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Analysis of Throughput with Reinforcement Learning of TD-CSMA System in Cognitive Radio Networks

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Abstract— Cognitive radio technology is widely accepted as an efficient approach to solve the problem of scarcity of the wireless spectrum resulting due to the rapid growth in the ubiquitous wireless applications. Several cognitive medium access control protocols have been proposed for the secondary users (non-licensed users) to take advantage of the vacant channels whenever they are not occupied by the primary users (licensed users). This paper analyses a cognitive radio scenario based on non-persistent carrier sense multiple access (CSMA) protocol for secondary user and time division multiple access (TDMA) for primary users in multi-channel TD-CSMA network. 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. Further, reinforcement learning is applied in conjunction with non-persistent CSMA which also enhances the throughput performance on same proportions.

Index Terms— Cognitive Radio, Multiple Access Scheme, Multichannel CSMA, Channel Assignment, Reinforcement Learning.

I. INTRODUCTION

The radio frequency spectrum is highly regulated, and communications service providers have been assigned licenses [1], which give them exclusive rights to use portions of the radio frequency spectrum. These licensed users are known as primary users. Investigations of spectrum utilization indicate that not all the spectrum is used in space (geographic location) or time [2]. Permitting unlicensed users to access licensed spectrum can greatly increase spectrum utilization efficiency, but it is vital that the unlicensed users (also known as secondary users) do not cause harmful interference to the licensed users. A cognitive radio is required to achieve this, typically through spectrum sensing and interference management.

Cognitive radio [3] is a promising technology to alleviate the increasing stress on the fixed and limited radio spectrum. The cognitive radio technology has received extensive attentions from not only academia but also from industry since it was first coined in 2000 [4]. In the cognitive radio networks, the secondary (unlicensed) users can periodically search and identify available channels in the spectrum. Based on the searched results, the secondary users dynamically tune its transceivers to the identified available channel to communicate among themselves without disturbing the communications of the primary (licensed) users.

Time division multiple accesses (TDMA) [5] 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. Several cognitive radio medium access CSMA protocols have been proposed in [6] for the secondary users to take advantage of the vacant channels that are not used by the primary users. These protocols are 1-persistent CSMA, p-persistent CSMA and non-persistent.

CSMA is a multiple access scheme [7] where individual users make their own decisions on how and when to access a channel. The 1-persistent CSMA protocol is devised in order to achieve acceptable throughput by never letting the channel go idle if some ready terminal is available. In this system, if channel is sensed busy, secondary user waits until the channel goes idle and only transmits the packet with probability one. In p-persistent CSMA, which is general case, the parameter p is chosen so as to reduce the level of interferences while keeping the idle periods between any two consecutive non overlapping transmissions as small as possible. On the other hand the non-persistent CSMA protocol is designed to maximize channel utilization and achieve optimum throughput by never letting the channel become idle. It limits the interference among packets by always rescheduling a packet which finds a channel busy upon arrival.

The throughput [8] is considered as an important parameter that measures the performance of each scheme. ie.TDMA and CSMA in TDMA combined with CSMA system. Throughput can be defined as the ratio of the transmission time of successful packets to the total transmission time in transmitting all packets. In [9] it has been observed that the non-persistent CSMA scheme increases the performance of the throughput of secondary users as compared to the earlier used scheme.

The authors in [10] have presented the throughput performance of CSMA users in TDMA combined with non-persistent CSMA system on a single channel for several values of offered traffic ratio, p, which is the proportion of CSMA users in the TD-CSMA system. Earlier in [11] authors have developed 1-persistent CSMA scheme combined with reinforcement learning (RL) for secondary users in TD-CSMA system. RL is a machine learning approach where an agent learns from trial-and-error interactions with an unknown environment [12]. In this context, in [13], the reinforcement learning (RL) is applied to SU which avoids unnecessary interaction amongst primary and secondary user.

This paper focuses on analyzing throughput performance of non-persistent CSMA users for several values of the offered traffic ratio (p) on multichannel TD-CSMA system. Here, the throughput characteristic of each scheme differs from a single scheme system. Further, reinforcement learning has been applied to

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non-persistent CSMA users and its effect on throughput performance of CSMA users in TD-CSMA model has been studied. Although cognitive radio has the abilities of spectrum awareness, intelligence and radio flexibility, and adapts itself to the changes in the local environment, reinforcement learning improves the system performance and the probability of a user to successfully communicate with others is increased. Reinforcement learning exploits the knowledge of past record of a particular channel and thus increases the throughput.

II. SYSTEM MODEL AND ASSUMPTIONS

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.

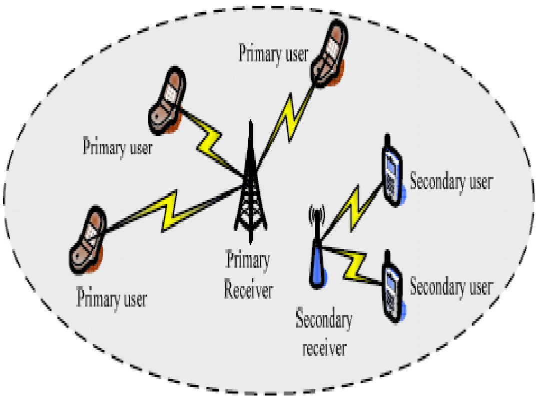

Figure 1: Cognitive Radio Scenario Model

In the above scenario, the probability of successful transmission will depend on the probability of collision. For analyzing of interaction amongst primary and secondary users, let us assume that

- SU can hear each other, i.e. there are no hidden terminals.
- The channels are noiseless and the only source of interference is packet overlap (collisions).
- The receivers are co-located and all users are at the same distance from the receivers.
- The delay is very small compared to the packet transmission time
- Both systems use one or more common frequency channels.
- All packets are of a common length.
- The propagation delay '*a*' is normalized to 0.05 relative to the transmission time *t*.
- Symbol bit rate: $256 * 10^3$ bits per second.
- Number of channels be 10
- Bandwidth per channel, 'B' is 128 KHz
- Total numbers of overall transmitters, 'M' is 100

The transmission procedure of non-persistent CSMA is modified as:

1) A user with ready packet senses all channels first. If more than one channel is sensed idle, then user will randomly choose one from those that are sensed idle.
2) If channels are sensed busy there will be random delay for retransmission according to random back off interval.

For analysis of the system, 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 CSMA on single and multichannel scenario and result will be shown. CSMA traffic ratio is taken to be 0, 0.5 and 0.9. Further, in this paper reinforcement learning is used with non-persistent CSMA users to improve the throughput of the CSMA system at various traffic loads.

III. SIMULATION METHODOLOGY

In this paper, an event-based simulation is used to simulate the TD-CSMA system. Monte Carlo method [14] is applied, which computes statistical results by repeating a large number of random trials. In order to generate a sufficient number of trials, we set the number of packets, N, to be transmitted by a TDMA user to be equal to 1000 and the simulation terminates after N packets have been successfully transmitted. We set the number of overall transmitters M to be equal to 100. According to the offered traffic ratio p, CSMA users have pM transmitters and TDMA users have (1-p)M transmitters in the TD-CSMA system. CSMA traffic ratio is taken to be 0, 0.5 and 0.9. In the CSMA transmission, if the channel is sensed busy or a packet suffers a collision, the transmitter schedules the retransmission of the packet according to a random back off time which is equal to the random inter-arrival 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 [15]. If a packet suffers a collision, the retransmission will start at a predefined slot in the next round.

The throughput S is expressed in terms of *a* (the ratio of propagation delay to packet transmission time) and G (offered traffic rate) [16] as

$$S=\frac{Ge^{-aG}}{G(1+2a)+e^{-aG}}$$

The channel capacity is found by maximizing S with respect to G. S/G represents merely the probability of a successful transmission and G/S is the average number of times a packet must be transmitted until success.

A. *Applying reinforcement learning to SU*

In order to avoid collisions among the primary and secondary users, we apply the RL to make SU aware of the radio environment and intelligently assign a channel with the best chance of successful packet transmission by considering the previous experiences on the channels. The RL assures that each secondary user is assigned an optimum channel through maximization of an average reward over the long-term [17]. Figure 2 depicts the transmission methodology for SU with reinforcement learning when sharing the same spectrum with primary users. We consider weight matrix [18] associated with each channel 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 according to the rule

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

where W_{t+1}, W_t, and f_{km} represent the new weight, the

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old weight, and the reward factor, respectively.

Without reinforcement learning we consider f_{km} to be 0 for both the successful transmission and the collision.

In case of reinforcement learning we consider f_{km} to be 1 for successful transmission and to be 0 for collision.

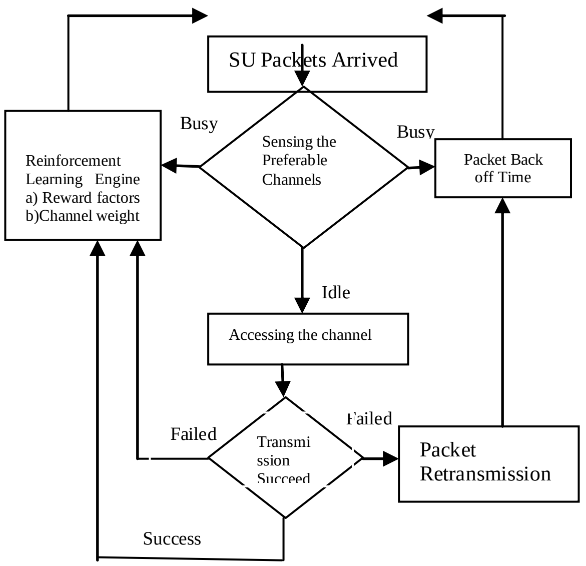

Figure 2: Methodology for applying Reinforcement Learning to secondary users

B. Simulation Results

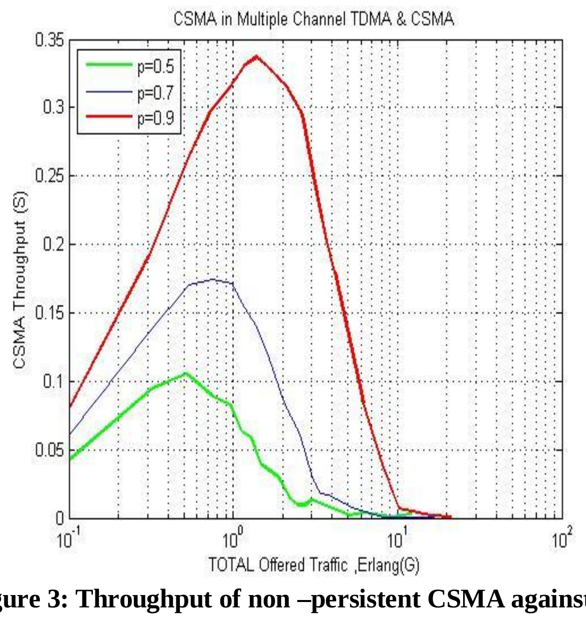

Figure 3: Throughput of non –persistent CSMA against overall offered traffic for varying CSMA traffic ratio p in TD-CSMA system in a single channel

Figure 3 depicts the comparison of the throughput characteristic of non-persistent CSMA for a single channel at different traffic ratio (p) i.e. 0.5, 0.7 and 0.9. The throughput performance of non-persistent CSMA rapidly descends when the ratio of CSMA traffic decreased in the TD-CSMA system. This is because increase in TDMA traffic causes a decrease in probability of the channel being sensed idle. From figure it is also clear that as total offered traffic is increased, the throughput of the CSMA users increases and attains a maximum. Further increase in the offered traffic load results in the decrease in the throughput of CSMA users. This is because the increase in the traffic of CSMA users results in more frequent collisions.

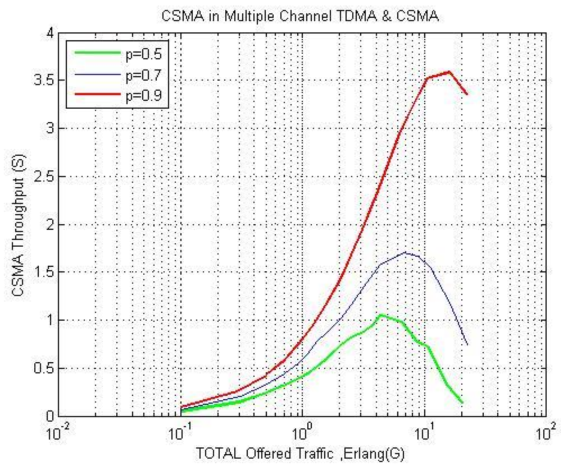

Figure 4: Throughput of non –persistent CSMA against overall offered traffic for varying CSMA traffic ratio p in TD CSMA system in a multichannel

Figure 4 shows the comparison of the throughput performance of CSMA for TD-CSMA system in multichannel scenario, where the number of channels is taken to be10. Increment in channels increases the performances of throughput of non-persistent CSMA because this increases the probability of successful transmission of CSMA packets. For example, as can be seen in figure 3, at the total offered traffic of 2 Erlangs the throughput achieved is around 0.34 for traffic ratio 0.9 and for the same traffic ratio, in figure 4, at the total offered traffic of 2 Erlangs throughput achieved is about 1.4. By comparing figure 3 and figure 4, a similar trend can be observed for traffic ratios of 0.7 and 0.5.

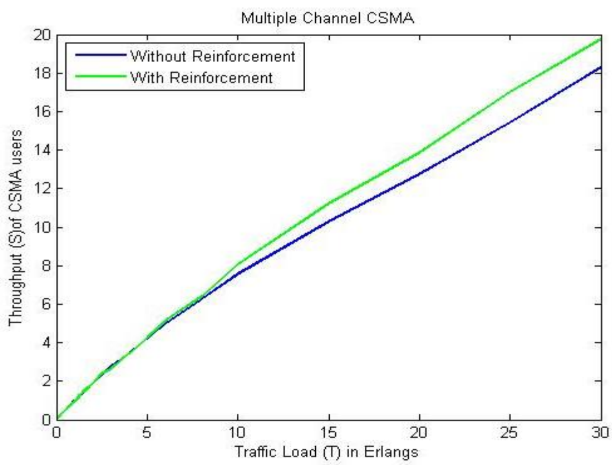

Figure 5: Effect of Reinforcement Learning on Throughput of non-persistent CSMA system with 10 channels and 1000 packets

In figure 5, the performances of secondary users, with and without reinforcement learning has been compared for the system with 10 channels and 1000 TDMA packets. 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. For example, from the figure it is clearly seen that at the traffic load of 25

Erlangs the achieved throughput is around 16 and 18 without and with reinforcement learning respectively. Thus, RL improves the throughput performance significantly.

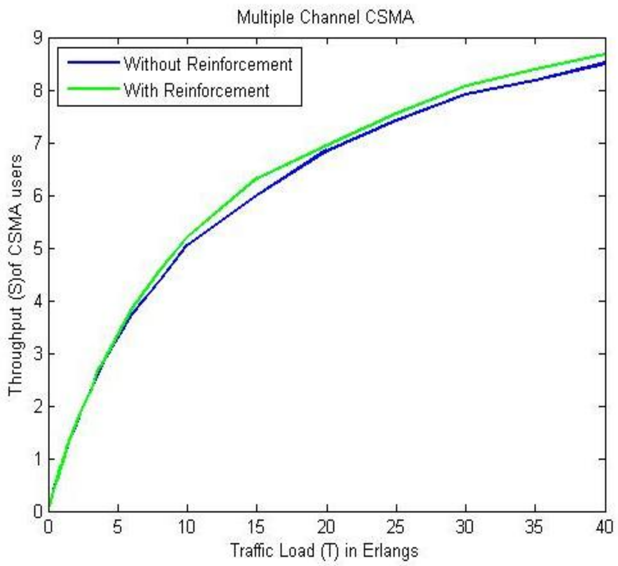

Figure 6: Effect of Reinforcement Learning on Throughput of non-persistent CSMA system with 10 channels, 1000 packets and increased traffic load.

In figure 6, the throughput variations are compared for the TD-CSMA system with 10 channels and 1000 TDMA packets when the offered traffic load is increased. It is seen that for smaller value of traffic load there is significant increase in the throughput. However as the offered traffic load is increased beyond 37 Erlangs the throughput becomes almost insensitive to the offered traffic load. This is because it is likely that increased traffic provides a high blocking probability from primary users and also the collision between TDMA and CSMA packets causes additional retransmissions for CSMA users. In this case RL, due to which SU intelligently choose channel has a minor effect on throughput performance of the CSMA users and attains a constant value as as traffic load increased.

IV. CONCLUSION

Simulation results show that multichannel TD-CSMA network provides better throughput performance of CSMA user as compared to the single channel network. 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.

Even though, it is clear from results that applying RL with SU maximizes channel utilization and achieve optimum throughput, if the total traffic in TD-CSMA combined with RL is increased the throughput performance of the CSMA users achieves a constant value. The reason for this is because the secondary users who use non-persistent CSMA suffer a very high blocking probability from primary users therefore the CSMA users need to wait longer for the channel to be sensed free. It can be concluded that to enhance the performances of CSMA users there should be more channels and less traffic load along with RL which reduce number of collision and increase the probability of successful transmission.

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