Performance Evaluation of CSMA/TDMA Cognitive Radio Using Genetic Algorithm

Maninder Jeet Kaur, Moin Uddin, Harsh K Verma

Abstract**:** ***Channel Assignment is a very important issue in the field of Wireless Networks. In this paper, we have evaluated the performance of a Multiple Channel TDMA/CSMA spectrum sharing scenario. We have combined the TDMA and the non-persistent CSMA system with multiple channels and analyzed the throughput and the throughput performance of the individual systems as a function of the actual offered traffic level. In this paper we have analyzed TDMA and CSMA in Cognitive Radio, where the primary users have higher priority than secondary users and secondary users need to monitor the channel in order to avoid the interference to the primary users. TDMA users are considered as primary users who can access the channel at any time and CSMA users are considered as secondary users who can share the channel when it is free.***

Index Terms**:** ***TDMA, CSMA, Cognitive Radio, Genetic Algorithm.***

I. INTRODUCTION

Cognitive Radio is a promising technology to alleviate the increasing stress on the fixed and limited radio spectrum [1]. An important issue in the design of a cellular radio network is to determine a spectrum efficient and conflict free allocation of channels among the cells while satisfying both the traffic demand and the electromagnetic compatibility (EMC) constraints. This issue is commonly referred to as channel assignment. Several Cognitive Radio Medium Access control (MAC) Protocols[2] have been proposed to take advantage of the vacant channels that are not used by the primary users in the context of the wireless Time division multiple access (TDMA)- based networks [3]-[5]. Authors of [4] proposed a cognitive MAC protocol to improve the channel utilization for the TDMA based cellular systems. IEEE 802.22 local area network (LAN)/metropolitan area network (MAN) standard is being developed for constructing a wireless regional area network (WRAN) utilizing white spaces (channels that are not being utilized) in the allocated TV frequency spectrum [6]. The two main approaches for spectrum sensing techniques for CR networks are [7]: primary transmitter detection and primary receiver detection. The primary transmitter detection is based on the detection of the weak signal from a primary transmitter through the local observations of CR users. The primary receiver detection aims at finding the PUs that are receiving data within the communication range of a CR user.

The primary network and the secondary network are independent with each other. In the primary network the primary users which are licensed to use the wireless spectrum have the highest priority to utilize the wireless channel. The primary users do not conceive the existence of the secondary network. The primary users communicate with the base stations with a single transmit and receive antenna. The primary users share the wireless resource in a time division manner i.e. the plink/ downlink is on the basis of TDMA scheduling. In particular, the time axis is divided into periodical frame periods, each of which consist of a constant number of time slots each with a length of Ts time units. In every frame period, each time slot is owned by a distinct primary user. On the other hand, the secondary users, each of which is equipped with a cognitive radio, are synchronized with the primary users. The secondary users know when every time slot of the primary network starts. From the perspective of the secondary users, there may be vacant time slots that are not used by the primary users. With the Cognitive Radio, the secondary users can periodically scan and identify vacant time slots in the spectrum [8]. In [9], apart from the sensing time on a single spectrum band, the time for searching multiple spectrum bands is also optimized In this paper, we propose yet another approach – the genetic algorithms (GAs) [10] – for solving this channel assignment problem. The CR works in an observe, decide and act cycle, so the knowledge observed from the radio environment needs a proper representation in the GA to get an optimized solution. This representation will allow the CR to accommodate the GA into them and this will help developing the CR adaptation ability [11]. In the spectrum allocation optimization problem in CR, the convergence behavior of the GA is of great benefit.

II. SYSTEM MODEL

This model will introduce two common multiple access techniques: Time Division Multiple Access (TDMA) for the Primary System and Carrier Sense Multiple Access for the secondary system. It is proposed that TDMA is used for primary users to access the channel and secondary users use slotted CSMA to sense the time slots of TDMA and transmit their packets during idle time slots. A CSMA based protocol is proposed in [12] that uses a single transceiver and in-band signaling. This protocol ensures coexistence among the CR users and the PUs by adapting the transmission power and rate of the CR network.

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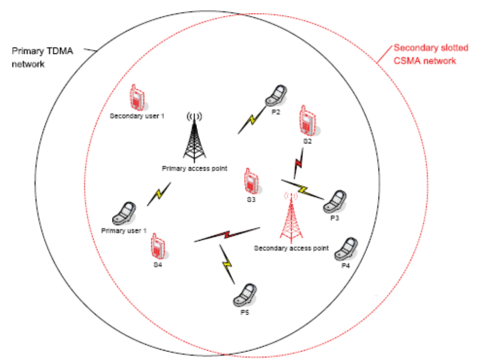

Figure 1- TDMA for Primary Users and CSMA for Secondary Users in a Cognitive Radio

The cellular radio network to be considered consists of n arbitrary cells. Without loss of generality, it is assumed that channels are evenly spaced in the radio frequency spectrum. Using an appropriate mapping, channels can be represented by consecutive positive integers.

○ **Single Channel Primary (TDMA) User –**

With the traditional TDMA scheme, the primary user transmits the packets (if any) once its assigned time slots arrive. Under the wireless fading channel environment, the number of packets that can be sent in a time slot depends on the number of buffered packets and the channel condition. It can be expected that in some time slot, the number of sent packets is small because either the number of buffered packets is small or the channel condition is poor. In this sense, such time slots are not utilized efficiently and the wireless resource is wasted. The wasted wireless resource can be utilized by the secondary users if we carefully design the TDMA scheduling scheme for the primary network. TDMA will evaluate the performance of the primary user system with single frequency channel. TDMA is contusion free multiple access scheme which employs a central entity (e.g. Base Station) to allocate capacity to individual users.

The fundamental requirements for the sensing based opportunistic spectrum usage is to protect the PU i.e ensure non-interference beyond some very limited scope. To quantify this scope, each PU has to specify a so called maximum interference time (t_{max}) which specifies the maximum time a reoccurring PU can tolerate from an SU before the interference is considered to be harmful. After this period the PU should be sure that no interference from SUs will take place. Obviously, tmax heavily depends on the service provided by the PU –it is e.g set to 2s for usage of white spaces in the TV bands. Complementary to tmax, the probability of not detecting the PU although it is present is defined. To ensure the proper protection of the PU a strict-very small- limit on the acceptable probability of these false negatives of the sensing process and tmax have to be specified- it is frequently postulated to fix these parameters by a legal act.

○ **Secondary (CSMA) User-**

The secondary (CSMA) user operates as follows. For an idle/busy time slot of TDMA, if a new packet of a secondary user is generated during a mini slot within the carrier sensing period, the corresponding secondary user will sense the channel at next sensing point. If the channel is idle, the packet will be transmitted immediately. If the channel is busy, the secondary user backs off and re-senses the channel with probability σ_{mi} at each sensing point during the remaining time of the current carrier sensing period until point *c* in the Figure 2. . If the channel is always sensed busy in carrier sensing busy period, this channel sensing process continues at each sensing point with probability σ_{mi} of following idle/busy successfully transmitted.

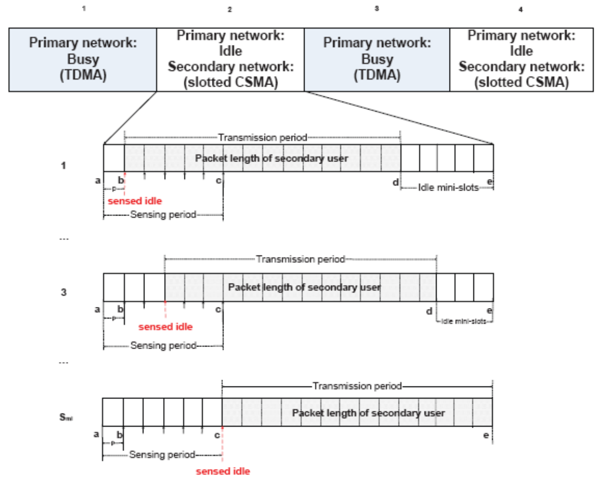

Figure 2 - Time slot structure of TDMA for primary users and CSMA for secondary users.

If a new packet of a secondary user is generated during a mini-slot outside carrier sensing period of an idle/busy time slot, it will keep the packet and sense the channel at each sensing point with probability σ_{mi} of the following carrier sensing periods until the channel is sensed idle and the packet is transmitted successfully. Here, we introduce that the transmission of a secondary user could begin from any sensing point of the carrier sensing period if the channel is sensed idle. If a transmission begins before the final sensing point of the carrier sensing period, some idle mini-slot could remain after the packet transmission. If a transmission begins from the final sensing point *c*, the transmission will finish at the end of current time slot and no idle mini-slots will remain. Therefore, a secondary user can sense a time slot of TDMA to determine if it is occupied or not by primary users, avoid busy time slots of the primary network and transmit its packet in idle time without introducing interference to the primary network [3].

III. GENETIC ALGORITHM

GA is search algorithm based on the mechanics of natural selection, genetics and evolution. They work with a population of solutions that are known as chromosomes or individuals or strings. Strings consist of genes that are usually binary numbers. At first, an initial population is provided either at random or by using problem specific formation. Then the fitness of each chromosome in the population is measured according to an optimization criterion and the fitter individuals are selected. Some of them undergo transformations to produce offspring for the next generation. The main transformations are crossover and mutation. Crossover creates two children by combining material from the initial chromosomes (parents) whereas mutation alters one or more genes. After that, the new population is ready for its next evaluation. The process is repeated and when a termination criterion is reached, the best chromosome is selected [14] [15].

GA has the following components:

- A genetic representation of solutions
- An evaluation or fitness function that plays the role of the optimization criterion
- Genetic operators
- Values for various parameters that GA uses(population size, probabilities of genetic operators etc)
- A termination criterion

GA is applied to solve the following characteristics [16]:

- Representation – A chromosome represents a cell from the cellular system where a call is referred and a binary gene corresponds to a channel. The number of bits in a chromosome is the number of channels that the cell may serve.
- Evaluation function – The evaluation function that determines the fitness of the chromosomes is the energy function of the model.
- Genetic operators: Biased random selection together with two point crossover and simple mutation are used. The probability P(i) of any individual to be selected from the population is defined as :

$$P(i) = \frac{f(i)}{\sum_j f(j)} \quad (1)$$

Where f(i) is the fitness of the ith chromosome in the population. This method favors the selection of the fittest individuals. Two point crossover selects two random chromosomes:

$$(b_1\, b_2 \ldots b_{pos1-1}\, \mathbf{b_{pos1}} \ldots \mathbf{b_{pos2}} b_{pos2+1} \ldots b_m) \quad (2)$$

$$(c_1 c_2 \ldots c_{pos1-1}\, \mathbf{c_{pos1}} \ldots \mathbf{c_{pos2}} c_{pos2+1} \ldots c_m) \quad (3)$$

And replace them with the pair of their offspring :

$$(b_1\, b_2 \ldots b_{pos1-1}\, \mathbf{c_{pos1}} \ldots \mathbf{c_{pos2}} b_{pos2+1} \ldots b_m) \quad (4)$$

$$(c_1 c_2 \ldots c_{pos1-1}\, \mathbf{b_{pos1}} \ldots \mathbf{b_{pos2}} 4 c_{pos2+1} \ldots c_m) \quad (5)$$

where pos1 , pos2 are random uniform numbers. Mutation simply alters the value of a selected bit from 0 to 1 or vice versa.

- GA parameters: A population size of 50 chromosomes is used. The population is initialized randomly. The probability of crossover (p_c) was set to 0.75 whereas the probability of mutation(p_m) to 0.05. These values are in line with the common Gas' parameters and were chosen after many experimental trials.
- Termination Criterion: The whole search is terminated after a maximum number of iterations where there are not presented significant changes in the energy value of the best chromosome between successive generations. For our case 100 generations were used. The best individual is the solution to the DCA problem and corresponds to the problem variable.

IV. METHODOLOGY

Throughput of the slotted CSMA network due to secondary terminals is analyzed. We suppose that all *Ns* secondary terminals, are independent from each other and we have the following joint probability distribution function [17] [18].

$$f(x_s, z_1, \ldots z_{Is-1}) = \frac{1}{X_s} e^{-\frac{xs}{Xs}} \prod_{i=1}^{Is-1} \frac{1}{Zs} e^{-\frac{zi}{Zs}} \quad (6)$$

The capture probability of a secondary terminal, $P_{scap}(I_s)$ can be derived as

$$P_{scap}(I_s) = \Pr\left(\frac{X_s}{\sum_{i=1}^{Is-1} Z_i} > R\right) \quad (7)$$

The throughput of slotted CSMA due to secondary terminals Sc is defined as the time taking rate of successful information carrying for secondary terminal during a time slot of primary TDMA network.

The conditional probability of occurrence of an idle time slot can be derived as

$$P_{idle} = \pi_0 (1-\sigma_p)^{Np} \quad (8)$$

V. RESULTS AND DISCUSSIONS

The performance evaluation of Single Channel combined TDMA/CSMA system shows that the two systems can operate together. With a total traffic load of 1 Erlang (the maximum the channel can support) the total throughput was close to 0.55 Erlangs, showing only 55% of the channel capacity is being used.

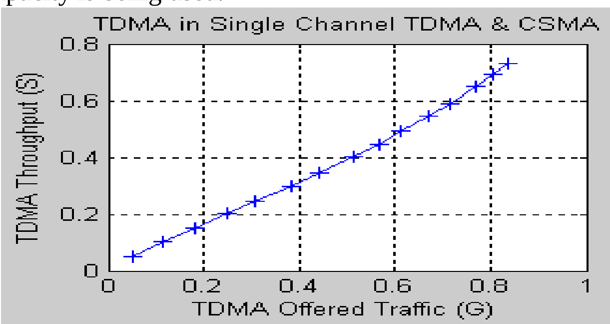

Figure 3 TDMA throughput for Single Channel combined System

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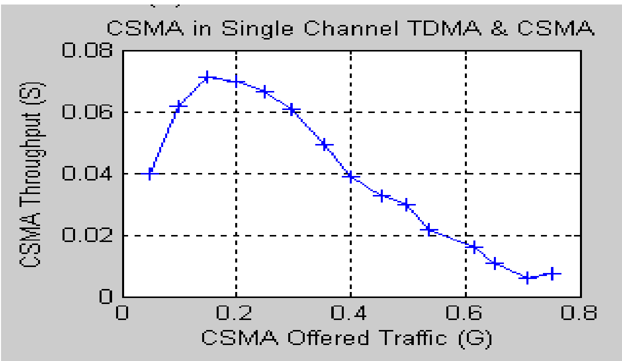

Figure 4 CSMA throughput for Single Channel combined System

The primary user system as shown in Figure 3 dominates channel access, although the throughput of the primary user system is reduced slightly by the presence of the secondary user system, indicating that the secondary users cannot completely avoid interfering with primary user transmissions. The throughput of the secondary user system as shown in Figure 4, is reduced significantly by the primary user system. At high offered traffic levels, the channel becomes heavily occupied by primary user transmissions. The secondary users have very little opportunity to transmit on the channel and so the throughput of the CSMA system is extremely low. At offered traffic levels, the throughput of the CSMA system is still very low, despite the channel being free a significant portion of the time.

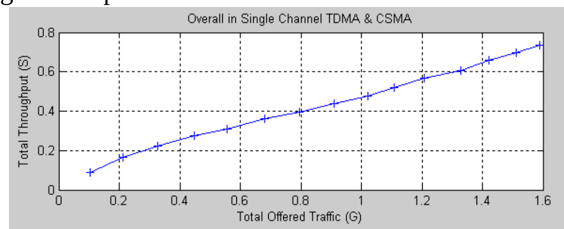

Figure 5 Total throughput for Single Channel combined System

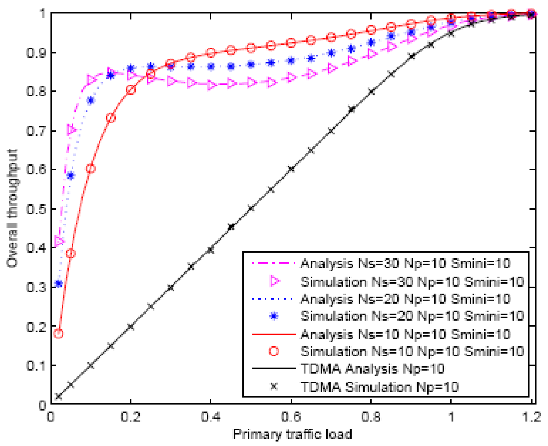

Figure 6 Throughput Analysis

The reduction in throughput of both systems as shown in Figure 6 is due to the following possible collision conditions:

- A TDMA user starts to transmit a packet during a CSMA transmission.
- A CSMA user transmits a packet during the vulnerable period (a) of a TDMA or CSMA packet transmission, which means that the channel is sensed idle but it is actually busy. This vulnerable period is a direct consequence of the propagation delay.

VI. CONCLUSION

In this paper, we outlined TDMA technique which is used by the primary users to access the channel and CSMA which is used by the secondary users in Cognitive Radio technology with the help if Genetic Algorithm. Specific recommendations include incorporating more formalized prediction algorithms into the cognitive engine loop in order to create more proactive operations; develop interdisciplinary architectures with cognitive scientists and investigate lesser known AI algorithms. This proposed model gives better performance in comparison with the model which do not uses Genetic Algorithm.

One of the main objectives of this research is to open a new view of intelligent agents using one of the Soft Computing Techniques for Cognitive Radio Multiple Access Schemes, which gives a degree of utilisation of this paradigm of intelligent agents, but that more practical research is needed in order to defend this idea as innovative. Future work of this research includes several lines of development, which are: Using other Soft Computing Techniques and Integration of those as well, for the Cognitive Radio performance analysis. Multiple Channel Combined system can also by analyzed on the same scenario to have better performance.

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