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MULTIUSER DETECTION BASED TIMING OFFSET ESTIMATION FOR UPLINK MOBILE WIMAX

[1]LAKSHMANAN. M, [2]P. S. MALLICK, [3]L. NITHYANANDAN
[1] Member IEEE,
[2] Senior Member IEEE
[3] Pondicherry Engineering College, India.
Email: [1]mlakshmanan@vit.ac.in , [2]psmallick@vit.ac.in , [3]nithi@pec.edu

ABSTRACT

The approval of the new mobile WiMAX helps in realizing the real time wireless broadband networks with large coverage area and high data rate. In mobile WiMAX whenever a subscriber comes into the cell radius of base station (BS), it has to get synchronized; this process in mobile WiMAX is termed as initial ranging. This paper proposes a novel Multiuser Detection for uplink mobile WiMAX with better timing offset estimation and reduces the multiple access interference (MAI) at the base station.

Key Words: *Initial Ranging, Timing Offset estimation, Multiple Access Interference (MAI), Round trip Transit Delay*

1. INTRODUCTION

The demand for broadband wireless technologies has been increased in leaps and bounds. The amendment to the IEEE802.16a gave birth to the mobile WiMAX standard IEEE802.16e2005 and made the things more realistic. The interesting feature of the IEEE802.16e is that it supports more than one physical layer. Orthogonal Frequency Division Multiple Access (OFDMA) is one of the interesting features of IEEE802.16e [4].

To meet the high data rate, wide coverage area and real time traffic, the new mobile WiMAX should be equipped with efficient and reliable protocols between the mobile subscriber station and the base station. OFDMA PHY mode of the new mobile WiMAX supports the multiple users. Here the base station divides the available subcarriers into subchannels. Some of the non-adjacent subcarriers are even grouped to make a subchannel. These divided subchannels are allocated to the mobile subscriber station in an adaptive way based on the requirement of subscriber station and the channel conditions. At the same time OFDM is robust against ISI (Inter Symbol Interference), frequency selective fading, another advantage of OFDMA over the Multi Carrier Code Division Multiple Access (MC-CDMA) is that MC-CDMA uses same set of subcarriers to all the subscriber station where as in OFDMA subscriber station use different set of frequencies resulting in less interference among the users and also OFDMA supports both soft and hard handover [3]

In multiple access system like OFDMA, synchronization is a very important process at the receiver for both bursty and continuous data. Whenever the subscriber enters into the cell radius of a base station, it first scans for the Downlink Link Channel (DL). The base station periodically broadcast the Uplink Channel Descriptor (UCD). The subscriber station requests for the network entry using the ULMAP (Uplink Multiple Accesses Protocol) and DLMAP (Downlink Multiple Accesses Protocol). This process in WiMAX standard is termed as ranging. In ranging process the Round Trip Transit Delay (RTD) is mainly estimated [4].

In initial ranging process the base station broadcasts all the available ranging codes (mostly PN sequence codes) in UCD. The subscriber station scans the UCD and selects randomly one of the available ranging codes, modulates it to an OFDM symbol. Then it replicates the OFDM symbol twice, adds the cyclic prefix (CP) for phase continuation [3] and transmits it to the base station. At the base station, CP is removed, demodulates it and tries to identify the code and the timing offset of each subscriber station. If the code is identified, then base station broadcast the identified codes with adjustment parameters of timing offset and power level. It is notified that whether the initial ranging process is successful or not.

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If any subscriber station's ranging process is failed (since the base station is busy or the number of subscriber station supported by a base station has reached to the saturation level) then the subscriber station sends back its information with some increased power. If the base station ignores, the subscriber station again sends the code with increased power and the process continues either the subscriber station reaches its maximum power or the base station accepts the code. If either of the two does not happen, the subscriber station should again start the initial ranging process from the beginning [4].

All the process mentioned above should take place within a tolerable delay while the subscriber stations are moving with high speeds. Therefore, the initial ranging methods should be very efficient, quick with precise timing offset estimation. In this paper a novel Multiuser Detection algorithm is proposed for initial ranging in uplink mobile WiMAX based on SMUD algorithm proposed by Ming, etal [2] and the performance of this algorithm is compared with the initial ranging for WiMAX (802.16e) proposed by Hisham A. Mahmood, etal [1].

Chapter 1 deals with introduction. Chapter 2 gives the system model used for the work. Chapter 3 discusses about the conventional methods for ranging process. Chapter 4 deals with the proposed SMUD algorithm for uplink mobile WiMAX. Chapter 5 gives the simulation results and analysis. Chapter 6 gives the conclusion.

2. SYSTEM MODEL

In this work, IEEE802.16e standard is considered. The Uplink of OFDMA has N_t subcarriers, in which, few subcarriers are assigned to guard band. Let N_d be the subcarriers grouped into Q subchannels, so each subchannel has N_d/Q subcarriers. The base station broadcasts all the ranging information regarding the ranging subchannels, ranging codes and ranging opportunities in the ULMAP [8].

The k^{th} user signal in frequency domain is denoted as

$$C_p^{(k)} = \left[C_p^{(k)}(0), C_p^{(k)}(1), \ldots, C_p^{(k)}(L-1)\right]^T \quad (1)$$

where p is the index of the randomly chosen ranging code and L is the length of the ranging code. The signal is then extended to the length of N_t by inserting $N_t - L$ zeros that result in

$$X_p^{(k)} = \left[X_p^{(k)}(0), X_p^{(k)}(1), \ldots\ldots, X_p^{(k)}(N_t - 1)\right]^T \quad (2)$$

Note that

$$X_p^{(k)}(m) = \begin{cases} C_p^{(k)}(n) & if\ m = i_r(n) \\ 0 & Otherwise \end{cases} \quad (3)$$

where $i_r(n)$ is the index of the n[th] ranging subcarrier.

The vector $X_p^{(k)}$ is then fed to an N_t point Inverse Discrete Fourier Transform (IDFT). The resulting signal in time domain is extended over two OFDMA symbols by repeating $X_p^{(k)}$ twice and adding the cyclic prefix and postfix. The transmitted signal $S_p^{(k)}$ is represented as

$$S_p^{(k)} = \left[S_p^{(k)}(0), S_p^{(k)}(1), \ldots\ldots, S_p^{(k)}(2N_t + 2CP - 1)\right]^T \quad (4)$$

$S_p^{(k)}$ is further expanded by using (2) as in (5)

$$S_p^{(k)} = \left[x_p^{(k)}(N_t - CP), \ldots, x_p^{(k)}(N_t - 1),\ x_p^{(k)}(0), \ldots, x_p^{(k)}(N_t - 1), x_p^{(k)}(0), \ldots, x_p^{(k)}(N_t - 1),\ x_p^{(k)}(0), \ldots, x_p^{(k)}(CP - 1)\right]^T \quad (5)$$

In this work, channel path of a Ranging Subscriber Station (RSS) is considered. The RSS's ranging code is $S_p^{(k)}$, and timing offset of the path is τ, then the observed RSS signal without any channel implications can be

$$b(n,\tau) = S_p^{(k)} \odot \mathrm{v}(\tau) \quad (6)$$

where $\odot$ denotes vector element-wise product, and $v(\tau)$ is a $N_r \times 1$ vector whose elements are given by

$$v(\tau)[m] = e^{-j2\pi N\beta[m](\tau-(N_g-\tau_{max}))} \quad (7)$$

The number of possible timing offsets is given as

$$M_t = \tau_{max} + d_{max} + L_{max} + 1 \quad (8)$$

where τ_{max} is the tolerable delay, L_{max} be the maximum channel length and d_{max} the maximum propagation delay. For all possible ranging codes N_c, there are $N_c \times M_t$ such possible paths and the observed ranging signal $\tilde{Y}$ can be expressed by a linear combination of them as

$$\tilde{Y}_2 = \sum_{n=1}^{N_C} \sum_{\tau=-\tau_{max}}^{d_{max}+L_{max}} \tilde{h}(n,\tau) b(n,\tau) + \widetilde{w}_2 \quad (9)$$

where $\widetilde{w}_2$ is the combined effect of noise and interference, $b(n,\tau)$ is given in (6) and $\tilde{h}(n,\tau)$ is the channel impulse response.

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3. CONVENTIONAL METHODS

The conventional way of detecting the received codes at the base station is by the process of correlation. The conventional process just blindly tries to correlate the received codes with the available codes at the base station, this process results in heavy computational complexity. If the number of codes received at the base station is L and the number of possible timing offset is T_i, then it requires L× T_i correlations to detect a code. This process requires huge computations. Since the multiplications take more time in this methodology, the correlation process is obsolete for fast moving subscriber station.

Another method is to auto-correlate the received signal with its delayed replica, by exploiting the repetition in the ranging code. In this method the subscriber station signal has been relieved from other user signal. This will increase the complexity and delay affecting the quality of other users' estimation [1].

In other WiMAX standards like 802.16a and 802.16b, the number of ranging codes used is 16 where as in 802.16e the codes used are 256 so the amount of computational complexity automatically increases and that would be eight times higher than that of 802.16a and 802.16b. In 802.16e the available codes are divided into initial ranging codes, bandwidth requests codes and periodic ranging codes. More codes are assigned to the initial ranging process [5-8].

3.1 INITIAL RANGING ALGORITHM

The Initial Ranging Algorithm has three steps.

3.1.1 ENERGY DETECTION

In this step the energy present in each signal received is measured. There are three possible OFDM symbols,

i) Symbols having no relevant data.
ii) Symbols with incomplete parts of a ranging code which causes interference to other Data Subscribers (DSS).
iii) Symbols with complete ranging code.

In this work, complete ranging code case is considered.

Measuring energy in this approach has got two advantages:

i) The probability of noise triggering the energy Detection is low in frequency domain because the subcarriers are not adjacent.

ii) Once the energy is detected in a ranging user and then the energy is used for the power estimation.

Energy within the ranging code is measured, a threshold η_1 has been set to decide if the OFDMA symbol contains a ranging code or not. To find the threshold η_1, the probability of a false alarm (P_{fa}) and the probability of misdetection (P_{md}) are defined. P_{fa} is the probability of a noise only symbol's energy exceeding threshold (η_1). P_{md} is the probability of the energy of an OFDMA symbol not exceeding (η_1) [11]. The measured energy in the ranging channel will be,

$$E_g = \sum_{n=0}^{L-1} |Y(m)|^2 \quad (10)$$

The probability of false alarm is

$$P_{fa} = erfc\left(\frac{\eta_1 - \mu_1}{\sqrt{2\pi\sigma_1^2}}\right) \quad (11)$$

where μ_1= LN_o

$$\sigma_1^2 = LN_o{}^2$$

where L is the normalized threshold and N_o is the variance of the channel.

Similarly the probability of missed detection P_{md} is

$$P_{md} = 1 - erfc\left(\frac{\eta_1 - \mu_2}{\sqrt{2\pi\sigma_2^2}}\right) \quad (12)$$

where μ_2 = L + LN_o

$$\sigma_2^2 = LN_o{}^2 + 2LNo$$

where L is the normalized threshold and N_o is the variance of the channel.

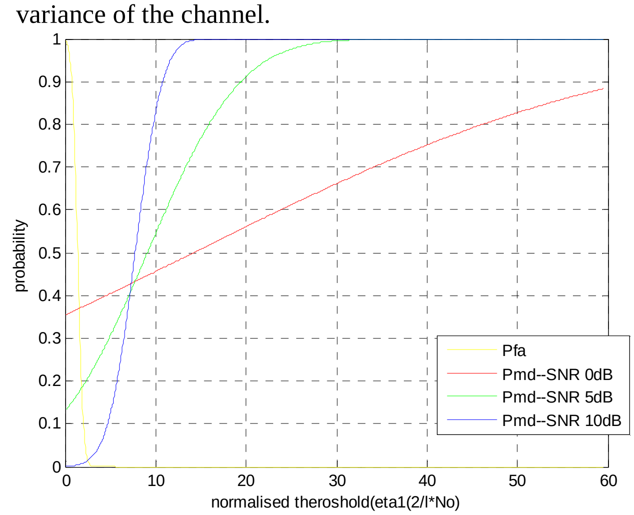

Fig. 1 P_{fa} and P_{md} for different noise levels

Fig. 1 shows the normalized threshold L and variance of channel N_o with the probability of false alarm P_{fa} and probability of misdetection P_{md}

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plotted for different values of SNR. From the Fig. 1, it is observed that the P_{fa} values remain constant. A convenient threshold is set from the Fig. 1 so that OFDM symbols with ranging code can be found.

3.1.2 TIMING OFFSET ESTIMATION

The received signal $Y(m)$ will be

$$Y(m) = \sum_{i=0}^{k-1} C_p^{(i)}(m) e^{j\emptyset_m(\tau_i)} + w(m) \qquad (13)$$

where $\emptyset_m(\tau_i) = 2\pi m\tau_i/\mathrm{N_t}$

Since the operations are done in frequency domain, the timing offset would be directly translated into linear phase shift. The linear phase shift for each code in the current OFDMA symbol is estimated.

Applying all possible linear phase shifts and considering the energy of the real part of the signal $E_r\ (u)$ as,

$$E_r\ (u) = \sum_{n=0}^{L-1}\sum_{i=0}^{K-1} C_p^{(i)}(m)\cos[\emptyset_m(\tau_i - \tau_u)] + W_R(m)\cos[\emptyset_m(\tau_u)] \qquad (14)$$

A peak value in the measured energy $E_r(u)$ is attained when $\tau_i = \tau_u$; it is required to set a threshold for detecting the peaks and thus estimate τ_i.

There are two cases:

Case (i): $\tau_i \neq \tau_u$ have the mean of μ_3 as

$$\mu_3 = \frac{L\left(K+\frac{No}{2}\right)}{2} \qquad (15)$$

Case (ii): $\tau_i = \tau_u$ have the mean of μ_4 as

$$\mu_4 = \frac{K+1+\frac{No}{2}}{2} \qquad (16)$$

The estimated mean $\bar{\mu}_i$ is given as

$$\bar{\mu}_i = \frac{\mu_i}{\bar{E}_r} \qquad (17)$$

where $\bar{E}_r$ is the normalized value of $E_r(u)$.

$$\bar{E}_r = \frac{K\mu_4 + (T_{max} - K)\mu_3}{T_{max}}\ ; \qquad K < T_{max} \qquad (18)$$

Fig. 2 shows the different ranging codes with normalized energy levels plotted for two cases: $\tau_i \neq \tau_u$, the mean is μ_3 (in Fig. 2 mentioned as 3); $\tau_i = \tau_u$, the mean is μ_4 (in Fig. 2 mentioned as 4). Fig. 2 is very useful to determine whether the found timing offset is within the acceptable level or not. When $\tau_i = \tau_u$ maximum peak energy level is attained, whereas $\tau_i \neq \tau_u$, the peak energy level is low. A threshold has to be set between these two peaks so that the timing offset is authenticated. It is also found that whenever the ranging codes per OFDM symbol increases the difference between the two peaks decreases. It is indicated that the timing offset estimation error increases as the number of ranging subscriber station increases.

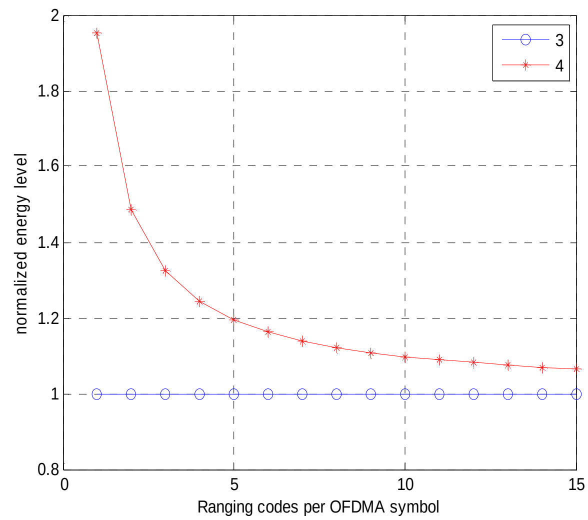

Fig. 2 μ_3 and μ_4 for different ranging codes

3.1.3 CODE DETECTION

In the previous steps, the ranging codes with noise and codes with huge timing offset are eliminated. This step is used to detect which code was transmitted out of the remaining ranging codes. After removing the linear phase shift corresponding to each ranging code and the cross-correlation is done with all possible ranging codes. The correlator output is given as,

$$E_c^{(v)}(i) = \sum_{n=0}^{L-1} \Re\{Y(m)e^{j\emptyset_m(\hat{\tau}_i)}\} C_p^{(i)}(n) \qquad (19)$$

The ranging code with maximum correlation is chosen [8].

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4. MULTIUSER DETECTION FOR MOBILE WIMAX

The ranging code with maximum correlation is obtained using Initial Ranging Algorithm for different iterations. At iteration 'i', let $\{\tilde{n}_1, \dots, \tilde{n}_{i-1}\}$ be the detected codes and the corresponding delays are $\{\tau_i, \dots, \tau_{i-1}\}$, Define $\tilde{b}_i = b(\tilde{n}_i, \tilde{\tau}_i)$ and $B_i = (\tilde{b}_1, \tilde{b}_2, \dots, \tilde{b}_i)$ [2].

The steps involved in Multiuser detection algorithm are as follows:

Step 1: Initialize the iteration number 'i'= 1 and an empty matrix B_0 of size (1 x i).

Step 2: Project $\tilde{Y}_2$ onto the null space of the detected paths as

$$\tilde{Y}_{2,i} = (I - B_{i-1}(B_{i-1}^H B_{i-1})^{-1} B_{i-1}^H)\tilde{Y}_2 \qquad (20)$$

Step 3: Define vector correlation function

$$R\left(b(n,\tau)\middle|\tilde{Y}_{2,1}\right) = \frac{\left|b(n,\tau)^H \tilde{Y}_{2,i}\right|}{\sqrt{\tilde{Y}_{2,i}^H \tilde{Y}_{2,1}}} = r_i \qquad (21)$$

The most likely valid path is determined by

$$\{\tilde{n}_i, \tilde{\tau}_i\} = \arg\max_{n \in [1, N_c] \quad \tau \in \mathrm{T}} R\left(b(n,\tau)\middle|\tilde{Y}_{2,1}\right) \qquad (22)$$

where T is the set of possible timing offsets.

Step 4: There are M_t possible invalid paths for an inactive ranging code. It might trigger the false alarm if one of the invalid paths passes the pre-defined threshold λ_t [5]. The probability of such an event is given by

$$P_{fa}(\lambda_t) = 1 - \left(\int_0^{\lambda_t} 2ue^{-u^2} du\right)^{M_t}$$
$$P_{fa}(\lambda_t) = 1 - \left(1 - e^{-\lambda_t{}^2}\right)^{M_t}$$
$$P_{fa}(\lambda_t) \approx M_t e^{-\lambda_t{}^2} \qquad (23)$$

Solving the above equation and neglecting the higher order terms of $e^{-\lambda_t^2}$ which decay very quickly the threshold value can be set as

$$\lambda_t = \sqrt{\log(M_t) - \log(\hat{P}_{fa})} \qquad (24)$$

Step 5: If $r_i < \lambda_t$, $b(\tilde{n}_i, \tilde{\tau}_i)$ is not a valid path, and the iteration stops. Otherwise, increment the iteration index i and start the next iteration from step 2.

The least square channel estimation is given by

$$\tilde{h}_i = (B_i^H B_i)^{-1} B_i^H \tilde{Y}_2 \qquad (25)$$

Equation (20) combines the interference cancellation and channel estimation in (25) as

$$\tilde{Y}_{2,i} = \tilde{Y}_2 - B_{i-1}\tilde{h}_{i-1}$$
$$= (I - B_{i-1}(B_{i-1}^H B_{i-1})^{-1} B_{i-1}^H)\tilde{Y}_2 \qquad (26)$$

After the iteration process, "I" sets of transmission parameters are obtained, each has the channel estimate $h_I[i]$, the timing offset $\tilde{\tau}_i$ and also the ranging code index $\tilde{n}_i$, where 'i' is the index of the valid path.

Let L_o be the total number of valid paths for a subscriber represented by b_k with channel h_k for all $k\epsilon[1, L_o]$ [9]. The ranging signal $\tilde{Y}_{2,i}$ after interference cancelation at iteration 'i' can be written as

$$\tilde{Y}_{2,i} = \sum_{k=1}^{L_o} \rho_{i,k} h_k\, b_k + \widetilde{\omega}_i \qquad (27)$$

where $\rho_{i,k}$ is the ratio of the residual channel estimation error to the original channel, $\widetilde{\omega}_i$ is the additive effect of noise of wrongly detected invalid paths. It can be seen that in the first iteration no interference has been cancelled since all of them are equal to one. The reduction of the interference can be observed by the values of $\{\rho_{i,k}\}$.

If the proposed algorithm detects a valid path then the value of $|\rho(i,k)|^2$ decreases over the iteration, whereas in an ideal case it would be $|\rho(i,k)|^2 = 0$.

This algorithm successively identifies the likely valid paths and tries to reduce their interference for further detection of other ranging subscriber signals.

The proposed Multiuser detection needs to compute (20) and (21) in each iteration. The simplification of (20) is given in [9]. Generally the number of subcarriers in one ranging opportunity N_r is much smaller than N_t. The complexity can be even reduced by using FFT pruning technique proposed in [10]. For the computation of (20), the complexity comes from the calculation of the matrix D_i for i[th] iteration and is given as

$$D_i = B_i(B_i^H B_i)^{-1} B_i^H \qquad (28)$$

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When i=1, ${B^H}_1 B_1 = N_r$ and calculation of D_1 is trivial. Now assume D_i is available, and the matrix at $(i+1)^{th}$ iteration can be calculated as

$$D_{i+1} = D_i + \frac{(D_i \tilde{b}_{i+1} - \tilde{b}_{i+1})(D_i \tilde{b}_{i+1} - \tilde{b}_{i+1})^H}{N_r - \tilde{b}_{i+1}^H D_i \tilde{b}_{i+1}} \quad (29)$$

Therefore, D_{i+1} can be computed recursively with low complexity. The complexity of the proposed Multiuser detection for mobile WiMAX has to be evaluated from the number of additions and multiplications required at each iteration [2]. At each iteration, the Multiuser Detection needs to perform $(12N_r^2 + 6N_r + 4N_c N \log_2 N + 2N_c M_t + 1)$ real multiplications and $(12N_r^2 + 7N_r + 4N_c N \log_2 N + 2N_c M_t - 2)$ real additions. The complexity of the algorithm also depends on the number iterations taken.

5. SIMULATION RESULTS AND ANALYSIS

The simulation parameters used in this system are summarized in Table 1.

Table 1: Simulation Parameters

Number of Sub carriers (N_t)	1024
Cyclic Prefix	128
Uplink Frame Length	12 OFDMA Symbols
Total Number of Ranging Codes	256
Length of a Ranging Code	144 bits
Ranging Channels	6
Maximum Tolerable delay	$N_t/128$
Sampling Rate for mobile WiMAX	11.2MHz
Modulation	QPSK

The ranging channel is made up of six subchannels and spanning 144 subcarriers per OFDMA symbol. A mobile subscriber station is considered and it is simulated using jakes spectrum with the speed of mobile considered to be 60kmph. Ranging subscribers use two consecutive OFDM symbols randomly to send their ranging code during the uplink frame with equal probability.

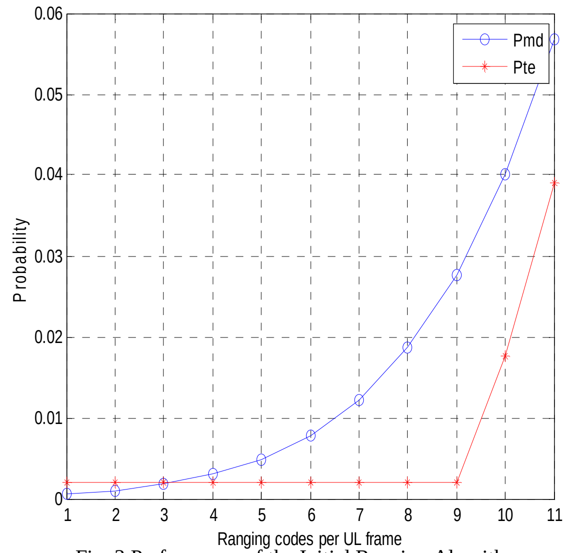

Fig. 3 Performance of the Initial Ranging Algorithm

Fig 3 shows the performance of the initial ranging algorithm for different numbers of ranging users. The probability of timing error, P_{te}, is the probability of making an error in the timing offset estimation for detected ranging codes. For 10 ranging users, the probability of missed detection is below 6%. The P_{te} is around 4% for maximum of 10 ranging users per uplink frame users.

Fig 4 shows the simulation results of initial ranging algorithm for a mobile user. The graph shows the probability of timing estimation is almost linearly increasing as the number users' increases in an uplink channel. It is found to be around 8% for a maximum of 12 users per uplink frame.

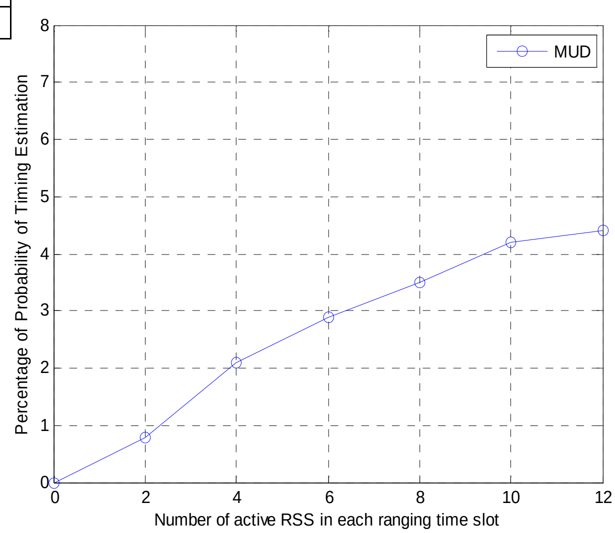

Fig. 4 Timing offset estimation of Initial Ranging Algorithm

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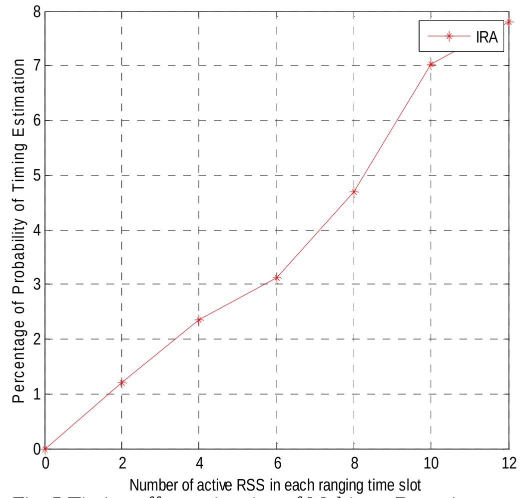

Fig. 5 Timing offset estimation of Multiuser Detection

Fig 5 gives the timing offset estimation of the proposed Multiuser Detection. It is slightly above 4% for a maximum of 12 users per uplink frame which is low when compared to the timing offset estimation of initial ranging algorithm in Fig 3.

Fig 6 shows the working of the Multiuser detection for a mobile subscriber station. In Multiuser Detection, jakes model is used to simulate the mobile user. For two to seven Ranging Subscriber Stations (RSS), the performance of the Multiuser Detection is good in the mobile environment. If the number of RSS exceeds more than ten then the number of iterations taken to resolve MAI is also increased and some residual interference is remained unresolved

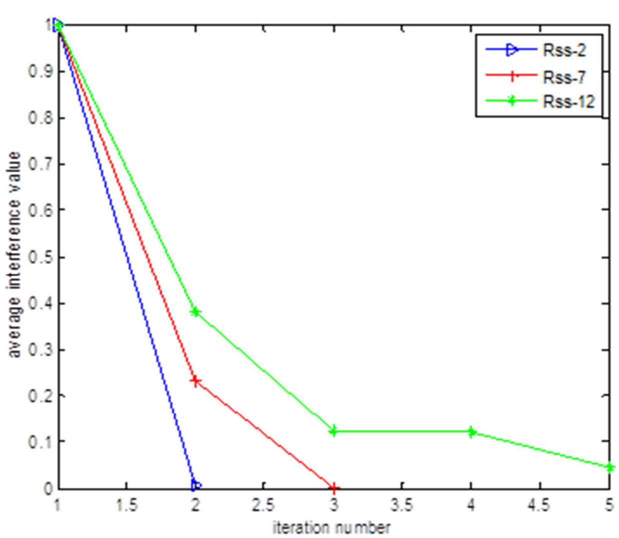

Fig. 6 MAI reduction over iteration for mobile subscriber station of Multiuser Detection

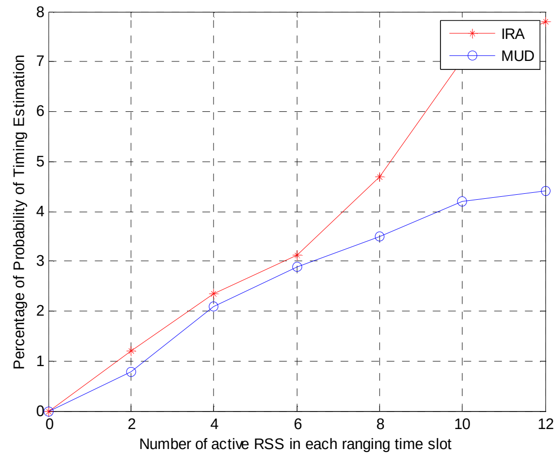

Fig. 7 Timing offset estimation performance of Multiuser Detection and Initial Ranging Algorithm

Fig 7 gives the comparison between the Initial ranging algorithm and the Multiuser Detection for mobile WiMAX in timing offset estimation.

From the Fig 7, the timing offset estimation error with twelve users in an uplink frame is about 8% in initial ranging algorithm for mobile subscriber station whereas in proposed Multiuser Detection the timing offset estimation error with twelve users in an uplink frame is around 4%.

The proposed Multiuser Detection algorithm has better timing offset estimation over the initial ranging algorithm because of its capability to reduce the MAI among the users. Thus from Fig 3, Fig 5, and Fig 7 it is clear that the proposed algorithm has better performance.

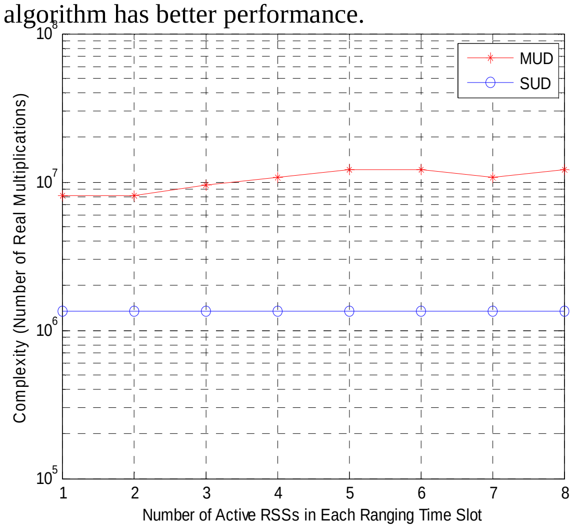

Fig. 8 Computational complexity of Multiuser Detection with that of single user Detection

The complexity as in Fig 8 is increased in the Multiuser Detection algorithm because of iterations

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required to resolve the MAI. With the cost of little computational complexity it is able to detect the active RSS with minimum timing estimation error, since the error in timing estimation has got more adverse effect than a misdetection.

6. CONCLUSION

In the initial ranging process, estimating the subscriber with precise timing offset is very important. If there is a huge error in the timing offset of a particular subscriber station, then that subscriber station may interfere with other ranging subscriber (or data subscriber) or it may be completely taken as a different subscriber resulting in system degradation. So the system has more adverse effect with an error in timing offset than a misdetection.

A Multiuser Detection algorithm for mobile WiMAX is proposed. From the simulation results it is evident that the proposed Multiuser Detection algorithm is superior to the initial ranging algorithm. The timing offset estimation performance of the Multiuser Detection algorithm is better than the initial ranging algorithm since its ability to reduce the Multiple Access Interference is higher resulting in better detection and parameter estimation.

The proposed Multiuser Detection, with a little computational complexity is able to detect the active ranging subscriber with minimum timing offset estimation error since an error in timing offset has got more adverse effect than a misdetection.

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