Initial Uplink Synchronization and Power Control (Ranging Process) for OFDMA Systems

Xiaoyu Fu and Hlaing Minn*, *Member, IEEE*
Department of Electrical Engineering, School of Engineering and Computer Science
The University of Texas at Dallas. ({xxf031000, hlaing.minn} @utdallas.edu)

Abstract— **We address initial ranging process in OFDMA systems such as IEEE 802.16a. The proposed ranging method includes three main tasks – timing estimation, multi-user ranging code detection, and power estimation. All tasks are performed based on a bank of correlators corresponding to ranging codes. The timing estimation scheme is based on the peak of correlator outputs. The multi-user ranging code detection is based on the correlator outputs and an adaptive threshold. A novel adaptive threshold setting is proposed. A simple user-power estimator is derived based on the correlator outputs. A scheme of initial power adjustment at the random access users is also proposed which brings in a significant improvement in ranging code detection performance. The simulation results show that the proposed method works well even in the presence of several simultaneous random-access users and is robust to other data-users' interference. The simplicity of the proposed method is also quite appealing.**

I. INTRODUCTION

Orthogonal frequency division multiple access (OFDMA) has recently received significant interest and has been adopted as one of the three physical layer modes in the IEEE wireless MAN standard 802.16a [1]. In OFDMA, sub-carriers are grouped into sub-channels which are assigned to multiple users for simultaneous transmissions. To maintain the orthogonality among the sub-carriers in the uplink of OFDMA systems, the signals from all active users must arrive at the base station (BS) synchronously. This is accomplished by an initial uplink synchronization called a ranging process by which ranging subscriber stations (RSSs) adjust their transmission time instants and transmitted powers so that at the BS their ranging signals synchronize to the mini-slot boundary of the BS and have equal power. By means of the ranging process, the system compensates for the near/far problems (different propagation delays, received powers) in large cells. Generally, a ranging process includes initial ranging and periodic ranging. Initial ranging shall be used by any RSS that wants to synchronize to the system for the first time. To account for the user-movement over time, periodic ranging is used. In this paper, we focus on initial ranging process.

In OFDMA, the RSS acquires downlink synchronization and uplink transmission parameters from downlink control frames, e.g., DL-MAP and UL-MAP in 802.16a [1]. Then, it shall choose randomly a time-slot and a ranging code (from a set of ranging codes) to perform the ranging process in ranging channel. The ranging channel, which is set by the BS, is composed of some sub-channels. The ranging code here acts as a CDMA code in frequency-domain. Different ranging codes are allowed to collide on the ranging channel. After the BS separates colliding codes and extracts information on timing and power, it will broadcast a ranging response message that advertises the received ranging code and the ranging time-slot where the ranging code has been identified. The ranging response message also contains adjustments information (e.g., timing and power adjustment) and a status notification (e.g., success, re-transmission). The main tasks of the ranging process at the BS are timing estimation, multi-user ranging code detection, and power estimation.

To our best knowledge, no work on the ranging method for OFDMA has appeared in the literature. This paper presents a simple ranging method for OFDMA systems which performs well in environments such as those in Wireless MAN 802.16a.

II. SIGNAL MODEL

Consider an OFDMA system that consists of N_d sub-carriers. These sub-carriers are grouped into Q sub-channels. Each sub-channel has $p = N_d/Q$ sub-carriers. Our considered system mainly follows the IEEE 802.16a. The BS broadcasts the ranging channel information through UL-MAP. Initial-ranging transmissions shall be performed during one ranging time-slot which has two OFDMA symbol-intervals. The same ranging code is modulated and transmitted on the ranging channel during both symbol-intervals. The transmitted ranging signal of k-th RSS which chooses m-th ranging code is given by

$$\begin{aligned}
\boldsymbol{x}_k &= [x_k(0), \ldots, x_k(2N_d+2N_g-1)]^T \\
x_k(n) &= x_k(n+N_d+N_g) \\
&= \begin{cases} A_k A' \sum\limits_{i=0}^{N_d-1} c_m[i] e^{\frac{j2\pi in}{N_d}} & n \in (N_g, \ldots, N_d+N_g-1) \\ x_k(N_d+n) & n \in (0, \ldots, N_g-1) \end{cases}
\end{aligned} \tag{1}$$

where N_g is the number of cyclic prefix (CP) samples and A' is a normalizing factor to make $E[|x_k(n)|^2] = A_k^2$. A_k is an amplitude factor of the signal from k-th RSS, $\boldsymbol{x}_k$ is a $2(N_d+N_g)\times 1$ vector, $c_m[i]$ is the i-th sub-carrier symbol corresponding to m-th ranging code. $c_m[i]$ is nonzero only at the sub-carriers corresponding to the ranging channel where the ranging code is transmitted using BPSK modulation.

We assume that the channel gains remain constant at least during one ranging time-slot. Since the locations of different RSSs are different, the corresponding transmission delays are different. Hence, at the beginning of the ranging process, their relative delays with respect to the BS's time-slot boundary are

---

*Contact Author

different. The maximum possible relative delay is the round-trip transmission delay for a user at the cell boundary. In practice, we know the maximum relative delay from the knowledge of cell radius.

At the receiver we form an observation window of $N_d+N_g+d_{\max}$ samples to make sure that at least one complete OFDM symbol fills in the observation window. Suppose that there are totally K RSSs with the corresponding ranging code set $\{C'\}$. The received signal vector in the observation window is

$$\boldsymbol{Y} = \boldsymbol{X}\boldsymbol{H} + \boldsymbol{w} \tag{2}$$

where

$$\begin{aligned}
\boldsymbol{Y} &\equiv [y(0), y(1), \ldots, y(N_d + N_g + d_{\max} - 1)]^T \\
\boldsymbol{H} &\equiv [\boldsymbol{h}_1^T, \boldsymbol{h}_2^T, \ldots, \boldsymbol{h}_K^T]^T \\
\boldsymbol{h}_k &\equiv [h_k(0), h_k(1), \ldots, h_k(L-1)]^T \\
\boldsymbol{X} &\equiv [\boldsymbol{X}_1, \boldsymbol{X}_2, \ldots, \boldsymbol{X}_K] \\
\boldsymbol{X}_k &\equiv [\boldsymbol{x}'_k(d_k), \boldsymbol{x}'_k(d_k+1), \ldots, \boldsymbol{x}'_k(d_k+L-1)] \\
\boldsymbol{x}'_k(d_k) &\equiv [\mathbf{0}_{d_k}, x_k(0), \ldots, x_k(N_d + N_g + d_{\max} - d_k - 1)]^T.
\end{aligned} \tag{3}$$

In the above, $\mathbf{0}_{d_k} = [0, \ldots, 0]^T_{(1\times d_k)}$, $\boldsymbol{h}_k$, $\boldsymbol{X}_k$, and d_k are channel impulse response vector, signal vector, and relative delay for k-th RSS, respectively, and the superscript T denotes the transpose operation. $\boldsymbol{w}$ is a vector of uncorrelated, circularly symmetric, complex Gaussian noise samples with zero mean and equal variance σ_w^2.

III. PROPOSED RANGING ALGORITHM

We assume that the number of active RSSs, K, in one ranging time-slot is less than the number of ranging code N_c and the ranging codes transmitted by different RSSs in one time-slot are different. By a proper system design, both can be satisfied almost all the time.

A. Timing Offset Estimation

According to the very low cross-correlation property of the ranging codes, we can use a bank of correlators corresponding to N_c ranging codes to separate different ranging codes present in the received signal. Each correlator's output can be used to estimate the relative delay (time offset) for a possible user. Let us define

$$\boldsymbol{S}_m(d) \equiv \frac{1}{A_m}[\mathbf{0}_d, x_m(0), \ldots, x_m(N_d + N_g - 1), \mathbf{0}_{d_{\max}-d}]^T. \tag{4}$$

The output of m-th correlator at d-th sample instant is

$$\begin{aligned}
\tilde{Y}_m(d) &= \boldsymbol{S}_m^H(d)\boldsymbol{Y} = \boldsymbol{S}_m^H(d)\boldsymbol{X}\boldsymbol{H} + \boldsymbol{S}_m^H(d)\boldsymbol{w} \\
&= \begin{cases}
\boldsymbol{S}_m^H(d)\boldsymbol{X}_m\boldsymbol{h}_m + \sum\limits_{\substack{k=1\\k\neq m}}^{K} \boldsymbol{S}_m^H(d)\boldsymbol{X}_k\boldsymbol{h}_k & \\
\qquad + \boldsymbol{S}_m^H(d)\boldsymbol{w}, & m \in \{C'\} \\
\sum\limits_{k=1}^{K} \boldsymbol{S}_m^H(d)\boldsymbol{X}_k\boldsymbol{h}_k + \boldsymbol{S}_m^H(d)\boldsymbol{w}, & \text{otherwise.}
\end{cases}
\end{aligned} \tag{5}$$

where the superscript H denotes the Hermitian transpose operation. Then the timing point estimate from the m-th correlator is given by

$$\hat{d}_m = arg\ max_d\{|\tilde{Y}_m(d)| : d = 0, \ldots, d_{\max}\}. \tag{6}$$

B. Multi-User Ranging Code Detection

The multi-user ranging code detection utilizes the correlator output at the timing point estimate and a adaptive threshold. If the correlator output is above the threshold, the detector decides that there is a RSS using the corresponding ranging code. The threshold is the same for all correlators but it is adaptive from time-slot to time-slot. In the following, we pursue how to find the threshold value.

Since the differences in cross-correlation values of different ranging signals are quite small, the second term in (5) for the case of $m \in \{C'\}$ can be approximated as

$$\begin{aligned}
\sum_{k=1,k\neq m}^{K} \boldsymbol{S}_m^H(\hat{d}_m)\boldsymbol{X}_k\boldsymbol{h}_k &= \sum_{k=1,k\neq m}^{K} A_k\boldsymbol{R}_{k,m}^T(\hat{d}_m - d_k)\boldsymbol{h}_k \\
&\approx \sum_{k=1,k\neq m}^{K} A_k\bar{\boldsymbol{R}}^T\boldsymbol{h}_k
\end{aligned} \tag{7}$$

where

$$\begin{aligned}
\boldsymbol{R}_{k,m}(d) &\equiv [r_{k,m}(d), r_{k,m}(d-1), \ldots, r_{k,m}(d-L+1)]^T \\
r_{k,m}(d) &\equiv \boldsymbol{S}_k^H(d + d_m)\boldsymbol{x}'_m(d_m) \\
\bar{\boldsymbol{R}} &= \frac{\sum\limits_{k=1}^{N_c}\sum\limits_{m=1,m\neq k}^{N_c}\sum\limits_{d=0}^{d_{\max}}\boldsymbol{R}_{k,m}(d)}{(N_c^2 - N_c)(d_{\max}+1)}.
\end{aligned}$$

Here, $\bar{\boldsymbol{R}}$ represents the average of $\{\boldsymbol{R}_{k,m}(d)\colon k \neq m,\ \ k,\ m = 1, \ldots, N_c\}$. When the timing estimate is perfect, the amplitude of $\tilde{Y}_m(\hat{d}_m)$ is

$$|\tilde{Y}_m(\hat{d}_m)| \approx \begin{cases} |\mathcal{S}_m + \mathcal{I}_m + \mathcal{N}_m|, & m \in \{C'\} \\ |\mathcal{I}_m + \mathcal{N}_m|, & \text{otherwise} \end{cases} \tag{8}$$

where

$$\begin{aligned}
\mathcal{S}_m &= A_m(\boldsymbol{R}_0^T - \bar{\boldsymbol{R}}^T)\boldsymbol{h}_m \\
\mathcal{I}_m + \mathcal{N}_m &= \sum_{k=1}^{K} A_k\bar{\boldsymbol{R}}^T\boldsymbol{h}_k + \boldsymbol{S}_m^H(d)\boldsymbol{w} \\
\boldsymbol{R}_0 &= [r(0), r(-1), \ldots r(-L+1)]^T \\
r(d) &= r_{m,m}(d),\ \ m \in \{1, \ldots, N_c\}.
\end{aligned} \tag{9}$$

$\mathcal{S}_m$ is the signal term which only depnds on $\boldsymbol{h}_m$ and the signal amplitude factor A_m. $\mathcal{I}_m$ is the interference term introduced by other ranging codes and it depends on K, $\{\boldsymbol{X}_k\}$, $\{\boldsymbol{h}_k\}$, and $\{A_k\}$. $\mathcal{N}_m$ is the Gaussian noise term.

Let $(\mathcal{J}_m)_I$ and $(\mathcal{J}_m)_Q$ be the in-phase and quadrature terms of $\mathcal{I}_m + \mathcal{N}_m$ with reference to $\mathcal{S}_m$. On the average the two terms would have the same amplitude $\frac{|\mathcal{I}_m+\mathcal{N}_m|}{\sqrt{2}}$ and each term is equally likely to be positive or negative. Then we can approximate an average value of $|\mathcal{S}_m + \mathcal{I}_m + \mathcal{N}_m|$ by considering four equally likely vectors $|\mathcal{S}_m| \pm |(\mathcal{J}_m)_I| \pm j|(\mathcal{J}_m)_Q|$ and then (8) becomes

$$|\tilde{Y}_m(\hat{d}_m)| \approx \begin{cases} \frac{|\mathcal{S}_m|}{2}\sqrt{2E + 2\sqrt{E^2 - F^2}}, & m \in \{C'\} \\ |\mathcal{I}_m + \mathcal{N}_m|, & \text{otherwise} \end{cases} \tag{10}$$

where $E = 1 + \frac{1}{2}(\frac{|(\mathcal{I}_m+\mathcal{N}_m)|}{|\mathcal{S}_m|})^2$, $F = \frac{|(\mathcal{I}_m+\mathcal{N}_m)|}{|\mathcal{S}_m|}$. From (10), it is seen that for a given set of K, $\{\boldsymbol{X}_k\}$, $\{\boldsymbol{h}_k\}$, and $\{A_k\}$, the correlator output values corresponding to two possible cases (whether the corresponding ranging code is present in the received signal or not) have a distance

$$M = \frac{|\mathcal{S}_m|}{2}\sqrt{2E + 2\sqrt{E^2 - F^2}} - |\mathcal{I}_m + \mathcal{N}_m|. \qquad (11)$$

We can simply set the threshold at the mid-point between the two values. The detection threshold at each correlator is then given by

$$\eta = |\mathcal{I}_m + \mathcal{N}_m| + \frac{M}{2}. \qquad (12)$$

In the following, we obtain the approximate values of $|\mathcal{S}_m|$ and $|\mathcal{I}_m + \mathcal{N}_m|$. Since the cross-correlation values among the ranging codes are approximately the same, $\mathcal{I}_m$ is approximately the same for each correlator in one ranging time-slot. Hence, we estimate the value of $|\mathcal{I}_m + \mathcal{N}_m|$ as follows:

$$|\widehat{\mathcal{I} + \mathcal{N}}| = \frac{\sum_{d=0}^{d_{\max}} |\tilde{Y}_i(d)|}{d_{\max} + 1} \qquad (13)$$

$$\text{where} \quad i = arg\, min_m(|\tilde{Y}_m(\hat{d}_m)|) : m \in \{1, \ldots, N_c\}. \qquad (14)$$

Since $K < N_c$, $\tilde{Y}_i$ corresponds to the output of the correlator whose ranging code is not transmitted in current time-slot. That means it only contains noise and interference term. The $|\mathcal{S}_m|$ can be expressed as

$$\begin{aligned} |\mathcal{S}_m| &= \sqrt{A_m \boldsymbol{h}_m^H (\boldsymbol{R}_0 - \bar{\boldsymbol{R}})^* (\boldsymbol{R}_0 - \bar{\boldsymbol{R}})^T \boldsymbol{h}_m A_m} \\ &\equiv A_m \sqrt{\boldsymbol{h}_m^H \boldsymbol{B} \boldsymbol{h}_m} \qquad (15) \end{aligned}$$

where the superscript * represents the conjugate operation. The autocorrelation of each ranging code decreases slowly within small correlation lag range (e.g.,from 0 to $L-1$) On the other hand, the cross-correlation of different ranging codes is quite small when compared with autocorrelation within small correlation lag range. So $\boldsymbol{B}$ can be approximately given by

$$\begin{aligned} \boldsymbol{B} &\approx [r(0)\boldsymbol{R}_0,\ r(1)\boldsymbol{R}_0,\ \ldots,\ r(L-1)\boldsymbol{R}_0]^T \\ &\approx r(0) \cdot \begin{bmatrix} r(0) & r(-1) & \ldots & r(-L+1) \\ r(1) & r(0) & \ldots & r(-L+2) \\ \vdots & \vdots & \ddots & \vdots \\ r(L-1) & r(L-2) & \ldots & r(0) \end{bmatrix} \\ &\equiv r(0)\boldsymbol{D}. \qquad (16) \end{aligned}$$

Then we have

$$|\mathcal{S}_m| \approx A_m \sqrt{r(0) \boldsymbol{h}_m^H \boldsymbol{D} \boldsymbol{h}_m} \qquad (17)$$

which together with (13) give the threshold in (12). Now, let us consider two schemes.

1) RSS without initial power adjustment: In this scheme, when a RSS initiates a ranging process, it transmits the ranging signal at a pre-defined minimum power level P_t as in IEEE.802.16a [1]. The signal amplitude factor A_m is given by

$$A_m = \sqrt{P_t}. \qquad (18)$$

Then (17) becomes

$$|\mathcal{S}_m| \approx \sqrt{P_t r(0) \boldsymbol{h}_m^H \boldsymbol{D} \boldsymbol{h}_m} = \sqrt{G P_t r(0)(N_d + N_g)} \qquad (19)$$

where $G = \frac{\boldsymbol{h}_m^H \boldsymbol{D} \boldsymbol{h}_m}{N_d + N_g}$ is the channel power gain and $\boldsymbol{h}_m^H \boldsymbol{D} \boldsymbol{h}_m$ is a random variable depending on the channel impulse response $\boldsymbol{h}_m$. Since G is unknown, a design parameter α can be used in place of $\sqrt{G}$. We will show the performance obtained with different values of α in section IV.

2) RSS with initial power adjustment: In this scheme, RSS estimates the received power (hence, obtains the channel power gain estimate $\hat{G}$) from the downlink control frames before initiating the ranging process. Note that the sub-carriers of a sub-channel are spread out over the entire band and hence, the channel power gain estimate obtained from the downlink control frame is approximately the same as the ranging channel power gain. Then RSS adjusts its transmission power to compensate for the power loss due to channel. The transmitted signal amplitude factor A_m in this case is given by

$$A_m = \sqrt{\frac{P_r}{\hat{G}}} \qquad (20)$$

where P_r is the target signal power of RSS at the BS. With this initial power adjustment scheme, all signal powers of RSSs are approximately the same at the BS, i.e., $P_r \approx \frac{A_m^2 \boldsymbol{h}_m^H \boldsymbol{D} \boldsymbol{h}_m}{N_d + N_g}$. So we have

$$A_m \approx \sqrt{\frac{P_r(N_d + N_g)}{\boldsymbol{h}_m^H \boldsymbol{D} \boldsymbol{h}_m}} \qquad (21)$$

and (17) now becomes

$$|\mathcal{S}_m| \approx \sqrt{P_r r(0)(N_d + N_g)}. \qquad (22)$$

C. RSS Power Estimation

From (8), (21), and (22), the signal power estimate at the BS for each RSS is obtained by

$$\begin{aligned} \hat{P}_k &= \frac{A_k^2 \boldsymbol{h}_k^H \boldsymbol{D} \boldsymbol{h}_k}{N_d + N_g} \approx \frac{|\mathcal{S}_k|^2}{r(0)(N_d + N_g)} \\ &\approx \frac{|\tilde{Y}_k(\hat{d}_k) - \widetilde{\mathcal{I} + \mathcal{N}}|^2}{r(0)(N_d + N_g)}, \quad k \in \{1, \ldots, N_c\} \qquad (23) \end{aligned}$$

where $\widetilde{\mathcal{I} + \mathcal{N}}$ is given by

$$\widetilde{\mathcal{I} + \mathcal{N}} = \frac{\sum_{d=0}^{d_{\max}} \tilde{Y}_i(d)}{d_{\max} + 1}. \qquad (24)$$

D. Ranging Process Algorithm

After obtaining the estimates of k-th RSS parameters, the BS compares them with ranging requirements. If they satisfy the requirements, the ranging process for k-th RSS is completed and successful. Otherwise, BS should send timing and power adjustments information and request RSS to re-transmit in a next available ranging time-slot. The whole ranging process at the BS is described in the following:

1) BS uses a correlator bank to calculate timing estimates and ranging code detection metric using (6) and (5).

2) BS determines whether each ranging code is active or not by comparing the corresponding detection metric $|\tilde{Y}_m(\hat{d}_m)|$ with the threshold η using (12).

3) BS estimates received signal power for each active RSS using (23).

4) For each detected active RSS, BS compares estimated values of timing point and power with the requirements. If they satisfy

the requirements, BS performs step 6). Otherwise, step 5).
5) BS sends timing and power adjustment parameters to RSS and requests RSS to re-transmit a ranging code in a next available ranging time-slot. Then the ranging process at the BS repeats starting from step 1).
6) BS informs RSS that ranging process is successful.

IV. SIMULATION RESULTS AND DISCUSSION

A. Simulation Parameters

The OFDMA system parameters are selected from [1]. The uplink bandwidth is 3 MHz, the sub-carrier spacing is 1.67 KHz, $N_d = 2048$ and $N_g = 64$. The duplexing mode is TDD. We use BPSK format for RSS and QPSK for data transmitting SS (DSS). The combined transmit and receive filter is a raised-cosine filter $g_T(t)$ with a roll-off factor of 0.5. The ranging channel has two sub-channels where each sub-channel is composed of 53 used sub-carriers and 11 unused sub-carriers. SUI-3 channel model with 3 paths [2] is considered in our simulation. The number of sample-spaced channel taps, L, is set to 7. Channels of different users are assumed to be independent.

The ranging parameter requirements are set as follows based on [1]. The timing requirement is that all uplink OFDM symbols should arrive at the BS within an accuracy of $\pm 25\%$ of the minimum guard-interval or better. In our case, it equals to 16 samples. The power requirement of [1] is that SNR of each RSS at the BS should be above 9.4 dB. In our method, we set it equal to 11 dB to account for the power estimation errors. We consider that the cell radius is 5 km which gives the maximum transmission delay (round trip) $d_{\max} \approx 34\text{us} = 114$. According to [1], the adjustment step sizes of power and time are 0.25 dB and 1 sample. Adjustment step index ranges of power and time are $(-2^{32}-1) \sim (2^{32}-1)$ and $(-2^8-1) \sim (2^8-1)$, respectively. One uplink frame has $3N+1$ OFDM symbols, where N is an arbitrary integer. One ranging time-slot equals to two OFDM symbols. We choose $N = \{1, 3, 5, 7, 9\}$, corresponding to $\{2, 5, 8, 11, 14\}$ ranging time-slots in one uplink frame. The number of ranging codes, N_c, is 16.

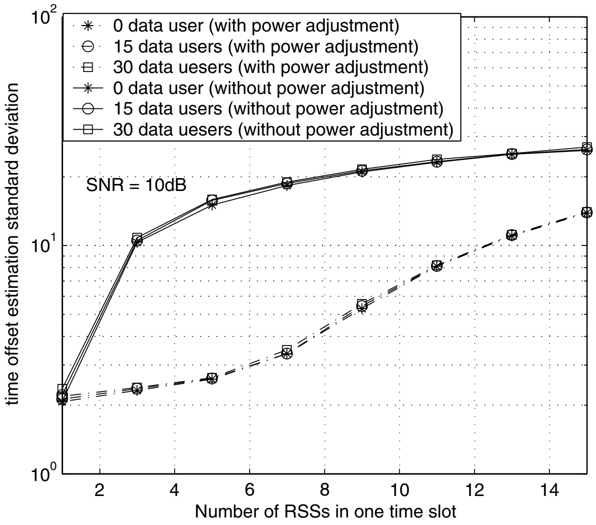

Fig. 1. The standard deviation of timing offset estimator

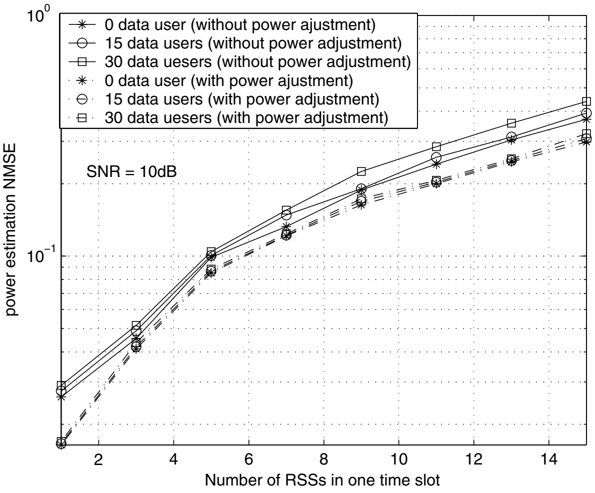

Fig. 2. The normalized MSE of the power estimator

B. Simulation Results

Fig. 1 shows the standard deviation of the timing estimate versus the number of RSS for the conditions of 0 DSS, 15 DSSs, and 30 DSSs in one ranging time-slot. Note that, 30 is maximum number of DSSs in OFDMA system defined in 802.16a. In each simulation run, the true timing offset is taken randomly from the interval $[0, d_{\max}]$. For a given number of RSSs, performance results are obtained from 10000 simulation runs. The performance of the timing estimator degrades as the number of RSSs increases. But as the number of DSSs increases, the performance loss is negligible. The proposed method without initial power adjustment (as in 802.16a) satisfies the timing requirement most of the time if the number of simultaneous RSSs within a time-slot is five or less. The proposed method with the proposed initial power adjustment satisfies the timing requirement most of the time even if there are 15 simultaneous RSSs within a time-slot.

Fig. 2 shows the normalized power estimation MSE defined as $E[(1-\frac{\hat{P}}{P})^2]$ versus the number of RSSs for 0 DSS, 15 DSSs, and 30 DSSs in one ranging time-slot. For most likely situations where there are only a few (say 4 or less) simultaneous RSSs within a ranging time-slot, the power estimates are most of the time within 90% accuracy. The performance degrades as RSS increases but it is robust to the DSS interference.

Fig. 3 shows the average detection error probability defined as $E[\frac{D_\rho}{N_c}]$ for the ranging code detector with different values of α for the scheme without initial power adjustment in RSS where D_ρ is the number of correlators with uncorrect detection in one rannging time-slot. Based on the results, a good choice for the value of α would be 1. For most likely situations where there are only a few (say 4 or less) simultaneous RSSs within a ranging time-slot, the detection error probability of the proposed method without initial power adjustment with $\alpha = 1$ is less than 0.1.

Fig. 4 shows the average detection error probability of the ranging code detector for the scheme with initial power adjustment in RSS. We assume in our simulation that the power estimation error of RSS is $\pm 10\%$. For most likely situations where

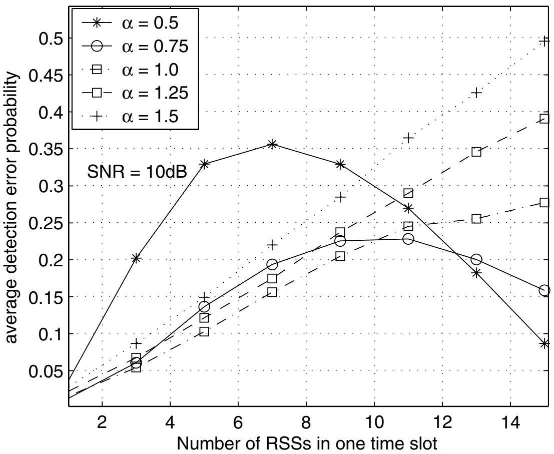

Fig. 3. The average detection error probability of the ranging code detector (without initial power adjustment in RSS)

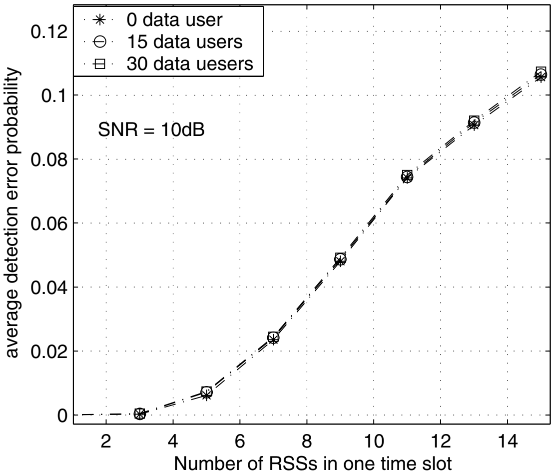

Fig. 4. The average detection error probability of the ranging code detector (with initial power adjustment in RSS)

there are only a few (say 4 or less) simultaneous RSSs within a ranging time-slot, the detection error probability of the proposed method with initial power adjustment is less than 0.005. The performance of the ranging code detector is also observed to be very robust against the number of DSSs. The proposed initial power adjustment brings in a significant improvement in detection performance as can be seen from Fig. 3 and Fig. 4. It also improves the timing and power estimation performance as can be seen in Fig. 1 and Fig. 2.

To quantify the worst-case performance of the whole ranging process, we evaluate the number of trials (uplink frames) required for successful completion of a group of RSSs that initiated ranging in the same uplink frame. This result shows the number of trials required for the most unfavorable RSS that finishes ranging in the last within the group. In our evaluation, the (initial) number of RSSs within the uplink frame where they initiate their ranging is fixed at 16. We consider several number of ranging time-slots in one uplink frame to cover different system environments. After each trial, some RSSs complete ranging process successfully and introduce DSS interference to the remaining RSSs in the next trial. When all RSSs complete ranging process, the whole ranging process for the group is completed and the number of trials is recorded. Fig. 5 shows the average of this worst-case number of trials required for a successful completion of the ranging process for a group of RSSs based on 1000 simulation runs of successful group ranging process. On the average, the most unfavorable RSS has to perform about 4 trials to finish a successful ranging process. The result also indicates that for 16 RSSs within an uplink frame, two ranging time-slots are sufficient.

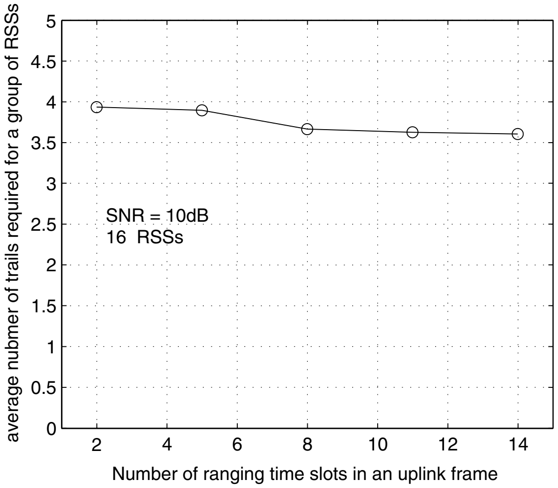

Fig. 5. The worst-case performance of the whole ranging process (with initial power adjustment)

V. CONCLUSIONS

We have presented an initial ranging method for OFDMA systems in multipath fading environments. The proposed method includes multi-user timing estimation, multi-user ranging code detection, and multi-user power estimation. The proposed method is based on a bank of correlators corresponding to ranging codes and is quite simple to implement. The timing estimation scheme is based on the peak of correlator outputs while the multi-user ranging code detection is performed by comparing the correlator outputs with an adaptive threshold. A novel adaptive threshold setting for ranging code detection is proposed. A simple user-power estimator is derived based on the correlator outputs. A scheme of initial power adjustment at the random access users is also proposed. This scheme brings in a significant improvement in ranging code detection performance and noticeable improvement in timing and power estimation performance. Hence, it is very useful in enhancing the IEEE 802.16a standard. Simulation results show that the proposed method works well even when there are several simultaneous random access users and it is quite robust to the interference introduced by other data users.

REFERENCES

[1] IEEE LAN/MAN Standards Committee, "Broadband Wireless Access: IEEE MAN standard," *IEEE 802.16 a*, 2003.

[2] IEEE LAN/MAN Standards Committee, "Channel Models for Fixed Wireless Applications," *Document IEEE.802.16.3c-01/29r4*.