A Distributed Network Q-Mac with Quality of Service Provisioning

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Keywords: Multi-channel, QoS, Q-MAC Protocol, Simulation, Distributed network.

Abstract. A new distributed Cognitive Radio network Q-MAC has been proposed in the paper. The Q-MAC Protocol provides an efficient approach to address quality of service provisioning of delay sensitive applications. This MAC Protocol guarantees the QoS of network for such applications by giving priority to applications with higher time delay requirements in the stage of channel reservation. The performance of the Q-MAC Protocol with those of two existing protocols are compared. The results show that the Q-mac provides better throughput than those existing protocols. The analysis model and simulation results show that the designed Q-MAC Protocol is simple and effective. This Protocol can recognize and meet the QoS requirements of delay-sensitive applications and can effectively deal with the problem of multi-channel hidden terminal.

Introduction

Traditional static spectrum allocation technology has a low utilization rate of radio frequency spectrum, and radio frequency spectrum, as an important part of the authorized spectrum, occupies a high proportion [1]. The insufficient utilization and lack of authorized spectrum make the spectrum allocation change from static state to dynamic state, which greatly promotes the development of cognitive radio network technology. Dynamic spectrum allocation technology allows secondary users to "wait for the opportunity" to use the authorized spectrum allocated to the primary user, which provides the possibility to improve the utilization of spectrum. In wireless channels, communication control and communication consultation are mainly focused on MAC layer, so the design of a fast and efficient MAC Protocol is critical to the successful establishment of cognitive radio network. Compared with other similar networks, distributed radio cognitive networks are very practical and easy to deploy, fast, complex and low cost [2]. MAC layer design of cognitive radio network is a hot research field. A series of MAC Protocol design methods are proposed [3]~[7]. In this paper, some common problems in MAC layer design of cognitive radio network are analyzed and studied.

A distributed network Q - MAC Protocol

The Q-MAC Protocol divides the time frame into periodic beacon time intervals, and the secondary user synchronizes through a periodic beacon signal. When a secondary user joins the net-work, it must first listen for at least one beacon signal on the common control channel to ensure that it is synchronized with other nodes in the network. If the secondary user does not listen for any beacon signals, it starts sending a beacon signal periodically as the first node in the network. In order to simplify the secondary user node model, this paper assumes that each secondary user node works in half duplex mode. The nodes in the network can only exchange control information using common control channels. The Q-MAC Protocol states that the user should be aware of each channel before selecting it. Therefore, in the stage of data transmission, users can effectively use the perceptual information of the channel in the perceptual stage. In the perception phase, the secondary user cannot send data. Therefore, the perceived results will not be disturbed by the neighboring users. Each secondary user is aware of the channel independently and ensures that each secondary user has a set of available channels at the end of the awareness phase.
At this stage, in order to participate in the channel negotiation and reservation mechanism, each secondary user to send data has to compete for the right to use the public control channel. The withdrawal mechanism adopted by the competition is the same as the withdrawal algorithm of the traditional IEEE802.11 DCF Protocol.

When there are several ordinary data transmission channels available between a pair of transceivers, this paper assumes that the receiver chooses one randomly in the channel negotiation stage. The Q-MAC Protocol works well with any choice strategy. This article assumes that the MAC layer packet size is fixed and that the user can send one or more packets during the data transfer phase. After each data packet is sent, it immediately waits for a short ACK sent by the receiving receiver. If the transmitter does not receive an ACK, the data transmission has not been successful. The total length of the data transfer phase can be expressed as the total amount of time spent sending multiple packets and ACK messages. Data transfers between different transceiver pairs are parallel and do not compete with other secondary user nodes. If a pair of transceiver nodes have a perception error in the perception phase, the master user will also have a perception error in the data transmission phase. However, this is rarely the case in real life. If this happens, the transmitter needs to continue channel sensing and competition for the next beacon cycle.

The Performance of Q-MAC Protocol Analysis

It is convenient to analyze the proposed Protocol by mathematical method. It is assumed that the Q-MAC Protocol does not require uniform available channels and that the data transfer rate can be determined by the specific service. If the channel utilization ratio of the main user is different; Average channel utilization rate varies according to location and time. The channel supports different data transmission range and data transmission rate in different frequency band. The Q-MAC Protocol stipulates that at the beginning of each frame, the node shall be aware of the state of the channel, and the paired sending and receiving nodes shall, through negotiation, select the channel on which both of them are "satisfied" to transmit data. The node can transmit data well regardless of the same or different channel utilization rate, data transmission range and data transmission rate.

In the competition stage, secondary users exchange control information through common control channels using access mechanisms similar to IEEE802.11 DCF. When the common control channel is idle, the time is divided into several time slots, each with a length of $\sigma$. If there is no node request to send data at the beginning of each slot, the slot is set to idle. Otherwise, a successful information exchange of length $T_s$ or an unsuccessful information exchange of length $T_c$ is initiated in the initial phase of the time slot. Suppose that in a randomly selected time slot, the probability of a node trying to send control information is $P_t$, the probability of collision of control information in the competition stage is $P_{cm}$, and the probability of channel being busy is $P_b$, $P_t$ and the probability of channel being busy is which can be expressed as:

$$P_t = \frac{\psi_1}{(1-P_b)(1-P_{cm})\psi_1+(1-2P_{cm})(\bar{W}+1)\psi_2+P_{cm}\bar{W}(1-(2P_{cm})^m)\psi_2}. \quad (1)$$

where $w$ is the size of the minimum competitive window in the avoidance algorithm, $m$ is the number of times the node performs the avoidance. The probability of busy channel of at least one data transmission is:

$$P_b = 1-(1-P_t)^N. \quad (2)$$

Assuming that there is only one secondary user node in a time slot, the conditional probability of successful data transmission is $P_{cs}$, which can be expressed as

$$P_{cs} = \frac{N.P_t(1-P_t)^{N-1}}{P_b}. \quad (3)$$
When the throughput of the network is estimated, the average number of channels that can be booked in $T_{con}$ period can be expressed as:

$$\overline{N} = \sum_{i=0}^{N_{ch}} \min(i, N_{succ}) \left(\frac{N_{ch}}{i}\right) P(1-P)^{N_{ch}-i}.$$  \hspace{1cm} (4)

The average throughput increment of the network can be expressed as:

$$\overline{S}_{im} = \overline{S} + \overline{N} \frac{4T_{DT}}{T_{BI}} = \frac{\overline{N}}{T_{BI}} \left[ T_{DT} + \left( T_{CON} - \frac{(\overline{N}+1)T_{BI}}{2} \right) \right],$$  \hspace{1cm} (5)

where $\overline{N_{T}} \leq T_{CON} < (\overline{N}+1)T_a$.

Assuming that some other parameters, such as $N_{e}$, $p_i$, $N_{ch}$ and $P$ known, $T_{con}$ can be obtained under known conditions by solving equation (6), so that the network throughput is maximized.

$$\max \text{imuze } \overline{S}_{im} = \frac{1}{T_{BI}} \left[ \overline{N}T_{DT} + \frac{T_{CON}}{2} (\overline{N} - 1) \right] \hspace{1cm} \text{subject to } T_{CON} \geq 0$$  \hspace{1cm} (6)

Since the reservation of a single channel occurs within the time period $T_a$, the objective function decreases slowly in the finite-continuous channel reservation period. The objective function is a convex function, and if $T_{con} = n T_a$ the throughput of the network can reach the maximum value in equation (6). Since $T_a$ is a constant, the equation (6) can be converted into solving the following integer equation:

$$\max \text{imuze } f(n) = \overline{N}(T_{BI} - T_{server}) - \frac{nT_{BI}}{2} - \frac{nT_{BI}}{2} \hspace{1cm} \text{subject to } n \in N^+$$  \hspace{1cm} (7)

where $N^+$ is a non-negative integer. If $n^*$ is the optimal value for $n$, so $n^* \leq N_{ch}$. A large number of search algorithms can be used to solve the problem.

**QoS Based on Q-MAC Protocol**

The competition stage of channel can be divided into two parts: one part is aimed at high-priority users; Some are aimed at ordinary users. Assuming that each high-priority user has at most one high-priority packet at any time, the access delay of the channel is only needed to be analyzed when studying the QoS performance of the network. The end-to-end delay of high-priority users can be simply approximated to the sum of the access delay of the channel and the data transmission duration $T_{DT}$. Figure 1 shows the delay when the node has a priority packet. Each state represents the number of beacon cycles that packets queued in the queue need to wait. The probability of state can be expressed as. Ensuring QoS the maximum channel access acceptable to a high-priority packet is expressed as. When a packet reaches a user's transmission queue, this state is denoted as initial state (denoted as state 0). Assuming the probability that the user can send data in each beacon cycle is, the probability that the user needs to wait until the next beacon stage is:

$$P_{nap} = 1 - P_{ap}$$  \hspace{1cm} (8)

Combined with figure 1, it can be obtained $P_a = P_{0}P_{nap}$. When reaching state $D+1$, the probability $P_{us}$ that does not meet QoS requirements can be expressed as:
Figure 1. State diagram of packets waiting to access the channel.

\[ P_{sat} = P_{D} - P_{nap} = P_{D}P_{D+1} \]  

(9)

Accordingly, the probability of satisfying QoS requirements is \( P_{sat} = P_{D} - P_{a} \). Therefore, in several beacon cycles, the average time delay of all high-priority users and ordinary users meeting QoS requirements can be expressed as follows:

\[ D_{QoS} = \frac{P_{sat}N_{p}D_{s} + N_{p}D_{s}}{P_{sat}N_{p} + N_{f}} \]  

(10)

When the network does not specify to ensure QoS, the channel access probability of any user is assumed to be \( P_{a} = 1 - P_{sat} \) per beacon cycle. The average access delay of the channel can be expressed as:

\[ D_{no-QoS} = \frac{P_{a}P_{ac}}{P_{a}} \]  

(11)

Suppose \( N_{f} \) users need to send data packets, among which \( N_{fp} \) users need to send data packets with QoS requirements, then the rest \( N_{f} = N_{f} - N_{fp} \) users are ordinary users. When there is no QoS demand on the network, users use all the competition stages, and the duration is denoted as \( T_{comp} \). When there is a demand for QoS, high-priority users use a specific competition stage, and the duration is denoted as \( T_{comp} \), so the duration of ordinary users using the competition stage is \( T_{con} = T_{con} - T_{comp} \).

**Conclusion**

In this paper, the performance of Q-MAC protocol is compared with some similar MAC protocols by Matlab software. In the simulation, beacon cycle length \( T_{bs} = 100ms \), the data transmission rate \( R = 1mbps \) of each data transmission channel. The data transfer rate of the common control channel are \( 1mbps \), \( t_{DIFS} = 128\mu s \), \( t_{SIFS} = 28\mu s \), \( \sigma = 50\mu s \). When the parameters \( P = 0.7, N_{f} = 70, T_{remin} = 10ms \) and \( P_{f} = 0.015 \) are fixed, the relationship between throughput and race phase duration and channel number is shown in figure 2.

As the value \( T_{con} \) increases, the throughput of the network starts to rise and reach the maximum. If the value \( T_{con} \) continues to increase, throughput begins to decline. The maximum throughput is achieved precisely at the moment when all available channels are reserved. As the value \( T_{con} \) increases, \( T_{DF} \) decreases but the average number \( N_{n}P \) of channels available for reservation remains unchanged, causing throughput to begin to decline.
As $T_{con}$ and P increase, the maximum realizable throughput increases. When is variable, the Q-MAC performance is better than that of fixed $T_{tor}$, which $T_{tor}$ is the result of the former using a part of competitive channel for data transmission. Figure 2 shows that Q-MAC can make efficient use of the idle spectrum of the primary user.

This paper proposes a MAC Protocol for distributed cognitive radio networks, which ensures that time-delay sensitive applications have a higher priority than ordinary users. Simulation analysis shows that the Protocol reduces the access delay of the channel and meets the QoS requirements of time-delay sensitive applications. This paper proposes a method to calculate the maximum number of such users according to the QoS requirements of high-priority applications. It can be used to improve the access control module of the channel.

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