OVERVIEW OF SECURE COGNITIVE RADIO MAC PROTOCOL IN THE PROPOSED 3.5 GHZ BAND

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ABSTRACT

Spectrum sharing between federal and commercial users is proposed by the FCC and NTIA to open up the 3.5 GHz band for wireless broadband use. The proposed technology requires the detection and subsequent allocation of available licensed spectrum for temporary use by other users without compromising the privacy of the licensed user. DoD has a documented requirement of 865 MHz by 2025 to support telemetry but only 445 MHz is presently available. Research is presently on-going at DoD to realize, test and evaluate spectrum efficient technology with the aim to develop, demonstrate, and evaluate technology components required to enable flight and ground test telemetry operations. The use of cognitive radio (CR) in spectrum sharing has gained much popularity in that CR senses the unused spectrum at a specific time and location and dynamically allocates to users as required. This paper will provide an overview of a secured CR Media Access Protocols using the IEEE 802.22. Carrier Sense Multiple Access Collision Avoidance (CSMA/CA) will be utilized for protocol transmission in order to properly identify user's location and identity thereby providing a secured network against false alarm from external attack.

INTRODUCTION

The demand for wireless spectrum, particularly wireless and mobile broadband services is growing every day, because of increasing mobile connectivity, see figure 1. This growth represents a significant economic opportunity but also presents a challenge, as increased usage strains the capacity of the available. Unfortunately, this growing demand is not limited to commercial users. Government departments have increased test system complexity and resultant high data rates to support new and modern weapon technology. This requires about 865 MHz in the near future to support telemetry with only 445 MHz presently available [1].

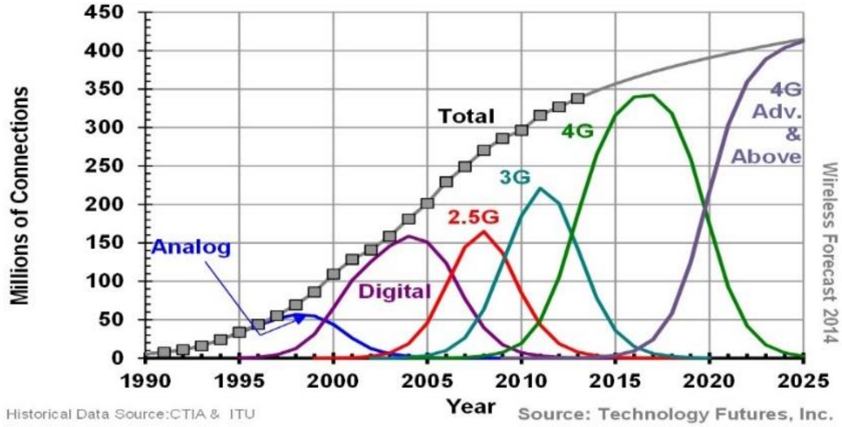


Figure 1: Technology Future Inc. Industry Wireless Generations Forecast
(https://tfi-ctfg.com/wireless-forecast/)

Spectrum by itself is non-depletable resources but limited in some constraint i.e. the same frequency, same technique cannot be used at the same time and same area. Securing additional spectrum has been difficult, partly because spectrum usable by today's mobile broadband technologies is currently designated for a variety of other uses [1]. Since spectrum is a finite resource, allocating more spectrum for some services inevitably requires consideration of re-allocation of spectrum from other uses, which can cause disruption and cost as spectrum is re-configured. As a result of this, the (Federal Communication Commission) FCC and the (National Telecommunications and Information Administration) NTIA are placing much greater emphasis on the efficiency with which spectrum is used. Presently, consideration is being given to far more innovative ways to use radio spectrum that has traditionally been considered – making available un-used gaps in spectrum [1].

To alleviate these challenges, efforts have turned to include spectrum sharing with incumbent users. One user may have priority over the other, but generally all users assigned to those frequencies can use them. Spectrum sharing between Federal and commercial users is a technique proposed by the FCC and NTIA to open up the 3.5 GHz band for wireless broadband use. The 3500-3650 MHz band is one of the candidate bands identified and recommended by the NTIA for reallocating 100 MHz of its 3550 – 3650 MHz for wireless broadband use within the shortest possible time [3, 4]. The band was selected by NTIA because WiMAX equipment has already been developed. NTIA understood this band to be used primarily for high power shipborne radars designed to operate in the 3500-3650 MHz band due to specific propagation and atmospheric conditions unique to this frequency range [5]. It is also used for communications with missile systems for data updates to the missile while in flight to its target. The radars in this band represent significant investment on the part of DoD and many are incorporated into ship and aircraft design. Redesigning for other frequency ranges to make this spectrum available for wireless broadband may require new technology, and significant redesign of their associated platforms.

However, the main challenge in spectrum sharing would be designing a system or network that protects the security of the licensed spectrum and users. The PU’s must be protected from unacceptable interference from unlicensed users this could be achieved through the use of a proactive spectrum selection and interference avoidance processes.

To allow unlicensed users to access a radio spectrum when not in use by licensed users, there is need to develop the wireless technology. Cognitive Radio (CR) wireless network allows the unlicensed user to use only unused spectrum opportunistically at a particular time to prevent interference with the licensed user [2]. CR therefore is a wireless radio that uses machine learning techniques for the allocation of spectrum dynamically over a given period. Figure 2 shows CR spectrum sharing network.

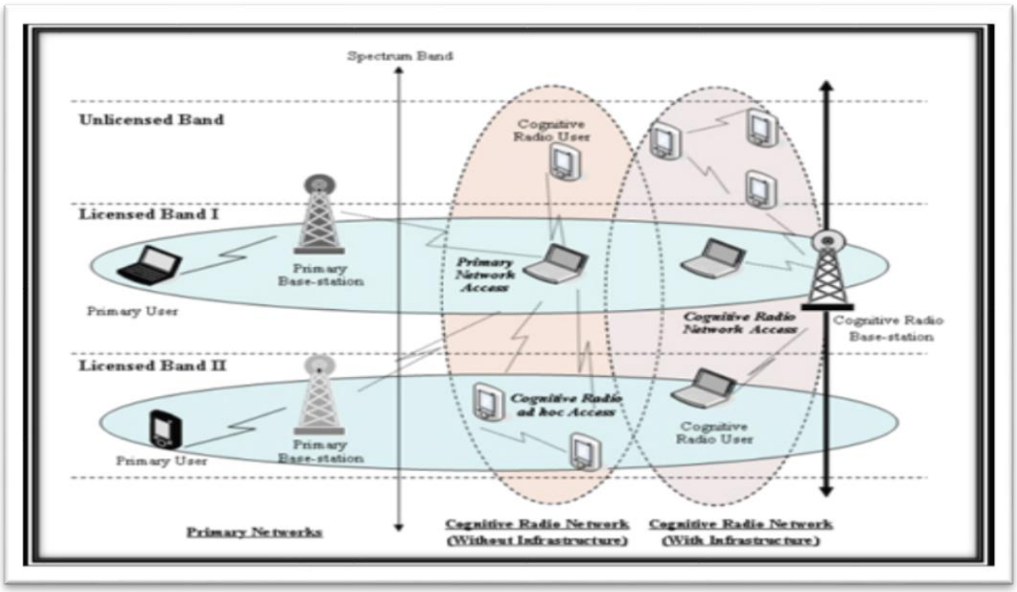


Figure 2: Cognitive Radio Network

(Image from http://bwn.ece.gatech.edu/CR/projectdescription.html)

To ensure proper coordination of information, spectrum sensing and interference free allocation between the licensed users also known as the primary users (PUs) and the unlicensed user, the secondary users (SUs), there is need to have a well-designed medium access control (MAC) protocol. The design must address how the SUs determine when and which channels they should use to transmit or receive SU packets without affecting communication among the primary users (PUs) [3].

For spectrum access, CR utilizes CSMA/CA protocol. In this protocol, after sensing, users back-off by a random time before transmission. If there is a collision of transmitted packets by any two users, the users double the back-off window and retransmit. This protocol entails appropriate scheduling algorithm to determine the right time to transmit over shared channel. The process of sharing could be briefly described as shown in figure 3.

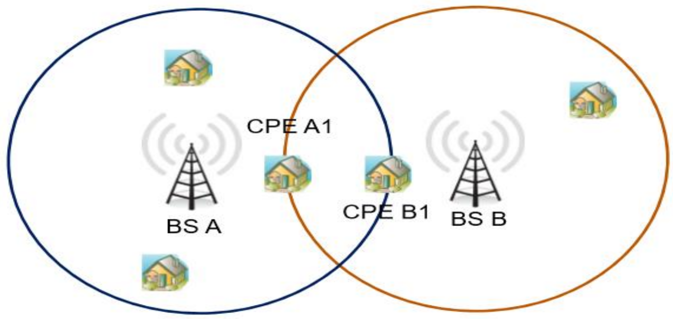


Figure 3: Cognitive Radio Spectrum Sharing Mechanism
(Diagram from https://jwcn-eurasipjournals.springeropen.com/articles/10.1186/1687-1499-2012-28)

In spectrum sharing, the spectrum is divided into a number of channels and suppose base station A (BS A) and customer premise equipment (CPE A) operate on a given channel N, when a new BS B and CPE B start operation, the channels are scanned to detect the available channels and CPE B1 eventually detects BS A's Super-frame Control Header (SCH) packet already transmitted by the BS A. Here a first coexistence mechanism is executed by BS B in order to avoid interference. The reallocated 100 MHz of the 3500-3650 MHz band could be divided into different channels for sharing purposes between the SUs and the PU.

The remaining part of the paper is organized as follows. Section 2 introduces the IEEE 802.22 standard, CR network infrastructure and the PHY/MAC layer. Section 3 provides the application of CSMA/CA protocol to CR and MATLAB implementation. In Section 4, the simulation results were analyzed while section 5 concludes the paper.

IEEE 802.22 STANDARD

The IEEE 802.22 working group provided the cognitive radio-based international standard for wireless regional area network (WRAN) with the purpose of providing broadband access in remote and rural areas by opportunistically exploiting the unused TV band. This is the first worldwide standard for Wireless Regional Area Network (WRAN) based on CR by exploiting the unused TV band. The WRAN systems can operate on vacant TV channels in VHF/UHF band ranging from 54 MHz to 862 MHz frequency and the average coverage area of WRAN cell is 33 km^2 with possibility for extension up to 100 km^2. This coverage area is larger than IEEE 802.11 based Wi-Fi and IEEE 802.16 based WiMAX. IEEE 802.22 incorporates advanced cognitive radio capabilities including dynamic spectrum access, incumbent database access, accurate geolocation techniques, spectrum sensing, regulatory domain dependent policies, spectrum etiquette, and coexistence for optimal use of the available spectrum. Figure 4a and 4b below shows the characteristics and network applications IEEE 802.22 standard relative to other IEEE 802 wireless data transmission standards.

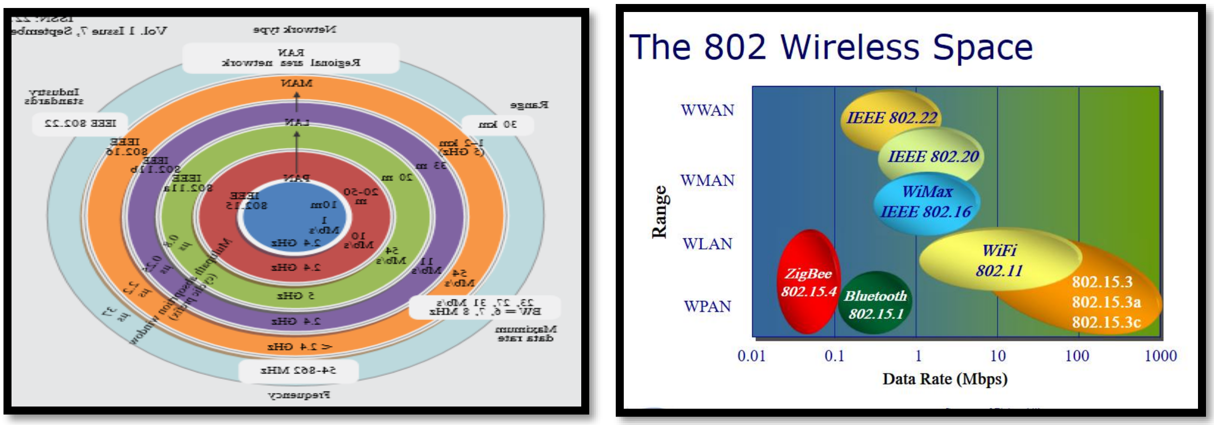


Figure 4: IEEE 802.22 standard relative to other IEEE 802 wireless data transmission standards
(Diagrams from http://amanuel-wran.blogspot.com/2011_06_01_archive.html and http://slideplayer.hu/slide/2129723/)

COGNITIVE RADIO NETWORK INFRASTRUCTURE

As shown in figure 5, the IEEE 802.22 network is based on master/slave architecture with single wireless regional area network base station (WRAN BS). This WRAN BS manages all the CPE through MAC. The BS controls all the communication in the cell, i.e. there is no peer-to-peer communication directly between the CPEs. Figures 5a and 5b below shows the basic infrastructural configurations of IEEE 802.22.

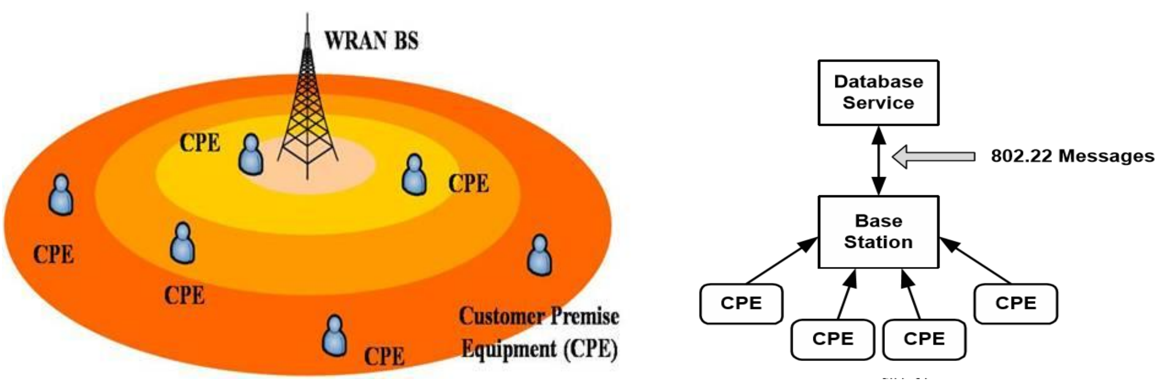


Figure 5: Cognitive Radio Infrastructure and 802.22 database interface model
(Diagrams from http://ecee.colorado.edu/~ecen4242/802_22/general_info. htmlhttp://slideplayer.com/slide/9906767/)

In CR network, no CPE is allowed to transmit without receiving any proper authorization from WRAN BS. The downstream transmission, where WRAN BS transmits and CPE receives, is based on time division multiplex (TDM) and the upstream transmissions are shared by CPEs on demand basis according to orthogonal frequency division multiplex (OFDMA) scheme [4].

PHY/MAC LAYER

The MAC and PHY specifications is a standard developed by the IEEE for designing how the SUs determine when and which channels they should use to transmit or receive SU packets without affecting communication among the primary users (PUs) [3] [4]. The IEEE 802.22 MAC provides mechanisms for flexible and efficient data transmission, and supports cognitive capabilities for both reliable protection of incumbent services in the TV band and self-coexistence among 802.22 systems. The MAC is a connection-oriented mechanism supporting unicast, multicast and broadcast services. Connection is defined by 12 bits; 9 bits are reserved for station ID (SID) and 3 bits are for flow ID (FID). The station being under the control of BS (CPE) is uniquely identified by SID. The FID represents a specific traffic flow assigned to a CPE. The combination of SID and FID defines a connection identifier (CID) for the particular CPE. The MAC facilitates up to 512 stations, each with a maximum of 8 service flows and each service flow requires a separate connection in a WRAN cell.

IEEE 802.22 PROTOCOL REFERENCE MODEL

The IEEE 802.22 protocol reference model defines the system architecture as shown in figure 6. The system is partitioned into data plane, management plane and cognitive plane. The data plane consists of the Physical Layer (PHY), the medium access control (MAC) layer and the convergence sublayer (CS). Service access points (SAPs) are added in between these layers to allow different components to communicate with each other. Security sublayers are appended between SAPs to provide data security functionalities and applications. The cognitive plane is composed of Spectrum Manager, Geolocation, Spectrum Sensing Automaton and Spectrum Sensing Function [5].

APPLICATION OF CSMA/CA PROTOCOL TO COGNITIVE RADIO NETWORK

To ensure interference free and to enhance QoS in spectrum sharing, the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol can be utilized by cognitive radios for spectrum access. In this protocol, after sensing, users back-off by a random time before transmission. If there is a collision of transmitted packets by any two users, the users double the back-off window and retransmit. The capacity of the WRAN cell as defined in IEEE 802.22 standard ranges from 1 to 512 CPEs. When CPE powers on or loses its association with the WRAN BS, it then attempts to register with the WRAN BS [5].

CSMA/CA PROTOCOL IMPLEMENTATION FOR SPECTRUM SHARING

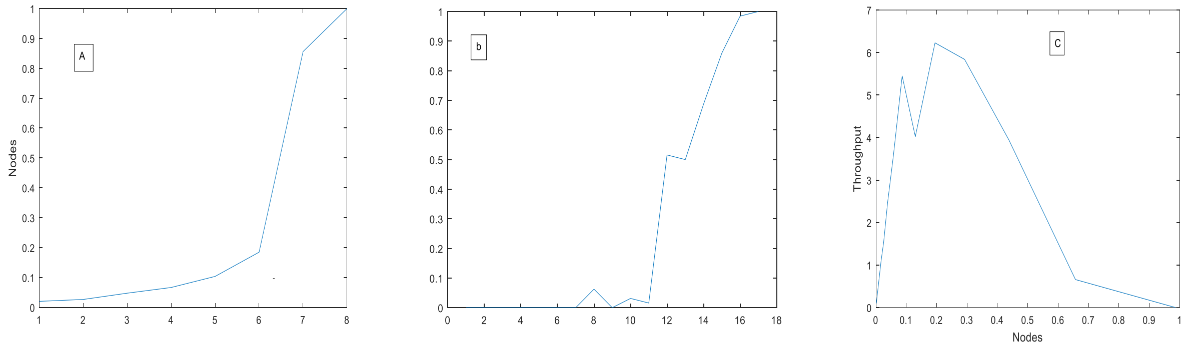
From figure 4, like the 802.11 CSMA/CA MAC layer, we propose the 802.22 CSMA/CA MAC layer using the CSMA/CA with request-to-send (RTS) and clear-to-send (CTS) exchange technique. This strategy is important since it has a more efficient performance in term of average throughput [6] and solves the hidden node/terminal problem [7] in the network.

Assuming we have a network with many terminals, (set of node pairs, consisting of a sender and receiver), one access point (AP) and N number of channels through which the CPEs send their registration requests to the WRAN BS. We assume that each CPE sends its registration request on separate channel. If two or more CPEs send their requests on the same channel at the same time, then collision occurs. However, with the CSMA/CA with RTS/CTS technique, if the channel is busy for the CPEs, each CPEs chooses randomly a backoff time in the interval [0, CW-1], where CW is a contention window. The wait counter freezes when the channel is busy, and resumes when the channel is available again. The backoff counter is decremented by one each time the channel is detected to be available for a Distributed Inter-Frame Space (DIFS) duration. When the backoff counter attempts zero, the source CPE randomly chooses one band over the N available bands to send a RTS to the destination node. It waits for receiving a CTS from the AP before transmitting data. The AP listens simultaneously to all RTS bands and if one or more RTS is detected, the AP broadcasts CTS over all the bands indicating the authorized station to communicate.

In this technique, the PU is given priority over all the SUs by making the PU to have smaller interframe space (IFS), IFS is the period of time a node has to wait before sending a packet to the AP when a channel is found idle. We want high priority wait for shorter time where wait time is calculated by specific range for each priority. For demonstration purposes, we simulated a CSMA and the CSMA/CA and showed how much performance increase is found using CSMA/CA. Although, this simulation was done in the MATLAB environment, this is not the best simulator for CR network simulation it does not have cognitive capability applications. Network Simulator v9 and above (NetSim) would be the applicable software because the library contains the network/protocols compactible with the simulation of Wireless Regional Area Network (WRAN). NetSim functionalities for CR (as per IEEE 802.22 MAC and PHY) includes but not limited to detection and channel switching and the cognitive plane [8]. It contains spectrum manager, spectrum sensing function, spectrum sensing automaton and channel model. We don’t have access to NetSim so we are using MATLAB for a modified simulation.

CSMA/CA MATLAB SIMULATION

The MATLAB program generates uniformly distributed mobile in 2 D space and computes the path loss between nodes. To ensure connectivity of all nodes, the program varies the power/range until full connections are established. After this, traffic is generated for this fully connected network and collisions associated with traffic are measured. We then increase the traffic and measures traffic throughput. The results are shown in the figures below. The simulation was done using an ideal physical layer (no path loss, no fading, no shadowing) is considered.



(a) (b) (c)

Figure 7: (a) and (b) Nodes connection and probability of collision with traffic without delay (c) throughput with all the nodes connected in the network with traffic

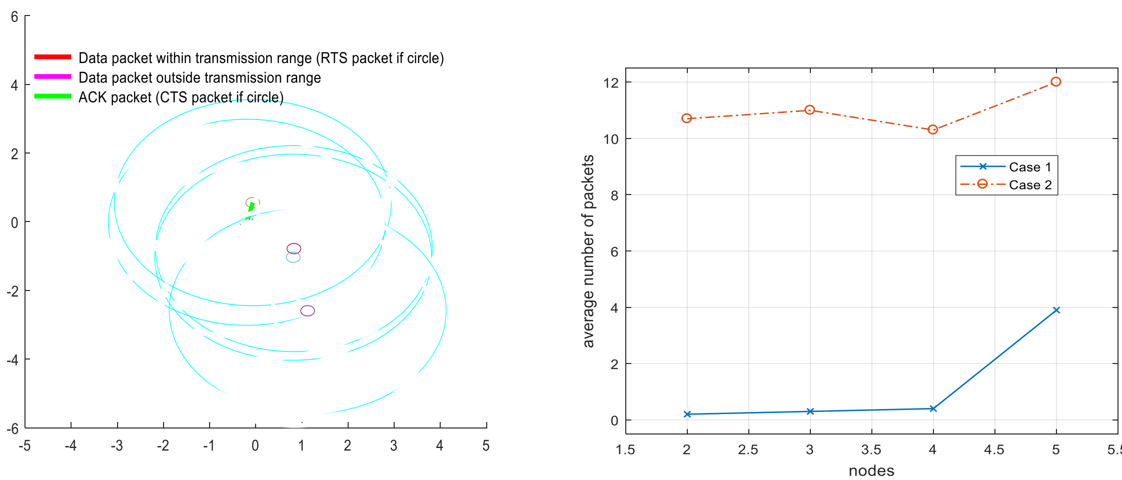


Figure 8: concentric circles showing RTS/CTS exchange and CSMA with without collision avoidance.

For example, assuming a node, A wants to transmit a data packet to another node B on the network, node A firstly broadcasts RTS packet then B broadcast CTS packet. Node A then send the data packet to node B and node B send an acknowledgement packet to node A upon successful completion of the data exchange. The probability of success, $P_s = Data \times PR_{nc} \times PC_{nc} \times PD_{nc}$, where P_s is the probability of success, PR_{nc} is the probability of sending RTS without collision, PC_{nc} is the probability of sending CTS without collision and PD_{nc} is the probability of sending data without collision. This could be translated as $p(1-p)^{N-1}$ where N is the number of nodes in the network.

Assuming N nodes are trying to send data in the network, the probability that a node is successful (i.e. no collisions) is $Np\ (1-p)^{N-1}$. We considered five nodes in this simulation and our focus is to determine the successful packet transmission rate of the network.

ANALYSIS

Figure 7a is a plot showing the nodes connections when power is sufficient for connectivity and figure 7b demonstrates that the collision probability increases with the number of nodes using CSMA protocol without collision avoidance. More nodes lead to deadlocks in the network. Figure 7c shows that the throughput decreases with increased network connectivity.

In figure 8a, the RTS/CTS exchange is shown using concentric circles where the red concentric circles denotes an RTS packet and green circles representing a CTS packet. The graphics were set-up using pointers to graphical objects where the objects were initially circles. For example, W (i) = plot (exp (j*ph)*(1+r), 'EraseMode', 'xor'); The MATLAB file "pilot1.m" changes the properties of these objects to show whether a packet is in range. The circle eventually get changed to lines to show packet transmission. At the initial exchange of RTS/CTS packets between the sender node and the recipient node, the sender transmits a DATA packet, which is represented by a red line. The receiving node sends an ACK packet back to the sender once the packet arrives. A green line represents an ACK packet.

The case 1 in figure 8b represents collision CSMA while case 2 is successful transmission CSMA/CA. The impact of RTS/CTS protocol on the system performance shows in figure 8 that there is improvement in packet transmission with reduced collision rate. We found out that the number of successful transmissions increased and the number of collisions (both DATA and ACK packet collisions) has decreased using CSMA/CA. The simulation was done using an ideal physical layer (no path loss, no fading, no shadowing) is considered.

CONCLUSION

In this paper, we have provided an overview of a secured CR MAC protocol using the IEEE 802.22 standard and suggested the application of CSMA/CA to cognitive network in order to reduce interference between the Primary and Secondary Users to increase throughput. Although, MATLAB does not support the cognitive functionality and IEEE 802.22 standards, we implemented the 802.11 MAC protocol and suggested the application of the strategy to IEEE 802.22 since both standards supports applications in the wireless networks. CSMA/CA was utilized for protocol transmission in order to properly identify user's location and identity. We have found that the inclusion of RTS/CTS handshaking greatly improves the performance of our simulated wireless network.

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