Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Ranging Improvement for 802.16e OFDMA PHY**
Date Submitted	**2004-06-25**
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Re:	IEEE P802.16-REVe/D3-2004 Ballot #14b
Abstract	The contribution proposes to improve the scalability and performance of the ranging channel for scalable OFDMA. Ranging performance is improved by using low PAPR sequences with good cross-correlation and eliminating interference caused by initial ranging timing offsets, and a a flexible ranging resource allocation is introduced that can adjust the ranging channel resources for scalable FFT sizes.
Purpose	Adoption of proposed changes into P802.16e
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Ranging Enhancement for 802.16e OFDMA PHY

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1. Introduction

This contribution proposes enhancements to the uplink ranging operation in IEEE 802.16e OFDMA PHY. The uplink ranging function fulfills very important tasks that can significantly influence the user experience. In the current draft of WirelessMAN-OFDMA PHY (REVd/D5), the ranging signal is transmitted on a single ranging channel that is comprised of a subset of 144 non-contiguous subcarriers specified in the UL-MAP message. A length-144 BPSK sequence is used to modulate the ranging subcarriers. The BPSK sequence is derived from a long Pseudo-Random Binary Sequence (PRBS) generated by the polynomial $1+X^1+X^4+X^7+X^{15}$. The number of available codes is 256 that are divided to a number of sub-groups each of which is used for a different ranging function.

The current scheme has these limitations:

1. The current scheme does not scale properly to the smaller FFT sizes for scalable OFDMA. The overhead associated with the fixed number of ranging subcarriers (144) becomes excessive for smaller FFT sizes, and does not even fit into the expected smallest FFT size of 128. Moreover, the maximum number ranging opportunities of the existing scheme is limited by the uplink duration, instead of being adjustable to the access needs.
2. The PAPR of the ranging signals is large (7-12 dB), which reduces the power output from an SS due to backoff requirement and thus reducing the link budget, especially for battery powered portable devices with small power amplifiers.
3. The cross correlation between any pair of the ranging waveforms or between ranging and data co-channel transmission at a neighbor sector is not optimized, which lowers the detection rate and increases the false alarm rate.
4. The initial ranging signals cause interference to both data traffic and other types of ranging.
5. Dispersing the ranging subcarriers across the whole band degrades the performance in timing offset estimation, especially for a delay-spread channel.

The scheme proposed in this contribution has the following advantages:

- It is designed to work well with scalable OFDMA. The overhead can be kept low for all FFT sizes and can be adjusted by the base according to the access need to guarantee low collision probability.

Signaling is defined to allow flexible division of the ranging opportunities in time, frequency, and code dimension.

- The ranging waveform has low PAPR (2.5-5 dB, as opposed to 7-12dB). So the uplink link budget is improved on the ranging channel for mobile devices with limited transmit power.
- The ranging waveforms used in same cell/sector or neighboring cells/sectors have optimized cross-correlation, which results in high success and low false alarm probabilities and good timing offset estimation.
- Interference caused by initial ranging to data or other types of ranging traffic is eliminated with the definition of a dedicated ranging interval.
- Contiguous subcarriers are used to reduce the irregular "aliasing" effect and thus improve timing offset estimation.
- A sub-band selection procedure takes advantage of the frequency selective channel characteristics to provide additional link budget gains.

Frequency domain processing at the BS keeps the processing complexity low.

2. Basis of the Proposed Ranging Scheme

The proposed scheme has the following features:

1. A dedicated ranging interval is used to eliminate interference caused by initial ranging. In particular, the dedicated ranging interval consists of a special OFDMA symbol with an extended CP that equals the summation of the regular CP length and the largest possible arrival timing difference to be accommodated. This "extended" OFDMA symbol will be appended by a "dead" interval that equals the largest timing difference. Then, the initial ranging will not interfere with any transmission that precedes and follows the ranging interval.
2. Ranging opportunities will be divided into non-interfering waveforms (separable in frequency or time) and interfering waveforms (low cross-correlation sequences), according to deployment scenarios and access needs. First, all the subcarriers will be divided into a pre-specified (but adjustable) number (N_{bl}) of frequency blocks with each using a number of contiguous subcarriers. Second, for each of the N_{bl} frequency blocks, a number of code groups will be pre-defined so that every group consists of N_c ranging codes and different groups can be assigned to different neighboring sectors. The number of groups and its size N_c can also be made adjustable. Third, for each ranging code in a group, an SS can further use one of the shifted versions of the time domain symbol (i.e., cyclically shifted by samples that are multiples of the extended CP length before appending an extended CP). This allows the BS to be able to separate the same ranging code in the time domain. The number of valid shifts N_{sh} is determined by the BS based on the extended CP length and the FFT size. The total number of ranging opportunities in one special OFDMA symbol is therefore $N_{bl}*N_c*N_{sh}$, which is shared among initial ranging, periodic ranging, and bandwidth request.
3. Dividing the ranging opportunities into frequency blocks provides the opportunity take advantage of the channel's frequency selective characteristics to further improve performance. When an SS has

information about the current frequency selective characteristics of the channel, it selects the best of the available frequency blocks for its ranging transmission. The SS may gain several dB of additional link margin from this process. The concept is similar in spirit to the "band AMC" option that already exists in the standard, but the proposed ranging scheme can be used with any of the sub-channel definitions, and does not require any feedback signaling in TDD systems.

4. The ranging codes used in the same group or different groups are all different, which are obtained from different "classes" of generalized chirp like (GCL) sequences (unit-amplitude complex-valued sequences). The time domain waveforms of the GCL-modulated OFDM signals used in all groups have low PAPR. In addition, because of the use of different "classes" of GCL sequences, any pair of the sequences, either from the same group or different groups, has low cross correlation at all time lags, which greatly improves the code detection and CIR estimation.

Definition of the dedicated ranging interval

There are two significant advantages to defining a dedicated ranging interval. First, confining initial ranging to a special ranging zone eliminates its interference to regular data traffic, periodic ranging, and bandwidth request. Second, it is more flexible to control the overhead and the total number of ranging opportunities, compared with the existing scheme that uses a fixed number of subcarriers.

The dedicated basic ranging interval is shown in Figure 1..

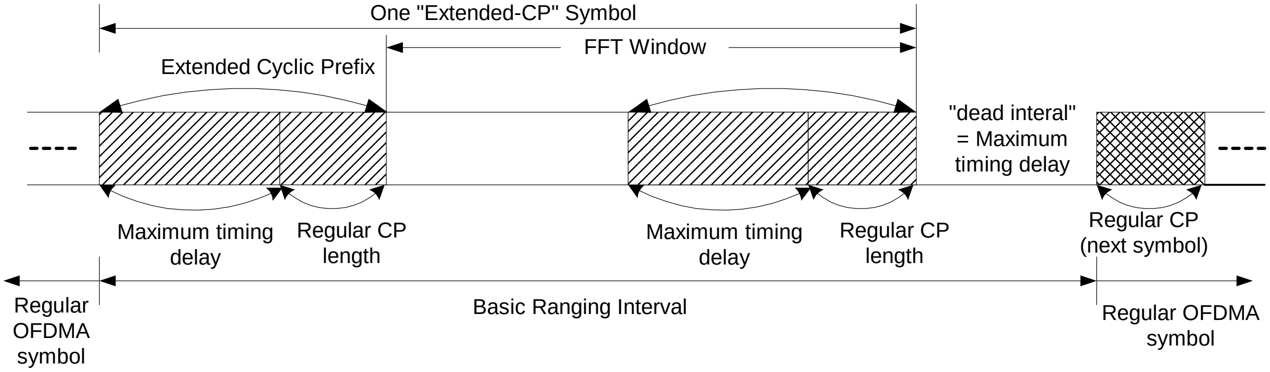


Figure 1. Basic Ranging Interval

The dedicated basic ranging interval consists of one special OFDMA symbol with an extended CP and a "dead" interval. The extended CP length equals to the summation of the regular CP length and the largest arrival timing difference to be accommodated. The "dead" interval equals to the largest timing difference.

With this definition of ranging interval, the initial ranging will not interfere with any transmission that precedes and follows the ranging interval. The maximum timing delay should be large enough to accommodate the maximum propagation delay for SSs that have not adjusted their timing (i.e., initial ranging users). The maximum timing delay is a parameter determined based on the cell size. It is easy to see that in the existing initial ranging design, the maximum detectable timing delay is equal to an OFDMA symbol (CP-excluded), which is larger than is needed in most of the cases, especially when the regular symbol time is long. More importantly, any signal energy outside of the "clean" FFT window is an interference source to others, so it should be minimized as much as possible. For the receiver, since the BS predefines the maximum timing delay in the proposed scheme, the BS should know how to adjust the position of the FFT window accordingly, as shown in the figure. The special FFT window can be any size in theory. A large special FFT window can reduce the proportion of extended CP to the special FFT size (i.e., overhead) and provide more ranging opportunities to reduce collision. The time span of the transmission also extended so that there will be more signal power arriving at the BS. However, the overall overhead of ranging as a portion of the uplink duration increases and more susceptible to mobility due to the inter-carrier interference caused by Doppler shift. The choice of special FFT size is also a practical consideration. For example, in OFDM systems, making it an integer multiple of the regular FFT size may simplify the BS processing.

The total ranging overhead, which is the ratio of the duration of the dedicated ranging interval to the entire uplink duration, depends only on the uplink duration not the FFT size. To reach an overhead that is lower than the current overhead level (i.e., 144 out of 1680 data subcarriers or fixed at 8.57%), there should be at least 11 regular OFDMA symbols in the uplink. The longer the uplink, the lower is the overhead. For modes that use an FFT size of smaller than 2048, the overhead of the existing scheme increases dramatically, but the overhead of the proposed scheme does not change with the FFT size. If the overhead due to the maximum timing delay becomes too excessive, the "dead" interval can be omitted at the price of generating inevitable interference to the next symbol, similar to what happens with the existing ranging scheme.

If more ranging opportunities are needed than what a basic ranging interval can provide, an extended ranging interval can be defined where one or more regular OFDMA symbols will be added in front of the extended-CP symbol (see Figure 2). This is an alternative to the design of enlarging the special FFT size mentioned before. Initial ranging transmission is allowed only during the extended-CP interval, but other ranging transmissions are allowed in any of the OFDMA symbols of the extended ranging interval.

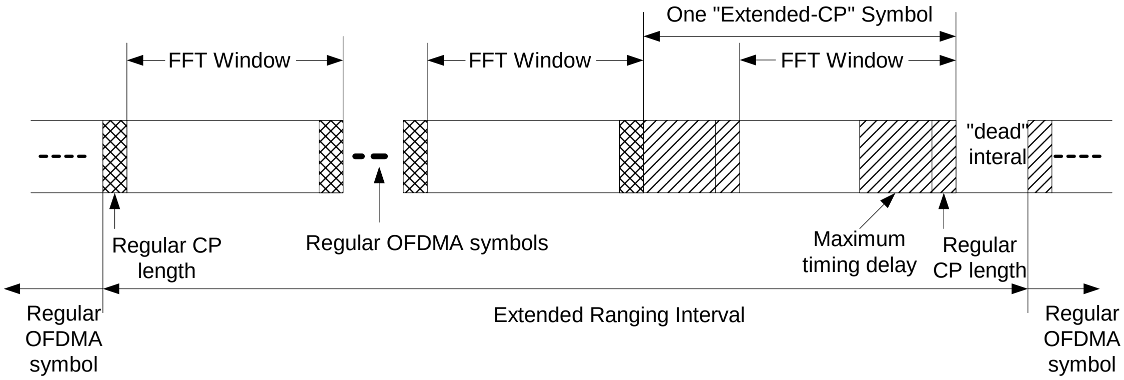


Figure 2. Extended Ranging Interval

Division of Ranging Opportunities in Frequency, Code, and Time

A ranging signal can be sent at one of the N_{bl} frequency blocks (non-interfering resource allocation, see Figure 3), using one of the N_c sequences (mutually interfering, but with good cross-correlation), and lastly, implementing one of the N_{sh} cyclic (circular) time shifts (non-interfering resource allocation), which gives $N_{bl}*N_c*N_{sh}$ total ranging opportunities to be shared with all types of ranging needs. The three parameters are jointly pre-defined for a system based on a number of considerations discussed in the following.

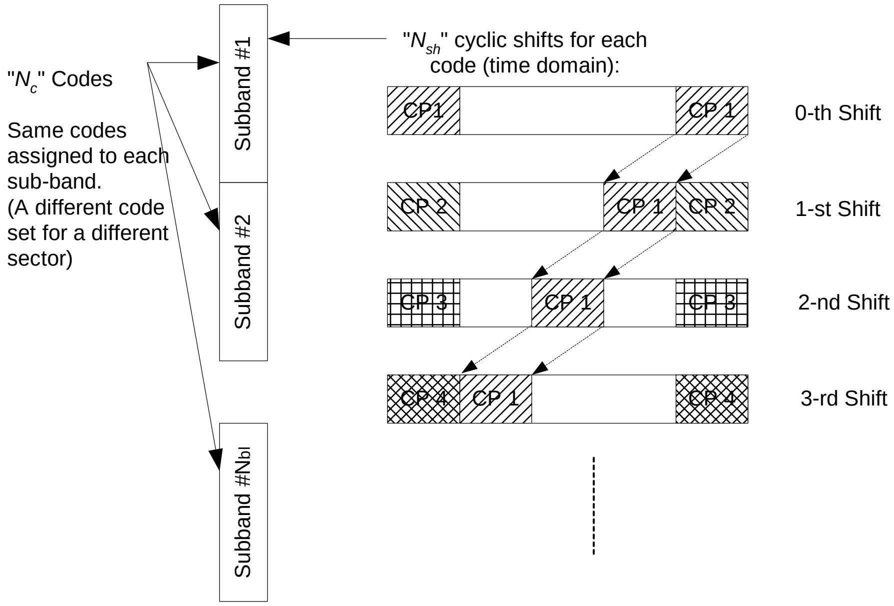


Figure 3. Ranging Opportunities in Frequency, Code, and Time

First, in the frequency domain the entire band is divided into N_{bl} frequency blocks (sub-bands) (e.g., N_{bl} =1 or 2 for 256-point FFT size and N_{bl} =16 for 2048-point system). A ranging signal transmission from a particular SS at a particular time occupies only one sub-band. The reason for dividing the bandwidth into orthogonal blocks is for better flexibility. First, the number of ranging opportunities can be made adjustable to the bandwidth: larger bandwidth systems need to provide more opportunities than narrower bandwidth systems for a similar collision rate. Second, transmitting on a narrow sub-band allows power boost on that band to achieve a better uplink SNR, even though narrowband transmission has lower timing resolution than wider bandwidth transmission (N_{bl} channel taps will collapse into one channel tap when only $1/N_{bl}$ of the bandwidth is excited). On the other hand, the number of subcarriers in each sub-band, which equals the length of the ranging sequence, affects the cross-correlation characteristics. For example, halving the number of subcarriers in a sub-band allows 3dB power boost on that band, but the interference from other co-channel ranging codes also increase by 3dB. So the number of subcarriers in a sub-band involves a tradeoff between SNR boost and interference tolerance. In summary, the parameter N_{bl} is specified by the BS based on the bandwidth (FFT size), uplink SNR requirement, timing precision requirement, suppression capability to co-channel interferences, and the number of ranging opportunities that needs to provide. It should also be specified jointly with the other two parameters N_c and N_{sh} described below.

Second, in each sub-band, a number of ranging codes (i.e., N_c sequences) will be allowed. Since these ranging codes occupy the same band, they interfere with each other. Sequences with good cross-correlation are desired for better code detection and channel estimation. In addition, a low PAPR of the time-domain ranging waveform is also very desirable in order to improve the uplink SNR. The details of the sequences that have these desirable properties will be discussed in the next section. Lastly, for cellular deployment, a number of sequence groups (with each has N_c sequences) are also required for allocating to different neighboring sectors. So when those codes are generated and grouped, any pair of codes from distinct groups needs to have good cross correlation, just like any pair of codes in the same group. In summary, the parameter N_c is determined by the BS based on the access needs and the maximally tolerable interference level at which the successful detection rate is still good. An example design is to choose N_c=8 for a sequence length of 1680/16=105 subcarriers.

Third, for each ranging code, N_{sh} cyclic time shifts of the time-domain waveform (phase rotation in frequency domain) can be used to further increase the number of ranging opportunities. In essence, code separability is achieved by the fact that the estimated channel is shifted in time domain by some multiples of the extended CP length (denoted as L_{CPe}). In particular, the frequency domain sequence, after the j^{th} shift is

$$s_j(k) = s\ (k)e^{-j2\pi k(j-1)L_{CP_e}/N}, \tag{1}$$

where $s(k)$ is the original (or 0th shift) sequence and N is the FFT size. Maximally, only $N_{sh} = \lfloor N/L_{CPe} \rfloor$ shifts are allowed, but a good practice is to set $N_{sh} = \lfloor N/L_{CPe} \rfloor$-1 so that a good estimation of the noise and interference level can be obtained from the "channel-free" IFFT samples. Since L_{CPe} can be significantly larger than the regular CP length (denoted as L_{CP}), which will reduce the allowed N_{sh}, we can confine the initial ranging to a certain number of (say N_{bl}') subbands on which the allowed number of shifts is only $N_{sh} = \lfloor N/L_{CPe} \rfloor$-1. But on the remaining $N_{bl}-N_{bl}'$ sub-bands, where only non-initial ranging is allowed, the number of shifts can be increased to $N_{sh}' = \lfloor N/L_{CP} \rfloor$-1. Therefore, the total ranging opportunities increases to $N_{sh}*N_c*N_{bl}'+N_{sh}'*N_c*(N_{bl}-N_{bl}')$.

GCL Ranging Codes

The existing ranging sequences are BPSK sequences that are mapped from different length-144 sections of a PRBS. The PAPR of the corresponding time-domain waveform is large in general for this BPSK-modulated OFDM signal. The cross correlation property of the time domain waveform (i.e., after IFFT) is also unsatisfactory because the PRBS is applied in the frequency domain. The cross correlation of any two time-domain PN sequence is different from that of the resulting waveforms when the PN sequences are applied onto OFDM subcarriers, in which case the correlation in time is the IFFT of an element-wise division of the two BPSK sequences. Note that the auto-correlation is not a concern here because any waveform that has a CP has an "ideal" auto-correlation during an interval of a CP length.

As described earlier, it is desirable to use ranging sequences that have low PAPR and good cross-correlation. A good candidate for ranging waveforms is the Generalized Chirp Like (GCL) sequences, which are non-binary unit-amplitude sequences [5]. Constant amplitude means that the subcarriers are excited evenly to allow unbiased channel estimation. When mapping a GCL sequence onto all OFDM subcarriers (or onto uniformly spaced subcarriers), the time domain signals also have a constant amplitude. But due to the guard subcarriers used in all practical OFDM systems and possible sub-band excitation, the time domain waveform is equivalent to an oversampled discrete-time sequence after passing through a "sinc" pulse-shaping filter. The resulting PAPR will not have exactly constant amplitude, but a large number of the GCL sequences still enjoy low PAPR (e.g., <3dB). For any particular sequence length N_G, there are a large number (N_G-1) of GCL sequences (referred to as "classes" later), so the classes of GCL sequences that give good PAPR can be chosen as the ranging codes.

The GCL sequence used for ranging is expressed as

$$s_u(k) = \exp\left\{-j2\pi u \frac{k(k+1)}{2N_G}\right\}, \quad k = 0\cdots N_G-1 \quad \text{and} \quad u\,(\text{"}class \quad index\text{"}) = 1\cdots N_G-1 \qquad (2)$$

where N_G is the length of the GCL sequence (chosen as a prime number, explained later) and u is referred to as the class index that is a non-zero integer chosen between 1 and N_G. The GCL sequence has the following important properties:

Property 1: The GCL sequence has constant amplitude, and its N_G -point DFT has also constant amplitude.

Property 2: The GCL sequences of any length have an "ideal" cyclic autocorrelation (i.e., the correlation with the circularly shifted version of itself is a delta function)

Property 3: The absolute value of the cyclic cross-correlation function between any two GCL sequences is constant and equal to $1/\sqrt{N_G}$, when $|u_1-u_2|$, u_1, and u_2 are all relatively prime to N_G (a condition that can be easily guaranteed if N_G is a prime number).

The cross-correlation $1/\sqrt{N_G}$ at all lags (Property 3) actually achieves the minimum cross-correlation value for any two sequences that have the ideal autocorrelation property (meaning that the theoretical minimum of the maximum value of the cross-correlation over all lags is achieved). The minimum is achieved when the cross correlations at all lags equal to $1/\sqrt{N_G}$. This property is important since several interfering sequences are used in each sub-band and in each sector (more interferers if in a multi-sector environment). The cross correlation property allows the interfering signal be evenly spread in the time domain after correlating the received signal with the desired sequence. Hence, at least the significant taps of the desired channel can be detected more reliably.

In general, the number of subcarriers in a sub-band is often not a prime number. For example, if a sub-band of 105 subcarriers are used (i.e., after dividing 1680 data subcarriers into N_{bl}=16 sub-bands), the length of the frequency-domain ranging sequence should be 105. In this case, the smallest prime number is chosen that is larger than the desired length (e.g., N_G=107 in this case), then it is truncated to the desired length of 105. An alternative is to choose the largest prime number that is smaller than the desired length (e.g., N_G=103 in this case), then it is cyclically extended to the desired length. When such a modification is performed, the three previously described properties will only hold approximately, but it is found that they still hold very well, especially when the sequence is reasonably long.

As mentioned earlier, due to the oversampling effect introduced by applying the sequence on only a sub-band, the PAPR will increase a little bit. However, only the sequence classes that give the best PAPR will be needed.

3. Proposed Text Changes

[Replace the “UIUC==12” portion of “Table 285- OFDMA UL-MAP IE format” on Page 534, and “Initial_Ranging_Allocation_IE()” portion of Table 267 on page 510]

----------------*Start from here* --

Syntax	Size	Notes
If (UIUC==12){		
OFDMA Symbol Offset	8 bits	
No. Additional OFDMA Symbols	2 bits	Number (up to 3) of regular OFDMA symbols used for BW request and periodic ranging, in addition to the last special OFDMA symbol with the extended CP
Extended CP Length	3 bits	In multiples of the regular CP length (Up to 8 times of regular CP length)
FFT size of the extended-CP symbol	2 bits	The FFT size of the special symbol with extended-CP can be multiples (up to 4 times) of the regular FFT size
Dead Interval Flag	1 bit	1: Include the “dead” interval after the extended CP; 0: Do not include for overhead reduction
Num Sub-bands	4 bits	Divide the whole band into up to 16 sub-bands
Num Sub-bands for Initial Ranging	3 bits	“000”: Initial ranging can use all sub-bands “001”: Uses every second sub-band, starting with the first sub-band “010”: Uses every fourth sub-band, “011”: Uses every eighth sub-band, “100”: Uses every sixteenth sub-band, “101”: Uses the first and last sub-bands “110-111”: reserved.
Reserved	1 bit	
}		

-----------------------*End here* ---

[Replacing section 8.4.7 OFDMA ranging with the following]

--------------------------*Start from here* ---

8.4.7 OFDMA Ranging

When used with the WirelessMAN-OFDMA PHY, the MAC layer shall define a dedicated ranging interval. This ranging interval is composed of one special OFDMA symbol with an extended cyclic prefix (CP) that may be preceded by up to four regular OFDMA symbols with a regular CP for providing more ranging opportunities if needed. The duration of the extended CP, which shall equal to the summation of the regular CP length and the largest timing difference to be accommodated, is signaled by the base in the UL-MAP message as an integer multiple of the regular CP. Similarly, the FFT size of the extended-CP symbol, which shall also be an integer multiple of the regular FFT size, is signaled in the UL-MAP message as well. Immediately after the special OFDMA symbol, there is a “dead” interval that equals the largest timing difference. But it may be omitted to trade performance degradation for overhead reduction. The UL-MAP message shall signal whether the dead interval is included. The dedicated ranging interval is shown in Figure XXXa.

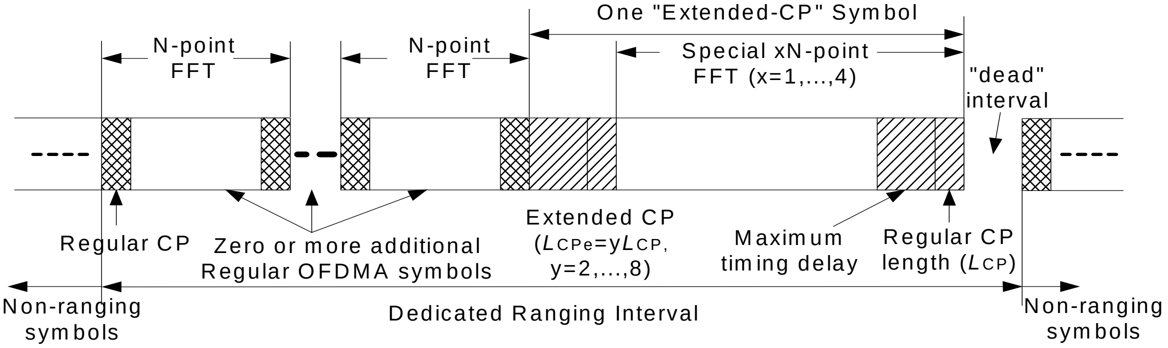


Figure XXXa. Dedicated ranging interval

A ranging signal shall use a ranging sequence that is randomly chosen from the code group allocated to the sector (denote the code group size as N_c). The sequences used in a code group and the allocation of groups to different sectors are specified in 8.4.7.3. The ranging sequence shall directly modulate the contiguous subcarriers in one frequency block. There are N_{bl} frequency blocks (subbands), where N_{bl} shall be determined based on the system bandwidth and known to the base and the SS. Note that initial ranging may be restricted to use only a specified subset of the total frequency blocks..

The method for selecting the frequency block used for the ranging transmission is as follows. In a TDD system, the SS shall measure the frequency selective channel power response during the downlink portion of the same TDD frame as the upcoming ranging transmission (e.g., based on the preamble and/or other pilot symbols in the downlink, or on frequency selective signal strength measurements). The SS shall then select the frequency block (out of the allowed frequency blocks) having the highest average channel power for its ranging transmission. For FDD systems, if the SS has frequency selective channel response information for the uplink (e.g., based on channel quality feedback from the BS), then the SS shall select the frequency block (out of the allowed frequency blocks) having the highest average channel power for its ranging transmission; otherwise, for FDD systems, the frequency block shall be selected randomly from the allowed frequency blocks.

Lastly, before the CP is inserted, the ranging signal shall be cyclically (circularly) shifted in time domain, where the shift is chosen randomly among N_{sh} allowed values that are known to the BS and SS. Mathematically, the frequency domain sequence, after the j^{th} shift is

$$s_j(k) = s\ (k) e^{-j2\pi k(j-1)L/N_{FFT}}, \tag{1}$$

where $s(k)$ is the original (or 0^{th} shift) sequence, L is the CP length and N_{FFT} is the FFT size. The suggested parameters for N_{sh}, N_c, and N_{bl} is given in 8.4.7.4 for the different FFT sizes and bandwidths. The division of ranging opportunities in frequency, time, and code is shown in Figure XXXb.

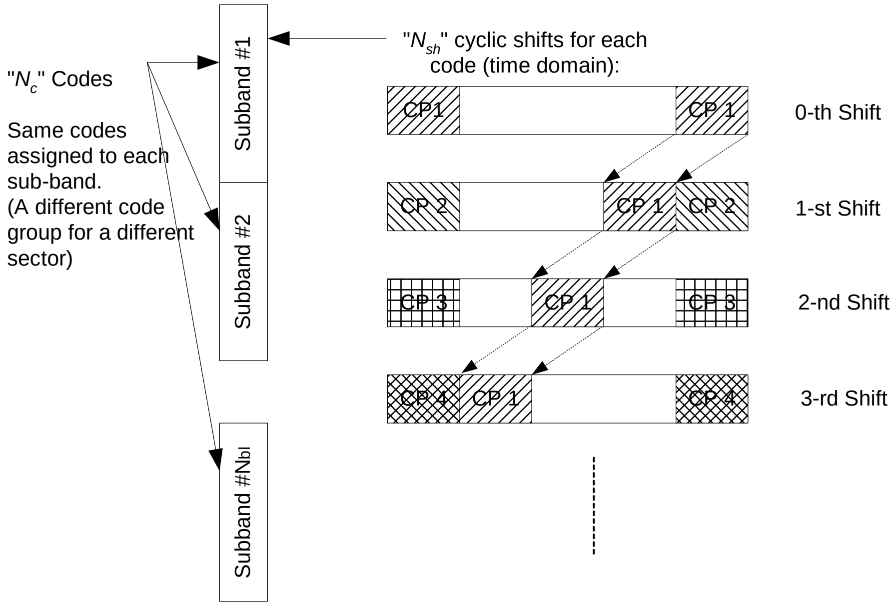


Figure XXXb. Ranging Opportunities in Frequency, Code, and Time

8.4.7.1 Initial ranging transmission

The initial ranging transmission shall be used by any SS that wants to synchronize to the system channel for the first time. The UL-MAP message (Table 285) shall specify the subbands that an initial ranging signal can use. All subbands or a specified number of the subbands starting from the lowest frequency offset may be allowed for initial ranging. For subbands that allow initial ranging, the allowed cyclic shift shall be set as $N_{sh}' = \lfloor xN/L_{CPe} \rfloor - 1$ where L_{CPe} is the length of the extended CP and xN is the FFT size of the special symbol with $x=1,2,3,$ *or*, 4 and N the regular FFT size. For subbands that do not allow initial ranging, the allowed cyclic shift shall be set as $N_{sh} = \lfloor xN/L_{CP} \rfloor - 1$ where L_{CP} is the length of the regular CP. If initial ranging is allowed on only N_{bl}' ($<N_{bl}$) subbands, the number of initial ranging opportunity is $N_{sh}' * N_c * N_{bl}'$. If initial ranging is allowed on all subbands, the total number of ranging opportunity is $N_{sh}' * N_c * N_{bl}$, of which a portion shall be assigned to initial ranging.

8.4.7.1 Periodic ranging and bandwidth request transmission

Periodic-ranging transmissions are sent periodically for system periodic ranging. Bandwidth-requests transmissions are for requesting uplink allocations from the BS.

These transmissions shall be sent only by SS that have already synchronized to the system. These transmissions can also use the additional OFDMA symbols if these symbols are allocated for ranging in the UL-MAP.

8.4.7.3 Ranging codes

The ranging waveforms shall use the Generalized Chirp Like (GCL) sequences that are truncated to the desired length that is equal to the number of subcarriers in one subband, as given by

$$s_u(k) = \exp\left\{-j2\pi u \frac{k(k+1)}{2N_G}\right\}, \quad k = 0 \cdots N_s - 1 \quad \text{and} \quad u\,(\text{"}\mathit{class \quad index}\text{"}) = 1 \cdots N_G - 1 \qquad (2)$$

where N_s is the desired length and N_G is the length of the whole GCL sequence before truncation. The parameter N_G shall be chosen as the smallest prime number that is large than or equal to N_s, and u is referred to as the class index and in theory can be any integer between 1 and N_G-1. But only the subset of u's that has good PAPR will be used and known to both the BS and MS. These sequences shall then be divided into a number (denoted as N_{gr}) of equal-size code groups, each of which is to be assigned to a sector. The number of sequences in each code group is N_c, and the number of groups shall be predetermined according to N_c and available u's. The mapping between the cell ID and the group index is

Group Index = mod(Decimal number corresponding to the last five bits of cell ID, N_{gr}) (3)

The BS can separate colliding codes and extract timing (ranging) information and power. In the process of user code detection, the BS gets the Channel Impulse Response (CIR) of the code, thus acquiring for the BS vast information about the user channel and condition. The time (ranging) and power measurements allow the system to compensate for the near/far user problems and the propagation delay caused by large cells.

8.4.7.4 Recommended parameters

If initial ranging is allowed at all subbands, the total number of ranging opportunity for the special OFDMA symbol is $N_{sh}*N_c*N_{bl}$=$\left(\lfloor xN/L_{CPe}\rfloor - 1\right)$ $*N_c*N_{bl}$, which shall be indexed and then assigned to initial ranging, bandwidth request, and periodic ranging in a parameter table (Table351 of REVd/D5). If initial ranging is allowed on N_{bl}' subbands only, there will be $N_{sh}'*N_c*N_{bl}'$= $\left(\lfloor xN/L_{CPe}\rfloor - 1\right)$ $*N_c*N_{bl}'$ initial ranging opportunities and $N_{sh}*N_c*(N_{bl}-N_{bl}')$= $\left(\lfloor xN/L_{CP}\rfloor - 1\right)$ $*N_c*(N_{bl}-N_{bl}')$ opportunities for bandwidth request and periodic ranging.

The parameter of N_{sh} does not need to be defined. The recommended parameters for N_{bl} and N_c are given in table YYYa,

Table YYYa. Recommended parameters for ranging

Regular FFT size (UL Subcarriers)	FFT X factor	N_{bl} (# of subband)	N_s (# of subcarriers)	N_G (GCL sequence length)	Used u's	# of code groups	N_c (# of codes in a group)	PAPR in dB

2048 (1681)	1	16	105	107	72	9	8	2.5-4.8
	2	16	210	211	168	21	8	2.5-5.4
	3	16	315	317	168	21	8	2.5-4.6
	4	16	420	421	168	21	8	2.5-4.4
1024 (841)	1	8	105	107	72	9	8	2.5-4.7
	2	8	210	211	168	21	8	2.5-5.4
	3	8	315	317	168	21	8	2.5-4.6
	4	8	420	421	168	21	8	2.5-4.4
512 (421)	1	4	105	107	72	9	8	2.5-4.8
	2	4	210	211	168	21	8	2.5-5.4
	3	4	315	317	168	21	8	2.5-4.6
	4	4	420	421	168	21	8	2.5-4.4
128 (106)	1	1	105	107	72	9	8	2.6-4.8
	2	1	210	211	168	21	8	2.7-5.3
	3	1	315	317	168	21	8	2.6-4.6
	4	1	420	421	168	21	8	2.4-4.3

Notes:

- The basic number of subcarrier in a subband is 105 for all the FFT sizes. If the special OFDMA symbol uses an FFT window that is a multiple ("X" factor) of the regular FFT size, the number of subcarriers scales by the X factor. However, due to the decrease of subcarrier spacing, the bandwidth of a subband is always fixed so that the time precision shall not be sacrificed. The fact that only four sequence lengths are needed for all FFT sizes simplify the receiver where the used sequence class u's are predetermined and stored.
- The number of used codes is 168, which is divided into 21 groups with N_c=8 in each group, except for the case of N_s= 105 where only 72 codes are used that is divided into 9 groups with 8 codes in each group, because the maximum number codes that can be used is only 106<168. Twenty-one groups allow each of the 21 sectors (center and second cell ring with three-sector cell) to use a different code group.
- The number of subcarriers allocated for ranging is the same as that in PUSC uplink (four-subcarrier tile option) for 2048 and 1024 FFT sizes. But for 512 and 128 FFT sizes, the subcarriers used for data are 421 and 85, respectively. However, the dedicated ranging does not have to follow the subcarrier assignment here because the ranging is not based on the subchannel definition anymore.

- An alternative design is to follow the UL subcarriers allocation for AMC case and PUSC that uses 3-subcarrier tile (both are the same). This subcarrier allocation uses more subcarriers than that in the other case of PUSC uplink with 4-subcarrier tile and the cases in downlink FUSC and PUSC. The modified design is given in Table YYYb

Table YYYb. Recommended parameters for ranging (alternative design)

Regular FFT size (UL Subcarriers)	FFT X factor	N_{bl} (# of subband)	N_s (# of subcarriers)	N_G (GCL sequence length)	Used u's	# of code groups	N_c (# of codes in a group)	PAPR in dB
2048 (1729)	1	16	108	109	72	9	8	2.5-4.8
	2	16	216	223	168	21	8	2.3-5.2
	3	16	324	331	168	21	8	2.3-4.5
	4	16	432	433	168	21	8	2.5-4.3
1024 (865)	1	8	105	107	72	9	8	2.5-4.8
	2	8	210	211	168	21	8	2.3-5.2
	3	8	315	317	168	21	8	2.3-4.5
	4	8	420	421	168	21	8	2.5-4.3
512 (433)	1	4	105	107	72	9	8	2.5-4.8
	2	4	210	211	168	21	8	2.3-5.2
	3	4	315	317	168	21	8	2.3-4.5
	4	4	420	421	168	21	8	2.5-4.3
128 (109)	1	1	105	107	72	9	8	2.3-4.8
	2	1	210	211	168	21	8	2.7-5.1
	3	1	315	317	168	21	8	2.5-4.5
	4	1	420	421	168	21	8	2.7-4.2

-----------------*End here* ---

[Replace section 8.4.5.4.3 with the following (Page 536)]

------------------------*Start from here* --

Table 288 –CDMA Allocation IE format

Syntax	Size	Notes
CDMA_Allocation_IE{}		
Duration	6 bits	
Repetition Coding Indication	2 bits	0b00 - No repetition coding 0b01 - Repetition coding of 2 used 0b10 - Repetition coding of 4 used 0b11 - Repetition coding of 6 used
Ranging Code	3 bits	Indicates which of the ranging code within the group is sent by the SS
Subband Index	4 bits	Indicates which of the subband is used by the SS
Cyclic Shift Index	6 bits	Indicates which of the cyclic time shift is used by the SS
Ranging time location	3 bits	
BW request mandatory	1 bit	1= yes, 0=no
Reserved	1 bit	
}		

Duration

Indicates the duration, in units of OFDMA slots, of the allocation.

Repetition coding indication

Indicates the repetition code used inside the allocated burst.

Ranging Code

Indicates which of the ranging code within the group is sent by the SS.

Subband Index

Indicates which of the subband is used by the SS.

Cyclic Shift Index

Indicates which of the cyclic time shift is used by the SS

Ranging time location

Indicates where the ranging is sent in the dedicated ranging interval
“100”: ranging sent at the last extended-CP symbol
“000”: ranging sent at the first additional regular symbol (counting backwards from the last symbol)
“001”: ranging sent at the second additional regular symbol (counting backwards from the last symbol)
“010”: ranging sent at the third additional regular symbol (counting backwards from the last symbol)

“011”: ranging sent at the fourth additional regular symbol (counting backwards from the last symbol)

BW request mandatory

Indicates whether the SS shall include a Bandwidth (BW) Request in the allocation.

---------- *End here* --

[Replace Table 367 with following (Page 672)]

------------------------*Start from here* --

Table 367—OFDMA-specific RNG-RSP message encodings

Name	Type	Length	Value
Ranging code attributes	150	3	Bits 24:18 - Used to indicate the cyclic shift used to transmit the ranging code. Bits 17:15 - Used to indicate the OFDM time symbol reference that was used to transmit the ranging code. Bits 14:11 - Used to indicate the subband used to transmit the ranging code. Bits 10:8 - Used to indicate the ranging code index within the group that was sent by the SS. Bits 7:0 - The 8 least significant bits of the frame number of the OFDMA frame where the SS sent the ranging code.

---------- *End here* --

[Replace “Ranging code attributes” paragraph, section 6.3.2.3.6, lines 37-40 with the following]

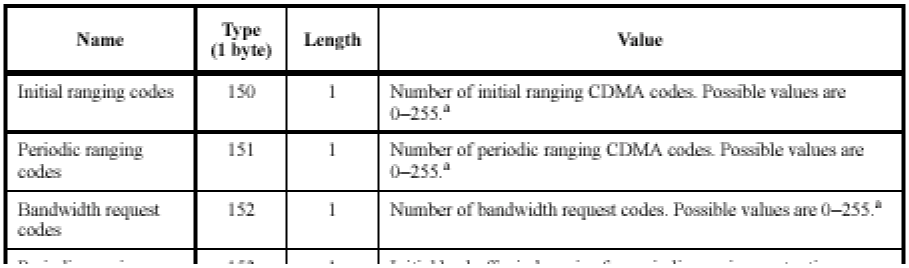
------------------------*Start from here* --

Ranging code attributes
Indicates the OFDMA time symbols reference, subband reference, cyclic shift, frame number used to transmit the ranging code, and the ranging code index that was sent by the SS.

---------- *End here* --

[Delete the first three rows of parameters in Table 351—UCD PHY-specific channel encodings — WirelessMAN-OFDMA, on page 658]
------------------------*Start from here* --

Instructions to editor: Delete the rows containing Initial ranging codes, Periodic ranging codes, and Bandwidth request codes.



Name	Type (1 byte)	Length	Value
Initial ranging codes	150	1	Number of initial ranging CDMA codes. Possible values are 0–255.[a]
Periodic ranging codes	151	1	Number of periodic ranging CDMA codes. Possible values are 0–255.[a]
Bandwidth request codes	152	1	Number of bandwidth request codes. Possible values are 0–255.[a]

---------- *End here* --

4. Detailed Supporting Materials

Background and Motivation

The ranging operation includes the initial ranging function for synchronizing an SS with a BS during the initial network entry or re-entry and cell handoff, the periodic ranging function for maintaining SS synchronization, and the bandwidth request function for each SS to request uplink bandwidth allocation.

The uplink ranging function, which includes initial ranging, periodic ranging, and bandwidth request, fulfills very important tasks that can significantly influence the user experience. For example, the bandwidth request ranging performance directly impacts the access latency perceived by a user, especially during sessions that consist of sporadic packet traffic that requires fast response, in which case high detection and low collision probabilities are very desirable. In another example, robust detection of an initial ranging signal is essential in order to allow a user to quickly enter the network or to be handed over to a new serving sector. Reliable extraction of accurate timing offsets from the initial ranging signals is also critical for achieving uplink synchronization that ensures user orthogonality (i.e., to make sure that each SS occupies its own allocated subcarriers without interfering with other SS). Other important information that the BS needs to extract from ranging includes power measurement and channel impulse response, etc.

In the current draft of WirelessMAN-OFDMA PHY (REVd/D5), the ranging signal is transmitted on a single ranging channel that is comprised of a subset of subcarriers specified in the UL-MAP message. According to the specification, "this ranging channel composed of one or more groups of six adjacent subchannels, where the groups are defined starting from the first subchannel. Optionally, ranging channel can be composed of eight adjacent subchannels using the symbol structure defined in 8.4.6.2.5." This means that 144 subcarriers are used in non-contiguous blocks of subcarriers with a block size of either 4 or 3 contiguous subcarriers. The remaining non-ranging subcarriers are allocated for data traffic.

A length-144 BPSK sequence is used to modulate the ranging subcarriers. The BPSK sequence is mapped simply from a binary sequence that is a section of the long Pseudo-Random Binary Sequence (PRBS) generated by the polynomial $1+X^1+X^4+X^7+X^{15}$. The number of available codes is 256 that are divided to a number of sub-groups. In a sub-group, the first *N* codes will be used for initial ranging; the next *M* and *L* codes will be used for periodic ranging and bandwidth request. According to the parameters in Table 351 on page 658 of REVd/D5, the total number of codes is $N+M+L=256$ that is shared by a number of subgroups.

Initial ranging waveform, which is different from other ranging signals that are just regular OFDMA symbols, uses an interval of two OFDMA symbols with the second one being a circularly shifted version of the first symbol (i.e., shift the CP-included waveform to the left by the length a CP). Because a BS processes the received signal on regular FFT windows, this "long symbol" design for initial ranging will give one "clean" FFT window no matter where the long symbol starts. Note that other ranging and uplink data transmissions are pre-adjusted in timing so that the signals arrive at the BS synchronized. In the "clean" FFT window, the initial ranging signal has a regular OFDMA symbol structure with a CP portion aligned with the CP portions of other synchronized signals. So, the signal will reside only on the specified ranging subcarriers and not interfere with other subcarriers (thus the word "clean").

The current ranging scheme claims to achieve some of the above-mentioned goals (section 8.4.7 pg. 582 of REVd/D5):

> "The BS can separate colliding codes and extract timing (ranging) information and power. In the process of user code detection, the BS gets the Channel Impulse Response (CIR) of the code, thus acquiring for the BS vast information about the user channel and condition. The time (ranging) and power measurements allow the system to compensate for the near/far user problems and the propagation delay caused by large cells."

However, in contributions [1][2] submitted in the year of 2001, the simulation results there showed unsatisfactory performance under realistic channel and traffic conditions (e.g., only 4-5 users can be accommodated by the existing scheme, instead of 20 contending users claimed in [3] with 90% success rate and 10 contention slots). There are several drawbacks for the unsatisfactory performance:

1. *The cross correlation property of the time domain waveform (i.e., after FFT) is degraded because the PRBS is applied to the frequency domain.* The cross correlation of any two time-domain PN sequence is different from the case if the PN sequences are applied onto OFDM subcarriers, in which case the correlation in time is the IFFT of an element-wise division of the two BPSK sequences. The presence of other ranging codes on the same set of subcarriers will severely distort the estimation of the desired

channel due to the unsatisfactory cross correlation property. This results in a lower detection rate and higher false alarm rate even just for the purpose of detecting the presence of a ranging code, needless to say the goal of obtaining accurate CIR. The performance becomes more degraded as the channel conditions become worse (for example, under larger delay spread) or the number of ranging users increases. Note that the auto-correlation is not a concern because it is still "ideal" during an interval of a CP length, as long as the waveform has a CP.

2. *The initial ranging signals cause interference to both data traffic and other types of ranging.* Even though the long symbol used for initial ranging provides a "clean" FFT window, the effect of initial ranging to the FFT windows right before and after that, can be significant depending on the timing offset. The interference is in the form of co-channel interference to other ranging signals that coexist on the same ranging subcarriers and inter-subcarrier interference to data traffic that uses other subcarriers.
3. *The ranging overhead introduced by using a moderately large number of subcarriers becomes excessive for smaller FFT sizes.* The ranging codes need to be kept as long as possible for acceptable correlation property. So the overhead can increase to an unacceptable level if the FFT size is small (e.g., 144 subcarriers out of around 200 used subcarriers in the 256-point FFT mode). The current ranging codes would not even fit into the expected smallest FFT size of 128.
4. *The PAPR of the ranging signals is large, which reduces the power output from an SS due to backoff requirement and thus reducing the link budget on the ranging channel.* Since the ranging signal is a BPSK modulated OFDM signal, its PAPR tends to be large, which requires more power backoff. The reduced average transmit power causes a decrease of the uplink SNR, which can be problematic for the BS to detect the ranging signals from mobile devices with limited power.
5. *The placement of ranging subcarriers across the whole band degrades the performance in both code detection and timing offset estimation.* Since the random-like subcarrier placement causes irregular aliasing in the time domain, timing offset estimation may be degraded due to this type of "self-interference." On the other hand, using a contiguous block of subcarriers can provide improved performance, as already reported in contribution [4], although at a price of reduced precision in timing offset estimation.
6. *The maximum number ranging opportunities of the existing scheme is limited by the uplink duration, instead of being adjustable to the access needs.* A good number of codes are currently assigned for ranging at each uplink OFDMA symbol, except for initial ranging that spans a two-symbol interval. So, the ranging opportunities decrease in the case of a short uplink, which is very possible because of an asymmetric traffic pattern, for example when a lot of SSs have only small packets to send. Since the ranging opportunities decrease due to a short uplink, but not the number of requests, collision rate will increase and thus causing large access latency.

Receive Processing at the Base

The uplink processing is discussed here to illustrate how the cross correlation property can be taken advantage of. Basically, a time-domain channel corresponding to each ranging user will be detected through a correlation process that can be performed efficiently in the frequency domain. For initial ranging users, the timing offset also needs to be extracted, which is straightforward after the channel is estimated in the process. The signal and interference power can also be estimated in the process.

Ranging code detection

The detection of the presence of a ranging code is often performed by comparing a pre-set threshold with the ratio of the peak of the estimated channel to the estimated noise floor.

At the BS, a bank of N_c detector/estimators run in parallel for each of the N_{bl} sub-bands, using the data resulting from taking an N-point FFT of the received signal at the appropriate FFT window. The processing described below is generalized to multiple BS antenna cases, although only a single antenna is simulated. Let the frequency domain data for receive antenna m be $Y_m(k)$ where k is a data subcarrier in a sub-band (e.g., k=1,2, …,105 in the above example). Note that $Y_m(k)$ consists of possibly more than one ranging code. $Y_m(k)$ will be correlated with all N_c ranging sequence candidates. The correlation is performed in the frequency domain and then transformed back to the time domain. In other words, we first multiply $Y_m(k)$ by a conjugate of each of the GCL candidates as follows:

$$\widetilde{H}_m(k) = Y_m(k) S_u^*(\mathrm{k}) \qquad (3)$$

Next the noisy estimates are transformed to the time domain through a P-point IFFT as:

$$\widetilde{h}_m(\ell) = \frac{1}{P}\sum_{k=0}^{K-1} \widetilde{H}_m(k) w(k - K/2) e^{j2\pi\ell k/P} \qquad 0 \le \ell \le P-1 \qquad (4)$$

where K is the number of subcarriers in the sub-band (i.e., K=105 in the previous example) and the IFFT size P can be chosen as the smallest power-of-2 integer that is larger than K (e.g., P=128 if K=105). $w(k)$ is an optional weighting window applied onto the noisy frequency response. The windowing is to reduce the power leakage problem caused by the discontinuity from the edge of the band to null subcarriers (since zeros are inserted in place of the null subcarriers before the IFFT). It can be thought as an artificial pulse-shaping filter that is a "sinc" function if a flat weighting is applied. The pulse-shaping filter can reduce the tail effect so that there will be fewer taps in $\widetilde{h}_m(\ell)$ introduced by "sinc" pulse shaping, rather than by true multipaths. An example is the traditional raised cosine pulse shaping whose tails decay much faster than that in the "sinc" function case. Similar to a raised cosine function, a "Hanning" window can be used, i.e.,

$$w(k) = (0.5 + 0.5\cos\frac{2\pi k}{\Gamma}), \qquad (5)$$

where the parameter Γ controls the shape of the window (an infinite Γ means a flat window). Γ should be larger than K.

In the case of a cyclic time-domain shift for the ranging code, the ranging users' channels are separable in the time domain. This means that an estimate of n^{th} user channel is simply contained in samples $(n\text{-}1)L_{\mathrm{CPe}}$ through $nL_{\mathrm{CPe}}\text{-}1$ of (4). If the last L_{CPe} is "channel-free", an estimation of the noise plus interference level for each of the M antennas can be obtained by averaging $|\widetilde{h}_m(\ell)|^2$ for $l=P\text{-}L_{CPe}, \ldots, P\text{-}1$, i.e.,

$$\sigma_m{}^2 = \frac{1}{L_{CPe}} \sum_{l=P-L_{CPe}}^{P-1} \left|\tilde{h}_m(\ell)\right|^2 \tag{6}$$

The detection variable for the n^{th} shift ranging user is then calculated as

$$z_n = \sum\nolimits_{m=1}^{M} \frac{\max_{l=(n-1)L_{CPe}}^{nL_{CPe}-1} |\tilde{h}_m(l)|^2}{\sigma_m{}^2} \tag{7}$$

This detection variable will be compared with a threshold. If z_n is greater than the threshold, detection is declared. A larger threshold value reduces the false alarm probability, but it also increases the probability of a "miss".

Another type of detection variable is the ratio between the peak and the mean power value, i.e.,

$$z_n' = \sum\nolimits_{m=1}^{M} \frac{\max_{l=(n-1)L_{CPe}}^{nL_{CPe}-1} |\tilde{h}_m(l)|^2}{{}^{1}\!/\!{}_{L_{CPe}} \sum\nolimits_{l=(n-1)L_{CPe}}^{nL_{CPe}-1} |\tilde{h}_m(l)|^2} \tag{8}$$

This detection value may be used when there is no "channel-free" region to estimate the noise floor.

Timing offset estimation

The timing offset can be estimated in the following way. First, over the region of the extended CP (L_{CPe}), a rectangular window of width L_{CP} slides through this extended-CP window. The estimated signal power is computed recursively as

$$x_n(i) = \sum\nolimits_{m=1}^{M} \sum\nolimits_{l=(n-1)L_{CPe}+i}^{(n-1)L_{CPe}+i+L_{CP}} |\tilde{h}_m(l)|^2, \quad for \quad i = 0,1,\cdots,L_{CPe} - L_{cp} - 1 \tag{9}$$

$x_n(i)$ will exhibit a plateau whose width depends on the number of "valid" timing compensation values. Ideally, the right edge of the plateau corresponds to the correct timing offset estimation. However, if the channel length L is smaller than the regular CP length L_{CP}, then L_{CP}-L sampling points before the correct timing point are all "valid" choices in the sense of not causing any SNR degradation. One conservative way to choose the timing point within the plateau is to choose the mid-point between the peak and the right edge of the plateau (defined as the point that $x_n(i)$ first falls below a certain percentage (say 95%) of the peak). Instead of trying to estimate the true timing offset and risking a significant SNR degradation occurred even when the estimate is just a few taps later than the true timing, this approach chooses a conservative timing advance compensation point that can often be earlier than the true timing offset, but the degradation of SNR is guaranteed to be minimal.

Channel estimation

The channel of the ranging user can also be estimated reasonably well if needed. This information can be helpful for closed loop antenna processing. To improve the channel estimation under low SINRs, a tap-selection or "de-noising" strategy is important. Tap selection simply means that the channel taps below some threshold, η, are set to zero. Hence, tap selection improves the channel estimation for relatively sparse channels by attempting to match the channel estimator to the instantaneous power delay profile for each user. A threshold of η =3dB stronger than the estimated σ_m^2 is an example of reasonable choices.

Let the time-domain channel estimate for a ranging user after tap selection be denoted as $\hat{h}_n(\ell)$ for $0 \le \ell \le L_{CP}-1$. Then the frequency-domain channel estimate for that sub-band is the P-point FFT of $\hat{h}_n(\ell)$:

$$H_n(k) = \frac{1}{w(k-K/2)} \sum_{\ell=0}^{L-1} \hat{h}_n(\ell) e^{-j2\pi\ell k/P} \qquad 0 \le k \le P-1 \tag{10}$$

Simulation Results

NOTE: The current simulation results do not include the benefits of selecting the best frequency block based on the channel frequency selective characteristics.

Let us first look at the PAPR and cross-correlation properties. The existing ranging codes and proposed GCL codes are compared below to illustrate the advantage of the GCL sequences. As mentioned earlier, due to the oversampling effect introduced by applying the GCL sequence on only a sub-band, the PAPR will increase a little bit. However, only the sequence classes that give the best PAPR will be needed. In the example of N_G-1=106 sequences that can be used (i.e., u=1,…,106), which there are 8 classes with the PAPR of the corresponding oversampled waveform (length-2048 discrete-time waveform) being less than 3dB (the minimum is around 2.5dB), and 30 classes with PAPR between 3 and 4dB, 36 classes with PAPR between 4 and 5dB, 26 classes with PAPR between 5 and 6dB, and 6 classes with PAPR between 6 and 6.5dB. In general, the longer the sequence, the larger is the number of sequences with below-5dB PAPR. Just as an example, if 4 groups of low-PAPR ranging codes (with each group contains N_c=8 codes) are needed, the PAPR of all 32 sequences can be guaranteed to be less than 3.8dB (see Table 1). The normalized cross-correlation at all lags is roughly around $1/\sqrt{N_G}$ =0.097, or about 20dB attenuation compared with the autocorrelation value of 1.

Table 1. Example of grouping of ranging sequences (length-105)

	GCL sequence class indices *u* (corresponding PAPR in dB)							
Group #1	106 (2.51)	36 (2.89)	67 (3.05)	89 (3.25)	98 (3.34)	95 (3.36)	33 (3.54)	6 (3.64)
Group #2	1 (2.51)	71 (2.89)	40 (3.05)	18 (3.25)	9 (3.34)	12 (3.36)	74 (3.54)	101 (3.64)
Group #3	27 (2.74)	54 (2.96)	43 (3.11)	46 (3.33)	32 (3.35)	73 (3.39)	68 (3.61)	56 (3.73)
Group #4	80 (2.74)	53 (2.96)	64 (3.11)	61 (3.33)	75 (3.35)	34 (3.39)	39 (3.61)	51 (3.73)

The existing ranging code compared is a length-144 BPSK sequence modulated on 144 scattered subcarriers (i.e., occupying subchannel #1 to #6 with each has 6 tiles of 4 contiguous subcarriers). The subcarriers indices are obtained using the tile permutation table and under the assumption of UL_ID_{cell}=0. For fair comparison, 144 ranging subcarriers are also used in the case of GCL ranging codes (the example given in the previous table uses

105, instead of 144, subcarriers). These subcarriers are contiguous and the sequences is truncated from length N_G=149 (a prime number).

First of all, it is found that the PAPR of the existing ranging codes ranges from 7.2dB to 11.23dB for all the 256 usable codes, while the PAPR of all the 148 usable GCL codes ranges from 2.39 to 6.29. Then, the 2048-point autocorrelation (upper plots) and cross correlation characteristics (bottom plots, among 30 randomly chosen codes) are plotted in Figure 4. The autocorrelation is just the 2048-point IFFT of 1's at those occupied subcarrier positions. As can be seen, using scattered subcarriers causes irregular aliasing at this sampling rate. Although the channel may be resolved at a granularity equal to the sample interval, the irregular aliasing can cause a lot of false taps. On the other hand, using contiguous subcarriers results in a "sinc" shape autocorrelation. The aliasing effect is regular that concentrates mainly in the close vicinity of the true channel tap, which translates into only a decrease in timing resolution when a smaller FFT size, or equivalently a lower sampling rate is used. Lastly, the cross-correlation comparison shows that in the GCL case the cross correlation is much more evenly distributed near the mean 1/sqrt(144)=0.0833 than in the BPSK PN sequence case. This translates into a more reliable detection because fewer false taps will arise and true taps are less distorted by interference.

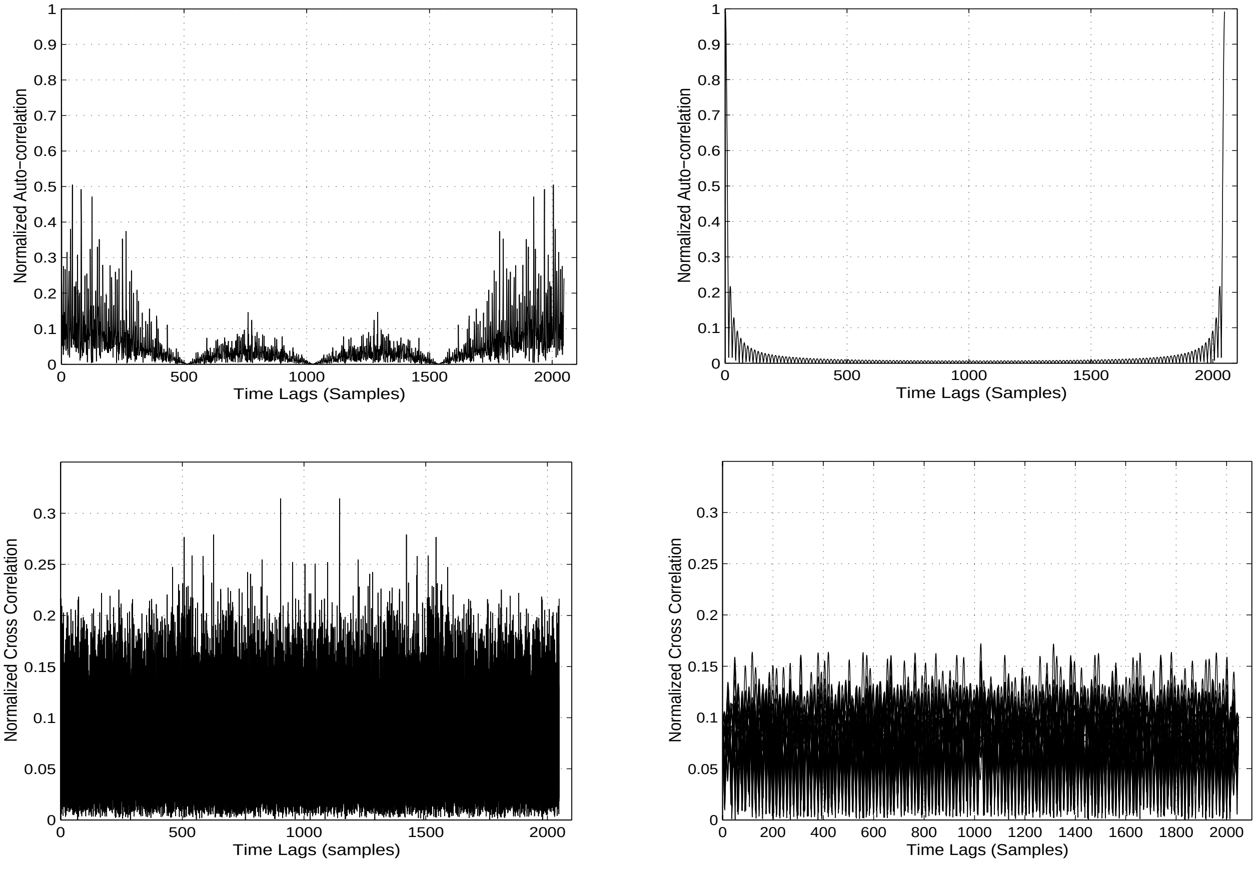


Figure 4. Auto- (upper) and cross- (bottom) correlation characteristics of BPSK PN ranging sequence on 144 scattered subcarriers and GCL sequences on 144 contiguous subcarriers

Further simulations results are provided here to show the advantages of the proposed ranging scheme. The dedicated basic ranging interval uses one extended-CP OFDMA symbol. The FFT window is 2048 with 1680 data subcarriers (excluding DC). A single antenna 20MHz system is assumed with a sampling clock of 25.6MHz that makes the OFDMA symbol time to be 80μs. A regular CP of 256 samples or 10μs is assumed and the extended CP is assumed to be 512 samples or 20μs to allow a maximum 10μs timing difference that is equivalent to 3000m in traveling distance.

The 1680 subcarriers is divided into N_{bl}=16 sub-bands or 105 subcarriers. Eight (N_c=8) GCL ranging codes are defined for each sub-band and three (N_{sh}=3) circular shifts are also allowed for each ranging codes. In total, there are 16*3*8=384 ranging opportunities (indexed from 0 to 383) from which a user can randomly pick. The GCL ranging codes are obtained as truncated GCL sequences from length N_G=107. Note that the existing scheme can provide a maximum 48*8=384 ranging opportunities during an uplink of 8 data OFDMA symbols if a sub-group of 48 codes are assigned for each sector and no initial ranging is allowed (but if the initial ranging uses 16 codes out of 48, only a total of 320 opportunities are provided). The proposed scheme is more flexible in terms of the capability to adjust the overhead for different FFT sizes and to provide a variable number of ranging opportunities depending on bandwidth and access needs.

Three environments with exponential power delay profiles are simulated that have different RMS delay spread (DS) of 0.1μs, 0.5μs, and 2μs to represent low, medium, and high scattering environments, respectively. Note that the channel peak becomes less prominent as the delay spread increases.

Interference-free ranging with noise only

First simulated is for the case that there is only one ranging code present at a certain shift and sub-band, i.e., with no other interference but noise. The sub-band SNRs simulated are –12, -8, -4, 0, 4, 8dB. The receive processing at the BS uses an IFFT of size P=128 in (4). The frequency-domain Hanning window of (5) is almost flat (i.e., $\Gamma >> P$). It is found that a smaller Γ (i.e., more attenuation at the edges) in (5) is only helpful to channel estimations at the edge subcarriers under very high SNRs and a large Γ should be used otherwise.

Code detection is declared if the detection ratio (7) is over a threshold. The successful detection probability is plotted as solid curves in Figure 5, Figure 6, and Figure 7, for environments with 0.1μs, 0.5μs, and 2μs delay spread, respectively. In each figure, five simulated SNR points correspond to fives curves. For each solid curve, there is a corresponding dashed curve that represents the false alarm probability. A false alarm happens when a detection is declared after correlating the signal with a code that is not actually transmitted. The false alarm probability is found to be zero if there is only noise, but it is not zero when an interference code is present. So reported in the figures is the false alarm with only one code being transmitted. Note there are N_c=8 code detectors running in parallel for each sub-band. The false alarm probability is for each code detector at each cyclic shift.

It can also been from the three figures that higher SNR improves both detection rate and false alarm rate. Also for the same SNR, when the peak channel tap become less prominent as the RMS delay spread increases in the three environment profiles, the detection rates drops and the false alarm rate increases, very slightly though. It can also be seen from the figure that both the detection and false alarm rate decrease when the threshold increases. The threshold should be chosen to provide a good detection rate while keeping the false alarm rate as low as possible. For example, a threshold of 10dB will keep the false alarm rate at about 0.15% while having a 99.53% detection rate (at SNR= -4dB and DS=0.5µs). To see better this kind of numbers from the figures, some results are tabulated in Table 2, where a “miss” is defined as a failure to detect the code that is present.

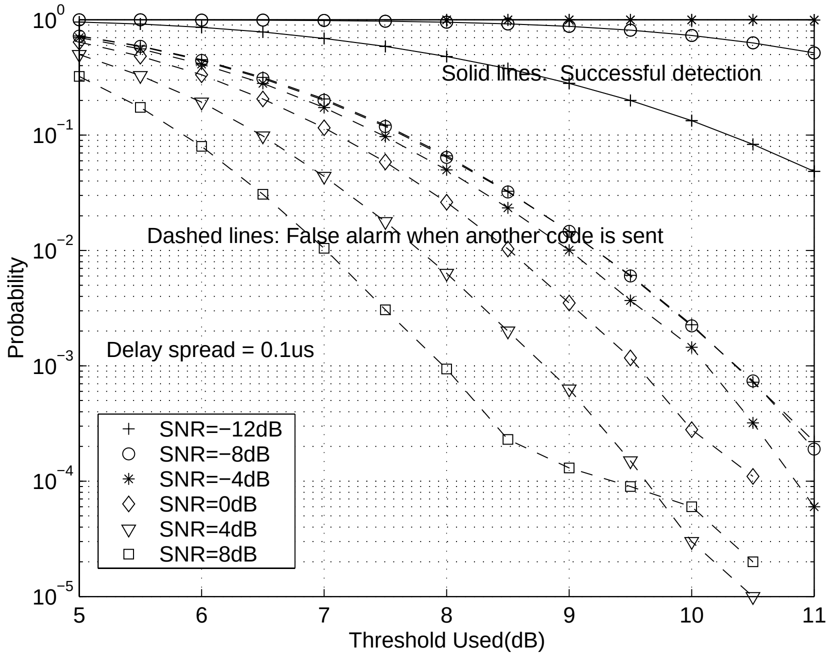


Figure 5. Detection and false alarm rate in the DS=0.1µs environment

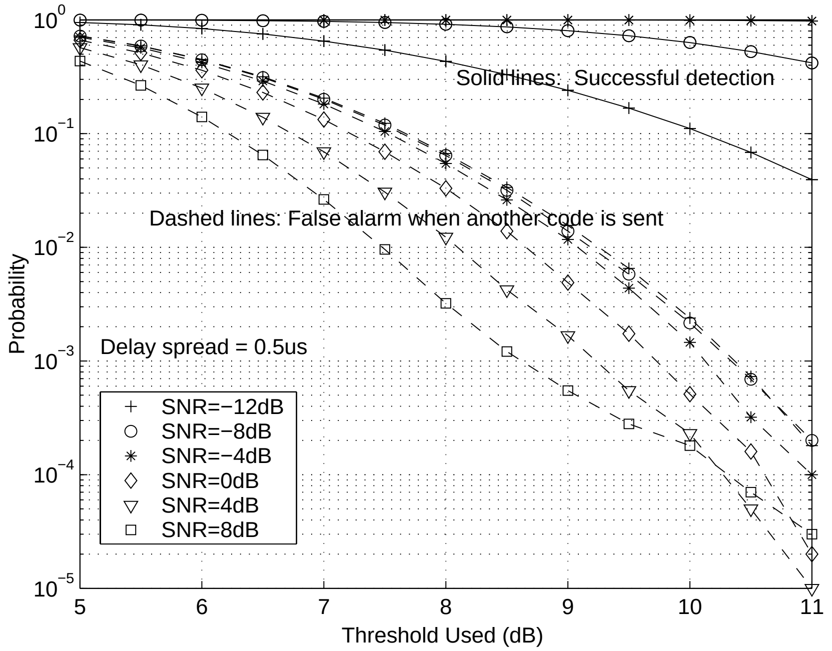


Figure 6. Detection and false alarm rate in the DS=0.5µs environment

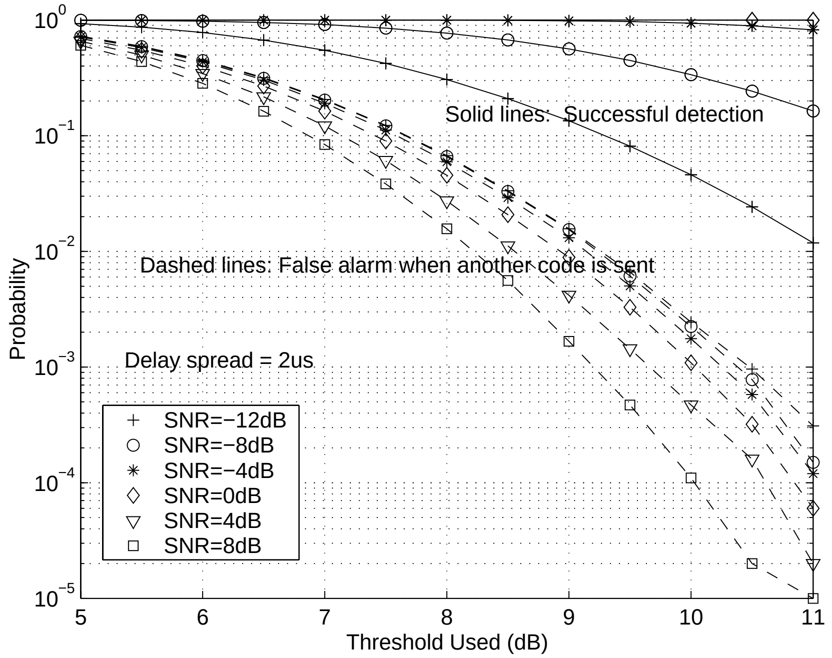


Figure 7. Detection and false alarm rate in the DS=2µs environment

Table 2. Detection and false alarm percentages at SNR= - 4dB (1 user present)

	Correct detection	Miss	False alarm (no code, noise only)	False alarm (another code present)
DS=0.1 (thres=9dB)	100	0	0	1.01
DS=0.1 (thres=10dB)	99.96	0.04	0	0.14
DS=0.5 (thres=9dB)	99.94	0.06	0	1.17
DS=0.5 (thres=10dB)	99.53	0.47	0	0.15
DS=2 (thres=9dB)	98.65	1.35	0	1.31
DS=2 (thres=10dB)	94.09	5.91	0	0.18

Ranging under mutual interference

Next simulated is for the case when there are a varying number of ranging codes present at a certain shift and sub-band, in other words, with the presence of co-channel interference. There are up to N_c=8 codes allowed that might occupy the same shift and same sub-band. Although it is very rare to have more than 6 distinct codes occupied without collision, it is possible to have even more than 8 interfering users with some of them colliding. When collisions happen, the non-colliding codes in the same band should still be detected even though the interference suffered from the colliding codes increases by several times due to the combined signal power from several colliding users. It is also assumed that all users has equal sub-band SNR of 0dB (Table 3) or 4dB (Table 4). Only the results under the environment of DS=0.5μs are reported here.

As expected, when the number of interfering users decreases (i.e., SINR increases), the successful detection rate increases. However, instead of a decreasing trend, the false alarm probability seems to be rather stable or even go up slightly. Note first that a false detection is made when the peak to noise plus interference level is above a threshold. The noise plus interference level arises with the number of users. That is why there is no strong correlation between number of users and false alarm rate. Second, when the number of interfering users is small, the correlation results will be less Gaussian-like, which can increase the false detection rate, as evidenced in the tables.

Table 3. Detection and false alarm percentages (“U” equal-power users each @0dB SNR)

	U=9 (-9.5dB SINR)	U=8 (-9dB SINR)	U=7 (-8.5dB SINR)	U=6 (-7.8dB SINR)	U=5 (-7dB SINR)	U=4 (-6dB SINR)	U=3 (-4.8dB SINR)	U=2 (-3dB SINR)	U=1 (0dB SINR)

thresh=9dB	60.8 (1.9)	66.2 (1.9)	67.6 (2.1)	83.15 (2.76)	90.12 (2.32)	98.1 (2.24)	99.5 (2.30)	99.92 (2.21)	100 (2.21)
thresh=10dB	41.9 (0.3)	45.0 (0.5)	49.9 (0.5)	67.83 (0.7)	79.42 (0.47)	94.2 (0.44)	98.1 (0.54)	99.65 (0.60)	99.99 (0.65)

Table 4. Detection and false alarm percentages ("U" equal-power users each @4dB SNR)

	U=9 (-9.2dB SINR)	U=8 (-8.7dB SINR)	U=7 (-8.1dB SINR)	U=6 (-7.3dB SINR)	U=5 (-6.4dB SINR)	U=4 (-5.3dB SINR)	U=3 (-3.8dB SINR)	U=2 (-1.5dB SINR)	U=1 (4dB SINR)
thresh=9dB	68.8 (2.3)	75.9 (2.5)	75.0 (2.0)	88.28 (1.33)	93.95 (2.45)	99.05 (2.00)	99.83 (2.07)	99.99 (2.08)	100 (2.67)
thresh=10dB	47.9 (0.3)	56.1 (0.4)	54.2 (0.44)	75.04 (0.30)	85.85 (0.50)	96.95 (0.49)	99.24 (0.55)	99.93 (0.76)	100 (1.29)

Overall detection performance

A varying number (from 1 to 100) of ranging users are simulated that all arrive with equal SNR of 0dB. With each number N_u, 10000 Monte Carlo trials are assumed where in each trial each of the N_u users chooses one of the 384 ranging opportunities with a uniform distribution. The number of collisions and non-collisions are recorded for each of the 48 non-interfering ranging allocation. The numbers of success, miss, and false alarm occurrences are computed based on the probabilities in Table 3 (assume a threshold of 10 dB). The mean success rate is given in Figure 8 and the absolute numbers of miss, collision, and false alarm occurrences are plotted in Figure 9. As can be seen, the overall success probability is satisfactory that degrades very gradually with the number of users. Even with a large of number of ranging (say 100), the success rate is still around 86% where most of failures are due to collision (see Figure 9). False alarm and miss are relatively rare.

As a reference, the performance of the existing ranging scheme reported in [3] is pasted in Figure 10. The text describing the simulation is copied below:

> "The simulation was done for period of 10 OFDMA symbols with one sub-channel allocated for Request Codes. Each user randomly selects (with uniform distribution) time symbol and Request code, the number of available codes was 16, with cross correlation factor of 8 – meaning that if more then 8 users selected the same opportunity (bucket) then all of them are lost, also if two or more users selected the same code, they are considered as failed. The conditions for the normal contention access assume that each request requires exactly one slot (if preamble should be required for each request, then the number of the transmission opportunities should have cut by half, and the results for the contention case would

be worst). The simulation deals with one attempt (with window size of 10 slots), retransmission will improve both of the scenarios, better for the CDMA case."

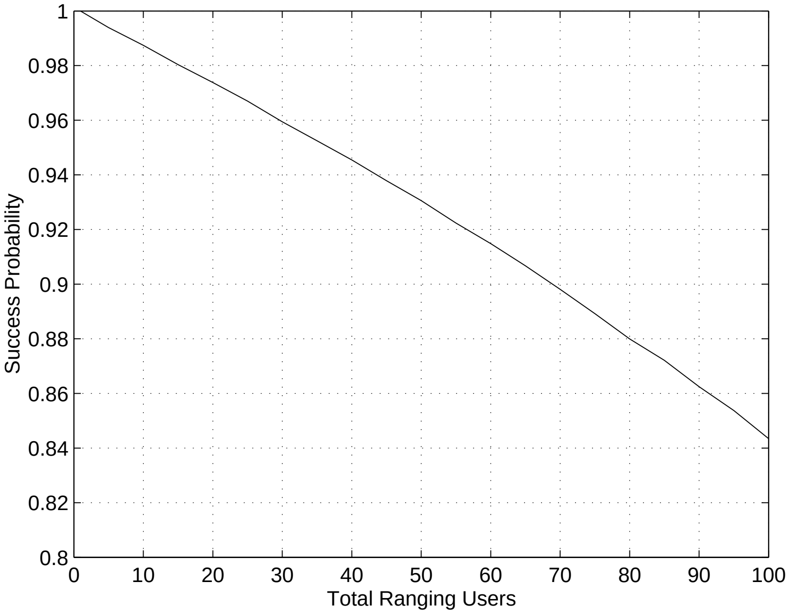


Figure 8. Overall Success Probability when all users have equal SNR of 0dB (DS=0.5µs and threshold=10dB)

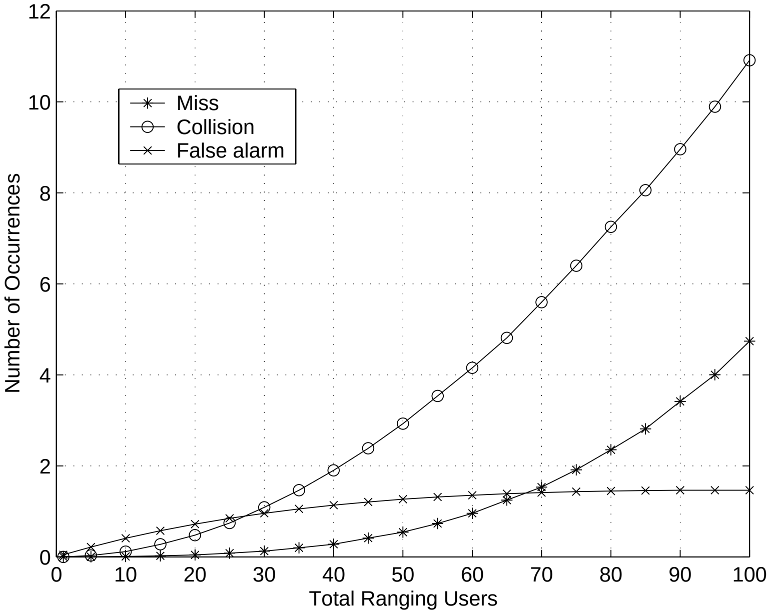


Figure 9. Number of missed, collision, and false alarm occurrences when all users have equal SNR of 0dB (DS=0.5μs and threshold=10dB)

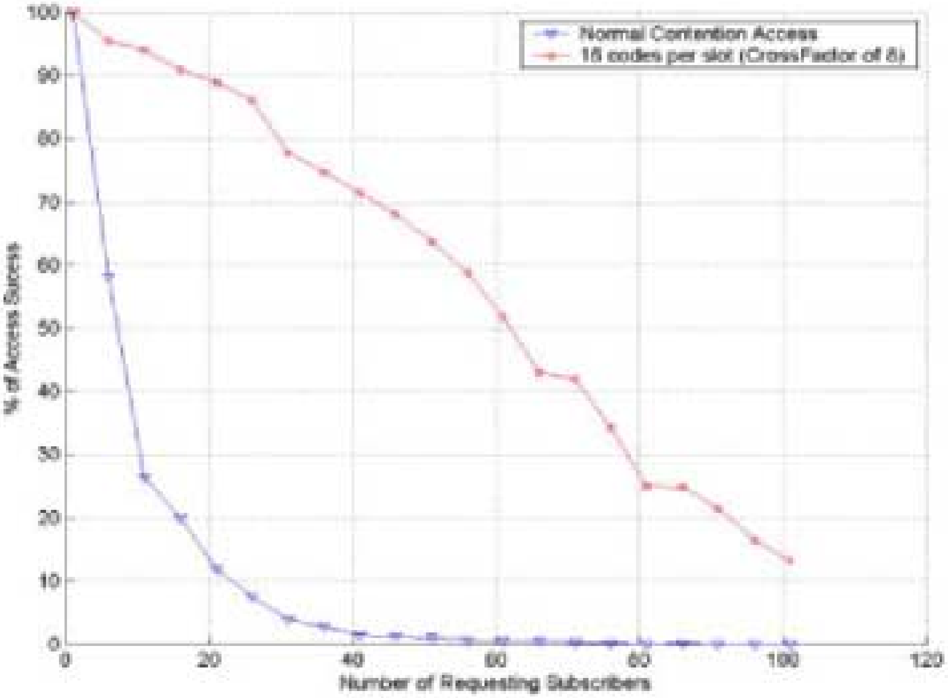


Figure 4. CDMA Request Vs. Contention Request for 10 time symbols

Figure 10. Copy of reported performance of existing ranging scheme in [3]

Timing offset compensation

The timing offset estimation for initial ranging users can be estimated from the plateau of (9). Without noise, the right edge of the plateau corresponds to the correct timing offset estimation. However, if the channel length L is smaller that than the regular CP length L_{CP}, the L_{CP}-L sampling points before the correct timing point are all good ones in the sense of not causing any SNR degradation or interference to other subcarriers.

The SNR degradation caused by incorrect timing offset compensation is due to the interference from the OFDM symbols that immediately precedes or follows the current symbol of interest, as well as inter-subcarrier interferences. If only a single user is concerned, the effect is then a self-interference that can translate into a decrease of SNR, as illustrated in Figure 11 for the example of an exponential power delay profile with 2μs delay spread and a regular CP length of 10μs. Note that the absolute SNR degradation depends on the SNR (which is 10dB in the plot). The actual degradation is more serious if the SNR is higher and less serious if the SNR is already low. From the figure, it can be seen that the degradation due to an early timing estimation is less serious than a late timing estimation. This is explained by the fact that the amplitude of channel taps decays in an exponential matter. So missing the early taps will cause more significant drop of useful signal power and incur more interference from the next symbol.

Therefore, instead of trying to estimate the true timing offset and risking a significant SNR degradation even if the estimate is just a few taps late relative to the true timing (referred to as a "risky" estimator), an alternative is to choose a conservative timing advance compensation point that can often be earlier than the true timing offset. An example is the mid-point between the peak and the right edge of the plateau (referred to as "conservative" estimator).

In the simulation, the edge is defined as the point right before $x_n(i)$ first falls below a certain percentage (e.g., 95%) of the peak. A user with a fixed timing delay of 7.8125µs is assumed (i.e., 200 samples at the rate of 25.6MHz). Note that the effective sampling interval after the 128 point IFFT is N_{bl}=16 times longer (i.e., coarser timing resolution). The mean and the standard deviation of the estimated timing offset point are tabulated in Table 5 (DS=0.1µs), Table 6 (DS=0.5µs), and Table 7 (DS=2µs). Also in the table, the percentages that the estimated timing is early (including exactly correct) or late are included. As expected, the variance of estimates decreases when SNR increases. Note that the mean is not a very good indicator because the conservative estimator has built-in bias toward being early. The variance of the conservative estimator seems slightly larger than the case of the risky estimator because that peak position used in the conservative estimator is sensitive to noise perturbation. Although the mean timing can be still a few microseconds from the true one, the most important thing is to look at the SNR degradation. From that perspective, the conservative timing offset estimator very rarely incurs any SNR degradation.

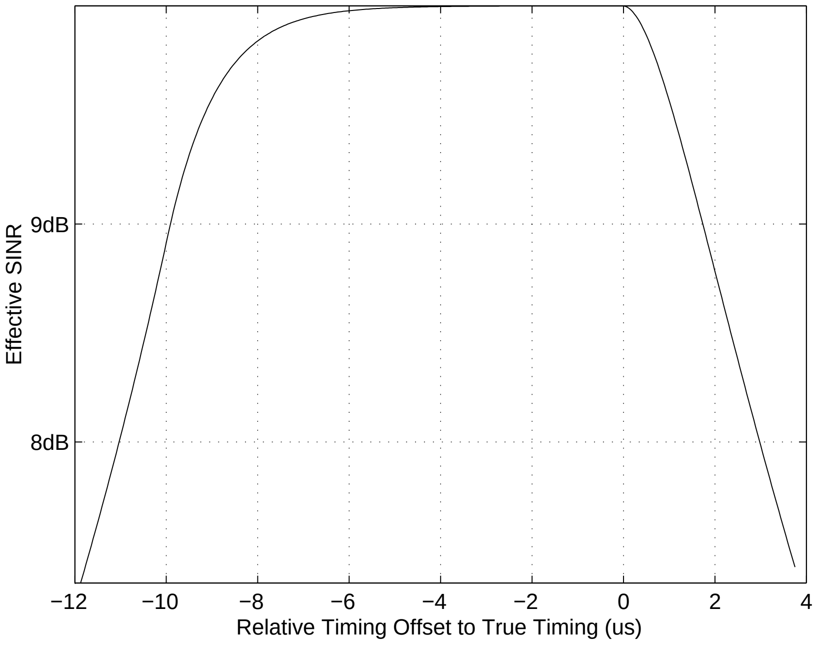


Figure 11. Effective SINR after timing adjustment (SNR=10dB, DS=2µs)

Table 5. Timing offset estimation (DS=0.1µs, True offset=7.8125µs)

	Mean (Std. Dev.) in µs	Incurs no SNR degradation (early)	Incurs SNR degradation (late)
Risky est. (plateau edge) SNR= -8dB	5.16 (2.42)	99.9%	0.1%
SNR= -4dB	5.78 (1.87)	100%	0%
SNR= 0dB	6.54 (0.97)	100%	0%
SNR= 4dB	6.87 (0.39)	100%	0%
SNR= 8dB	6.93 (0.34)	100%	0%
Conservative est. SNR= -8dB	4.28 (2.38)	99.93%	0.07%
SNR= -4dB	4.52 (1.96)	100%	0%
SNR= 0dB	4.85 (1.38)	100%	0%
SNR= 4dB	4.99 (0.98)	100%	0%
SNR= 8dB	4.97 (0.77)	100%	0%

Table 6. Timing offset estimation (DS=0.5µs, True offset=7.8125µs)

	Mean (Std. Dev.) in µs	Incurs no SNR degradation (early)	Incurs SNR degradation (late)
Risky est. (plateau edge) SNR= -8dB	5.45 (2.45)	97.5%	2.5%
SNR= -4dB	6.15 (1.86)	99.2%	0.8%
SNR= 0dB	6.90 (0.99)	99.6%	0.4%
SNR= 4dB	7.22 (0.49)	99.7%	0.3%
SNR= 8dB	7.28 (0.43)	99.7%	0.3%
Conservative est. SNR= -8dB	4.58 (2.42)	98.7%	1.3%
SNR= -4dB	4.91 (1.95)	99.8%	0.2%
SNR= 0dB	5.26 (1.36)	99.95%	0.05%
SNR= 4dB	5.39 (0.98)	99.99%	0.01%
SNR= 8dB	5.40 (0.77)	100%	0%

Table 7. Timing offset estimation (DS=2µs, True offset=7.8125µs)

	Mean (Std. Dev.) in µs	Incurs no SNR degradation (early)	Incurs SNR degradation (late)
Risky est. (plateau edge) SNR= -8dB	6.64 (2.07)	80.7%	19.3%
SNR= -4dB	7.31 (1.19)	85.6%	14.4%
SNR= 0dB	7.67 (0.56)	87.7%	12.3%
SNR= 4dB	7.75 (0.39)	88.6%	11.4%
SNR= 8dB	7.77 (0.36)	89.0%	11%
Conservative est. SNR= -8dB	5.93 (2.1)	87.8%	12.2%
SNR= -4dB	6.50 (1.36)	93.1%	6.9%
SNR= 0dB	6.87 (0.84)	95.7%	4.3%
SNR= 4dB	7.02 (0.62)	96.8%	3.2%
SNR= 8dB	7.07 (0.54)	97.4%	2.6%

5. References:

[1] Chin-Chen Lee, “Ranging Process Analysis And Improvement Recommendations,” IEEE 802.16abc-01//23, August 2001

[2] Jerry Krinock, et al, “Comments on OFDMA Ranging Scheme Described in IEEE 802.16ab-01/01r1,” IEEE 802.16abc-01//24, August 2001

[3] Itzik Kitroser, et al, “Bandwidth Request Using CDMA Codes in OFDMA (OFDM) Base PHY,” IEEE 802.16.3c-01/55, April 2001

[4] IEEE C802.16d-04/47r1, “OFDMA PHY Enhancement for Ranging,” March 2004

[5] B.M. Popovic, “Generalized Chirp-like Polyphase Sequences with Optimal Correlation Properties,” IEEE Trans. Info. Theory, vol. 38, pp. 1406-1409, July 1992