Dynamic Open Spectrum Sharing (DOSS) MAC Protocol with Back-off Algorithm

Abeer Al Attal, Saleh Hussin, Mohammed Fouad

Electronics and communication department, Faculty of engineering,
Zagazig University, Egypt

abeer_alattal@yahoo.com , SISaleh@eng.zu.edu.eg , fouadzu@gmail.com

Abstract

Current independent radio spectrum measurements illustrate that a major portion of the licensed spectrum band (e.g. TV bands) is not used. On contrary, a growth of wireless application devices in the unlicensed spectrum bands is increasing frequently, these bands became overcrowded.

Therefore, a new technology to make a better utilization of the available spectrum resource is required with a trade of avoiding overlapping interference. This technology is called cognitive radio (CR).

Cognitive radio is a type of radios that is able to be programmed and configured dynamically. The CR network can be classified according to infrastructure into (i) A centralized CR network (CCRN): An infrastructure CR network which consists of CR centralized base-station and cognitive users. (ii) A cognitive radio ad-hoc network (CRAHN): Consists of cognitive users only without centralizing base-station. This research will be focused on CRAHN.

One of the main cognitive functions is medium access control (MAC) protocol which is a challenge in the performance of the CR networks. The MAC protocols for cognitive radio networks can be classified into (i) random access protocols like dynamic open spectrum sharing MAC protocol, (ii) time slotted protocols like opportunistic MAC protocol, and (iii) hybrid access protocols like synchronized MAC protocol. In this paper, the dynamic open spectrum sharing (DOSS) MAC protocol is presented, analyzed and simulated. Moreover, an enhancement to DOSS MAC protocol will be executed using an implementation of Back-off algorithm.

Keywords: *Access control, cognitive radio,back-off algorithm, dynamic open spectrum sharing, spectrum access, spectrum sharing.*

1. Introduction

Since the 20th century, the radio frequency bands are regulated by organizations like federal communications commission (FCC) in the United State (US). These bands are assigned to license users. For example, very high frequency (VHF) and ultra-high frequency (UHF) broadcast are assigned for television (TV) stations, or a part of super high frequency (SHF) and a part of UHF for mobile communication.Not all spectrum bands are licensed, there are few and small parts left free for using by anyone, these bands are called unlicensed bands.There is a major problem in wireless networks called spectrum scarcity problem. This problem results from the limited available spectrum bands with the growth demand of applications.

The cognitive radio (CR) [1][2] is a futuristic technology adapted to solve the spectrum scarcity problem using Software Defined Radios SDR [3]. The CR networks can be classified according to infrastructure to centralized cognitive radio networks CCRNs and decentralized or ad-hoc cognitive radio networks DCRNs.

Each network has two types of users: Primary users (PUs) and cognitive radio (CR) or secondary (SUs) users. In this paper, the terms secondary users (SUs), or cognitive radio (CR) users may be used interchangeably. The SU allocates the spectrum bands using opportunistically identifying the unoccupied portions of spectrum (spectrum holes). Then, it transmits data over spectrum holes, when ensuring that the licensed or PUs are not influenced.

An important consideration is avoiding performance declension of the licensed users with the best possible performance of SUs; that can be achieved by providing efficient means of sensing, sharing and keeping tolerable interference levels for the PUs which have a priority of transmission. The process of sharing of unoccupied portion of spectrum (spectrum holes) called dynamic spectrum sharing (DSS) or dynamic spectrum access (DSA) [4]. DSS technique allows CR users to share holes dynamically whenever PU is absent. The SUs senses the spectrum bands and determine the available bands. Then, the SUs determine the best available bands according to its quality of service (QoS) requirements using DSS technique for data exchanging between SUs. Once any PU appears in these holes, the SUs vacate the band immediately and search for another hole to avoid interference as shown in Fig. 1.

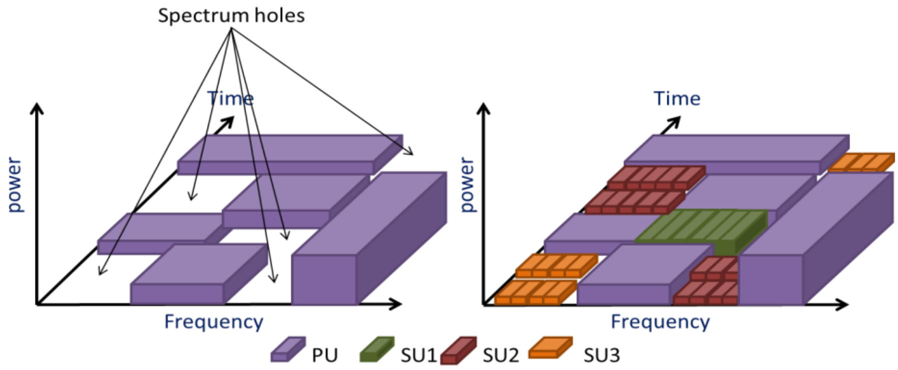

Fig.1. Dynamic Spectrum Sharing

The cycle of cognitive radio networks which consists of four main functions:

A.Spectrum sensing :

The SU can use only free portion of the spectrum (holes). So, spectrum sensing provides information on spectrum availability [5]. The most effective method to sense spectrum holes is to detect PU [6] [7]. However, the PU may be not in the transmission range of the SU or there are some barriers between PUs and SUs leads to some cooperation.

The cooperative sensing between SUs is vital to share information about the PUs appearance. If the detection time is long the transmission time will be short and the throughput will below. Therefore, it is important to control the sensing time.

B.Spectrum decision :

Once the available holes are allocated, it is necessary to select the most suitable one for SUs according to their quality of service (QoS) requirements [8]. Both spectrum selection and routing formation are included in spectrum decision. That is done in the beginning of the transmission period. A Dynamic Decision Protocol For Adhoc Network can be illustrated in [9].

Spectrum decision consists of three steps: First step, each spectrum band is analyzed based on the local observations of SUs and the statistical information of networks, this is called spectrum analysis. Second step, based on this analysis, the best spectrum band can be selected and this step is called spectrum selection function. Third step, the SUs need to reconfigure communication hardware to the selected spectrum band, this function is called reconfiguration.

C. Spectrum sharing :

It is responsible for avoiding collisions in overlapping parts of the spectrum during data transmission.

D. Spectrum mobility :

If the PU is detected in the specific portion of the spectrum in use, SUs should leave the spectrum immediately and continue their transmission using another hole.

Spectrum access protocols can be classified by various methods [10] [11]. It can be classified based on the nature of channel access as following:

A. Random access CR MAC protocols [12]:

This category needs no time synchronization and based on the carrier sense multiple access / carrier avoidance (CSMA/CA) principle .

B. Time slotted MAC protocols:

These MAC protocols need synchronization, because the time is divided into various time slots for both the control channel and data transmission.

C. Hybrid protocols:

These protocols are partially time slotted. Control signalling occurs over synchronized time slots. But, the data transmission occurs in a random-access manner, without any time synchronization.

The proposed protocol is dynamic open spectrum sharing (DOSS) [13] MAC protocol which belongs to the random-access category mechanism. Random access control protocols depend on IEEE 802.11 standardization [14] that is called also request to send and clear to send (RTS-CTS) hand shaking. The SUs sense the spectrum band to detect the free holes, and then it transmits on the free hole after back-off duration to avoid collision. Both request to send (RTS) and clear to send (CTS) control message prevent the SU’s neighbours from transmission for the duration of the main packet. This is known as the IEEE 802.11 RTS/CTS exchange.

• **Paper organization**

The remainder of the paper is organized as follows. Section II presents DOSS protocol; Section III investigates DOSS protocol with back-off algorithm. The simulation results are provided in Section IV. Finally, section V concludes the paper.

2. Dynamic Open Spectrum Sharing (DOSS) algorithm

DOSS protocol consists of five steps. The steps can be illustrated as following:

(A). PU detection

When PU is absent the SU can be allocated only on spectrum holes. Using the wide band spectrum sensing [15], [16] capability, The SUs determine the used spectrum bands and decide on the available spectrum holes. A free usage list (FUL) is filled with free spectrum bands or channels. Also, a currently using list (CUL) is filled with busy spectrum bands or channels that are used currently.

(B). Set-up of three operational bands

A frequency band is needed for actual data transmission, and control signals require another band for sending beacons. Beacons are very important to inform neighbors with any change in any spectrum band status. Moreover, a third narrow frequency band for busy tone is also needed. Busy tone is an issue for a direct one-to-one mapping with the data transmission bands. It also works as a flag of informing about the busy band to its neighbors.

(C). Spectrum mapping

The spectrum mapping is used for executing the mapping of the busy tones with the data transmission bands. This can be occurred by observing narrow band receiver-initiated busy tones as shown in Fig. 2, a node knows all the data receiving activities in its neighbourhood. Denote the busy tone band as [fl, fu] and the data band as [Fl, Fu].

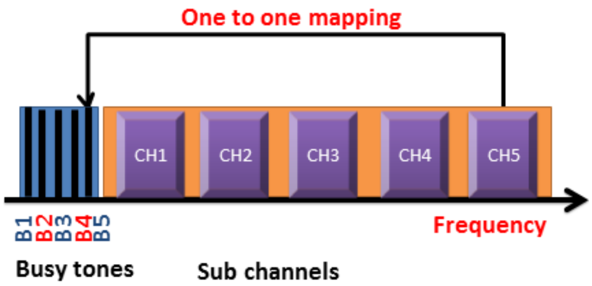

Fig.2. Spectrum mapping

(D). Spectrum negotiation

The spectrum negotiation among the sender and receiver occurs according to IEEE 802.11 standardization as follows:

i. The transmitter sends RTS to the receiver.
ii.The receiver refers to the spectrum mapping and turn on the corresponding busy tone.
iii.If the receiver is free, it sends CTS signal either a blocking occurs.

(E). Data transmission

After negotiation between the sender and receiver, the transmitter sends data. After successfully receiving, a data acknowledgment DATA-ACK signal is sent by the receiver to inform with the end of data transmission.

3. Dynamic Open Spectrum Sharing (DOSS) protocol with Back-Off algorithm

Back-off algorithm (BOA) [17] is a collision resolution mechanism which is generally used in the Ethernet to schedule re-transmissions after collisions. This algorithm has been implemented during the contention interval to enhance the number of successful data packets of users and hence increase the throughput of cognitive radio network. The competition and collision among the cognitive users has seriously minimized by reserving the unused licensed channels. The back-off mechanism has been implemented to resolve the contention among the collided cognitive users to increase the number of successful users. So, if the collision is detected among cognitive users, the collided cognitive users attempt to utilize another contention slot in the same cycle-time. That can be occurred using back-off mechanism .

If a collision takes place between 2 stations or nodes in the network, they may restart transmission as soon as they can after the collision. This will always lead to another collision and form an infinite loop of collisions leading a deadlock. To prevent such scenario the back-off algorithm is used.

The nodes involved in the collision randomly pick up an integer number from a set K, where K is called the contention window. If the nodes collide again because they picked up the same integer, the contention window size is doubled. The contention window size is calculated by the relation (2n-1), where n is collision number or collision order. Before the involved nodes in the collision start the transmission, they listen to the channel and transmit only if the channel is idle. The node is picked the smallest integer in the contention window for successful frame transmission. So, Back-off algorithm defines a waiting time for the nodes involved in the collision; In other words, the station should wait time slots before re-transmission.

In [18], back-off algorithm is discussed and implemented in the self-scheduled multi-channel MAC (SMC-MAC) protocol for solving the connection among the SUs and holding the suitable licensed channels for data transmission .

The SMC-MAC with back-off algorithm [19] is presented with a system model and its numerical analysis. The spectrum mapping of busy tone in SMC-MAC protocol occurs in time domain by dividing sensing sharing period into time slots. The frame structure [19] of SMC-MACcan be shown in Fig 3. In contrast, mapping of busy tone in DOSS-MAC protocol occurs in frequency domain using one to one mapping as shown in Fig 2. The SMC-MAC protocol belongs to the hybrid protocols which are affected by the synchronization problem.

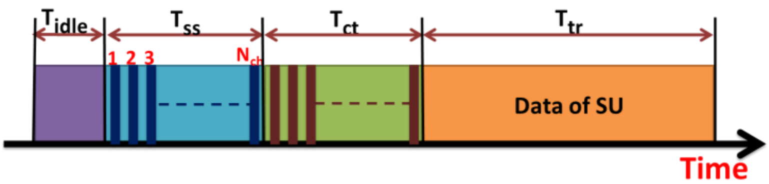

Fig.3 SMC-MAC frame

While, the DOSS-MAC protocol can be implemented and analyzed with simulation for enhancing network performance as driven in section 4. The main reasons of choosing DOSS-MAC algorithm can be summarized in the following points:

i. It is a very simple protocol.
ii. This protocol doesn't need synchronization.
iii. The protocol is appropriated for mobile ad-hoc networks.

The proposed DOSS protocol with back-off algorithm (BOA-DOSS) can be illustrated using pseudo code as shown in Fig. 4. At the beginning of network initialization, the frequency bands should be set up. Then, a frequency mapping is formulated as illustrated in DOSS scheme. In the case of the CR networks, there is PUs which has a priority of transmission without any delay or interference. Other SUs are allocated sharing the spectrum holes with PUs. When SU wants to start data transmission, it sends RTS to idle or free channel according to IEEE 802.11 standardization .

If the channel is immediately free, the receiver replies with CTS signal. When the source node receives the signal, it starts to transmit data and turn on the corresponding busy tone. At the case of collision occurrence by conflicting with another SU, both of the sender and receiver nodes tag the collision and calculate its order. If the collision order less than max number of re transmissions allowed, it retransmits data. Else a blocking occurs and calculated. At the end of successful data transmission, the receiver replies with data acknowledgment (DATA-ACK). Then, counter of successful data increases. If a PU is appeared, the corresponding SU should leave the channel immediately and the dropping is occurred. The dropping counter will increase. At the end of simulation time block, drop, and success counters can be obtained.

The ordinary DOSS scheme selects a control channel in a random method. The common control channel is fixed and tuned only with a fixed frequency. Hence, high traffic over common control channel and the probability of blocking occurs without any minimization. So, using BOA-DOSS algorithm, the probability of blocking can be decreased. In case of BOA-DOSS algorithm, it has been proposed that each cognitive user randomly chooses a contention slot which makes it more vulnerable to collision among the cognitive users. In order to reduce the number of collisions, the control channel's contention interval can be modified by using the back-off algorithm in the contention interval. For example, if the SU collides with another, the collided cognitive users can select another contention slot in the same cycle time with the help of back-off algorithm. And if the selected contention slots are different, both the cognitive users become successful. Otherwise, if again there is collision, then the contention window size is increased, and same procedure is followed.This whole procedure has been presented using simulation as shown in the next section.

4. Simulation assumptions and results

4.1. Simulation assumptions:

To evaluate the performance of the proposed method and the ordinary DOSS algorithm, a simulation experiments are carried out using Matlab™ with the following network assumptions

i. The network consists of five nodes with four connected links; each link consists of 10 sub channels.

ii. All licensed channels are homogeneously.

iii. The arrival rate of PUs and SUs is assumed to be Poisson distribution with rate $\lambda pu = 0.2$ and $\lambda su = 0.2$, sequentially .

iv. The service rate of the PUs and SUs are assumed to be with rate $\mu pu = 0.25$ and $\mu su = 0.2$, respectively .

v. Simulation time is 100,000 time unit.

vi. Dropping occurs when a PU interrupts the transmission of SUs.

$$\text{Dropping ratio} = \frac{\text{number of dropped data packets}}{\text{total number of transmitted packets}}$$

vii. Blocking in DOSS protocol occurs when all channels are busy or common control channel is used by other SU .

$$\text{Blocking ratio} = \frac{\text{number of blocked data packets}}{\text{total number of transmitted packets}}$$

Viii. Blocking in DOSS with back-off algorithm occurs when collision order exceeds the max number of allowable data re transmissions.

ix.The throughput [19] can be calculated by:

$$\text{Throughtput} = \frac{\text{number of data packets received successfully}}{\textit{total transmission time}}$$

4.2. Simulation results

The blocking and dropping ratios can be estimated at 5 retransmission trials. In these results, the DOSS algorithm will be represented if number of retransmission n=0; Otherwise, it will be DOSS with back-off algorithm. Moreover, the effect of varying PU arrival rate λpu from 0 to 1 can be analyzed .

As shown in Fig. 4, the blocking ratio is increased linearly when PU arrival rate increases. This linear increment occurs due to the decreasing in free spectrum bands. This linear increment stops at appoint of network saturation. At this point, the number of blocked data is seemed to be fixed.

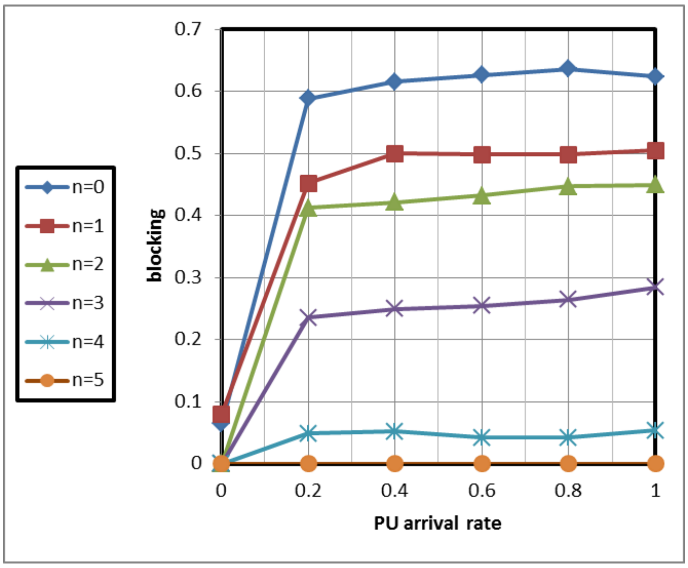

Fig. 4. Blocking ratio versus PU arrival rate

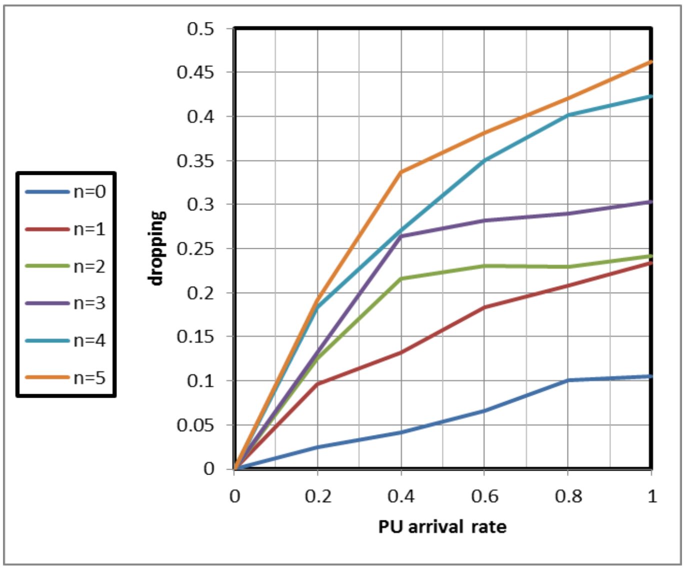

Fig. 5. Dropping ratio versus PU arrival rate

Fig. 5 represents the dropping ratio versus PU arrival rate. The dropping ratio is increased with PU arrival rate. The probability of dropping increases with increasing PU activity in the network. This increment is expected because of the increasing of PUs increases the probability of applying on a used spectrum portion by SUs, which leads to drop the SU immediately with respect to PU priority.

After using back-off algorithm the blocking ratios decreased due to increasing number of data re transmissions which increases the probability of delivering data successfully without blocking while, the dropping ratio is increased. After a certain number of data retransmission times, the network congestion is occurred. Therefore, the optimum number of data retransmission times can be selected.

The trade-off is to select an optimum number of data re transmissions that decrease blocking and dropping ratio. Drawing the relation between blocking and dropping ratios versus number of data re transmissions can be reported as shown in Fig. 6

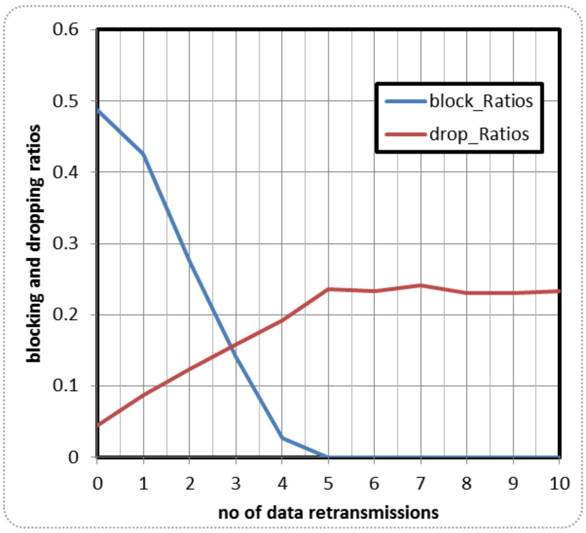

Fig. 6. Blocking and dropping ratios versus number of data

After 5 trials of data re transmissions blocking ratio will be nearly saturated as shown in Fig. 6 While, dropping seems to be stabled. Any more trials than 5 will be worthless and increase network traffic. Hence, the optimum number of data re transmission for this network scenario is five trials .

The optimum point of retransmissions will be at n=5. When PU arrival rate equal to zero, the licensed channels will be occupied by SUs only, the SU dropping ratio and blocking ratio will be zero in both MAC protocols. The collision ratio is high if many users transmit in the beginning of time slot. Thus, the collision ratio in DOSS-MAC protocol is higher than the collision ratio in the BOT-DOSS MAC protocol.

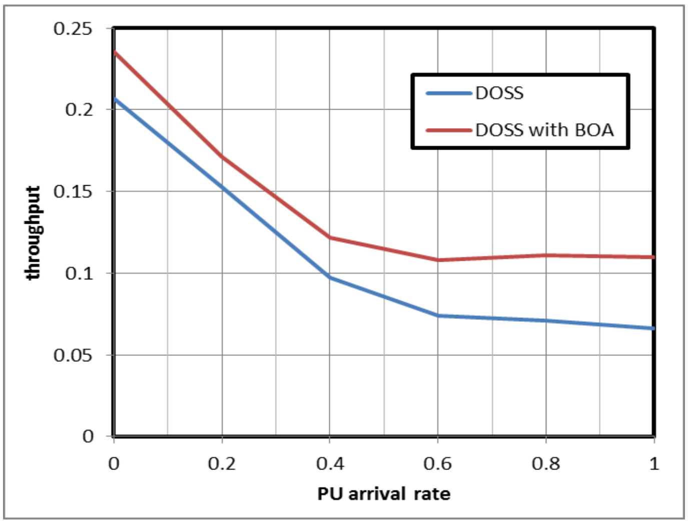

Fig. 7. Throughput of DOSS and DOSS with BOAversus PU arrival rate

Therefore, the throughput of DOSS-MAC protocol will be lower than the throughput of BOT-DOSS MAC protocol as shown in Fig. 7. By increasing the PU arrival rate, the collision, SU blocking and SU dropping ratios will be increased. Hence, the throughput will decrease. Due to the BOT technique, the throughput of the BOT-DOSS MAC protocol is higher than the throughput of the ordinary DOSS MAC protocol.

All of these results can be summarized in Table 1 and Table 2. Numerically, the following two tables illustrate the cases of blocking ratios, dropping ratios, and successful data transmission ratios in both case of ordinary DOSS MAC protocol and DOSS MAC protocol with BOA. It is noticed clearly that succession ratios in case of DOSS MAC protocol with BOA is enhanced more than 20 % against ordinary DOSS MAC protocol. It refers to successfully delivered packets. Moreover, blocking ratios are decreased by nearly 40%.

Table 1 :Summary of data obtained from simulation of ordinary DOSS MAC and DOSS MAC protocol with BOA

	DOSS MAC protocol			DOSS MAC protocol with BOA		
λ_{pu}	Blocking ratio	Dropping ratio	Successful data ratio	Blocking ratio	Dropping ratio	Successful data ratio
0.2	0.0642	0	0.9358	0	0.0146	0.9854
0.4	0.5885	0.0244	0.3871	0	0.1916	0.8084
0.6	0.6159	0.0418	0.3423	0	0.3365	0.6635
0.8	0.6265	0.0665	0.307	0	0.3812	0.6188
1	0.6364	0.1006	0.263	0	0.4212	0.5788

5. Conclusion

In this research, an overview of the state of the art for cognitive radio cycle and accessing protocols is presented. The ordinary DOSS-MAC protocol for the cognitive radio based wireless networks is explained briefly. Back-off algorithm is illustrated. A modified DOSS algorithm based on BOT mechanism is investigated. Moreover, a simulation study between the proposed technique and the ordinary DOSS-MAC protocol is illustrated.The accessing channel mechanism of ordinary DOSS-MAC protocol occurs by selecting a free channel from predefined free usage list for control signals without any investigation or minimization to blocking probability.Applying back-off algorithm (BOA) on DOSS-MAC protocol increases the data transmission with priority of illuminating blocking ratios.

Using simulation analysis, the proposed DOSS with BOA method has significantly enhanced the performance. The number of successful data delivered for cognitive users is increased. Hence, the proposed DOSS with BOA method has enhanced the throughput compare with the ordinary DOSS-MAC protocol .The simulated performance analyses of the network for applying both of strategies prove that using BOA-DOSS algorithm can decrease blocking ratio and increase throughput without interfering with PU activities.

6. Future works

In this research, an overview of the dynamic open spectrum sharing (DOSS) MAC protocol is presented, analyzed and simulated with an enhancement by using Back-off algorithm. It is expected to apply the enhancement idea of BOA on others' MAC protocols.Also, it is a big encouragement to apply the enhancement idea in case of multi-hob communications. All simulation results obtained in case of a single hop multi-channel communication network.Further, it is preferred to study the effect of heterogeneous channels instead of used homogeneous channels and compare results.

References

[1]. Akyildiz, W. Lee and K. Chowdhury, "CRAHNs: Cognitive radio ad hoc networks", Ad Hoc Networks, vol. 7, no. 5, pp. 810-836, 2009.

[2]. S. Tripathi and M. Shah, "A dynamic opportunistic spectrum access MAC protocol for Cognitive Radio networks", International Conference on Advances in Computing, Communications and Informatics (ICACCI), 2014

[3]. Rowayda A. Sadek, “An Agile Internet of Things (IoT) based Software Defined Network (SDN) Architecture,” Egyptian Computer Science journal, vol. 42, no. 2, May 2018.

[4]. M. Safwat, "Dynamic spectrum access with traffic prioritization in Cognitive Radio networks", International Symposium on Networks, Computers and Communications (ISNCC), 2015

[5]. B. Wild and K. Ramchandran, “Detecting primary receivers for cognitive radio applications,” First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2005

[6]. H. Kim and K. G. Shin, “Fast Discovery of Spectrum Opportunities in Cognitive Radio Networks,” 2008 3rd IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks, 2008.

[7]. H. Kim and K. Shin, “Efficient Discovery of Spectrum Opportunities with MAC-Layer Sensing in Cognitive Radio Networks,” IEEE Transactions on Mobile Computing, vol. 7, no. 5, pp. 533–545, 2008.

[8]. R. Tandra and A. Sahai, “SNR Walls for Signal Detection,” IEEE Journal of Selected Topics in Signal Processing, vol. 2, no. 1, pp. 4–17, 2008

[9]. Mohamed Othman, “ Dynamic Decision Protocol For Adhoc Network ,” Egyptian Computer Science journal, ECS,Vol. 37 No. 1, January 2013.

[10]. O. Mehanna, A. Sultan, and H. E. Gamal, “Blind Cognitive MAC Protocols,” 2009 IEEE International Conference on Communications, 2009.

[11]. C. Cormio and K. R. Chowdhury, “A survey on MAC protocols for cognitive radio networks,” Ad Hoc Networks, vol. 7, no. 7, pp. 1315–1329, 2009

[12]. B. KAN, J. FAN and J. WANG, "MAC Protocols for Cognitive Radio Networks", Journal of Software, vol. 23, no. 7, pp. 1824-1837, 2012.

[13]. Q. Chen, Y. Liang, M. Motani and W. Wong, "CR-CSMA: A Random Access MAC Protocol for Cognitive Radio Networks", IEEE 20th International Symposium on Personal, Indoor and Mobile Radio Communications, 2009.

[14]. Qian Chen, Wai-Choong Wong, M. Motani and Ying-Chang Liang, "MAC Protocol Design and Performance Analysis for Random Access Cognitive Radio Networks", IEEE Journal on Selected Areas in Communications, vol. 31, no. 11, pp. 2289-2300, 2013.

[15]. S. Roy, S. Kundu, G. Ferrari and R. Raheli, "Cognitive radio CDMA networking with spectrum sensing", International Journal of Communication Systems, vol. 27, no. 10, pp. 1582-1600, 2012.

[16]. I. Akyildiz, B. Lo and R. Balakrishnan, "Cooperative spectrum sensing in cognitive radio networks: A survey", Physical Communication, vol. 4, no. 1, pp. 40-62, 2011.

[17]. N. Xie, L. Zhang, J. Wu and H. Wang, "An Adaptive Backoff Algorithm Based on Channel Utilization for IEEE 802.11", Wireless Personal Communications, vol. 83, no. 4, pp. 2965-2973, 2015.

[18]. S. Pandit and G. Singh, “Backoff Algorithm in Cognitive Radio MAC Protocol for Throughput Enhancement,” IEEE Transactions on Vehicular Technology, vol. 64, no. 5, pp. 1991–2000, 2015

[19]. R. Rubeena and I. Bala, “Throughput Enhancement of Cognitive Radio Networks through Improved Frame Structure,” International Journal of Computer Applications, vol. 109, no. 14, pp. 40–43, 2015