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(54) **METHODS AND APPARATUS FOR RANDOM ACCESS IN MULTI-CARRIER COMMUNICATION SYSTEMS**

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Related U.S. Application Data

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(60) Provisional application No. 60/551,589, filed on Mar. 9, 2004.

(51) **Int. Cl.**
H04Q 7/216 (2006.01)

(52) **U.S. Cl.**
USPC **370/342**; 370/329

(58) **Field of Classification Search**
USPC 370/342
See application file for complete search history.

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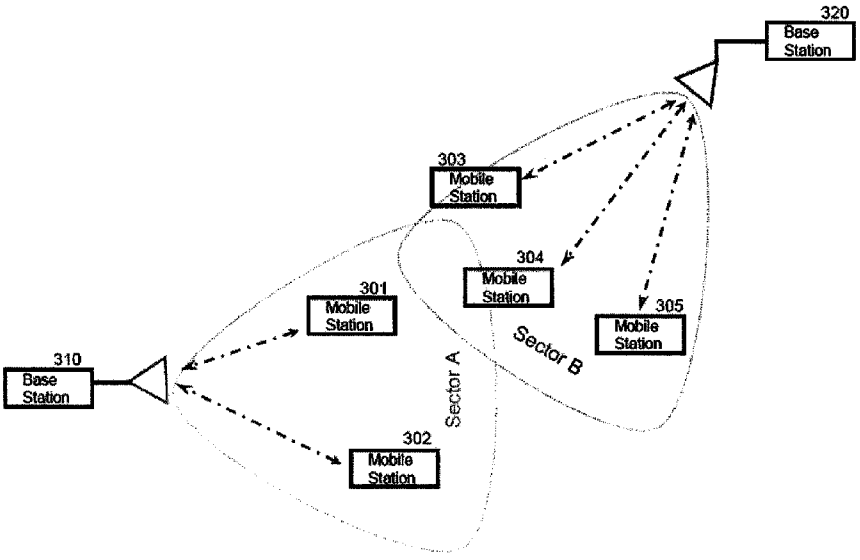
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(57) **ABSTRACT**

Methods and apparatus in a multi-carrier cellular wireless network with random access improve receiving reliability and reduce interference of uplink signals of a random access, while improving the detection performance of a base station receiver by employing specifically configured ranging signals.

24 Claims, 8 Drawing Sheets



HONDA 1001

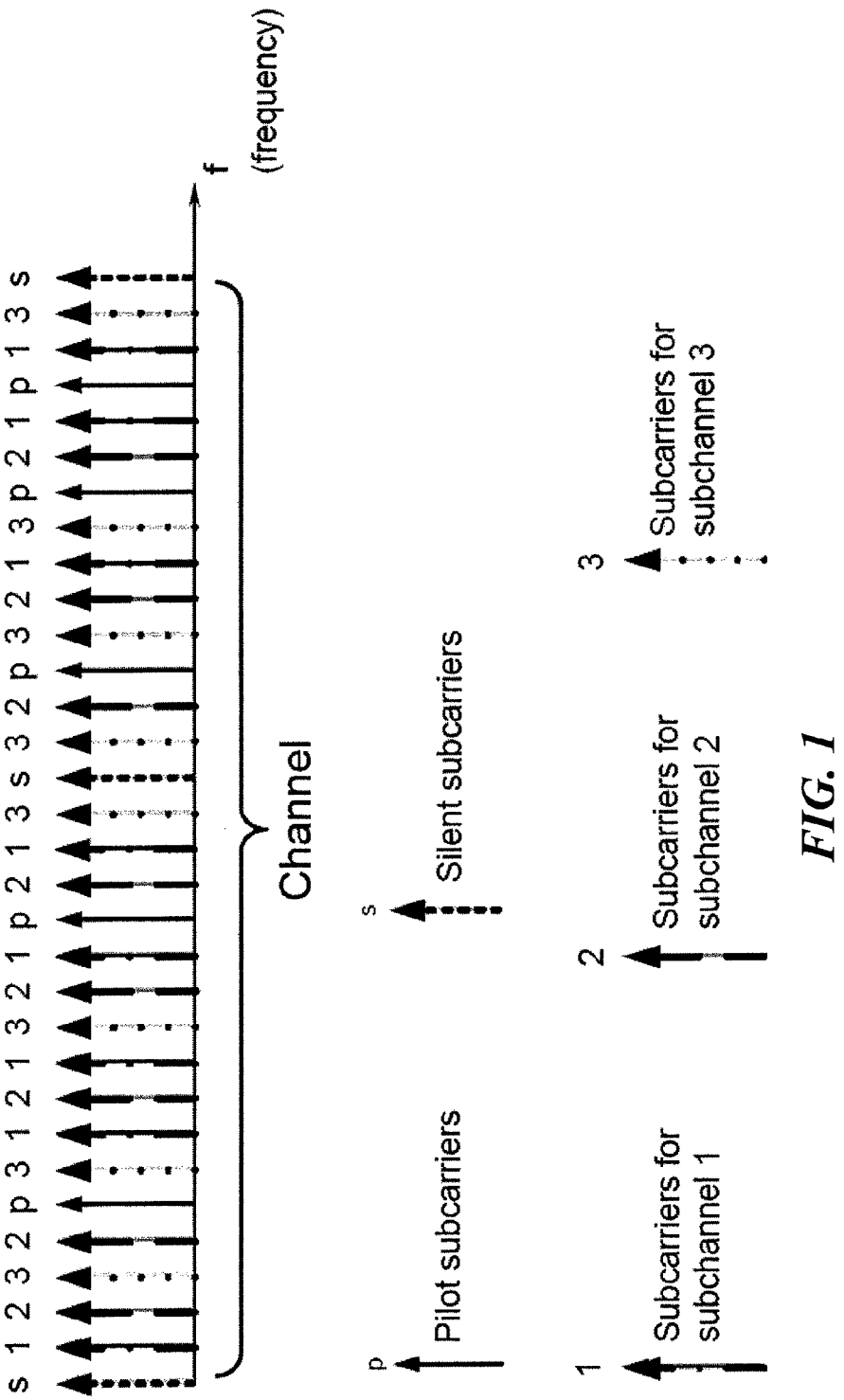

f (frequency)
s 1 2 3 2 p 3 1 2 1 3 2 1 p 2 1 3 s 3 2 p 3 2 1 3 p 2 1 p 1 3 s
Channel
p
Pilot subcarriers
s
Silent subcarriers
1
Subcarriers for subchannel 1
2
Subcarriers for subchannel 2
3
Subcarriers for subchannel 3

FIG. 1

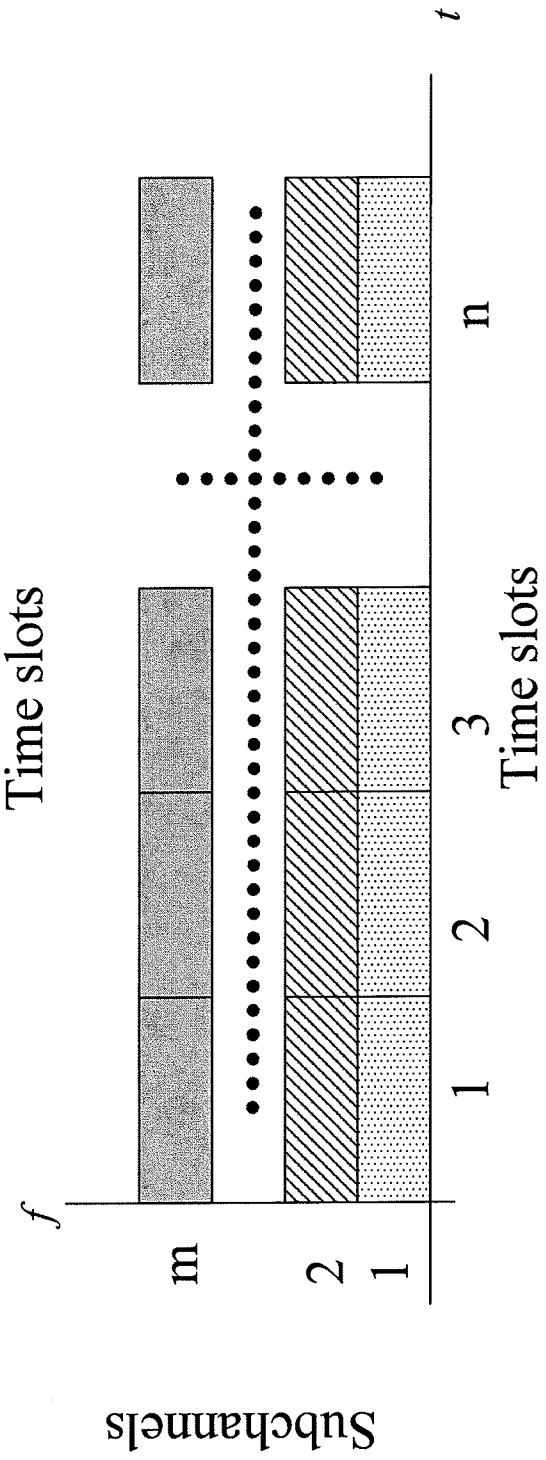


FIG. 2

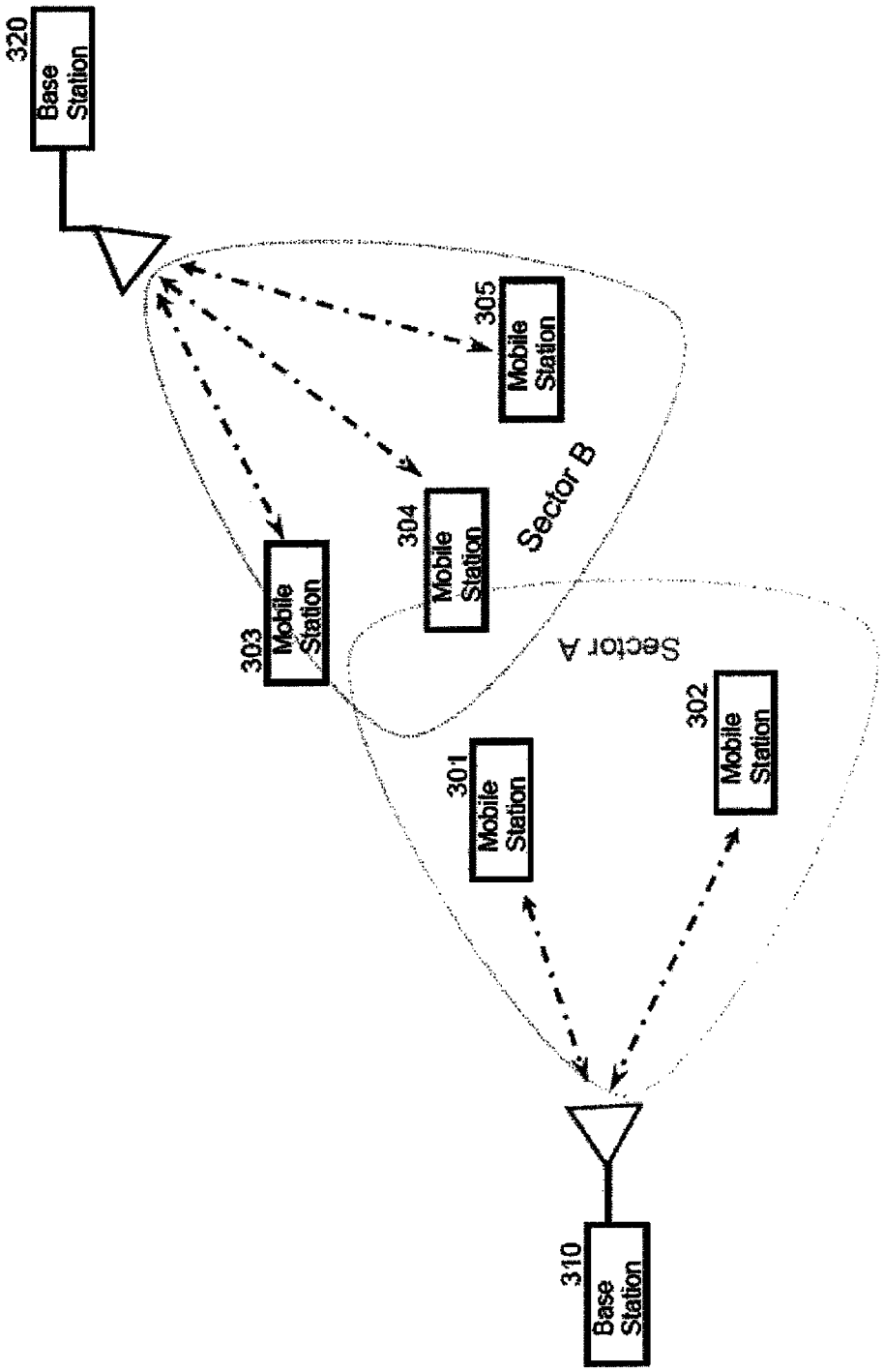

320
Base Station
305
Mobile Station
304
Mobile Station
303
Mobile Station
Sector B
Sector A
302
Mobile Station
301
Mobile Station
310
Base Station

FIG. 3

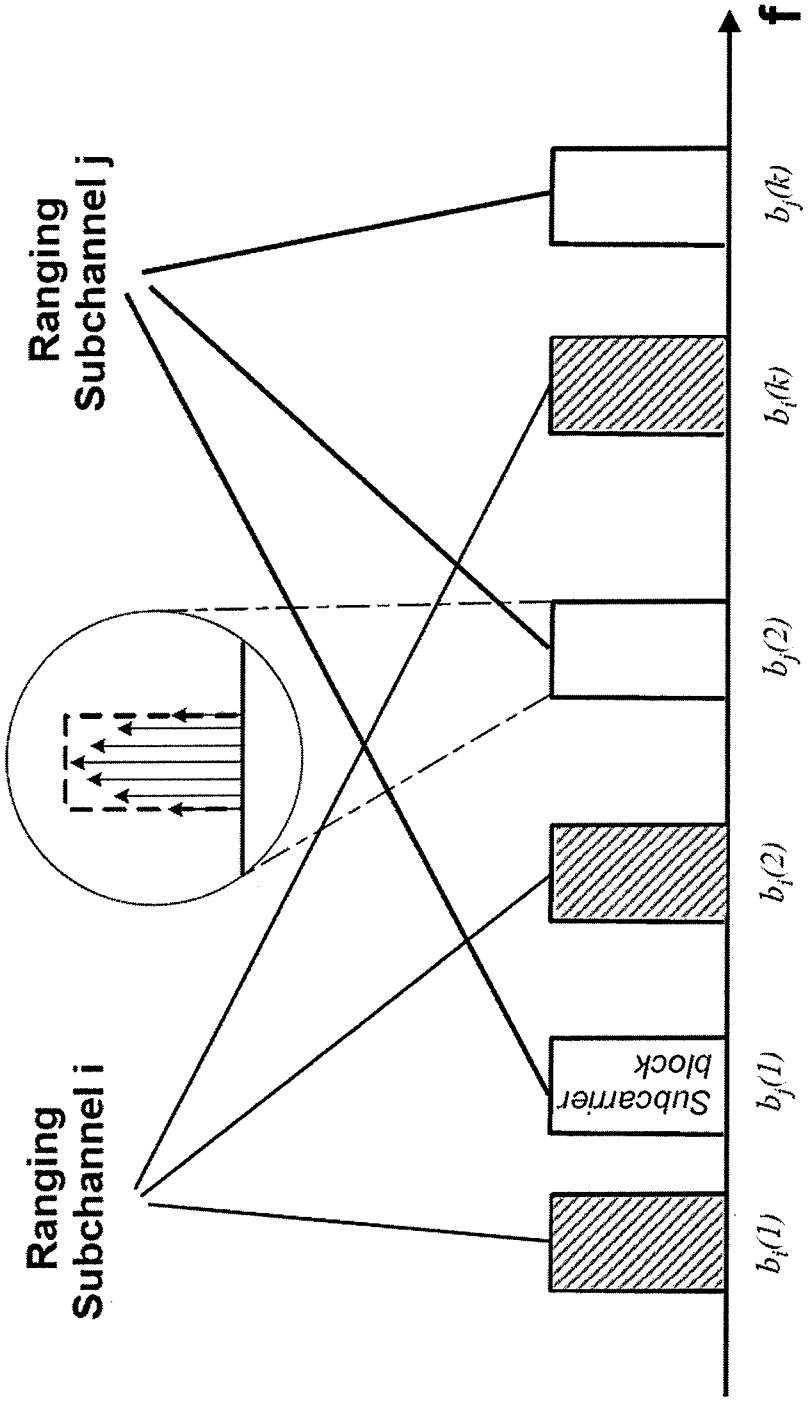

Ranging Subchannel j
Ranging Subchannel i
Subcarrier block
f
$b_j(k)$
$b_i(k)$
$b_j(2)$
$b_i(2)$
$b_j(1)$
$b_i(1)$

FIG. 4

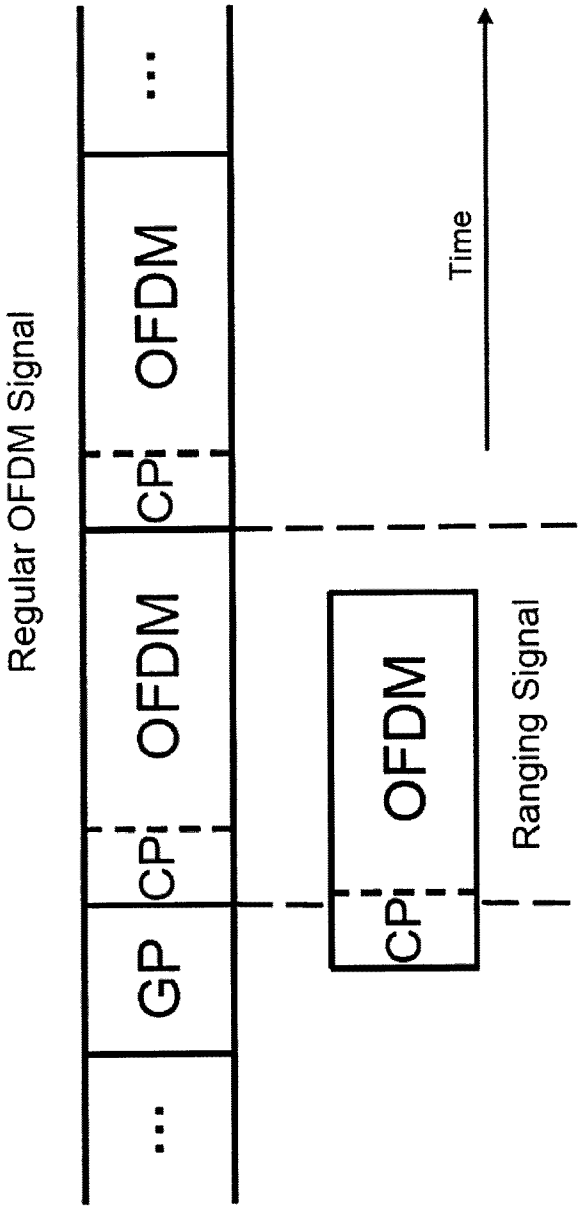

Regular OFDM Signal
...
GP
CP
OFDM
CP
OFDM
...
Time
CP
OFDM
Ranging Signal

FIG. 5

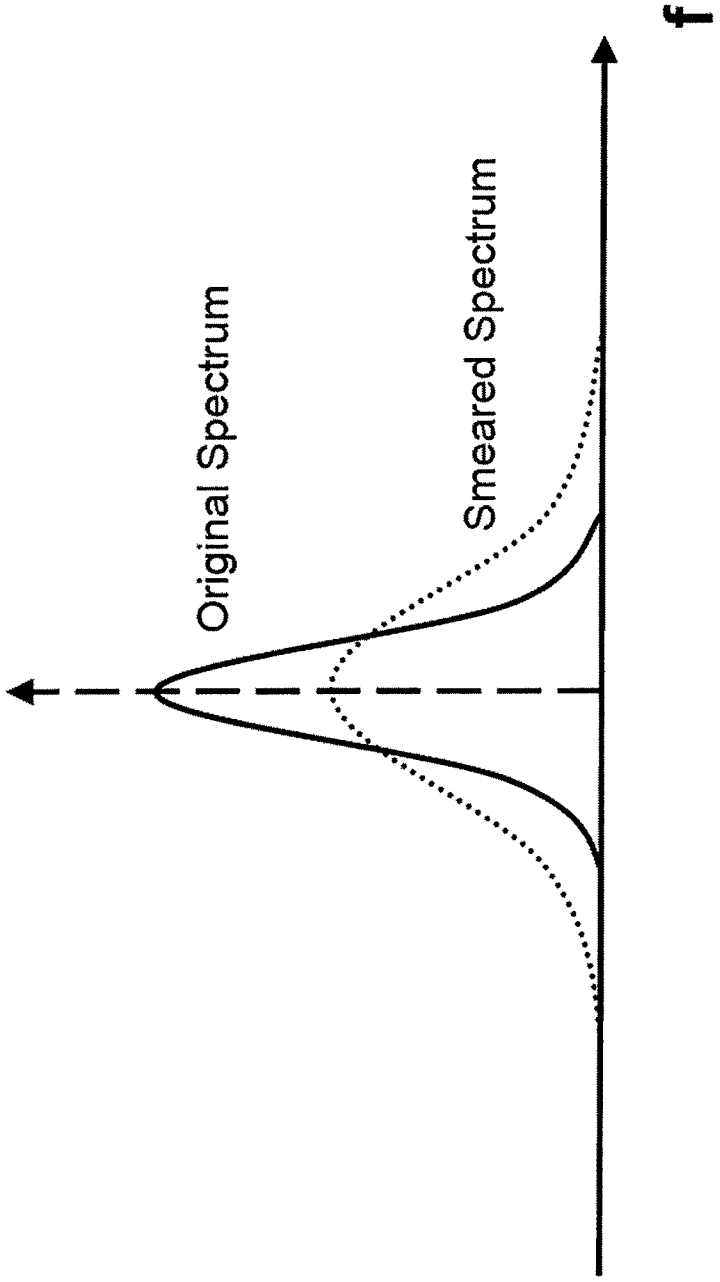


FIG. 6

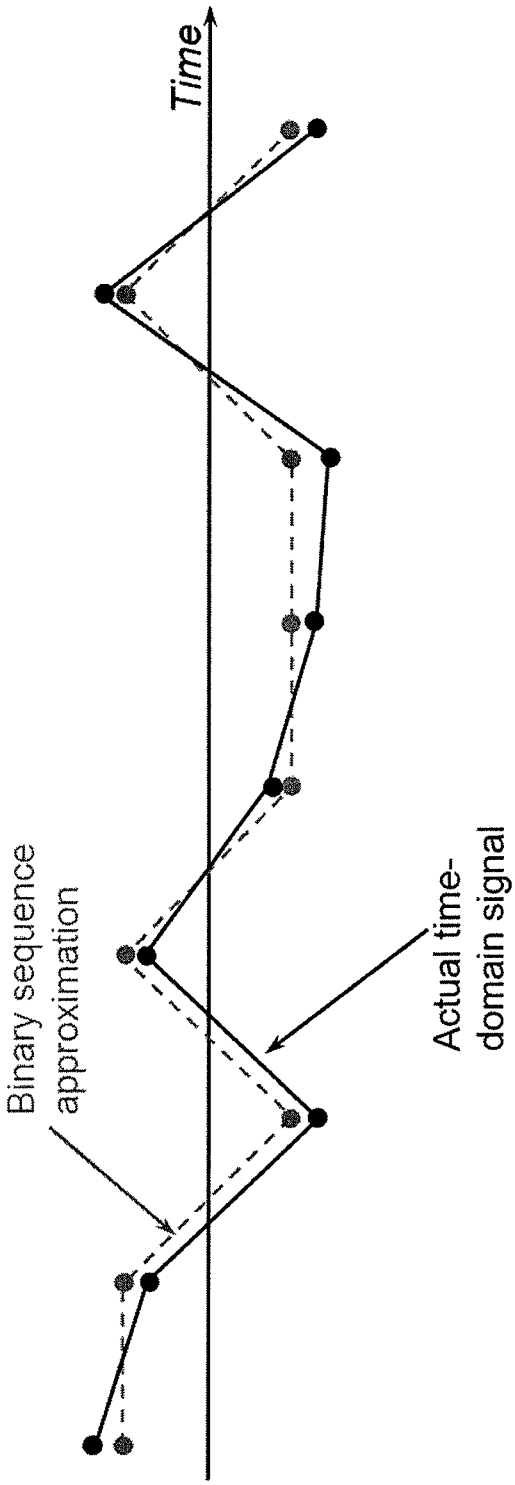

Time
Binary sequence approximation
Actual time-domain signal

FIG. 7

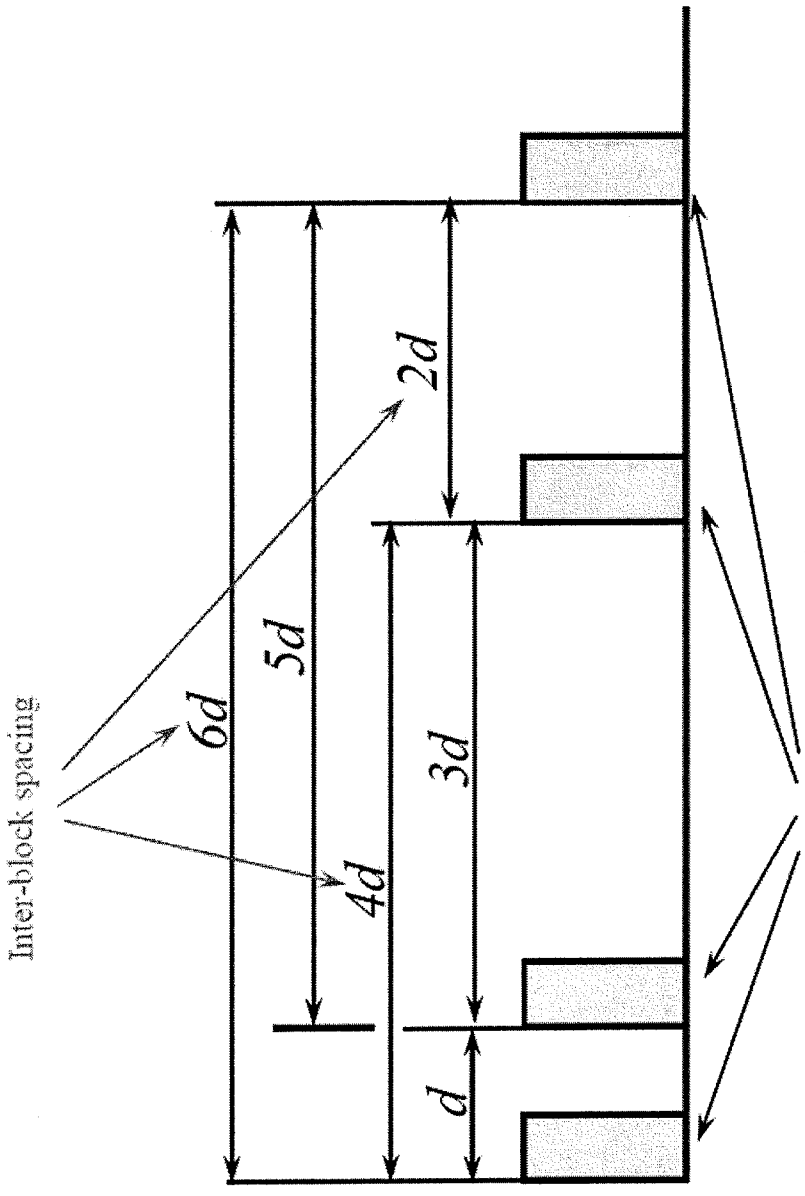

Inter-block spacing
6d
5d
4d
3d
2d
d
Blocks of a ranging subchannel

FIG. 8

METHODS AND APPARATUS FOR RANDOM ACCESS IN MULTI-CARRIER COMMUNICATION SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application is a continuation of U.S. patent application Ser. No. 10/583,158, entitled "METHODS AND APPARATUS FOR RANDOM ACCESS IN MULTI-CARRIER COMMUNICATION SYSTEMS", filed Aug. 27, 2008, which is a U.S. National Stage application of PCT/US05/08169, entitled "METHODS AND APPARATUS FOR RANDOM ACCESS IN MULTI-CARRIER COMMUNICATION SYSTEMS", filed Mar. 9, 2005, which claims the benefit of U.S. Provisional Patent Application No. 60/551,589, entitled "METHODS AND APPARATUS FOR RANDOM ACCESS IN MULTI-CARRIER COMMUNICATION SYSTEMS", filed Mar. 9, 2004.

BACKGROUND

In a wireless communication system, a mobile station first needs to perform a random access for establishing communication with a base station. The random access typically includes two steps: (1) Ranging and (2) Resource Request and Allocation. During Ranging, the mobile station sends a signal to the base station, so that the base station can identify the mobile station and measure the power and time delay of the mobile station, and inform the mobile station for power adjustment and time advance. During Resource Request and Allocation, the uplink and downlink resources for communication are requested and allocated. Ranging is a critical part of multi-carrier wireless communication system, and there are several important issues related to ranging:

1. The bandwidth efficiency of the ranging signals
2. The interference of ranging signal with other uplink signals
3. The detection performance and complexity at the base station receiver

The ranging process typically involves an exchange of messages between the base station and the mobile station by which the mobile station aligns itself with the start of each time slot after compensating for propagation delay and other factors. One problem in a shared medium communication network involves the ranging of many mobile stations. When many mobile stations attempt to perform the ranging simultaneously, they are forced to contend for access to the shared channel and it becomes difficult for any of the mobile stations to complete the ranging process due to the large number of collisions. As a result, the time needed for all of the mobile stations to complete the ranging process is excessive, and much bandwidth on the shared channel is wasted.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts a basic structure of a multi-carrier signal in the frequency domain, made up of subcarriers.

FIG. **2** shows a radio resource divided into small units in both the frequency domain (subchannels) and the time domain (time slots).

FIG. **3** shows a cellular system with at least one cell and one base station.

FIG. **4** depicts a ranging subchannel composed of at least one block of subcarriers.

FIG. **5** illustrates a case of time misalignment in a ranging signal, with a base station OFDM time frame, due to uncertainty of a mobile station's round trip delay at an initial stage of random access.

FIG. **6** depicts a smeared spectrum of a subcarrier in a ranging subchannel when the ranging signal is received using a regular OFDM time frame.

FIG. **7** illustrates a ranging sequence's corresponding time-domain signal that can be approximated with a binary sequence.

FIG. **8** shows a ranging subchannel arrangement in which spacing between subcarrier blocks in the frequency domain has no, or minimum, repetition.

DETAILED DESCRIPTION

In the following description, the invention is explained with respect to some of its various embodiments, and provides specific details for a thorough understanding. However, one skilled in the art will understand that the invention may be practiced without such details. In other instances, well-known structures and functions have not been shown or described in detail to avoid obscuring aspects of the embodiments.

Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to." Words using the singular or plural number also include the plural or singular number respectively. Additionally, the words "herein," "above," "below" and words of similar import, when used in this application, shall refer to this application as a whole and not to any particular portions of this application. When the claims use the word "or" in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list and any combination of the items in the list.

The embodiments of this invention disclose methods and apparatus for random access in a multi-carrier system. In particular, ranging signals are designed to improve receiving reliability and to reduce interference with other uplink signals. Furthermore, methods and apparatus are described that improve the detection performance at the base station receiver.

In a multi-carrier communication system such as multi-carrier code division multiple access (MC-CDMA) and orthogonal frequency division multiple access (OFDMA) systems, information data are multiplexed on subcarriers that are mutually orthogonal in the frequency domain. In effect, a frequency selective channel is partitioned in frequency into a number of parallel, but small, segments that can be treated as flat fading channels and can employ simple one-tap equalizers. The modulation/demodulation can be performed using the fast Fourier transform (FFT).

In a multi-carrier communication system the physical media resource (e.g., radio or cable) can be divided in both the frequency and time domains. This canonical division provides a high flexibility and fine granularity for resource sharing. A basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers, and within a particular spectral band or channel there are a fixed number of subcarriers. There are three types of subcarriers:

1. Data subcarriers, which carry information data;
2. Pilot subcarriers, whose phases and amplitudes are predetermined and made known to all receivers and which

are used for assisting system functions such as estimation of system parameters; and

3. Silent subcarriers, which have no energy and are used for guard-bands and DC carriers.

The data subcarriers can be arranged into groups called subchannels to support scalability and multiple-access. The carriers forming one subchannel are not necessarily adjacent to each other. Each user may use part or all of the subchannels. The concept is illustrated in FIG. **1** for the interleaved subchannels at the base station transmitter. Data subcarriers can be grouped into subchannels in a particular way and the pilot subcarriers are also distributed over the entire channel in a particular way. The basic structure of a multi-carrier signal in the time domain is made up of time slots to support multiple-access. The resource division in both the frequency and time domains is depicted in FIG. **2**.

FIG. **3** illustrates a typical cellular structure. In this illustration no distinction is made between a cell and a sector. If a cell is divided into sectors, from a system engineering point of view each sector can be considered a cell. In this context, the terms "cell" and "sector" are interchangeable. Both of them are generally called a cell. In the communication system of FIG. **3** Base Station **310** is communicating with Mobile Stations **301** and **302** in Sector A of its cell site while Base Station **320** is communicating with Mobile Stations **303**, **304**, and **305** in Sector B of its cell site.

FIG. **4** illustrates two ranging subchannels, each of which is composed of multiple blocks of subcarriers. The subcarriers in each block are contiguous in frequency. FIG. **4** schematically shows that the signal power of the subcarriers towards the boundary (the lower ends and the higher ends in frequency) of a block is lower than that of the subcarriers towards the center of the block. (In a special case, the power levels of the two subcarriers at both ends of a block are set to zero.) Because different factors may cause possible overlap of two subcarrier blocks from to different transmitters, the attenuated boundary subcarriers will minimize the resulting interference.

In accordance with aspects of some embodiments, the ranging signal is carried over a ranging subchannel that contains multiple subcarriers. Either binary or non-binary signals can be modulated on the subcarriers of a ranging subchannel.

The sequence of modulating signals in a ranging subchannel is called a ranging sequence. Multiple ranging sequences are permitted in a cell. A mobile station chooses a ranging sequence for random access and uses the sequence to identify itself in the initial communication with a base station. The period of a ranging signal is called a ranging slot. A ranging slot may last over one or multiple OFDM symbols. Multiple ranging slots can be provided to increase the random access opportunity and reduce the collision probability.

In one embodiment, different cells may have different subcarrier configurations for their ranging subchannels. Different cells may also have different ranging sequence sets. These differences may be used to identify the association of a mobile station with a cell.

FIG. **5** illustrates the timing of regular uplink data signals and ranging signals (with a Guard Period G.P.). In the beginning of a random access attempt, the mobile station is unaware of its round-trip time to the base station. As a result, the arrival time of ranging signal at the base station may be misaligned with other signals which have been synchronized to the base station clock. As depicted in FIG. **5**, the random access Ranging Signal does not coincide with the expected arrival time at the base station. As shown in FIG. **6**, time misalignment of regular signals and ranging signals can cause spectrum of ranging signals to be smeared when it is received using the OFDM time window of regular signals. Therefore, misaligned subcarriers within a ranging subchannel will interfere with each other and with other data subchannels that are adjacent to them. In the following description, several methods are presented to address such problems.

In one embodiment, the ranging subchannel is composed of multiple blocks of subcarriers. The subcarriers in each block are contiguous in frequency. The signal power of the subcarriers towards the boundary (the lower ends and the higher ends in frequency) of a block is lower than that of the subcarriers towards the center of the block. In a special case, the power levels of the two subcarriers at both ends of a block are set to zero.

In yet another embodiment, each segment of a ranging sequence is a Hadamard sequence and a full ranging sequence is composed of multiple Hadamard sequences. Each segment corresponds to a block of contiguous subcarriers. In Table 1, a typical example is shown for two ranging sequences. Each segment is a 4-bit Hadamard sequence and each ranging sequence is composed of 4 segments. The two ranging sequences are segment-wise orthogonal to each other.

TABLE 1

Example of ranging sequences				
Ranging Sequence 1	+1 −1 +1 −1	+1 +1 +1 +1	+1 +1 −1 −1	+1 −1 −1 +1
Ranging Sequence 2	+1 +1 +1 +1	+1 −1 −1 +1	+1 −1 +1 −1	+1 +1 −1 −1

In addition, other properties in signal processing can be exploited in sequence design. In one embodiment of the implementation, the ranging sequence is designed such that its corresponding time-domain signal exhibits relatively low peak-to-average power ratio. This improves the power efficiency of the mobile station transmission power amplifier. Furthermore, the ranging signal is designed such that the time signal can be approximated with a binary sequence (e.g., FIG. **7**), thereby reducing the complexity of the receiver correlator. While in theory, and even in practice, each modulating digit of a ranging sequence can represent a range of logic levels, a binary format is practically the simplest representation and requires the simplest receiver components for its processing. FIG. **7** illustrates a ranging sequence's corresponding time-domain signal that can be approximated with a binary sequence.

In another embodiment, the blocks of a ranging subchannel can be distributed or allocated in such a way that the autocorrelation of a ranging sequence corresponding to the ranging subchannel, in time-domain, exhibits a set of desired properties such as a narrow main peak and low sidelobes. For example, the blocks can be distributed in the frequency band of interest such that there is minimum redundancy in a co-sampling function. In other words, spacing between the blocks of a ranging subchannel in the frequency domain has no or minimum repetition, as illustrated in FIG. **8**, where the spacing consists of the set {d, 2d, 3d, 4d, 5d, 6d}.

FIG. **8** is merely an example of such possible arrangements, where an autocorrelation process only produces one major peak, regardless of the ranging sequence carried by the ranging subchannel blocks. During an autocorrelation process, two copies of a ranging signal move in parallel with respect to each other, in a step-wise manner, and at each step the sum of the multiplication of their corresponding values is computed and recorded. Note that in an interval of a ranging

subchannel where there are no subcarriers, the ranging signal value is zero. Therefore, employing the proposed arrangements, at any step except for the step during which the two copies of the ranging signal are substantially aligned, most of the non-zero values of either copy will correspond to the zero values of the other copy and the multiplication result of the corresponding values will be zero, which results in low side-lobe values.

With regard to controlling the power settings of a ranging signal, before a random access, a mobile station estimates the path loss from a base station, using the received downlink signal. It uses open-loop power control to set the power level of the ranging signal. In one embodiment, the mobile station adds a negative offset to the open-loop power setting and gradually ramps up the transmission power of the ranging signal as the number of random access failures and retrials increase.

In one embodiment, the base station receiver detects the presence of each ranging signal, its time delay, and its power level through the use of a matched filter, a correlator, or other means in the time domain, the frequency domain, or both.

In another embodiment, when the ranging subchannel is composed of blocks of contiguous subcarriers, the base station performs hierarchical detection: first in frequency domain, then in time domain. The detection process is as follows:

1. The FFT is applied to a selected window of the received time-domain signal, s(t).
2. For a particular ranging subchannel, its received version, $\{\vec{r}(k)\}_{k=1}^{K}$, is correlated in the frequency domain with the ranging sequences associated with the cell, in a segment-wise fashion, where K is the total number of blocks in a ranging subchannel. If the m^{th} sequence associated with the cell is denoted by $\{\vec{b}_m(k)\}_{k=1}^{K}$, the correlation value, P_m, is computed by:

$$P_m = \sum_{k=1}^{K} \left| \langle \vec{r}(k) \cdot \vec{b}_m(k) \rangle \right|^2,$$

where the dot-product is computed by:

$$\langle \vec{r}(k) \cdot \vec{b}_m(k) \rangle = \sum_{n=1}^{N} x(k, n) \cdot [c_m(k, n)]^*$$

and where N denotes the number of subcarriers in a block, x(k,n) denotes the received version of the n^{th} subcarrier of the k^{th} block in the given ranging subchannel, and $c_m(k,n)$ represents the value of the n^{th} subcarrier of the k^{th} block in the given ranging subchannel for the m^{th} sequence. It is noted that that both $\vec{r}(k)$ and $\vec{b}_m(k)$ are vectors of the dimension same as the segment length. If P_m is greater than a given threshold, this indicates that a ranging signal corresponding to the m^{th} sequence has been detected.

3. For the ranging signal identified in Step 2, a time-domain correlation of the full sequence of the ranging signal is performed, in a sliding-window fashion, to find the time delay of that ranging signal, that is:

$$C(\tau) = \left| \sum_{t=0}^{T} s(t+\tau) \cdot z^*(t) \right| \text{ for } \tau = 0, 1, \ldots, D$$

where T denotes the length of the time-domain ranging sequence, D corresponds to the maximum time delay allowed by the system, and z*(t) represents the time-domain signal of the detected ranging sequence. The maximum value of $C(\tau)$ for $\tau=0, 1, \ldots, D$ is the estimate of the power of the ranging signal and the corresponding value of τ indicates the time delay associated with the ranging signal.

In the case of ranging sequences composed of Hadamard sequences, the dot-products of the received signal and the ranging sequence in a particular segment in Step 2 can be evaluated simultaneously using a single Fast Hadamard Transform (FHT), thereby simultaneously detecting multiple ranging sequences.

The above detailed description of the embodiments of the invention is not intended to be exhaustive or to limit the invention to the precise form disclosed above or to the particular field of usage mentioned in this disclosure. While specific embodiments of, and examples for, the invention are described above for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. Also, the teachings of the invention provided herein can be applied to other systems, not necessarily the system described above. The elements and acts of the various embodiments described above can be combined to provide further embodiments.

All of the above patents and applications and other references, including any that may be listed in accompanying filing papers, are incorporated herein by reference. Aspects of the invention can be modified, if necessary, to employ the systems, functions, and concepts of the various references described above to provide yet further embodiments of the invention.

Changes can be made to the invention in light of the above "Detailed Description." While the above description details certain embodiments of the invention and describes the best mode contemplated, no matter how detailed the above appears in text, the invention can be practiced in many ways. Therefore, implementation details may vary considerably while still being encompassed by the invention disclosed herein. As noted above, particular terminology used when describing certain features or aspects of the invention should not be taken to imply that the terminology is being redefined herein to be restricted to any specific characteristics, features, or aspects of the invention with which that terminology is associated.

In general, the terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification, unless the above Detailed Description section explicitly defines such terms. Accordingly, the actual scope of the invention encompasses not only the disclosed embodiments, but also all equivalent ways of practicing or implementing the invention under the claims.

While certain aspects of the invention are presented below in certain claim forms, the inventors contemplate the various aspects of the invention in any number of claim forms. Accordingly, the inventors reserve the right to add additional claims after filing the application to pursue such additional claim forms for other aspects of the invention.

We claim:

1. In a multi-cell orthogonal frequency division multiple access (OFDMA) wireless communication system comprising a plurality of base stations and mobile stations, a mobile station configured to communicate with a serving base station in a cell via a communication channel, the mobile station comprising:

an apparatus configured to transmit a data signal to the serving base station in the cell over a data subchannel, wherein the data subchannel comprises a plurality of adjacent or non-adjacent subcarriers within the communication channel; and

an apparatus configured to transmit a ranging signal to the serving base station in the cell over a ranging subchannel for random access, wherein:

the ranging signal is formed from a ranging sequence selected from a set of ranging sequences associated with the cell for identifying the mobile station;

the ranging signal lasts over a period of one or multiple orthogonal frequency division multiplexing (OFDM) symbols and the ranging signal exhibits a low peak-to-average power ratio in the time domain; and

the ranging subchannel comprises at least one block of subcarriers within the communication channel and power levels of subcarriers at both ends of a block are set to zero.

2. The mobile station of claim 1, wherein the subcarrier configuration of the ranging subchannel for the cell is different from subcarrier configurations of ranging subchannels for other cells.

3. The mobile station of claim 1, wherein the set of ranging sequences for the cell is different from sets of ranging sequences for other cells.

4. The mobile station of claim 1, wherein subcarriers in a block are contiguous in frequency.

5. The mobile station of claim 1, further comprising an apparatus configured to control a transmission power of the ranging signal using an open-loop power control method by:

estimating a path loss between the serving base station and the mobile station based on a received downlink signal;

setting the transmission power of the ranging signal based on the path loss; and

increasing the transmission power of the ranging signal for retransmission.

6. The mobile station of claim 1, wherein a power level of subcarriers towards the high-end and low-end frequency boundaries of a block of subcarriers is lower than a power level of subcarriers towards the center of the block.

7. The mobile station of claim 1, wherein boundary subcarriers of a block of subcarriers in the ranging subchannel are attenuated to reduce interference with other uplink signals when signal time misalignment occurs at the base station.

8. The mobile station of claim 1, wherein the ranging sequence is a binary or non-binary sequence.

9. In a multi-cell orthogonal frequency division multiple access (OFDMA) wireless communication system, a base station configured to communicate with mobile stations in a cell via a communication channel, the base station comprising:

an apparatus configured to receive a data signal from a first mobile station in the cell over a data subchannel, wherein the data subchannel comprises a plurality of adjacent or non-adjacent subcarriers within the communication channel; and

an apparatus configured to receive a ranging signal from a second mobile station in the cell over a ranging subchannel for random access, wherein:

the ranging signal is formed from a ranging sequence selected from a set of ranging sequences associated with the cell for identifying a mobile station;

the ranging signal lasts over a period of one or multiple orthogonal frequency division multiplexing (OFDM) symbols and the ranging signal exhibits a low peak-to-average power ratio in the time domain; and

the ranging subchannel comprises at least one block of subcarriers within the communication channel and power levels of subcarriers at both ends of a block are set to zero.

10. The base station of claim 9, wherein the subcarrier configuration of the ranging subchannel for the cell is different from subcarrier configurations of ranging subchannels for other cells.

11. The base station of claim 9, wherein the set of ranging sequences for the cell is different from sets of ranging sequences for other cells.

12. The base station of claim 9, further comprising an apparatus configured to detect the ranging sequence in the received ranging signal in the time domain, frequency domain, or both time and frequency domain.

13. The base station of claim 12, wherein the apparatus applies matched filtering to the received ranging signal to detect the ranging sequence.

14. The base station of claim 12, wherein the apparatus correlates the received ranging signal with a ranging sequence stored at the base station to detect the ranging sequence.

15. The base station of claim 9, further comprising an apparatus configured to detect a time delay of the received ranging signal and to inform the second mobile station to adjust transmission time based on the detected time delay.

16. The base station of claim 9, further comprising an apparatus configured to detect a power level of the received ranging signal and to inform the second mobile station to adjust a transmission power based on the detected power level.

17. In an orthogonal frequency division multiple access (OFDMA) wireless communication system, a method for signal transmission by a mobile station to a serving base station via a communication channel, the method comprising:

transmitting a data signal over a data subchannel to the serving base station, wherein the data subchannel comprises a plurality of adjacent or non-adjacent subcarriers within the communication channel; and

transmitting a ranging signal over a ranging subchannel to the serving base station for random access, wherein:

the ranging signal is formed from a ranging sequence selected from a set of ranging sequences for identifying the mobile station;

the ranging signal lasts over a period of one or multiple orthogonal frequency division multiplexing (OFDM) symbols and the ranging signal exhibits a low peak-to-average power ratio in the time domain; and

the ranging subchannel comprises at least one block of subcarriers within the communication channel and power levels of subcarriers at both ends of a block are set to zero.

18. The method of claim 17, wherein a power level of subcarriers towards the high-end and low-end frequency boundaries of a block of subcarriers is lower than a power level of subcarriers towards the center of the block.

19. The method of claim 17, wherein boundary subcarriers of a block of subcarriers in the ranging subchannel are attenuated to reduce interference with other uplink signals when signal time misalignment occurs at the base station.

20. The method of claim 17, wherein subcarriers in a block are contiguous in frequency.

21. The method of claim 17, further comprising controlling a transmission power of the ranging signal using an open-loop power control method by:

estimating a path loss between the serving base station and the mobile station based on a received downlink signal;

setting the transmission power of the ranging signal based on the path loss; and

increasing the transmission power of the ranging signal for retransmission.

22. In an orthogonal frequency division multiple access (OFDMA) wireless communication system, a method for receiving signals by a base station from a plurality of mobile stations via a communication channel, the method comprising:

receiving a data signal over a data subchannel from a first mobile station, wherein the data subchannel comprises a plurality of adjacent or non-adjacent subcarriers within the communication channel; and

receiving a ranging signal over a ranging subchannel for random access by a second mobile station, wherein:

the ranging signal is formed from a ranging sequence selected from a set of ranging sequences for identifying the mobile station;

the ranging signal lasts over a period of one or multiple orthogonal frequency division multiplexing (OFDM) symbols and the ranging signal exhibits a low peak-to-average power ratio in the time domain; and

the ranging subchannel comprises at least one block of subcarriers within the communication channel and power levels of subcarriers at both ends of a block are set to zero.

23. The method of claim 22, further comprising detecting a time delay of the received ranging signal and informing the second mobile station to adjust transmission time based on the detected time delay.

24. The method of claim 22, further comprising detecting a power level of the received ranging signal and informing the second mobile station to adjust a transmission power based on the detected power level.

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