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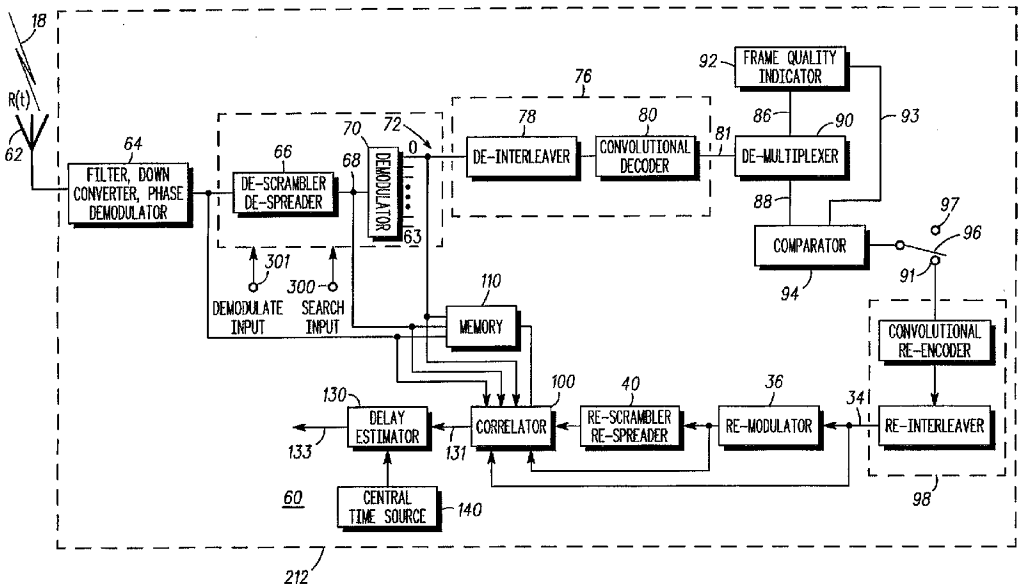
(54) **PROCEDE DE LOCALISATION D'UNE STATION MOBILE**
(54) **METHOD FOR LOCATING A MOBILE STATION**



(57) Le procédé faisant l'objet de cette invention consiste à recevoir (404) sur une première station de base (212) un signal (215) transmis depuis la station mobile (216); à démoduler (406) ce signal à la première station de base (212) afin de former un signal démodulé; à remoduler (408) au moins une partie du signal démodulé pour former un signal de référence; à recevoir (412) sur la première station de base (212) et sur une seconde station de base (210, 214) un signal retransmis (217); à comparer (414, 416) sur la première station de base (212) le signal retransmis (217) avec le signal de référence, afin de déterminer un premier décalage; à comparer (414, 416), sur la seconde station de base (210, 214), le second signal retransmis (217) avec le signal de référence, afin de déterminer un second décalage; et, sur la base de ces premier et second décalages, à déterminer (420) la position de la station mobile (216).

(57) The method includes receiving (404) by a first base station (212) a signal (215) transmitted from the mobile station (216); demodulating (406) the signal by the first base station (212) to form a demodulated signal; remodulating (408) at least a portion of the demodulated signal to form a reference signal; receiving (412) by the first base station (212) and a second base station (210, 214) a retransmitted signal (217); comparing (414, 416), by the first base station (212), the retransmitted signal (217) with the reference signal to determine a first delay; comparing (414, 416), by the second base station (210, 214), the retransmitted second signal (217) with the reference signal to determine a second delay; and based on the first and second delays, determining (420) a location of the mobile station (216).

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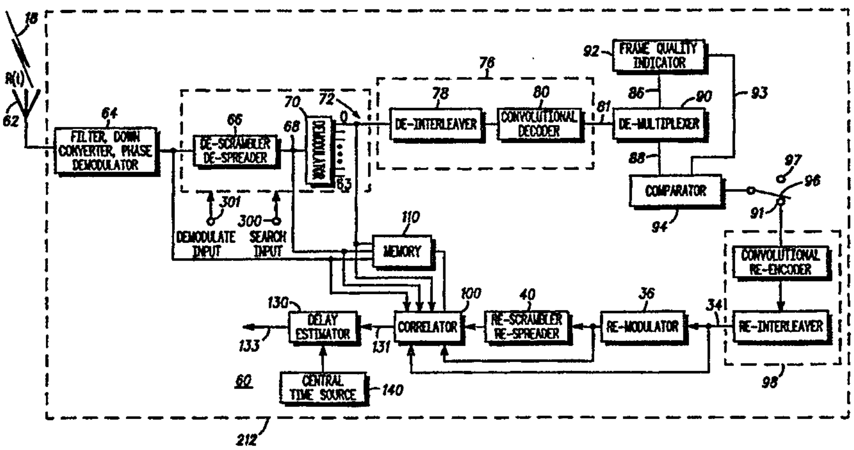


(57) Abstract

The method includes receiving (404) by a first base station (212) a signal (215) transmitted from the mobile station (216); demodulating (406) the signal by the first base station (212) to form a demodulated signal; remodulating (408) at least a portion of the demodulated signal to form a reference signal; receiving (412) by the first base station (212) and a second base station (210, 214) a retransmitted signal (217); comparing (414, 416), by the first base station (212), the retransmitted signal (217) with the reference signal to determine a first delay; comparing (414, 416), by the second base station (210, 214), the retransmitted second signal (217) with the reference signal to determine a second delay; and based on the first and second delays, determining (420) a location of the mobile station (216).

METHOD FOR LOCATING A MOBILE STATION

Field of the Invention

This invention relates generally to wireless communication systems, and, more particularly, to a method and apparatus for locating a mobile station in a spread spectrum communication system.

Background of the Invention

In a typical wireless communication system such as a digital radio frequency (RF) radiotelephone system, a base station having a controller and a plurality of transmitters and receivers communicates with a mobile station operating within an area served by the base station.

Transmitting a communication signal over an RF channel through a medium such as air causes a received communication signal to significantly differ from an originally transmitted communication signal. As shown in FIG. 1, a transmitted communication signal S(T) **12** may be altered during transmission over a channel by a slowly-changing channel parameter D **14**, which represents, for example, a time delay for communication signal S(T) **12** to travel from the mobile station to a base station, and may further be corrupted by a channel variable representing an amount of noise N **16**. Thus, a received communication signal R(T) **18** may be represented by an expression such as $R(T) = S(T - D) + N$.

It is well known that a mobile station's location within the wireless communication system may be determined using a trilateration method. According to the trilateration method, distances between the mobile station and three base stations are calculated based on the measurement of time delay D **14** of a signal traveling between the mobile station and each base station.

Trilateration, however, may be ineffective when one or more base stations do not reliably receive the signal transmitted from the mobile station. For example, in a spread-spectrum system such as a code division multiple access (CDMA) system, when the mobile station is close to one base station, the signal-to-noise (SNR) ratio of the signal received by other base stations may be diminished, often making the measurement of D **14** difficult and inaccurate. Thus, there may be regions within the CDMA system where the mobile station's geographic location cannot be determined, referred to as coverage holes.

There is therefore a need for a method and apparatus for locating a mobile station in a spread spectrum communication system which improves the estimation of time delay D **14** and diminishes coverage holes.

Summary of the Invention

According to an aspect of the present invention, the foregoing need is addressed by a method for locating a mobile station in a spread spectrum communication system, which includes transmitting a first signal comprising a plurality of transmitted symbols from a first base station to the mobile station; receiving by the first base station from the mobile station a second signal comprising a first plurality of received symbols in response to the first signal; demodulating the second signal by the first base station to form a demodulated signal; reencoding at least a portion of the demodulated signal by the first base station to form a reference signal; receiving the reference signal by a second base station; receiving by the first base station and the second base station a retransmitted second signal comprising a second plurality of received symbols from the mobile station, the retransmitted second signal in response to a retransmitted first signal comprising a plurality of retransmitted symbols directed to the mobile station; comparing, by the first base station, the retransmitted second signal with the reference signal at a first time and at a second time; comparing, by the second base station, the retransmitted second signal with the reference signal at the first time and at the second time; based on the comparisons at the first base station, determining a first delay of the retransmitted second signal, the first delay representing a travel time of the retransmitted second signal from the mobile station to the first base station; based on the comparisons at the second base station, determining a second delay of the retransmitted second signal, the second delay representing a travel time of the retransmitted second signal from the mobile station to the second base station; and based on the first and second delays, determining a location of the mobile station.

According to another aspect of the present invention, a method for locating a mobile station in a spread spectrum communication system includes receiving by a first base station a signal transmitted from the mobile station; demodulating the signal by the first base station to form a demodulated signal; remodulating at least a portion of the demodulated signal to form a reference signal; receiving by the first base station and a second base station a retransmitted signal; comparing, by the first base station, the retransmitted signal with the reference signal to determine a first delay; comparing, by the second base station, the retransmitted second signal with the reference signal to determine a second delay; and based on the first and second delays, determining a location of the mobile station.

According to a further aspect of the present invention, an apparatus for locating a mobile station in a spread spectrum communication system includes a first base station responsive to the mobile station. The first base station includes a first antenna transmitting a first signal to the mobile station. The first antenna receives a second signal from the mobile station in response to the first signal. A first demodulator is responsive to the second signal, producing a demodulated signal. A reencoder is responsive to the demodulated signal, forming a reference signal. A first correlator compares the reference signal to a retransmitted second signal received by the first antenna to determine a first delay, which represents a travel time of the retransmitted second signal from the mobile station to the first base station. A second base station is also responsive to the mobile station and the reference signal. The second base station includes a second antenna receiving the retransmitted second signal from the mobile station and receives the reference signal. A second correlator compares the reference signal to the retransmitted second signal to determine a second delay, which represents a travel time of the retransmitted second signal from the mobile station to the second base station. A controller is responsive to the first and second base stations. The controller determines a location of the mobile station based on the first delay and the second delay.

According to a still further aspect of the present invention, a method for locating a mobile station in a spread spectrum communication system includes receiving by a first base station a signal transmitted by the mobile station, the signal comprising a received frame, the received frame having a plurality of received symbols; storing the signal by the first base station in a first memory; receiving the signal by a second base station; storing the signal by the second base station in a second memory; demodulating the received frame by the first base station to form a demodulated frame; receiving the demodulated frame by the second base station; at the first base station, reencoding the demodulated frame to form a reencoded frame, the reencoded frame having a plurality of encoded symbols; at the second base station, reencoding the demodulated frame to form the reencoded frame; at the first base station, comparing at a first plurality of times each of the plurality of received symbols in the first memory with each of the plurality of reencoded symbols; based on the comparisons at the first plurality of times, determining a first delay representing a travel time of the signal from the mobile station to the first base station; at the second base station, comparing at a second plurality of times each of the plurality of received symbols in the second memory with each of the plurality of reencoded symbols; based on the comparisons at the second plurality of times, determining a second delay representing a travel time of the signal from the mobile station to the second base station; and based on the first and second delays, determining a location of the mobile station.

Advantages of the present invention will become readily apparent to those skilled in the art from the following description of the preferred embodiment of the invention which has been shown and described by way of illustration. As will be realized, the invention is capable of other and different embodiments, and its details are capable of modifications in various respects. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive.

Brief Description of the Drawings

FIG. 1 is an example of a transmitted communication signal S(T) which has been altered during transmission by time delay D and noise N, resulting in received communication signal R(T).

FIG. 2 illustrates a cellular communication system according to a preferred embodiment of the present invention.

FIG. 3 is a block diagram of a mobile station transmitter for generating a communication signal waveform.

FIG. 4 is a diagram of a reverse-link channel frame for transmission at a rate of 9600 bits per second.

FIG. 5 is a diagram of a digitally encoded and interleaved frame created by the transmitter of FIG. 3.

FIG. 6 is a partial block diagram of a base station, including a receiver, for receiving the communication signal waveform generated by the transmitter depicted in FIG. 3, according to a preferred embodiment of the present invention.

FIG. 7 is a diagram of a received frame in the receiver illustrated in FIG. 6.

FIG. 8 is a diagram of a demodulated frame in the receiver illustrated in FIG. 6.

FIG. 9 is a flowchart of a method for determining a location of a mobile station in a spread spectrum communication system according to a preferred embodiment of the present invention.

Detailed Description of the Preferred Embodiments

Turning now to the drawings, wherein like numerals designate like components, FIG. 2 illustrates a wireless communication system **200**, such as a code division multiple access (CDMA) digital radiotelephone system. Base stations **210**, **212** and **214** communicate with a mobile station **216** operating within an area **220** served by base station **212**. Areas **222** and **224** are served by base stations **214** and **210**, respectively. Base stations **210**, **212** and **214** are coupled to a base station controller **250**, which includes, among other things, a processor **252** and a memory **254**, and which is in turn coupled to a mobile switching center **260**, also including a processor **262** and a memory **264**.

Multiple access wireless communication between base stations **210**, **212** and **214** and mobile station **216** occurs via radio frequency (RF) channels which provide physical paths over which digital communication signals such as voice, data and video are transmitted. Base-to-mobile station communications are said to occur on a forward-link channel, while mobile-to-base station communications are referred to as being on a reverse-link channel. A communication system using CDMA channelization is described in detail in TIA/EIA Interim Standard IS-95A, Mobile Station-Base Station Compatibility Standards for Dual-Mode Wideband Spread Spectrum Cellular Systems, Telecommunications Industry Association, Washington, D.C. July 1993 [IS-95A], and "TIA Telecommunications Systems Bulletin: Support for 14.4 kbps Data Rate and PCS Interaction for Wideband Spread Spectrum Cellular Systems", February 1996 [the Bulletin], both IS-95A and the Bulletin incorporated herein by reference.

As shown in FIG. 2, communication signal **213** has been transmitted on an IS-95 forward-link channel such as a Paging Channel or a traffic channel by base station **212** to mobile station **216**. Communication signal **215** has been transmitted via an IS-95 reverse-link channel such as an Access Channel or a traffic channel by mobile station **216** in response to communication signal **213** from base station **212**. Communication signal **217** is substantially similar to communication signal **215**, communication signal **215** having been re-transmitted by mobile station **216** as communication signal **217**.

In many applications, such as determining a location of mobile station **216**, it may be desirable to estimate time delay D **14** (shown in FIG. 1) for a given S(t) **12** (also shown in FIG. 1), such as communication signals **215**, **217**, transmitted from mobile station **216** to base station **210**, **212** or **214**.

For example, time delay D **14** of second signal **215** or of re-transmitted second signal **217** from mobile station **216** to base station **212** may be estimated. As a first step, base station **212** may transmit a first signal **213** to mobile station **216**. The first signal may be, for example, a Request Message such as a Status Request Message, transmitted over the Paging Channel, or may be another type of message transmitted over a traffic channel. First signal **213** preferably provides a vehicle for base station **212** to query mobile station **216** about its fixed attributes, such as mobile station's **216** electronic serial number (ESN) and power class. Next, mobile station **216** responds to first signal **213** via a second signal **215**, which may be a Status Response Message transmitted over the Access Channel, or via another message transmitted over a traffic channel, so that base station **212** is able to elicit a known data transmission from mobile station **216**.

FIG. 3 is a block diagram of a transmitter **10**, for use in a mobile station such as mobile station **216**, for generating second signal **215**. A data bit stream **17** enters a variable-rate coder **19**, which produces a signal **21** comprised of a series of transmit channel frames (discussed further below) having varying transmit data rates. The transmit data rate of each frame depends on the characteristics of data bit stream **17**.

FIG. 4 is a diagram of a transmit channel frame **20**, produced by coder **19**, for transmission at a rate of 9600 bits per second (bps) (unless otherwise specified, all IS-95 reverse-link channel examples herein correspond to a 9600 bps transmission rate). Frame **20** includes: an information portion **22** having 172 information bits; a frame quality indicator portion **24**, calculated from information portion **22** according to a polynomial set forth in IS-95, at sec. 6.1.3.3.2.1 of IS-95; and eight encoder tail bits **26**.

Referring to FIG. 3, encoder block **28** includes a convolutional encoder **30** and an interleaver **32**. At convolutional encoder **30**, each frame **20** may be encoded by a rate 1/3 encoder using well-known algorithms such as convolutional encoding algorithms which facilitate subsequent decoding of frames **20**. Interleaver **32** operates to shuffle the contents of frames **20** using commonly-known techniques such as block interleaving techniques.

As shown in FIG. 5, each frame **34** of digitally coded and interleaved bits includes ninety-six groups of six coded bits, for a total of 576 bits. Each group of six coded bits represents an index **35** to one of sixty-four symbols such as Walsh codes. A Walsh code corresponds to a single row or column of a sixty-four-by-sixty-four Hadamard matrix, a square matrix of bits with a dimension that is a power of two. Typically, the bits comprising a Walsh code are referred to as Walsh chips.

Referring again to FIG. 3, each of the ninety-six Walsh code indices **35** in frame **34** are input to an M-ary orthogonal modulator **36**, which is preferably a sixty-four-ary orthogonal modulator. For each input Walsh code index **35**, M-ary orthogonal modulator **36** generates at output **38** a corresponding sixty-four-bit Walsh code W **39**. Thus, a series of ninety-six Walsh codes W **39** is generated for each frame **34** input to M-ary orthogonal modulator **36**.

Scrambler/spreader block **40**, among other things, applies a pseudorandom noise (PN) sequence to the series of Walsh codes W **39** using well-known scrambling techniques. At block **42**, the scrambled series of Walsh codes W **39** is phase modulated using an offset binary phase-shift keying (BPSK) modulation process or another modulation process, up-converted and transmitted as communication signal S(T) **12** from antenna **46**.

FIG. 6 is a partial block diagram of base station **212** (shown in FIG. 2), including a receiver **60**, constructed according to a preferred embodiment of the present invention. Base stations **210** and **214** are similarly constructed. Receiver **60** may detect a communication signal R(T) **14**, such as second signal

215, traveling from mobile station **216** to base station **212**. Receiver **60** is preferably a RAKE receiver having a number of fingers, although only a single finger is shown. Receiver **60** may be coherent, non-coherent or quasi-coherent.

Antenna **62** receives communication signal R(T) **18**, which comprises a number of received frames (discussed further below). Front-end processing such as filtering, frequency down-converting and phase demodulation of communication signal R(T) **18** is performed by well-known methods and circuits at block **64**.

When search input **300** is selected, receiver **60** operates as a searcher, the operation and construction of searchers being generally well-known, in an effort to lock onto received signal R(T) **18** at approximately the time of reception of R(T) **18**. Receiver **60** looks for R(T) **18** at a plurality of time offsets. Once receiver **60** has locked onto signal R(T) **18** at the time offset which approximates the actual time of reception of R(T) **18**, receiver **60** may activate demodulate input **301**, and reassign the RAKE finger based on the best estimate of the time of reception of signal R(T) **18**.

De-scrambler/de-spreader block **66**, among other things, removes the PN code applied by scrambler block **44** (shown in FIG. 3) to the series of Walsh codes W **39** (also shown in FIG. 3). In the IS-95 reverse-link channel, a received frame (discussed further below) of received signal **18** includes ninety-six received symbols, or Walsh codes, which are each sixty-four bits long.

FIG. 7 is a diagram representing a received frame **45** that has emerged from de-scrambler/de-spreader block **66**. Received frame **45** includes ninety-six groups of sixty-four received signal samples, each group of received signal samples RS **68** corresponding to a transmitted Walsh code. Each group of signal samples has been corrupted by, for example, a slowly-changing channel parameter such as time delay D **14** (shown in FIG. 1) and a channel variable such as N **16** (also shown in FIG. 1).

Referring again to FIG. 6, each received group of received signal samples RS **68**, after leaving de-scrambler/de-spreader **66**, is input to an orthogonal demodulator **70**, such as a Fast Hadamard Transform (FHT). FHT **70** may be implemented using commercially available hardware as an array of adders or as a multiplexed adder, depending on its size. Alternatively, FHT **70** may be implemented utilizing a conventional digital signal processor (DSP) such as a Motorola DSP, part no. 56166 or an application specific integrated circuit (ASIC).

Upon receiving a group of received signal samples RS **68**, FHT **70** generates a number of output signals **72**. Sixty-four output signals **72** are generated per signal sample group RS **68** in the IS-95 reverse-link channel. Each output signal **72** has an index which references one of the sixty-four possible Walsh codes W **39** generated by M-ary orthogonal modulator **36** (shown in FIG. 3). Thus, in the IS-95 reverse link channel, when a received signal sample group RS **68** is input to FHT **70**, sixty-four output signals **72** which correlate to sixty-four possible transmitted Walsh codes **39** are produced. It should be understood that in addition to having an index, each output signal 72 also has an associated complex number, C. For simplicity, the index and the complex number will be referred to collectively as output signal **72**.

Each output signal **72** further has an associated energy value C^2 (not shown), commonly calculated by magnitude-squaring the complex number C associated with output signal **72**. The energy value C^2 generally corresponds to a measure of confidence, or a likelihood, that output signal **72** indexes a Walsh code W **39** which corresponds to a group of received signal samples RS **68** input to FHT **70**. In about twenty percent of the cases, however, the energy value C^2 representing the highest measure of confidence is wrong--that is, output signal **72** associated with the greatest energy value C^2 does not actually index a Walsh code W **39** which was transmitted.

Decoder block **76**, which may include a de-interleaver **78** and a convolutional decoder **80**, further demodulates received signal R(T) **18**, that is, second signal **215**, estimating transmitted signal S(T) **12** (shown in FIG. 3), which is comprised of a series of channel frames, to form a series of demodulated frames (discussed further below). Decoder block **76** may be implemented in a variety of ways. For example, a Maximum Likelihood decoder, implemented in hardware or software according to well-known methods, may be used within decoder block **76**.

FIG. 8 illustrates a demodulated frame **85** which appears at output **81** of decoder block **76**. Demodulated frame **85** includes a demodulated information portion **86**, a demodulated frame quality indicator **88**, and may also include a demodulated tail bit portion **89**.

Referring again to FIG. 6, and also to other figures as necessary, a demultiplexer **90** separates demodulated information portion **86** of frame **85** from demodulated frame quality indicator **88**. Frame quality indicator circuit **92** uses demodulated portion **86** to calculate a re-computed frame quality indicator **93**. Re-computed frame quality indicator **93** is then compared to demodulated frame quality indicator **88** at comparator **94**, to determine whether a particular demodulated frame **85** matches a particular channel frame **20** produced by coder **19**.

When demodulated frame **85** does not match channel frame **20**, it fails, and is discarded by switch **96** at point **97**.

When demodulated frame **85** matches transmit channel frame **20**, demodulated frame **85** passes. As shown in FIG. 6, demodulated frame **85** has passed. Demodulated information portion **86** is passed by switch **96** at point **91** to re-encoder block **98**, which is preferably substantially similar to encoder block **28**, depicted in FIG. 3. Thus, an encoded frame **34** exiting re-encoder block **98** is essentially a reproduction of frame **34** (shown in FIG. 5), which may be referred to as a reference frame or a reference signal. As illustrated in FIG. 5, encoded frame **34** includes up to ninety-six groups of six coded bits, each group of six coded bits representing an index **35** to one of sixty-four Walsh codes.

If demodulated frame **85** has been successfully decoded, and communication signal S(T) **12** has been retrieved, base station **212** would have obtained a good estimate of channel parameter information such as time delay D **14** from which the distance between mobile station **216** and base station **212** could be determined. To accurately determine the location of mobile **216** using the trilateration method, however, it is desirable to know the distances between mobile station **216** and at least two other base stations, such as base stations **210** and **214**. These distances may be determined from time delays of a communication signal such as signals **215** or **217** transmitted from mobile station **216** to base stations **210** and **214**.

To determine time delays of a communication signal from mobile station **216** to all three base stations **210**, **212** and **214**, base station **212** may, according to one embodiment of the present invention, re-transmit first signal **213** to mobile station **216**, receiving in response a retransmitted second signal **217**, substantially identical to originally transmitted second signal **215**. Base station **212** may communicate originally transmitted second signal **215**, present at output **81** of decoder block **76**, or may alternatively communicate the reference signal which has been output as re-encoded frame **34** from block **98**, to base stations **210** and **214**. Base stations **210** and **214** also receive retransmitted signal **217**. Then, receiver **60** in all three base stations may operate as a special searcher to accurately determine the time delays of communication signal **217** between mobile station **216** and base stations **210**, **212** and **214**.

Assuming that the reference signal was forwarded to base stations **210** and **214**, receiver **60** may re-M-ary orthogonally modulate each of the ninety-six Walsh code indices **35** in re-encoded frame **34**. For each input Walsh code index **35**, a sixty-four-bit signal sample group, or Walsh code, is generated. Thus, a series of ninety-six Walsh codes is generated for each frame **34**. Optionally, the M-ary orthogonally modulated signal may be re-scrambled and re-spread by applying a PN sequence to the series of Walsh codes using well-known scrambling techniques. The re-modulation and re-scrambling/spreading processes are preferably substantially similar to the corresponding processes in transmitter **10** of mobile station **216**, described in connection with FIG. 3.

The re-modulated indices **35** are then correlated with the received signal samples RS **68** associated with communication signal **217** at a plurality of time offsets. The time offset at which re-transmitted second signal **217** and re-encoded originally-transmitted second signal **215** have a high degree of correlation may be output from correlator **100** at line **131**.

Alternatively, correlator **100** may compare, at a plurality of time offsets, a particular encoded index **35** (shown in FIG. 5) of a particular frame **34** received from re-encoder block **98** to re-transmitted second signal **217** at the point where an output signal **72** corresponding to the particular index corresponding to encoded index **35** exits FHT **70**. The time offset at which a frame of re-transmitted second signal **217** and a frame of re-encoded originally-transmitted second signal **215** has a high degree of correlation may be output from correlator **100** at line **131**.

The time delays D **14**, and hence the distances, between mobile station **216** and each base station **210**, **212** and **214** may be determined by comparing, at block **130**, the time offsets at which the high degree of correlation occurred with a central time source **140**.

To obtain an accurate delay estimation under low signal-to-noise ratio (SNR), the signals to be correlated may span a time duration much longer than the channel coherent time, and the special search process may be realized in two steps. In the case where re-modulated indices **35** are correlated with received signal samples RS **68** associated with communication signal **217**, received signal samples **68** and re-modulated indices **35** are first each divided into a plurality of segments, preferably of equal length, each segment spanning a time duration less than the channel coherent time, and correlations are performed over each pair of segments. Second, the correlation results, which are complex numbers, are magnitude-squared and summed together to form the final search results. The second step may be referred to as non-coherent combining.

In the case where correlator **100** compares a particular encoded index **35** from re-encoder block **98** to re-transmitted second signal **217** at the point where an output signal **72** corresponding to the particular index corresponding to encoded index **35** exits FHT **70**, the special search process may be performed using FHT **70**. The received signal sample groups exiting de-scrambler/de-spreader block **66** are divided into a plurality of segments, each of which spans a time duration less than the channel coherent time. Each group of received signal samples is processed by FHT **70** and the complex number output C with the index equal to the corresponding re-encoded 6-bit group is selected. Within a segment, these selected FHT outputs are summed to form a combined complex FHT output. The combined complex FHT output is mangitude-squared and summed with the magnitude-squared combined complex FHT outputs from other segments to form the final search results.

According to another embodiment of the present invention, mobile station **216** does not transmit signal **217**. A memory **110**, which may be a commercially available computer-readable random-access memory, for example, may be positioned at a point within receiver **60** in base stations **210**, **212** and **214** to capture second signal **215** as it is received. As shown in FIG. 6, memory **110** is responsive to front end processing block **64**, to descrambler/despreader block **66** and to demodulator **70**, although it may also be responsive to other receiver elements. Then, search processes as described herein may be performed for the captured second signal in base stations **210**, **212** and **214** to determine the time delays, or the distances, between mobile station **216** and the base stations. The estimated memory size is 0.5 Mbytes per 0.1 second of samples, when the number of samples stored is two times the Walsh chip rate.

It is also contemplated that second signal **215** may be any normal traffic signal transmitted by mobile station **216**, without the preceding transmission of first signal **213** from base station **212**. In this case, base stations **210**, **212** and **214** would preferably store signal **215** at a common predetermined time. It may be desirable, however, to direct mobile station **216** to transmit at a full-rate, for example, by sending first signal **213** to request that mobile station **216** transmit a blank-and-burst or dim-and-burst signal, to ensure that signal **215** includes full-rate frames.

A method for determining time delay D **14** resulting from second signal **215** or **217** traveling between mobile station **216** and base station **212** may be summarized as follows: a delayed signal R(T) **18** represented at the output of FHT **70** as a number of stored output signals **72** is known, either having been (1) retransmitted as second signal **217** by mobile station **216**, or (2) transmitted by mobile station **216** as signal **215** and captured in memory **110**. Values of S(T) **12** corresponding to R(T) **18** are given by indices **35** of encoded frames **34** exiting re-encoder block **98**. Correlator **100** correlates the received signals and the re-modulated and/or re-spread and re-scrambled signals, or, as the case may be, determines differences between output signals **72** and matching corresponding indices **35**, and forwards to delay estimator **130** at line **131** the time offset at which correlation between a frame of R(T) **18** and a frame of S(T) **12** is high. Calculation of the correct time offset for a particular frame is generally corrupted only by an amount of noise N **16**. To reduce energy from noise N **16**, the time offset calculations may be performed over a period of time, for example, for several frames.

Then, at delay estimator block **130**, the selected time offset at line **131** is compared with a central time source **140**, such as a 20 millisecond integral multiple of the IS-95 System Time available at base station **212**, to estimate time delay D **14** of second signal **215** or **217** from mobile station **216** to base stations **210, 212** and **214**.

When it is desired to determine a location of mobile station **216,** a controller, such as base station controller **250** or mobile station controller **260,** may initiate a command to one or more base stations such as base stations **210, 212** and **214** to determine time delay D **14** of a signal **215** or **217** traveling from mobile station **216** to base stations **210, 212** and **214,** as described above. Then, time delays D **14** calculated by each base station may be forwarded, along with base station identification information, to a central location such as base station controller **250** or mobile switching center **260.** Location of mobile station **216** may be determined by considering time delays D **14** for each base station, along with the two- or three-dimensional geographic coordinates of the receiving base stations, and calculating the unique point (or small region of highest probability) where the signal propagation paths between the base stations and the mobile station intersect. For example, a suitable calculation for determining the geographic coordinates of mobile station **216** is provided in U.S. Patent Number 5,508,708 to Ghosh et al., incorporated herein by reference.

One preferred method for determining a location of a mobile station in a spread spectrum communication system is outlined in the flowchart of FIG. 9. The method starts at block **400,** and continues to block **402,** where a first base station transmits a first signal to a mobile station. At block **404,** the first base station receives a second signal from the mobile station, in response to the first signal. Next, at block **406,** the first base station demodulates the second signal to form a demodulated signal, and at block **408** the first base station re-encodes the demodulated signal to form a reference signal. The second base station receives the reference signal at block **410**. The first and second base stations receive a retransmitted second signal at block **412**, the retransmitted second signal sent from the mobile station in response to a retransmitted first signal directed to the mobile station. At block **414**, the first and second base stations compare the retransmitted second signal with the reference signal at a first time and at a second time. Based on the comparisons at the first base station, at block **416**, a first delay of the retransmitted second signal is determined, the first delay representing a travel time of the retransmitted second signal from the mobile station to the first base station. At block **418**, based on the comparisons at the second base station, a second delay of the retransmitted second signal is determined, the second delay representing a travel time of the retransmitted second signal from the mobile station to the second base station. At block **420**, the location of the mobile station is determined based on the first and second delays.

In a first alternative embodiment, the second base station may receive the demodulated signal and both the first base station and the second base station may re-modulate the demodulated signal to form the reference signal. In a second alternative embodiment, both the first and second base stations may store the first signal in a memory such as memory **110**, demodulate the first signal to form a demodulated signal, re-modulate the demodulated signal, and compare the re-modulated signal with the contents of the memory.

The methods and apparatuses for locating a mobile station in a spread spectrum communication system described herein have many advantages. For example, base station receivers **60** have prior knowledge of the exact signal S(T) **12**, for example, signal **215** or **217**, transmitted by mobile station **216**. Thus, a receiver **60** operating as a searcher may determine time delay D **14** associated with received signal R(T) by correlating signal R(T) **18** with transmitted signal S(T) **12** at a number of offset times over a long integration period, for example, over two or more frames. This method may result in signal-to-noise ratio (SNR) gains of up to 12 dB, and should significantly shrink coverage holes.

On the other hand, lengthening the integration period without prior knowledge of S(T) **12** would yield little improvement in estimation of time delay D **14**, and should not reduce coverage holes, because receiver **60** would have to use the well-known winning Walsh symbol method to estimate delay D **14** under low SNR conditions.

Although receiver **60** has been described herein in terms of specific logical/functional circuitry and relationships, it is contemplated that receiver **60** may be configured in a variety of ways, such as with programmed processors or application-specific integrated circuits (ASICs).

The IS-95 reverse link channel has been specifically referred to herein, but the present invention is applicable to any digital channel, including but not limited to the forward-link IS-95 channel and to all forward- and reverse-link TDMA channels, in all TDMA systems, such as Groupe Special Mobile (GSM), a European TDMA system, Pacific Digital Cellular (PDC), a Japanese TDMA system, and Interim Standard 54 (IS-54), a U.S. TDMA system.

The principles of the present invention which apply to cellular-based digital communication systems may also apply to other types of communication systems, including but not limited to personal communication systems, trunked systems, satellite communication systems and data networks. Likewise, the principles of the present invention which apply to all types of digital radio frequency channels also apply to other types of communication channels, such as radio frequency signaling channels, electronic data buses, wireline channels, optical fiber links and satellite links.

It will furthermore be apparent that other and further forms of the invention, and embodiments other than the specific embodiments described above, may be devised without departing from the spirit and scope of the appended claims and their equivalents, and therefore it is intended that the scope of this invention will only be governed by the following claims and their equivalents.

Claims

We claim:

1. A method for locating a mobile station in a spread spectrum communication system, the method comprising the steps of:

transmitting a first signal comprising a plurality of transmitted symbols from a first base station to the mobile station;

receiving by the first base station from the mobile station a second signal comprising a first plurality of received symbols in response to the first signal;

demodulating the second signal by the first base station to form a demodulated signal;

reencoding at least a portion of the demodulated signal by the first base station to form a reference signal;

receiving the reference signal by a second base station;

receiving by the first base station and the second base station a retransmitted second signal comprising a second plurality of received symbols from the mobile station, the retransmitted second signal in response to a retransmitted first signal comprising a plurality of retransmitted symbols directed to the mobile station;

comparing, by the first base station, the retransmitted second signal with the reference signal at a first time and at a second time;

comparing, by the second base station, the retransmitted second signal with the reference signal at the first time and at the second time;

based on the comparisons at the first base station, determining a first delay of the retransmitted second signal, the first delay representing a travel time of the retransmitted second signal from the mobile station to the first base station;

based on the comparisons at the second base station, determining a second delay of the retransmitted second signal, the second delay representing a travel time of the retransmitted second signal from the mobile station to the second base station; and

based on the first and second delays, determining a location of the mobile station.

2. The method according to claim 1, wherein the step of determining the location of the mobile station further comprises the step of:

utilizing predetermined information about the first and second base stations.

3. The method according to claim 2, wherein the predetermined information comprises one of three-dimensional geographic coordinates of the first and second base stations and two-dimensional geographic coordinates of the first and second base stations.

4. The method according to claim 1, wherein the first signal and the retransmitted first signal are transmitted on a paging channel of a code division multiple access (CDMA) communication system.

5. The method according to claim 1, wherein the second signal and the retransmitted second signal are transmitted on an access channel of a CDMA communication system.

6. The method according to claim 1, wherein the first and second signals and the first and second

retransmitted signals are transmitted on a traffic channel of a CDMA communication system.

7. The method according to claim 1, further comprising the step of:

directing, by a central controller, the first base station to transmit the first signal.

8. The method according to claim 1, wherein the step of demodulating the second signal further comprises the step of:

inputting one of the first plurality of received symbols to a first demodulator associated with the first base station, the first demodulator having a number of outputs, each of the number of outputs having a value.

9. The method according to claim 8, wherein each value represents a likelihood that the one of the first plurality of received symbols corresponds to one of the plurality of transmitted symbols.

10. The method according to claim 8, wherein the first demodulator comprises a Fast Hadamard Transform (FHT).

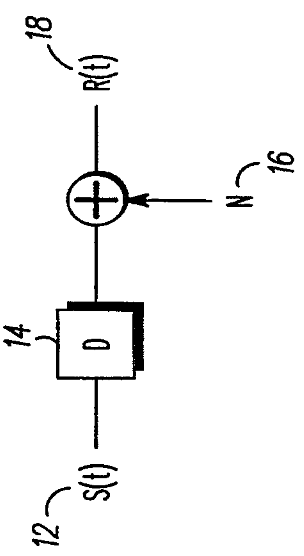
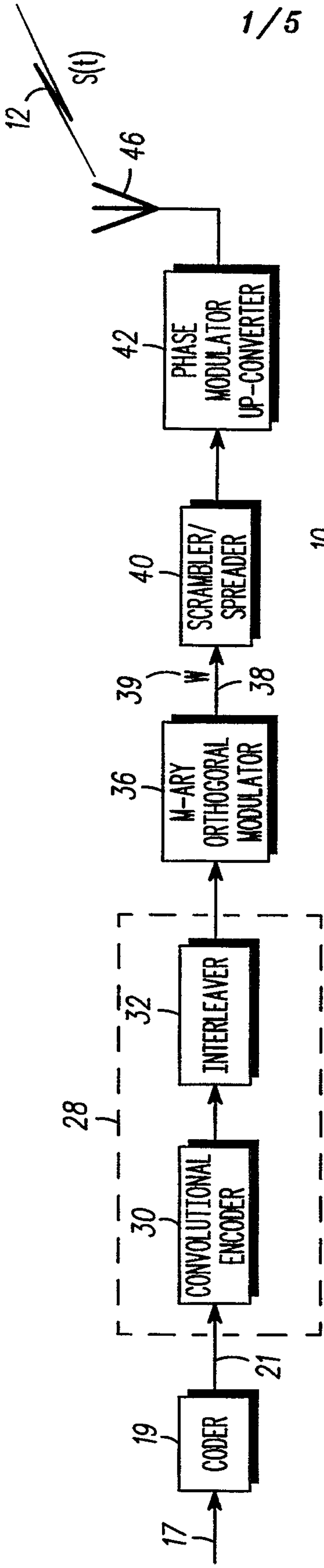
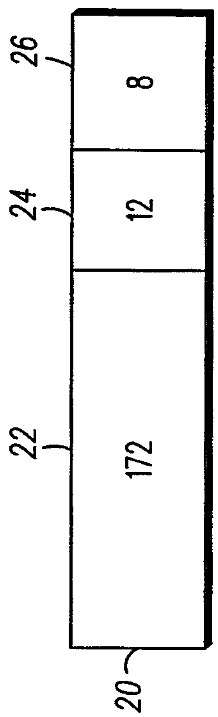


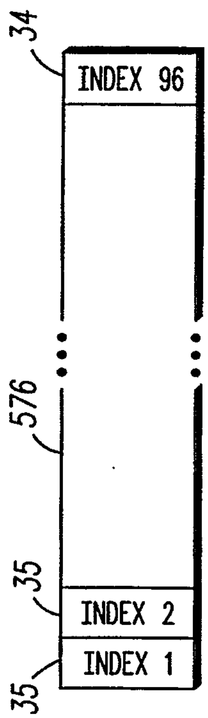
FIG.1
-PRIOR ART-



-PRIOR ART-
FIG.3



-PRIOR ART-
FIG.4



-PRIOR ART-
FIG.5

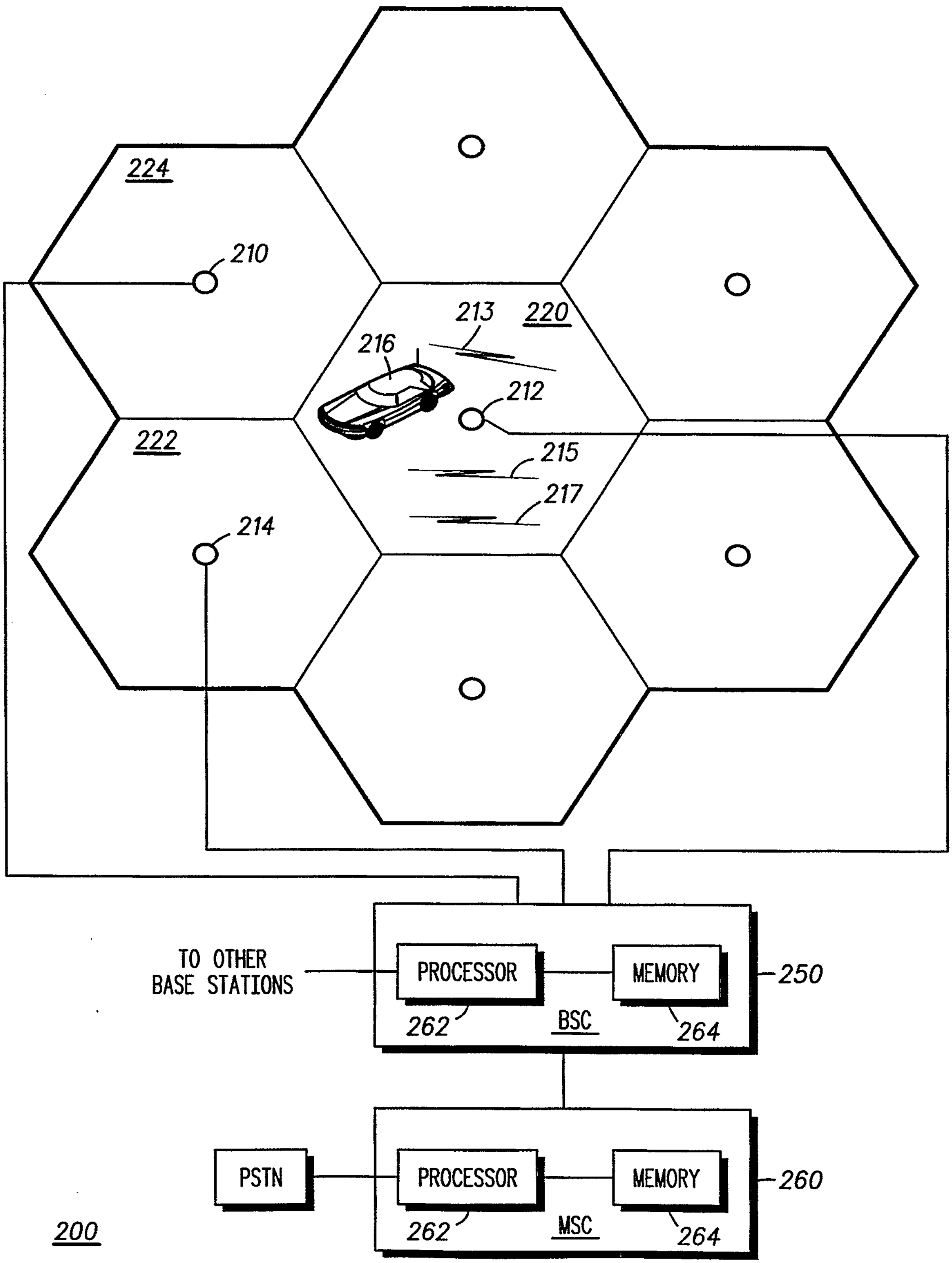

224
210
213
220
216
212
222
215
217
214
TO OTHER BASE STATIONS
PROCESSOR
MEMORY
250
262
BSC
264
PSTN
PROCESSOR
MEMORY
260
262
MSC
264
200

FIG. 2

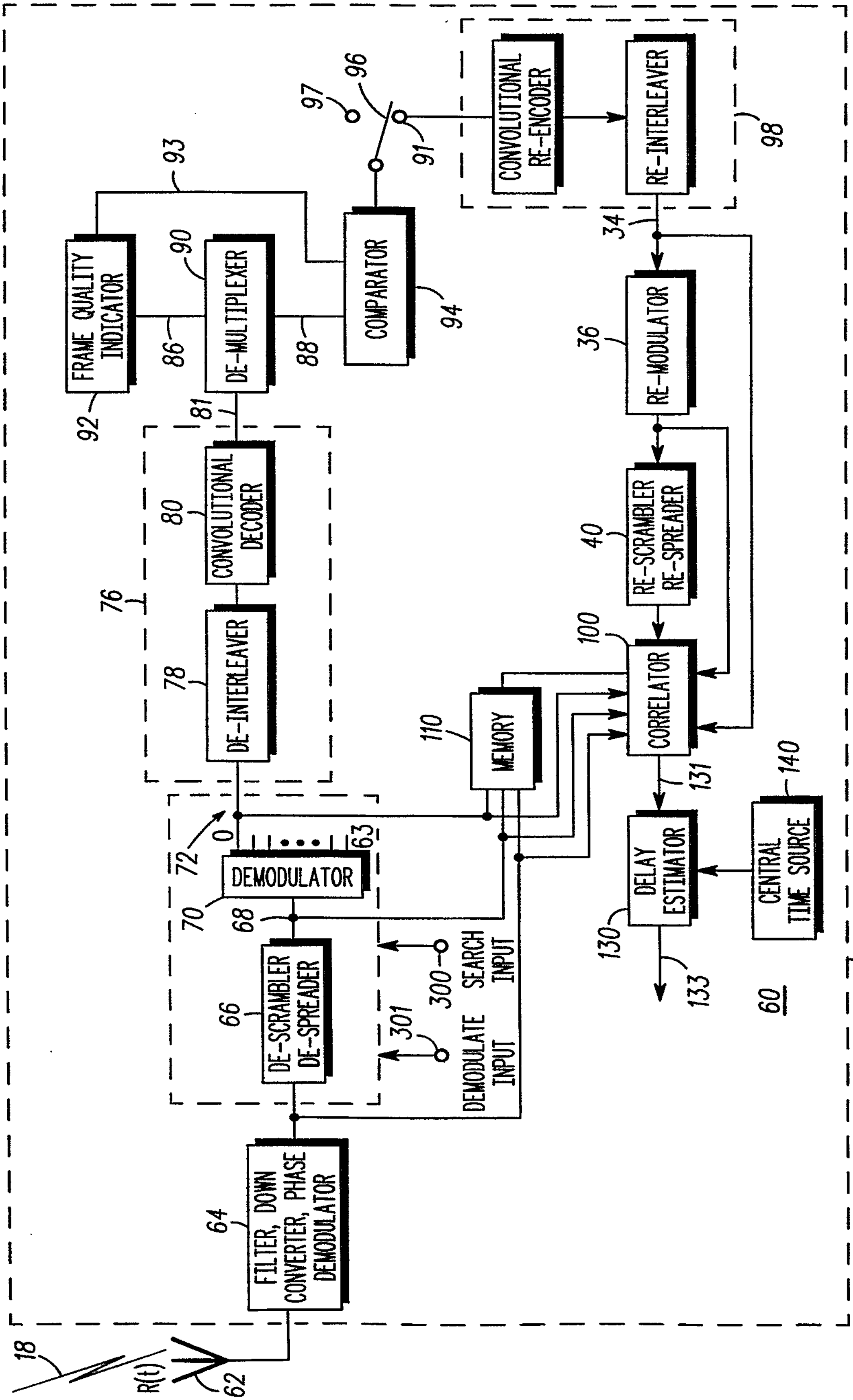

FRAME QUALITY INDICATOR
DE-MULTIPLEXER
COMPARATOR
CONVOLUTIONAL RE-ENCODER
RE-INTERLEAVER
RE-MODULATOR
RE-SCRAMBLER RE-SPREADER
CONVOLUTIONAL DECODER
DE-INTERLEAVER
CORRELATOR
MEMORY
DELAY ESTIMATOR
CENTRAL TIME SOURCE
DEMODULATOR
DE-SCRAMBLER DE-SPREADER
FILTER, DOWN CONVERTER, PHASE DEMODULATOR
SEARCH INPUT
DEMODULATE INPUT
R(t)
18
62
64
66
68
70
72
0
63
76
78
80
81
86
88
90
92
93
94
96
97
91
98
34
36
40
100
110
130
131
133
140
300
301
60
212

FIG. 6

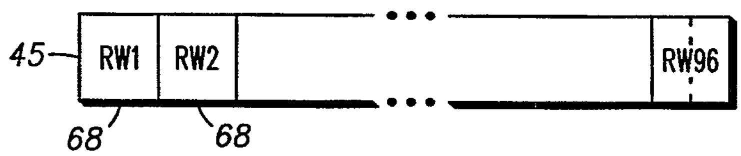


FIG. 7

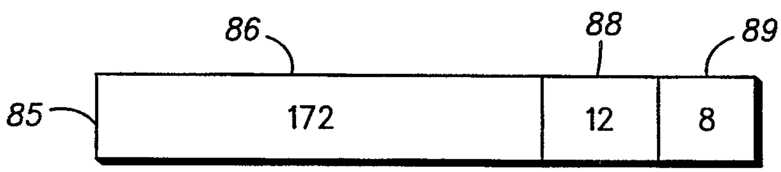


FIG. 8

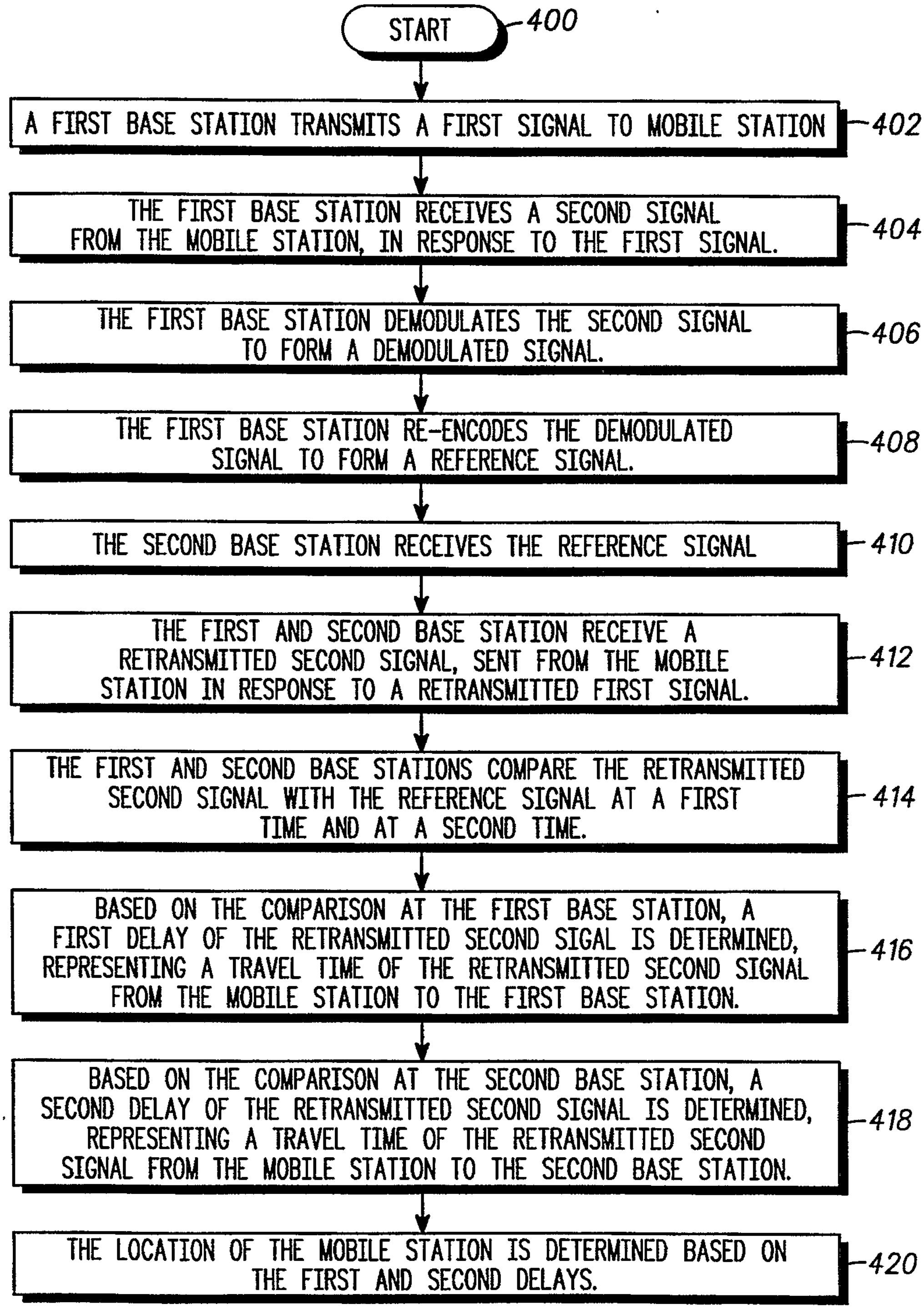
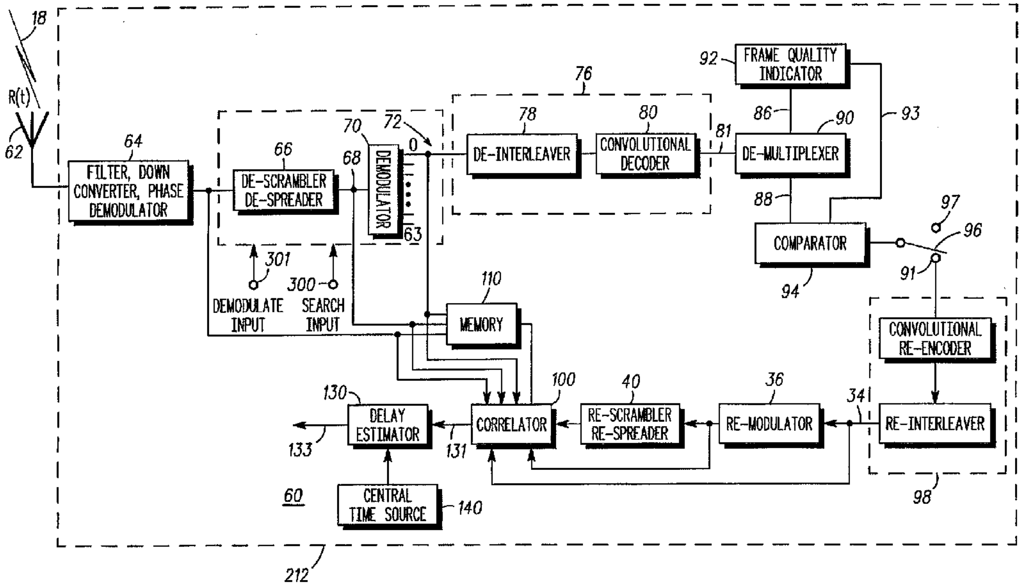

START
400
A FIRST BASE STATION TRANSMITS A FIRST SIGNAL TO MOBILE STATION
402
THE FIRST BASE STATION RECEIVES A SECOND SIGNAL FROM THE MOBILE STATION, IN RESPONSE TO THE FIRST SIGNAL.
404
THE FIRST BASE STATION DEMODULATES THE SECOND SIGNAL TO FORM A DEMODULATED SIGNAL.
406
THE FIRST BASE STATION RE-ENCODES THE DEMODULATED SIGNAL TO FORM A REFERENCE SIGNAL.
408
THE SECOND BASE STATION RECEIVES THE REFERENCE SIGNAL
410
THE FIRST AND SECOND BASE STATION RECEIVE A RETRANSMITTED SECOND SIGNAL, SENT FROM THE MOBILE STATION IN RESPONSE TO A RETRANSMITTED FIRST SIGNAL.
412
THE FIRST AND SECOND BASE STATIONS COMPARE THE RETRANSMITTED SECOND SIGNAL WITH THE REFERENCE SIGNAL AT A FIRST TIME AND AT A SECOND TIME.
414
BASED ON THE COMPARISON AT THE FIRST BASE STATION, A FIRST DELAY OF THE RETRANSMITTED SECOND SIGAL IS DETERMINED, REPRESENTING A TRAVEL TIME OF THE RETRANSMITTED SECOND SIGNAL FROM THE MOBILE STATION TO THE FIRST BASE STATION.
416
BASED ON THE COMPARISON AT THE SECOND BASE STATION, A SECOND DELAY OF THE RETRANSMITTED SECOND SIGNAL IS DETERMINED, REPRESENTING A TRAVEL TIME OF THE RETRANSMITTED SECOND SIGNAL FROM THE MOBILE STATION TO THE SECOND BASE STATION.
418
THE LOCATION OF THE MOBILE STATION IS DETERMINED BASED ON THE FIRST AND SECOND DELAYS.
420

FIG. 9


18
R(t)
62
64
FILTER, DOWN CONVERTER, PHASE DEMODULATOR
66
DE-SCRAMBLER DE-SPREADER
68
70
DEMODULATOR
72
0
63
301
300
DEMODULATE INPUT
SEARCH INPUT
76
78
DE-INTERLEAVER
80
CONVOLUTIONAL DECODER
81
92
FRAME QUALITY INDICATOR
86
90
DE-MULTIPLEXER
93
88
COMPARATOR
97
96
91
94
110
MEMORY
CONVOLUTIONAL RE-ENCODER
100
40
36
34
CORRELATOR
RE-SCRAMBLER RE-SPREADER
RE-MODULATOR
RE-INTERLEAVER
130
DELAY ESTIMATOR
133
131
98
60
CENTRAL TIME SOURCE
140
212