

A Robust Ranging Detection with MAI Cancellation for OFDMA Systems

Chieh-Lung Lin^{ab}, Szu-Lin Su^a

^a Institute of Computer and Communication Engineering, Department of Electrical Engineering,
National Cheng Kung University, Tainan City, Taiwan, R.O.C

^b Telecom Technology Center, Kaohsiung County, Taiwan, R.O.C
reed@pcnw3.ee.ncku.edu.tw, ssl@ee.ncku.edu.tw

Abstract— During the initial uplink synchronization, the BS communicates with MSs to adjust timing and power offsets. The common method to achieve the objective is to use the orthogonal code in the frequency domain for OFDMA systems. Due to the timing offset, the orthogonality of codes is decayed and multiple access interference (MAI) becomes serious. In order to decrease this influence, we proposed the idea which combines the channel estimation and the multiuser detection. On the strength of cancelling the MAI step by step, ranging users can be detected one by one. The proposed idea is robust to achieve a significant improvement on the ranging detection rate over the multipath Rayleigh fading channel.

Keywords— IEEE802.16e, ranging, OFDMA, uplink, multiuser ranging detection, timing estimation, power estimation.

I. INTRODUCTION

Ranging is the technology used to achieve the uplink synchronization on timing and power. Orthogonal codes used to identify ranging users are called ranging codes. Ranging users can be detected by the cross correlation method. Because of code orthogonality, it is possible to find out several ranging users at the same time. Due to many signals send from different locations, there are many kinds of channel conditions and round trip delays (RTD). The aggregated phenomenon makes the detection on the base station (BS) more complex.

The regular ranging detection method is proposed by [1] and [2] over AWGN and multipath Rayleigh fading channels. They give the complete analysis on signal detection, timing estimation and power estimation. The paper [3] designs the good phase-shift orthogonal ranging code over the time domain. So the optimum detection threshold can be derived directly. Jianqiang Zeng and Hlaing Minn contribute on the MIMO ranging user detection very much. The timing offset estimation is simplified by the special ranging code arrangement. They also provide multiuser and multi-antenna diversity gains to achieve significant power saving for the subscriber stations [5] and [6].

The proposed method uses the multiple access interference cancellation method to increase the detection probability. The same idea of MAI cancellation was adapted in the paper [7] but the proposed method uses different methods to realize it.

[7] sees each multipath as one independent signal and use the successive interference cancellation (SIC) method to find out each recognized signal. By this way, the ranging detection rate can be improved very much. But the calculation complexity of correlation will grow up with the multipath number. In view of this, we propose one method that can prevent this situation to happen by focusing on one ranging user signal, not multipath. The more detail information will be stated in latter chapters. Simulation results show this algorithm has better detection rate and higher precision on power and timing estimation than the conventional method and [7] over multipath Rayleigh fading channels.

The rest of this paper is organized as follows. The system model is described in Section II. Section III focuses on the proposed method including multiuser detection, channel estimation, iterative amendment and power estimation. Section IV shows the simulation results and discussions. Finally we conclude the paper in Section V.

II. SYSTEM DESCRIPTION

We consider an uplink of an OFDMA system with N subcarriers. The ranging signals are transmitted on the ranging slot. One ranging slot occupies one ranging sub-channel in the frequency domain and 3 consecutive OFDMA symbols in the time domain. Each ranging subscriber station (RSS) has γ_R subcarriers and each data subscriber station (DSS) has γ_D subcarriers. One ranging slot contains N_R RSSs and the other residual subcarriers belong to N_D DSSs.

One ranging code is selected randomly from a predefined code set as $\{C_1, C_2, \dots, C_Z\}$, with $C_i = [c_i(1), c_i(2), \dots, c_i(\gamma_R)]^T$. c_i is modulated by binary phase shift keying (BPSK) from the pseudonoise sequence. The frequency domain signal of i -th RSS is given by

$$X_{i,R}(k) = X_{i,R}(v(m)) = A_{i,R} c_i(m) \quad (1)$$

where $A_{i,R}$ is the amplitude factor of i -th RSS. k and m are the subcarrier index and the ranging code bit index separately. The function v maps the ranging code bit index m into the subcarrier index k .

Denote the N -point unitary inverse discrete Fourier transform (IDFT) of $X_{i,R}$ by $[x_{i,R}(1), x_{i,R}(2), \dots, x_{i,R}(N)]^T$. The signal of i -th RSS in the time domain is given by

$$x_{i,R}(n) = \frac{1}{\sqrt{N}} \sum_{k=1}^N X_{i,R}(k) e^{j2\pi k(n-N_g)/N}$$

$$n = 0, \dots, 2(N + N_g) - 1 \quad (2)$$

where N_g is the cyclic prefix (CP) length and n is the time domain index.

Our ranging signal adopts a phase-continuous signal with the length of two OFDMA symbols. This design can help BS to capture a full ranging signal during the second OFDMA symbol in a ranging slot to overcome large timing offsets. Besides, we consider a multipath Rayleigh fading channel $h_{i,R}$ with L sample-spaced taps. It was simulated by Jakes' models. The ranging signal through the channel becomes

$$y_{i,R}(n) = \sum_{\ell=0}^{L-1} h_{i,R}(\ell, n) x_{i,R}(n - \ell - d_{i,R}) e^{j2\pi \varepsilon_{i,R} n} \quad (3)$$

where $d_{i,R}$ is the RTD of i -th RSS and ℓ is the channel tap index. $\varepsilon_{i,R}$ is the carrier frequency offset (CFO) of i -th RSS. There are N_R RSSs with the signal $y_{i,R}$ and N_D DSSs with the signal $y_{i,D}$. The time-domain received signal at the BS side will be

$$y(n) = \sum_{i=1}^{N_R} y_{i,R}(n) + \sum_{i=1}^{N_D} y_{i,D}(n) + w(n) \quad (4)$$

where $\{w(n)\}$ are independent and identically-distributed (i.i.d.), circularly-symmetric complex Gaussian noise samples with zero mean and variance σ_w^2 .

III. PROPOSED RANGING ALGORITHM

According to [2], the detected ranging users are determined by the cross-correlation values that are larger than the threshold after the received ranging signal is transferred by FFT. But the cross-correlation R_i value usually is interfered by the MAI and noise as shown in the following equation.

$$R_i(\hat{d}_{i,R}) = D_i + I_i + W_i \quad (5)$$

where D_i is the detected user's cross-correlation value with the ranging code $\hat{C}_i$, I_i is the other users' interference and W_i is AWGN. $\hat{d}_{i,R}$ is the estimated time delay of i -th RSS. For simplicity, we ignore the CFO effect in the following equations.

$$D_i(\hat{d}_{i,R}) = H_{i,R} X_{i,R} \hat{C}_i \quad (6)$$

$$= \sum_{m=1}^{N_R} H_{i,R}(v(m)) A_{i,R}(v(m)) c_i(m) \hat{C}_i(m) e^{j2\pi v(m)(\hat{d}_{i,R} - d_{i,R})/N}$$

$$I_i(\hat{d}_{i,R}) = \sum_{r=1, r \neq i}^{N_R} \Theta_{(\hat{d}_{i,R} - d_{r,R})} H_{r,R} X_{r,R} \hat{C}_i \quad (7)$$

$$= \sum_{r=1, r \neq i}^{N_R} \sum_{m=1}^{N_R} e^{j2\pi v(m)(\hat{d}_{i,R} - d_{r,R})/N} H_{r,R}(v(m)) A_{r,R}(v(m)) c_r(m) \hat{C}_i(m)$$

$$W(\hat{d}_{i,R}) = \frac{1}{\sqrt{N}} \sum_{m=1}^{N_R} \sum_{n=0}^{N-1} w(n) e^{-j2\pi n v(m)} \hat{C}_i(m) e^{j2\pi n v(m) \hat{d}_{i,R}} \quad (8)$$

where $H_{i,R}(k)$ is the channel frequency response of i -th RSS.

$$H_{i,R}(k) = \sum_{n=0}^{N-1} \sum_{\ell=0}^{L-1} h_{i,R}(\ell, n) e^{-j2\pi k \ell / N} \quad (9)$$

where Θ_d is the phase shift for each subcarrier due to the relative time delay d . This is the reason why the ranging code will decrease their orthogonality. In order to suppress the influence of MAI, we adopt the successive interference cancellation and the iterative multiuser signal detection to estimate each RSS signal. Here, we separate this method into four parts to introduce.

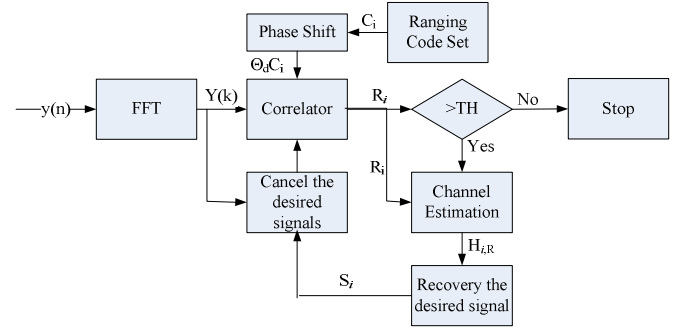


Figure 1. Successive Ranging Multiuser Detection

A. Successive Ranging Multiuser Detection Method

Figure 1. shows the flow chart of the detection method. After a FFT, we take the relative γ_R subcarriers to do the cross correlation. Since the channel model includes multipath, we use a sliding window with the length L_w to collect the multipath power and find the most possible timing region. Then we can find the desired user who has the maximum correlation value from L_w correlation values. Here, R_i' is the power summation of L_w correlation values.

$$(R_i'(\hat{d}_{i,w}))^2 = \sum_{\ell=1}^{L_w} |R_{i,R}(\hat{d}_{i,w} + \ell)|^2 \quad (10)$$

$\hat{d}_{i,w}$ means the timing offset of the estimated sliding window.

$$\hat{d}_{i,w} = \arg \max \{ |R_i'(d)| : d = 0, \dots, d_{\max} + L - 1 - L_w \} \quad (11)$$

where $d_{\max}$ is the maximum RTD calculated from the cell radius. Inside this window, we can find out the RSS's timing offset $\hat{d}_{i,R}$ by searching the maximum cross correlation value.

$$\hat{d}_{i,R} = \arg \max \{ |R_i(d)| : d = \hat{d}_{i,w}, \dots, \hat{d}_{i,w} + L_w - 1 \} \quad (12)$$

The probability density function (PDF) for 0 and 1 RSS cases are central and non-central Rayleigh distribution defined as equation (13).

$$f_{R_i}(t) = \begin{cases} \frac{t}{\sigma^2} e^{-t^2/(2\sigma^2)} & \text{for 0 RSS} \\ \frac{t}{\sigma^2} e^{-(t^2 + \eta^2)/(2\sigma^2)} I_0\left(\frac{t\eta}{\sigma^2}\right) & \text{for 1 RSS} \end{cases} \quad (13)$$

where η means the expecting mean amplitude of the ranging signal. σ^2 is the noise variance. I_0 and t are the modified Bessel function and the average bit amplitude respectively. They can be defined as below.

$$I_0(s) = \frac{1}{2\pi} \int_0^{2\pi} e^{s \cos \theta} d\theta \quad (14)$$

$$t = |R_{i,R}(\hat{d}_{i,R})| / \gamma_R \quad (15)$$

From equation (13), the threshold is defined at the cross point of two distributions. If the probability of existing ranging user is larger than that of non-ranging user, the new RSS is detected.

We know that

$$|R_i| = \begin{cases} |D_i + I_i + W| & \text{for } i \in \text{RSS} \\ |I_i + W| & \text{for } i \notin \text{RSS} \end{cases} \quad (16)$$

According to [1], the noise estimation can be obtained by averaging the cross-correlation values of other RSSs' codes.

Here, we propose a simplified method to estimate the noise variance by meaning cross correlation values outside the deterministic sliding window for each ranging code.

$$\sigma_i^2 = \left(\sum_{t=0}^{d_{i,w}-1} R_i(t) R_i^*(t) / \gamma_R^2 + \sum_{t=d_{i,w}+L_w-1}^D R_i(t) R_i^*(t) / \gamma_R^2 \right) / (D - L_w + 1) \quad (17)$$

where $D = d_{\max} + L$ and $*$ means complex conjugate function. σ_i^2 is the estimated noise variance of i -th RSS. Therefore, different RSS processes have different thresholds with different noise variances.

When one RSS is detected, the ranging signal needs to be analysed to get the channel impulse response (CIR) by the channel estimation. After one ranging user's CIR is determined, one ranging user signal can be cancelled from the previous residual signal. Until no RSS is detected, the procedure can be stopped. So the i -th residual signal $Y^{(i)}$ which has been cancelled ($i-1$) RSSs signals can be described as

$$Y^{(i)} = Y^{(i-1)} - \hat{S}_{i-1} = Y^{(i-1)} - \hat{\Theta}_{\hat{d}_{i-1,R}} \hat{H}_{i-1,R} \hat{C}_{i-1} \quad (18)$$

$$Y^{(0)}(k) = \sum_{n=N+2 \times CP-1}^{2(N+CP)-1} y(n) e^{-j2\pi k n / N} \Theta_{CP} \quad (19)$$

where $\hat{S}_{i-1}$ is the ($i-1$)-th detected ranging signal and $Y^{(0)}$ is the original signal in the frequency domain.

After cancelling one RSS, the residual MAI becomes smaller. The estimated noise variance will be close to the true AWGN. The threshold follows it and moves to an appropriate position. This improves the miss detection rate and the false alarm rate.

B. Channel Estimation

Since the multipath effect will result in the frequency selective channel, there is usually the pilot signal to estimate that. For the ranging detection, it is impossible to get the CIR directly, like the zero forcing when many RSSs transmit. Rely on observing the reason of the frequency selective effect. We try to find out each multipath signal. The main idea is similar to the successive ranging multiuser detection.

In each channel estimation process, we only consider one desired ranging signal. The searching ranging timing is allocated between $\hat{d}_{i,R}$ and $\hat{d}_{i,R} + L_w - 1$. The cross correlation value $R_i^{(q)}$ can be gotten from the signal $Y^{(i)(q-1)}$. $Y^{(i)(q-1)}$ means the i -th residual signal $Y^{(i)}$ cancels ($q-1$) multipath signals of i -th RSS. According to equation (6), we can separate the desired user signal into several parts. Assume $d_{i,R} = \hat{d}_{i,R}$, then the equation will be

$$S_i = H_{i,R} X_{i,R} \hat{C}_i \quad (20)$$

$$= (H_{i,R}^{(0)} + H_{i,R}^{(1)} e^{j2\pi k(\hat{d}_{i,R} - d_{i,R}^{(1)})/N} + \dots + H_{i,R}^{(L-1)} e^{j2\pi k(\hat{d}_{i,R} - d_{i,R}^{(L-1)})/N}) X_{i,R} \hat{C}_i$$

From above equation, we can find that the other multipath signals become interference to affect the cross correlation result. In order to lower this effect, we adopt the successive interference cancellation to calculate multipath amplitudes. Here, we use the orthogonality of PN codes to find the position and amplitude of each multipath signal. The CIR of q -th multipath can be gotten from $Y^{(i)(q-1)}$ and presented as

$$\begin{aligned} \hat{H}_{i,R}^{(q)} &= \left(\sum_{m=1}^{\gamma_R} Y^{(i)(q-1)}(v(m)) \hat{c}_i(m) e^{\frac{j2\pi v(m) \hat{d}_{i,R}^{(q)}}{N}} \right) / \gamma_R \\ &= R_{i,R}^{(q-1)}(\hat{d}_{i,R}^{(q)}) / \gamma_R \end{aligned} \quad (21)$$

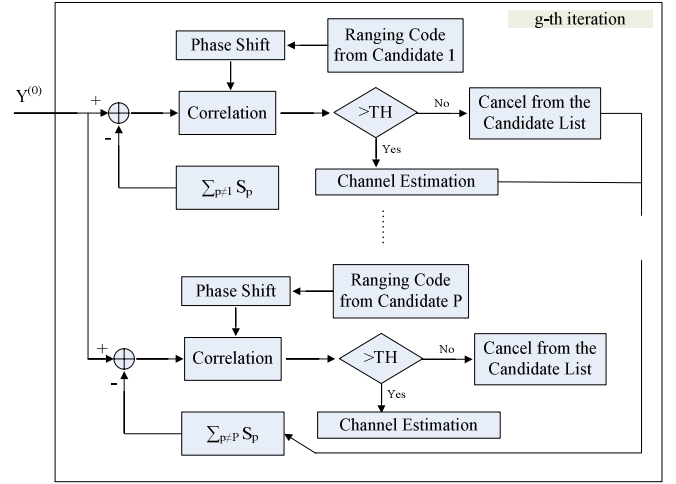


Figure 2. Iterative RSS Amendment

$$\hat{d}_{i,R}^{(q)} = \arg \max \{ |R_{i,R}^{(q-1)}(d)| : d = \hat{d}_{i,w}, \dots, \hat{d}_{i,w} + L_w - 1 \} \quad (22)$$

According to equation (13), let $t = \hat{H}_{i,R}^{(q)}$. If t is larger than threshold, cancel this multipath as the following equation and go on searching the next multipath.

$$Y^{(i)(q)} = Y^{(i)(q-1)} - \hat{\Theta}_{\hat{d}_{i,R}^{(q)}} \hat{H}_{i,R}^{(q)} \hat{C}_i \quad (23)$$

By means of the iterative method, we can find the timing and power of all multipath signals. Then we can get the updated CIR $\hat{H}_{i,R}$.

$$\hat{H}_{i,R} = \hat{H}_{i,R}^{(0)} + \hat{H}_{i,R}^{(1)} e^{j2\pi k(\hat{d}_{i,R}^{(0)} - \hat{d}_{i,R}^{(1)})/N} + \dots + \hat{H}_{i,R}^{(Q-1)} e^{j2\pi k(\hat{d}_{i,R}^{(0)} - \hat{d}_{i,R}^{(Q-1)})/N} \quad (24)$$

where Q is the total number of detected multipath.

The first multipath signal does not always have the largest power. In order to know the accuracy of the timing estimation clearly, set $\hat{d}_{i,R}$ equal to the smallest time delay among all detected multipath signals. At the same time, ISI can be prevented after completing the timing adjustment based on the first multipath signal.

C. Iterative RSS Amendment

We get the candidate list from the multiuser detection. However, there is still the residual interference and false alarm RSSs to influence the performance. The former makes some noise to the power estimation. The latter produces the virtual ranging signal during the cancellation process. In view of both factors, we introduce the iterative RSS amendment method to compensate this degradation of ranging successful rate. From Figure 2, we can clearly understand that we cancel the other candidates' signals first when we want to re-check whether the candidate is false and amend CIR of the target signal. That is because we don't consider all the other RSSs' interference at the successive ranging multiuser detection stage. The interference makes the higher miss probability and false alarm rate. After cancelling other signals, we re-check again. If the value is smaller than the threshold, we remove it from the candidate list. Otherwise, we update the CIR. For the next candidate, we cancel the others' signals and do it again.

After an iterative RSS amendment, the residual power of the ranging slot shall be reduced. Theoretically, the final

residual signal is noise, if there is no remaining RSS signal. Therefore, the iteration is stopped when the residual power $|Y^{(Q)}|$ is larger than or equal to that in the previous iteration. The estimated CIR will be recovered to the previous CIR.

D. Power Estimation

According to the channel estimation result, we can finish the power estimation by the following equation.

$$P_i = \sum_{q=0}^{L-1} (H_{i,R}^{(q)} H_{i,R}^{(q)*} |A_{i,R}|^2) \approx \sum_{q=0}^{Q-1} |\hat{H}_{i,R}^{(q)}|^2 / c_i(m) \hat{c}_i(m) \quad (25)$$

If $c_i(m) = \hat{c}_i(m)$ and $|c_i(m) \hat{c}_i(m)| = 1$, then we get

$$P_i = \sum_{q=0}^{Q-1} |\hat{H}_{i,R}^{(q)}|^2 \quad (26)$$

IV. NUMERICAL RESULTS

A. Simulation Parameters

The relative system settings are summarized in the Table1. For the simulation system, there is one ranging slot during one frame. Each ranging slot has $\gamma_R=144$ subcarriers. The other subcarriers except the guard band are used for the data transmission. The ranging code is selected randomly from 64 PN codes and no collision happens.

The multipath Rayleigh fading channels for RSSs and DSSs were simulated by several independent Jakes' models. The mobile speed is 60km/hr corresponding to the normalized fading rate 0.0124. The fading channel is simulated by the ITU-R M.1225 Veh-A 60kmph channel model which has the power distribution [0 -1 -9 -10 -15 -20] dB and the tap delay [0 310 710 1090 1730 2510]* 10^{-9} sec. The SNR is 10dB at the BS side for all RSSs and DSSs.

B. Simulation Results

Figure 3. shows the probabilities of miss detection rate P_{miss} and false alarm rate P_{false} at different ranging user numbers from 2 to 14. Here, P_{miss} is defined as $E[D_m/N_R]$, where D_m is the number of non-detected RSSs. P_{false} is defined as $E[(N_R - D_m)/(Z - N_R)]$. The proposed method is compared with Successive Multiuser Detector (SMUD) which is proposed by [7]. It was simulated by 2 false alarm probability settings which are 0.01 and 0.001. The false alarm probability of conventional method is 0.01.

According to the simulation results, the proposed method is better than SMUD method. That's because the difference of threshold definition. For the SIC detection, false signals are harmful to the performance. Cancelling wrong signals will cause the error propagation and result in larger deviations on timing offsets and power estimation. That's why the false alarm rate of SMUD is larger than the conventional method and becomes larger as RSS increases in Figure 3. The sum of miss detection and false alarm of the proposed method is lower than SMUD. Naturally, the error propagation is not serious. So we shall consider lowering both rates in place of the fixed false alarm rate. That's why the proposed method is better than SMUD. Comparing with the conventional method, the proposed method also achieves an excellent performance.

TABLE 1. SIMULATION PARAMETERS

Parameters	Value
Center Frequency	2.5GHz
Channel B.W.	10MHz
Sampling Frequency	11.429MHz
Useful Symbol Time	89.6μs
FFT Size	1024
Subcarrier spacing	11.16kHz
CP length	128 samples
Cell Radius	3km
Max RSS timing offset d_{max}	229 samples
Channel Model (ITU)	Veh A-60kmph
Ranging code length	144
Ranging Code Set	64
RSS/DSS Modulation	BPSK/QPSK
Timing Requirement	± 8 samples
Power Requirement	± 1 dB
Residual normalized frequency offsets	[-0.02, 0.02]

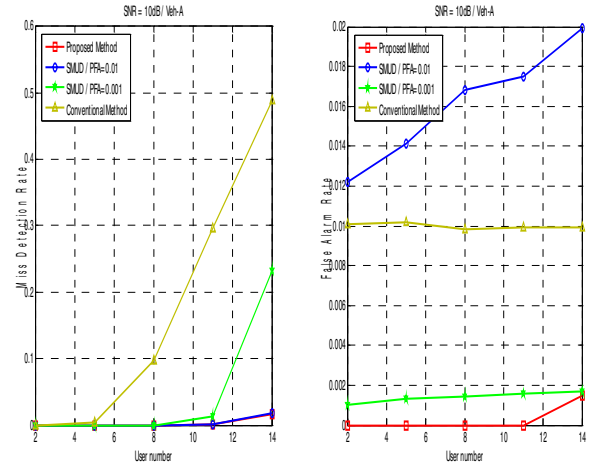


Figure 3. The probability of miss detection rate and false alarm rate

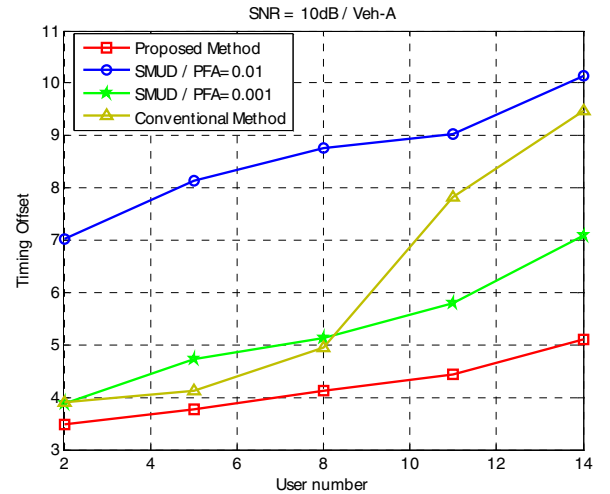


Figure 4. The comparison of timing offsets

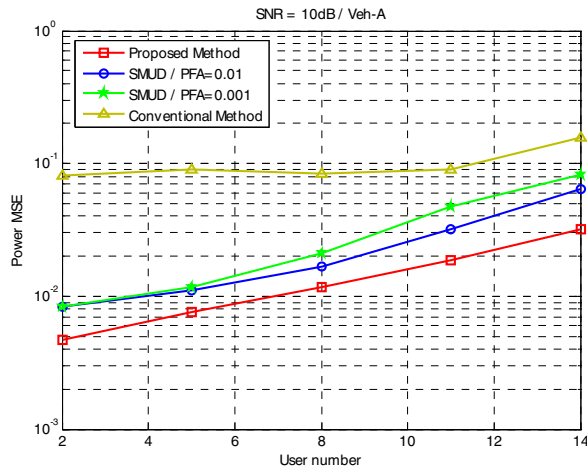


Figure 5. The mean square error of power estimation

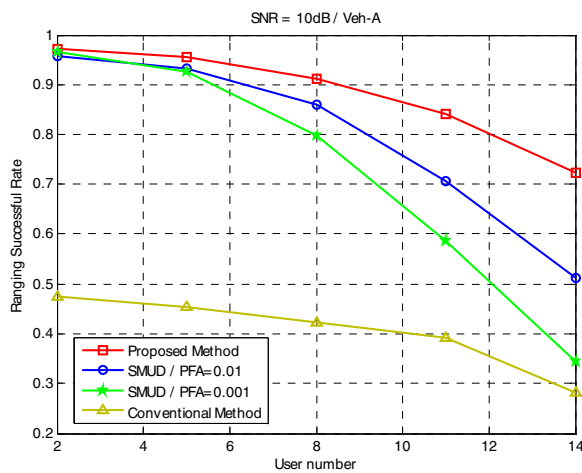


Figure 6. The ranging successful rate

Figure 4. shows the standard deviation of the timing offset estimation. The function is defined as $\sqrt{E(\hat{d}_{i,R} - d_{i,R})^2}$. The real timing offsets are chosen randomly during $[0, 229]$ samples. According to the simulation results, the timing precision becomes worse as the number of RSSs increases. The proposed method is more accurate than SMUD and the conventional method, due to the sliding window. The sliding window filters the false alarm multipath outside the window. It prevents the timing estimation occur a large deviation. Besides, the iterative RSS amendment can adjust the timing estimation after cancelling other interference. This is another important difference between SMUD and the proposed method.

Figure 5. shows the power estimation. The mean square error of power estimation is defined as $E[(1 - \hat{P}_i / P_i)^2]$. Figure 6. shows the successful ranging detection rate which is defined by 2 criterions. One is the remaining MS power deviation shall be within ± 1 dB of the target power level. Another is timing error shall be within $\pm T_b/128$ duration of the target arrival time. Here, T_b is the OFDMA symbol time.

The performance deviation between the proposed method and SMUD increases as the user number becomes large. The precision of power estimation is the main reason to cause that. The estimated power is influenced by the miss detection rate and the false alarm rate. Missed RSSs or the false-alarm RSSs result in more MAI. The proposed method can achieve higher power accuracy because of low MAI. Finally, we can find that the ranging successful rate is seventy percent when there are 14 RSSs on the same ranging slot. It improves performance 40% of SMUD and 160% of conventional method.

V. CONCLUSIONS

In this paper, we proposed a robust ranging detection method that takes the MAI cancellation into account. This idea can be applied on random access systems that belong to the interference-limited systems. For non-ideal ranging code systems, more RSSs mean more MAI. The probability of retransmitting ranging signals is increased. This situation also enlarges the total MAI. The proposed method can lower the MAI and shorten the ranging access time by combining the channel estimation and the multiuser ranging detection. The simulation shows the excellent improvements on the detection rate, false alarm rate, timing estimation and power estimation over the multipath Rayleigh fading channel.

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