Channel Transition Monitoring Based Spectrum Sensing in Mobile Cognitive Radio Networks

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Abstract. Spectrum sensing is a key technique for providing an opportunistic spectrum band in cognitive radio networks. The opportunistic spectrum is determined by the channel state. Mobility makes the problem of the traditional sensing mechanism more severe than in static scenarios. In this paper the channel transition monitoring based spectrum sensing mechanism is proposed. The proposed scheme not only reduces the influence of mobility on the current sensing mechanism, but also ensures reliability of the sensing and improves the spectrum efficiency. Our simulation results show that the proposed mechanism outperforms the traditional mechanism. Our method supplements the traditional sensing mechanism and enhances the efficiency of cognitive radio networks.

Keywords: Channel transition monitoring · Spectrum sensing · Mobile cognitive radio · Opportunistic spectrum

1 Introduction

Cognitive radio (CR) is one of the most promising ways to solve the spectrum scarcity problem; it opportunistically accesses a temporarily available licensed spectrum band [1–3]. Some research measurements for wireless radio spectrum show that the spectrum band is idle in range of 15% to 85% in both the time and spatial domain. For CR networks, the idle spectrum is called the opportunistic spectrum [4,5]. Spectrum sensing is a critical technology for finding the idle spectrum [6]. The task of the sensing mechanism is to sense the current spectrum and allocate the idle spectrum to the appropriate users. Additionally, it aims to reduce the overhead and interference to primary user (PU) as much as possible.

Currently, most of researches on traditional sensing mechanism focuses on periodic sensing mechanism, and some focuses on proactive sensing mechanism [7]. Research on periodic sensing employs the adaptive period to improve the spectrum efficiency [8]. This can reduce the sensing time according to the channel environment and greatly improve the throughput. However, the intrinsic problems–such as high overhead, wasting of the spectrum, and interference to the PU–still exist. Additionally, the above research has an implied condition that

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the CR user is always inside the primary protected region (PPR). This assumption is reasonable in large-scale coverage, such as digital television (DTV) base station, the coverage of which is about 50-60km [9]. The CR user's coverage is smaller than the PU's, and the sensing is always reliable. However, in small-scale-coverage PUs, such as wireless microphones (MWs), LTE networks and other networks, the sensing reliability of CR users is not always high because the users may leave the PPR. In these networks, user mobility has a significant effect on the spectrum sensing. The sensing capacity can be increased significantly in the presence of PU mobility [10]. The sensing accuracy exhibits threshold behavior that is a function of the sensing time when the users are mobile [11]. The sensor mobility information is exploited in the process of sensor localization with two range measurement models, namely, the time-of-arrival (TOA) model and the received signal strength (RSS) model [12]. A cognitive MAC protocol with mobility support (CM-MAC) is proposed in [13], addressing the decentralized control and local observation for spectrum management, where the CR mobile nodes move into the primary exclusive region. The study does not consider the impact of the mobility on the spectrum sensing mechanism.

In fact, mobility further increases the uncertainty of the spatial location. It makes the intrinsic problems of periodic sensing more serious. In mobile CR networks, in order to guarantee sensing accuracy, the periodic sensing should be more frequent than in static scenarios. Even though periodic sensing provides sensing reliability, it requires a short period to ensure that interference is minimized. The short sensing period increases the overhead and reduces the spectrum efficiency. Different opportunistic spectrums need different sensing techniques; especially in the spatial opportunistic spectrum, time sensing is not necessary.

We attempt to find a sensing mechanism that maximizes the opportunistic spectrum and reduces interference to the PU.

2 System Model and Problem Statement

In order to demonstrate the specific scenario, we provide a simple system model. Regardless of PU or CR user, the opportunistic spectrum is greatly affected by the user's mobility.

2.1 System Model

The CR network consists of PU and one or several CR users, as shown in Fig.1. t_1 and t_2 denote different times. The PPR is covered by R. In static scenario, for example, at time t_2, the CR user is always in the PPR. In mobile scenario, CR user is inside or outside the PPR. During the sensing operation, the distance between the PU and CR user changes over time, such as from the time t_1 to time t_2. If the CR user is inside the PPR, the distance is less than R. The opportunistic spectrum is the time opportunistic spectrum. If and only if the PUs is inactive, the CR user can occupy the spectrum band. Otherwise, the distance is larger than R, the opportunistic spectrum is the spatial opportunistic spectrum.

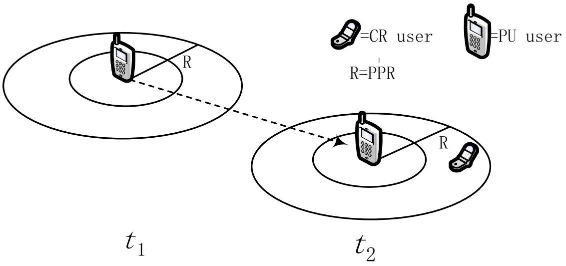


Fig. 1. The mobility system model of PU

Regardless of the PU's state, the CR user can always occupy the spectrum band. Therefore, at time t_1, the CR user accesses the spectrum directly without sensing. At time t_2, since the PU may be active or inactive, the CR user must sense.

The system model is very simple. But it can be extended to a complex system that is composed of multiple CR users and multiple PUs.

2.2 Problem Statement

In mobile scenario, as shown in the above system model, the intrinsic problems of the current sensing mechanism becomes more severe. Furthermore, the sensing reliability is very difficult to be achieved.

Firstly, owing the mobility, the channel is time-varying. In order to achieve accurate sensing, the sensing operation must be more frequent than in static scenarios. Consequently, the overhead is greater than in static scenarios. The wasting of the spectrum band and the interference to the PU are still present.

Secondly, the mobility makes the user change its location. When the user steps out of the PPR, it still senses the spectrum with traditional sensing method, which gives an incorrect result. If an individual user with an incorrect sensing result cooperates with other users, the cooperative performance is degraded.

Thirdly, the sensing technique is extended to be suitable for the spatial opportunistic spectrum. Most algorithms for spatial sensing depend on the localization and tracking of mobile users. The algorithms are very complex. Additionally, they add the complexity to the sensing .

The channel state is the most influential factor. As long as the channel state is determined, the user can easily access to it. In this paper, we investigate a new sensing mechanism.

3 Channel Transition Monitoring Based Spectrum Sensing

The objectives of spectrum sensing are to maximize the opportunistic spectrum, minimize the interference to the PU and reduce the overhead. The types of the opportunistic spectrum are different, which depends on the channel state. Taking this into consideration, we proposed the channel transition monitoring based spectrum sensing mechanism.

3.1 Channel Transition Monitoring

A mobility-unware scheme is required in sensing the spectrum in the mobile environment. If we consider the PU signal state, the channel state changes only at the transition between the PU states: ON and OFF. We assumed that the CR user and PU do not transmit simultaneously and the CR user can identify its own signal.

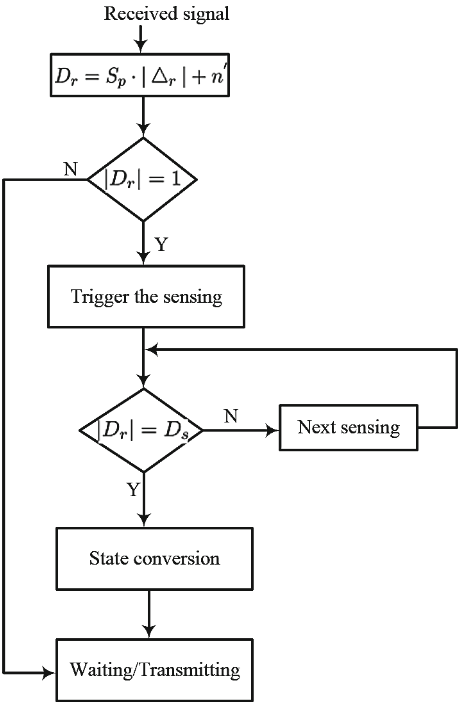


Fig. 2. The channel transition monitoring unit and its processing sequence

The channel transition monitoring should not affect the spectrum band. The monitoring unit is an internal processor in the receiver. The monitoring processing is parallel with the receiving processing and adopts the differential processing to differentiate the current channel state from the previous one, as shown in Fig.2. If the the monitoring result $|D_r|$ does not equal one, which means that the channel state has not changed, the CR users continue waiting or transmitting.

If the result $|D_r|$ equals one, which means that the channel state has changed, the CR user stops the current operation immediately and begins sensing to further determine the channel state. If the two results–i.e., the monitoring result D_r and the sensing result D_s–indicate that the channel state has changed, the next operation of the CR user is different from the previous operation. If the results indicate the different channel states, the CR user continues sensing until the two results indicate the channel state are the same. This also prevents sharp change in the channel from being affected by sudden change of background noise.

The received signal of the monitoring unit is $r(n)$ as follows:

$$r(n) = \eta h_p s_p(n) + (1-\eta) h_s s_s(n) + n(n) \tag{1}$$

where $\eta \in \{0, 1\}$ denotes the absence or presence of the signal. h_p represents the channel coefficient between the PU and the CR user. s_p is the primary signal. h_s is the channel coefficient between the two CR users. s_s denotes the CR user's signal.

The received signal is $r(n-1)$. At the monitoring unit, the differential result $D_r(n)$ is as follows:

$$\begin{aligned} D_r(n) &= r(n) - r(n-1) \\ &= \eta h_p s_n + (1-\eta) h_s s_s(n) - \eta^{'} h_p s_{n-1} - (1-\eta^{'}) h_s s_s + n^{'} \end{aligned} \tag{2}$$

where $n^{'}$ denotes the differential noise. Given $s(n) = s(n-1)$, if the channel coefficient is constant, the above equation becomes:

$$D_r = h_p s_p (\eta - \eta^{'}) + h_s s_s (\eta^{'} - \eta) + n^{'} \tag{3}$$

$h_s s_s$ is known since s_s is given. Therefore, the above equation becomes:

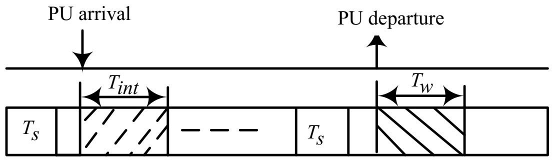
$$D_r = S_p \cdot | \triangle_r | + n^{'} \tag{4}$$

where $S_p = h_p s_p$ and $\triangle_r = \eta - \eta^{'}$. When $\triangle_r = 0$, the channel state does not change. When $| \triangle_r | = 1$, the channel state has changed. $\triangle_r = 1$ represents the arrival of the PU's signal at the present time or the CR user steps into the PPR. The channel state changes from IDLE to BUSY. $\triangle_r = -1$ represents the departure of the PU's signal at the present time or the CR user steps out of the PPR. The channel state changes from BUSY to IDLE.

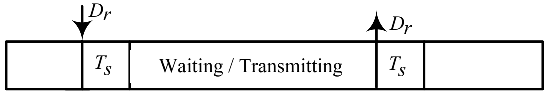
An appropriate threshold is selected to decide two states. When $| \triangle_r | = 1$, $|D_r| = 1$. The monitoring unit makes the CR user stop the current operation and immediately trigger the sensing process. With the CR sensing result, the next operation can be determined. When $\triangle_r = 0$, $|D_r| = 0$. No channel transition is occurring. The CR user continues the previous operation.

3.2 Spectrum Sensing Based on Channel Transition Monitoring

The result of the channel transition monitoring presents only at the transition of the channel. If and only if the result equals to 1, the sensing process is triggered to further determine the channel state, as shown in Fig.3 (b).



(a) The periodic scheme



(b) The proposed scheme

Fig. 3. The two sensing schemes: (a) the periodic sensing (b) the channel transition monitoring based sensing mechanism

Case 1: The uncooperative CR users
In the networks, the uncooperative user performs the channel transition monitoring when the PU's signal is received. The result $D_r = 0$ indicates that the channel state does not change. The CR user continues the previous operation: waiting or transmitting. In this process, the CR user's operation is not interrupted. The result $|D_r| = 1$ indicates that the channel state changes from IDLE to BUSY or vice versa. The initial result should be further verified by the sensing. Once the sensing operation is triggered, the CR user immediately stops the current operation. After the sensing result is determined, the CR user begins the next operation. The channel transition monitoring is only an internal operation that does not influence the spectrum band.

Case 2: The cooperative CR users
In current CR networks, multiple users cooperate with one another to overcome multiple pathes fading, shadowing fading, and receiver uncertainty. The channel transition monitoring based cooperative spectrum sensing adopts the proactive approach with "sound signal" in broadcasting way [7]. If the monitoring result shows that a channel transition has occurred, the CR user that monitors the spectrum sends the sound signal in broadcasting way to other users and requests them to perform the sensing. When the other users receive the sound signal, they immediately stop their current operation. Then they begin to sense the spectrum and send the local sensing result to the requesting user. The monitoring user combines the local sensing results and provides the global spectrum sensing result. When the monitoring result and the sensing result indicate same channel state, the CR user starts the next operation. If the current user does not need the spectrum, the spectrum information is stored in the spectrum database. Other users that need the spectrum query the database and access it.

It is pointed out that the user of the sensing schemes can be extended from the time opportunistic spectrum to the spatial opportunistic spectrum, or other potential opportunistic spectrum. The sensing schemes must provide reliable and efficient spectrum sensing. In the channel transition monitoring based spectrum sensing scheme, the sensing operation only occurs at the channel state transition. At other time, the CR users need to access the channel by searching the spectrum database. The approach does not waste the spectrum except the spectrum for sensing at the channel transition. The overhead, the wasting of the spectrum and interference are greatly reduced. The interference to PUs is related to the processing delay of the monitoring unit. When the channel is not in transition, the users that access the spectrum do not need to sense the spectrum. In order to obtain the potential spectrum, they only query the spectrum database. The delay involved in accessing the channel decreases.

It must be emphasized that the proposed scheme supplements the traditional spectrum sensing and improves the sensing performance. The only cost is the internal processor that monitors the channel transition.

4 Performance Analysis

Our channel transition monitoring based spectrum sensing mechanism provides the sensing operation at the end of the channel transition. The presence of a channel transition depends on the two factors. One is whether the PU changes its state. The other is whether the CR user leaves the PPR or vice versa. If the former leads to a channel transition, the detection performance is only related to the PU's OFF state. However, the latter will lead to a change in the opportunistic spectrum types.

4.1 Mobility-Enabled Sensing Capacity

In mobile scenarios, the CR user may be inside the PPR or outside the PPR. The mobility-aware detection capacity is as follows [10]:

$$C^{mob} = \zeta \rho W[(1 - P(I) + P_{off} P(I))] \tag{5}$$

where ζ, ρ, W and P_{off} represent the sensing efficiency, the spectral efficiency of the band, the bandwidth and the OFF state probability of the PU, respectively. From equation (5), $P(I)$ is the probability of that the CR user is inside the PPR. When $P(I) = 1$, the CR users are always inside the PPR. Therefore $C^{mob} = C^{statis}$. The probability of the PU's OFF state affects the capacity. The time sensing is adequate because there is only the time opportunistic spectrum. If $P(I) < 1$, the CR user locates inside or outside the PPR. Therefore, $C^{mob} > C^{statis}$. Both time sensing and spatial sensing are needed. In mobile scenarios, the value of capacity improvement is mainly from the value of the spatial opportunistic spectrum. The faster the users move in the certain coverage of the PPR, the shorter the sojourn time is. The smaller the probability within the PPR is, the larger the spatial opportunistic spectrum is. The detection capacity further improves.

4.2 Comparison Between the Two Scheme

Mobility results in the CR user being located in different positions. This leads to $P(I)$ and $1 - P(I)$. If $P(I) = 1$, the CR user is inside the PPR, and sensing reliability is provided. In general, the number of the PU's presence and departure are fewer than that of the sensing. From PU's arrival to PU's departure, the CR user has no opportunity to access the spectrum. However, from PU's departure to PU's arrival, the CR user can access the spectrum. In the periodic sensing, as shown in Fig.3(a), the CR transmission is frequently interrupted. T_{int} and T_w are inevitably greater than zeros. This leads to overhead, wasting of the spectrum and interference to the PUs. Whatever methods are adopted , the intrinsic problems can not be avoided. The proposed scheme, as shown in Fig.3(b), shows that the sensing operates only at the end of channel transition. It reduces the wasted spectrum band T_w, the interfering band T_{int}, and the number of the sensing. In a short, the proposed sensing scheme greatly decreases the sensing overhead.

If $P(I) < 1$, sometimes the CR user is outside the PPR. The users can access the spectrum band directly without sensing. The channel state is unchanging regardless of the PU's state. If the CR user is located inside the PPR, the user need to sense. The sensing result depends on the channel states: BUSY or IDLE. A channel state transition is caused by the arrival or departure of the PU's signal. The transition can also occur when the CR user's location changes from inside to outside the PPR or vice versa. Therefore, the channel transition monitoring based spectrum sensing is suitable for the time spectrum sensing as well as the spatial spectrum sensing. It not only greatly reduces sensing overhead but also utilizes the spectrum as much as possible.

5 Numerical Result

In this paper, we mainly consider the mobile CR networks, which have time and spatial opportunistic spectrums at different times. Simulation sets are based on the probabilities $P(Q)$, P_{off}, and different sizes of R etc..

The proposed scheme is based on the channel state transition, and the number of the PU's arrival or departure is an important factor. Fig.4 shows the impact of the number of the PU's arrival N_1 in two schemes on the throughput. The number of the PU's departure is $N_2 = N_1 - 1$. If the probability of the PU's OFF state is fixed, the throughput of the proposed scheme decreases as the number of the PU's departure/arrival increase; while the throughput of the periodic sensing is not greatly affected by the channel state transition. When the number of the departure/arrival are greater than a specific number, for example, $N = 7$, with $P_{off} = 0.5$, the throughput of the periodic sensing is greater than that of the proposed scheme. Because of the number of the PU's departure/arrival increasing, the interference increases. For the proposed scheme, if the number of the PU's departure/arrival increases, the time used to sense the spectrum increases, and the throughput decreases. However, the PU's state transition interval is longer

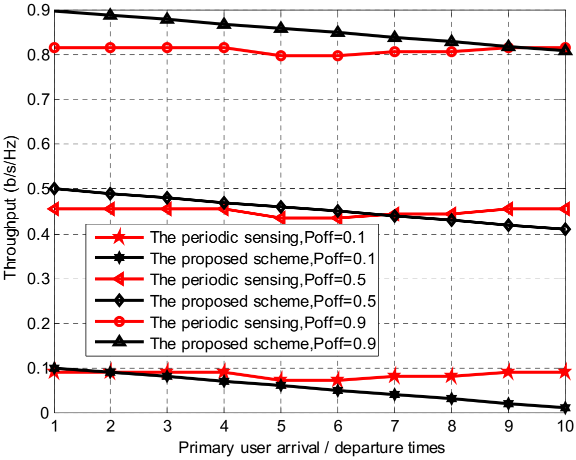


Fig. 4. The throughput vs. the number of the PU arrival/departure

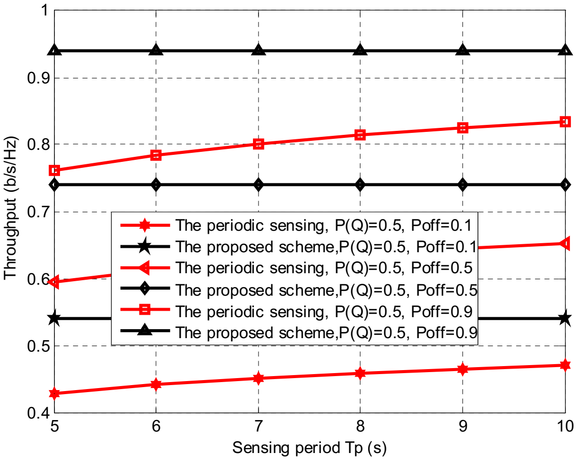


Fig. 5. The throughput relative to the sensing period

than the periodic sensing interval. In general, the throughput of the proposed scheme outperforms that of the periodic scheme.

Fig.5 shows the relationship between the throughput of the CR and the sensing period when $P(Q) = 0.5$. The active probabilities of PUs are varied. The number of the PUs arrival and departure are $N_1 = N_2 = 2$. The proposed scheme is robust in relation to the sensing period. It is dependent only on the state-changing number of the PUs. Therefore, if the number of PU arrival or departure is fixed, the throughput is determined only except influence of sensing time T_s. The periodic sensing mechanism adopts periodic sensing regardless of

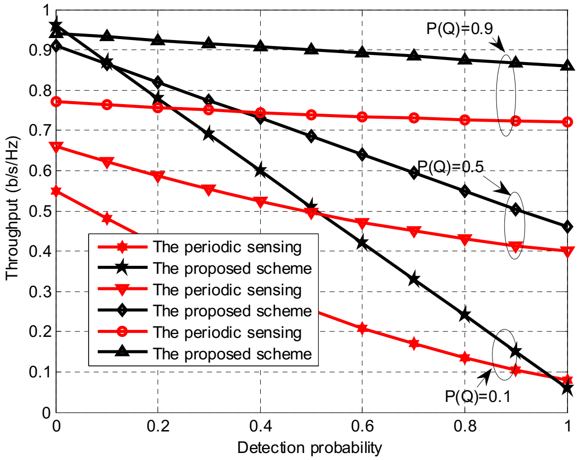


Fig. 6. The throughput v.s. detection probability

the PU's state. Throughput is not only affected by the periodic sensing time, but also related to the idle state of the channel. If the idle channel is fixed, a shorter sensing period leads to a lower throughput, greater wasting of the spectrum, and more interference. The shorter the sensing period is, the higher the overhead is. In a short, periodic sensing is seriously constrained by its intrinsic problems. The proposed scheme is constrained only by the channel transition state. The performance of the proposed scheme is better than that of the periodic sensing.

Fig.6 shows how the throughput is related to the detection probability. The throughput increases as the spatial opportunistic spectrum increases, i.e. $P(Q)$ increases. The throughput decreases with increasing of detection probability. If the CR users moves from the region outside to the region inside the PPR, the detection probability gradually increases, so the throughput decreases. The three lines indicate the throughput for different $P(Q)$. P_d ranges from 0 to 1, which means that the PU is gradually changing from the inactive state to the active state or from outside to inside the PPR. The opportunistic spectrum changes from the spatial domain to the time domain. For each sensing mechanism, the higher the idle spectrum probability, the higher is the throughput. For the specific probability of the idle spectrum, the throughput of the proposed sensing mechanism is higher than that of the periodic sensing mechanism. The far left points of the lines indicate the throughput at $P_{off} = 1$, when the maximum opportunistic spectrum exists. The improvement of the proposed scheme's throughput is greater than that of the periodic sensing from $P_d = 1$ to $P_d = 0$. Regardless of the behaviors of the users and the sensing techniques, the proposed scheme outperforms the periodic sensing.

Fig.7 shows how the throughput increases as the velocity of the users increases. The root cause is that mobility makes the user location changeable. The spatial opportunistic spectrum without sensing has greatly improved the

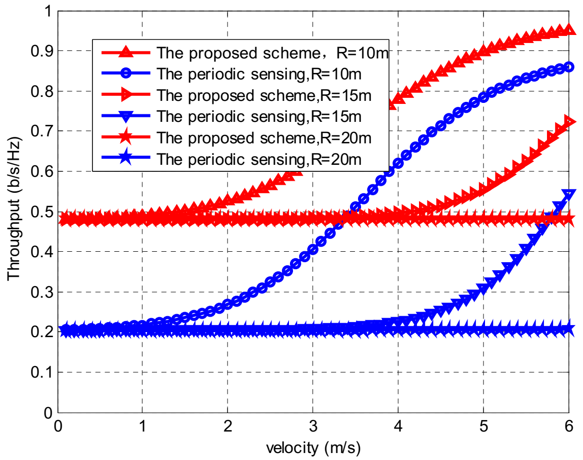


Fig. 7. The throughput related to the velocity of the users

throughput. The velocity affects the time inside or outside the PPR regardless of the mobility models. If R is fixed, the sojourn time decreases, and the time of outside the PPR increases as the velocity of the users increases. The more spatial opportunistic spectrum is obtained. For the same velocity with changing of R, the probability of being inside the PPR increases as R increases. The larger the coverage R is, the longer the sojourn time is, the shorter the time of outside the PPR is. The smaller spatial opportunistic spectrum is. Therefore, in small-scale-coverage PUs, such as MWs, the spatial opportunistic spectrum should be considered. In a short, in complex networks, the different opportunistic spectrums are the potential spectrums to enhance the throughput of CR networks.

In summary, in the proposed sensing mechanism, because the internal monitoring unit of the channel transition is used, the throughput is significantly improved and the interference to the PU is reduced. The wasting of the spectrum is shorter than that of the periodic mechanism. Therefore, the proposed scheme outperforms the traditional sensing mechanism.

6 Conclusion

In this paper, we proposed a spectrum sensing mechanism based on channel transition monitoring to improve the reliability of the sensing and the utilization efficiency of the opportunistic spectrum. Owing to user mobility, the users location varies over time. This leads to unreliability of the sensing. The proposed sensing mechanism based on channel transition monitoring not only reduces the influence of the intrinsic problems of the periodic sensing, but also overcomes the unreliability of the sensing. More importantly, it improves the utilization efficiency of the spectrum. The proposed sensing mechanism is suitable for both static and mobile scenarios. The method supplements the traditional sensing mechanism.

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