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Congestion Aware Reliable Transport Protocol for Cognitive Radio Ad Hoc Networks

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Abstract - A stochastic model of congestion in CRAHNs is presented in this research work. The queue length is taken as the congestion parameter. The underlying stochastic model is taken as a Semi-Markov Chain (SMC). An SMC is a generalization of a Continuous-Time Markov Chain (CTMC) in which the time between transitions from one state to another is not exponentially distributed but rather is generally distributed. Based on this a MAC protocol named congestion aware reliable transport protocol is proposed. Performance metrics such as success rate, average broadcast delay are taken into account for comparison. Simulation results portrays that the proposed CARTP outperforms in terms of the chosen performance metrics.

Key Words: Cognitive Radio Ad Hoc Network, Continuous-Time Markov Chain, Cognitive Radio, Dynamic Spectrum Access.

I. INTRODUCTION

In current new technological advances have resulted in the development of wireless ad hoc networks composed of devices that are self-organizing and can be deployed without infrastructure support. These gadgets by and large have small form factors, and have embedded storage, processing and communication ability. While ad hoc networks may support different wireless standards, the present best in class has been for the most part restricted to their operations in the 900 MHz and the 2.4 GHz Industrial, Scientific and Medical (ISM) bands. With the developing expansion of wireless gadgets, these bands are progressively getting congested. In the meantime, there are several frequency bands licensed to operators, for example, in the 400–700 MHz run, that are utilized sporadically or under-used for transmission. The permitting of the wireless spectrum is presently attempted on a long haul premise over unlimited geographical regions. With a specific end goal to address the basic issue of spectrum scarcity, the FCC has as of late affirmed the utilization of unlicensed gadgets in licensed bands. Thus, Dynamic Spectrum Access (DSA) procedures are proposed to take care of these present spectrum inefficiency issues. This new range of research predicts the advancement of Cognitive Radio (CR) networks to further improve spectrum efficiency. The fundamental thought of CR networks is that the unlicensed gadgets (likewise called cognitive radio clients or optional clients) need to clear the band once the licensed gadget (otherwise called an essential client) is detected. CR networks, in any case, force one of kind difficulties because of the high change in the accessible spectrum and also assorted Quality of-Service (QoS) requirements. In particular, in CR Ad Hoc Networks (CRAHNs), the distributed multi-hop architecture, the dynamic network topology, and the time and area shifting spectrum availability are a portion of the key recognizing factors. These difficulties require novel outline systems that all the while address an extensive variety of communication issues crossing several layers of the protocol stack. Cognitive radio innovation is the key innovation that empowers a CRAHN to utilize spectrum in a dynamic way. The term, cognitive radio, can formally be characterized as takes after A "Cognitive Radio" is a radio that can change its transmitter parameters in view of collaboration with the earth in which it works.

II. LITERATURE REVIEW

The frequency spectrum is, indisputably, the most valuable resource in wireless communications because of its limited availability. Moreover, the use of available frequency spectrum resources is very inconsistent. There are unlicensed bands which have been overcrowded with growing technology uses, such as Bluetooth, Wi-Fi, etc. In contrast, there are licensed bands which are absolutely under-utilized. A novel solution is required in order to address both the problem where the spectrum available for certain uses is congested, and the problem where the spectrum available for other uses is allocated inefficiently. As a promising solution for this unbalanced situation, Cognitive Radio (CR) technology has been developed in order to enable the efficient exploitation of radio spectrum resources. CR technology has the potential to solve the wireless communications problems that result from the limited available spectrum and the inefficient use of that spectrum [1].It is the cognitive capability that enables CR to sense and capture vital information regarding the temporal and spatial variations in the existing radio environment. CR has the ability to change its transmission parameters (e.g., transmit power, modulation scheme, and operating frequency) based upon observations of, and interactions with, the surrounding environment. The CR parameters are reconfigured depending upon the characteristics of the spectrum in order to cope with the changing radio environment [2]. This CR capability opens the door for dynamic spectrum access mechanisms that allow the opportunistic use of an underutilized frequency spectrum, thereby ensuring that both the optimum spectrum and the most convenient transmission parameters are selected.

A Cognitive Radio Network (CRN) consists of wireless nodes equipped with CR capability that gives them a unique proficiency in sensing the frequency spectrum, reconfiguring the radios and exploiting spectrum holes based on the spectral environment [3]. Such nodes represent Secondary Users (SUs), or cognitive users. In a CRN, the licensed users are called Primary Users (PUs) and have an inherent priority to operate in certain licensed frequency bands. Whenever an SU has data to transmit, it is supposed to opportunistically use the licensed spectrum that is currently unused by a PU. Therefore, the major responsibility for any SU is to ensure the opportunistic use of the available spectrum without imposing any kind of interference for the PU.A Cognitive Radio Ad Hoc Network (CRAHN) is a special type of CRN with no centralized network entity. As a result, SUs need cooperation schemes in order to exchange network related information, such as the presence of a PU, the node configuration, and spectrum holes. This information is obtained through local observation and spectrum sensing, and can be used for reconfiguration and routing purposes. CRAHNs are also distinguished by their inherent features, [5] including dynamic topologies, spectrum heterogeneity, multi-hop architectures, self-configuration, and energy constrained power supplies [4]. In fact, these challenges make CRAHNs a very interesting field for researchers to work in. Consequently, a considerable amount of research and development effort has been put into ensuring CRAHNs are able to support a wide range of applications with the utmost efficiency.

III. PROPOSED WORK

The future behaviour of the queue length is completely characterized by CR current state; the underlying stochastic model will be a Semi-Markov Chain (SMC). To completely specify the SMC of queue length, the density functions of the input rate and the attainable sending rate of a CR node are required. An SMC is a generalization of a Continuous-Time Markov Chain (CTMC) in which the time between transitions from one state to another is not exponentially distributed but rather is generally distributed. Transition probabilities: Since RI and RS are continuous random variables, the result $P(RI=RS)=0$ will be obtained.

$$P(RI>RS)+P(RI<RS)=1. \quad (1)$$

In the operating mode, a CR node operates based on a multichannel MAC protocol of which its behaviour is inspired from the CSMA/CA mechanism. The CR node first senses the spectrum and selects a channel which is free of primary users. After selecting a free channel, CR node enters into the operating mode to send data on the selected channel. In the operating mode, if CR node has a packet to send, it selects a random double backoff time BT from the range $[0, BT_{\min}]$ with a continuous uniform distribution, where $BT_{\min}$ is the minimum backoff time. At the end of the first backoff period, the carrier sensing is realized on the considered channel; if the channel is free of the other CR nodes, the sending of packet is started; else an exponential backoff algorithm is started again. The backoff algorithm is performed continuously. CR nodes are only permitted to commence their transmissions at the end of the backoff time. In the backoff attempt i, BT is randomly selected from the range $[0, 2^i BT_{\min}]$ with a continuous uniform distribution. Backoff attempts are repeated until the channel is free of CR nodes at the end of the backoff period, or until the maximum number of backoff attempts K is reached, after that the packet is sent. At the end of the operating mode, CR node operations are [5] stopped and the node enters into the spectrum sensing mode again.

If the node cannot find a free channel in the spectrum sensing period, enters into the operating mode without sending any packet. In the next sensing period, the node has another chance to find a free channel; if there is no free channel for second time, the packet will be dropped. The handoff time between two channels by a CR user will increase the MAC delay overhead slightly. In our modelling, the handoff time is ignored. As far as congestion control scheme in the proposed work is concerned, sending rate in the transport layer of the CR collecting sensors is adjusted based on the received control decisions from the sink station.

The PDFs of input and output rates of CR relays depend on the routing protocol used and the established routes between CR collecting sensors and the sink station. A node selects one of the next hop nodes in order to forward a particular packet with a certain probability, which does not change rapidly overtime. A CR node in hop h forwards a particular packet to any of $(h+1)$ hop relays with the probability of $P^{FW}_{n_h, n_{h+1}}$ where $h=0,...H, n_h=1,...N_h \text{ and } n_{h+1}=1,... N_{h+1}$. The input rate of a CR relay node depends on the drop and collision probabilities of the packets which are sent from different nodes of previous hop. The collided and dropped packets are not queued in the CR relay node of next hop and the input rate of the relay node decreases based on the packet drop and collision probabilities. Therefore, RI_{h,n_h} is obtained. At operating phase of MAC layer, each CR node is at one of the following states: backoff states, sending state and dropping state. Let us adopt the notations $BF_i, SND \text{ and } DRP$ representing the backoff state $i\,(i=0,...,K-1)$, sending and dropping states, respectively.

3.1. Congestion Probability In The CRAHN

Based on the PDFs of input and the attainable sending rates of a CR node in the CRAHN, i.e., $f_{RI_{h,n}}(r)$ and $f_{RS}(r)$, the queue length distribution of a CR node is obtained through Eq. (6). If the queue length of a CR sensor be equal or greater than $l_{\max}$ (queue length threshold), the CR node is detected as the congested node and the sink station sends a congestion notification command to the sources of the congested path in order to decrease their sending rates. The congestion probability of a CR node is obtained as follows:

$$\Omega = \sum_{l=l_{\max}}^{B} Q_l \qquad (2)$$

Where $l_{\max}$ the probability that queue length of CR node equals l. Q_l is calculated through. The congestion probability of a path is considered as the congestion probability of the most congested node in the path. Sending rate of the collecting CR sensor of a path is adjusted by rate-based congestion control scheme. Therefore, we have different path congestion probabilities Ω_r per all possible sending rates of path source node $(r=1,\ldots,R_{\max})$.

IV. SIMULATION SETTINGS

Table - 1

Number of SUs N	16
Number of PUs K	40
Number of Channels M	20
Side length of the simulation area L	10(unit length)
Radius of the sensing range r_s	2(unit length)
Radius of the transmission range r_c	2(unit length)
Number of selected channels n	1
The normalized PU arrival rate λ_p	0.5
The PU Packet length L_p	10 (times slots)
The probability of a successful transmission σ	1

V. RESULTS AND DISCUSSIONS

5.1. Number of Secondary Users Vs Success Rate

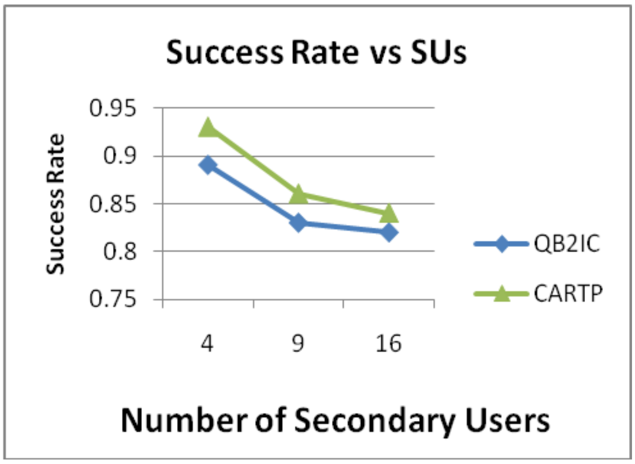

Figure.5.1.Number of Secondary Users Vs Success Rate

Table.5.1.Number of Secondary Users Vs Success Rate

	Protocols	
No. of SUs	QB2IC	CARTP
4	0.89	0.93
9	0.83	0.86
16	0.82	0.84

Fig.5.1. Portrays the success rate performance subject to increasing the number of secondary users of the CARTP compared with QB2IC. It is evident that CARTP attains better success rate than that of QB2IC protocols. The simulation result values are shown in Table.5.1

5.2. Number of Secondary Users Vs Average Broadcast Delay

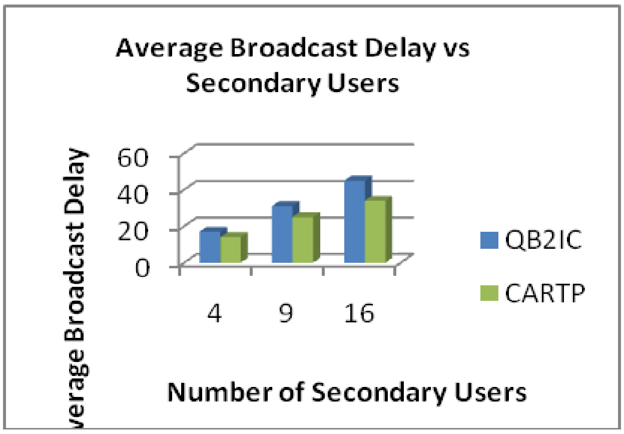

Figure.5.2.Number of Secondary Users Vs Average Broadcast Delay

Fig.5.2.Projects the average broadcast delay performance subject to increasing the number of secondary users of the CARTP compared with QB2IC. It is obvious that CARTP attains less broadcast delay than that of QB2IC protocols. The simulation result values are shown in Table.5.2

Table.5.2.Number of Secondary Users Vs Average Broadcast Delay

	Protocols	
No. of SUs	QB2IC	CARTP
4	17	14
9	31	25
16	45	34

5.3. Number of Primary Users Vs Success Rate

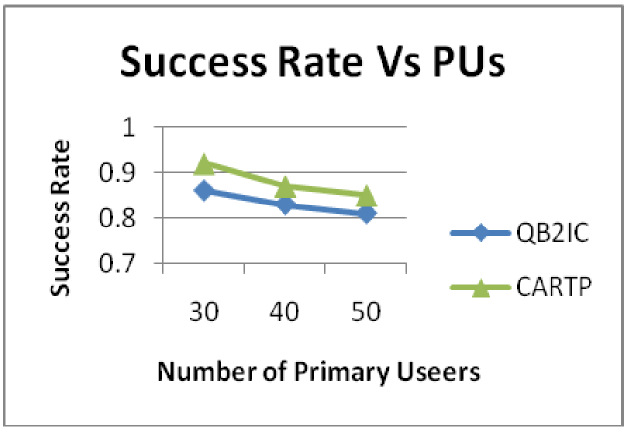

Figure.5.3. Number of Primary Users Vs Success Rate

Fig.5.3. Projects the success rate performance subject to increasing the number of primary users of the CARTP compared with QB2IC. It is certain that CARTP attains increased success rate than that of QB2IC protocols. The simulation result values are shown in Table.5.3.

Table.5.3. Number of Primary Users Vs Success Rate

	Protocols	
No. of SUs	QB2IC	CARTP
30	0.86	0.92
40	0.83	0.87
50	0.81	0.85

5.4. Number of Primary Users Vs Average Broadcast Delay

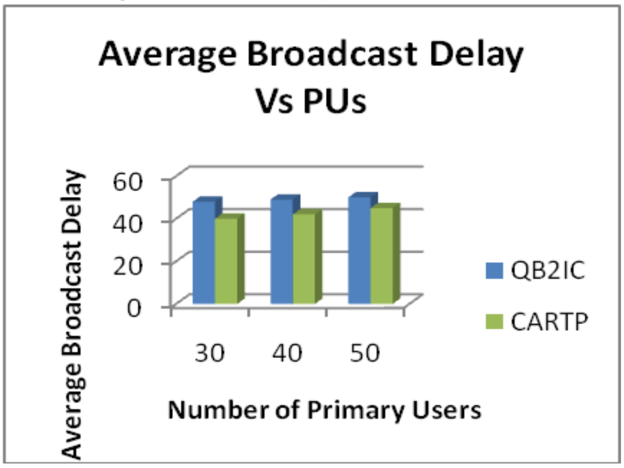

Figure.5.4.Number of Primary Users Vs Average Broadcast Delay

Fig.5.4. showcases the average broadcast delay performance subject to increasing the number of primary users of the CARTP compared with QB2IC. It is evident that CARTP attains less broadcast delay than that of QB2IC protocols. The simulation result values are shown in Table.5.4.

Table.5.4.Number of Primary Users Vs Average Broadcast Delay

	Protocols	
No. of SUs	QB2IC	CARTP
30	48	40
40	49	42
50	50	45

5.5. Number of Channels Vs Success Rate

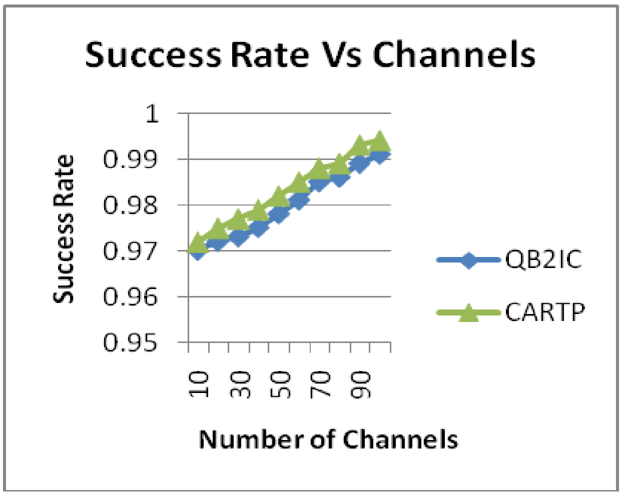

Figure.5.5.Number of Channels Vs Success Rate

Fig.5.5.envisage the success rate performance subject to increasing the number of channels of the CARTP compared with QB2IC. It is certain that CARTP attains increased success rate than that of QB2IC protocols. The simulation result values are shown in Table.5.5

Table.5.5.Number of Channels Vs Success Rate

	Protocols	
No. of SUs	QB2IC	CARTP
10	0.97	0.972
20	0.972	0.975
30	0.973	0.977
40	0.975	0.979
50	0.978	0.982

60	0.981	0.985
70	0.985	0.988
80	0.986	0.989
90	0.989	0.993
100	0.991	0.994

5.6. Number of Channels Vs Average Broadcast Delay

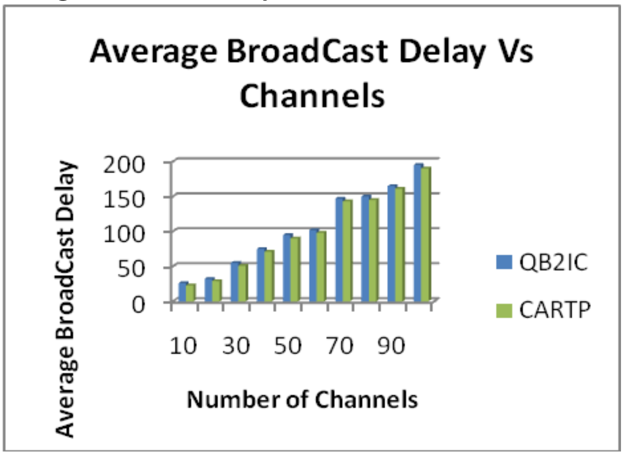

Figure.5.6. Number of Channels Vs Average Broadcast Delay

Fig.5.6.projects the average broadcast delay performance subject to increasing the number of channels to the CARTP compared with QB2IC. It is obvious that CARTP attains less broadcast delay than that of QB2IC protocols. The simulation result values are shown in Table.5.6.

Table.5.6. Number of Channels Vs Average Broadcast Delay

	Protocols	
No. of SUs	QB2IC	CARTP
10	26	23
20	32	29
30	55	51
40	75	71
50	95	90
60	102	98
70	147	143
80	150	145
90	165	161
100	195	190

5.7. Number of Unsynchronized Time Slots Vs Success Rate

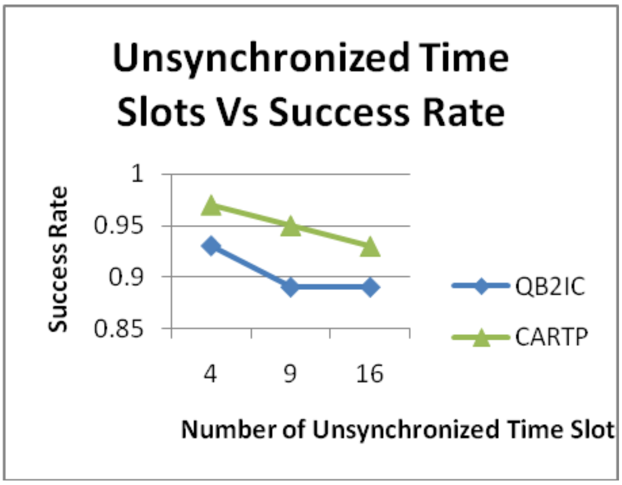

Figure.5.7.Number of Unsynchronized Time Slots Vs Success Rate

Fig.5.7. envisages the success rate performance subject to increasing the unsynchronized time slots to the CARTP compared with QB2IC. It is certain that CARTP attains increased success rate than that of QB2IC protocols. The simulation result values are shown in Table.5.7.

Table.4.5.7.Number of Unsynchronized Time Slots Vs Success Rate

	Protocols	
No. of SUs	QB2IC	CARTP
4	0.93	0.97
9	0.89	0.95
16	0.89	0.93

5.8. Number of Unsynchronized Time Slots Vs Average Broadcast Delay

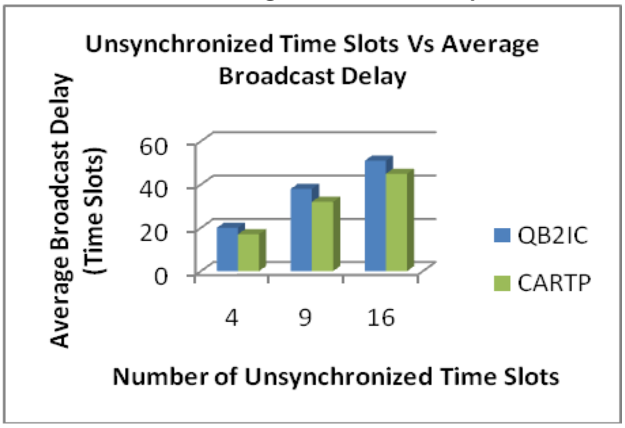

Figure.5.8. Number of Unsynchronized Time Slots Vs Average Broadcast Delay

Fig.5.8. projects the average broadcast delay performance subject to increasing the number of unsynchronized time slots to the CARTP compared with QB2IC. It is obvious that CARTP attains less broadcast delay than that of QB2IC protocols. The simulation result values are shown in Table .5.8.

Table.5.8. Number of Unsynchronized Time Slots Vs Average Broadcast Delay

	Protocols	
No. of SUs	QB2IC	CARTP
4	20	17
9	38	32
16	51	45

VI. CONCLUSION AND FUTURE WORK

This paper focuses on providing adaptive delay tolerant routing protocol for heterogeneous cognitive radio ad hoc networks. Simulations are carried out using cognitive radio cognitive network (CRCN) simulator. The performance metrics such as throughput, packet delivery ratio and delay are taken into account based on pause time. Simulation results prove that the proposed routing protocol CARTP has better performance in terms of increased throughput, better packet delivery ratio, decreased packet drop and reduced delay. The protocol can be further extended by incorporating security mechanism in the near future.

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