Performance Analysis of Ranging Process in IEEE 802.16e OFDMA Systems

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ABSTRACT

In this paper, ranging process in IEEE 802.16e OFDMA systems is analyzed and performance is evaluated. Ranging process provides initial network entry, uplink synchronization, and system coordination. In the system initialization state, multiple users transmit randomly selected ranging code set and BS conducts multiple user identification by ranging code identification and uplink synchronization by transmission delay estimation. Ranging detection is based on peak detection exploiting the cross-correlation property of ranging code. However, the cross-correlation property is prone to be affected by channel characteristics and interference in the multipath fading channel. This paper analyzed the performance of ranging process in the multipath fading channel with 6 practical channel models and investigated the effect of channel characteristics and SNR. For the probabilistic analysis, PDF of ranging signal is also induced using Rayleigh approximation. Metrics of the performance evaluation consider both PHY and MAC layer. Simulations are conducted concerning various factors such as multipath profiles, ranging detection miss and error thresholds, cyclic prefix duration, and MAC layer parameters. The results of will give a thorough understanding on ranging process.

Index Terms
IEEE 802.16e, Ranging, Wireless Access, OFDMA

1. INTRODUCTION

IEEE 802.16e broadband wireless access (BWA) systems have drawn much attention these days. The standardization work has been finished and its commercialization is expected to be commenced in the near future [1]. Particularly, WiBro has already provided BWA services based on IEEE 802.16e systems since June 2006 in Korea [2]. IEEE 802.16e is based on OFDM(A) systems which has advantages in high data transmission rate thanks to spectral efficiency, capability to cope with inter symbol interference, and robustness in multipath propagation environment [3]. Originally, IEEE 802.16e is suggested as an enhancement version of IEEE Std. 802.16-2004 to provide mobile station (MS) with mobility at vehicular speed. It specifies BWA systems for both fixed and mobile MS simultaneously, and supports various PHY modes such as WirelessMAN-SCa, WirelessMAN-OFDM, and WirelessMAN-OFDMA to achieve the flexible mobility [4], [5]. In this paper, we focused on WirelessMAN-OFDMA to analyze wireless initial access process.

In IEEE 802.16e OFDMA systems, wireless initial access is carried out through ranging process, authorization, and registration. In the beginning, MS notifies the request of the wireless initial access to base station (BS) by transmitting ranging signals. If BS detects MS’s ranging signal successfully, BS allocates downlink and uplink resources to MS for further communications. Then, MS transmits its identification information to BS through allocated channels. Finally, authorization and registration are performed.

Ranging process refers the first step of wireless initial access and consists of ranging signal transmission, ranging detection, and resource allocation. If multiple MSs transmit their ranging signals simultaneously, BS has to recognize each MS by ranging code identification. Due to diverse mobility and location, each MS has different transmission time delay (TTD). BS has to perform uplink time synchronization to compensate TTD of each MS. Both code identification and uplink time synchronization are based on peak detection of received signals by exploiting the cross-correlation property of CDMA codes. Under the benign channel environment, interferences are supposed to be removed by the cross-correlation property of CDMA codes. However, it is prone to be affected by channel characteristics in the multipath fading channel. In practice each MS’s ranging signal experiences different channel environment, which yields that the cross-correlation property of CDMA codes is much likely to be broken in real environment.

There are several researches on ranging process [8]-[11]. The previous researches studied ranging process only in the benign channel environment with high SNR and the effect of multipath fading channel at low SNR has not been analyzed
yet. Ref. [8]-[11] considered ranging process in terms of physical layer aspects such as ranging signal transmission and detection. There exist few researches on ranging process concerning PHY and MAC layer simultaneously. For instance, mean ranging success time in IEEE 802.16e systems has not been studied yet as far as our best knowledge. Mean ranging success time refers the necessary time for MS to be associated with BS, which needs MAC layer information such as ranging retransmission policy, back off policy of detection miss, and penalty time of detection error, and so on.

In this paper, we analyzed ranging process and evaluated the performance in multipath fading channel environment considering both PHY and MAC layer parameters. Firstly, a thorough description on ranging process is given including mathematical description of probability density function (PDF) of the received ranging signal. Secondly, five ranging process states are four metrics for the performance evaluation are defined exploiting state transition diagram. Thirdly, the performance of ranging process is analyzed by computer simulations. Both PHY layer aspects such as detection success rate, detection miss rate and detection error rate, and MAC layer aspect such as mean ranging success time are analyzed. Fourthly, the effect of PHY system parameters and MAC layer parameters are investigated. Through our whole analysis, we considered the severe multipath fading channel environment with low SNR to investigate the low bound of ranging process functionality. For the simulations, we adopted 6 different channels which measured in the real environment at the 2.3 GHz frequency band [13]. It will reduce the discrepancy between simulation and realistic world.

The remainder of this paper organized as follow. Section 2 provides the background of ranging process and Section 3 describes the system model including transmitter, receiver, and channel model. Section 4 gives a probabilistic analysis on ranging process and Section 5 analyzes the performance of ranging process by computer simulations. Finally, Section 6 summarizes and concludes this paper.

2. BACKGROUND

2.1 Ranging process

Ranging process consists of initial, handover (HO), periodic ranging, and bandwidth request ranging. Initial ranging allows MS to perform initial network entry and to be associated with BS. HO ranging provides the same function against a Target BS during HO. Both initial and HO ranging transmissions are carried out during two of four consecutive OFDMA uplink symbols. The identical ranging signal is transmitted on each symbol without phase discontinuity. Due to the absence of time reference between MS and BS, multiple OFDMA symbols are needed for the uplink time synchronization. Periodic ranging and bandwidth request ranging are performed to maintain the connection between MS and BS, and to request uplink channel allocation, respectively. Both periodic and bandwidth request ranging are performed using one OFDMA symbol since they are conducted after the system initiation.

Ranging process provides wireless multiple access functionality as well. Wireless access opportunity is given by contention-based random access way or contention-free predefined way. In the former case, Multiple MSs transmit their own ranging signals to BS on contention-based random access channel. Then, BS has to identify each MSs ranging signal. In the latter case, which occurs often during HO, MS has contention-free wireless access opportunity and transmit ranging signal on the predefined ranging channel. In this case, pre-negotiation between current BS and neighboring BS is necessary to allocate predefined ranging channel.

2.2 Ranging Sequences

Ranging sequence is generated from pseudo random binary sequences (PRBS) generation function defined by Eq. (1).

\[ 1 + x + x^4 + x^7 + x^{10}. \]  

(1)

Figure 1 illustrates ranging sequence generator. In IEEE 802.16e standard, PRBS is expressed as CDMA codes since it is mainly used in CDMA systems, and this paper also follows it for the convenience. The \( m \)th user’s ranging sequence is expressed as \( C_m = (C_{m}[0], C_{m}[1], \ldots, C_{m}[SF - 1]) \), and ranging signals are BPSK modulated as Eq. (2).

\[ \text{Re}\{c_{m}[i]\} = 2\left(\frac{1}{2} - C_{m}[i]\right), \quad \text{Im}\{c_{m}[i]\} = 0, \]  

(2)

where \( c_{m}[i] \) is the \( i \)th ranging sub-carrier signal of the \( m \)th user, and \( SF \) is number of ranging sub-carriers. In IEEE 802.16e systems, 144 sub-carriers are commonly used. In this case ranging sequences generated by Eq. (1) have 256 different codes set and each MS will randomly select one of them.

2.3 Ranging Detection

Ranging detection refers the code identification and TTD estimation conducted by BS. Ranging code identification is performed exploiting the cross-correlation property of CDMA codes. As shown in Eq. (3), the summation of multiplied two CDMA codes have peak only when two codes matches.

\[ \sum \quad \text{peak} \quad (if \ m = n), \quad \text{non - peak} \quad (otherwise). \]  

(3)
Transmission propagation delay of the $m$th user ($\Delta_{\text{off}}$) causes the phase shift amount of $\exp\{-j2\pi(f_c+i\cdot f_s)\Delta_{\text{off}}\}$ to the $i$th subcarrier in the frequency domain, which yields that TTD estimation in the time domain is equivalent to the phase shift compensation in the frequency domain. Hereby, $f_c$ and $f_s$ denotes the center frequency and subcarrier spacing. The phase shift, which is complex value, can be compensated by multiplying the complex conjugation. Thus, TTD estimation is conducted in the frequency domain by multiplying complex conjugated phase shift. In practice, ranging detection is performed by peak detection as shown in Eq. (4) because BS is unaware of both randomly selected ranging code and transmission propagation delay. The output of ranging detection will have peak only when both ranging code identification and TTD estimation are conducted successfully. If ranging detection succeeds, BS will transmit the ranging success message to MS and allocate downlink and uplink channel resources for further communications. Then, MS transmits its identification information to BS through allocated channels.

\[
\sum_{m=0}^{M} c_m \exp\{j2\pi(f_c+i\cdot f_s)(M_{\text{off}}-t_{\text{off}}^m)\} = \begin{cases} \text{peak} & (\text{if } m=n \text{ and } \Delta_{\text{off}}=t_{\text{off}}^m) \\ \text{non-peak (otherwise)} \end{cases}, \tag{4}
\]

3. SYSTEM MODEL

3.1 Transmitter Model

Figure 2 shows the transmitter and receiver structure of ranging process. Consider an OFDMA system with total $N_s$ sub-carriers. Among them $SF$ sub-carriers are allocated for ranging process. The $m$th user’s transmitted signal is described as

\[
s_m(t) = \sum_{i=0}^{SF-1} s_{m,i}(t), \tag{5}
\]

where $s_{m,i}(t)$ is transmitted signal of the $i$th sub-carrier defined as

\[
s_{m,i}(t) = c_{m,i}[\exp\{j2\pi(f_c+i\cdot f_s)t\}]. \tag{6}
\]

Since the same ranging sequence is transmitted over two consecutive OFDMA symbols in initial and HO ranging, transmitted signal is written as below.

\[
s_{m,i}(t) = c_{m,i}[\exp\{j2\pi(f_c+i\cdot f_s)t\}], s_m(t+T_s) = s_m(t). \tag{7}
\]

where $T_s$ is duration of one OFDMA symbol.

3.2 Channel Model

$N$-ary multipath Rayleigh fading channel model is adopted in this paper. The $m$th user’s $i$th sub-carrier channel model $h_{m,i}(t)$ is given as

\[
h_{m,i}(t) = \sum_{n=0}^{N} A_{m,n}^i e^{j\phi_n} \delta(t-t_{\text{off}}^n), \tag{8}
\]

where $N$ is the number of multipath, $A_{m,n}^i$, $\phi_n$, and $t_{\text{off}}^n$ are the attenuation factor, magnitude, phase and multipath delay of the $i$th delay path, respectively. $A_{m,n}^i$ and $t_{\text{off}}^n$ highly depend on channel environments such as geometry and user’s mobility. $A_{m,n}^i$ and $\phi_n$ are independent and identically distributed Rayleigh random variables and uniform random variables, respectively. PDF of $A_{m,n}^i$ and $\phi_n$ are given as

\[
f_{A_{m,n}^i}(\alpha_{m,n}^i) = \frac{\alpha_{m,n}^i}{(\sigma_{m,n}^i)^2} \exp\left(-\frac{\alpha_{m,n}^i}{2(\sigma_{m,n}^i)^2}\right), (0 \leq \alpha_{m,n}^i < \infty), \tag{9a}
\]

\[
f_{\phi_n}(\phi_n) = 1/2\pi, (0 \leq \phi_n < 2\pi), \tag{9b}
\]

where $(\sigma_{m,n}^i)^2$ is the variance of in-phase and quadrature parts of the $i$th transmitted sub-carrier.

3.3 Receiver Model

Assuming $M$ users transmit ranging signals simultaneously, received ranging signal $r(t)$ is described as
where ( ) is AWGN with variance /2 and off mt is TTD of the mth user. After FFT block processing, receiver multiplies { } co of fcjt c o to the ith sub-carrier. and off∆ are for the sake of code identification and TTD estimation, respectively. The frequency domain description of received ranging signal 0 R is given as Eq. (11).

\[ R_o = \sum_{m=0}^{M-1} \sum_{c=0}^{N_c-1} A + \eta, \]

(11a)

\[ A = c_m[i]c_c[i]A_{\alpha_m}A_{\phi_m^c} \exp \left[ j \left( 2\pi (f_c + i f_m) (\tau_{m_c} - \tau_{c_m}^o) + \phi_{m_c}^c \right) \right]. \]

(11b)

where A is the simple substitution due to page limit and \( \eta \) is the noise component in the frequency domain. The ranging detection is conducted based on peak detection among all possible ranging code sets. If the maximum \( |R_o| \) of each ranging code to the predefined threshold. For instance, five MSs transmitted their own ranging code sets, the maximum \( |R_o| \) of only those ranging code sets will bigger than the predefined threshold.

\[ \sum \left( \arg \max_{\Delta_{\phi_m^c}} R_o \right) \]

where \( R_o \) is the simple substitution due to page limit and \( \eta \) is the noise component in the frequency domain. The ranging detection is conducted based on peak detection among all possible ranging code sets and TTD as below.

\[ \left( C_i, \Delta_{\phi_m^c}\right)_{\text{selected}} = \arg \max_{C_i, \Delta_{\phi_m^c}} R_o. \]

(12)

Since initial ranging and HO ranging is done during the system initiation, compensation of the phase shift \( \phi_{m_c} \) and power variation \( A_{\alpha_m}A_{\phi_m^c} \) due to channel is not conducted. It causes the performance degradation by deteriorating the cross-correlation property of CDMA codes. The amount of the performance degradation depends on channel characteristics, SNR, and number of interfering users.

Figure 3 illustrates ranging detection process for multiple users. BS conducts ranging detection process for all possible ranging code sets. If the maximum \( |R_o| \) of ranging code set \( C_i \) is bigger than the predefined threshold, BS determines that ranging code set \( C_i \) is selected by MS. In this way BS is able to distinguish multiple user by comparing the maximum \( |R_o| \) of each ranging code to the predefined threshold. For instance, five MSs transmitted their own ranging code sets, the maximum \( |R_o| \) of only those ranging code sets will bigger than the predefined threshold.

4. PROBABILISTIC ANALYSIS OF RANGING PROCESS

4.1 Definitions of Ranging Process States

In this section, we will analyze ranging process mathematically. For the convenience, index of desired user \( m \) and randomly selected ranging code set are assumed to be zero and \( C_o \). The maximum \( |R_o| \) and estimated TTD in Eq. (12) are defined as \( |R_o| \) and \( \Delta_{\phi_m^c}\) selected \( \), respectively. Assuming the predefined thresholds of code identification and TTD estimation as \( \alpha \) and \( \beta \), the probability of the code identification success and TTD estimation success are given as follows.
\[ pr\{\text{code identification success}\} = pr\{|R_{id}| > \alpha\}. \]  
(13a)

\[ pr\{\text{TTD estimation identification success}\} = pr\{|\Delta_{selected}| < \beta\}. \]  
(13b)

To further analysis utilizing state transition diagram, five states of ranging process are defined as follows.

2. Detection miss – code identification error.
5. Penalty time – BS and MS continue further communication with incorrect TTD estimation.

If both code identification and TTD estimation succeed, BS transmits ranging success message continues further communications with MS such as registration and authorization. In case of detection miss, BS does not transmit ranging success message to MS since BS can not recognize MS’s ranging signal. If MS does not receive the ranging success message from BS although it transmitted ranging signal, MS determines ranging state as detection miss and retransmits ranging signal after random backoff. In case of detection error, BS recognizes the MS’s ranging signal with incorrect TTD estimation. However, BS does not know whether TTD estimation is correct or not and transmits ranging success message to MS. Then, MS regards ranging state as detection success. MS and BS continue further communication using incorrect information until they recognize that ranging detection was error. After the recognition of ranging detection error, MS performs random backoff and retransmits ranging signal. The additional processing time caused by detection error is defined as penalty time and the period of penalty time is defined as penalty time state.

4.2 Metrics of Performance Analysis

To evaluate the performance of ranging process, four metrics are given as follows.

1. Detection success rate (\( P_s \)) – the rate of detection success.
2. Detection miss rate (\( P_m \)) – the rate of detection miss, which causes random backoff time.
3. Detection error rate (\( P_e \)) – the rate of detection error, which causes penalty time.
4. Mean ranging process success time (\( E[T_s] \)) – the average time for MS to succeed ranging process.

\[ P_s + P_m + P_e = 1 \]  
(14)

\( R_{id} \) in Eq. (13a) consists desired user's signal, other users’ interference, and noise as shown in Eq. (18).

\[ R_{id} = S + I + \eta, \]  
(18)

where \( S \), \( I \), and \( \eta \) refer the desired user’s signal, other users’ interferences, and noise, respectively. They are given as follows.

\[ S = \sum_{i=0}^{N_r-1} \sum_{l=0}^{N_d-1} A_i l m r_{id} \exp\{j2\pi(f_r + i\cdot f_d)(-t_{id}^s + \phi_{id})\}. \]  
(19a)

\[ I = \sum_{i=1}^{N_r-1} \sum_{l=1}^{N_d-1} c_{ij}[l][l] A_i l m r_{id} \exp\{j2\pi(f_r + i\cdot f_d)(\Delta_{selected} - t_{id}^s + t_{id}^e + \phi_{id})\} \]  
(19b)

\[ \eta = \sum_{i=0}^{N_r-1} N(f_d) \exp\{j2\pi(f_r + i\cdot f_d)(\Delta_{selected})\}. \]  
(19c)

\[ E[T_s] \] is obtained exploiting state transition diagram [12]. Figure 4 shows the state diagram of ranging process, \( H_1(z) \), \( H_2(z) \), \( H_3(z) \), \( H_4(z) \), and \( H_5(z) \) refer the state of detection success, detection miss, detection error, random backoff, penalty time, respectively. They are shown as follows.

\[ H_1(z) = P_s Z^/, H_2(z) = P_m Z^/, H_3(z) = P_e Z^/, \]
\[ H_4(z) = Z^{\tau_B}, H_5(z) = Z^{\tau_P}. \]  
(15)

where \( T_B \) and \( J \) denote one period of ranging process opportunity, random backoff coefficient, and penalty time coefficient, respectively. They depend on MAC layer policy.

The generating function is given as Eq. (16) and \( E[T_s] \) is obtained as Eq. (17).

\[ H(z) = 1 - H_2(z)H_3(z) - H_5(z)H_4(z)H_5(z) \]  
(16)

\[ E[T_s] = \left. \frac{\partial}{\partial z} \ln H(z) \right|_{z=1} = \left[ 1 + (1 + B) \frac{P_m}{P_s} + (1 + B + J) \frac{P_e}{P_s} \right]. \]  
(17)

As shown in Eq. (17), \( E[T_s] \) depends on both PHY and MAC layer aspects.

4.3 Probability Density Function of Ranging Signal
where \( N(f) \) is the noise narrowband noise in the frequency domain. Each component in Eq. (18) consists of in-phase and quadrature component as shown in Eq. (20).

\[
R_u = R_u^0 + jR_u^0 = (S^0 + I^0 + \eta^0) + j(S^0 + I^0 + \eta^0),
\]

(20)

As confirmed by Eq. (19a) and (19b), \( S \) and \( I \) are composed of linear combination of independent Rayleigh random variable, \( \alpha_{\nu}^k \), and uniform random variable, \( \phi_{\nu}^k \). It yields that \( S^0, S^0, I^0, I^0, \) and \( \eta^0 \) also consist of independent Gaussian random variables. Furthermore, it is easily confirmed that \( \eta^0 \) and \( \eta^0 \) also consist of independent Gaussian random variables. In addition, \( S, I, \) and \( \eta \) consist of \( N \cdot SF, (M-1)N \cdot SF, \) and \( SF \) random variables, respectively, which is big enough to adopt central limit theorem. Thus, \( S^0, S^0, I^0, I^0, \eta^0, \) and \( \eta^0 \) are determined as Gaussian random variables. \( R_u^0 \) and \( R_u^0 \) are also determined to be Gaussian random variables since they are summation of independent Gaussian random variables. Then, \( |R_u| \) is Rayleigh random variable [14].

Figure 5 shows the distribution of 1000 samples of \( R_u \) in the rural Rayleigh fading channel with 5 users. The ranging transmit power is normalized to 1. X axis and Y axis refer \( R_u \) and \( R_u^0 \). Figure 6 shows the distribution of \( |R_u| \) and PDF of Rayleigh random variable, and both curves are well-matched. Figure 6 proves that \( |R_u| \) can be approximated to Rayleigh random variable and PDF of \( |R_u| \) is given as Eq. (21).

\[
f_{|R_u|}(x) = \frac{x}{\sigma_{R_u}^2 \sqrt{2\pi}} \exp \left( -\frac{x^2}{2\sigma_{R_u}^2} \right), \quad (0 \leq x < \infty),
\]

(21)

where \( \sigma_{R_u}^2 \) refers the second momentum of \( R_u \), which is equal to that of \( R_u^0 \). \( \sigma_{R_u}^2 \) depends on channel characteristics and SNR.

### 4.4 Mathematical Analysis of Detection Miss Rate and Detection Error Rate

Detection miss rate is approximated as Eq. (22) using PDF of \( |R_u| \).

\[
pr\{\text{detection miss rate}\} = \int_{\alpha}^\infty f_{|R_u|}(x) \, dx = 1 - \exp(-\alpha^2 / 2\sigma_{R_u}^2). \quad (22)
\]

Detection error rate is described by conditional probability as Eq. (24), which is the probability of the maximum \( |R_u| \) within TTD estimation threshold is smaller than the maximum \( |R_u| \) out of TTD estimation threshold given that code identification is successful.

\[
pr\{\text{detection error rate}\} = pr\{(\arg \max_{\nu \in \theta} |R_u| < \arg \max_{\nu \in \theta} |R_u| | (|R_u| > \alpha)\}. \quad (23)
\]

### 5. PERFORMANCE ANALYSIS OF RANGING PROCESS

#### 5.1 Simulation Parameters

IEEE 802.16e systems provide various set of system parameters [4], [5]. Among them most appropriate system parameters are chosen for our analysis. Details are given in Table 1. They are compatible with WiBro [6], [7] as well. TDD duplex model is considered and 144 subcarriers are adopted for ranging process from total 1024 carriers. The tone spacing is 9.766 KHz, which yields raging channel bandwidth to 1.4 MHz out of total 10 MHz bandwidth. One OFDMA symbol duration is 115.2 \( \mu \)sec including 12.8 \( \mu \)sec of cyclic prefix.

To reduce the discrepancy between simulation and realistic world, we adopt 6 practical channel models which are obtained from the real measurement [13] at the 2.3 GHz
frequency band. They are measured in the rural, suburban, suburban-alternative, micro-cell hilly, urban high-rise, and urban rooftop environment, respectively. To investigate the lower bound of ranging process performance, SNR is set to relatively low from -4 dB to 6 dB and multipath Rayleigh fading channel is considered. Interfering users are assumed to be randomly located in the cell and number of interfering users is also randomly set between 0 and 10. Since MAC parameters regarding ranging process are not specified in the IEEE 802.16e standard, we assume that BS provides ranging opportunity every frame, and random back off coefficient $B$ and penalty time coefficient $J$ are set to 2 and 5, respectively.

5.2 Simulation Results

Figure 7 illustrates the probability density of $|R_u|$. It was obtained from 10000 times of computer simulations in the rural channel. Dot line represents the exemplary detection miss threshold, which is 20 % of received ranging signal power when SNR equals to 0 dB. The left side of dot line indicates detection miss and detection miss rate is obtained by cumulating the left region of dot line. Comparing the area in the left side of dot line, it is easily confirmed that detection miss occurs more frequently when SNR is low. Solid curves in Fig. 8 show detection miss rate with various detection miss threshold. $\alpha$ To find the optimum $\alpha$, all of detection miss rate, detection error rate, and target SNR should be considered. For the fixed SNR, detection miss rate is reduced as $\alpha$ decreases. However, detection error rate increases since $|R_u|$ with TTD estimation error will not removed due to decreased $\alpha$. If $\alpha$ is set too high, ranging process at low SNR does not work properly. For instance, when SNR equals to -4 dB, more than 45% of ranging signal will be missed due to high ranging detection threshold. On the other hand, if $\alpha$ is set too low, code identification function will not work properly. Not transmitted ranging code set may be regarded as transmitted due to low ranging detection threshold. Considering above and simulation results, $\alpha$ is set to 0.2 in our analysis.

As stated in the previous section, $|R_u|$ has Rayleigh distribution. The second momentum of in-phase component $\sigma_{x_u}^2$ is given in Table 2. Detection miss rate can be obtained analytically using Eq. (22) and Table 2. Dot curves in Fig. 8 show detection miss rate obtained from Rayleigh approximation. Dot curves are well matched to solid curves. Hence, Rayleigh approximation of $|R_u|$ can be determined to hold true. Detection miss rate of other 5 channels can be approximated from Eq. (22) and Table 2 as well.

Figure 9 shows cumulative distribution function (CDF) of TTD estimation offset $\Delta t_{\text{est}} - t_{\text{ref}}$ given that code identification success. $\Delta t_{\text{est}} - t_{\text{ref}}$ means the difference between the estimated and real TTD. If it is bigger than predefined threshold, detection error occurs and ranging state will be penalty time state. Dot line in Fig. 8 represents detection error threshold which is set to 12.5 % of cyclic

| Table 1. System parameters of IEEE 802.16e systems. |
|---------------------------------|------------------|
| Frame length | 5 msec |
| OFDMA symbol duration | 115.2 $\mu$sec |
| Cyclic prefix duration | 12.8 $\mu$sec |
| FFT size | 1024 |
| Total number of sub-carriers | 1024 |
| Number of ranging sub-carriers | 144 |
| Total bandwidth | 10 MHz |
| Ranging channel bandwidth | 1.406 MHz |
| Subcarrier spacing | 9.766 KHz |
| Cell size | 1 Km |
prefix duration. Cross points between 5 curves and dot line refers detection success rate given that code identification success.

Table 3 shows \( P_d \), \( P_e \), and \( E[T_a] \) obtained from rural and suburban-alternative channel, which are the most benign and severe channel environment among 6 channels. \( P_d \) is abbreviated due to page limit, however it can be calculated using Eq. (14). \( P_d \) of both channel converges to zero as SNR increases. It is because \( P_d \) depends on the second momentum of in-phase component, i.e. the power of the received ranging signal. As shown in Table 2, \( \sigma_{I_0}^2 \) increases as SNR increases in all channels, which yields that \( P_d \) of all channels will converge to zero as SNR increases. Meanwhile, \( P_e \) shows interesting results. Only \( P_e \) of the rural channel converges to zero as SNR increases while that of the suburban-alternative channel does not. This difference comes from multipath channel profiles. RMS and maximum delay of the suburban-alternative channel is 0.994 \( \mu \text{s} \) and 8.124 \( \mu \text{s} \) while they are 0.235 \( \mu \text{s} \) and 5.872 \( \mu \text{s} \) in the rural channel [13]. In the suburban-alternative channel, multipath delays, which arrive later than detection error threshold, cause detection error although SNR is high. Due to the difference of \( P_e \), \( E[T_a] \) in the suburban-alternative channel does not converges to 5 \( \mu \text{s} \) as \( E[T_a] \) in the rural channel converges closely to 5 \( \mu \text{s} \) as SNR increases. 5 \( \mu \text{s} \) of \( E[T_a] \) is the ideal case which means ranging process is expected to succeed within one frame without failure.

5.3 Effects of the System Parameters

Undesirable performance of the suburban-alternative channel is due to relatively long multipath delays comparing to cyclic prefix duration. It is possible to improve the performance by slight extension of cyclic prefix duration. Figure 10 shows the effect of cyclic prefix duration. Cyclic prefix duration of rural channel is fixed to 12.8 \( \mu \text{s} \) for the comparisons and that of suburban-alternative channel is set from 12.8 \( \mu \text{s} \) to 14.4 \( \mu \text{s} \). It is easily confirmed that \( E[T_a] \) in the suburban-alternative channel with extended cyclic prefix duration also converges to 5 \( \mu \text{s} \) as SNR increases. suburban-alternative channel shows almost similar results with rural channel when cyclic prefix duration equals to 13.6 \( \mu \text{s} \). Moreover, it shows the better performance than rural channel when cyclic prefix duration is longer than 13.6 \( \mu \text{s} \).

In our analysis, \( B \) and \( J \) are set to 2 and 5 considering the current target system. \( B \) is related with the anticipated number of interfering users. As the number of interfering users increase, \( B \) has to be increased to avoid collisions. \( J \) depends on MAC layer policy such as ranging signal retransmission policy and backbone network conditions. Some simulation results with various \( B \) and \( J \) in the rural channel are illustrated in Table 3.
in Fig. 11. It is confirmed that the performance of $E[T_{p}]$ degraded as $B$ and $J$ increases. The degradation is severe at low SNR while it is endurable at high SNR. Thus, it is necessary to maintain the power of received ranging signal over the certain level.

6. CONCLUSIONS
In this paper, ranging process of IEEE 802.16e systems is analyzed. Ranging process refers ranging signal transmission by MS and its detection by BS. It consists of initial, handover, period ranging, and bandwidth request ranging process and provides initial network entry, uplink synchronization. Multiple users transmit randomly selected ranging signals to BS. To identify multiple users and estimated propagation delay, BS has to perform ranging detection for all possible ranging code sets and propagation delays. If BS conducts ranging signal detection success fully, it allocates channel resource and continues further communication with MS. Otherwise, MS has to retransmit ranging signal.

To analyze ranging process properly, we defined five states of ranging process and four performance evaluation metrics utilizing state transition diagram. Simulations are conducted in the multipath fading channel at relatively low SNR to figure out the lower bound of ranging process. The performance of ranging process is analyzed based on four metrics and the effect of PHY and MAC layer parameters are also investigated. Through our analysis, it is confirmed that low SNR and long multipath delays degrades the performance of ranging process. To overcome the performance degradation caused by low SNR, it is necessary to maintain the power of received ranging signal over the certain level, which can be achieved by power control or utilizing relay station. The undesirable effect of multipath delays can be reduced by slight extension of cyclic prefix length.

7. REFERENCES
[7] Telecommunication Technology Association, Specifications for 2.3GHz band portable Internet service: Medium access control layer. TTAS.KO-06.0065R1, Dec. 2004