Channel Statistical MAC Protocol for Cognitive Radio

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***Abstract*—opportunistic spectrum access (OSA) allows unlicensed users to share licensed spectrum in space and time with no or little interference to primary users, with bring new research challenges in MAC design. We propose a cognitive MAC protocol using statistical channel information and selecting appropriate idle channel for transmission. The protocol based on the CSMA/CA, exploits statistics of spectrum usage for decision making on channel access. Idle channel availability, spectrum hole sufficiency and available channel condition will be included in algorithm statistical information. The model include the control channel and data channel, the transmitter negotiates with receiver on transmission parameters through control channel, statistical decision results (successful rate of transmission) from exchanged transmission parameters of control channel should pass the threshold and decide the data transmission with spectrum hole on data channel. A dynamical sensing range as a important parameter introduced to maintain the our protocol performance. The proposed protocol's simulation will show that proposed protocol does improve the throughput performance via traditional opportunistic spectrum access MAC protocol.**

***Index Terms*—cognitive radio, opportunistic spectrum access, channel availability, spectrum hole sufficiency, channel condition, channel selecting, ad-hoc networks**

I. INTRODUCTION

CURRENTLY, the spectrum is allocated to licensed users with a static manner, while the spectrum demand nowadays for GSM, WLAN, WIMAX etc is increasing. The traditional allocation policy faces spectrum scarcity in particular spectrum bands. But under the observation of the Federal Communication Commission (FCC) [1], it was shown that over 70% of the allocated spectrum is not used at any given time even in a crowded area where the spectral usage is intensive. So the concept of cognitive radio has been proposed to make use of the unused spectrum at a given time and place. In cognitive radio networks, unlicensed (secondary) users can make use of licensed frequency bands without violating the licensed (primary) users. Also in cognitive radio wireless ad-hoc networks, secondary users do not have pre-assigned frequency bands but they opportunistically search, find and operate in an available and without constraining the primary users [2]-[4].

The appropriate cognitive radio MAC protocol need be designed according to the characteristic of cognitive radio ad-hoc networks. 3 important issues need be considered. Firstly, according to the sensing and channel statistical information, find the appropriate idle channels for second user. Secondly, it has to coexist with primary users. Thirdly, second user data transmission need avoid interference with primary, or reduce the interference below an acceptable level.

Some proposed papers have given us some ways to design the cognitive MAC protocol. But they have less focus on the channel condition information statistical [5]-[7]. Some paper focus on the channel statistical information, but the statistical is more complicated and the statistical information is difficult to collect in actual network [8]. We proposed a new cognitive radio MAC protocol for finding appropriate idle (white) channel, and using it for second user data transmission. The channel selecting algorithm will base on the series channel statistical information exchanged in control channel. And we will make sure that the interference that is induced by second user transmission below an acceptable level.

The remainder of the paper is organized as follows. Section II presents our proposed protocol, section III provides simulation results, and in section IV, we will give the conclusion of our paper.

II. CHANNEL STATISTICAL ALLOCATION PROTOCOL

One of the most challenging tasks in developing opportunistic spectrum access (OSA) networks is the design of cognitive medium access control (MAC) protocols. The typical issues focus on how to find the white spectrum space, exchange and negotiate the channel statistical information, make idle channel allocation decision and avoid the interference with primary users in data transmission. According to it, our proposed protocol will be introduced by follows section: sensing and learning environment, RTS/CTS exchange over control channel, and DATA/ACK transmission over data channel.

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A. Overview of protocol

The proposed protocol based on the CSMA/CA protocol, and the two kinds of channel (control channel and data channel) are included in it. For avoiding collision, control channel and data channel are added the collision avoidance windows before packet (control packet and data packet) transmission. Through exchange the channel statistical information with RTS and CTS in control channel, calculating and making decision of the idle channel allocation. Usable data packets are transmitted in negotiated and allocated idle channel, and end it as receiving the ACK packet in transmitter.

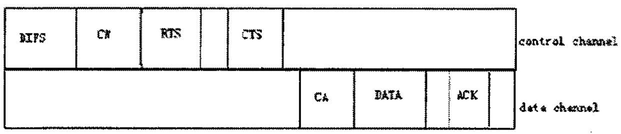

Fig. 1. The process structure of protocol.

B. Sensing and learning environment

Sensing and learning environment is for finding the statistical information of each channel before true data transmission. In our protocol, it is not necessary to sense and learn all of the channels in spectrum. Each node is allocated a sensing range, which based on each node device's MAC address to spread the central channels of devices over the whole spectrum. It achieves spectrum load balancing nicely. In our protocol, what we need get the channel statistical information is the: V_{Ni} average usable probability of neighbor for channel i and V_{Pi} average usable probability of primary user for the channel i. All of that can be get through past statistical of each channel.

C. RTS/CTS exchange over control channel

In our protocol, we introduce a control channel that provides a common channel for initiation hand-shaking. The access to this single control channel is implemented by CSMA/CA mechanism so that our protocol is still a decentralized one.

When a CR wants to initiate a transmission, it follows the standard CSMA/CA protocol to access the control channel to negotiate with the receiver. To be more specific, the sender listens to the control channel and waits until it becomes idle. Then, it waits for the channel to remain idle for DIFS duration before it begins the countdown of the contention window. If the channel is still idle after the contention window period, it transmits a RTS packet, which includes the potential transmission data packet that has the length "L". Upon receiving RTS, the receiver screens the potential transmission opportunities based on its own sensing range, and find the channel availability probability. It represents the availability probability of allocating m channels in the sensing range.

$$P_C = \prod_{i=1}^{m}\left(1-\frac{V_{N,i}}{1-V_{P,i}}\right) \quad i \in r \tag{1}$$

Where "i" is the channel index in the sensing range and m is the number of data channels in channel aggregation for the transmission opportunity under evaluation. A large sensing range gives the CR device higher flexibility on opportunity selection and higher probability on finding qualified ones.

At the same time, we assume that each node detection probability is P_d, it means the node sensing capability. When the channel is idle, and the node sense and detect it idle

$$P_d = P(H_0 / H_0) \tag{2}$$

Where H_0 means the channel is idle. H_1 means the channel is busy. So P_d is means that the node correctly sense the channel's probability. It is a hardware parameter.

Also, according to the potential idle channel, calculates the spectrum holes sufficiency

$$P_L = (p_d)^m \prod_{i=1}^{m} (f(0;\lambda_i)) \tag{3}$$

We assume each channel has the same data rate, if we use m channels for transmission. The duration of each channel is L/m. The equation (3) represents the probability of a specific packet of length L can fit the spectrum holes that selected for transmission. Where "λ_i" is the primary user average appearing probability of the channel i during the unit time, the f equation is the passion distribution as follows

$$f(k;\lambda) = \frac{\lambda^k e^{-\lambda}}{k!} \tag{4}$$

Where, the e is the base of the natural logarithm, k is the number of occurrences, and the λ is the average rate in the unit time, usually $\lambda \in [0.04, 0.2]$. So the probability that there is no primary user on the channel i duration the unit time is $f(0;\lambda)$.

By combining equations (1) and (3), the successful rate for a packet of length L to be transmitted on channels group can be written as

$$P_{CL}(m, L) = P_C P_L \tag{5}$$

For all idle channels and their combinations will be as replies with a CTS packet. If there is a collision on RTS or CTS, the sender would repeat the negotiation process but double the contention window size. At the same time, receiver also transmitted the check packet on selected idle data channel to sender. When the sender receive the check packet, it will evaluate all the idle channel condition, and calculate the successful rate again and then select the highest one as the prediction to the successful rate.

$$P = \max\{P_{CL}(m,r,L)\} \qquad (6)$$

For example, the number available channel is d, so the kinds of channel combination is $d!+1$, and calculates the successful rate of each situation, chooses the highest successful rate.

D. Data transmission over data channels

Before the data channel transmission, a collision avoidance window for the coming transmission is designed. This back-off window is designed to reduce the probability of collision resulted by two transmission pairs that happen to select the same or overlapped data channels for transmission. After the collision avoidance window, if the data channel is also idle, the data will be transmitted, the process will be end as the sender received the ACK from the receiver.

III. SIMULATIONS

Our simulation environment consists of one primary service network and one cognitive radio network. We use "Matlab" to make this protocol simulation. The system parameters are shown in table 1.

TABLE 1
PARAMETERS OF CONTROL AND DATA CHANNELS

parameter	Assigned value
DIFS	50us
SIFS	10us
CRTS	160bits
CCTS	112bits
CW average	20
CA	16
Payload	110000bits
ACK	112bits
Control channel rate	5.5mbps
Data channel rate	29.7mbps

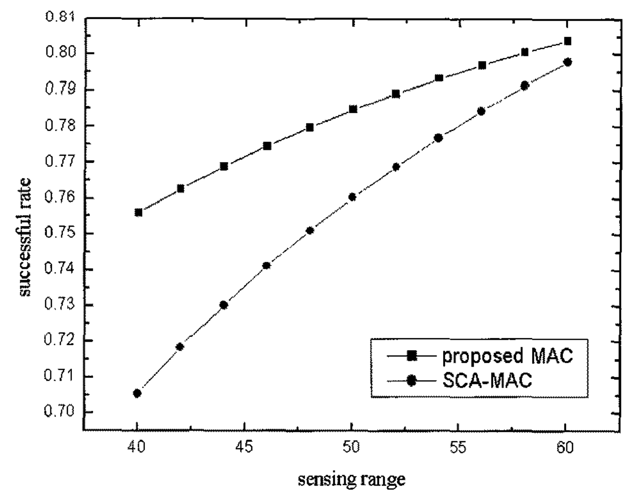

Fig. 2. Successful rate vs. sensing range.

As seeing in the figure 2, if we increase the sensing range, it gives the CR device higher flexibility on opportunity selection and a higher probability on finding qualified ones. So if we increase the sensing range, the successful rate will increase. Seeing from figure 2, our proposed MAC protocol has more successful rate than SCA-MAC protocol when they have the same operating range.

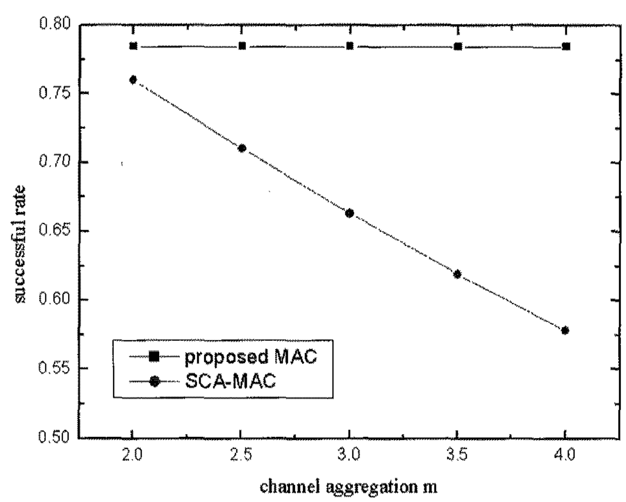

Fig. 3. Successful rate vs. channel aggregation.

As seeing in the figure 3, we will see the relationship between the successful rate and the channel aggregation. If we increase the number of available channels for data transmission, we should predict the channel availability probability and spectrum holes sufficiency over all the channel aggregation. And in our proposed MAC protocol, we use passion distribution to analysis successful rate. So the successful rate in every channel will increase as the m increases. But we should predict every channel at the same time. So the will have a little decrease. We can see from the figure 3, our propose MAC protocol has more successful rate than the SCA-MAC protocol.

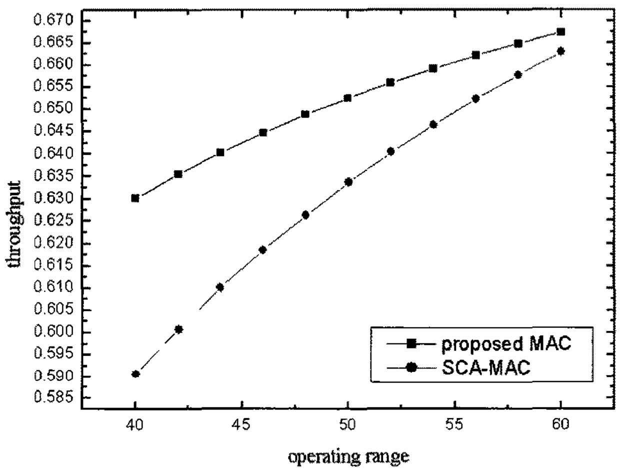

Fig. 4. The throughput vs. sensing range.

As seeing in the figure 4, it shows the relationship between the throughput and the operating range. If we increase the sensing range, the successful rate will increase as show in the figure 2. And the throughput will be increase as the successful rate increases.

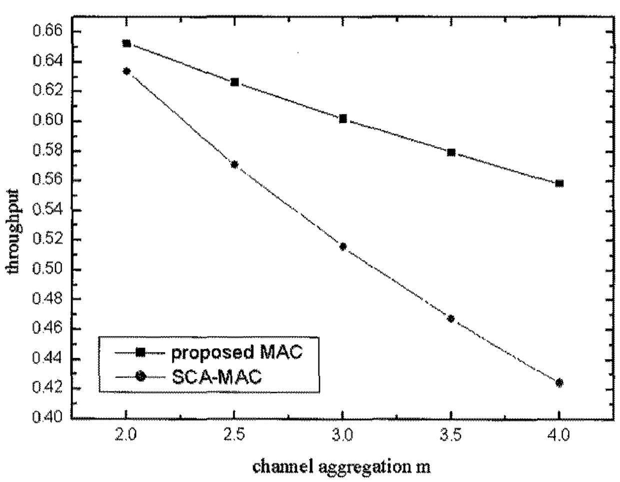

Fig. 5. The throughput vs. channel aggregation.

As seeing in the figure 5, it shows the relationship between the throughput and the channel aggregation. Because the length of be transmitted data is constant in this simulation. And see in the figure 3, the successful rate will decrease as the m increases. So the throughput will be decrease. In our proposed protocol, the through has the deeply relationship with successful rate. But the total data transmission time will be reduced because of the channel aggregation.

IV. CONCLUSIONS

In this paper, we proposed a new MAC protocol in cognitive radio wireless ad-hoc network, by using channel statistical allocation. We show the protocol model and algorithm. By collecting the channel statistical information and calculating, the appropriate channel can be selected for second user transmission. Through the simulation results, we can get the better successful rate and throughput than the traditional MAC protocol.

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