OFDM Signal Sensing Method Based on Cyclostationary Detection

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Abstract- **Cognitive Radio is an advanced enabling technology for efficient utilization of vacant spectrum due to its ability to sense the spectrum environment. Various detection methods have been proposed for spectrum sensing, which is the key function in implementing cognitive radio. Most of the existing methods put their interests in detecting TV signal and wireless microphone signals. In this paper, we explore the cyclostationarity of the equally spaced pilot subcarriers in OFDM signal. By averaging over several symbols, the peak property is able to be captured. Simulations in various fading environments show that the proposed cyclostationary based detection method works well for OFDM signal.**

I. INTRODUCTION

In recent years, we believe there is a spectrum scarcity at frequency resource, which is partly caused by the great increasing interest of consumers in wireless services and in return the driving evolution of wireless networks toward high-speed data networks. This concern has arisen from the intense competition for use of spectra at frequencies below 3 GHz. The Federal Communications Commission's (FCC) frequency allocation chart indicates overlapping allocation over all of the frequency bands, which intensifies the scarcity reality. With the emergence of new applications and the increasing need for new mobile Internet accesses, it is commonly believed that the suffering from the spectrum scarcity is expected to grow more and more severely.

On the other hand, not all of the allocated spectrums are used efficiently, especially in the 3-6MHz bands. This point of view is supported by recent studies of the FCC's Spectrum Policy Task Force who reported vast temporal and geographic variations in the usage of allocated spectrum with utilization ranging from 15% to 85% [1]. Evidently, there are many 'white holes' in the spectrum that is not utilized. This finding shows clearly that the current spectrum scarcity is largely due to the inefficient fixed frequency allocations, rather than the physical shortage of spectrum resource.

In order to utilize these spectrum 'white holes', in 2003, the FCC announced a Notice of Proposed Rule Making (NPRM) advancing Cognitive Radio (CR) technology as a candidate to implement the opportunistic spectrum sharing and spectrum efficiency improving. Cognitive Radio, coined by Joseph Mitola in 2000, is a promising technology proposed as a novel approach for improving the efficiency of spectrum utilization.

CR which is based on Software Defined Radio (SDR) is a smart radio that can sense the spectral environment over a wide frequency band and exploit this information to opportunistically provide wireless service accesses that best meet the requirements of customers. By exploiting the existence of spectrum holes, CR has been considered as the effective technology to promote the efficient use of the spectrum. Furthermore, CR is defined as an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes on certain operating parameters (e.g., transmit power, carrier frequency and modulation strategy) in real-time [2].

Since CRs are considered as the secondary or lower priority users of spectrum allocated to a primary user, their fundamental requirement is to avoid interference to potential primary users in the vicinity. Spectrum sensing has been considered as a key function to ensure this requirement.

Spectrum sensing method is usually divided to energy detection, matched filter based method and cyclostationary based method [3]. Energy detection takes the advantage of simple structure. However, in order to increase the reliability, we have to average over several consecutive symbols. Matched filter based method can maximize the received Signal to Noise Ratio (SNR), whereas all the signal characteristics should be known beforehand in the receiver. Cyclostationary based method utilizes the cyclic properties of the signal in frequency domain, which is robust to random noise at the cost of increasing the complexity.

Generally, spectrum sensing functionality is cataloged to two steps. The first as well as the basic step is to find whether the band of interest is vacant. It ensures the operation of primary users without any interference. Energy detection is believed to be a suitable solution. The other is to identify what kind of primary user signal occupies the band of interest. If we are able to recognize the signal, it is easy to estimate what

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type of system occupies the spectrum. Based on this information, the spectrum resource could be well managed. (e.g. whether the band of interest is occupied by primary users or cognitive radio users). Considering the performance and ability to recognize different signals, cyclostationary based method is much better then matched filter based method.

In this paper, we explore the cyclostationarity of OFDM signal. By using the property of pilot that is widely used in all OFDM based systems, we can recognize whether OFDM signal is in the band of interest. Moreover, we can estimate the parameters by calculating the pilot spacing carefully, which could be a proof to recognize different OFDM systems. In section II, we review the cyclostationary detection method. Then the OFDM signal detection based on cyclostationarity of pilot is proposed, and the detection procedure is introduced in detail in section III. Some simulation results and analysis are shown in section IV. Finally, we conclude this paper on section V.

II. Cyclostationary Detection

Generally, the signal of interest is modeled as a stationary random process. However, in most of the modern communication systems, the signal of interest can be modeled as a cyclostationary random process instead. Under this assumption, another catalog of signal detection methods could be explored; even the signal classification can be realized under certain circumstances. The concept of cyclostationary theory described by [4][5][6] will be introduced briefly in this section.

A process, for instance x(t), is said to be cyclostationary in the wide sense if its mean and autocorrelation are periodic with some period, say T [4]:

$$m_x(t+T) = m_x(t) \tag{1}$$

$$R_x(t+T+\frac{\tau}{2}, t+T-\frac{\tau}{2}) = R_x(t+\frac{\tau}{2}, t-\frac{\tau}{2}) \tag{2}$$

where $R_x(t+\tau/2, t-\tau/2)$, the function of two independent variables t and τ, is periodic in t with period T for each value of τ.

The spectral correlation function (SCF) is also known as the cyclic spectral density function, which could be measured by the normalized correlation between two spectral components of x(t) at frequencies $(f+\alpha/2)$ and $(f-\alpha/2)$ over an interval of length Δt.

$$S_{xT}^{\alpha}(f)_{\Delta t} = \frac{1}{\Delta t}\int_{-\Delta t/2}^{\Delta t/2} \frac{1}{\sqrt{T}} X_T(t, f+\alpha/2) \cdot \frac{1}{\sqrt{T}} X_T^*(t, f-\alpha/2) dt \tag{3}$$

In (3) the spectral of x(t) over the time interval [t-T/2,t+T/2] is defined by:

$$X_T(t, v) = \int_{t-T/2}^{t+T/2} x(u) e^{-j2\pi vu} du \tag{4}$$

The ideal measurement of the SCF for the received signal x(t) is given by:

$$S_x^{\alpha}(f) = \lim_{T\to\infty} \lim_{\Delta t\to\infty} S_{xT}^{\alpha}(f)_{\Delta t} \tag{5}$$

In order to generate the SCF, the procedure in fig. 1 can be used [5].

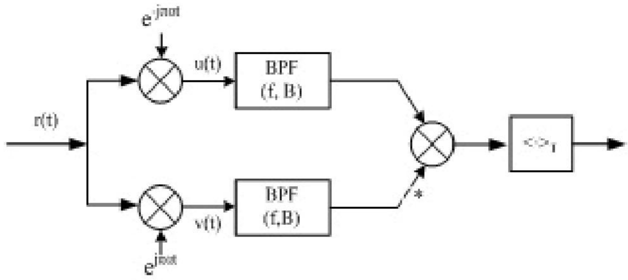

Figure. 1. Spectral correlation function generation

The spectral correlation characteristic of the cyclostationary signals provides us a richer domain signal detection method. By searching the cyclic frequencies of different kinds of modulated signals, the detection can be accomplished. Moreover, the information such as carrier frequency and chip rate could be calculated according to the cyclic frequencies. Another reason for why spectral correlation based method is attractive in the area of signal detection is its robustness against random noise and interference. It is obvious to obtain that the spectral correlation is significantly large when the cyclic frequency equals to zero comparing to that of other values. Because cyclic frequency is an essential characteristic of various signals, it can be utilized to classify signal type.

Fig. 2 illustrates the spectral correlation function of OFDM signal. It is unable to recognize any signal characteristic except the "wall" effect when α equals 0. The key point of using the cyclostationarity to recognize the signal relies on the symmetric or periodic feature of signal of interest in frequency domain. However, because OFDM system carries information by orthogonal subcarriers in frequency domain, there is no symmetric or periodic feature that could be caught in frequency domain. Although it is possible to observe cyclic feature subcarrier by subcarrier, it makes the resolution of α below several kilohertz for observing a signal with several megahertz bandwidth, which increases the complexity significantly. Therefore, it is hard to detect and classify OFDM signal by using the general cyclostationary detection method.

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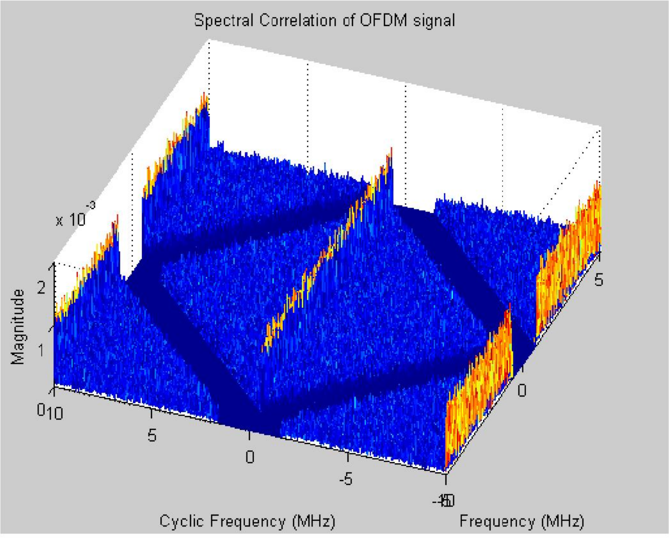

Fig. 2. Spectral correlation of OFDM signal

III. PROPOSED OFDM DETECTION METHOD

As explained in previous section, it is difficult to identify the cyclic frequency which is unique to OFDM signal. In the paper, we explore the periodic property of the repeated pilot subcarrier, which is utilized to recognize OFDM signal.

Conventionally, pilot subcarriers are allocated in the frequency domain for the purpose of synchronization and channel estimation. There are several characteristics about the pilot subcarrier allocation. First, pilot subcarriers should be allocated with constant spacing which is usually larger than coherence bandwidth. Second, pilot subcarriers generally locate in the same position of each symbol, except for some specific systems such as Digital Video Broadcasting - Terrestrial (DVB-T), where the pilot subcarriers location is repeated by several symbols. Third, the power of pilot subcarrier is always boosted up by almost 2.5dB compared to

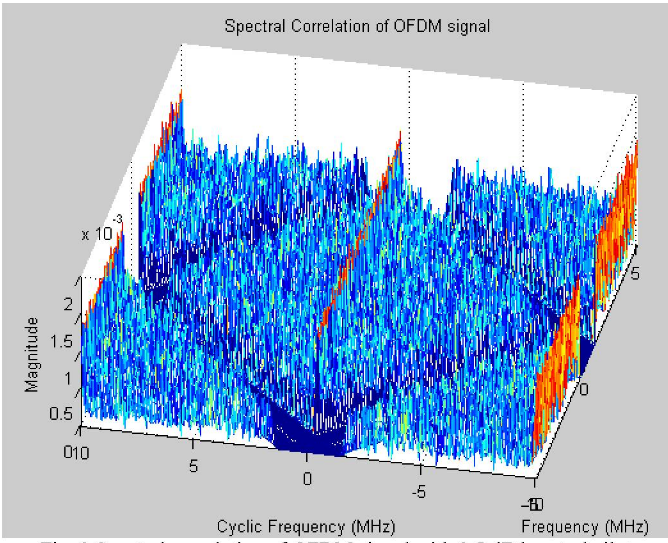

Fig. 3 Spectral correlation of OFDM signal with 2.5 dB boosted pilot subcarrier one symbol

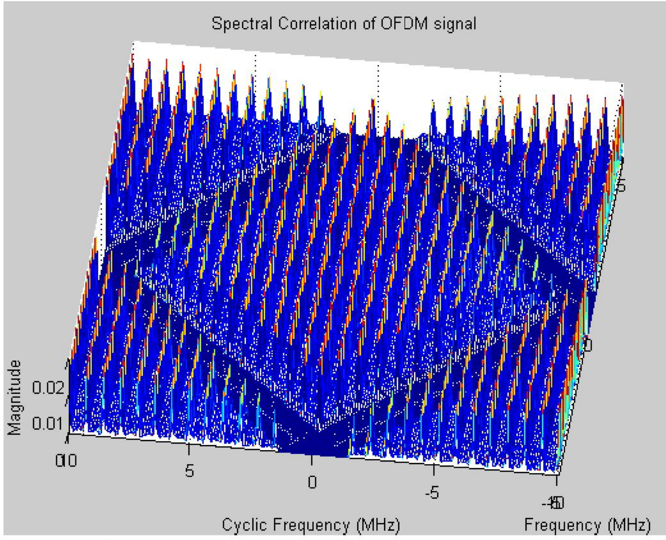

Fig. 4 Spectral correlation of OFDM signal with 10dB boosted pilot subcarrier one symbol

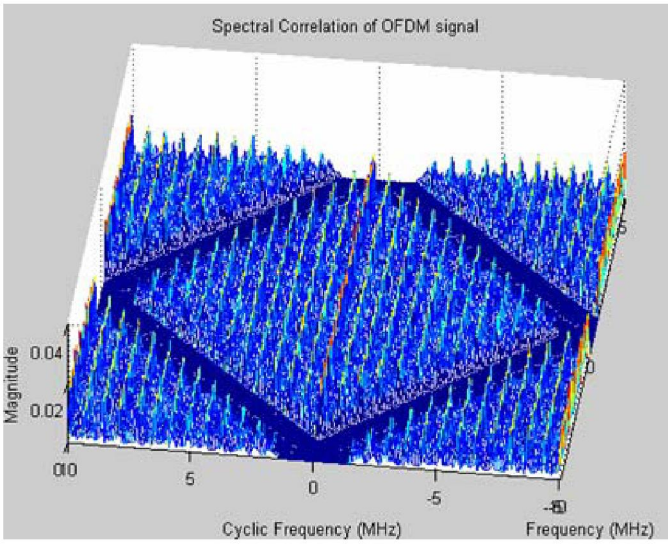

Fig. 5 Spectral correlation of OFDM signal with 2.5dB boosted pilot subcarrier averaging over 5 symbols

that of data subcarrier for the purpose of accurate synchronization and channel estimation.

The proposed method uses the characteristics of pilot subcarrier as described before. The fixed pilot subcarrier spacing guarantees the periodic feature of OFDM signal; meanwhile, the 2.5dB boosted power makes it easier to distinguish the pilot subcarriers from the data subcarriers. However, due to some impairment, even if the pilot power is 2.5dB higher, it is almost impossible to recognize them. As shown in Fig. 3, pilot subcarriers are 2.5dB boosted in the OFDM symbol. With the help of boosted pilot, it is still impossible to recognize any cyclic feature. However, if the pilot subcarriers are boosted with larger power such as 10 dB, as shown in Fig.4, the cyclic wall property is visible. Therefore, the boosted pilot subcarrier with enough power is

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helpful to recognize OFDM signal. Instead of just increasing the power of pilot subcarrier, the averaging over several consecutive symbols can reduce the effect of impairment and improve the visibility of the pilot subcarrier. As described before, unlike the data subcarriers with random phase, pilot subcarriers are generally allocated in the same position of each symbol with same phase. Averaging over several symbols will reduce the power of data subcarriers while increase the power of pilot subcarriers. Therefore, it is feasible to achieve enough power of pilot subcarriers through symbol averaging. Fig. 5 illustrates the spectral correlation function of 5-symbol averaged OFDM signal with 2.5 dB boosted pilot subcarriers.

By searching the constant spacing between consecutive pilot subcarriers, we propose an OFDM signal detection method based on the cyclic feature of pilot subcarriers.

As shown in the Fig. 5, the effect of pilot is obviously to be seen. After calculating the spectral correlation of the received signal, we generate the m(α), by averaging all the frequency components in a specific cyclic frequency, as shown in Fig. 6. Instead of exploring the spectral correlation function, our decision is mainly based on the peak property in m(α).

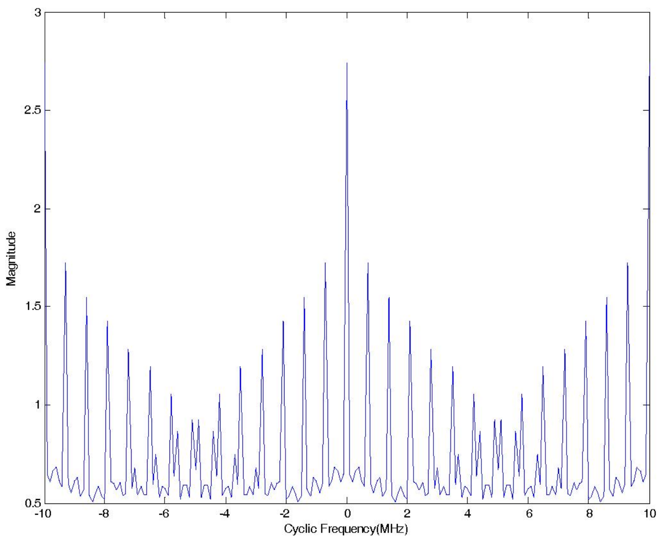

Fig. 6 m(α) plot based on spectral correlation of OFDM signal

It is obvious to see, there are several peaks in the m(α) with constant spacing. The three main peaks which are located in the middle and two sides indicate the average of the power spectral density function of the received signal. Other peaks are due to the correlation between the pilot subcarriers which are boosted by 2.5 dB. The lower part in m(α) indicates the roll off region in the spectrum of OFDM signal.

Based on the property of m(α) function, a two-stage decision procedure is proposed to guarantee the accuracy of the proposed detection method.

A). As shown in Fig. 6, pilot subcarriers are indicated by the peaks. Due to the roll-off characteristic of OFDM signal, there always be a lower area in m(α) which is fixed from symbol to symbol. The peak in this area is selected as the minimum peak threshold, say Th_1 to select the peaks in m(α). It is defined that the peaks larger than Th_1 are used for the second stage of decision. Since the useful peaks are selected according to the rules, the number of these peaks is counted as a parameter for the final decision.

B). Based on the location of the selected peaks, the spacing between two consecutive peaks are calculated and compared with each other. Ideally, the spacing between two consecutive selected peaks should be a constant. However, due to the noise and channel effects, the amplitude of some peaks is reduced which would make the spacing between two consecutive peaks no longer constant. Therefore, the number of peaks with constant peak spacing is always smaller than the number of peaks counted in stage A.

Finally, the decision is made based on the ratio as indicated in (6).

$$\frac{\#\ of\ \ peaks\ with\ cons\tan t\ spacing}{\#\ of\ \ peaks} \tag{6}$$

A threshold, say Th_2, is defined to decide whether the signal of interest is OFDM signal. Generally, Th_1 is set by trails to maintain the requirement on the detection of false alarm.

IV. Simulation Results

Computer Simulations are made in order to verify the performance of the proposed detection method for OFDM signal. The parameters used in the simulation are listed in Table I.

TABLE I

Simulation Parameter

Parameter	Value
Bandwidth	10MHz
Number of Subcarrier	1024
Subcarrier Spacing	9.76kHz
FFT Duration	102.45 usec
GI Duration	12.80 usec
Symbol Duration	115.25 usec
Pilot Spacing	87.84KHz
Pilot Boosting Level	2.5dB boosting
Data Subcarrier Modulation	QPSK
Pilot Subcarrier Modulation	BPSK
Channel Model	ITU-R m.1225

In order to verify the performance under multipath environment, ITU-R m.1225 channel models are used as listed in Table II [7].

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TABLE II

ITU-R M.1225 CHANNEL MODEL

Ped. A	Tap 1	Tap2	Tap3	Tap4	Tap5	Tap6
Relative delay(ns)	0	110	190	410	-	-
Ave.Power(dB)	0	-9.7	-19.2	-22.8	-	-
Ped. B	Tap 1	Tap2	Tap3	Tap4	Tap5	Tap6
Relative delay(ns)	0	200	800	1200	2300	3700
Ave.Power(dB)	0	-0.9	-4.9	-8.0	-7.8	-23.9
Veh. A	Tap 1	Tap2	Tap3	Tap4	Tap5	Tap6
Relative delay(ns)	0	310	710	1090	1730	2510
Ave.Power(dB)	0	-1.0	-9.0	-10.0	-15.0	-20.0
Veh. A	Tap 1	Tap2	Tap3	Tap4	Tap5	Tap6
Relative delay(ns)	0	300	8900	12900	17100	20000
Ave.Power(dB)	-2.5	0	-12.8	-10.0	-25.2	-16.0

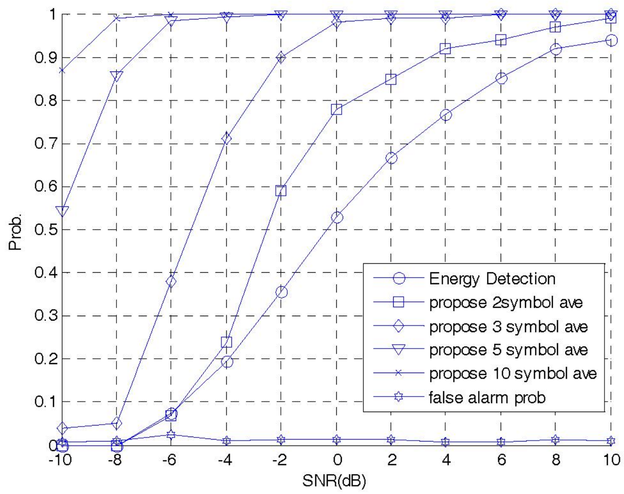

Fig. 7 Performance compared to energy detection with different number of averaging symbols under AWGN

Fig. 7 represents the performance of proposed method under AWGN compared to energy detection. As illustrated, the proposed method outperforms energy detection even with averaging over only two symbols on probability of detection. The false alarm probability is as low as 3% due to the constant spacing between consecutive peaks. As the number of the averaged symbols increases, the detection probability increases rapidly. With averaging over 5 consecutive symbols, the detection probability can almost reach 90% even when the SNR is as low as -10 dB.

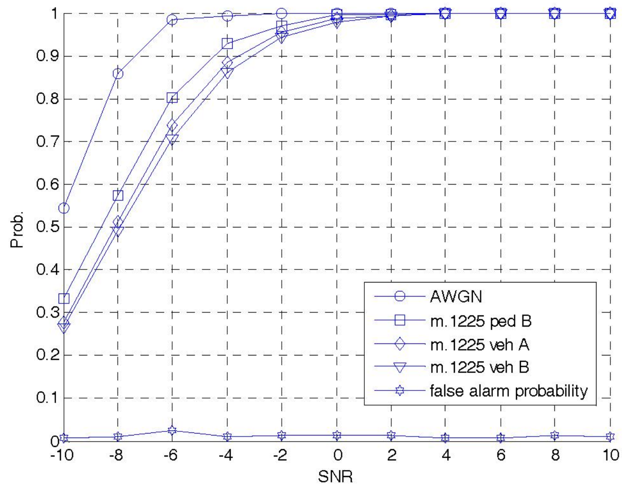

Fig. 8 Performance compared to AWGN with different fading environment averaging over 5 symbols

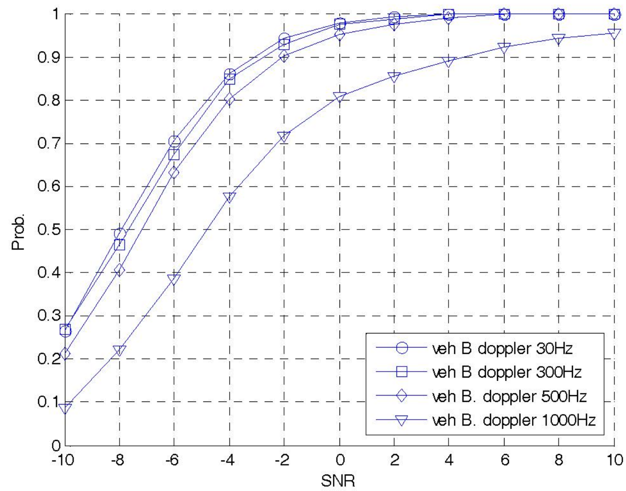

Fig. 9 Performance compared with different vehicle speed averaging over 5 symbols

As shown in Fig. 8, there is certain degree of degradation under multipath environment compared to that under AWGN. The performance degradation is mainly due to the frequency selectivity, which causes some pilot subcarriers buried in data subcarriers. The buried pilot subcarriers would lead to the reduction of the number of peaks, therefore, degrade the performance under multipath environment.

One of the important factors that impact the performance under multipath environment is doppler frequency caused by the motion of vehicle. If OFDM signal suffers from time varying channel, the phase of pilot subcarrier changes according to doppler frequency at each symbol. Therefore, the symbol averaging is unable to boost the power of pilot subcarriers from data subcarriers.

As illustrated in Fig. 8, detection probability degrades as the doppler frequency increases. However, the detection

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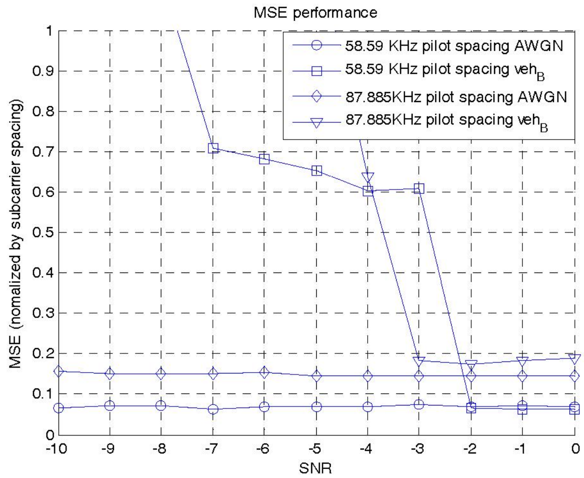

Fig. 10 MSE performance comparison with different subcarrier spacing averaging over 5 symbols

probability is acceptable even when the vehicle speed is 240km/h with the corresponding doppler frequency 500Hz on the assumption of 2.3GHz carrier frequency.

Fig. 10 represents the Mean Square Error (MSE) performance which is normalized by subcarrier spacing. MSE indicates the estimation accuracy of pilot spacing. As can be seen, the MSE saturates when the detection probability is more than 0.9. When SNR is low, the estimated pilot spacing is smaller than subcarrier spacing in the multipath environment, because it is impossible for the detector to find all of peaks correctly in m(α). Additionally, MSE saturates at a specific level even with the increasing of SNR due to the resolution of cyclic frequency. Fine cyclic resolution can increase the accuracy of estimation.

V. CONCLUSIONS

In this paper, we propose a detection method for spectrum sensing which is based on the cyclostationarity of boosted pilot subcarrier in OFDM signal. By averaging over several OFDM symbols, the effect of the pilot subcarrier is obvious to capture. A two-threshold decision procedure is proposed based on the constant spacing property of m(α). Simulations are carried out in both AWGN and multipath environment, where the detection probability as well as the false alarm probability is measured. The results indicate the proposed method outperforms energy detection; moreover, the proposed method could be used to recognize the parameters such as the pilot spacing of the detected OFDM signal. The accuracy of pilot spacing estimation is well described, which requires more intensive research.

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