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Du Shengyong
School of Management Science and Engineering, Shandong University of Finance and Economics, dushy@163.com

Song Qingmei
University Assets Office, Shandong University of Finance and Economics, sdiesong@163.com

Qin Shengping
School of Management Science and Engineering, Shandong University of Finance and Economics, qinshengping@sina.com

Zhang Shoumei
University Assets Office, Shandong University of Finance and Economics, 15064023068@163.com

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Mobile E-business Platform: Collaboration System of Wi-Fi and WAVE Based on Cognitive Radio

Shengyong Du[1], *Qingmei Song*[2], *Shengping Qin*[1], *Shoumei Zhang*[1]
[1]School of Management Science and Engineering, Shandong University of Finance and Economics, China
[2]University Assets Office, Shandong University of Finance and Economics, China

Abstract: The new international standard IEEE802.11p (WAVE) defined enhancements to IEEE802.11 (Wi-Fi). A new mobile e-business platform of Wi-Fi and WAVE is described. Based on cognitive radio, the popular wireless network Wi-Fi can collaborate with WAVE in their common unlicensed spectrum band and licensed spectrum band. As a core technology in the cognitive radio field, OFDM is introduced, and a novel frequency estimation algorithm for them is presented.

Keywords: Collaboration, Wi-Fi, WAVE, OFDM, Frequency Estimation, Cognitive Radio

1. INTRODUCTION

Wi-Fi is popularly used in the Notebook Computers and 3G/4G mobile phones, which is regard as the most important mobile E-business Platform. On the other hand, as a new communication technology for the Intelligent Transportation Systems (ITS), the IEEE 802.11p is an approved amendment to the IEEE 802.11 standard (the basis of products marketed as Wi-Fi) to add the Wireless Access in Vehicular Environments (WAVE). This includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz) [1]. Moreover, Ministry of Industry and Information Technology of the People's Republic of China issued the Frequency Band Layout of 24GHz for Short-Range Vehicular Radar Equipment in Nov. 2012, which is a good symbol for the application of Dedicated Short Range Communications (DSRC) or WAVE [2]. WAVE will be used as the groundwork for DSRC, a U.S. Department of Transportation project based on the ISO Communications, Air-interface, Long and Medium range (CALM) architecture standard looking at vehicle-based communication networks, particularly for applications such as toll collection, vehicle safety services, and commerce transactions via vehicles. The ultimate vision is a nationwide network that enables communications between vehicles and roadside access points or other vehicles [1]. In this paper, it is described that the cognitive radio makes it possible that Wi-Fi and WAVE can collaborate as a higher efficient mobile e-business network infrastructure. In section 2, cognitive radio and the mobile e-business network of Wi-Fi and WAVE are described. In section 3, the core technology OFDM of this network is discussed. In Section 4, the algorithm of the frequency estimation in the wireless OFDM network is presented. Section 5 concludes this paper.

2. Cognitive Radio and the wireless collaborative e-business network of Wi-Fi and WAVE

As the demand for mobile e-business grows, it is very important for efficient utilization of the scarce radio spectrum resource. In November 2002, the Federal Communications Commission (FCC) reported that most of the licensed spectrum is currently under-utilized [3]. Cognitive radio is a novel approach for improving the

Corresponding author. Email: dushy@163.com(Shengyong Du) , sdiesong@163.com (Qingmei Song), qinshengping@sina.com(Shengping Qin), 15064023068@163.com (Shoumei Zhang)

utilization by making it possible for unlicensed users to access frequency bands which are not being used by the primary licensed users in some geographical location. Cognitive radio is defined as an intelligent wireless communication system that is aware of its environment and uses the methodology of understanding-by-building to learn from the environment and adapt to statistical variations in the input stimuli, with two primary objectives in mind: one is highly reliable communication whenever and wherever needed; the other is efficient utilization of the radio spectrum [4].

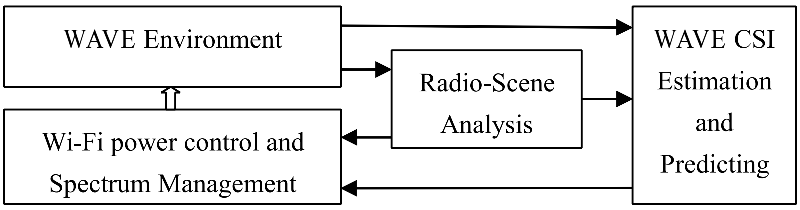

Figure 1. The collaborative e-business platform of Wi-Fi and WAVE based on cognitive radio

The wireless collaborative e-business platform of Wi-Fi and WAVE based on cognitive radio is shown in Figure 1. In this system, WAVE CSI (Channel State Information) estimation and predicting, radio-scene analysis can be carried out in the Wi-Fi's receiver, and power control and spectrum management can be carried out in the Wi-Fi transmitter. Through collaboration of Wi-Fi and WAVE, a cognitive cycle will be formed. In this collaborative network, a feedback channel is urgently needed from the Wi-Fi's receiver to its transmitter. By the feedback channel, the Wi-Fi's receiver can send information of the communication performance to its transmitter. So it is indeed a feedback communication system!

3. OFDM

From the time that Cognitive radio was defined [4-6] on, Orthogonal Frequency Division Multiplexing (OFDM) is regarded as the core technology which is well-matched for cognitive radio systems. Most exciting, OFDM has already been being the core technology of Wi-Fi and WAVE before the time that Cognitive radio is defined.

A schematic view of baseband OFDM system is shown in Figure 2.

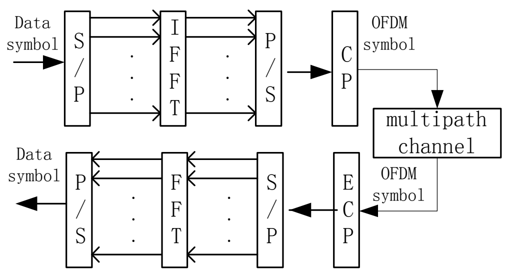

Figure 2. Baseband OFDM System

OFDM modulation, transferring the serial data to parallel data, is completed by Inverse Fast Fourier Transform (IFFT), which can be expressed as [7],

$$x(m) = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} s(i) e^{j\frac{2\pi}{N}im} \tag{1}$$

where $s(i)$ is data symbol, N is the number of subcarriers. Considering Additive White Gauss Noise (AWGN) the received discrete OFDM symbol is [9]

$$r(m) = x(m) + n(m) \tag{2}$$

And OFDM demodulation is written as

$$Y(k) = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} r(m) e^{-j\frac{2\pi}{N}km} \tag{3}$$

where $r(m)$ is the received parallel data symbol, not including cyclic prefix (CP).

Since the serial data is transformed into parallel data during the process of OFDM transmitting, the parallel data symbol duration increases. As a result, OFDM can reduce the effects of inter-symbol interference (ISI) under the multipath channels by making the block period much larger than single carrier system [8]. Under this condition, the channel can be considered to be flat fading channel, which make it possible that the system has a better performance [9].

4. Frequency Estimation

Frequency Estimation for WAVE is one of the important parts of Radio-Scene Analysis. And Frequency Estimation can be gotten by the carrier frequency offset. If the carrier frequency offset appears, a normalized frequency offset with respect to frequency offset can be defined as [10]

$$\varepsilon = \frac{f_d}{\Delta f} = \frac{N f_d}{f_s} \tag{4}$$

where f_d is frequency offset, $f_s = 1/T_s$ is transmitting rate of data $s(i)$, is also sampling frequency, Δf is the interval of subcarriers.

Considering AWGN the received discrete sequence is expressed as [9,10]

$$r_f(m) = x(m) \times e^{j\frac{2\pi}{N}m\varepsilon} + n(m) \tag{5}$$

From formula (1)-(5),

$$Y(k) = S(k)\frac{\sin \pi\varepsilon e^{-j\pi\varepsilon(1-\frac{1}{N})}}{N \sin\frac{\pi\varepsilon}{N}} + \sum_{\substack{i=0 \\ i\neq k}}^{N-1} S(i)\frac{\sin \pi\varepsilon e^{-j\pi(i+\varepsilon-k)(1-\frac{1}{N})}}{N \sin\frac{\pi(i+\varepsilon-k)}{N}} + Z(k) \tag{6}$$

where $Z(k)$ is the FFT of AWGN, $S(k)\frac{\sin \pi\varepsilon e^{-j\pi\varepsilon(1-\frac{1}{N})}}{N \sin\frac{\pi\varepsilon}{N}}$ is the useful signal, $\sum_{\substack{i=0 \\ i\neq k}}^{N-1} S(i)\frac{\sin \pi\varepsilon e^{-j\pi(i+\varepsilon-k)(1-\frac{1}{N})}}{N \sin\frac{\pi(i+\varepsilon-k)}{N}}$ is the inter-channel interference.

In WAVE network, OFDM pilot symbol at the head of the packet can be adopted PN sequence, which is shown in **Table 1**.

Table 1. PN sequence

0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 0, ···, 0, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1	…	

For $r_f(m)$, the phase change between the former half and latter half is $37\times\frac{2\pi}{N}$, where $N=64$. According the character of PN sequence, the frequency offset ε can be estimated as

$$\hat{\varepsilon}=\frac{N}{74\pi}phase[\frac{\sum_{k=38}^{N-1}r_f(m)P_{PN}}{\sum_{k=1}^{26}r_f(m)P_{PN}}] \tag{6}$$

where P_{PN} is shown in **Table** 1.

A simulation is conducted to verify the presented frequency offset estimation algorithm. The corresponding simulation parameters are listed in Table 2.

Table 2. Information system levels

Name of parameter	Size
Number of subcarrier	64
Carrier frequency	2.4GHz
Normalized Carrier frequency offset	0.06
Bandwidth	2MHz
Pilot	IEEE802.11a
Sample Rate	2Mbits/s

The simulation results are shown in the Figure 3. From Figure 3, the error mean and the variance (VAR) of the frequency offset estimation algorithm are low. And with the Signal Noise Ratio (SNR) increasing, the error mean and the variance could be much lower.

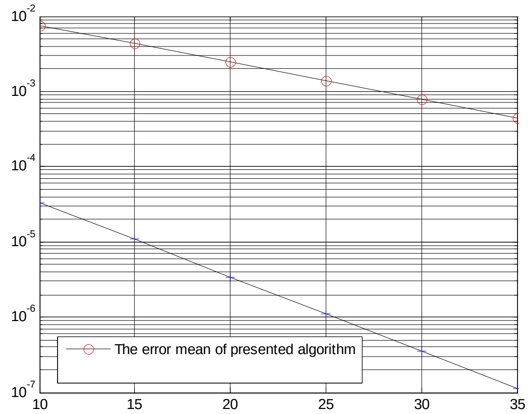

Figure 3. The mean and the variance of frequency offset estimation

5. CONCLUSIONS

In this paper, the mobile e-business platform Wi-Fi collaborated with WAVE based on cognitive radio is described. The core technology OFDM of this platform is discussed. The algorithm of the frequency estimation in the wireless OFDM network is presented. The results of simulation prove that both the error mean and the variance (VAR) of the frequency offset estimation algorithm are low.

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