

A Robust Frame Synchronization of Mobile WiMax 802.16e

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Abstract After the IEEE 802.16-2004 standard was published, much attention was drawn to providing broadband access in rural and developing areas over fixed wireless channels [1], [2]. Recently, the IEEE 802.16e standard for Mobile WiMax has been published. It is known that Mobile WiMax will incorporate error-correction capacity and will be an enhance the available IEEE 802.16 standard with mobility support. In the downlink stage, based on the preamble of the base stations, the mobile terminal will start to negotiate the communication. All useful information like a transmit power of each base station, a state of wireless channel can be achieve in this stage. In this paper, we focus into downlink stage and propose a novel robust frame synchronization specified for Mobile WiMAX standard.

Keyword Mobile WiMAX, Frame Detection, OFDMA.

1. Introduction

Mobile WiMAX is a broadband wireless solution that enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture[3]. The Mobile WiMAX adopts OFDMA (Orthogonal Frequency Division Multiple Access) for improved multipath performance in NLOS (non-line-of-sight) environments.

OFDMA based on Orthogonal Frequency Division Multiplexing (OFDM) is a multiple access technology for BSs (Base Stations) and MSs (Mobile Stations). In OFDM system, input data stream is divided into several parallel sub-streams of reduce data rate (thus increased symbol duration) and each sub-stream is modulated and transmitted on a separate orthogonal subcarrier. The IEEE 802.16e PHY (physical layer) supports TDD (Time Division Duplex) and Full and Half-Duplex FDD (Frequency Division Duplex) operation; however the initial release of Mobile WiMax certification profiles will only include TDD [3]. Figure 1 illustrates the OFDM frame structure for a TDD implementation. Each frame is divided into downlink (DL) and uplink (UL) sub-frame. DL and UL subframe are separated by TTG and RTG (Transmit/Receive and Receive/ Transmit Transmission Gap, respectively) to prevent DL and UL transmission collision. A preamble, used for synchronization, is the first OFDM symbol in every frame. BSs assigned with different segment index compromise the individual PN code in preamble. Other useful information such as FCH (Frame Control Header), DL-MAP and UL-MAP, UL Ranging etc. are used to establish a communication

channel between BSs and MSs.

In order to implement the frame synchronization in MS, the OFDM symbol synchronization is used to start the FFT and OFDM demodulation [4]. To detect the preamble in TDD frame, the matched filters are used in every OFDM symbols. Due to the large number of PN code to compromise the preamble, the task of frame synchronizing requires lots of computation. In this paper, we propose the preamble detection to reduce the complexity of the frame synchronization. The rest of the paper is organized as follow: Section 2 discusses the signal model. The proposed preamble detection and frame synchronization are provided in Sect. 3. The simulation results and the conclusions are hence provided in Sect.4 and Sect. 5.

2. OFDM Signal Model

The transmitted complex baseband signal can be described as

$$s(t) = \frac{1}{\sqrt{T_c}} \sum_{l=-\infty}^{+\infty} \sum_{k=-N_c/2}^{N_c/2-1} a(l,k) \psi(l,k,t) \quad (1)$$

Where l denotes OFDM symbol time index and k denotes the subcarrier frequency index. T_c is effective symbol duration, T_g is guard interval duration and T_s is OFDM symbol duration.

$$\psi(l,k,t) = e^{j2\pi(k/T_c)(t-T_c-lT_s)} u(t-lT_s) \quad (2)$$
$$u(t) = \begin{cases} 1, & 0 \leq t \leq T_s \\ 0, & \text{otherwise} \end{cases}$$

2.1. Transmission in AWGN Channel

The received signal is given as follow

$$r(t) = s(t) + n(t) \quad (3)$$

Sampling the signal at time instant $t_n = nT = n \frac{T_s}{N}$

yields

$$r(t_n) = s(nT) + n(nT) \quad (4)$$

After removing the guard interval for further receiver processing, the l th received OFDM symbol is represented by N samples

$$\mathbf{r}(l) = \{r(l,0), r(l,1), \dots, r(l, N-1)\}$$

$$r(l, n) = r\left[\left(n + N_g + lN_s\right)T\right]$$

Demodulation of subcarriers via fast Fourier transform (FFT) yields the received data symbols

$$\begin{aligned} z(l, k) &= \sum_{n=0}^{N-1} r(l, n) e^{-j2\pi(n/N)k} \\ &= a(l, k) + n(l, k) \end{aligned} \quad (5)$$

Where $n(l, k)$ is a complex-valued additive white Gaussian noise (AWGN).

Squaring both side of Eq. (5) yields the follow

$$z(l, k)^2 = a(l, k)^2 + n(l, k)^2 + 2 \cdot a(l, k) \cdot n(l, k)$$

Inverse-FFT transformation of the result series from frequency domain to time domain yields the follow

$$\begin{aligned} c(l, n) &= F^{-1} \left[z(l, k)^2 \right] \\ &= F^{-1} \left[a(l, k)^2 \right] + F^{-1} \left[n(l, k)^2 \right] \\ &\quad + 2 \cdot F^{-1} \left[a(l, k) \cdot n(l, k) \right] \end{aligned} \quad (6)$$

From the above equation, we would like to prove that:

- The first term of Equation (6) has form of impulses incase of preamble, otherwise it is a white noise in time domain.
- The second and third terms of Equation (6) are white noises in time domain.

If OFDM signal is preamble, the first term of Equation (6) can be derived as

$$\begin{aligned} p(l, n) &= F^{-1} \left[a(l, k) \cdot a(l, k) \right] \\ &= F^{-1} \left\{ d^2(kp) \cdot \delta \left[k - (k_{offset} + 3kp) \right] \right\} \end{aligned} \quad (7)$$

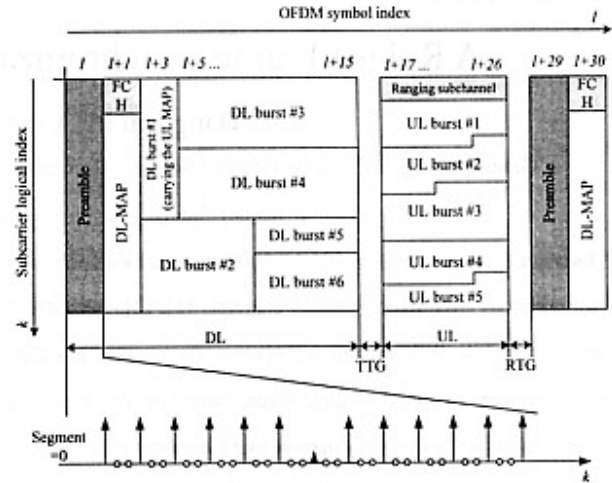


Fig.1. OFDMA Frame structure.

Where $kp \in KP$ is number of pilot tones in preamble.

$k_{offset} = 0..2$ is number of preamble carrier-set.

$d(kp) = \pm 4\sqrt{2}(1/2 - w(kp))$ is BPSK signal of pilot tone $w(kp)$.

Equation (11) can be rewritten as

$$\begin{aligned} p(l, n) &= |d|^2 \cdot F^{-1} \left\{ \delta \left[k - (k_{offset} + 3kp) \right] \right\} \\ &= \begin{cases} |d|^2 \frac{(KP-1)}{3} \cdot \sum_{m=0}^2 \delta \left(l, n - \frac{mN_c}{3} \right), & k_{offset} = 0 \\ |d|^2 \frac{KP}{3} \cdot \sum_{m=0}^2 \delta \left(l, n - \frac{mN_c}{3} \right), & k_{offset} \neq 0 \end{cases} \end{aligned} \quad (8)$$

Therefore, the time series $p(l, n)$ has a form of impulses in time domain. Applying the Parseval's Theorem, the power of the impulses can be derived as

$$\begin{aligned} P_1 &= \sum_n |p(l, n)|^2 \\ &= \begin{cases} |d|^4 (KP-1)^2, & k_{offset} = 0 \\ |d|^4 KP^2, & k_{offset} \neq 0 \end{cases} \end{aligned} \quad (9)$$

Otherwise, if OFDM symbol is not preamble, since the OFDM signal is broadband signal, the first term of can be considered as noise in time domain. Similarly the second and the third term of the Eq. (6) can be considered as white noise in time domain. Applying the Parseval's

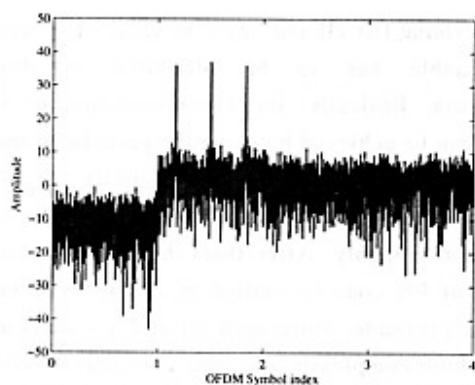


Fig.2. Amplitude of $c(l, n)$ in AWGN channel condition with SNR=6dB.

Theorem, power of time series $c(l, n)$ can be derived as

$$P = \sum_{k=0}^{N_c-1} |a(l, k) + n(l, k)|^4 \quad (10)$$

Applying the triangle property, the upper bound of power of time-series is given as

$$P \leq \sum_{k=0}^{N_c-1} |a(l, k)|^4 + |n(l, k)|^4 \quad (11)$$

2.2. Transmission in Multipath Channel

In multipath channel condition, the received signal is given as

$$r(t) = h(t) \otimes s(t) + n(t) \quad (12)$$

Where $h(t)$ is channel impulse response (CIR) of multipath channel.

Similarly, after sampling and transforming into frequency domain by FFT, the OFDM demodulated signal can be represented as

$$\begin{aligned} z(l, k) &= \sum_{n=0}^{N-1} r(l, n) e^{-j2\pi(n/N)k} \\ &= H(l, k) \cdot a(l, k) + n(l, k) \end{aligned} \quad (13)$$

Where $H(l, k)$ is channel transfer function (CTF) at k th subcarrier of l th OFDM symbol.

$$H(l, k) = \sum_{n=0}^{N-1} h(n) e^{-j2\pi(n/N)k} \quad (14)$$

In multipath condition, the time series in Eq. (6) is rewritten as

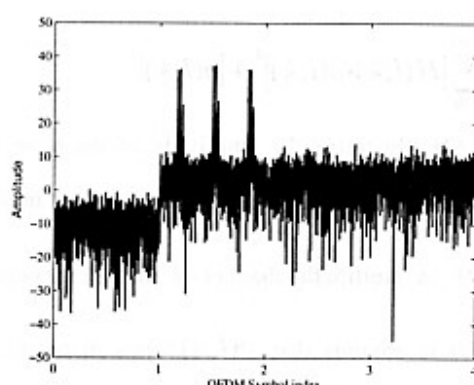


Fig.3. Amplitude of $c(l, n)$ in multipath channel condition with SNR=6dB.

$$\begin{aligned} c(l, n) &= F^{-1} [z(l, k)^2] \\ &= F^{-1} [(H(l, k) \cdot a(l, k))^2] + F^{-1} [n(l, k)^2] \\ &\quad + 2 \cdot F^{-1} [H(l, k) \cdot a(l, k) \cdot n(l, k)] \end{aligned} \quad (15)$$

As explained in Sect. 2.1, the second and third terms of Eq. (15) can be also considered as noises.

If the OFDM symbol is preamble, the first term of Eq. (15) can be expressed as

$$\begin{aligned} p(l, n) &= F^{-1} [(H(l, k) \cdot a(l, k))^2] \quad (16) \\ &= \begin{cases} |d|^2 \frac{(KP-1)}{3} \sum_{n=0}^2 \left\{ h(n) \otimes h(n) \otimes \delta(l, n - \frac{mN_c}{3}) \right\}, & k_{offset} = 0 \\ |d|^2 \frac{KP}{3} \sum_{n=0}^2 \left\{ h(n) \otimes h(n) \otimes \delta(l, n - \frac{mN_c}{3}) \right\}, & k_{offset} \neq 0 \end{cases} \end{aligned}$$

The first term in Eq. (15) $p(l, n)$ has a form of impulses in time domain. Its power can be derived as

$$P_1 = \sum_n |p(l, n)|^2 \quad (17)$$

$$\begin{aligned} &= \begin{cases} |d|^4 (KP-1)^2 \sum_{\tau} |h(n, \tau)|^4, & k_{offset} = 0 \\ |d|^4 KP^2 \sum_{\tau} |h(n, \tau)|^4, & k_{offset} \neq 0 \end{cases} \end{aligned}$$

Applying the triangle property, the upper bound of power of time-series is given as

$$P \leq \sum_{k=0}^{N_c-1} |H(l,k) \cdot a(l,k)|^4 + |n(l,k)|^4 \quad (18)$$

Figure (2) illustrates the amplitude of the time series $c(l,n)$ in AWGN channel with SNR=6dB. The amplitude of $c(l,n)$ in multipath channel is also represented in Fig. (3). It is obvious that $c(l,n)$ forms distinguishable impulses in case of preamble, otherwise the series is likely a white noise.

3. Proposed Frame Detection for Mobile WiMAX

The first symbol of downlink transmission is the preamble; there are three types of preamble carrier sets, those are defined by allocation of different subcarriers for each one of them. Those subcarriers are modulated using boosted BPSK modulation with specific PN code [3]. Regarding to Mobile WiMAX standard, there are more than hundred sets of PN code to generate the preamble. Each BS selects the individual set of PN code based on its individual IDCell and Segment value to generate its preamble. In downlink scenarios, MS tries to access mobile network from sleep mode, MS must scan through all possible sets of PN code to identify IDCell and Segment value of each BS. MS also gathers useful information of specific BS and its associated wireless channel before starting to arrange the communication.

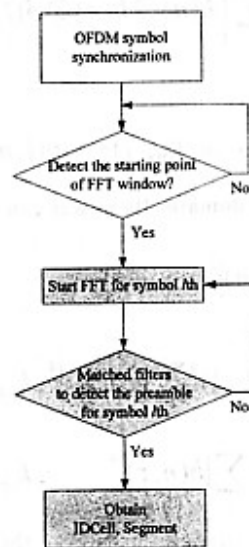


Fig.4. A flowchart of the conventional frame detection for Mobile WiMAX.

To determine IDCell and Segment value of specific BS, the preamble has to be identified in downlink transmission. Basically, the synchronization of OFDM symbols can be achieved by using the periodic property of each OFDM symbol and its cyclic prefix. In [4], the issues of synchronization of OFDM symbol have been discussed thoroughly. After that, the matched filter for each set of PN code is applied in frequency domain to detect the preamble. Since each set of PN code is unique, the very high complexity and time consumption to detect the preamble is required. Figure 4 illustrates the flowchart of the conventional preamble detection for Mobile WiMAX.

According to the properties of the preamble investigated in Sect. 2, we propose the novel frame synchronization for Mobile WiMAX. Figure 5 shows the flowchart of the proposed method, in which the OFDM symbol synchronization is unchanged. After determining the starting point of OFDM symbols, the FFT is used to convert OFDM symbols into frequency domain. Applying the result from Sect. 2, the proposed preamble detection is deployed. Meanwhile, one OFDM symbol is stored in memory. If the OFDM symbols storing in memory is indicated to be the preamble, the matched filters are used to determine the IDCell and Segment value corresponding to each BS; otherwise the next OFDM symbol is stored into memory and so forth. By using the proposed method, the process of scanning through all possible PN codes can be conducted serially in one TDD frame. Thus the

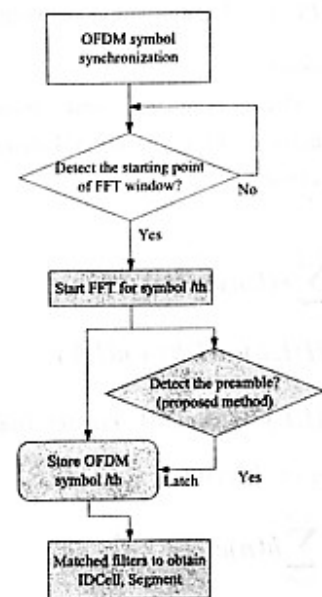


Fig.5. A flowchart of the proposed frame detection for Mobile WiMAX.

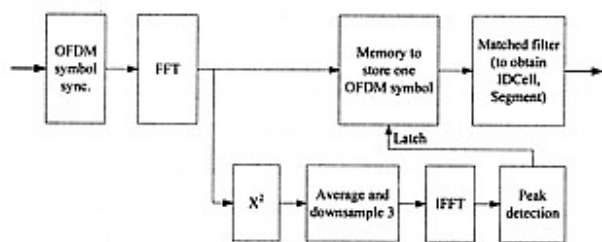


Fig.6. The detail schematic diagram of the proposed frame synchronization for Mobile WiMAX.

complexity of the frame synchronization is greatly reduced.

Figure 6 shows the diagram of the proposed frame synchronization for Mobile WiMAX in detail. The OFDM symbol synchronization is conducted by exploiting the cyclic prefix and the periodic property of OFDM symbol. After converting OFDM symbols back into frequency domain, data of one OFDM symbol is store in memory of one OFDM symbol's size. The proposed preamble detection is deployed including squaring, IFFT. In addition, averaging and down-sampling of three are added to enhance the performance of the proposed method in multi-user environment. In other words, since BSs use different sets of PN code with different subcarrier offset in the preamble, the steps of averaging and

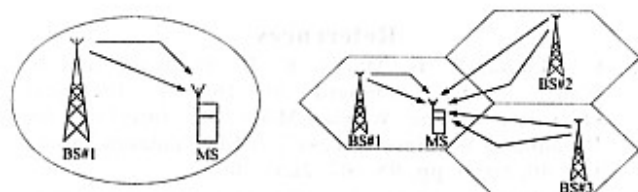


Fig.7. Illustrations of the Single-cell and Multi-cell environment.

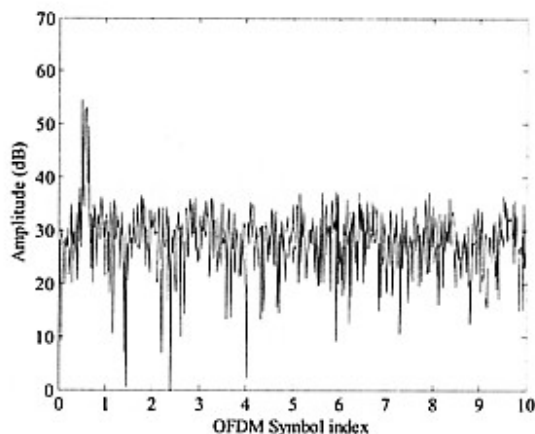
Table 1. Simulation conditions

Single-cell and Multipath channel condition.

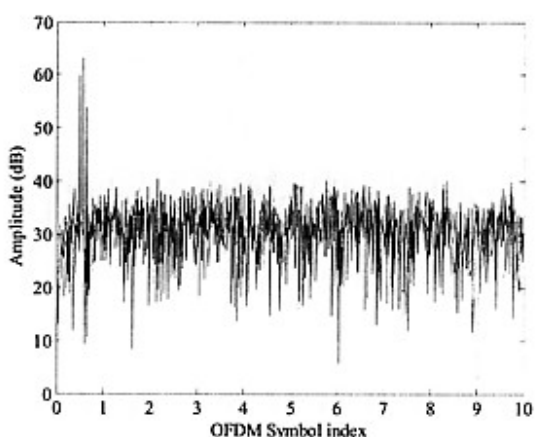
Path No.	Power (dB)	Delay Spread (μ s)
Path 1	0dB	0 μ s
Path 2	-3dB	2.4 μ s

Muti-cell and Multipath channel condition.

Multipath channel corresponding to BS #1		
Path No.	Power (dB)	Delay Spread (μ s)
Path 1	0dB	Direct path
Path 2	-3dB	2.4 μ s
Multipath channel corresponding to BS #2		
Path 1	0dB	6.4 μ s
Path 2	-3dB	7.6 μ s
Multipath channel corresponding to BS #3		
Path 1	0dB	9.2 μ s
Path 2	-3dB	12.0 μ s



(a)



(b)

Fig.8. The preamble detections with (a) 64-points and (b) 128-points IFFT in single-cell environment.

down-sampling of three will enhance the peak at the output of IFFT. Thus, at the output of IFFT, the peak detection is used to indicate the preamble. If data storing in memory is preamble, matched filters are possessed to obtain IDCell and Segment values corresponding to every BSs.

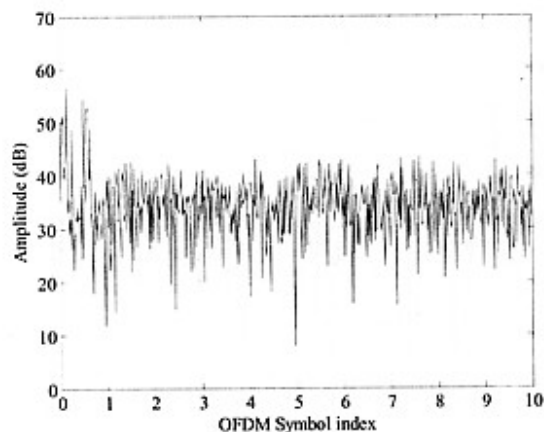
Furthermore, to reduce the complexity of the preamble detection, the performances of IFFTs with different size are measured. In the next section, the simulation results in various conditions are given and discussed.

4. Simulation Results

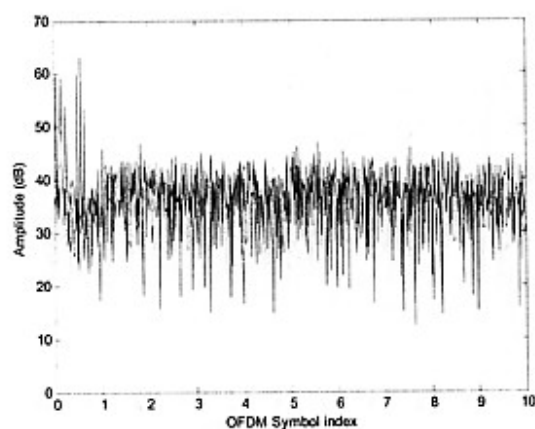
In this section, simulation results of the proposed preamble detection and frame synchronization for Mobile WiMAX are given in various conditions. Table 1 denotes the simulation conditions.

4.1. Single-cell and Multipath Channel.

In this condition, only one BS explores the whole



(a)



(b)

Fig.9. The preamble detections with (a) 64-points and (b) 128-points IFFT in multi-cell environment.

OFDMA spectrum. Moreover, the received signal experiences the two-path channel condition with DUR (Desired-to-Undesired Ratio) of 3dB and the delay spread of 2.4 μ s. Figure 8 (a) and (b) show the output of 64-points and 128-points IFFT, respectively.

As shown in this figure, in case the OFDM symbol is the preamble, the peak is generated at the output of IFFT. Otherwise, the noise-like signals are outputted. Furthermore, the power of the peak by using the 128-points IFFT is about 7dB more than that by using 64-points IFFT. Therefore, the more length of IFFT, is using the more robustness of the preamble detection but also increasing the system's complexity.

4.2. Multi-cell and Multipath Channel.

In this condition, multi-cell environment is simulated. In downlink scenarios, MS can receive maximum three adjacent BSs in one TDD frame of OFDMA transmission technology. Additionally, signal that is transmitted from

different BS experiences different multipath channel condition.

Figure 9 (a) and (b) show the output of 64-points and 128-points IFFT, respectively. In the multi-cell environment, the peaks are more broadened than that in single-cell environment. In other words, the peaks are not pulse-like shape in severe channel condition; however, the peaks are still dominantly distinguished comparing with noise-like signal. The preamble detection still generate peaks with power of about 30dB and 37dB distinguishing with noise-like signal in case of 64-point and 128-point IFFT, respectively.

5. Conclusions

In this paper, the robust frame synchronization is proposed. We investigate the property of the preamble in TDD OFDMA frame of IEEE 802.16e standard, and hence propose the novel preamble detection that would be applied to the frame synchronization. Our proposed method greatly reduces the complexity of the system.

The simulation results are given and show that the preamble detection is robust in various conditions. The peak generated at the preamble usually has its power of 30dB to 37dB comparing with noise-like signal. It is also proved that the complexity of the system can be reduced furthermore by using IFFT transformation with smaller length.

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