Cross-Layer Analytical Model for Cognitive Radio Network under Engset and M/G/1/m Traffic

Sajib Kumar Kuri, Risala Tasin Khan and Md. Imdadul Islam
Correspondence E-mail: *sajibkuri@gmail.com*

Abstract—**This paper deals with the performance of secondary users (SUs) based on dynamic scheduling of users based on cross-layer analytical model. Under this scheme the number secondary users in a network are kept limited to discourage malicious users hence Engset's traffic model is more appropriate than the Erlang's model of previous literature. We also incorporate M/G/1(m) traffic model, applicable for ATM/TCP-IP traffic, in cognitive radio network under cross-layer analytical model. Finally, impact of spectrum sensing period and probability of false alarm on blocking probability of secondary users are analyzed.**

Index Terms—**Cognitive radio network, dynamic spectrum access, limited user traffic, false alarm and cross-layer model.**

I. Introduction

The radio spectrum (RS) is the most valuable resource of a wireless network hence its optimum utilization must be ensured to achieve the optimum satisfaction from both user and service provider's point of view. In a cognitive radio network two types of users are available: Primary Users (PU) and Secondary Users (SU); where the PUs are the licensed users can access the traffic channel in case of availability of channel but SUs have only opportunity if channel is unutilized at that moment [1-2]. A secondary user continuously monitors the spectrum of a traffic channel (usually combination of time slot and carrier frequency) to ensure the availability of a PU. In case of absence of PU, the SU starts communication at the same time it senses the presence of PU. If PU arrives in the midst of communication of a SU, it has to release the traffic channel and again go in sensing mode. Above operation is done using two hypothesis models where the basic concept is based on [3-4] like: if the sensed signal strength is greater than a threshold then the SU assume the presence of a PU otherwise there is no PU. Two most important parameters under above hypothesis are probability of false alarm and misdetection. False alarms occur if an idle channel is detected as busy i.e. absence of PU is detected as its presence, and missed detections occur when a busy channel is detected as idle i.e. presence of PU is detected as its absence. The concept of misdetection and false alarm are summarized in [5-7].

The quality of service (QoS) provisioning and capacity evolution for the SUs is a challenging task due to the dynamic nature of availability of spectrum for SUs hence cross layer analytical model is used to evaluate the performance. The cross layer traffic model of cognitive radio of [8] uses Erlang's traffic model for both the PU and SU i.e. the case of unlimited users. In this paper we use the combination of unlimited and limited user's traffic of [9-10]. Here the limited number of users is considered for PU users hence Engset traffic model will be used for it. The combination of Erlang's and Engset's model under cross layer environment is analyzed in section II of the paper.

Above traffic model is suitable for circuit switched network but it is found that packet switching network shows better performance compared to circuit switched network hence it becomes popular in both wired and wireless communication. In this paper we also include M/G/1(m) traffic model under cross layer algorithm of cognitive radio network. It is a single server queue system where call arrivals are random follow Poisson process and service time has general distribution [11]. The performance of cognitive radio network under cross layer model is analyzed for both circuit and picketed switching cases, specially we determine blocking probability of SU against different traffic parameters.

The paper is organized like: section II, provides the analytical model of cross layer traffic under both Engset and M/G/1/m, section III depicts the results based on section II and finally section IV concludes the entire analysis.

II. SYSTEM MODEL

In this section we consider two different traffic models for SU: (a) SU under M/M/n/K/N and (b) SU under M/G/1/m but PU group is always under Erlang's traffic.

A. SU under M/M/n/k/N traffic model

Let us assume that primary users (PUs) have access to total n channels. If the arrival and termination rate of offered traffic are λ_p and μ_p respectively, then any probability state of PUs based on M/M/n/n/α traffic will be [12-13],

$$P_x = \left(A^x / x!\right) / \sum_{i=0}^{n} A^i / i!; \tag{1}$$

Where the offered traffic, $A = \lambda_P / \mu_P$

Again the blocking probability and carried traffic of PUs will be,

$$B_P = \left(A^n / n!\right) / \sum_{i=0}^{n} A^i / i! \tag{2}$$

and $$\overline{X}_P = \sum_{x=1}^{n} x P_x = A_P(1 - B_P) \tag{3}$$

Finally the channel utilization, $$\eta = A_P(1 - B_P)/n \tag{4}$$

The cross layer approach of quality of service (QoS) provisioning of the secondary users (SUs) of [8, 14] proposed that no more l SUs calls are admitted or allowed in the network which is equivalent to Erlang's traffic model of l

channels. Let us assume the arrival and termination rate of SUs are λ_S and μ_S respectively.

Now the probability state and call blocking probability of SUs will be,

$$P_j^s = \left(A_s^j / j!\right) / \sum_{m=0}^{l} A_s^m / m! \quad (5)$$

and $B_s = B_i(A_s) = \left(A_s^l / l!\right) / \sum_{m=0}^{l} A_s^m / m!$ (6)

Where, the offered traffic of SUs $A_s = \lambda_s/\mu_s$

Here we consider a limited number of SUs N therefore Engset traffic model is applicable for SUs case. Now assuming traffic per user of SUs case is a_s and the number of channel is l. Now the probability state and blocking probability will be,

$$P_x^s = \binom{N}{x} \frac{a_s^x}{x!} / \left\{ \sum_{m=0}^{l} A \binom{N}{m} \frac{a_s^m}{m!} \right\} \quad (7)$$

and $B_s = \binom{N}{l} \frac{a_s^l}{x!} / \left\{ \sum_{m=0}^{l} A \binom{N}{m} \frac{a_s^m}{m!} \right\}$ (8)

The carried traffic of SU, $\overline{X}_s = \sum_{j=1}^{n} j P_j^s = A_s(1 - B_s)$

Now the probability that a channel of PU is unoccupied, can be obtained as,

$$P_u = \frac{\left(1 - X_p\right)}{n}(1 - P_f) \quad (9)$$

Where P_f is the probability of false alarm.

Let, the duration of spectrum sensing is T_p. Now the probability that r channels of PU are unoccupied during the sensing period $[0,T_p]$ will be [14],

$$Y_r = \binom{n}{r} P_u^r \left(1 - P_u\right)^{n-r} e^{-\lambda_p T_p} \quad (10)$$

If the bandwidth of a PU channel is, k times greater than the bandwidth channel of SU, therefore we can designate channel of a SU as sub channel.

Let r channels of PU are unoccupied which is equivalent to $k.r$ sub channels are available for SUs. If j SUs arrive in the network where $j > k.r$ then (j-$s.r$) calls will be dropped during the spectrum sensing period.

Considering the number of available channels of kr, the probability of drop of j-kr calls of SU can be expressed as:

$$P_r = \left(\sum_{i=0}^{r} Y_i \right)^{q-1} \quad (11)$$

Where q-1 is the number of sensing period during which the dropped calls will be tried to sense.

Finally, the call dropping probability of SU,

$$B_d = \frac{Mean \quad number\ of\ dropped\ calls\ of\ SU}{Mean \quad number\ of\ SU\ calls\ in\ the\ network}$$

$$= \frac{\sum_{j=0}^{l} P_j^s \sum_{r=0}^{\left\lceil \frac{j}{k} \right\rceil} (j - rk) Y_r \left(\sum_{i=0}^{r} Y_i \right)^{q-1}}{\overline{X}_s} \quad (12)$$

B. SU under M/G/1(m) traffic

Let us introduce the concept of a wireless network where the length of wireless link is small and the SU has only the opportunity of using wireless packet network. Let λ_{su}, h_{su}, V_{su} and y_{su} are call arrival rate, mean call holding (connection) time, data speed and data activity rate for SU. The input traffic load a and the utilization ρ_{co} of the transmission line are given by,

$$a = \lambda_{su} h_{su} \quad (13)$$

$$\rho_{co} = (1 - B)\frac{L_c}{L_p}\frac{1}{c}\lambda_{su} h_{su} V_{su} y_{su} \quad (14)$$

; where B is the call blocking probability, L_c is the cell length (L_c = 53 bytes for ATM, the payload length is 48 bytes and the header length is 5bytes) and c the transmission speed in bps.

From Erlang's loss formula,

$$B = \frac{a^s}{s!} / \sum_{i=0}^{s} \frac{a^i}{i!} \quad (15)$$

;where s is the number of virtual channels (VC's) assigned to the transmission line.

According to [11,15] for M/G/1 system,

$$\Pi_j^* = p_j \Pi_0^* + \sum_{k=1}^{j+1} p_{j-k+1} \Pi_k^* ;\ j = 0, 1, 2, \ldots \quad (16)$$

;where p_j is the probability that j calls arrive during the service time.

For M/G/1(m) system, $\Pi_j^* = 0$ for $j > m+1$ and above equation takes the recurrence form like:

$$\Pi_{j+1}^* = \left(\Pi_j^* - p_j \Pi_0^* - \sum_{k=1}^{j} p_{j-k+1} \Pi_k^* \right) p_0^{-1} ;\ j = 0, 1, 2, \ldots, m\text{-}1 \quad (17)$$

Taking, $C_j = \frac{\Pi_j^*}{\Pi_0^*}$ we get,

$$C_{j+1} = \left(C_j - p_j - \sum_{k=1}^{j} p_{j-k+1} C_k \right) p_0^{-1} ;\ j = 0, 1, 2, \ldots, m\text{-}1 \quad (18)$$

Let, $C = \sum_{j=0}^{m} C_j$ with $C_0 = 1$

Now combining above equations,

$$\Pi_j = \Pi_j^* = P_j = \frac{C_j}{1 + aC} \quad (19)$$

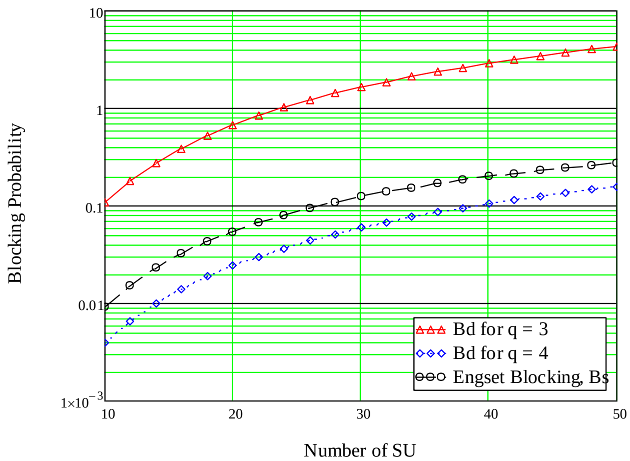
The cell loss rate, $B = P_{m+1} = 1 - \sum_{j=0}^{m} P_j = 1 - \sum_{j=0}^{m} \frac{C_j}{1 + aC} = 1 - \frac{C}{1 + \rho_{co} C}$

Finally, the cell drop probability of SU,

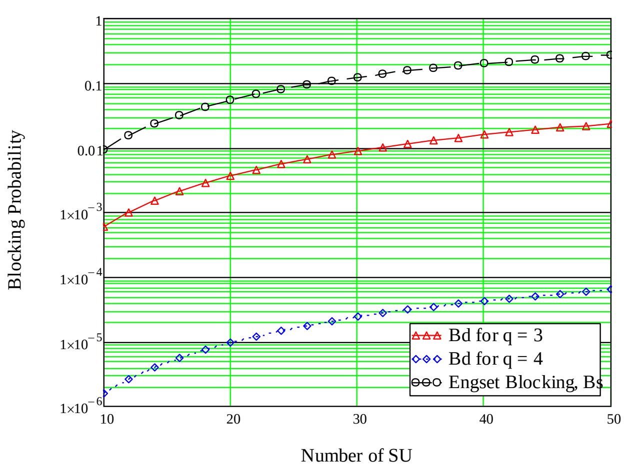
$$B_{SU} = \frac{\sum_{j=0}^{l} \Pi_j \sum_{r=0}^{\left[\frac{j}{k}\right]} (j - rk) Y_r \left(\sum_{i=0}^{r} Y_i \right)^{q-1}}{\overline{X}_s} \qquad (20)$$

III. RESULTS

Considering the traffic parameters: the number of sub-channels of SU is 3, probability of false alarm p_f = 0.04, number of sub-channels of PU is 17, arrival rate λ_p = 2 calls/unit time, offered traffic of PUs A_p = 20 Erls, offered traffic of SUs A_s = 0.05 Erls/user and the duration of spectrum sensing period T_p = 1ms. Taking above parameters we plot the blocking probability of SU against the number of SU where the number of consecutive spectrum sensing periods are taken as: q = 3 and 4. The blocking probability increases with increase in the number of SU but decreases with increase in q. The pure Engset blocking lies between two curves visualized from the fig.1(a).



(a)T_p = 1ms, P_f = 0.04



(b) T_p = 2ms, P_f = 0.14

Fig.1. Variation of blocking probability of SU against the number of SU taking q as a parameter

Changing the spectrum sensing period and probability of false alarm like, T_p = 2ms, P_f = 0.14, the blocking probability is reduced tremendously shown in fig. 1(b). The blocking probability of SU is found more sensitive to T_p compared to P_f is visualized from fig. 1(b). Since increment in P_f from 0.04 to 0.14 should increase the blocking probability but the increment of T_p from 1ms to 2ms not only overcome the impact of P_f but also reduce the blocking probability compared to figure-1(a). In this case, both the curves fall below the pure Engset traffic curve.

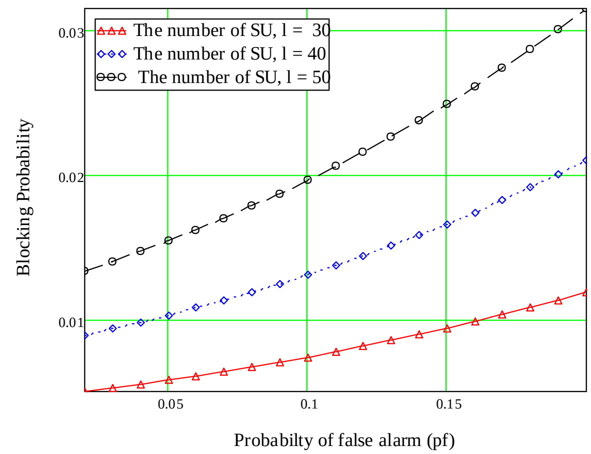


Fig.2. Impact of false alarm on blocking probability of SU

The impact of false alarm on blocking probability is shown in fig.2 where the number of SU (l = 30, 40, 50) is taken as a parameter. The relation between B_s and P_f are non-linear and the curves flare at higher value of P_f. At lower value of P_f i.e. below 0.1 the curves are almost parallel. Hence the impact of P_f on B_s are equally prominent (three curves of l = 30, 40, 50) at lower value of P_f but at higher value of P_f, it influence B_s more prominently for higher value of l.

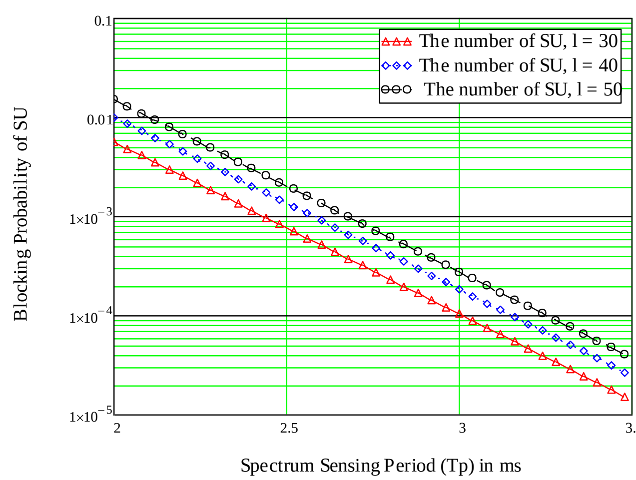


Fig .3. Impact of spectrum sensing period on blocking probability of SU

The figure-3 shows the variation of Bs against spectrum sensing period T_p taking the number of SU as parameters (l = 30, 40, 50). The three curves are parallel and maintain liner relationship under logarithmic scale between B_s and T_p hence the relationship will be exponential under linear scale. The B_s curves go up with increase in the number of SU. Considering the traffic of SU as M/G/1(m) we determine blocking probability of SU against offered of PU in taking link capacity of 150 Mbps, 125 Mbps and 100 Mbps. The other traffic parameters are: the length of queue *m* = 32, offered traffic per channel 0.736 Erls. The blocking probability increases with increase in offered traffic but decreases with increase in link capacity visualized from fig.4.

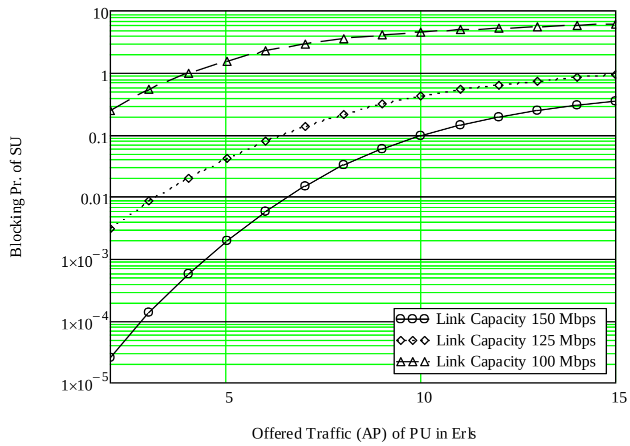


Fig. 4. Variation of blocking probability of SU against offered traffic of PU

Finally blocking probability is again plotted against false alarm P_f in fig. 5 taking link capacity of 50 Mbps, 85 Mbps and 100 Mbps. The blocking probability increase with P_f but decreases with increase in link capacity.

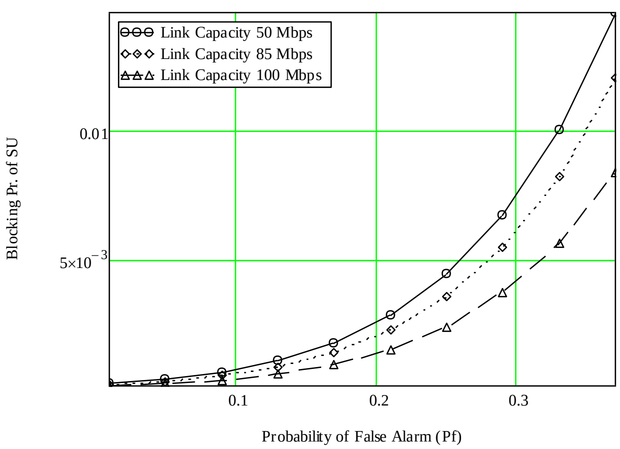


Fig. 5. Variation of blocking probability of SU against probability of false alarm, where link capacity = 50, 85, 100 Mbps.

IV. CONCLUSIONS

In this paper, an analytical cross layer model is developed to measure the performance of SUs by dynamic scheduling. The cross layer approach is developed here for fixed SUs which is fit for Engset's traffic model. We investigate the call drop probability of SUs under circuit switching traffic of *M/M/n/K/N* and packet switching network of *M/G/1(m)* applicable for ATM or TCP/IP traffic. Finally blocking probability of SUs is observed with variation of spectrum sensing period and probability of false alarm. The entire work can be extended using fading parameters of wireless link and packet scheduling of IEEE 802.16e.

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Sajib Kumar Kuri has completed his B.Sc. (Hons) in Computer Science & Engineering from Jahangirnagar University, Dhaka in 2010 and M.Sc from the same university in 2012. He has completed Cisco Certified Network Associate (Academic) program in 2008 and Linux System Administration & Server Configuration in 2010 program from Bangladesh University of Science & Technology, Dhaka. He is now working as a Data-communication Engineer in Huawei Technologies (Bangladesh) Ltd. (A Chinese Multinational Networking and Telecommunication Company) from June-2012. He has very good field experiences in planning, design and commissioning Route, Switch, Firewall and wireless networking system devices of CISCO, HUAWEI & MOTOROLA. He has very good understanding of different routing protocols (RIP, EIGRP, OSPF and BGP).
Mr. Sajib also completed Cisco Certified Network Associate (CCNA) & Cisco Certified Network Professional (CCNP) vendor certification.

Risala Tasin Khan has completed her B.Sc. Hons. in Computer Science and Engineering from Jahangirnagar University, Savar, Dhaka in 2006 and M.Sc. in Computer Science and Engineering from the same University. She is now doing PhD at the department of Computer Science and Engineering, J.U. She worked as a lecturer in the department of Computer Science and Engineering, Daffodil International University, Dhaka. She is now working as an assistant professor at Institute of Information Technology, Jahangirnagar University, Savar, Dhaka, Bangladesh. Her research field is network traffic and network security.

Md. Imdadul Islam has completed his B.Sc. and M.Sc Engineering in Electrical and Electronic Engineering from Bangladesh University of Engineering and Technology, Dhaka, Bangladesh in 1993 and 1998 respectively and has completed his PhD degree from the Department of Computer Science and Engineering, Jahangirnagar University, Dhaka, Bangladesh in the field of network traffic engineering in 2010. He is now working as a Professor at the Department of Computer Science and Engineering, Jahangirnagar University, Savar, Dhaka, Bangladesh. Previously, he worked as an Assistant Engineer in Sheba Telecom (Pvt.) LTD (A joint venture company between Bangladesh and Malaysia, for Mobile cellular and WLL), from Sept.1994 to July 1996. Dr Islam has a very good field experience in installation of Radio Base Stations and Switching Centers for WLL. His research field is network traffic, wireless communications, wavelet transform, OFDMA, WCDMA, adaptive filter theory, ANFIS and array antenna systems. He has more than 150 research papers in national and international journals and conference proceedings.