Throughput Analysis of Multi-channel TD-CSMA System and Reinforcement Learning

Sachin Bhutani, Deepti Kakkar, Arun Khosla

Abstract:- This study generates a cognitive radio scenario based on non-persistent carrier sense multiple access (CSMA) and time division multiple access (TDMA) systems sharing a multi-channel wireless network. TDMA users are considered as primary users who can access the channel at any time, and non-persistent CSMA users are considered as secondary users who can share the channel when it is free. Then system performance is evaluated for a variety of proportions of non-persistent CSMA and TDMA traffic levels. Simulation results are presented and effect on throughput for different traffic ratio is shown. Further effect of reinforcement learning on system model is shown how throughput increases.

Index Terms:- Cognitive Radio, Monte Carlo Method, Reinforcement Learning, TD-CSMA System.

I. INTRODUCTION

From the day radio communication came into existence in the early 19th century, the application of wireless communication has been extensively and rapidly utilizing the limited radio spectrum [1].In order to struggle with the spectrum scarcity and to secure the best use of spectrum, the current policy of spectrum allocation in which users are assigned a license to use the specific radio spectrum band, and users without a license cannot use the band which has already been assigned to licensed users [2]. However, the Ofcom spectrum framework review in 2004 [3] showed that the demand for some spectrum bands have exceeded supply, but in spite of this there still remains a large portion of unused spectral bands within the entire spectrum. This implies that the shortage of spectrum is due to current spectrum policies that allow little sharing, since regulators grant licenses that only offer exclusive access to spectrum. This causes spectrum to sit idle even when licensed users are not active [4]. Cognitive radio (CR) [5] promises to increase spectrum usage by supporting secondary users to share licensed bands.

Considering the features of CR technology, spectrum sharing is one of the most important aspects of CR technology, in which a secondary user can access the spectrum when and where channels are detected idle [8]. However, the interference between primary users and secondary users is a crucial issue. Therefore as a start up to the development of more sophisticated multiple access schemes for CR [9, 10], the purpose of this paper is to develop a TD-CSMA model which fulfill the basic characteristics of CR and users are modeled by two traditional schemes when operating in combination, sharing the same spectrum. Specifically, these are non-persistent carrier sense multiple access (CSMA) used to describe the behaviour of a CR that has the ability to sense and access a free channel, and time division multiple access (TDMA) [11] is used to characterise the primary user who has the primary right and have purchased license to access channel whenever they have information to send.

The analysis focuses on the interaction between these two schemes. During the analysis of the combined system, the throughput [12] is considered as an important parameter that measures the performance of each scheme. Throughput can be defined in several ways according to different system requirements. In this paper, it is the ratio of the transmission time of successful packets to the total transmission time in transmitting all packets, and the unit is the Erlang. We consider a fixed number of packets to be transmitted by primary user and when it is done, it is considered as end point for simulation. In the TD-CSMA (TDMA combined with non persistent CSMA) system [14] here, the throughput characteristic of each scheme differs from a single scheme system, in that throughput values vary by changing the proportion of primary user and secondary user traffic. The output of this paper focuses on analysing the throughput variation at different CSMA to TDMA offered traffic ratios. Based on the simulation results, the relationship between the throughput and the offered traffic ratio is clarified. After this we apply reinforcement learning to a separate CSMA model for showing its effect on throughput. Reinforcement learning is learning what to do-how to map a particular situation in to one of actions. The system is not told which channel to choose, as in most forms of machine learning, but instead must discover which actions yield the most reward by trying them. In the most interesting and challenging cases, actions may affect not only the immediate reward but also the next situation and, through that, all subsequent rewards. These two characteristics--trial-and-error search and delayed reward--are the two most important distinguishing features of reinforcement learning. In this way Reinforcement learning[18 ,19] can be used to use the past record of a particular channel and this will increase throughput.

II. SYSTEM MODEL

We consider the system model as two multiple access schemes sharing a group of channel in a combined wireless system.

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Sachin Bhutani, ECE Department, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India (e-mail: sachinbhutani.nitj@gmail.com).

Deepti Kakkar, ECE Department, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India (e-mail: kakkard@nitj.ac.in).

Arun Khosla, ECE Department, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar, Punjab, India (e-mail: arun.khosla@gmail.com).

In this combined system, each user in the CSMA sub-network has the capability of sensing the channel, not only CSMA transmissions but also TDMA transmissions. In contrast to the CSMA users, the users in the TDMA sub-network have perfect scheduling and can send packets in discrete timeslots whenever they have information to send.

On considering the interaction between CSMA and TDMA in this system, the probability of the channel being sensed idle by a CSMA user will be changed compared with a pure CSMA scheme, which leads to the probability of a successful transmission being varied. In particular, TDMA packets will block some extra CSMA packets, thus changing the CSMA throughput. On the other hand, a TDMA user in the TD-CSMA system will suffer from additional collisions from CSMA users, because TDMA users have no sensing ability. Therefore the probability of successful transmission will depend on the probability of collision in the TD-CSMA system. Ideally, in a real CR system, secondary users should give preference to primary users, in order to avoid interference. We assume the scenario is non-capture and that the propagation delay is very small compared to the packet transmission time. All packets are of constant length and are transmitted over a noiseless channel. In addition, with the non-persistent CSMA transmissions, it is assumed that the time for carrier sensing is negligible. The propagation delay 'a' is normalised to 0.05 relative to the transmission time t. For applying reinforcement learning we consider a 40 channel CSMA system.

III. SIMULATIONS

In this section, simulation results are obtained according to varying total offered traffic levels and different CSMA traffic to total offered traffic ratios. The total offered traffic range is varied from 0.1 Erlang to 100 Erlangs and the CSMA traffic ratio is defined in a range between 0 and 1. For specific values of the ratio, the simulation will determine the throughput of TDMA and CSMA and result will be shown.

A. Simulation Methodology

In this paper, an event-based simulation is used to simulate the TD-CSMA system. This has been constructed in MATLAB. In simulation, a Monte Carlo method [15] is applied, which computes statistical results by repeating a large number of random trials. Each packet is considered as an individual random trial which can be transmitted on any of the 5 available channels. In order to generate a sufficient number of trials, we set the number of packets to be transmitted by a TDMA user N equals to 1000, and the simulation will be terminated after N packets have been successfully transmitted. We set the number of overall transmitters M is equal to 100, according to the offered traffic ratio p, CSMA users have pM transmitters and TDMA have (1-p)M transmitters in the TD-CSMA system. In order to approximate a Poisson arrival process [16] at the receivers, N packets are generated randomly, constantly and independently from M transmitters. In the CSMA transmission, if a packet suffers a collision, then the transmitter schedules the retransmission of the packet according to a random backoff time which is equal to the random interarrival time whose mean is T_{inter} according to the CSMA offered traffic. With the TDMA transmission, all transmitters are assigned a time slot one by one with a fixed order. The transmissions are synchronised and are forced to start only at the beginning of a predefined slot. If a packet suffers a collision, then the retransmission will start at a predefined slot in the next round.

Reinforcement learning [17] is applied as follows:

Fig 1 shows the flow diagram how reinforcement learning can be applied to any system. We consider weight matrix with number of channels, k as row and number of row, m as column in which a cell is updated on deciding whether transmission is successful or not.

W_t (k, m) being the channel weight of user *k* on the channel *m* at the time *t* and the user updates the weight.

$$W_{t+1}(k, m) = W_t(k, m) + f_{km}$$

f_{km} is considered as 0,0 for successful transmission, collision in case of without reinforcement learning and 1,0 for successful transmission, collision in case of reinforcement learning.

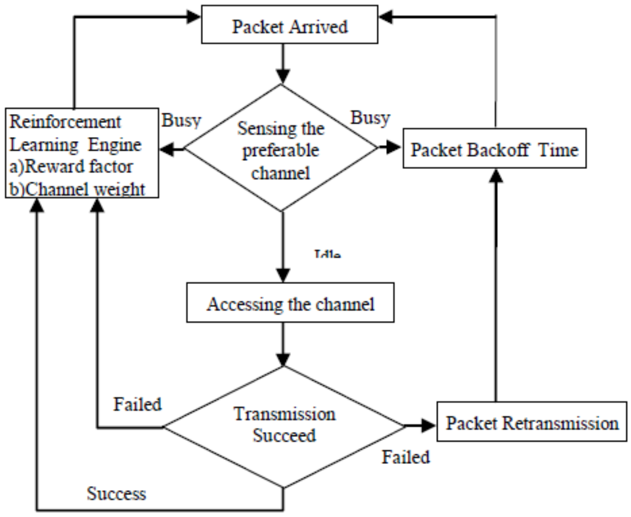

Figure 1: Methodology for applying Reinforcement Learning to secondary users

B. Simulations Results

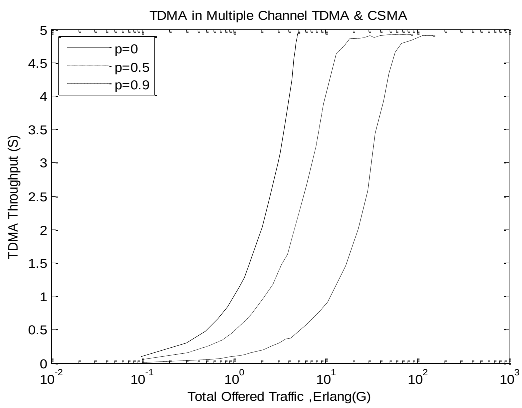

Figure 2 : Throughput of TDMA against Total offered traffic for varying CSMA traffic ratio p in the TD-CSMA system

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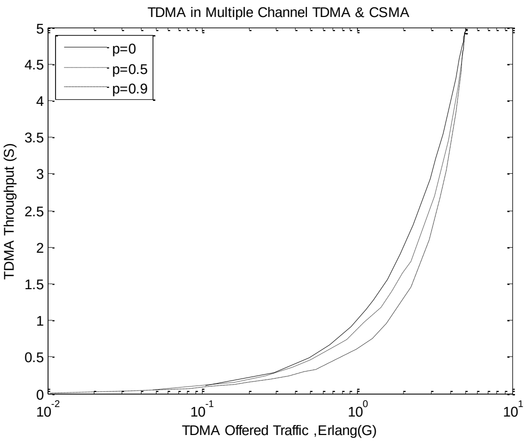

Figure 3 : Throughput of TDMA against TDMA offered traffic for varying CSMA traffic ratio p in the TD-CSMA system

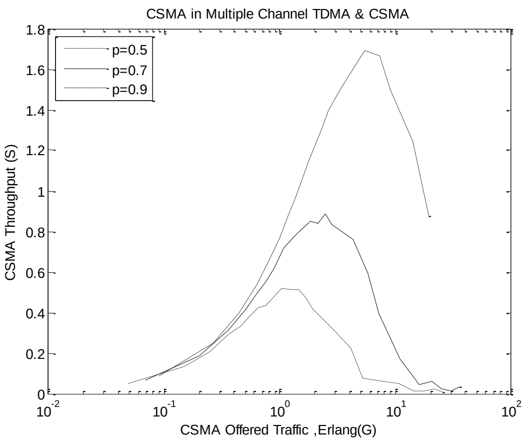

Figure 4 : Throughput of non-persistent CSMA against CSMA offered traffic for varying CSMA traffic ratio p in the TD-CSMA system

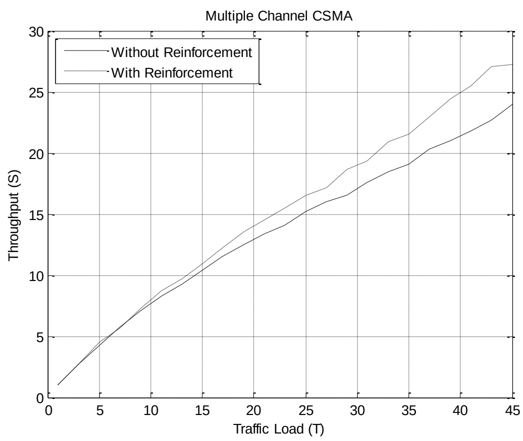

Figure 5 : Effect of Reinforcement Learning on Throughput of non-persistent CSMA system with 40 channels

IV. RESULT ANALYSIS

The importance of different curves is explained in this section. Fig. 2 shows the throughput of TDMA against overall offered traffic for varying CSMA traffic ratio p. It can be seen that the peak throughput occurs at higher levels of offered traffic, due to the fact that the level of TDMA traffic decreases corresponding to a decrease in the ratio of TDMA traffic to overall traffic. In order to clearly distinguish them in the figure, we select three p values to be plotted in Fig. 3, which are p=0, p=0.5 and p=0.9. (p =1 is not shown as the system is pure CSMA, and hence the TDMA offered traffic and throughput are zero). Fig. 3 shows that the characteristic of TDMA throughput in the TD-CSMA system is almost the same as with a pure TDMA scheme (p=0) at different TDMA traffic levels. This result is very important since it confirms that primary users that that have license to use the spectrum can transmit information without any significant harmful interference from secondary users who use the CSMA scheme in the combined TD-CSMA system. However, since TDMA users can transmit at any time relative to the CSMA transmission period, there is a probability of a collision occurring between TDMA and CSMA during a CSMA transmission; therefore the throughput of TDMA at different CSMA traffic ratios is not exactly identical to the throughput of the pure TDMA system. Fig. 4 shows the throughput of non-persistent CSMA against CSMA offered traffic, for varying CSMA traffic ratio p in the TD-CSMA system. p=0 denotes the TD-CSMA system is pure TDMA offered traffic, and p=1 denotes the TD-CSMA system is pure CSMA offered traffic. In contrast to the TDMA throughput characteristic, the throughput characteristic of nonpersistent CSMA rapidly descends when the ratio of CSMA traffic is decreased in the TD-CSMA system. Fig. 5 shows the throughput result of without reinforcement learning and with learning for same system and performance with RL is better. In starting it is identical but after learning if shows an increase.

V. CONCLUSIONS

For different ratios of TDMA and CSMA traffic, the results show that the chance of CSMA access to the channel rapidly decreases when the ratio of TDMA traffic increases. This characteristic has a close similarity with a basic CR, in that the secondary user must give preferance when the primary user wishes to transmit packets.

On applying reinforcement learning, throughput of system is improved, learning can reduce number of collision and increase the probability of successful transmission.

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AUTHORS PROFILE

Sachin Bhutani received his B.Tech Degree in 2009 from Department of Electronics & Communication Engineering, PDMCE, Haryana, India and pursuing his M.Tech degree from NIT, Jalandhar, India. His research interest includes Wireless Communication and Cognitive Radio.

Deepti Kakkar is pursuing her PhD degree from NIT Jalandhar. She is presently working as Assistant Professor in the Department of Electronics and Communication Engineering, National Institute of Technology, Jalandhar, India. She has been reviewer for various National conferences. Her research interest includes Wireless Communication and Cognitive Radio. She has over 6 Years of teaching experience and had guided several B. Tech projects.

Arun Khosla received his PhD degree from Indraprastha University, Delhi in the field of Information Technology. He is presently working as Associate Professor in the Department of Electronics and Communication Engineering, National Institute of Technology, Jalandhar, India.
Dr. Khosla has been reviewer for various IEEE and other National and International conferences and also serves on the editorial board of International Journal of Swarm Intelligence Research. He is a life member of Indian Society of Technical Education.

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