization of lower layer parameters, i.e. spectrum sensing, physical layer modulation, data-link frame size, and coding scheme are considered to enhance the TCP throughput. In [11], an optimal spectrum sensing framework is developed for solving both the interference avoidance and the spectrum efficiency problem. In [12], a GNU radio based platform a point to multipoint transport protocol is specifically designed for cognitive radio environments. TFRC-CR [13] is proposed as the first equation-based transport protocol based on the TCP friendly rate control for cognitive radio network. It leverages the recent FCC mandated spectrum databases information instead of relying on any intermediate node feedback to have minimum querying overhead. The transmission rate enables to adjust its rate by making the difference between true and fake congestion situation. However, TFRC-CR has a slow response to an immediate reduction of loss event rate. Therefore, it needs longer time to adjust the rate of new available capacity. As a result, the wasting of time will have an effect on RTO value. OHTP [14] is an opportunistic hybrid transport protocol, which is proposed to overcome the spectrum scarcity over cognitive radio network. In fact, it is a hybrid congestion control algorithm between rate-based (TFRC-CR) and window-based transport protocol. In a greatly congested situation, where CWND value remains low, rate-based transmission, which is well-suited to give smoother throughput, otherwise, window-based transmission, is a better option.

3. CRSN architecture

In this paper, we investigate the CRSN architecture as shown in Figure 1. A CRN consists of wireless nodes equipped with cognitive radios, where the radios have cognitive and recon?gurable features and the capability to detect and exploit the spectrum holes for their communications. A key issue in CRNs is the uncertainty of the spectrum availability that poses several challenges in wireless networking and communications.

The cognitive radio sensor network is divided into the primary network and the CR WSN. The primary network is referred to as an existing network, where the PUs have a license to operate in a certain spectrum band. If primary networks have an infrastructure support, the operations of the PUs are controlled through primary base stations. Due to their priority in spectrum access, the PUs should not be affected by unlicensed users. The secondary network is a typical WSN, where the SUs have CR capabilities. On the other hand, the CR network (also referred to as secondary network, or unlicensed network) has no priority to operate in the licensed spectrum bands.

The SUs have the ability to sense the channels and find the underutilized spectrum in licensed and unlicensed spectrum bands opportunistically. Hence, it is equipped with additional functionalities, e.g., the spectrum sensing, to identify and opportunistically use the spectrum holes, these functionalities are essential to satisfy the QOS requirements and guarantee the protection of the primary systems from harmful interference.

Also, CR users are mobile, and can communicate with each other in a multihop manner on both licensed and unlicensed spectrum bands. The secondary network may include spectrum brokers that play a role in distributing the spectrum resources among SUs. There are three main spectrum sharing paradigms: underlay,

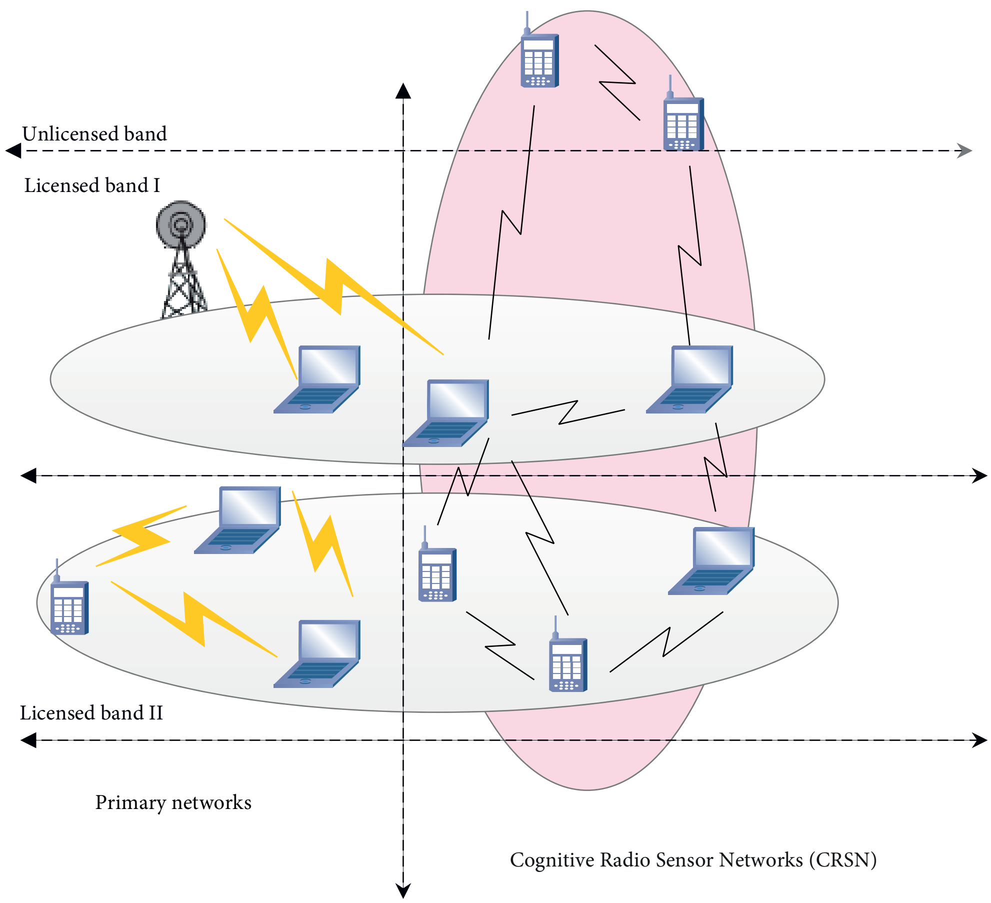

Figure 1. CRSN architecture.

overlay, and interweave. The overlay strategy is selected in our scenario. By using overlay spectrum sharing strategy, the SU can select a vacant channel, while ensuring that they impose no interference on PUs. The maximum interference period between a PU and a SU is the duration of sensing cycle. This unavailable (and sometimes negligible) interference is accepted by all cognitive radio systems [15].

Hence, spectrum sensing is the first step to detect PU activity for cognitive radio networks. Spectrum sensing accuracy is calculated by two parameters: probability of detection (P_d) and probability of false alarm (P_f). Probability of detection is the probability that the channel is occupied by PUs and the spectrum sensing has detected that the channel is busy. Probability of false alarm is the probability that CR user senses that the channel is busy but the spectrum is not used by PUs. The main objective of spectrum sensing is to operate in a channel that is free of PUs. It is important to find a free channel without interfering with the operations of the licensed network. There are various sensing methods which are used to find free channel in CRSNs. Cognitive network simulator (COGNS) simulator [16] uses a posteriori energy detection for spectrum sensing.

A CR node, which is known here as SU, has two main modes: sensing and operating modes. First, it senses the channel to find an idle licensed spectrum. If a vacant channel is found, the CR node enters the operating mode. These nodes opportunistically send data to the next available nodes and eventually sink node as its ultimate destination. The PUs' activity is modelled as exponentially distributed interarrivals; thus, their arrival to their related channels is independent. The traffic of a PU can be modelled as a two-state entrance-departure process with entrance rate of α and departure rate of β. A PU has two states: ON and OFF. The ON state denotes the period during which the PU operates on the channel and the OFF state is the period of time that channel is not occupied by PU.

4. Problem definition and formulation

TCP is a window-based, non-real-time transport protocol that provides reliable data transmission over the Internet. It is inherently designed to perform well for wired networks. It was later enhanced to deal with the channel errors in wireless networks. As mentioned, TCP has to face the SBL in CRSN. When a PU wishes to access a channel in which a secondary transmission is in progress, in our model, the SU will have to cease transmission in a short span of time. It is therefore important to analyze the capacity and performance of secondary systems in dynamic spectrum access. In this section, an analytical model is developed to determine the SU's behavior. Furthermore, blocking probability of SUs is denoted as P_{block}, is calculated in CRSN. Assuming that there are "n" available channels and one PU per each channel, the SU senses the channel to determine whether the channel is idle or busy by one PU in the sensing timing. 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 on the channel. The SU's communication may be blocked due to:

- Presence of PU in the channel
- Lack of any vacant channel

Accordingly, the SU must search for an alternative vacant channel or wait until the PU evacuates the channel. For each transition from one channel to another channel due to the PU's activity, there is a delay involved in the transition called spectrum hand-off delay.

All these factors decrease the predictability of the cause of transit delay and subsequent packet loss on the network. The time latency during channel hand-off in cognitive networks might cause the TCP round trip timer to time out. TCP will wrongly recognize the delays and losses due to the above factors as network congestion and immediately take steps to reduce the congestion window size not knowing the cause of packet delay. This reduces the efficiency of the protocol in such environments.

In this section, we will propose an analytical model to incorporate the effect of PU and SU traffic on the TCP performance. The PU and SU traffic are modelled using Markov chain and the blocking probability of the SUs is calculated. The system is modelled by discrete time Markov chain as shown in Figure 2.

We have a set of states,

$$S = \sum i = 0^n \sum_{j=0}^{n} ((i,j), \ldots, P_{block\,(i,ni)}) \tag{1}$$

Each state has been denoted by (i,j), where i and j represent the number of active SUs and PUs in the CRSN, respectively. For example, in 3-channel model ($n = 3$), (2, 1) denotes a state which 2 SUs occupy 2 channels and one channels is allocated to one PU. The process starts with one of these states and moves successively from one state to another. Each move is called a step. If the chain is currently in one state, then it moves to its adjacent state at the next step. The PU/SU's traffic is assumed to follow a Poisson arrival process and the service rate with mean rates λ_p, $\lambda_{s,}\,\mu_p$, and μ_s, respectively. These probabilities are called transition probabilities. P_{block}

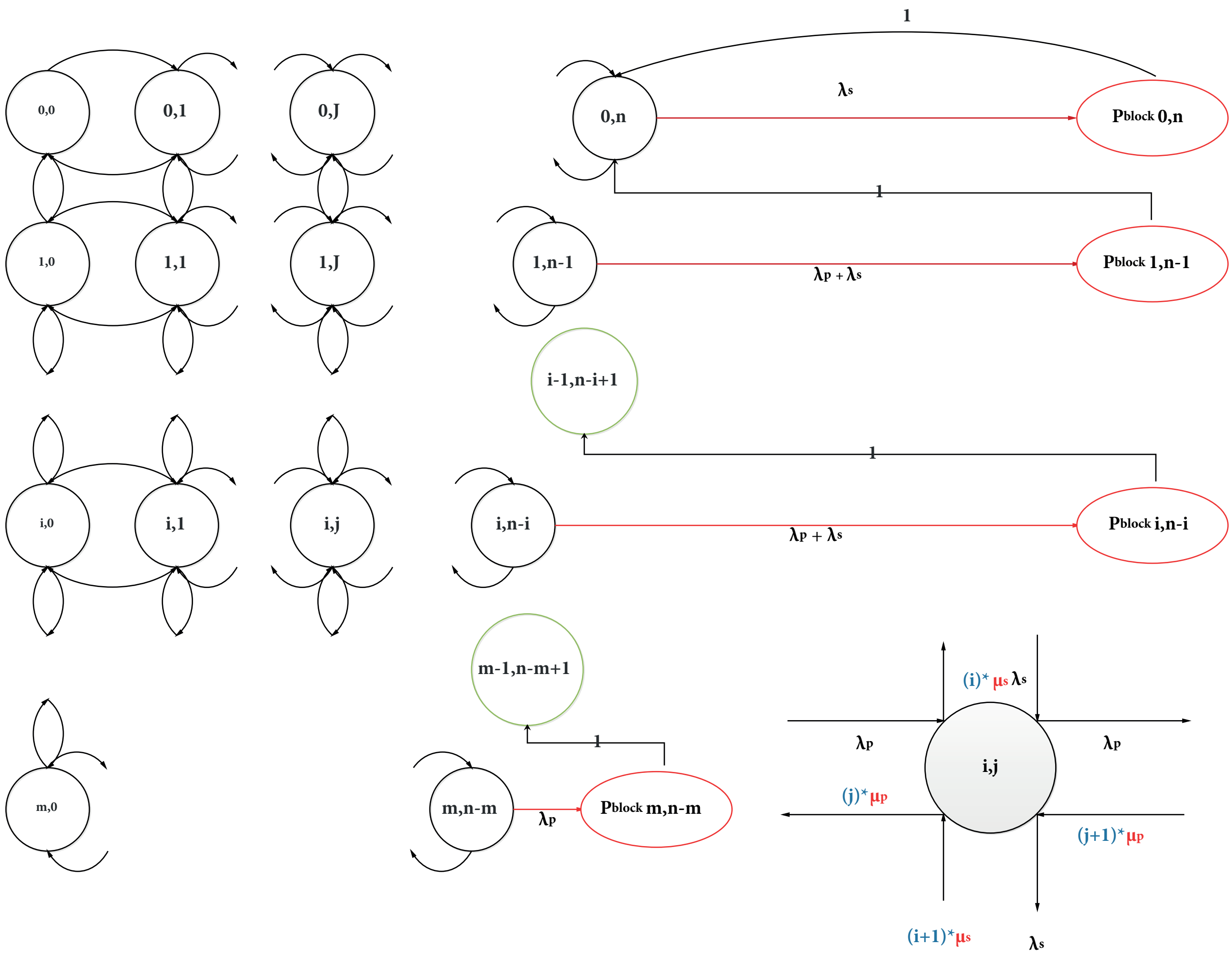

Figure 2. n channels Markov model and transition matrix.

is a state in which the SU is blocked either due to PU activities or lack of free channels. $P_{block\,(i,ni)}$ Represents a state in which all the channels are full and there are no free channels.

This model is represented in general by a discrete-state Markov chain governed by a two dimensional probability space $\pi\ (i,j),\ i=0,...n, j=0,...n,$ where indices i and j represent the number of SUs and PUs occupying the channels, respectively. Each $\pi(i,j)$ is denoted as the steady-state probability of state (i,j). $\pi_{blocki,\,n-i}$ denotes the steady-state probability of state (block $_{i,\,n-i}$). It means that there are n channels and "i" channels are occupied by i PUs and other channels are occupied by "$n-i$" SUs. Moving from one state to P$_{block}$ happens due to the following reasons.

- One PU returns to the channel and wants to send packets.
- All of the "n" channels are occupied and there are no vacant channels.

Figure 3 shows the 3-channel Markov chain, where the value of "n" is equal to 3 $(n=3)$. States (3,0), (1,2), (2,1), and (3,0) show the events that all channels are full in 3-channels model $(i+j=3)$.

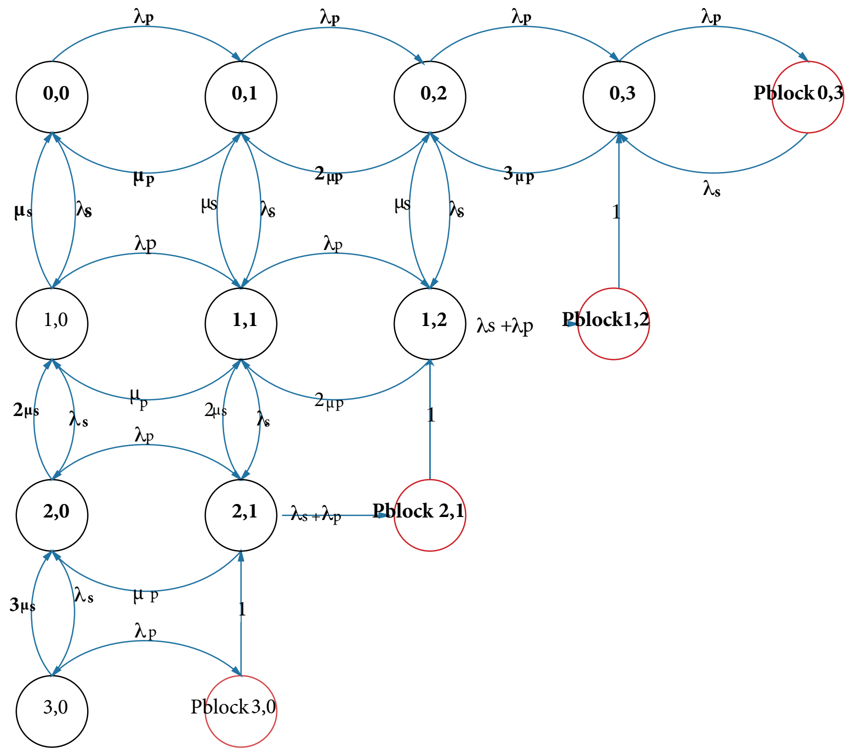

Figure 3. 3 channels Markov model.

The state (1,2) is considered, where all 3 channels are occupied by one SU and two PUs (state (1,2)). All 3 channels are occupied by one SU and two PUs (state (1,2)). When the third 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 the state (1, 2) to state P$_{block1,2}$. Consequently, the channel is allocated to the newly arrived PU. This event transition is denoted by moving from the state (P$_{block1,2}$) to state (0, 3) in the Markov model.

The steady-state probabilities are uniquely found using Eqs. (2) and (3):

$$\pi_{i,j} = \sum_{m,n} \pi_{m,n} * (p\,(m,n) \rightarrow p\,(i,j)\,), \qquad i\ =\ 0,\,..n\,,\ j\ =\ 0,\,..n \tag{2}$$

$$\sum_{\substack{0 \leq\ i\ \leq\ n \\ 0 < j < n}} \pi\,(i,j) = 1, \tag{3}$$

where the steady-state probability of state (i,j) is equal to sum of steady-state probability of the states that move to state (i,j) by the transition probability of $(p\,(m,n) \rightarrow p\,(i,j)\,)$. In the three channels model, states (0,1) and (1,0) transfer to state (0,0) by transition probabilities of μ_p and μ_s, respectively. They are the possible ways to get to the state (i,j). We denote $\pi\,(i,j)$ as the steady-state probability of state (i,j). The steady-state probabilities of the reposed DTMC model can be found using the following pseudo code.

According to Eq. (3), we also have,

$$\sum_{i=0}^{i=n} \sum_{j=0}^{j=n} \pi\,(i,j) = 1 \tag{4}$$

$for\ (i=1; i\leq n1; i++)$

$for\,(j=1, j<ni, j++)$

$if\ (i+j\neq n)$

$\pi\,(i,j)=\pi\,(i+1,j)\times(i+1)\mu_s+\pi\,(i,j+1)\times(j+1)\mu_p+\pi\,(i,j1)\times\lambda_p+\pi\,(i1,j)\times\lambda_s$

$else\{$

$\pi\,(i,j)=\ \pi\,(i,j1)*\lambda_p+\pi\,(i1,j)\,\lambda_s+\pi_{block(i,j1)}$

$for\,(i=0; i\leq n1; i++)$

$if\,(i\neq 0\,\&\&\,i\neq n)\,\{\,\pi\,(i,0)=\ \pi\,(i+1,0)\times(i+1)\mu_s+\pi\,(i1,0)\times\lambda_s+\pi\,(i,1)\,\mu_p\}$

$else\,if\,(i==0)\,\{\,\pi\,(i,0)=\pi\,(0,1)\times\mu_s+\pi\,(1,0)*\mu_p\}$

$else\,\{\,\pi\,(n,0)=\pi\,(n1,0)\,\lambda_s$

$for\,(j=1; j\leq n1; j++)$

$\pi\,(0,j)=\pi\,(0,j1)\times\lambda_p+(0,j+1)\times(j+1)\times\mu_p+\pi\,(1,j)\times\mu_s+\}$

At the block state, $\pi_{block(i,j)}$ is calculated according to following balance equation,

$for\ (i=0; i\leq n; i++)$

$for\,(j=1, j<ni, j++)$

$if\,(i+j==n\,\&\&\,i\neq 0\,\&\&\,i\neq n)\ \{\pi_{block(i,j)}=\pi\,(i,j)\times(\lambda_p+\lambda_s)$

$else\,if\ (\,i+j==n\,\&\&i==0)\,\{\pi_{block(i,j)}=\pi\,(i,j)\times(\lambda_s)\}$

$else\,if\ (i+j==n\,\&\&\,i==n)\,\{\pi_{block(i,j)}=\pi\,(i,j)\times(\lambda_p)\}$

P_{block} in the Eq. (5), is the whole blocking probability of SUs is given by sum of all blocking probability

$$P_{block}=\sum_{i=0}^{i=n}\pi_{block(i\,,\,ni)} \tag{5}$$

For example, whole blocking probability is calculated according to the following equation in 3-channel model.

$$P_{block}=\pi_{block(0,3)}+\pi_{block(1,2)}+\pi_{block(2,1)}+\pi_{block(3,0)} \tag{6}$$

$\mathbf{P_{block}}$ is known here as SBL probability. Furthermore, the calculated blocking probability by DTMC model is used for calculating TCP throughput. The value of P_{block} obtained using Eq. (5) will be used in the calculation of Tw in Eq. (9).

The Eq. (7) is developed to calculate TCP throughput of the SUs in the presence of the PUs. TCP throughput depends on the packet loss, segment size, and round trip time (RTT) [17].

$$Throughput=\frac{TCP\ \text{packet size}}{RTT}\sqrt{\frac{3}{2*\ \text{Packet loss probability}}} \tag{7}$$

RTT is the TCP packet round-trip time and it can be formulated as:

$$RTT = 2T_{sr} + kT_p * N_f + T_o + T_w \tag{8}$$

where the T_{sr} denotes one-way packet delivery time. N_f is the number of link layer (LL) frame retransmissions per TCP packet. "k" is the average number of LL frame retransmissions. T_p is the delay of automatic repeat request (ARQ) protocol and T_o is the channel scanning time. It is spectrum sensing duration to check the presence of a PU on the channel. T_w is the average delay that a packet incurs when the channel is not available. It can be defined as

$$T_W = \frac{T_i\left[P_{block} + P_f(1P_{block)})\right]}{1\left[P_{block} + P_f(1P_{block}\right]}, \tag{9}$$

where P_f is the probability of false alarm detection and T_i is the inter-scanning interval (operation duration). P_{Block} is the blocking probability of SUs which is achieved by aforementioned DTMC model. If no PU is detected on the channel, the SU is permitted to communicate on this free channel; otherwise, it should periodically wait for the next sensing duration.

5. Experimental results

In this section, performance of the proposed model is evaluated under the simulation environment described in Section 3, using the NS2 simulator. The COGNS framework is used under the cognitive radio sensor network environment with the simulating parameters listed in Table. P_{block} is evaluated by the analytical model (see Section 4) and verified by NS2. It was calculated by the analytical model in the former section. There are "n" licensed spectrum channels and the value of "n" was set to 2, 3, 4, and 5. As it is described in Section 3, each channel is occupied by a PU based on the ON/OFF model with the departure rate of β (when the channel is not used by a PU and can be used by a SU) and the entrance rate of α when the channel is occupied by a PU. The PU activity (β, α) is considered by the length of OFF and ON periods of PU transmissions. The default duration of ON/OFF state (β, α) is set to (1,1) on all channels; but these 2 rates are changed for various experiments. The SU's sensing time (T_o) and operating time (T_p) are considered as 0.02 and 0.04 s. The users (including SUs and PUs) are distributed on a 500 × 500 m^2 area. Number of sensor nodes are 25 with random motion. Constant bit rate (CBR) traffics are generated using TCP sources. The packet size is 500 bytes. The source sends packet at the rate of 512 packets per second. The routing protocol is Ad hoc on demand distance vector (AODV) and there are 10 wireless channels. For each wireless channel, the bandwidth is set to be 1 MHz. The SU blocking probability was calculated from several experimental results for different PU activity values.

Figure 4 shows the impact of primary and SU traffic (λ_p and λ_s) as well as number of channels on the SU blocking probability. The Eq. (5) obtained using DTMC model is used for calculating P_{block}.

In Figure 4a, the following parameters were used: number of channels were set to n = 2, 3, 4, and 5, respectively; λ_s= 0.3;0.1 $\leq \lambda_p \leq$ 0.5. The P_{block} variation with λ_p is shown in Figure 4a. As it is observable in Figure 4a, with more PU arrivals, there will be more PUs in the channels; hence more SUs are blocked.

In Figure 4b, the following parameters were used: number of channels were set to n = 2, 3, 4, and 5, respectively; λ_p= 0.3;0.1 $\leq \lambda_s \leq$ 0.5. The P_{block} variation with λ_s is shown in Figure 4b. Intuitively, with more frequent arrivals of SUs, the P_{block} will increase. When SU's traffic is increased, the competition between

Table. Simulation parameters.

Simulation parameters	Values
Network area size	500 × 500 m^2
Number of channels	1, 2, 3, 4, 5
Number of PU per channel	1
Routing algorithm	AODV
Transport protocol	TCP
Traffic type	CBR
Link layer frame size	512 bytes
Packet size	512 bytes
Packet error probability	10^{-6}
Channel bandwidth	1 Mbps
Queuing model	Drop tail
α	1
β	1
λ_p	0.1, 0.2, 0.3, 0.4, 0.5
N_f	2
T_{sr}	5 ms
T_p	0.04 s
T_o (spectrum sensing duration)	0.02 s

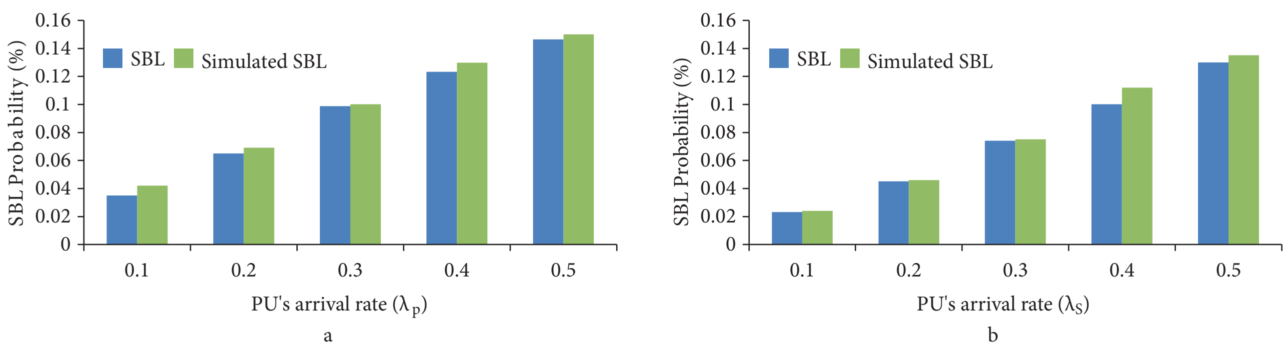

Figure 4. Variation of P_{block} as a function of λ_p (a) and λ_s (b).

SUs to access the vacant channel is increased tending to more SUs blocking. Figure 4a and 4b show that the calculated results are close to the simulation results.

Figure 5 shows the SBL probability as a function of PU activity. It is observed that by increasing the 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, the SU's chance to occupy the channel and transmission of data increases. Furthermore, when the PU entrance rate (α) is greater than the PU departure rate (β), 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. According to Figure 5, the SBL probability is increased during the high PU activities, that is (1,2) and (1,3).

The value of throughput is proportional to the number of channels in Figure 6. It is observed that by increasing of the number of channels (n), the total throughput is increased. This enhancement is due to the fact that by an increasing number of channels, the SU's chance to find a vacant channel has increased. This is in accordance with the general rule in the traffic theory that increase in the number of channels gives a better offered throughput.

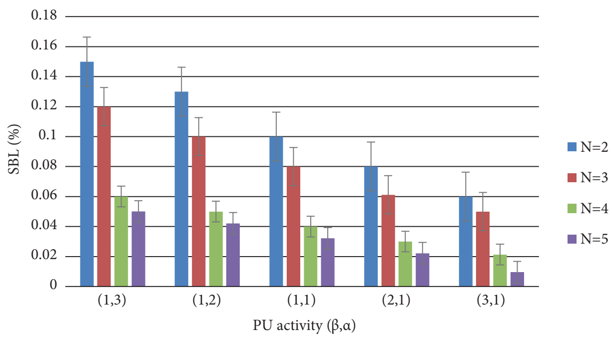

Figure 5. SBL probability according to the PU activities.

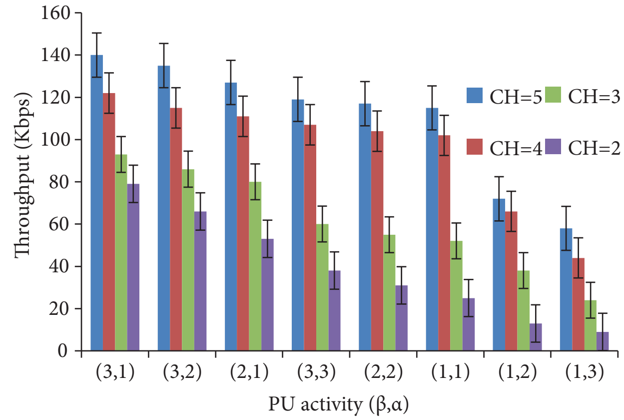

Figure 6. Comparison between TCP throughputs as a function of number of channels.

6. Conclusion

In this paper, TCP behavior is investigated as a well-known transport protocol on 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. Many reasons are given for CRSN performance degradation as a term of throughput parameter. We introduced SBL as a new type of packet loss by considering the impact of two factors: (i) PU activities, (ii) SU blocking. The PU has the prioritized access to the channel. Therefore, PU's activity plays the main role in occurring SU hands-off. In case of PU detection during the SU, the connection is blocked. Second factor is the SU blocking. The SBL detection is very significant to obtain optimal throughput. The packet loss caused by this condition is wrongly guessed as congestion. For distinguishing between SBL and packet loss due to congestion, the SUs dynamic spectrum access is modelled by the DTMC. The proposed analytical model considers effects of PUs and SUs arrival and service rates in estimating SU blocking probability. Meanwhile, an analytical model is developed to estimate the TCP throughput in the presence of SBL probability. The calculated results according to the PU activities are in a good agreement with the simulated results. The experimental results will be compared to well-known transmission control protocols in the future works.

Acknowledgment

The author would like to the thank Islamic Azad University, Ayatollah Amoli Branch for the financial and mental support of this research, which is based on a research project contract.

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