Signal transmission model for the substations grounding grid

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ABSTRACT

The signal of the wireless sensor network in Grounding grid, owing to energy loss, network congestion, path constraints and other factors, is easy to delay even partially losing. In order to ensure that the signal can be transmitted effectively in grounding grids for the substation, this paper presents a method based on traffic model of back-off balanced multiple sensor network cooperation model. As we all know, cognitive radio (CR) technology is adopted in multi-channel wireless networks to provide enough channels for data transmission. The MAC protocols should enable the secondary users to maintain the accurate channel state information to identify and utilize the leftover frequency spectrum in a way that constrains the level of interference to the primary users. We proposed a novel cooperation spectrum sensing scheme in which the secondary users adopt backoff-based sensing policy based on the traffic model of the primary users to maximum the throughput of the network. To obtain the full accurate information of the spectrum is a difficult task so that we propose the backoff sensing as a sub-optimal strategy. Since the secondary users sense only a subset of the channels in our proposed scheme, less time is spent to get the channel state information as more time is saved for the data transmission. And while dealing the signal data, I combine the intensity transfer method instead of the priority method. This can effectively reduce the network congestion, to ensure that the main information can be transfer well. It is also very useful to signal transmission for the Multi-sensor in Grounding Grids for Substations.

Index Terms— Cooperative Sensing, Backoff, Qos

Ⅰ. INTRODUCTION

As the grounding grids for the substation that the author is studying, is similar to the existing wireless sensor network, so in the establishment of the model of signal transmission, we no longer emphasizes grounding grids. In fact, the model is also practical for other wireless network. Allocating a fixed spectrum band to each wireless service has been proved to be inefficient since more than 90% of the spectrum is unused in most of the time while spectrum scarcity becomes a serious problem. As a result, Cognitive radio (CR) is developed to solve the problems resulting from limited spectrum resources and low utilization of the spectrum. CR network (CRN) allows the unlicensed users dynamically access the licensed spectrum to enable communication or improve service quality while no transmission of the primary users processing. Although the basic idea of the CR technology is simple, it imposes new challenges to the design of the MAC protocol. One of the most difficult, but important, design problems is how the secondary users effectively detect the existence of the primary users.

Different sensing policies are proposed in [1]-[4] as possible solutions to this problem. Particularly, the authors in [1] suggest the secondary users shall know the state of each channel of the primary network which is modeled as an ON-OFF source alternating between state ON (active) and state OFF (inactive), however, when there are many channels to sense, the reporting phase will take a large portion of the slot which cannot be ignored. Therefore, the efficiency can be quite low due to the fact that the data transmission occurs only in the negotiating phase. In [2], the author use the statistical channel allocation to predict future spectrum usage and decide which channel to sense and access, but unfortunately, the complexity of this scheme increases quickly with the number of the licensed channels. The authors of [3] adopt stopping rule for the spectrum sensing as hardware restrictions are taken into consideration. However, the sensing priority is not discussed problem in this work. In [4], dissemination scheme for channel state information is studied with sensing priorities considered.

The backoff-based sensing strategy proposed in this paper is actually a sensing priority adjustment scheme based on the traffic model of the primary users. Meanwhile, using the intensity transfer method, we transfer the data directly. The length of the traffic is modeled with exponential distribution, which is simple but effective, especially for the on-line traffic.

The rest of the paper is organized as follows: Section Ⅱ introduces the traffic model of the primary network and presents the proposed cooperative sensing scheme. This is followed by Section Ⅲ which provides the performance of the proposed scheme with some numerical results obtained from the simulation for the Grounding Grids in some Substation. Finally, the paper is concluded with section Ⅳ.

Ⅱ. PROPOSED CHANNEL SENSING SCHEME

A. System Model Overview

We consider a licensed spectrum band divided into *n* data channels. Each licensed channel is time-slotted such that the primary users communicate with each other in a synchronous manner. Meanwhile, a number of ad-hoc network users, which are synchronized with the primary users, opportunistically access the licensed spectrum without imposing interference to the primary users. In this paper, we mainly focus on the scenarios where all secondary users utilize the licensed channels used by the same set of primary users. This implies that the licensed channel availability information sensed by each secondary user is consistent among all secondary users. The spectrum band is divided into N data channels index by *i* with *i*=1, 2… N and one control channel. Spectrum band of the control channel is pre-assigned and is disturbed from the primary users.

In our proposed cognitive radio-based multi-channel MAC protocols, each secondary user is equipped with two transceivers. The first transceiver is devoted to operating over the dedicated control channel. The secondary users use their control transceivers to obtain the sensing results of the un-used licensed channels from other secondary users, and to negotiate with the other secondary users through the contention-based algorithms, such as IEEE 802.11 distributed coordination function (DCF) and Carrier Sense Multiple Access (CSMA) protocols. The second transceiver consists of a SDR module such that it can tune to any one of the *n* licensed channels to sense for spare spectrum, receive/transmit the secondary users' packets. For convenience, we call the first transceiver the control transceiver and the second transceiver the SDR transceiver, respectively, in the rest of this paper. Each time slot is divided into sensing phase and negotiating phase. Sensing phase is used for channel sensing and information reporting while negotiating phase for data transmission and resources allocation among secondary users. Four types of packets are introduced into our scheme for exchanging control messages:

1) C-RTS/C-CTS: contention and spectrum reservation during the negotiating phase.
2) T-RTS/T-CTS: notify the other secondary users the completion of the transmission.
3) D-RTS/D-CTS: negotiate with the receiver node and initial the transmission.
4) RP: notify the other secondary users the sensing results.

B. Traffic Model

Traditionally, we assume that the primary user transmission request arrival is a Poisson stream, while the service time for each primary user is exponentially distributed. Thus, applying M/M/1 queuing model, we can model each channel as a Markov chain as shown in Fig. 2, where the variable in the circle represents the number of the primary user waiting for spectrum resources. The transition probability, denoted by $q_{i,j}$, of the Markov chain can be written as:

$$q_{i,j} = \Pr\{S(t+\Delta t) = j \mid S(t) = i\}$$
$$= \begin{cases} \lambda\Delta t + O(\Delta t), i = j-1 \\ \mu\Delta t + O(\Delta t), i = j+1 \\ O(\Delta t), |i-j| \ge 2 \end{cases} \quad (1)$$

Thus, we are able to derive the probability transition matrix for the Markov chain $S_j(t)$, denoted by Q , as follows:

$$Q = \{q_{i,j}\}$$
$$= \begin{bmatrix} 1-\lambda & \lambda & 0 & \cdots & \\ \mu & 1-\lambda-\mu & \lambda & 0 & \cdots \\ 0 & 2\mu & 1-\lambda-2\mu & \lambda & 0 \\ \cdots & \cdots & & & \end{bmatrix} \quad (2)$$

Since the channel will be busy when $S_i(t) \ge 1$, we can simplify this Markov model to an ON/OFF channel usage model alternating between state ON (active) and state OFF (inactive). An ON/OFF channel usage model specifies a time slot in which the primary user signals is or isn't occupying a channel. The secondary users can utilize the OFF time slot to transmit their own packets. Suppose that each channel changes its state independently. Let α_i be the probability that *i*-th channel transits from state ON to state OFF and β_i be the probability that *i*-th channel transits from state OFF to state ON, where $1 \le i \le N$. Then, the channel state can be characterized by a two-state Markov chain as shown in Fig. 1. The probability transition matrix is derived as follows:

$$Q = \{q_{i,j}\} = \begin{bmatrix} 1-\alpha_i & \alpha \\ \beta & 1-\beta_i \end{bmatrix} \quad (3)$$

Let $P(n)$ denotes the probability that the transmission on i-th channel lasts for *n* time slots, thus, we are able to derive that $P(n)$ is geometrically distributed:

$$P(n) = (1-\alpha_i)^{n-1}\alpha_i \, (n \ge 1) \quad (4)$$

Based on Eq. (4), the mathematic expectation, denoted by $E[P(n)]$, of the traffic length can be derived as:

$$E[P(n)] = \sum_{n=1}^{\infty} nP(n) = \frac{1}{\alpha_i} \quad (5)$$

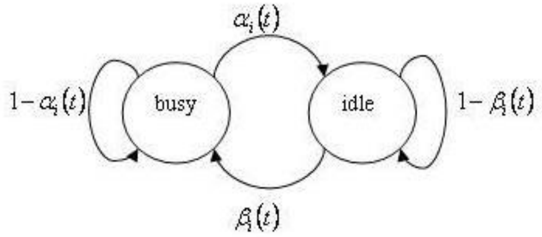


Fig. 1. two-state Markov chain

C. Intensity transfer method for the data

The so-called intensity transfer method is as below. When the control system is accurate input, the exact value put the linguistic variable value acquired from the former conditional statements to the next linguistic variable value. In most cases, fuzzy controller is a double input and single output controller. Wherein, an input for the deviation, another input for the rate of change of the deviation. Set input deviation X1, the change rate of the deviation X2, output Y, and their linguistic variables respectively Ai1, Bi2 and Yi said. Therefore,

$X_1 = \{A_{11}, A_{21}, \ldots, A_{j1}\}$

$X_2 = \{B_{12}, B_{22}, \ldots, B_{n2}\}$

$Y = \{Y_1, Y_2, \ldots, Y_r, \ldots, Y_m\}$

In addition,

If $X_1 = A_{11}$ and $X_2 = B_{12}$ then $Y = Y_1$

If X1=A11 and X2=B22 then Y=Y1

……

If X1=A11 and X2=Bn2 then Y=Yr

if X1=A21 and X2=B12 then Y=Y2

……

If X1=Aj1 and X2=Bn2 then Y=Ym

Detailed steps for the Intensity Transfer Method are as follows:

1) For a previous linguistic variable intensity

Set input x1=a1, x2=a2; A1, A2 is an accurate value. According to the first rule, A1, A2 corresponding to language variables B11, B12 in the parameter X1, X2, then membership grades respectively are

$$w_{11} = \mu_{A_{11}}(a_1) \wedge \mu_{B_{12}}(a_2)$$

Analog，

$$w_{12} = \mu_{A_{11}}(a_1) \wedge \mu_{B_{22}}(a_2)$$

$$\ldots\ldots$$

$$w_{1n} = \mu_{A_{11}}(a_1) \wedge \mu_{B_{n2}}(a_2)$$

Can infer

$$w_{21} = \mu_{A_{21}}(a_1) \wedge \mu_{B_{12}}(a_2)$$

$$\ldots\ldots$$

$$w_{jn} = \mu_{A_{j1}}(a_1) \wedge \mu_{B_{n2}}(a_2)$$

2) Seek the result of reasoning

Due to the intensity transfer method is putting on the former role to transfer to a later. Then put the exact value to the membership grade of the next fuzzy quantity before. Therefore, for the first conditional, the reasoning results are

$$Y_{11}^* = w_{11} = (y_1)Y_1$$

Analogy, from the second conditional to the $j \times k$ conditional, the reasoning results are

$$Y_{12}^* = w_{12} = (y_1)Y_1$$

$$\ldots\ldots$$

$$Y_{1n}^* = w_{1n} = (y_r)Y_r$$

$$Y_{21}^* = w_{21} = (y_2)Y_2$$

$$\ldots\ldots$$

$$Y_{jn}^* = w_{jn} = (y_m)Y_m$$

According to the general result of reasoning, we can get the element that the later correspond to

$$y_1, \; y_2, \; \ldots, y_m$$

3) Get the output accurate value b from the general results of reasoning

Generally speaking we use the method with the centre of gravity to get the exact output value B, i.e.

$$b = \frac{\int Y^*(y) y dy}{\int Y^*(y) dy}$$

4) Take Y_{11}^* as the membership grade for Y_1, Y_{12}^* as the membership grade for Y_2, Y_{1n}^* as the membership grade for Y_r; Meanwhile, take Y_{22}^* as the membership grade for Y_2, Y_{jn}^* as the membership grade for Y_m, At this time, when Y1, Y2,..., Ym is a monotone function, B can also be expressed as:

$$b = \frac{\sum_{p=1}^{j}\sum_{q=1}^{n} Y_{pq}^* \times y_t}{\sum_{p=1}^{j}\sum_{q=1}^{n} Y_{pq}^*}$$

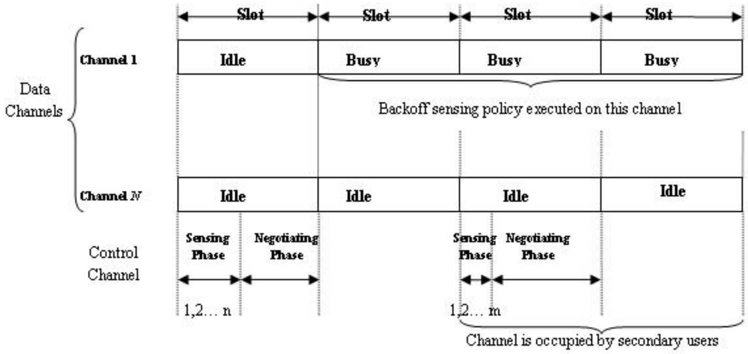
In equation above, $t=0, 1, 2\ldots m$.

After contrasting to the Mamdani fuzzy control method, fuzzy Smith control method and strength transfer method, we find the Mamdani fuzzy control method has two shortcomings whose adaptive ability is poor and the control precision is not high. Going through a two degree unstable object, dynamic performance and stability of the Mamdani fuzzy control method is weak [5]. Combining the Fuzzy control method and the Smith pre-estimation control method together, we can solve the time delay, time-varying, nonlinear complex system problems, but it is very complex to achieve [6]. And the variable domain of Intensity-transferring method is simple, intuitive, easy to understand, but also has a high control accuracy, According to the above analysis, we chose the variable domain of Intensity-transferring method in this method.

D. Backoff-based Channel Sensing Policy

The basic idea of our backoff-based channel sensing policy is that the secondary user will postpone the next sensing when the channel sensing result is turned out to be busy. Using Eq.4 to get the numerical results, we can further obtain that the probability decreases exponentially as the time slot increases. Therefore, it makes sense that the optimal performance is expected when adopting exponential backoff sensing policy. For the rest of this section, we will discuss details of our backoff-based channel sensing policy.

Fig. 2. Frame Construction of our proposed scheme



As Fig. 2 shows, for the *i*-th channel in time slot indexed by *t* with *t* =1, 2,… , T, (T +1), (T +2), …, the state of the *i*-th channel, denoted by $s_i(t)$, corresponds to a binary random variable, with 0 and 1 representing the *idle* and the *active* states, respectively. A Backoff Time Counter (BTC) is used to record the backoff slots remained for each channel. From the view of the secondary users, the Let $a_i(t)$ denotes the channel state of the *i*-th channel kept in the channel state table by the secondary users, $a_i(t)$ may have the one of the four following values and it is updated whenever the secondary user senses the *i*-th channel or receives sensing results of the *i*-th channel from other secondary user:

·0: *Unsensed*: Channel that are not sensed and occupied by the other secondary users.

·1: *Busy*: Channel is occupied by primary users or other secondary users.

·2: *Available*: Channel is available according to the sensing results or the information in the report packets received from other secondary users.

·3 *Backoff-Active*: Backoff-based channel sensing policies active on this channel ($b_i(t) > 0$).

Let $d_j(t)$ denotes the *j*-th secondary user state, $d_j(t)$ may have one of the three following values:

0: The secondary user reserves enough channel resources for its data transmission,

1: The secondary user needs more resources for data transmission.

2: The secondary user has no data to transmit.

From the view point of the secondary users, the licensed channels are split into four subsets $N_0 \sim N_3$ according to the $a_i(t)$ values in any given *t*-th time slot, $N_j = \{i \mid a_i(t) = j\}(j = 0...3)$. Note that no common elements exist between any two of these sets and N_2 has no elements at the start of a slot since no channel has been sensed. The sensing phase of each slot is divided into *n* mini-slots, where *n* is the number of elements in N_0. Following the settings in IEEE 802.11a [7], we assume each mini-slot last for T_{MS} =9μs, which is long enough to determine whether a channel is busy or not, the sensing process is error free. If we denote T_S, T_{RP}, T_{NP} as the time duration of the time slot, the reporting phase, and the negotiating phase, respectively, then we obtain:

$$T_S = T_{RP} + T_{NP} = nT_{MS} + T_{NP} \tag{2}$$

Transmission only happens during the negotiating phase, let N_{IDLE} denote the number of channels sensed to be idle, then we have the reward function in the given time slot:

$$F(t) = N_{IDLE}T_{NP} = N_{IDLE}(T_S - nT_{MS}) \tag{3}$$

We try our best to maximum *F*(*t*) by reducing *n* remarkably while N_{IDLE} is comparable with the number of available channels in the network.

At each mini-slot, a secondary user with $d_j(t) > 0$ randomly selects a channel in N_1 to sense while the other secondary users waiting for the channel report. Consider the *j*-th secondary user select i-th channel to sense, the SDR transceiver is tuned to the dedicated channel to get the channel information. Therefore, $s_i(t)$ is known by the *j*-th secondary user.

If $s_i(t) = 1$, the secondary user updates $a_i(t)$ to 3 and sets a backoff period for this channel. The channel will be adding to N_3 and won't be sensed until it expires. The length of the backoff window is set as W_0 slots, where the integer W_0 denotes the minimum window size. After waiting for this amount of backoff time, update $a_i(t)$ to 0 and sense the channel again. Every time the sensing result turns out to be busy, the backoff window for the channel will be multiplied by the backoff factor *r*. We predefined a constant value *K* represents the maximum times that the backoff-based sensing policy can be executed. After *K* times unsuccessful channel sensing, the backoff window will remain unchanged until the channel sensed to be idle.

If $s_i(t)$=0, the *j*-th secondary user realize the *i*-th channel is idle and will make the decision whether to keep it for transmission or not. If $d_j(t)$=1, the *j*-th secondary user will reserve i-th channel for data transmission. Therefore, the *j*-th node update $a_i(t)$ to 1 and $d_j(t)$ base on the channel resources which has been reserved and spectrum required for transmission. $a_i(t)$ will be updated to 2 when $d_j(t)$=2, since the *j*-th node have no data to transmit.

After a secondary user has reserved enough channel resources for its data transmission, transmission will be initialized by sending D-RTS packet to the receiver. After successfully receive a D-CTS packet since sending the last D-RTS, it gets the permission to transmit data packets in the coming next time slot. Since primary users may access channels at any time, the channels which are reserved by the secondary users still need to be periodically sensed to avoid colliding with the primary users. However, it is unnecessary to sense these channels with cooperation from all the secondary users of the network. Cooperation will only be operated between the sender and receiver which access these channels for transmission. Therefore, the frames have a different construction as shown in Fig.1.

When primary user become active on the channels kept by the secondary user or the secondary user have finished their transmission, the secondary user will free the spectrum resources by sending T-RTS/T-CTS, which carries the index of the channels kept. The other secondary users, however, mark these channels with $a_i(t)$=0 at the start of the next time slot which indicates that channels are available for sense.

At the end of each mini-slot, $a_i(t)$ will be passed out to the other secondary users by sending a RP packet. The other secondary users, however, update their channel information table upon receiving the RP packet.

Ⅲ. PERFORMANCE EVALUATION

A. Simulation Model

To the grounding grid for an 110KV substation, we make a simulated test. The substation grounding conductor consists of flat steel structure, the cross section is $40mm \times 6mm$ and the depth is $0.9m$. The substantially shape can be shown in figure 3.

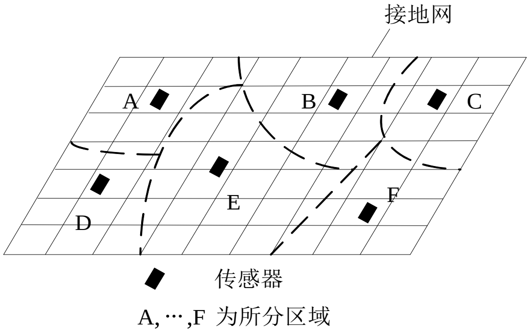


Fig. 3. Schematic diagram of real grounding grid

The 6 group of sensors are embedded in the A, B, C, D, E, F Figure 3 shows for the first. Assuming sensors and grounding conductor are in the same horizontal position, then the grounding conductor and the sensor are in the same soil environment. It can be identified that all the drift current comes from the grounding conductor will go through the electrode of the sensor entirely. So the sensor can transmit all the information of the grounding conductors. It is worth to point out, the A, B, C grid region is variable, and the final results should be decided by Tabu search. And the grounding grids for the substation is too small to transmit much information. The paper presents the date comes frome the tower.

We compare the performance of our proposed scheme with the negotiation-based sensing policy proposed in [1]. The duration of traffic subject is to exponential distribution with an average length of 500 time slots. The spectrum utilization is denoted by γ, while the number of the data channels is denoted by n. We investigate the throughput results of the backoff-based sensing policy with different γ's and n's. Secondary users are distributed over a square with a side length of 100m. The secondary users' movement and sensing errors are not considered in order to concentrate on the spectrum sensing. The length of time slot and mini-slot are set as 0.54ms and 9μs, respectively. Each secondary user generates packets of 40 bytes by Poisson process at rate 100 packets per second. The physical transmission rate is 40Mbps for the spectrum of data channels. The backoff factor(r) set as 2 and maximum backoff times set as 5. Total simulation time is 1 hour.

B. Simulation Results

We investigate the throughput performance differences between our proposed scheme and the comparison scheme. We obtain the numerical results for the saturation throughput achieved by two different channel-sensing policies under different situations. Fig. 4 and Fig. 5 plot the average throughput of the network against the channel utilization (γ) of the primary users and the average throughput of the secondary users against the number of channels (x), respectively.

First, we investigate the impact of the channel utilization of the primary users on the performance of our proposed MAC protocols. The number (x) of licensed channels is set to 40. From Fig. 4, we observe that the average throughput of the network achieved by the backoff-based sensing policy is larger than that achieved by the negotiation-based sensing policy proposed in [1] for the same γ and x. Note that under the backoff-based sensing policy the average throughput of γ= 0.5 is the close to that achieved by the comparison scheme. This is because based on the backoff-based sensing policy, some time slots of the available channels are left to be unsensed, in other words, wasted, and the wasted transmission time cannot be ignored when the utilization is high. On the other hand, the performance become closer when γ is small, which makes sense since backoff-based sensing policy is only executed for a few channels.

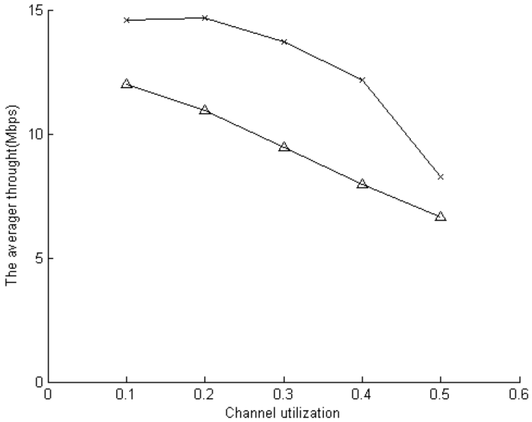


Fig. 4. the average throughput of the network achieved

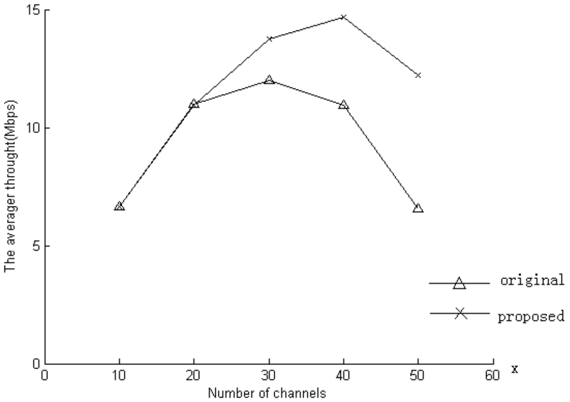


Fig. 5. The average throughput of the system according to the number of the channels

Fig. 5 plots the impact of different number of channels on the average throughput of the system under both the backoff-based sensing policy and the comparison scheme, when the channel utilization is set as 0.2. Note that the data rate for a single channel remains the same during the simulation; the increase in the number of channels means a wider spectrum of the primary network. The average throughput of the network decreases remarkably against the number of the channels because more time is spent to get the message about the channel usage. Given γ and x, the saturation throughput achieved by the backoff-based sensing policy is higher than that by the comparison policy. Note that the length of the time slot is typically very short, while the number of channels of is typically very large. Take GSM cellular network for an example, the time-slot length is 577 μs and the number of traffic channels is 172. The throughput of the comparison scheme will decrease rapidly as the number of channels increases which is expected since a large portion of a time slot is used for getting the channel state map of the network. Our proposed scheme provides a possible solution to this problem.

Ⅳ. CONCLUSION

We proposed and analyzed the opportunistic multi-channel MAC protocols for the cognitive radio-based wireless networks. Specifically, we provide a solution for selecting a channel for sensing and exchanging sensing results between the secondary users. It is hard for a secondary user to perfectly know the channel environment of the primary network; therefore, backoff-based channel sensing policy is studied as a possible solution. Instead of getting the accurate information of all the channels, we proposed backoff-based sensing policy as a sub-optimal solution. Applying the negative-exponential traffic model, we develop analytical models to evaluate the performance of our proposed scheme and the comparison scheme under different combination of channel utilization and number of channels for the saturation network case. And combining the intensity transfer method can effectively reduce the incidence of the network congestion. Because we only discuss the dissemination of information, the grounding wireless sensor networks are of not too much exposition [8]. Our analyses provide the guidelines to support the QoS requirements over cognitive radio based wireless networks.

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