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Throughput Analysis of TDMA-CSMA System using Reinforcement Learning in Cognitive Radio

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***Abstract*— Cognitive Radio [does promise to increase spectrum utilization, spectrum being a scare resource because radio spectrum is being used in various services from air traffic control to wireless Internet. The spectrum scarcity is due to current spectrum policies. In order to get the most beneficent usage of spectrum, Cognitive Radio enables unlicensed users to explore and use any spectrum holes present in spectrum owned by the licensed users. The concept of a Cognition Cycle is the key element of Cognitive Radio to provide context awareness and intelligence so that each unlicensed user has ability to observe and perform an optimal process on its operating environment for performance enhancement of the system. In Cognitive Radio a TD-CSMA system may be considered in which a primary user is characterized as contention-free time division multiple access (TDMA) user and to describe the characteristic behavior of secondary user which requires sensing a channel prior to transmission, we consider contention-based non-persistent carrier sense multiple access (CSMA). Performance of secondary users is evaluated for a various proportions of non-persistent CSMA and TDMA traffic levels. Simulations results show that the throughput performance of CSMA users improves when multichannel are used and CSMA traffic ratio increased in cognitive radio networks. Further effect of reinforcement learning on system model is shown how throughput increases.**

***Index Terms*— TD-CSMA System, Cognitive Radio, Monte Carlo Method, Reinforcement Learning, Channel Allocation**

I. INTRODUCTION

The proliferation of emerging wireless applications requires a better utilization of radio channels [1]. To address the increasing demand for wireless bandwidth, cognitive radio networks (CRNs) have been proposed to increase the efficiency of channel utilization under the current static channel allocation policy [2]. They enable unlicensed users to use licensed channels on a non-interference basis, thus serve as a solution to the current low usage of radio channels [3].

In CRNs [4], there are two types of users: primary users and secondary users. Primary users are licensed users who are assigned with certain channels, and secondary users are unlicensed users who are allowed to use the channels assigned to a primary user only when they do not cause if a primary user's signal is detected, the secondary user should not use those channels to avoid interfering with the transmission of any harmful interference to the primary user [5]. If a primary user's signal is detected, the secondary user should not use those channels to avoid interfering with the transmission of the primary user. Therefore as a start up to the development of more sophisticated multiple access schemes for CR [6], 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)[7] used to describe the behavior of a CR that has the ability to sense and access a free channel, and time division multiple access (TDMA) [8] is used to characterize 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 [9] 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. 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. We see throughput performance of system for different value of offered traffic ratio (p) which is proportion of CSMA users in the system.

Further after considering a multi-channel system and increasing its throughput, we apply Reinforcement Learning [10]] to secondary users, which is a theoretical tool for studying the principles of agents learning[11] to act, for constructing autonomous system that improves itself with experience. It supports individual learning by directly interacting with environment. Reinforcement learning uses the past record of a particular channel and it intelligently assigns a channel [12] with the best chance of successful packet transmission, in turn increasing the throughput of the system. Out of two methods of selecting channel, [13] i.e. random choice and idle choice, we will use idle choice. In this the user firstly senses all channels and then randomly allocates data to one of channel which is being sensed free. Therefore we apply idle choice as the basic channel assignment scheme. The simulation results compare the throughput performance of two types of schemes i.e. with reinforcement learning and without reinforcement Learning in which with reinforcement learning schemes shows better throughput performances of the system.

II. SYSTEM MODEL

We consider the system model as two multiple access schemes sharing a group of channel in a combined wireless system [14]. In this combined system, each user in the CSMA

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sub-network has the capability of sensing the channel, not only CSMA transmissions but also TDMA transmissions.

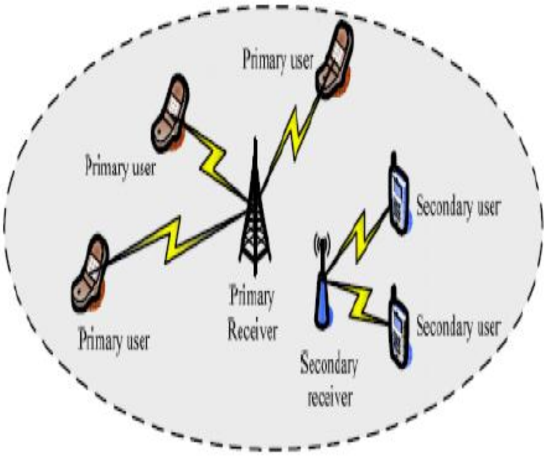

Figure 1: Cognitive Radio Scenario Model

During transmission TDMA users have top priority to transmit data packets in their designated time slots on a specific channel, and they do not perceive the existence of secondary users. As a secondary user in CR model, each user contains a reinforcement learning engine that acquires its transmission experiences as a reward value to adjust the next transmission. 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.

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. Ideally, in a real CR system, secondary users should give preference to primary users, in order to avoid interference. In addition, with the non-persistent CSMA transmissions, it is assumed that the time for carrier sensing is negligible. The propagation delay ‘a’ is normalized to 0.05 relative to the transmission time t. For applying reinforcement learning we consider a 40 channel CSMA system.

III. SIMULATION ANALYSIS

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 Erlangs to 100 Erlangs and the CSMA traffic ratio is defined in a range between 0 and 1.

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. With the TDMA transmission, all transmitters are assigned a time slot one by one with a fixed order. The transmissions are synchronized 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.

Methodology which are used are shown in Figure. 2, in which it is shown that Reinforcement Learning engine has to be updated if the channel is busy and on basis of transmission getting successful or failed. If the channel is found busy or transmission gets failed, the retry will be done after a random backoff time. In this we assign weighing factor for each process. In this way the Weight of channels get changed after each packet transmission and a channel having higher weight will have preference over other channels when a user wants to transmit data. In this way the channel having more success in past is used again and again, resulting to increase in throughput and better spectrum utilization.

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. Wt (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

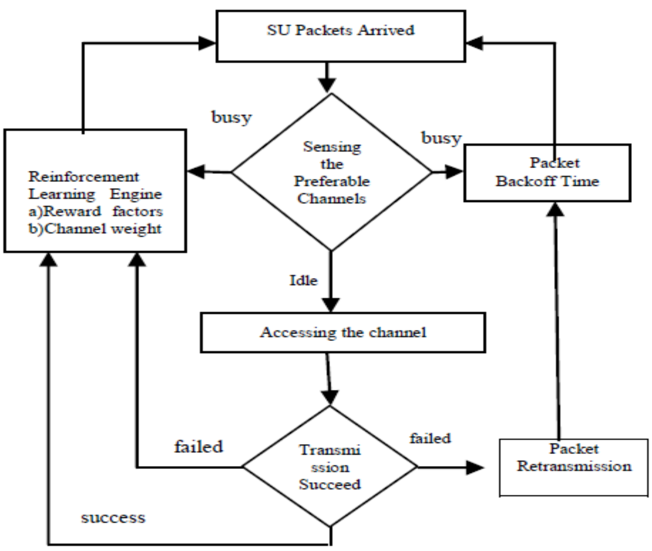

Figure 2: Methodology for applying Reinforcement Learning to secondary users

B.Simulation Results

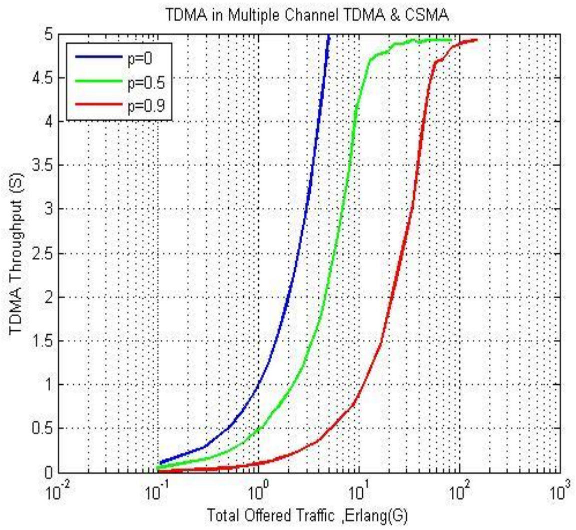

Figure 3: Throughput of TDMA against overall offered traffic for varying CSMA traffic ratio p in TD CSMA system in a multichannel

Figure 3 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 and as the CSMA ratio increased throughput of TDMA decreased in the TD-CSMA system. 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

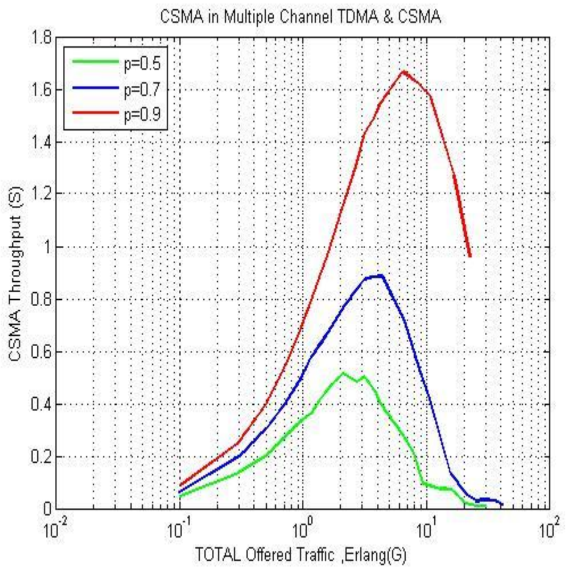

Figure 4: Throughput of non –persistent CSMA against overall offered traffic for varying CSMA traffic ratio p in TD CSMA system in a multichannel

Fig. 4 shows the throughput of non-persistent CSMA against CSMA offered traffic, for varying CSMA traffic ratio p in the TD-CSMA system. In contrast to the TDMA throughput characteristic, the throughput characteristic of non persistent CSMA rapidly descends when the ratio of CSMA traffic is decreased in the TD-CSMA system. The reason for this is because the secondary users who use non-persistent CSMA suffer a very high blocking probability from primary users who use the TDMA scheme, therefore the CSMA users need to wait longer for the channel to be sensed free prior to transmission compared with a pure CSMA system .Also, the collision between TDMA and CSMA causes additional retransmissions for CSMA users, which also decreases the probability of successful transmission of CSMA packets.

Fig. 5 shows the throughput result of without reinforcement learning and with learning for TD-CSMA system. It can be seen that the throughput of secondary users show better performance with RL. This is because reinforcement learning enables secondary users to intelligently choose the channels with more successful transmission probability of the CSMA packets. In the beginning it is seen that throughput

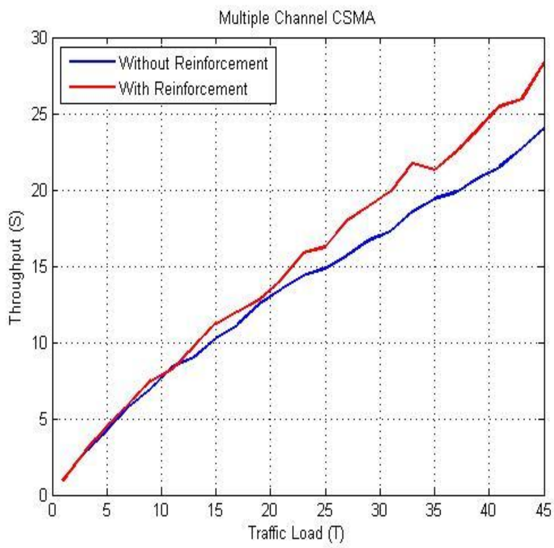

Figure 5: Effect of Reinforcement Learning on Throughput of non-persistent CSMA system

performance of CSMA for with and without RL is identical but after learning if shows an increase in the throughput.

IV. 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 way when the traffic of primary user increases. It is clear from results that applying RL with SU maximizes channel utilization and achieve optimum throughput. Learning can reduce number of collision and increase the probability of successful transmission.

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