Analysis of Efficient Cognitive Radio MAC Protocol for Ad Hoc Networks

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***Abstract*—Cognitive Radio (CR) is an emerging technology to exploit the existing spectrum dynamically. It can intelligently access the vacant spectrum frequency bands. Although a number of methodologies have been suggested for improving the performance of CR networks, little attention has been given to efficient usage, management and energy efficiency. In this paper, a modern paradigm pertaining to the spectrum allotment and usage, manifested as CR, has been introduced as a potential solution to this problem, where the CR (unlicensed) users can opportunistically deploy the available free licensed spectrum bands in such a way that restricts the degree of interference to the extent that the primary (licensed) users can allow. In this article, we analysis and compare various protocols, in addition, we evaluate CREAM MAC, RMC MAC, SWITCH MAC, EECR MAC protocols related to the CR MAC in term of different parameters such as throughput, data transmission and time efficiency. We conclude the most efficient protocol, which have similar features named as Proposed Efficient Cognitive Radio MAC (PECR-MAC) protocol.**

Keywords*—Ad Hoc networks; cognitive radio (CR); backup channel; energy efficient protocols; MAC protocol; primary users; secondary users

I. Introduction

There has been an escalation in wireless technology due to increasing demand of wireless services and gadgets, which has led to the Scarcity and crowding of prevailing spectrum. This persuasion of the excessively congested spectrum is not due to the paucity of the spectrum, but due to the inefficient usage and static management policies of the spectrum. CR is a robust technology, which utilizes existing spectrum more efficiently and effectively. Joseph Mitola III and Gerald Q. Maguire is the first analyst of Cognitive Radio in 1999 whereas early assessment of spectrum accessing in term of licensed and unlicensed published in 1995 [1]. Moreover, software defined radio (SDR) is used in radio devices is also propound by Joseph which was not used in radio devices before. Now this software is used in all the devices.

Additionally, Primary Users (PUs) are assigned fixed segments of the spectrum, which they do not deploy all the time. It is noticed that spectrum may be inefficient to meet the demand in some bands, however, it is also relatively much underutilized or partially utilized. Traditionally, spectrum is assigned to PUs through the authorized bodies in a licensed way. This means that PUs are the licensed users which have the exclusive right access to the bands of the spectrum. CR users are called secondary users (SUs) which are unlicensed users. CR will recover the spectrum utilization in wireless communication system while obliging the increasing demand of wireless devices, services and applications such as, Global System for Mobile Communication (GSM) networks, next generation technologies, satellite transmission, public protection and navy purpose.

Furthermore, there are several computer science researchers are working on the Analysis of Cognitive Radio MAC Protocols for AdHoc Network. There are a number of propositions have been outlined by them, but many of them have different deficiencies such as power efficiencies, collision between nodes, multi-channel hidden node problems and many others. The rest of the paper is structured as follows:

Section II includes the discussion of various protocols pertaining to CR MAC Protocol. Section III includes comparison of various protocols, Section IV evaluates the graphical evaluation and performance of benchmark CR MAC Protocols in term of throughput, time and rate of Data transmission on MATLAB Simulation tool. Section V defines the determined time diagram. Section VI describes the concluded result and discusses the future work.

II. Discussion of CR-MAC Protocols

The research community has developed many structures less opportunistic MAC protocols. One of the most crucial and difficult model disputes is how the SUs examine when and which channel use to transmit the secondary user packets avoiding the interference to the PUs. Secondly, the backup channel (BCH) problem with the appearance of Primary user during the occupation of SUs. The obstacles become more difficult and challenges because there is no centralized controller used in the wireless Ad Hoc Networks.

The research community has designed many AdHoc opportunistic MAC protocols. Thus, I evaluated some of them which are explained below:

A. AMAC Protocol

In [2], the author has proposed adaptive MAC Layer Protocol (AMAC) for supporting MAC layer adaptation in CR Networks. The control information is distributed between nearby radios using Global Control Plane (GCP) based on the "Cognet" protocol. This protocol mainly focuses on how to switch between different protocols. The proposed architecture in this paper consists of two planes, the Global Control Plane (GCP) and the data plane. The GCP is used to carry all the control information and the data plane is dedicated for data transmission. The transmitted data is established using the GCP protocols. The GCP assists in establishing PHY, MAC and routing parameters. AMAC includes three phases, including Baseline MAC selection, PHY adoption, and MAC adaptation, which dynamically change the MAC behavior. In addition, it is seen that VOIP, data transmission using AMAC reaches four times, throughput of static CSMA and twice the throughput of TDMA and also each node has the ability to reach the common based MAC protocol on most nodes interest. The results obtained based on the proposed MAC protocol show the switching latency and control overhead is not excessive.

B. DSA MAC Protocol

In article [3] the writer has proposed a novel MAC protocol in Multi-channel networks using the Dynamic Spectrum Allocation (DSA) on Cognitive Radio QOS support. It is implemented in the control and data channels with the procedure of FRQ/FRP/ACK-hello and DAT/ACK respectively. In addition, the results are discussed showing the proposed DSA-MAC improves the throughput significantly compared to IEEE 802.11 MAC. It is based on CSMA/CA Scheme. This protocol is adaptive for Multiple Input and Multiple-Output (MIMO) and orthogonal Frequency Division Multiplexing Techniques. This Protocol achieves higher throughput over higher network load.

C. DDMAC Protocol

In article [4] the author has proposed a Distance Dependent MAC Protocol that attempts to maximize the CRN throughput. This protocol introduces a probabilistic channel assignment algorithm considering the traffic profile. This protocol is tested and it efficiently reduces the blocking rate of transmission requests by around 30% which increases the network throughput. This protocol seems to be simple and can also be incorporated into existing multi-channel system with the extra processing overhead. The best throughput values in the packet / slot are obtained. Finally, the robustness of the Proposed DDMAC to inaccurate distance estimation mainly results from multipath distance estimation and fading effects. This protocol is also assigned channels with lower average SINR to shorter transmission distances. Finally, we conclude that Though DDMAC required two CR users to communicate over a channel it provides better spectrum utilization in terms of smaller connections, blocking throughput and larger system throughput.

D. CMAC Protocol

The proposed CMAC Protocol [5] operates over Multi-channel wireless networks. It is effectively deals with resource availability by primary user signal detection mechanism. In CMAC each channel is logically divided into recurring super frames and a Rendezvous channel (RC) is employed to support multi-cast channel. In addition, the CMAC protocol is implemented with the five numbers of available channels and the communication range of 25m using single Half duplex radio. The CMAC operates over Multiple channels and able to effectively deal with the dynamics of resource availability.

E. COMAC Protocol

Cognitive Radio MAC (COMAC) [6] protocol enables unlicensed users to dynamically utilize the spectrum limiting the interference of the primary users. The novelty of this protocol lies in the fact that it is not presuming any CR to PR power mask. This protocol is studied in a conceptual hybrid environment consisting of group of PDA's to exploit the underutilized spectrum in a WiMAX Network. Stochastic models have been developed for primary to primary and then primary to secondary interferences. In addition, this distributed and asynchronous protocol uses Contention-based handshaking for the exchange of control information. The transmission power used is 1 Watt and Antenna length 5cm.

F. CREAM MAC Protocol

The author of the [7] proposed a robust Cognitive radio enabled Multi-Channel MAC protocol called as CREAM MAC protocol, which incorporate two prospects. Firstly, it has the concerted sequential spectrum observing that work at physical layer which is aimed of enhancing the exactness of spectrum observing scheme to minimize the intrusion imposed to the PUs. Sensors can discover multiple vacant licensed channels to use at the same time with the level of interference that PUs can tolerate.

Secondly, it has packet scheduling at the MAC layer, over the wireless dynamic spectrum access networks. In the CREAM MAC protocol, all the secondary users are attired with software defined radio-based transceiver which is called SDR. The SDR may intelligently utilize one or multiple PUs licensed channels to send or receive the secondary user packets. The CREAM MAC protocol can also effectively handle the traditional single and multichannel hidden nodes problems with the help of four-way handshakes of the control channel. Moreover, one of the most vital components of the CREAM MAC is the Common Control Channel (CCCH). There are four types (two pair) of control packets such as Ready-to-Send (RTS) / Clear-to-send (CTS) and Channel-State Transmitter (CST) / Channel-State Receiver (CSR).

All these control frames are exchanged over the control channel. The handshake of RTS/CTS prevents the nearby SUs from using the same channel for transmission, to ensure the avoidance of collision among SUs. On the other hand, the exchange of the CST/CSR packets solves the hidden terminal problem efficiently and effectively. The main purpose of the CST/CSR is to prevent the collision between SUs and PUs

G. SWITCH Protocol

The writer of the paper [8] presented a Multichannel MAC Protocol for Cognitive Radio Ad Hoc Networks. In SWITCH MAC Protocol, the author mentioned two problems such, as spectrum shortage and sudden appearance of PU which is the most crucial feature of the distributed Cognitive Radio MAC Protocols. The writer also suggested the solution which reacts efficiently to the PUs appearance. The SWITCH Protocol is an asynchronous and contention base protocol. The contention-based protocols depend on the CSMA/CA method which senses the carrier continuously.

In addition, the author of this paper classified the Mac protocol into two main groups according to the way the SUs deal with the instant appearance of the PUs. Firstly, the MAC protocols that are capable of buffering connections preempt by the PUs. Secondly, the MAC protocols that are capable of switching connection to other vacant channel on the appearance of the PUs. SWITCH Protocol also have the CCC to cope up the problem of coordination between SUs and the BC to wave out the problem of sudden appearance of PUs which is already selected before the data transmission. The CCC is a rendezvous channel for the interchange of the control packet over the control channel.

Moreover, the SWITCH Protocol uses two types of spectrum allocation data structures such as Neighbors Channel List (NCL) and Free Channel List (FCL). The Neighbors Channel List consists of list of neighbor channel occupied by neighboring nodes. The Free Channel List contains the list of available free channels in the transmission range of the node. Also, handshake process is used for the access of medium and data transmission. There are two modes of handshake are used such as: two-way RTS/CTS and Three-way Handshake.

H. RMC-MAC Protocol

In paper [9], the writer presented a Reactive Multi-Channel MAC Protocol, which work in scattered AdHoc Cognitive Networks. According to the writer, shortage of the spectrum is not due to the deficit of usable radio frequencies, but to the present static spectrum inefficient usage policy. In order to recover this deficiency, the author proposed a Reactive Multi-Channel MAC Protocol that integrates a robust cooperative sensing method to achieve the existing free spectrum dynamically called Dynamic Spectrum Access (DSA).

The main purpose is to present a robust Reactive Sensing Period (RSP) used in order to observe the impression of PUs by the neighbor node while the transmission. Time is distributed into three fixed time slots such as sensing period to observe the PU activities, a contention slot to communicate channels to use during the data period transmission. A restoration method is proposed which is based on a hand-off mechanism to decrease the forced ending possibility which concludes increased capability for SU. This protocol modifies the transmission according to a particular power control and a specific sensing of PU.

Moreover, the proposed protocol considers the three different periods such as sensing period, data transmission period and contention period. For example, if a secondary sender A wants to send data to the secondary receiver B. Then secondary sender A send a Ready to Send (RTS) message to B and if B has a single vacant channel in its Available Channel List (ACL) then it will reply with the message Clear to Send (CTS). There is one more additional period is involved in this protocol which is called the Reactive Sensing Period (RSP). This protocol achieved this detection of PUs by keeping an idle channel during the transmission period, which is continuously sensing the appearance of the PU's.

I. EECR MAC Protocol

The author of the paper [10] presented an Energy Efficient Cognitive Radio MAC Protocol, which describes that there has been a number of approaches proposed to increase the performance of CR networks, but a little importance has been given to the power efficiency which is very crucial part. The protocol utilizes an adaptive aggregation technique, which aggregates the packet to improve the energy efficiency.

Moreover, there are rules define to the selection of the control and data channel. The CR terminals are continuously observing the Available Channels List (ACL) before admitting the network. If there is no ACL, then A will reveal its ACL regardless of the neighboring nodes. Suppose, the node B observes that there is a common free channel between A and B then this information is transmitted by B using the AACL. After successful sharing the ACL and AACL, each cognitive pair must satisfy the condition of the vacant data channels >= 2 due to backup channel. This process is based on the number of acknowledgements on each channel. For an instant, the channel with high number acknowledgements means less transmission.

III. Comparison of Selected CR-MAC Protocols

Fig. 1 explains the various similar features of the MAC for managing spectrum availability on longer timescales and handling resource management on shorter timescales and hence to enhance the QoS, Arshad et al. (2014) develop a model that works across multiple service providers using a service level agreement. Their approach could be used for simple scenarios such as (i) an Adhoc network of users in a mall, office or at home sharing files, or (ii) a more complex task to access the internet. Mitola et al (2014) on the other hand advocate a public-private radio interference management framework to enable near-term spectrum sharing with positive gain in 5G price, performance, and total user QoE.

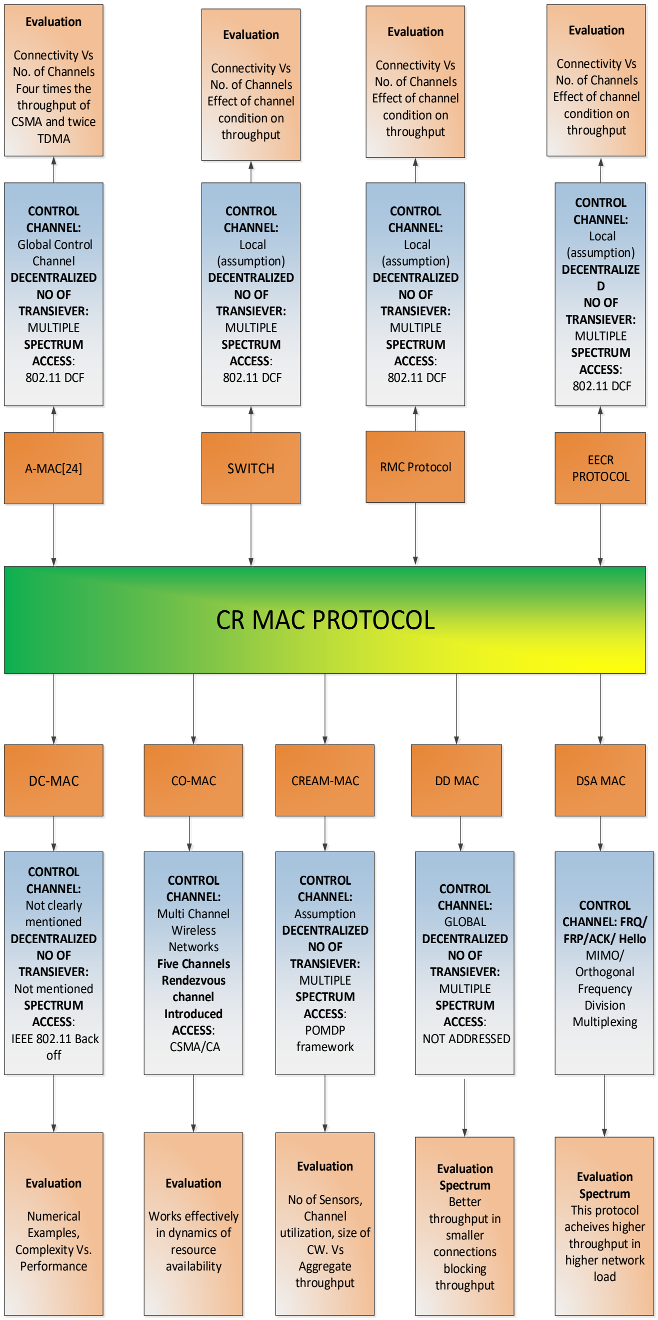

Fig. 1. Comparison Chart of Various Protocols.

IV. Simulation Outcomes

Simulation is done in MATLAB according to the throughput equations used in the related protocols. MATLAB is derived from matrix laboratory. Its version is 7.9 (R2009b). The MATLAB is a product of established by MathWorks. MATLAB is a multi-prototype numerical computing domain. MATLAB is fourth-generation programming language, which is used for implementation of algorithms, enables matrix manipulations, formation of user interfaces (UI) and projection of the function and data. MATLAB is also enabling to connect with programs written in other languages such as C, C++, Java, and Fortran. MATLAB allows constructing commands to create and process variables. In addition, MATLAB is an array-based language where variables can be vector matrixes and multi-dimensional arrays. It also permits to make functions or use function of MATLAB library. It authorizes to plot graphs and surfaces [11].

A. Data Transmission Performance

In this section, the performance of data transmission results of different protocols are demonstrated in the below given Fig. 2. It also shows the successful data transmission among SUs for each run. It is apparently revealed that EECR MAC protocol has the highest data transmission among SUs for each run than three other well-known protocols. The number of flows is from one to ten, as the amount of flows increase, data transmission of the EECR MAC Protocol also increases.

Fig. 3 describes the time required for data transmission. It shows that EECR MAC protocol utilize less time to transfer the frame without aggregation, which saves around about 5.56% time than other three protocols. However, it also has the facility to aggregate the frame which saves more time. EECR MAC protocol saves overall 9% time with aggregation of the frames, which results in to decrease the processing time among the Cognitive terminals that's save the energy as well.

B. Throughput Performance

In this section, throughput results of different protocols are presented in the following Fig. 4, where the normalized throughput of three well-known protocols varying the number of flows is measured. The successful transmission of the data per second is called the throughput. The number of simultaneous flows is varied from one to ten and clearly indicates that the EECR MAC protocol offers significantly better performance than all other CR-MAC protocols. The EECR MAC protocol accomplishes 40% more throughput than SWITCH Protocol, 43% more than CREAM MAC and 48% more than RMC MAC protocol. Throughput of CEARM MAC is less because there is no backup channel for continuing the transmission. As a result, many packets dropped or delayed, resulting less throughput.

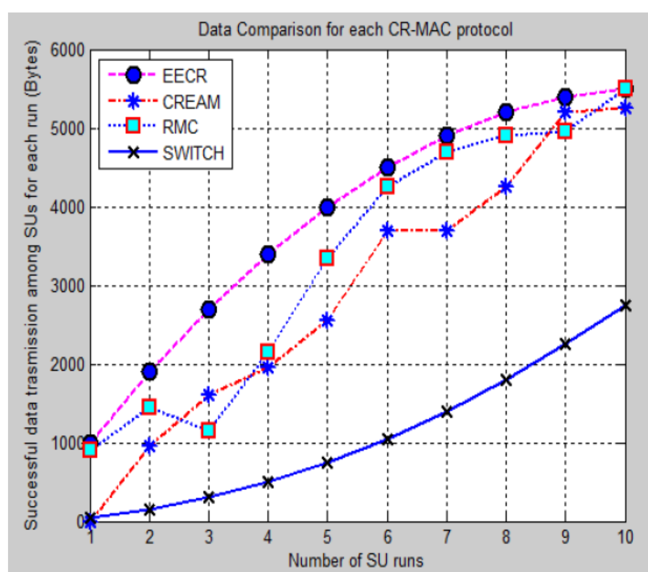

Fig. 2. Data Transmission Comparison.

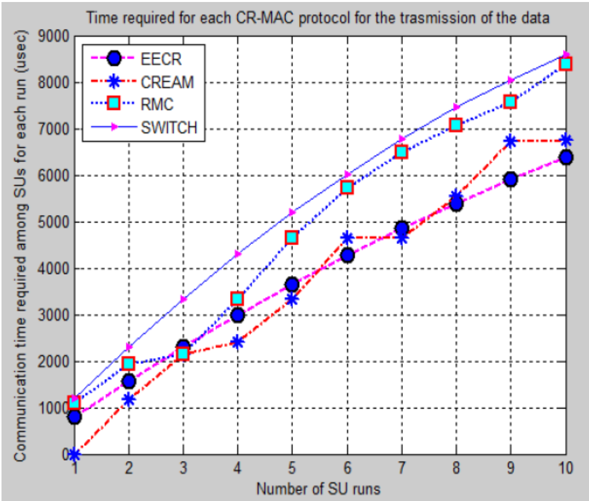

Fig. 3. Time Required for Data Transmission.

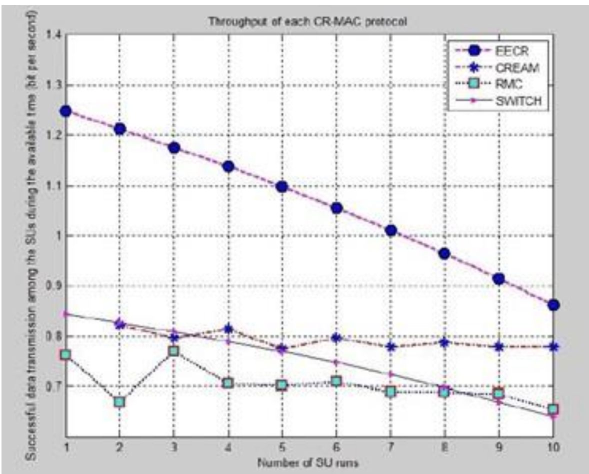

Fig. 4. Throughput of Each CR-MAC Protocol.

C. Transmission Time Performance

In Transmission Time Performance, time results of different protocols are presented in the below given Fig. 3.

V. Determined Timing Diagram

In the results time diagram, the performance of various pertaining Cognitive Radio MAC protocols have been investigated in term of throughput, data transmission and delay. The number of flows in the entire figure is 10 Mbps. The transmission data rate is 11 Mbps.

It is clearly demonstrated in the above Fig. 5 that CREAM MAC and SWITCH protocol take nearly same time to transmit the data. The RMC MAC protocol takes less time to transmit data than the CREAM MAC and SWITCH protocol. However, the EECR MAC protocol takes the minimum time to transmit the data than all other protocols. Moreover, this is also revealed from the above simulation results.

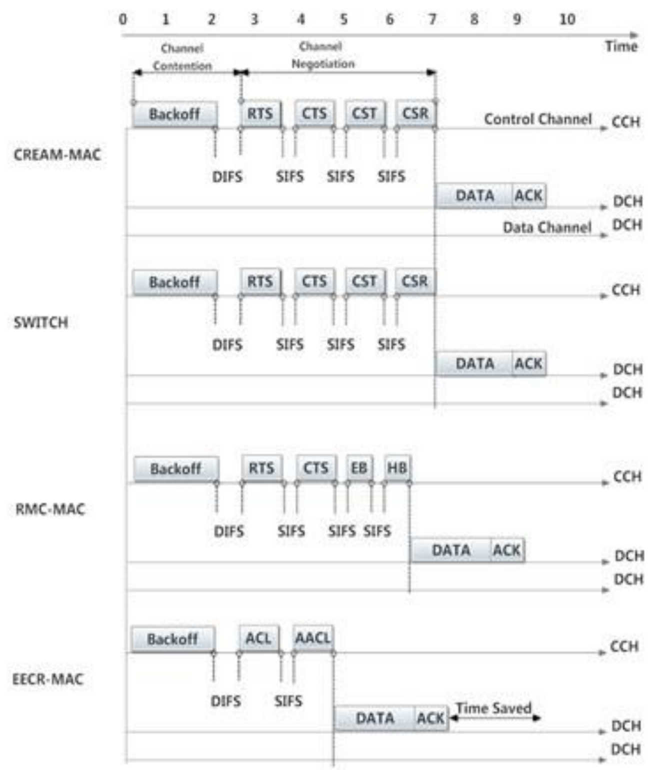

Fig. 5. Designed Time Diagram.

VI. Conclusion and Future Work

It is concluded that the simulation results show that CR protocols such as CREAM, SWITCH, RMC and EECR MAC protocols were presented and described in this paper. However, few results are depicted to justify the validity of the proposed framework. It is concluded that CREAM MAC has high throughput, but it did not consider the Backup Channel. On the other hand, the SWITCH MAC is capable in throughput, time, and provides backup channel as well. Moreover, RMC MAC specifies throughput and backup channel. Thus, EECR MAC protocol is better than other protocol because it is efficient in data transmission, throughput and energy. It also accommodates the backup channel. Overall, significant throughput gains, the rate of data transmission, time efficiency and a diminution in unlicensed user power exhaustion are evident. Results achieved from measured data are comparable with those obtained from simulated results. According to the analysis and its results, the further recommendation has been proposed in the area of CR MAC protocols with name of Proposed Efficient CR MAC protocol, represented as PECR-MAC protocol. In PECR-MAC protocol, data is transmitted on multiple data channels simultaneously to achieve better results as mentioned earlier. The illustration of the PECR-MAC protocol is shown in the following Fig. 6.

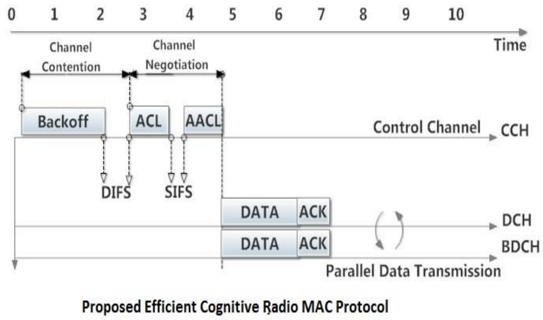

Fig. 6. Proposed Efficient Cognitive Radio MAC Protocol.

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