# A Novel Spectrum Sensing Scheme for Dynamic Traffic Environments

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***Abstract*—This paper proposes a novel spectrum sensing scheme for dynamic traffic circumstances, where a Primary User (PU) signal may randomly depart or arrive during the sensing period, and thus, the conventional schemes developed under the assumption of the static traffic circumstances perform poorly. In the proposed scheme, a sensing period is partitioned into several sub-periods and the final decision on the existence of the PU signal is made by combining sensing decisions during each sub-period. From numerical results, it is confirmed that the proposed scheme has an improved detection performance compared with those of the conventional schemes.**

***Keywords*—*Spectrum sensing; Cognitive radio; Dynamic traffic circumstance; Detection probability***

## I. INTRODUCTION

The spectrum sensing determines the existence of a Primary User (PU) signal on frequency bands and thus enables the Cognitive Radio (CR) to allocate a vacant frequency band to a Secondary User (SU) without interfering the PU [1][2]. So far, most spectrum sensing techniques [3]-[5] have been developed under the assumption of static traffic circumstances where the PU is present or absent during the whole sensing period [6]. In practical wireless communications, however, the PU traffic could be dynamic, i.e., the PU could arrive at or depart from the frequency band in the middle of a sensing period randomly, and in such a dynamic traffic circumstance, the conventional spectrum sensing techniques where the PU traffic is assumed to be static would perform poorly [5].

An interesting spectrum sensing scheme [7] was proposed for dynamic traffic circumstances, where the dynamic behavior of the PU signals is modeled as a Poisson random process and an improvement in detection performance over the conventional schemes was shown. However, the scheme of [7] requires additional information including the arrival and departure rates of PU signals and the performance improvement is not significant especially in low Signal-to-Noise Ratios (SNRs) of practical interest. In this paper, we propose a novel spectrum sensing scheme based on partitioning of a sensing period, where a sensing period is partitioned into several sub-periods and the final decision on the existence of a PU signal is made by combining sensing decisions during each sub-period. Numerical results demonstrate that the proposed scheme provides a better detection performance than those of the conventional schemes.

The rest of this paper is organized as follows. Section II introduces the received signal model of the CR systems in the dynamic traffic circumstances. In Section III, we explain the proposed spectrum sensing scheme based on sensing period partitioning. The proposed scheme is confirmed to perform better than the conventional ones in Section IV, and finally, Section V concludes the paper.

## II. SYSTEM MODEL

In the dynamic traffic circumstances, the spectrum sensing problem can be modeled as a binary hypothesis testing problem with the null hypothesis $H_0$ and the alternative hypothesis $H_1$:

$$H_0 : y[n] = \begin{cases} x[n]+w[n] & \text{for } n = 1,\ 2,\ ...,\ J_0, \\ w[n] & \text{for } n = J_0+1,\ J_0+2,\ ...,\ N, \end{cases} \tag{1}$$

and

$$H_1 : y[n] = \begin{cases} w[n] & \text{for } n = 1,\ 2,\ ...,\ J_1, \\ x[n]+w[n] & \text{for } n = J_1+1,\ J_1+2,\ ...,\ N, \end{cases} \tag{2}$$

where $y[n]$ is the $n$th sample of the received signal, $x[n]$ is the $n$th sample of the PU signal, $w[n]$ is the $n$th additive white Gaussian noise sample, $N$ is the number of observed samples, and the hypothesis $H_0$ ($H_1$) represents that a PU signal is present (absent) on the frequency band at the beginning of a sensing period and then the PU signal departs from (arrives at) the band between the $J_0$th ($J_1$th) and the $(J_0+1)$th ($(J_1+1)$th) samples. In this paper, we assume that the departure or arrival of PU signals follows a Poisson random process and occurs only once in the sensing period, as in [7].

## III. PROPOSED SPECTRUM SENSING SCHEME

### A. Test Statistics

To solve the hypothesis testing problem in the dynamic traffic circumstances, first, we partition a sensing period composed of $N$ observed samples into $K$ sub-periods with $N/K$ samples each, where $N$ is assumed to be divisible by $K$ and a set of samples in the $k$th sub-period is denoted by

$$G_k = \{y[n]\}_{n=1+(k-1)N/K}^{k(N/K)}. \tag{3}$$

Then, we perform energy detection to determine the existence of a PU signal during each sub-period with a threshold $\lambda_G$ predetermined by a given false alarm probability. Thus, the test statistic $T_{G_k}$ corresponding to the $k$th sub-period is obtained as

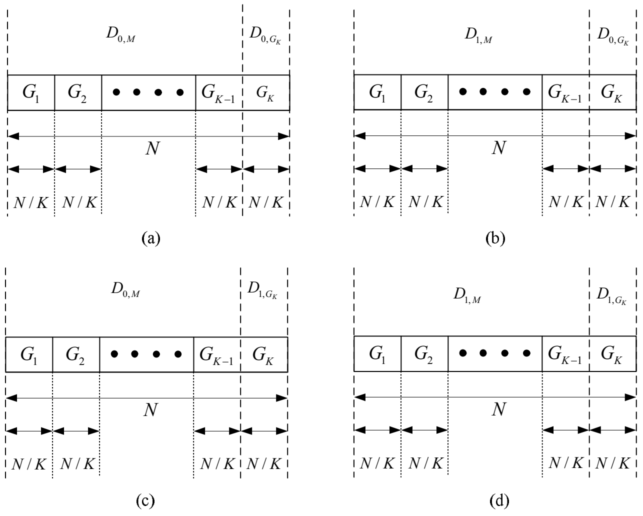
$$T_{G_k} = \sum_{n=1+(k-1)N/K}^{k(N/K)} |y[n]|^2,\ k = 1,\ 2,\ 3,\ ...,\ K. \tag{4}$$

Comparing $T_{G_k}$ with $\lambda_G$, finally, we decide the existence of the PU signal during the $k$th sub-period:

$$T_{G_k} \underset{D_{0,\,G_k}}{\overset{D_{1,\,G_k}}{\gtrless}} \lambda_G, \text{ for } k = 1,\ 2,\ \ldots,\ K, \tag{5}$$

where $D_{1,\,G_k}$ ($D_{0,\,G_k}$) represents that the PU is present (absent) during the $k$th sub-period.

If a PU signal arrives at (departs from) the frequency band at the end of a sensing period in a dynamic traffic circumstance, the probability that the whole energy in a sensing period



(a) (b) (c) (d)

Fig. 1. Four cases of $(D_{x,\,M},\, D_{y,\,G_K})$.

exceeds the threshold would be small (large) even if the PU signal is actually present (absent) at the end of the sensing period, and thus, the conventional spectrum sensing techniques using simply the whole energy during a sensing period would yield a wrong decision on the existence of the PU signal. To solve this problem, we use the sensing decisions from $K$ sub-periods as follows. Depending on the presence or absence of the PU signal in each sub-period, firstly, we represents the $k$th sensing decision $x_{G_k}$ as 1 or 0, i.e.,

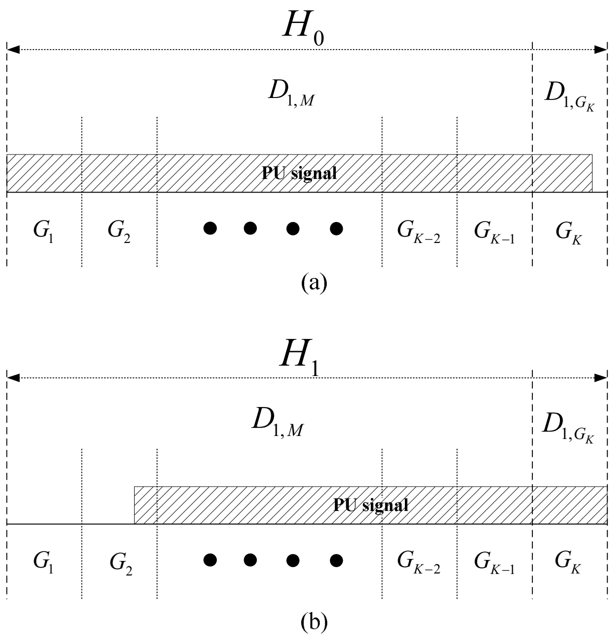
$$x_{G_k} = \begin{cases} 1 \text{ when } T_{G_k} > \lambda_G \\ 0 \text{ when } T_{G_k} \leq \lambda_G \end{cases} \qquad (6)$$

for $k = 1, \cdots, K-1$. Using the majority rule, subsequently, we make an intermediate-decision as

$$\sum_{k=1}^{K-1} x_{G_k} \underset{D_{0,\,M}}{\overset{D_{1,M}}{\substack{\geq \\ <}}} \frac{K-1}{2}, \qquad (7)$$

where the intermediate decision $D_{1,\,M}$ ($D_{0,\,M}$) represents that the PU is present (absent) during the first $K-1$ sub-periods and it is combined with the sensing decision $D_{1,\,G_K}$ or $D_{0,\,G_K}$ corresponding to the $K$th sub-period, yielding the final decision on the existence of the PU signal. We have four different combinations $(D_{1,\,M},\, D_{0,\,G_K})$, $(D_{0,\,M},\, D_{0,\,G_K})$, $(D_{0,\,M},\, D_{1,\,G_K})$, and $(D_{1,\,M},\, D_{1,\,G_K})$ as shown in Figure 1 and it is easy to see that the hypotheses $H_0$ and $H_1$ are finally declared for $(D_{1,\,M},\, D_{0,\,G_K})$ and $(D_{0,\,M},\, D_{0,\,G_K})$ and for $(D_{0,\,M},\, D_{1,\,G_K})$, respectively. On the other hand, as shown in Figure 2, we have two cases corresponding to $H_0$ (Figure 2(a)) and $H_1$ (Figure 2(b)), respectively, for $(D_{1,\,M},\, D_{1,\,G_k})$. Thus, the final decision is made by comparing the average of the test statistics $\{T_{G_k}\}_{k=1}^{K-1}$ with the test statistic $T_{G_K}$ of the $K$th sub-period for those cases. Finally, the decision rule can be summarized as

$$\begin{cases} H_0 \text{ for } (D_{0,M},\, D_{0,G_K}) \text{ and } (D_{1,M},\, D_{0,G_K}) \\ H_1 \text{ for } (D_{0,M},\, D_{1,G_K}) \\ \frac{\sum_{k=1}^{K-1} T_{G_k}}{K-1} \underset{H_0}{\overset{H_1}{\substack{< \\ >}}} T_{G_K} \text{ for } (D_{1,M},\, D_{1,G_K}). \end{cases} \qquad (8)$$



(a) (b)

Fig. 2. Random departure and arrival cases of $(D_{1,\,M},\, D_{1,\,G_K})$.

In other words, in case of $(D_{1,\,M},\, D_{1,\,G_k})$, the proposed scheme compares the $T_{G_K}$ with average of $\{T_{G_k}\}_{k=1}^{K-1}$. In other cases, the proposed scheme decides the existence of the PU signal based on the detection result of sub-period $G_K$.

### *B. Distribution of Test Statistics*

In this section, we derive the probability density function (PDF) of the test statistic $T_{G_k}$. Assuming that the additive white Gaussian noise samples $\{w[n]\}_{n=1}^{N}$ have zero-mean and unit-variance, we can easily see that $T_{G_k}$ follows the non-central chi-square distribution

$$p_{T_1}(T_{G_k}) = \left(\frac{T_{G_k}}{2s_k^2}\right)^{\frac{(\frac{N}{K}-2)}{4}} e^{\frac{-(s_k^2+T_{G_k})}{2}} I_{\frac{N}{2K}-1}\left(s_k\sqrt{T_{G_k}}\right) \qquad (9)$$

when a PU signal is present, where

$$s_k^2 = \sum_{n=1+(k-1)N/K}^{k(N/K)} x^2[n] \qquad (10)$$

and

$$I_\alpha(x) = \sum_{k=0}^{\infty} \frac{(x/2)^{\alpha+2k}}{k!\Gamma(\alpha+k+1)} \qquad (11)$$

is the $\alpha$th-order modified Bessel function of the first kind with $\Gamma(x) = \int_0^\infty t^{x-1}e^{-t}dt$ and $x > 0$.

When a PU signal is absent, on the other hand, $y[n] = w[n]$ and thus $T_{G_k}$ obeys the central chi-square distribution

$$p_{T_2}(T_{G_k}) = \frac{1}{2^{\frac{N}{2K}}\Gamma(\frac{N}{2K})} T_{G_k}^{\frac{N}{2K}-1} e^{-\frac{T_{G_k}}{2}}. \qquad (12)$$

## IV. NUMERICAL RESULTS

In this section, we compare the spectrum sensing performances of the proposed and conventional [3][7] schemes in terms of the detection probability defined as $\Pr(H_1|H_1)$. For simulations, $N$ is set to 200 and the SNR is defined as $\sigma_s^2/\sigma_n^2$,

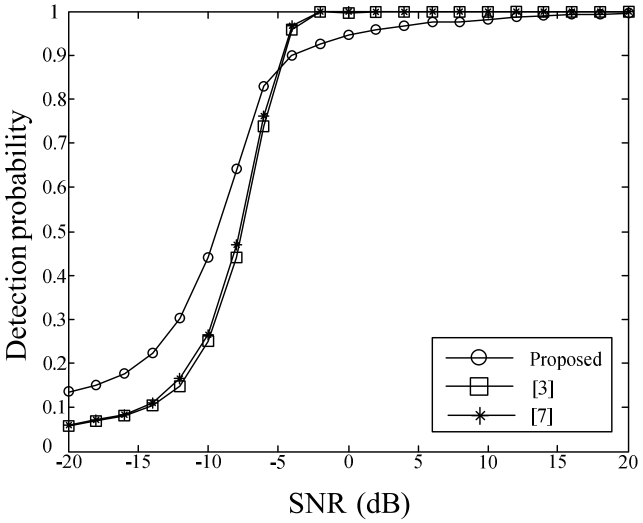


Fig. 3. The detection probability as a function of the Signal-to-Noise Ratio when $P_{fa} = 0.05$.

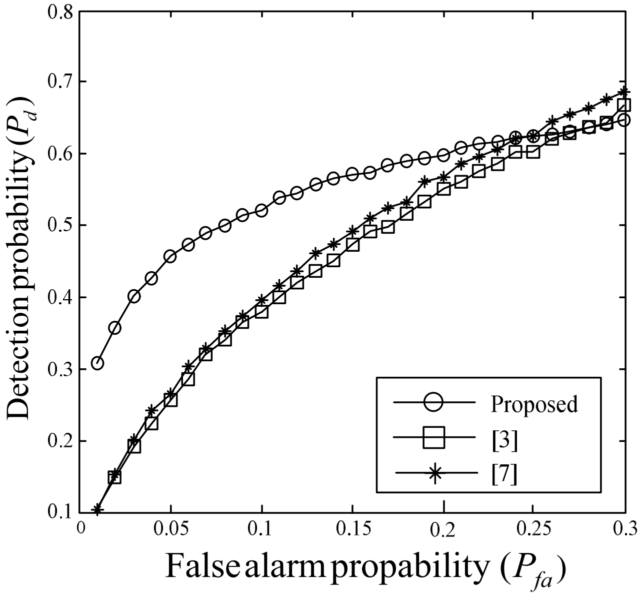


Fig. 4. The ROC curves when SNR$= -10$ dB.

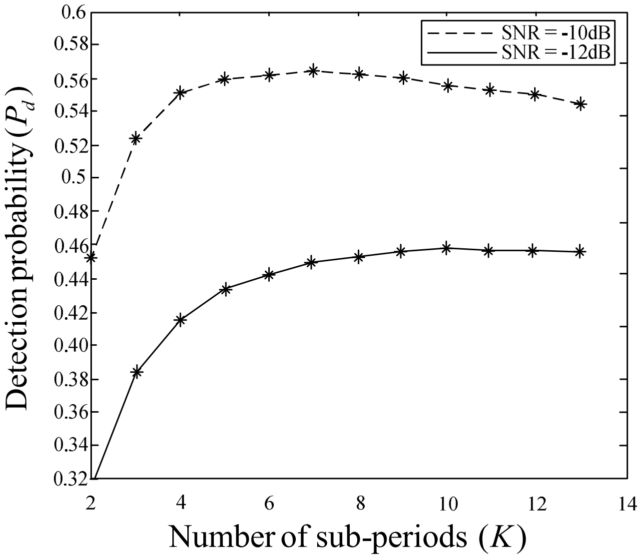


Fig. 5. The detection probability as a function of $K$ when SNR $= -10$dB and $-12$dB, and $P_{fa} = 0.05$.

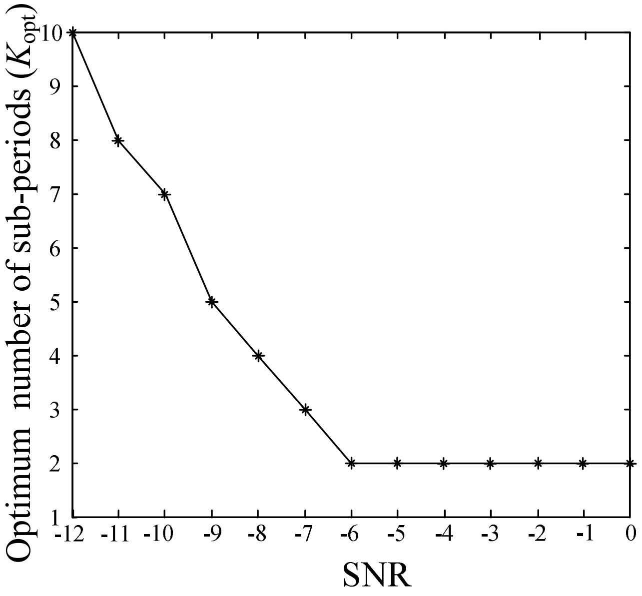


Fig. 6. The optimum number of sub-periods as a function of the Signal-to-Noise Ratio when $P_{fa} = 0.05$.

where $\sigma_s^2$ and $\sigma_n^2$ are variances of the PU signal and noise, respectively. For the scheme of [7], the product of the arrival or departure rate and the sensing period is set to $0.1$.

Figure 3 shows the detection probabilities as a function of the SNR when the false alarm rate $P_{fa}$ is 0.05 and $K = 2$, where we can clearly observe that the proposed scheme offers a detection probability improvement over the conventional schemes at low SNRs of practical interest $(-20\,\text{dB} < \text{SNR} < -5\,\text{dB})$. Although the detection probability of the proposed scheme is a little bit lower than those of the conventional schemes at high SNRs, it should be noted that all of the schemes perform well at high SNRs, and so, the difference in performance between the proposed and conventional schemes is insignificant.

Figure 4 shows the Receiver Operation Characteristic (ROC) curves of the proposed and conventional spectrum sensing schemes when the SNR = -10 dB and $K$ = 2. From the figure, the proposed scheme is found to offer a ROC performance improvement over the conventional schemes when the false alarm probability is smaller than 0.25, which is a practical range of the false alarm probability in spectrum sensing. Specifically, it is observed that that the proposed scheme has a larger detection probability (a smaller false alarm probability) than those of the conventional schemes for a fixed false alarm (detection) probability.

The superiority of the proposed scheme over the conventional ones shown in Figure 3 and Figure 4 stems from the fact that the proposed scheme makes the final decision on the existence of the PU by giving a more weight to the sensing decision from the last sub-period unlike the conventional schemes where all of the sensing decisions from sub-periods have the same weight.

As the value of $K$ increases, the sensing decision from the last sub-period would recognize the existence and nonexistence of the PU signal after a given sensing period more exactly; however, the reliability of the sensing decision from each sub-period would be worse, since the number of samples used during each sub-period decreases. From this observation, we can see that there exists an optimum value of $K$. Figure 5 shows the detection probabilities of the proposed scheme as a function of $K$ when SNR = -12 dB and -10dB, and $P_{fa}$ = 0.05. In this simulation, $N$ is set to a multiple of $K$ that is the closest to 200 when $N$ is indivisible by $K$. From the figure, we can observe that 7 is the optimum value of $K$ when SNR is -10dB, and 10 is the optimum value of $K$ when SNR is -12dB. In addition, it is seen from Figure 6 that the optimum value $K_{\text{opt}}$ decreases as the value of the SNR increases and eventually becomes saturated. This is because more samples are required in each sensing period to maintain the reliability of the sensing decision from each sensing period. It should be noted that the optimum number of the sub-periods is not over 10 in the SNR ranges (-12 dB $\sim$ 0 dB) of practical interest, i.e., the proposed scheme does not involve a significant increase in complexity. Thus, the proposed scheme should be applicable to real-time applications.

## V. CONCLUSION

In this paper, we have proposed a novel spectrum sensing scheme for dynamic traffic environments. Specifically, we have first partitioned a sensing period into several sub-periods and then have performed energy detection during each sub-period. Finally, we have obtained a decision rule on the existence of a PU signal by combining the sensing decisions from sub-periods. From numerical results, we have confirmed that the proposed scheme offers a noticeable performance improvement, and also, have determined an optimum number of sub-periods.

## ACKNOWLEDGMENT

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## REFERENCES

[1] J. Mitola, “Cognitive radio: An integrated agent architecture for software defined radio,” Ph.D. dissertation, Teleinformatics, Royal Inst. Technol. (KTH), Stockholm, Sweden, May 2000.

[2] J. Lunden, S. A. Kassam, and V. Koivunen, “Robust nonparametric cyclic correlation-based spectrum sensing for cognitive radio,” *IEEE Trans. Signal Process.*, vol. 58, no. 1, pp. 38-52, Jan. 2010.

[3] F. F. Digham, M.-S. Alouini, and M. K. Simon, “On the energy detection of unknown signals over fading channels,” *IEEE Trans. Commun.*, vol. 55, no. 1, pp. 21-24, Jan. 2007.

[4] T. S. Shehata and M. El-Tanany, “A novel adaptive structure of the energy detector applied to cognitive radio networks,” in *Proc. Canadian Workshop Inform. Theory*, Ottawa, Canada, May 2009, pp. 95-98.

[5] T. Wang, Y. Chen, E. L. Hines, and B. Zhao, “Analysis of effect of primary user traffic on spectrum sensing performance,” in *Proc. Chinacom*, Xian, China, Aug. 2009, pp. 1-5.

[6] M. Luís, A. Furtado, R. Oliveira, R. Dinis, and L. Bernardo, “Towards a realistic primary users behavior in single transceiver cognitive networks,” *IEEE Commun. Lett.*, vol. 17, no. 2, pp. 309-312, Feb. 2013.

[7] N. C. Beaulieu and Y. Chen, “Improved energy detectors for cognitive radios with randomly arriving or departing primary users,” *IEEE Signal Process. Lett.*, vol. 17, no. 10, pp. 867-870, Oct. 2010.