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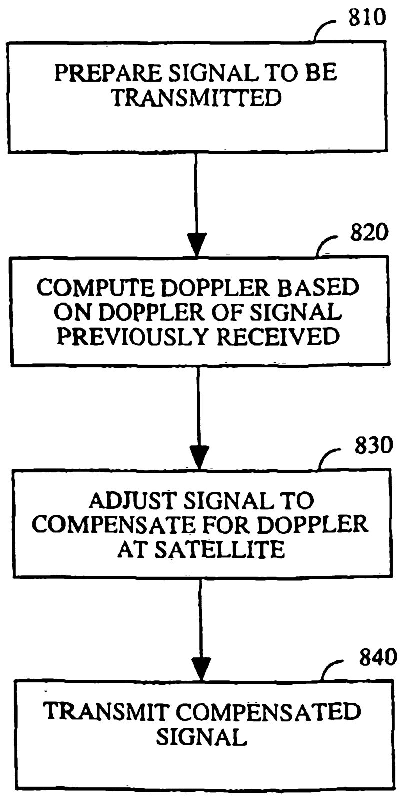
(57) Abstract

A method and apparatus for precorrecting timing and frequency in a communication system (100) that employs satellites (116, 118) to reduce timing uncertainty and frequency uncertainty due to satellite motion. A transmitted signal (410) is precorrected, or compensated (342), to account for effects based on known satellite mo tion as the transmitted signal propagates from the transmitter (120) to the satellite (116). Removing these effects reduces the amount of uncertainty in the transmitted signal when it arrives at the receiver (124), thereby making the task of signal reception easier.



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METHOD AND APPARATUS FOR PRECORRECTING TIMING AND FREQUENCY IN COMMUNICATION SYSTEMS

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates generally to spread spectrum communication systems, and more particularly, to receiving a communication signal in the presence of large amounts of signal Doppler. The present invention further relates to a novel and improved method of precorrecting the communication signal in time and frequency to compensate for this signal Doppler.

II. Description of the Related Art

Typical advanced terrestrial communication systems, such as wireless data or telephone systems, use base stations, also referred to as cell sites, within predefined geographical regions or cells, to relay communication signals to and from one or more user terminals or system subscribers. Typical satellite-based communication systems use base stations referred to as gateways, and one or more satellites to relay communications signals between the gateways and one or more user terminals. Base stations and gateways provide communication links from each user terminal to other user terminals or users of other connected communications systems, such as a public telephone switching network. User terminals in such systems can be fixed or mobile, such as a mobile telephone, and positioned near a gateway or remotely located.

Some communications systems employ code division multiple access (CDMA) spread-spectrum signals, as disclosed in U.S. Patent No. 4,901,307, issued February 13, 1990, entitled *"Spread Spectrum Multiple Access Communication System Using Satellite Or Terrestrial Repeaters,"* and U. S. Patent Application Serial No. 08/368,570, filed January 4, 1995, entitled *"Method And Apparatus For Using Full Spectrum Transmitted Power In A Spread Spectrum Communication System For Tracking Individual Recipient Phase Time And Energy,"* both of which are assigned to the assignee of the present invention, and are incorporated herein by reference.

In a typical spread spectrum communications system, one or more preselected pseudonoise (PN) code sequences are used to modulate or "spread" information signals over a predetermined spectral band prior to modulation onto a carrier signal for transmission as communications signals. PN code spreading, a method of spread spectrum transmission that is well known in the art, produces signals for transmission having a bandwidth much greater than that of the data signal. In a base station- or gateway-to-user terminal communication link, PN spreading codes or binary sequences are used to discriminate between signals transmitted by different base stations or over different beams, as well as between multipath signals.

In a typical CDMA spread spectrum system, channelizing codes are used to differentiate signals intended for various user terminals within a cell or a satellite sub-beam on a forward link (i.e., the signal path from the base station or gateway to the user terminal transceiver). Each user transceiver has its own orthogonal channel provided on the forward link by using a unique "channelizing" orthogonal code. Signals transferred on these channels are generally referred to as "traffic signals." Additional forward link channels or signals are provided for "paging," "synchronization," and other signals transmitted to system users. Walsh functions are generally used to implement the channelizing codes.

Additional details of the operation of this type of transmission apparatus are found in U. S. Patent No. 5,103,459, entitled *"System And Method For Generating Signal Waveforms In A CDMA Cellular Telephone,"* assigned to the same assignee as the present invention and incorporated herein by reference.

CDMA spread-spectrum communications systems, such as disclosed in the above patents, contemplate the use of coherent modulation and demodulation for forward link user terminal communications. In communications systems using this approach, a "pilot" carrier signal, or simply a "pilot signal," is used as a coherent phase reference for forward link signals. A pilot signal is a signal which generally contains no data modulation, and is transmitted by a gateway, or base station, throughout a region of coverage as a reference.

Pilot signals are used by user terminals to obtain initial system synchronization and time, frequency, and phase tracking of other signals transmitted by base stations or gateways. Phase information obtained from tracking a pilot signal carrier is used as a carrier phase reference for coherent demodulation of other system signals or traffic (data) signals. This technique allows many traffic signals to share a common pilot signal as a phase reference, providing for a less costly and more efficient tracking mechanism. A single pilot signal is typically transmitted by each base station or gateway for each frequency used, referred to as CDMA channels or sub-beams, and shared by all user terminals receiving signals from that source or gateway on that frequency.

When user terminals are not receiving or transmitting traffic signals, information can be conveyed to them using one or more signals known as paging signals or channels. For example, when a call has been placed to a particular mobile phone, a base station or gateway alerts that mobile phone by means of a paging signal. Paging signals are used to designate the presence of a call, which traffic channel to use, and to also distribute system overhead information, along with system subscriber specific messages. A communication system may have several paging signals or channels. Synchronization signals can also be used to transfer system information useful to facilitate time synchronization. All of these signals act as shared resources in a manner similar to pilot signals.

User terminals can respond to a message on a paging signal by sending an access signal over the reverse link. That is, the signal path from the user terminal to the base station or gateway. Access signals are also used by user terminals when they originate calls, and are sometimes referred to as access probes. Additional long PN codes are typically used to create reverse link traffic channels. At the same time, a form of M-ary modulation using a set of orthogonal codes can be used to improve reverse link data transfer.

As with any communication system, the forward link communication signals are received by the user terminal and downconverted into a baseband frequency for further processing. Once downconverted, the signals are processed digitally to detect the particular pilot signal or signals being received, and to demodulate associated paging, synchronization, and traffic signals. During demodulation, the PN spreading codes are applied to despread the signals and channelizing codes are correlated with the signals to provide data.

In order for the reception, downconversion, and demodulation processing to work correctly in such systems, the user terminal must share a common frequency reference and a common timing reference with base stations or gateways transmitting the signals being processed. That is, because information is carried in the phase of the signal carrier, the carrier frequency must be accurately detected, and the position of relative phases of multiple carriers must also be determined. Without reasonably accurate frequency tuning, the carrier cannot be properly removed and the digital signals accurately despread and demodulated.

Because the PN spreading codes are sequences applied to the signals, the timing of the signal must be determined to properly despread or demodulate the spreading codes from the signals to provide the data. PN spreading codes and orthogonal channelizing codes cannot be accurately removed without appropriate system timing or signal synchronization. If the codes are applied with incorrect synchronization, the signals will simply appear as noise and no information is conveyed. Determining the positions of satellites, user terminals, and code timing offsets used in such systems, also depends on an accurate knowledge of time or relative temporal displacement. User terminals rely on the accuracy of local oscillators to maintain an appropriate clock rate, event timing, and relative time values with respect to base station or gateway timing, and absolute chronological history or relationships.

Communication systems employing satellites with non-geostationary orbits exhibit a high degree of relative user terminal and satellite motion. The relative motion creates fairly substantial Doppler components or shifts in the carrier frequency of signals within the communication links. Because these Doppler components vary with user terminal and satellite motion, they create a range of uncertainty in the frequency of the carrier signal, or more simply, frequency uncertainty.

Besides such frequency shifts Doppler effects also cause apparent time or timing shifts into the various codes used, including PN codes, symbols, and so forth. These apparent time shifts are also referred to as code Doppler. In particular, code Doppler is an effect of satellite motion introduced into the baseband signal. Thus, the codes do not arrive at the receiver with a correct code timing.

In addition to code Doppler, the satellite motion also creates a large amount of uncertainty in the propagation delay, or timing uncertainty, for signals within the communication links. The propagation delay varies from a minimum when the satellite is directly overhead of the user terminal collocated at the gateway to a maximum when the satellite is at a horizon of the user terminal collocated at the gateway. In other words, the propagation delay is at its minimum when the distance from the gateway to the satellite to the user terminal is at a minimum. Likewise, the propagation delay is at its maximum when the distance from the gateway to the satellite to the user terminal is at a maximum.

In order to acquire a communication signal in a spread spectrum communication system, the communication system must detect the carrier frequency of the signal and synchronize timing with the signal. Typical communication systems "search" for the correct frequency and timing by comparing the signal with "hypotheses" comprised of various frequency and timing values within their respective ranges of uncertainty. The hypothesis with the highest correlation to the signal above a predetermined threshold includes the correct frequency and timing to despread and demodulate the signal.

However, typical communications systems have heretofore been faced with relatively small "search spaces," or sets of timing and frequency hypotheses due to relatively small frequency and timing uncertainties. For example, terrestrial communication systems or satellite communication systems employing geosynchronous satellites exhibit timing uncertainties in the range of 1 to 2 ms or more, and Doppler uncertainties on the order of 1 parts per million (ppm). In contrast, communication systems employing non-geosynchronous satellites exhibit timing uncertainties in the range of 10 to 20 ms, or more, and Doppler uncertainties on the order of 10 ppm, or more. Thus, all other things being equal, a communication system employing non-geosynchronous satellites has a search space that is orders of magnitude, 100 times or more, greater than that of the terrestrial or geosynchronous communication system.

The larger search space requires either a longer time to acquire the signal or multiple searching receivers operating in parallel on a portion of the search space. Each of these alternatives is undesirable.

What is needed is a method and apparatus for reducing the search space of a communication system that operates under conditions of high Doppler.

SUMMARY OF THE INVENTION

The present invention is directed toward acquiring a signal in a communication system that experiences Doppler due to relative motion of satellite repeaters and user terminals. This type of system has wide ranges of frequency uncertainty and timing uncertainty due to the Doppler shifts and variations in propagation delay due to the relative motion. The present invention reduces the ranges of frequency and timing uncertainties in the communication system.

A feature of the present invention is that additional searching receivers are not required in order to resolve the frequency and timing uncertainties. This is because a search space comprised of a range of frequency uncertainty and a range of timing uncertainty is reduced. Thus, fewer frequency and timing hypotheses have to be searched in order to acquire the signal. This also reduces the amount of time required to acquire the signal.

According to one embodiment of the present invention, a transmitter, located at a gateway of the communication system, pre-corrects a frequency of a forward link signal to compensate for a Doppler shift due to the relative motion between the satellite and the gateway. Because the relative motion of the satellite with respect to the gateway is well known, the signal is compensated so that when the signal reaches the satellite, the signal does not appear to have experienced any Doppler shift due to the relative motion. In other words, an uplink portion of the forward link signal (i.e., the portion of the forward link from the gateway to the satellite) is precorrected by the transmitter to compensate for the Doppler shift.

However, the relative motion of the satellite with respect to the user terminal is not well known. Thus, when a downlink portion of the forward link signal is repeated, or transmitted by the satellite to the user terminal, the signal will experience an unknown Doppler shift due to the relative motion between the satellite and the user terminal. Therefore, according to the present invention, precorrecting the frequency on the uplink portion of the forward link signal does not entirely remove the frequency uncertainty but rather reduces the overall frequency uncertainty in the forward link signal at the user terminal. Precorrecting the frequency reduces the search space of a receiver attempting to acquired the signal.

According to another embodiment of the present invention, a transmitter, located at the user terminal of the communication system, transmits a reverse link signal whose carrier frequency has been precorrected to compensate for a Doppler shift due to the relative motion between the user terminal and the satellite. This may be accomplished in one of two ways. Either the user terminal is aware, via various methods, of the relative motion of the satellite, or the user terminal adjusts the reverse link signal based on the Doppler present in the downlink portion of the forward link signal. In either case, the user terminal effectively removes Doppler from the uplink portion of the reverse link signal. In this case, the uplink portion of the reverse link signal arrives at the satellite without any apparent Doppler but still experiences Doppler on the downlink portion.

In yet another embodiment of the present invention, a transmitter at the gateway precorrects the timing of the uplink portion of the forward link signal. In this embodiment, the timing of the signal is continuously adjusted so that the signal arrives at any of the satellites employed by the communication system at the same time, referred to as satellite time. Thus, the transmitter adjusts the timing of a signal transmitted to a user terminal through each satellite so that the signal is synchronized at the satellites at a predetermined time regardless of the distance between the gateway and the satellite. Thus, the signal arrives at each satellite substantially simultaneously. This means that in many cases the signal will be transmitted at different times at the gateway to the various satellites.

One result of precorrecting the timing is that the timing uncertainty at the user terminal due to variations in propagation delay is reduced. Because the timing of the uplink portion of the forward link signal is known, the only uncertainty due to propagation delay occurs in the downlink portion of the forward link. Thus, by precorrecting the timing, the timing uncertainty in the forward link signal is reduced to approximately one half.

Continuously precorrecting the timing of the signal in a CDMA communication system results in each code in a PN spreading code sequence arriving at any particular satellite with a starting time substantially synchronized with that in any other satellite regardless of the distance between the gateway and the satellite. In other words, the uplink portion of the forward link signal at the satellite does not exhibit any code Doppler. Thus, the receiver must only correct for code Doppler experienced in the downlink portion of the forward link signal. This reduces the requirements of a timing tracking loop in the receiver of the user terminal.

In yet still another embodiment of the present invention, a transmitter at the user terminal precorrects the timing of the reverse link signal. In this embodiment, the timing of the reverse link signal is continuously adjusted so that the signal arrives with a starting time substantially synchronized with that in any of the satellites at the satellite time. Thus, the transmitter adjusts the timing of the signal transmitted to the satellite so that the signal is synchronized at the satellites regardless of the distance between the user terminal and the satellite. This means that in many cases the signal will be transmitted at different user terminal times depending on the distance between the user terminal and the satellite. As with the forward link, precorrecting the timing reduces the timing uncertainty and code Doppler present in the reverse link signal.

In a preferred embodiment of the present invention, both timing and frequency precorrection are performed on the uplink portions of the forward link signal and the reverse link signal. Because the timing and frequency uncertainties are reduced by approximately one half as a result of the precorrection, the overall search space of the system according to the present invention is reduced by approximately one fourth. This results in a substantial savings in either hardware costs or acquisition time.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout, the left-most digit(s) of a reference number identifies the drawing in which the reference number first appears, and wherein:

FIG. 1 illustrates a typical communication system in which the present invention is used;

FIG. 2 illustrates exemplary transceiver apparatus for use in a user terminal;

FIG. 3 illustrates exemplary transmission and reception apparatus for use in a gateway or base station;

FIG. 4 illustrates a forward link and a reverse link transmission between a gateway and a user terminal;

FIG. 5 illustrates various frequencies associated with a forward link signal for which no frequency precorrection has been performed;

FIG. 6 illustrates various frequencies associated with a forward link signal for which frequency precorrection has been performed;

FIG. 7 illustrates the steps performed to precorrect frequency for a forward link transmission from a gateway;

FIG. 8 illustrates the steps performed to precorrect frequency for a reverse link transmission from a user terminal;

FIG. 9 illustrates a forward link and a reverse link transmission for which no timing precorrection has been performed;

FIG. 10 illustrates a forward link and a reverse link transmission for a traffic channel for which timing precorrection has been performed according to the present invention;

FIG. 11 illustrates a forward link and a reverse link transmission for an access channel for which timing precorrection has been performed according to the present invention;

FIG. 12 illustrates the steps performed to precorrect timing for a forward link transmission from a gateway; and

FIG. 13 illustrates the steps performed to precorrect timing for a reverse link transmission from a user terminal.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a method and apparatus for precorrecting timing and frequency shifting due to Doppler in order to reduce the timing and frequency uncertainties in a communication system. The present invention accomplishes this, in part, by determining and compensating for the Doppler experienced by an uplink portion of a forward link signal as it is transmitted from a gateway to a satellite. Thus, all forward link signals arrive at the satellite precorrected to the same frequency. The downlink portion of the forward link signal is uncompensated because the relative motion between the satellite and a user terminal is unknown. Even though the downlink portion is uncompensated, the overall frequency uncertainty in the forward link signal is greatly reduced (approximately one half). This results in a corresponding reduction in the search space required by the forward link receiver to acquire the signal.

The present invention is particularly suited for use in communications systems employing Low Earth Orbit satellites. However, as would be apparent to one skilled in the relevant art, the concept of the present invention can also be applied to satellite systems that are not utilized for communications purposes. The invention is also applicable to satellite systems in which the satellites travel in non-LEO orbits, or to non-satellite repeater systems, if there is sufficient relative motion between gateways or base stations and user terminals to impact the frequencies of the signals being received, or if there is sufficient uncertainty in the propagation delay of the signals.

The preferred embodiment of the invention is discussed in detail below. While specific steps, configurations and arrangements are discussed, it should be understood that this is done for illustrative purposes only. A person skilled in the relevant art will recognize that other steps, configurations and arrangements can be used without departing from the spirit and scope of the present invention. The present invention could find use in a variety of wireless information and communication systems, including those intended for position determination, and satellite and terrestrial cellular telephone systems. A preferred application is in CDMA wireless spread spectrum communication systems for mobile or portable telephone service, typically using satellites to transfer signals.

An exemplary wireless communication system in which the present invention is useful, is illustrated in FIG. 1. It is contemplated that this communication system uses CDMA type communication signals, but this is not required by the present invention. In a portion of a communication system **100** illustrated in FIG. 1, one base station **112**, two satellites **116** and **118**, and two associated gateways or hubs **120** and **122** are shown for effecting communications with two remote user terminals **124** and **126**. Typically, the base stations and satellites/gateways are components of separate communication systems, referred to as being terrestrial and satellite based, although, this is not necessary. The total number of base stations, gateways, and satellites in such systems depend on desired system capacity and other factors well understood in the art.

User terminals **124** and **126** each have or comprise a wireless communication device such as, but not limited to, a cellular telephone, a data transceiver, or a paging or position determination receiver, and can be hand-held or vehicle mounted as desired. Here, the user terminals are illustrated as hand held telephones. However, it is also understood that the teachings of the invention are applicable to fixed units where remote wireless service is desired, including "inside" as well as "open air" locations.

Generally, beams from satellites **116** and **118** cover different geographical areas in predefined patterns. Beams at different frequencies, also referred to as CDMA channels or "sub-beams," can be directed to overlap the same region. It is also readily understood by those skilled in the art that beam coverage or service areas for multiple satellites, or antenna patterns for multiple base stations, might be designed to overlap completely or partially in a given region depending on the communication system design and the type of service being offered, and whether space diversity is being achieved.

A variety of multi-satellite communication systems have been proposed with an exemplary system employing on the order of 48 or more satellites, traveling in eight different orbital planes in Low Earth Orbit (LEO) for servicing a large number of user terminals. However, those skilled in the art will readily understand how the teachings of the present invention are applicable to a variety of satellite system and gateway configurations, including other orbital distances and constellations. At the same time, the invention is equally applicable to terrestrial based systems of various base station configurations.

In FIG. 1, some possible signal paths are illustrated for communications being established between user terminals **124** and **126** and base station **112**, or through satellites **116** and **118**, with gateways **120** and **122**. The base station-user terminal communication links are illustrated by lines **130** and **132**. The satellite-user terminal communication links between satellites **116** and **118**, and user terminals **124** and **126** are illustrated by lines **140**, **142**, and **144**. The gateway-satellite communication links, between gateways **120** and **122** and satellites **116** and **118**, are illustrated by lines **146**, **148**, **150**, and **152**. Gateways **120** and **122**, and base station **112**, may be used as part of one or two-way communication systems or simply to transfer messages or date to user terminals **124** and **126**.

An exemplary transceiver **200** for use in a user terminal **106** is illustrated in FIG. 2. Transceiver **200** uses at least one antenna **210** for receiving communication signals which are transferred to an analog receiver **214**, where they are downconverted, amplified, and digitized. A duplexer element **212** is typically used to allow the same antenna to serve both transmit and receive functions. However, some systems employ separate antennas for operating at different transmit and receive frequencies.

Digital communication signals output by analog receiver **214** are transferred to at least one digital data receiver **216A** and at least one digital searcher receiver **218**. Additional digital data receivers **216B-216N** can be used to obtain desired levels of signal diversity, depending on the acceptable level of unit complexity, as would be apparent to one skilled in the relevant art.

At least one user terminal control processor **220** is coupled to data receivers **216A-216N** and searcher receiver **218**. Control processor **220** provides, among other functions, basic signal processing, timing, power and handoff control or coordination, and selection of frequency used for signal carriers. Another basic control function often performed by control processor **220** is the selection or manipulation of PN code sequences or orthogonal functions to be used for processing communication signal waveforms. Control processor **220** signal processing can include a determination of relative signal strength and computation of various related signal parameters. Such computations of signal parameters, such as relative timing and frequency may include the use of additional or separate dedicated circuitry to provide increased efficiency or speed in measurements or improved allocation of control processing resources.

The outputs of digital data receivers 216A-216N are coupled to digital baseband circuitry 222 within the user terminal. User digital baseband circuitry 222 comprises processing and presentation elements used to transfer information to and from a user terminal user. That is, signal or data storage elements, such as transient or long term digital memory; input and output devices such as display screens, speakers, keypad terminals, and handsets; A/D elements, vocoders and other voice and analog signal processing elements; etc., all form parts of the user terminal baseband circuitry using elements well known in the art. If diversity signal processing is employed, user digital baseband circuitry 222 can comprise a diversity combiner and decoder. Some of these elements may also operate under the control of, or in communication with, control processor 220.

When voice or other data is prepared as an output message or communications signal originating with the user terminal, user digital baseband circuitry 222 is used to receive, store, process, and otherwise prepare the desired data for transmission. User digital baseband circuitry 222 provides this data to a transmit modulator 226 operating under the control of control processor 220. The output of transmit modulator 226 is transferred to a power controller 228 which provides output power control to a transmit power amplifier 230 for final transmission of the output signal from antenna 210 to a gateway.

As discussed further below, in order to implement embodiments of the present invention, user terminal 200 can also employ one or more precorrection elements or precorrectors 232 and 234. Preferably, a precorrection element 232 is used to adjust the frequency of the digital output of digital power controller 228 at baseband frequency. The baseband spectral information including the frequency adjustment is translated to the appropriate center frequency during the up-conversion performed in transmit power amplifier 230.

The precorrection or frequency adjustment is accomplished using techniques known in the art. For example, the precorrection can be effected by a complex signal rotation, which is equivalent to multiplying the signal by a factor of $e^{j\omega t}$, where ω is computed on the basis of known satellite ephemrides and desired channel frequency. This is very useful where communication signals are processed as in-phase (I) and quadrature phase channels (Q). A direct digital synthesis device can be used to generate some of the rotation products. Alternatively, a coordinate rotation digital computation element can be used that employs binary shifts, adds, and subtracts to perform a series of discrete rotations, resulting in the desired overall rotation. Such techniques, and related hardware. are well understood in the art.

As an alternative, precorrection element 234 can be disposed in the transmission path on the output of transmit power amplifier 230, to adjust the frequency of the outgoing signal. This can be accomplished using well known techniques of, such as, up- or down-conversion of the transmission waveform. However, changing the frequency on the output of the analog transmitter can be more difficult in that there are often a series of filters used to shape the waveform, and changes at this juncture may interfere with the filtering process. In the alternative, a precorrection element 232 234 can form part of a frequency selection or control mechanism for the analog up-conversion and modulation stage (230) of the user terminal so that an appropriately adjusted frequency is used to convert the digital signal to a desired transmission frequency in one step.

As also discussed in further detail below, user terminal 200 can also employ precorrection elements 232, 234 in the transmission path to adjust the timing of the outgoing signal, where timing precorrection circuits form part of such elements. This can be accomplished using well known techniques of adding or subtracting delay in the transmission waveform. In addition, time precorrection elements similar to and in addition to (not shown) precorrection elements 232 and 234, can be used, as desired, that are dedicated to implementing timing changes. Time precorrection can be used with or without frequency precorrection, to alter the relative timing of signals, or PN codes.

However, timing adjustments are generally accomplished by having the control processor adjust code generation and timing or other signal parameter timing when a signal is generated at baseband and prior to output by power controller 228. Controller 220 can, for example, determine when codes are generated, and their timing and application to signals, as well as when signals are acted upon by transit modulator 226 and transmitted to various satellites by power controller 228.

At least one time reference element 238 is used to generate and store chronological information such as date and time, which can be used to assist in determining satellite positions within known orbits. The time can be stored and updated periodically, and a Universal Time (UT) signal from a

GPS receiver can be used as part of this process in some applications. The time may also be supplied to the user terminal periodically by a gateway. In addition, current time can be stored when a user terminal enters an inactive mode, such as when it is "turned off", and used to determine various time dependent signal parameters.

As shown in FIG. 2, a local or reference oscillator **240** is used as a reference for analog receiver **214**, analog transmitter **230**, and for a clock circuit used by time reference element **238**. Oscillator **240** is also used as a frequency standard or reference for a timing circuit **242** the generates timing signals for other stages or processing elements within user terminal **200** such as, time tracking circuits, or the correlators in digital receivers **216A-N** and **218**, or transmit modulator **226**, time reference element **238**, and control processor **220**.

The frequency of the oscillator output may be adjusted, using known circuitry, to form the desired timing signals, as well known in the art. Such timing signals are typically referred to as clock signals for many circuits. Timing circuit **242** can also be configured to produce delays or retarding, or advancing in the relative timing of clock signals, under processor control. That is, time tracking can be adjusted by predetermined amounts. This also allows the application of codes to be advanced or retarded from "normal" timing, typically by one or more chip periods, so that PN codes or chips making up the codes can be applied with different timing, as desired.

Information or data corresponding to one or more measured signal parameters for received communication signals, or one or more shared resource signals, can be sent to the gateway using a variety of techniques known in the art. For example, the information can be transferred as a separate information signal or be appended to other messages prepared by user digital baseband circuitry **222**. Alternatively, the information can be inserted as predetermined control bits by transmit modulator **226** or transmit power controller **228** under control of control processor **220**.

Data receivers **216A-N** and searcher receiver **218** are configured with signal correlation elements to demodulate and track specific signals. Searcher receiver **218** is used to search for pilot signals, or other relatively fixed pattern strong signals, while digital receivers **216A-N** are used to demodulate other signals associated with detected pilot signals. A data receiver **416** can also be assigned to track or demodulate a pilot signal after acquisition. Therefore, the outputs of these units can be monitored to determine the energy in or frequency of the pilot signal or other signals.

These receivers employ frequency tracking elements that can be monitored to provide current frequency and timing information, to control processor **220** for signals being demodulated.

Control processor **220** uses such information to determine to what extent the received signals are offset form an expected reception frequency or the oscillator frequency, when scaled to the same frequency band, as appropriate. This and other information related to frequency errors and Doppler shifts, as discussed below, can be stored in one or more error/Doppler storage or memory elements **236**, as desired. This information can be used by control processor **220** to adjust the oscillator operating frequency, or can be transferred to gateways or base stations using various communication signals.

An exemplary transmission and reception apparatus **300** for use in a gateways **120** and **122**, or a base station, is illustrated in FIG. 3. Such apparatus is known in the art and discussed in the patents referenced above. For example, additional details on the operation of this type of apparatus are found in U. S. Patent No. 5,103,459, issued April 7, 1992, entitled *"System And Method For Generating Signal Waveforms In A CDMA Cellular Telephone,"* assigned to the same assignee as the present invention and incorporated herein by reference.

The portion of gateway **120**, **122** illustrated in FIG. **3** has one or more analog receivers **314** connected to an antenna **310** for receiving communication signals which are then downconverted, amplified, and digitized using various schemes well known in the art. Multiple antennas **310** are used in some communication systems. Digitized signals output by analog receiver **314** are provided as inputs to at least one digital receiver module, indicated by dashed lines generally at **324**.

Each digital receiver module **324** corresponds to signal processing elements used to manage communications between a gateway **120**, **122** and one user terminal **124**, **126**, although certain variations are known in the art. One analog receiver **314** can provide inputs for many digital receiver modules **324**, and a number of such modules are typically used in gateways **102** to accommodate all of the satellite beams and possible diversity mode signals being handled at any given time. Each digital receiver module **324** has one or more digital data receivers **316** and searcher receivers **318**. A searcher receiver **318** generally searches for appropriate diversity modes of signals other than pilot signals. Where implemented in the communication system, multiple digital data receivers **316A-316N** are used for diversity signal reception.

The outputs of data receivers **316** are provided to subsequent baseband processing elements **322** comprising apparatus well known in the art and not illustrated in further detail here. Exemplary baseband apparatus includes diversity combiners and decoders to combine multipath signals into one output for each user. Exemplary baseband apparatus also includes interface circuits for providing output data, typically to a digital switch or network. A variety of other known elements such as, but not limited to, vocoders, data modems, and digital data switching and storage components may form a part of baseband processing elements **322**. These elements operate to also control or direct the transfer of data signals to one or more transmit modules **334**.

Signals to be transmitted to user terminals are each coupled to one or more appropriate transmit modules **334**. A typical gateway uses a number of such transmit modules **334** to provide service to many user terminals **124, 126** at a time, and for several satellites and beams at a time. The number of transmission modules **334** used by gateways **120, 122** is determined by factors well known in the art, including system complexity, number of satellites in view, user capacity, degree of diversity chosen, and the like.

Each transmit module **334** includes a transmit modulator **326** which spread spectrum modulates data for transmission and has an output coupled to a digital transmit power controller **328**, which controls the transmission power used for the outgoing digital signal. Digital transmit power controller **328** applies a minimum level of power for purposes of interference reduction and resource allocation, but applies appropriate levels of power when needed to compensate for attenuation in the transmission path and other path transfer characteristics. At least one PN generator **332** is used by transmit modulator **326** in spreading the signals. This code generation can also form a functional part of one or more control processors or storage elements used in gateways **122, 124**, or base station **112**, and may be time shared.

The output of transmit power controller **328** is transferred to a summer **336** where it is summed with the outputs from other transmit power control circuits. Those outputs are signals for transmission to other user terminals **124, 126** at the same frequency and within the same beam as the output of transmit power controller **328**. The output of summer **336** is provided to an analog transmitter **338** for digital-to-analog conversion,

conversion to the appropriate RF carrier frequency, further amplification, filtering, and output to one or more antennas **340** for radiating to user terminals **124**, **126**. Antennas **310** and **340** may be the same antennas depending on the complexity and configuration of the system.

In order to implement embodiments of the present invention, one or more precorrectors or frequency/timing precorrection elements **342** and **344** are used. Preferably, a precorrection element **342** is used to adjust the frequency of the digital output of digital power controller **328** at baseband frequency. As in the user terminal, baseband spectral information including the frequency adjustment is translated to the appropriate center frequency during the up-conversion performed in analog transmitter **338**. The frequency precorrection is accomplished using techniques known in the art, such as the complex signal rotation discussed above, where the angle of rotation is computed on the basis of known satellite ephemrides and desired channel frequency. As in the user terminal, other signal rotation techniques, and related hardware, are well understood in the art.

In FIG. **3**, precorrector **342** is shown disposed in the transmission path prior to summer **336**. This allows individual control over each user terminal signal as desired. However, a single frequency precorrection element can be used when precorrection is performed after summer **336**, because user terminals share the same transmission path from the gateway to the satellite.

As an alternative, a precorrector **344** can be disposed in the transmission path on the output of analog transmitter **338**, to adjust the frequency/timing of the outgoing signal, using well known techniques. However, changing the frequency on the output of the analog transmitter can be more difficult, and may interfere with signal filtering processes. Alternatively, the output frequency of analog transmitter **338** can be adjusted directly by control processor **320** to provide a shifted output frequency, offset from the normal center frequency.

As discussed above for user terminal **200**, precorrection elements **342**, **344** can be used in the transmission path to adjust the timing of outgoing signals using known precorrection circuits that can form part of such elements. This can be accomplished using well known techniques of adding or subtracting delay in the transmission waveform. . In addition, time precorrection elements similar to and in addition to (not shown) precorrection elements **342** and **344**, can be used, as desired, that are dedicated to implementing timing changes. Time precorrection can also be used with or without frequency precorrection, to alter the relative timing of signals, or PN codes.

However, timing adjustments are generally accomplished by having the control processor adjust code generation and timing or other signal parameter timing when a signal is generated at baseband and prior to output by power controller 328. Controller 320, for example, determines code timing and application, as well as when signals are transmitted to various satellites and user terminals by power controller 328.

The amount of frequency and/or timing correction imposed on an outgoing user terminal signal, forward link, is based on known Doppler between the gateway and each satellite through which communication is established. The amount of shifting required to account for the satellite Doppler can be computed by control processor 320 using known satellite orbital position data. This data can be stored in and retrieved from one or more storage elements 346, such as lookup tables or memory elements. This data can also be provided from other data sources, as desired. A variety of well known devices such as RAM and ROM circuits, or magnetic storage devices can be used to construct storage elements 346. This information is used to establish the frequency or timing adjustment for each satellite being used by the gateway at any given time.

As shown in FIG. 3, a time and frequency unit (TFU) 348 provides reference frequency signals for the analog receiver 314 . A Universal Time (UT) signal from a GPS receiver can be used as part of this process in some applications. It can also be employed in multiple intermediate conversion steps, as desired. As shown, TFU 348 also serves as a reference for analog transmitter 338. TFU 348 also provides timing signals to other stages or processing elements within gateway or base station 300 such as the correlators in digital receivers 316A-N and 318, or transmit modulator 326, and control processor 320. TFU 348 is also configured to retard or advance the relative timing of (clock) signals, under processor control, by predetermined amounts, as desired.

At least one gateway control processor 320 is coupled to receiver modules 324, transmit modules 334, and baseband circuitry 322; these units may be physically separated from each other. Control processor 320 provides command and control signals to effect functions such as, but not limited to, signal processing, timing signal generation, power control, handoff control, diversity combining, and system interfacing. In addition, control processor

320 assigns PN spreading codes, orthogonal code sequences, and specific transmitters and receivers or modules for use in user communications.

Control processor 320 also controls the generation and power of pilot, synchronization, and paging channel signals and their coupling to transmit power controller 328. The pilot channel is simply a signal that is not modulated by data, and may use a repetitive unchanging pattern or non-varying frame structure type input to transmit modulator 326. That is, the orthogonal function, Walsh code, used to form the channel for the pilot signal generally has a constant value, such as all 1's or 0's, or a well known repetitive pattern, such as a structured pattern of interspersed 1's and 0's. This effectively results in transmitting only the PN spreading codes applied from PN generator 332. 332.

While control processor 320 can be coupled directly to the elements of a module, such as transmit module 334 or receive module 324, each module generally comprises a module-specific processor, such as transmit processor 330 or receive processor 321, which controls the elements of that module. Thus, in a preferred embodiment, control processor 320 is coupled to transmit processor 330 and receive processor 321, as shown in FIG. 3. In this manner a single control processor 320 can control the operations of a large number of modules and resources more efficiently. Transmit processor 330 controls generation of, and signal power for, pilot, synchronization, paging signals, and traffic channel signals, and their respective coupling to power controller 328. Receiver processor 321 controls searching, PN spreading codes for demodulation and monitoring received power.

For certain operations, such as shared resource power control, gateways 120 and 122 receive information such as received signal strength, frequency measurements, or other received signal parameters from user terminals in communication signals. This information can be derived from the demodulated outputs of data receivers 316 by receive processors 321. Alternatively, this information can be detected as occurring at predefined locations in the signals being monitored by control processor 320, or receive processors 321, and transferred to control processor 320. Control processor 320 uses this information (as described below) to control the timing and frequency of signals being transmitted and processed using transmit power controllers 328 and analog transmitter 338.

During communication system 100 operation, a communication signal s(t), referred to as a forward link signal is transmitted by a gateway (120, 122) to a user terminal (124, 126) using a gateway generated carrier frequency of A_0. The forward link signal experiences time delays, a propagation delay, frequency shifts due to Doppler, and other effects. The forward link signal experiences these effects first, while transiting from a gateway to the satellites (i.e., on an uplink portion of the forward link signal), and second, when transiting from satellites to user terminals (i.e., on a downlink portion of the forward link signal). Once the signal is received, there is a further delay in sending a return or reverse link signal, a propagation delay, and Doppler in the transition from the user terminal to the satellite (i.e. on an uplink portion of the reverse link signal) and again from the satellite to the gateway (i.e. on a downlink portion of the reverse link signal).

FIG. 4 illustrates the various signals transmitted in communication system **100**. Gateway **120** transmits a forward link signal **410** to user terminal **124** via satellite repeater **116**. Forward link signal **410** is comprised of an uplink portion **412** from gateway **120** to satellite repeater **116** and a downlink portion from satellite repeater **116** to user terminal **124**. User terminal **124** transmits a reverse link signal **420** to gateway **120** via satellite repeater **116**. Reverse link signal **420** is comprised of an uplink portion **422** from user terminal **124** to satellite repeater **116** and a downlink portion **424** from satellite repeater **116** to gateway **120**.

When gateway **120** transmits forward link signal **410** to satellite repeater **116**, uplink portion **412** experiences frequency Doppler and code Doppler as a result of the relative motion between gateway **120** and satellite repeater **116** (i.e., as satellite repeater **116** moves). As is well known, as satellite repeater **116** approaches gateway **120**, uplink portion **412** experiences an increase in its carrier frequency as a result of the frequency Doppler. Uplink portion **412** also experiences a decrease in code or pulse width of its PN code sequence as a result of the code Doppler. The opposite effects occur to uplink portion **412** as satellite repeater **116** recedes from gateway **120**.

Likewise when satellite repeater **116** transmits forward link signal **410** to user terminal **124**, downlink portion **414** experiences frequency Doppler and code Doppler as a result of the relative motion between satellite repeater **116** and user terminal **124** (i.e., as both satellite repeater **116** and user terminal **124** move). As is well known, as satellite repeater **116** approaches user terminal **124**, downlink portion **414** experiences an increase in its carrier frequency as a result of the frequency Doppler. Downlink portion **414** also experiences a decrease in code or pulse width of its PN code sequence as a result of the code Doppler. The opposite effects occur to downlink portion **414** as satellite repeater **116** recedes from user terminal **124**.

The effects of Doppler on the carrier frequency is described with reference to FIG. 5. FIG. **5** illustrates, for example, the effects of Doppler on a carrier frequency **510** of a forward link signal **410** as satellite repeater **116** approaches both gateway **120** and user terminal **124**. Forward link signal **410**, having a carrier frequency **510** ($f_{carrier}$ 510), is transmitted from gateway **120**. Uplink portion **412** experiences an increase in its carrier frequency due to Doppler which is shown in FIG. **5** as uplink Doppler frequency **520** (f_{uplink} 520). Thus, the frequency of forward link signal **410** at satellite repeater (f_{SAT}) is the sum of carrier frequency **510** and uplink Doppler frequency **520**. Downlink portion **414** experiences an increase in its frequency due to Doppler which is shown in FIG. **5** as downlink Doppler frequency **530** ($f_{downlink}$ 530). Thus, the frequency of forward link signal **410** at user terminal **124** (f_{UT}) is the sum of carrier frequency **510**, uplink Doppler frequency **520**, and downlink Doppler frequency **530**.

Because uplink Doppler frequency **520** and downlink Doppler frequency **530** vary depending on the relative motion of satellite repeater **116**, the frequency of forward link signal **410** at user terminal **124** also varies. This variance is referred to as a frequency uncertainty. In a communication system **100** that employs LEO satellites, the frequency uncertainty is in the range of 50 to 300 kHz, or more.

FIG. 6 illustrates an example of frequency precorrection processing performed according to one embodiment of the present invention. Forward link signal **410** has desired frequency of carrier frequency **510** ($f_{carrier}$ 510). Prior to being transmitted from gateway **120**, forward link signal **410** is adjusted by precorrector **342** by a precorrect frequency, precorrection factor, **610**. Frequency precorrect **610** is equal in magnitude and opposite in sign to uplink Doppler frequency **520**. Thus, when forward link signal **410** is transmitted from gateway **120**, forward link signal **410** has an initial frequency of carrier frequency **510** plus precorrect frequency **610**. Then, uplink portion **412** of forward link signal **410** experiences a change in its frequency due to uplink Doppler frequency **520**. In the present invention, the frequency (f_{SAT}) of forward link signal **410** at satellite repeater **116** is the sum of carrier frequency **510**, precorrect frequency **610**, and uplink Doppler frequency **520**. Because precorrect frequency **610** and uplink Doppler frequency are equal and opposite, the frequency of forward link **410** at satellite repeater **116** is equal to carrier frequency **510**.

Downlink portion **414** still experiences a change in its frequency due to downlink Doppler frequency 530. However, according to the present invention, the frequency (f_{UT}) of forward link signal **410** at user terminal **124** is the sum of carrier frequency **510** and downlink Doppler frequency **530.** The frequency of forward link signal **410** at user terminal **124** only varies from carrier frequency **510** by downlink Doppler frequency **530.** Thus, in the present invention, the frequency uncertainty is only a result of the uncertainty in downlink Doppler frequency **530.** For practical purposes, the present invention reduces frequency uncertainty by a factor of one half for user terminals **124** who are relatively stationary in comparison with satellite repeater **116.**

FIG. 7 illustrates the steps performed to precorrect frequency for forward link signal **410** from gateway **120** according to one embodiment of the present invention. In a step **710,** transmitter **338** prepares forward link signal **410** to be transmitted to one or more satellite repeaters **116.** In a step **720,** control processor **320** computes a relative motion and associated uplink Doppler frequency **520** for each satellite repeater **116** to which forward link signal **410** is to be transmitted. Next, in a step **730,** precorrector **342** precorrects or compensates forward link signal **410** to account for uplink Doppler frequency **520.** Finally, in a step **740,** transmitter **338** transmits forward link signal **410** at carrier frequency **510** precorrected by uplink Doppler frequency **520.**

Another embodiment of the present invention operates in a similar fashion on reverse link signal **420.** In this embodiment, user terminal **124** does not have knowledge of the relative motion of satellite repeater **116.** Therefore, user terminal **124** must employ a different technique to determine uplink Doppler frequency **520.** User terminal **124** does this based on the known carrier frequency **510** and the frequency of forward link signal **410.** The difference between these frequencies is downlink Doppler frequency **530.** Based on the assumption that the relative motion of the satellite does not change significantly between user terminal **124** receiving forward link signal **410** and transmitting reverse link signal **420,** downlink Doppler frequency **530** of forward link signal **410** is approximately the same as uplink Doppler frequency **510** of reverse link signal **420.** This technique is discussed in further detail in co-pending patent application Serial No. 08/723,724 entitled *"Determination Of Frequency Offsets In Communication Systems,"* incorporated above.

FIG. 8 illustrates the steps performed to precorrect frequency for a reverse link signal **420** from user terminal **124**. In a step **810**, transmitter **230** prepares reverse link signal **420** to be transmitted to satellite repeater **116**. In a step **820**, control processor **220** computes downlink Doppler frequency **530** based on known carrier frequency **510** and the frequency of the most recently received forward link signal **410**. The difference between these two frequencies is downlink Doppler frequency **530** of forward link signal **410**. This is approximately uplink Doppler frequency **520** for reverse link signal **420**. Next, in a step **830**, precorrector **232** precorrects or compensates reverse link signal **420** to account for uplink Doppler frequency **520**. Finally, in a step **840**, transmitter **230** transmits reverse link signal **420** at carrier frequency **510** precorrected by uplink Doppler frequency **520**.

Other embodiments of the present invention are based on further knowledge of the position and dynamics of user terminal **124**. If the position and dynamics of user terminal **124** are known, for example, by incorporating a positioning device in user terminal **124**, both uplink Doppler frequency **520** and downlink Doppler frequency **530** may be computed to compensate for their effects. In fact, if both of these Doppler frequencies are known, either precorrection or post-correction of the signal could be used. In either case, the frequency uncertainty associated with the signal would be virtually removed.

Another problem associated with transmitting signals via satellites is a variance in propagation delay for satellites located closely to a transmitter, for example, located in a gateway and for satellites located farther from the transmitter. This variance is referred to as timing uncertainty. FIG. 9 illustrates timing uncertainty for a forward link signal **910** and a reverse link signal **920**. As shown in FIG. 9, forward link signal **910** is actually two signals: a forward link signal **910A** transmitted to user terminal **124** via a farthest satellite **930**, and a forward link signal **910B** transmitted to user terminal **124** via a nearest satellite **940**. For purposes of this discussion, forward link signal **910A** and **910B** are the same signal in terms of information. The difference between these signals is that gateway **120** directs them to separate satellites. FIG. 9 also shows user terminal **124** twice in separate locations. This is done for drawing clarity. For purposes of the discussion with respect to FIG. 9, user terminal **124** refers to the same physical device. In other words, forward link signals **910A** and **910B** reach the same user terminal **124** even though they do so via different satellites **930, 940**. Forward link signal **910A** includes an uplink portion **912A** and a downlink portion 914A. Likewise, forward link signal 910B includes an uplink portion 912B and a downlink portion 914B.

Reverse link signal 920 is also shown as two signals in FIG. 9: a reverse link signal 920A transmitted to gateway 120 via farthest satellite 930, and a reverse link signal 920B transmitted to gateway 120 via nearest satellite 940. Reverse link signal 920A includes an uplink portion 922A and a downlink portion 924A. Likewise, reverse link signal 920B includes an uplink portion 922B and a downlink portion 924B.

Because of the differences in the distances between gateway 120 and satellites 930, 940, respectively, forward link signals 910A, 910B arrive at user terminal 124 at different times. As shown in FIG. 9, forward link signal 910A arrives at user terminal 124 at a time 960 while forward link signal 910B arrives at user terminal 124 at a time 950. The difference between these two times represents the range of time at which forward link signal 910 can be expected to arrive at user terminal 124. In other words, when a signal is transmitted from gateway 120, it will arrive at user terminal 124 within the range of time bounded by time 950 and time 960. This range, in general, is referred to as timing uncertainty. With respect to forward link signal 910, this timing uncertainty is referred to as the user terminal (UT) forward timing uncertainty.

FIG. 9 also shows the timing uncertainty for reverse link signal 920. Reverse link signal 920A arrives at gateway 120 at a time 980 while reverse link signal 920B arrives at gateway 120 at a time 970. The difference between these two times represents the range of time at which reverse link signal 920 can be expected to arrive at gateway 120. This timing uncertainty, bounded by time 970 and 980, is referred to as the gateway (GW) reverse timing uncertainty. In a communication system 100 that employs LEO satellites, the timing uncertainty is approximately 10 to 20 ms, or more, as compared with terrestrial or geosynchronous satellite communication systems whose timing uncertainty is 1 to 2 ms.

As discussed above, the problem with timing uncertainty is that the receiver must search the entire range of timing in order to acquire a spread spectrum communication signal. This is especially true for systems that use PN code sequences. The present invention reduces the timing uncertainty by transmitting the communication signal at different times based on the distance between the transmitter and the satellite so that a given communication signal arrives at all satellites to which the signal is being transmitted at the same time, regardless of the distance.

FIG. 10 illustrates timing uncertainty for forward link signal **910** and reverse link signal **920** according to one embodiment of the present invention. According to the present invention, forward link signal **910A** is transmitted by gateway **120** at a time **1010** to user terminal **124** via farthest satellite **930**. At a time **1020**, forward link signal **910B** is transmitted by gateway **120** to user terminal **124** via nearest satellite **940**. The difference between time **1010** and time **1020** is referred to as a precorrection time, or in this case more specifically as forward link precorrection time. Forward link precorrection time is determined based on the distance and associated propagation delay between gateway **120** and the satellite receiving the signal so that regardless of the distance, the signal arrives at the satellite at the same time. For example, forward link signal **910A** arrives at farthest satellite **930** and forward link signal **910B** arrives at nearest satellite **940** at the same time, a time **1030** (referred to as satellite time **1030**).

Each satellite **930, 940** repeats forward link signal **910** to user terminal **124**. Forward link signal **910A** arrives at user terminal **124** at time **1050**. Forward link signal **910B** arrives at user terminal **124** at time **1040**. The difference between time **1050** and time **1040** represent the user terminal forward timing uncertainty of the present invention. In effect, the present invention reduces the user terminal forward timing uncertainty by the amount of timing uncertainty associated with uplink portion **912** of forward link signal **910** because forward link signal **910** is "known" to arrive at satellites **930, 940** at satellite time **1030**.

FIG. 10 illustrates the worst case timing uncertainty based on farthest satellite **930** and nearest satellite **940**. While the above discussion refers to transmitting forward link signal **910** to one or more satellites, this may not be the case. For example, only one satellite may be within the line-of-sight of a particular gateway **120**. In this case, gateway **120** may only be able to transmit to one satellite. In another example, a particular communication system **100** may not be performing diversity processing thereby making multiple transmissions of the same signal useless. Regardless, of the number of satellites used, the present invention reduces timing uncertainty in the received signal by precorrecting the timing of the transmission of the signal so that the signal arrives at the satellite at a known time.

One embodiment of the present invention not only precorrects the start of the transmission of the signal but continuously precorrects the signal as it is transmitted so that each component of the signal (i.e., PN code) arrives at the satellite at a known time. This embodiment of the present invention compensates for code Doppler in addition to reducing the timing uncertainty. As with the frequency precorrection discussed above, code Doppler is only precorrected on uplink portion **912** of forward link signal because the timing is known or correct at the satellite. Nonetheless, the uncertainty due to code Doppler is reduced thereby making the tasks of a time tracking loop much easier.

FIG. **11** illustrates timing uncertainty for forward link signal **910** and reverse link signal **920** according to another embodiment of the present invention. According to this embodiment of the present invention, forward link signal **910** is transmitted by gateway **120** in a manner identical to that described above with respect to FIG. **9**. This embodiment employs a similar technique with respect to reverse link signal **920**. At a time **1110**, user terminal **124** transmits reverse link signal **920**A to gateway **120** via farthest satellite **930**. At a time **1120**, user terminal **124** transmits reverse link signal **920**B to gateway **120** via nearest satellite **940**. The difference between time **1110** and time **1120** is referred to as a reverse link precorrection time. Because user terminal **124** has no knowledge of its own position, user terminal **124** determines reverse link precorrection time based on the time difference between satellite time **1030** and the time forward link signal **910** arrives at user terminal **124**. This time difference corresponds to the propagation delay of downlink portion **914** of forward link signal **910**. As before, assuming little relative motion during reception of forward link signal **910** and transmission of reverse link signal **920**, the propagation delay of downlink portion **914** is the same as the propagation delay of uplink portion **922** of reverse link signal **920**, and hence, is the necessary reverse link precorrection time.

Reverse link precorrection time is used to adjust or compensate the transmission of reverse link signal **920** so that it arrives at the satellite at a known time referred to as satellite time **1130**. The satellite repeats reverse link signal **920** to user terminal **124**. Reverse link signal **920**A arrives at user terminal **124** at time **1150**. Reverse link signal **920**B arrives at user terminal **124** at time **1140**. The difference between time **1150** and time **1140** represent the gateway reverse timing uncertainty of the present invention. In effect, this embodiment of the present invention reduces both the user terminal forward timing uncertainty as well as the gateway reverse timing uncertainty. With respect to forward link **910**, the user terminal forward timing uncertainty is reduced by the amount of timing uncertainty associated with uplink portion **912**. With respect to reverse link **920**, the gateway reverse timing uncertainty is reduced by the amount of timing uncertainty associated with uplink portion **922**.

FIG. **12** illustrates the steps performed to precorrect timing for forward link signal **910** at gateway **120** according to one embodiment of the present invention. In a step **1210**, control processor **320** computes a distance between gateway **120** and each satellite **930, 940** to which forward link signal **910** is to be transmitted. Next, in a step **1220**, control processor **320** computes a propagation delay based on each of these distances.

Such distances can be obtained, for example, by measuring round-trip delays for signals transmitted from a satellite to a user terminal and back, either immediately or after a known delay, and then dividing the result by two and multiplying the result by the speed of the signal (light).. The round-trip delay can be measured by transmitting a signal containing a known running PN sequence or spreading code, and comparing the state of the PN sequence in the retransmitted signal as received at the gateway with that of the transmitted signal. The difference in states is used to determine the total round-trip delay, which includes known gateway-to-satellite delays. Using known satellite ephemerides, the known delays are computed by various methods well known in the art. Alternatively, the distance is measured using round-trip delays of signals transmitted through one satellite and returned through a second satellite. However, some additional information regarding their relative position is required, which is generally supplied using other signal parameters. Such techniques are discussed in further detail in the co-pending patent applications incorporated above, relating to position determination.

In a step **1230**, precorrector **342** precorrects or compensates forward link signal **410** to account for the propagation delay to each satellite **930, 940**. Finally, in a step **1240**, transmitter 338 transmits forward link signal **410** whose timing has been precorrected to the appropriate satellite **930, 940**.

FIG. **13** illustrates the steps performed to precorrect timing for reverse link signal **920** at user terminal **124** according to one embodiment of the present invention. In a step **1310**, control processor **220** computes a propagation delay based on the most recently received forward link signal **910** from each of satellites **930, 940** to which reverse link signal **920** is to be transmitted. In a step **1320**, precorrector **232** precorrects or compensates reverse link signal **920** to account for the propagation delay to each satellite **930, 940**. Finally, in a step **1330**, transmitter **230** transmits reverse link signal **920** whose timing has been precorrected to the appropriate satellite **930, 940**.

In addition to reducing the timing uncertainty and hence the search space of a receiver attempting to acquire the signal, the present invention also reduces the amount of deskew memory buffers required by communication systems **100** employing diversity processing. These types of systems must buffer incoming signals over the entire range of timing uncertainty in order to "receive" the signal from all possible paths. By reducing the timing uncertainty (i.e. the time within which the signal from all possible paths can be expected), the deskew memory can correspondingly be reduced.

A preferred embodiment of the present invention incorporates a precorrector that employs both frequency and timing precorrection. As discussed above, the frequency precorrection and the timing precorrection each reduce their respective uncertainties by a factor of approximately one half. Thus, the preferred embodiment of the present invention is able to reduce the search space of a receiver to approximately a factor of one fourth of the original search space. Hence, gateways **120** or user terminals **124** that incorporate the preferred embodiment of the present invention are able to acquire signals in roughly one fourth the amount of time or with one fourth the number of searching receivers as their conventional counterparts.

The previous description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

What I claims as my invention is:

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method for transmitting a signal in a communication system employing satellites that reduces the effects of Doppler on a receiver, the method comprising the steps of:

continuously computing a Doppler frequency of a satellite relative to a transmitter based on known ephemerides of said satellite, a position of said transmitter, and a transmit frequency of the signal, said satellite receiving the signal from said transmitter, said satellite repeating the signal to the receiver; and

adjusting [a] said transmit frequency of the signal as a function of said computed Doppler frequency so that the signal is received at said satellite as if there is no Doppler.

2. A method for transmitting a signal in a communication system that reduces the effects of Doppler, the communication system having a transmitter, a receiver and a satellite, the satellite for receiving the signal from the transmitter and for repeating the signal to the receiver, the method comprising the steps of:

continuously computing a Doppler frequency of the satellite relative to the transmitter based on known ephemerides of the satellite, a position of the transmitter, and a desired frequency of the signal;

continuously determining a propagation time required for the signal to traverse a distance between the satellite and the transmitter, said distance computed based on said known ephemerides of the satellite and said position of the transmitter;

adjusting a transmit frequency of the signal as a function of said computed Doppler frequency so that the signal arrives at the satellite at said desired frequency; and

adjusting a transmit time of the signal as a function of said determined propagation time so that the signal arrives at said satellite at a predetermined time, whereby said transmit frequency and said transmit time adjustments reduce frequency and timing uncertainties at the receiver in the communication system.

3. A method for transmitting a signal in a communication system employing satellites that reduces the effects of Doppler in a receiver, the signal having a plurality of components, the method comprising the steps of:

continuously computing a distance between a satellite and a transmitter based on known ephemerides of said satellite and a position of said transmitter, said satellite receiving the signal from said transmitter;

determining a propagation time required for the signal to traverse said computed distance;

adjusting a timing of the start of the transmission of the signal based on said propagation time; and

continuously adjusting a timing of the transmission of the signal based on said propagation time so that each of the plurality of components of the signal is received at the satellite at a predetermined time,

whereby continuously adjusting said timing of the transmission of the signal reduces the effect of code Doppler on the signal.

4. For use in a wireless communication system including a gateway, a satellite, and a user terminal remote from the gateway, a system for correcting at least one of frequency and timing shifts in signals being communicated between the gateway and the user terminal via the satellite, comprising:

an antenna coupled to at least one of the gateway and the user terminal;

a transmitter coupled to said antenna for transmitting a spread spectrum modulated signal from the gateway to the user terminal or vice versa via the satellite; and

a precorrector coupled to said transmitter for shifting at least one of frequency and timing of said spread spectrum modulated signal based on known Doppler frequency and timing shifts between said transmitter and the satellite.

5. For use in a wireless communication system including a gateway, a satellite, and a user terminal remote from the gateway, a system for correcting frequency shifts in signals being communicated between the gateway and the user terminal via the satellite, comprising:

an antenna coupled to at least one of the gateway and the user terminal;

a transmitter coupled to said antenna for transmitting an uplink carrier signal having a predefined frequency from the gateway to the user terminal or vice versa via the satellite; and

a precorrector coupled to said transmitter for shifting the uplink carrier signal frequency based on known Doppler frequency shifts between said transmitter and the satellite.

6. A system according to claim 5, wherein said precorrector comprises:

motion determining means for determining the relative motion between the gateway and the satellite and for determining the Doppler frequency based on said relative motion; and

means coupled to said motion determining means for combining said Doppler frequency with said uplink carrier signal frequency to thereby compensate for Doppler shift between said transmitter and the satellite.

7. A system according to claim 6, wherein said antenna and said transmitter are located at said gateway, and said uplink carrier signal is transmitted from the gateway to the user terminal.

8. A system according to claim 5, wherein said antenna is coupled to the user terminal, and further comprising:

means for determining the frequency difference between a known carrier frequency and the most recent forward link signal received at the user terminal from the gateway via the satellite; and

means for combining said frequency difference with an uplink carrier signal transmitted from the user terminal to the gateway via the satellite.

Dated this 20th day of December 1999

QUALCOMM INCORPORATED
By its Patent Attorneys
MADDERNS

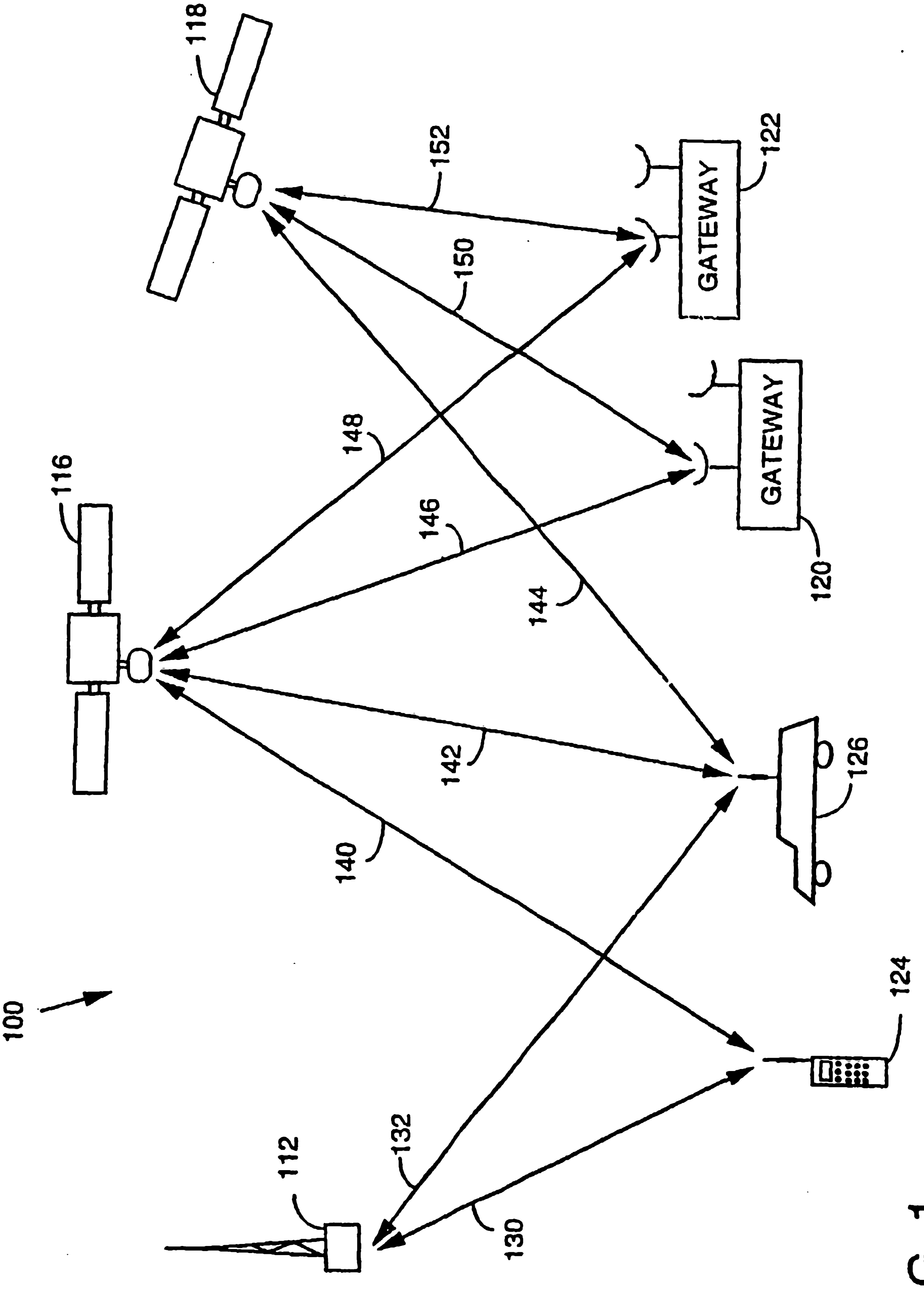

118
152
GATEWAY
122
150
GATEWAY
148
116
146
120
144
142
126
140
100
124
112
132
130

FIG. 1

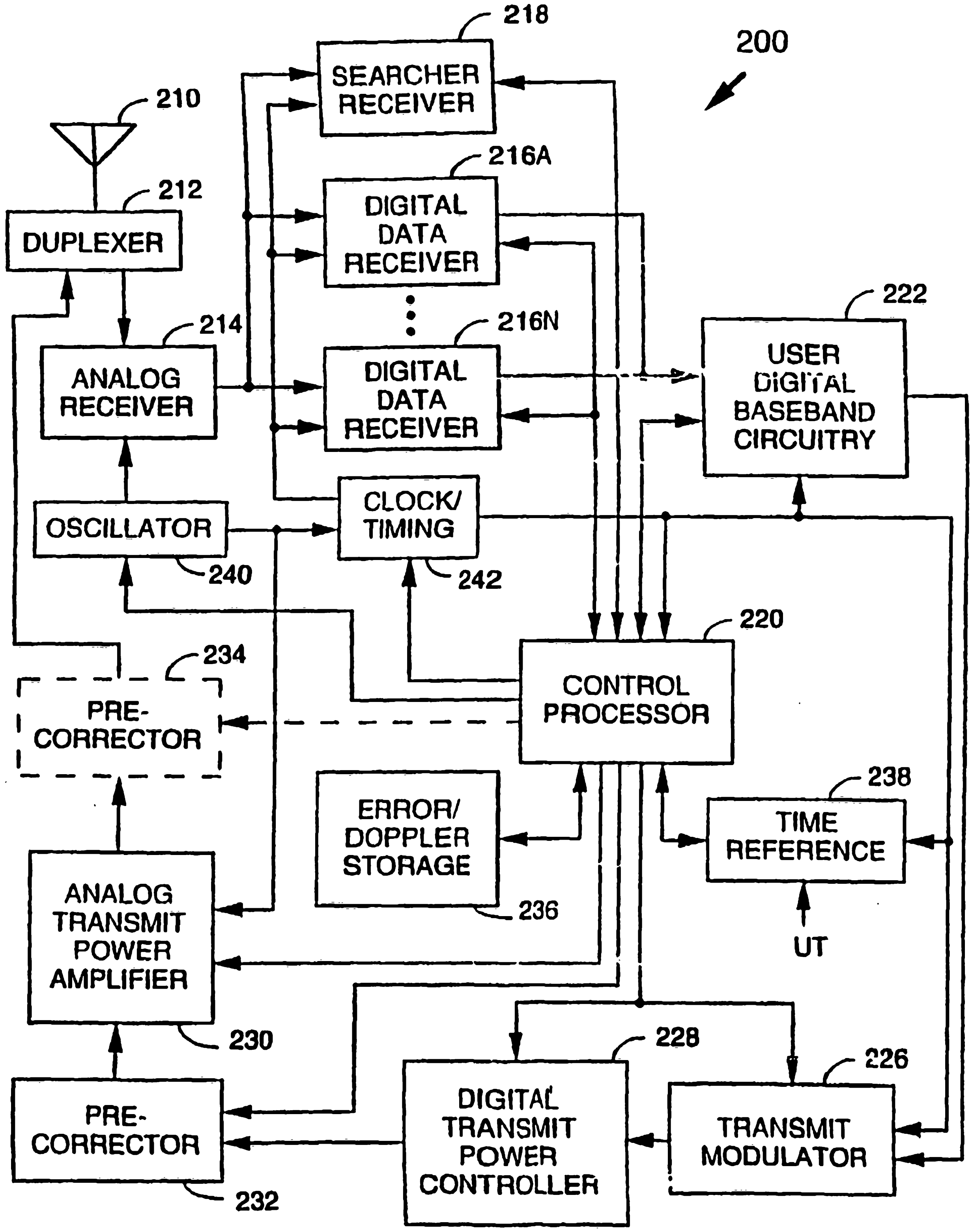
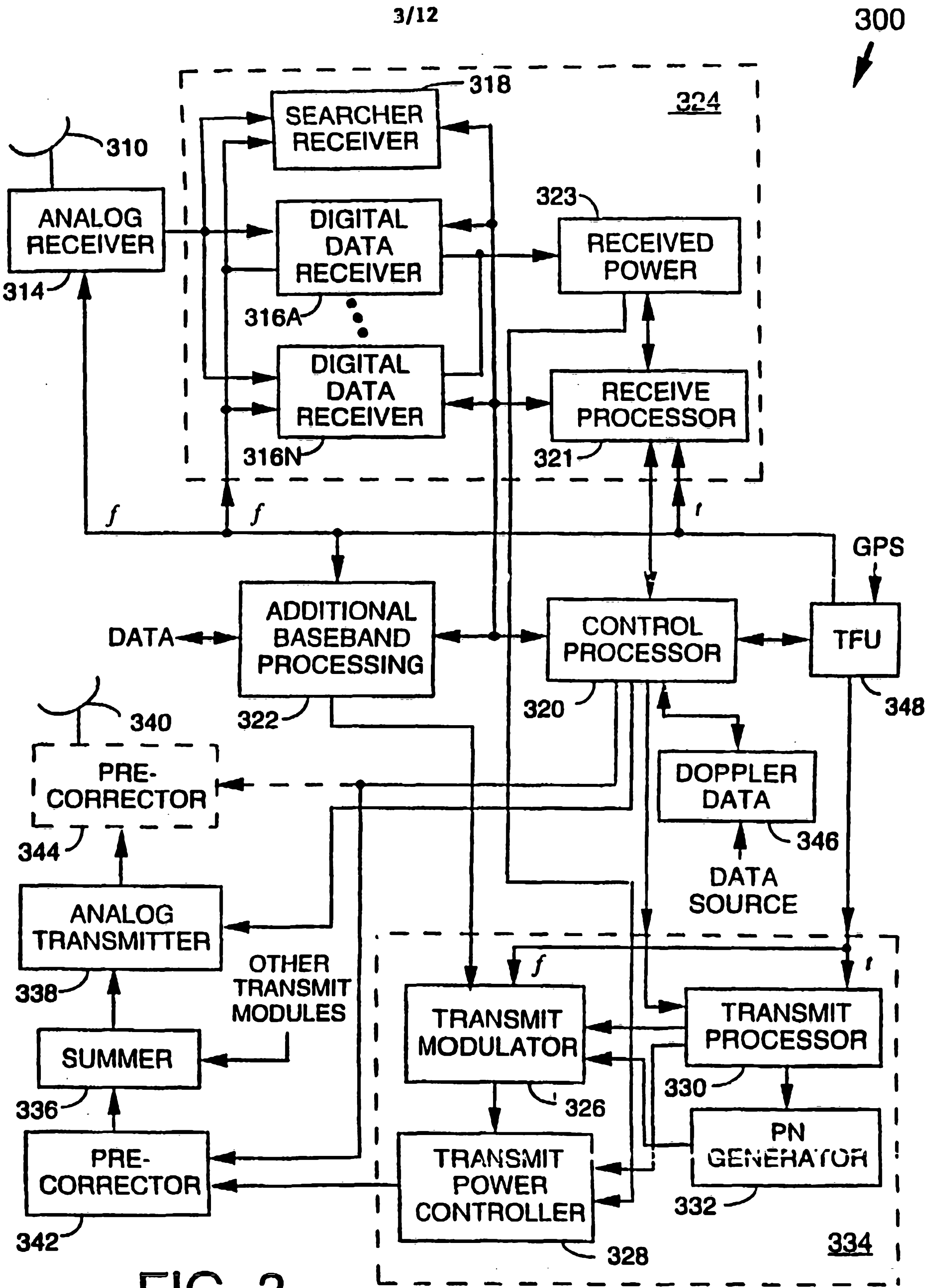

200
218
SEARCHER RECEIVER
210
212
DUPLEXER
216A
DIGITAL DATA RECEIVER
214
ANALOG RECEIVER
216N
DIGITAL DATA RECEIVER
222
USER DIGITAL BASEBAND CIRCUITRY
OSCILLATOR
240
CLOCK/ TIMING
242
220
CONTROL PROCESSOR
234
PRE-CORRECTOR
ERROR/ DOPPLER STORAGE
236
238
TIME REFERENCE
UT
ANALOG TRANSMIT POWER AMPLIFIER
230
228
226
PRE-CORRECTOR
232
DIGITAL TRANSMIT POWER CONTROLLER
TRANSMIT MODULATOR

FIG. 2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318
324
SEARCHER RECEIVER
310
ANALOG RECEIVER
DIGITAL DATA RECEIVER
323
RECEIVED POWER
314
316A
DIGITAL DATA RECEIVER
RECEIVE PROCESSOR
316N
321
f
f
f
GPS
ADDITIONAL BASEBAND PROCESSING
DATA
CONTROL PROCESSOR
TFU
322
320
348
340
PRE-CORRECTOR
DOPPLER DATA
344
346
DATA SOURCE
ANALOG TRANSMITTER
OTHER TRANSMIT MODULES
338
f
f
TRANSMIT MODULATOR
TRANSMIT PROCESSOR
SUMMER
336
330
326
PN GENERATOR
PRE-CORRECTOR
TRANSMIT POWER CONTROLLER
332
342
328
334

FIG. 3

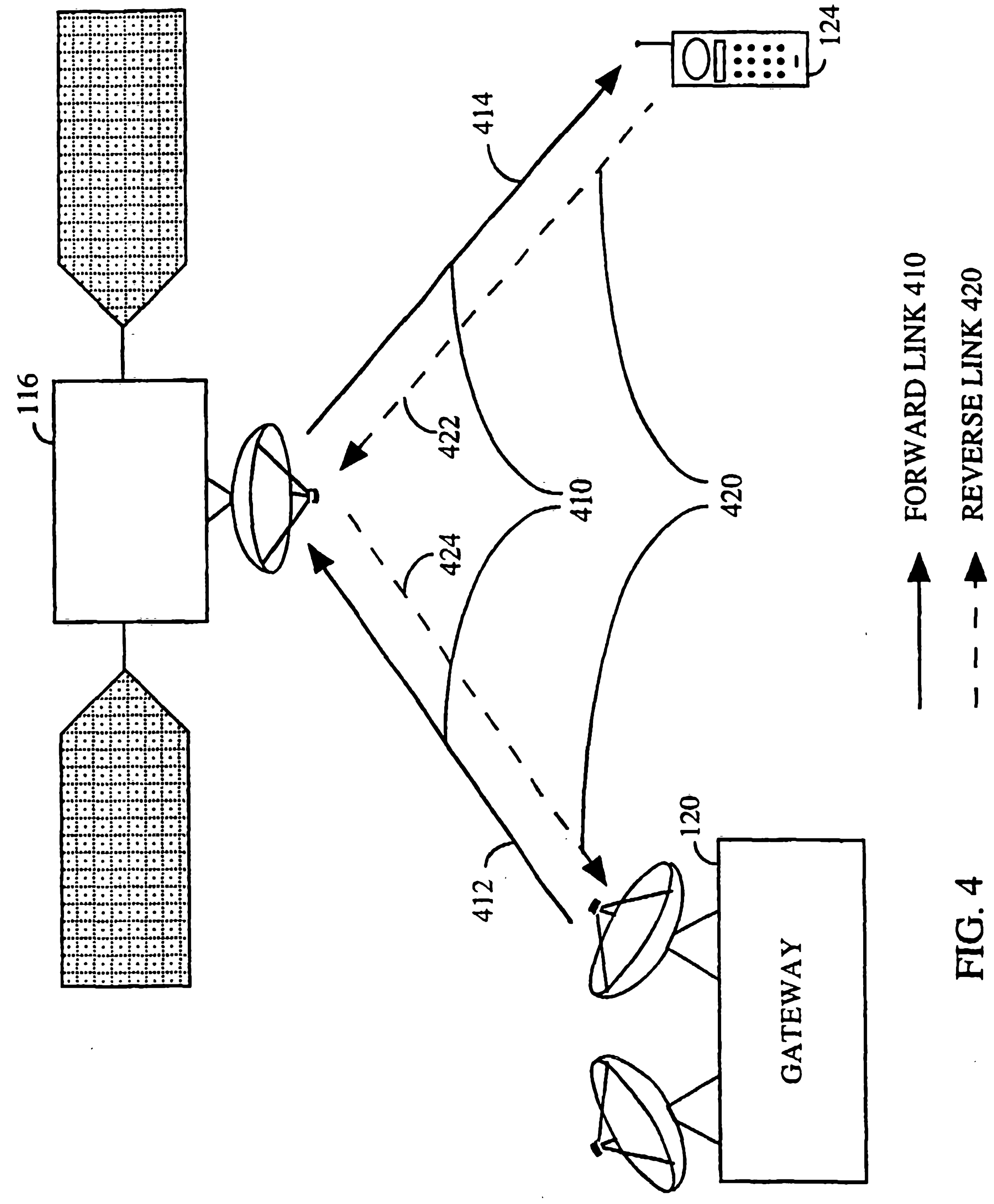
116
124
414
422
410
420
424
412
120
GATEWAY
FORWARD LINK 410
REVERSE LINK 420

FIG. 4

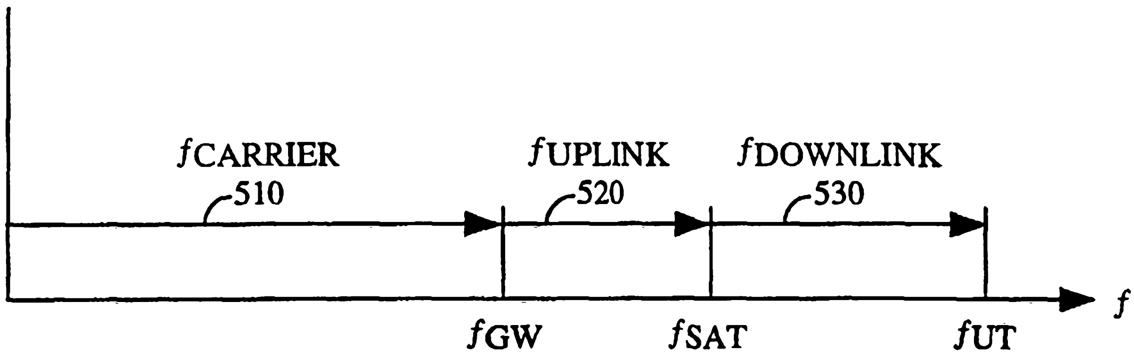
fCARRIER
510
fUPLINK
520
fDOWNLINK
530
fGW
fSAT
fUT
f

FIG. 5

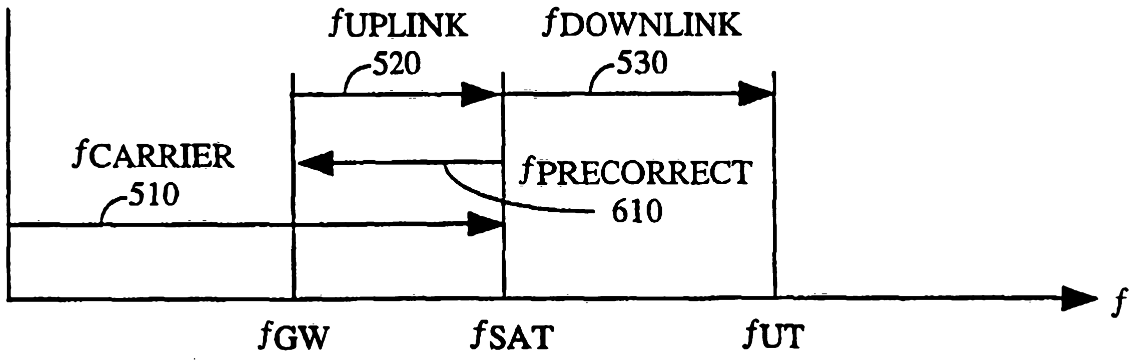
fUPLINK
520
fDOWNLINK
530
fCARRIER
510
fPRECORRECT
610
fGW
fSAT
fUT
f

FIG. 6

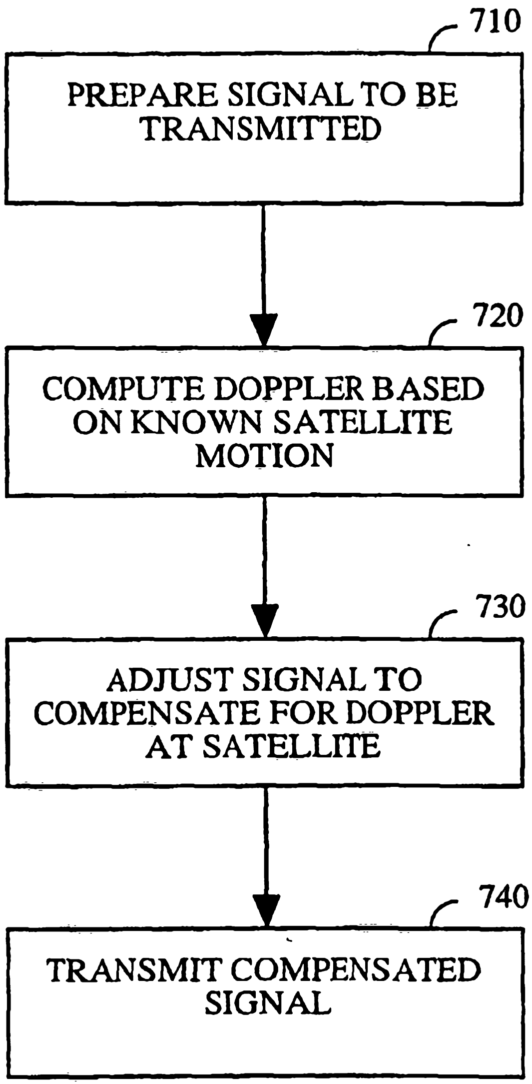
710
PREPARE SIGNAL TO BE TRANSMITTED
720
COMPUTE DOPPLER BASED ON KNOWN SATELLITE MOTION
730
ADJUST SIGNAL TO COMPENSATE FOR DOPPLER AT SATELLITE
740
TRANSMIT COMPENSATED SIGNAL

FIG. 7

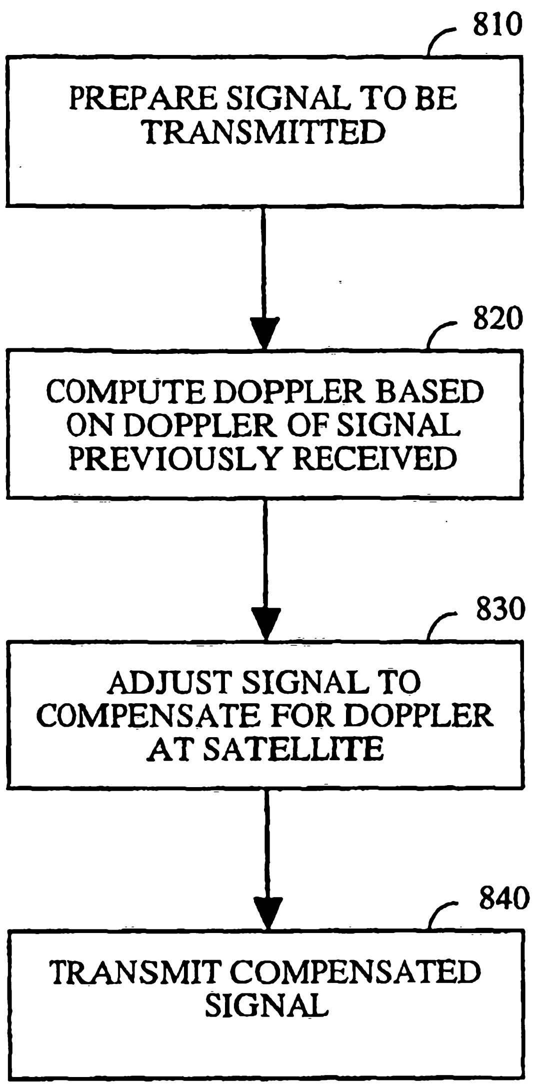
810
PREPARE SIGNAL TO BE TRANSMITTED
820
COMPUTE DOPPLER BASED ON DOPPLER OF SIGNAL PREVIOUSLY RECEIVED
830
ADJUST SIGNAL TO COMPENSATE FOR DOPPLER AT SATELLITE
840
TRANSMIT COMPENSATED SIGNAL

FIG. 8

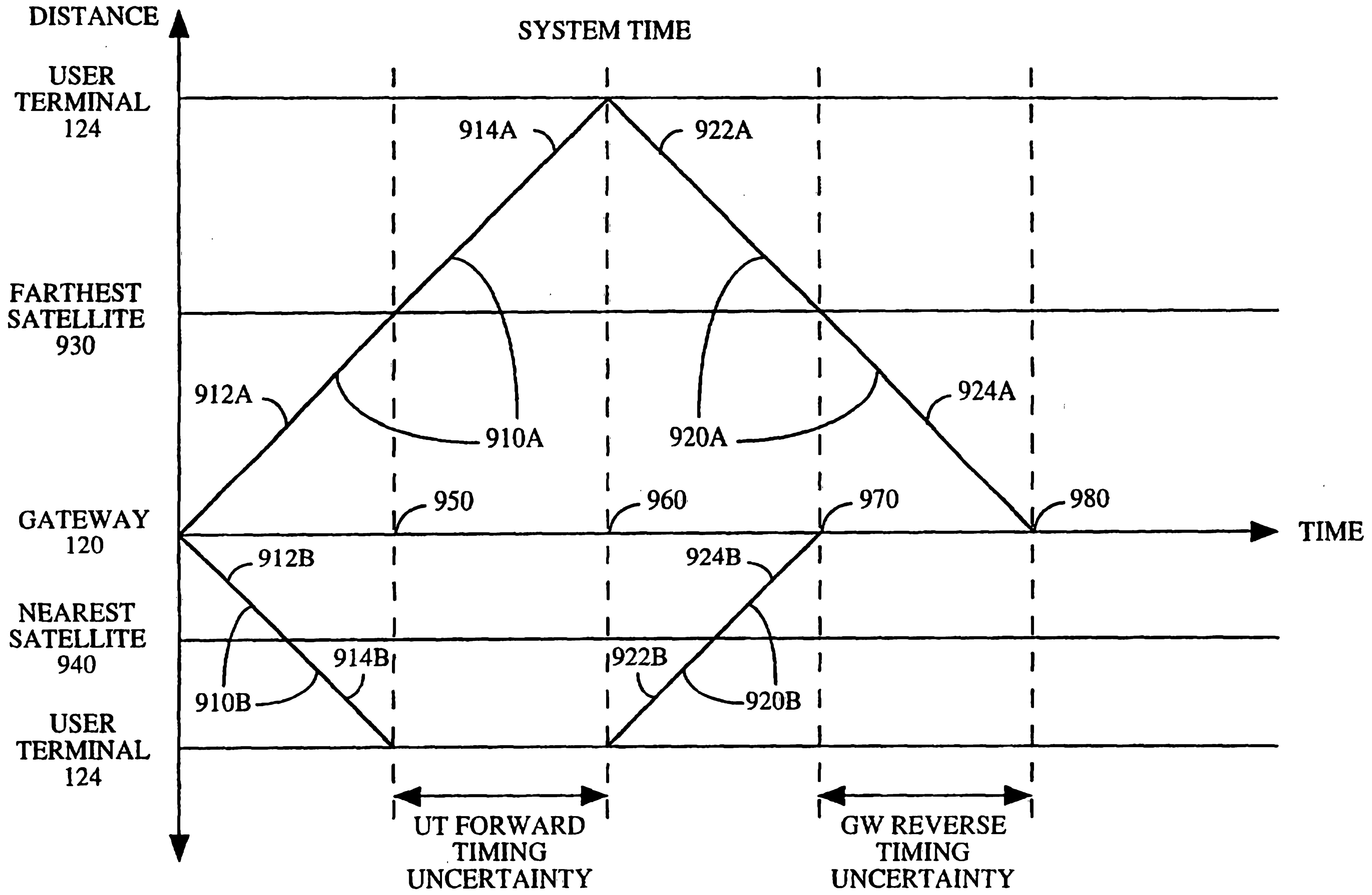
DISTANCE
SYSTEM TIME
USER TERMINAL 124
914A
922A
FARTHEST SATELLITE 930
912A
910A
920A
924A
950
960
970
980
GATEWAY 120
TIME
912B
924B
NEAREST SATELLITE 940
914B
922B
910B
920B
USER TERMINAL 124
UT FORWARD TIMING UNCERTAINTY
GW REVERSE TIMING UNCERTAINTY

FIG. 9

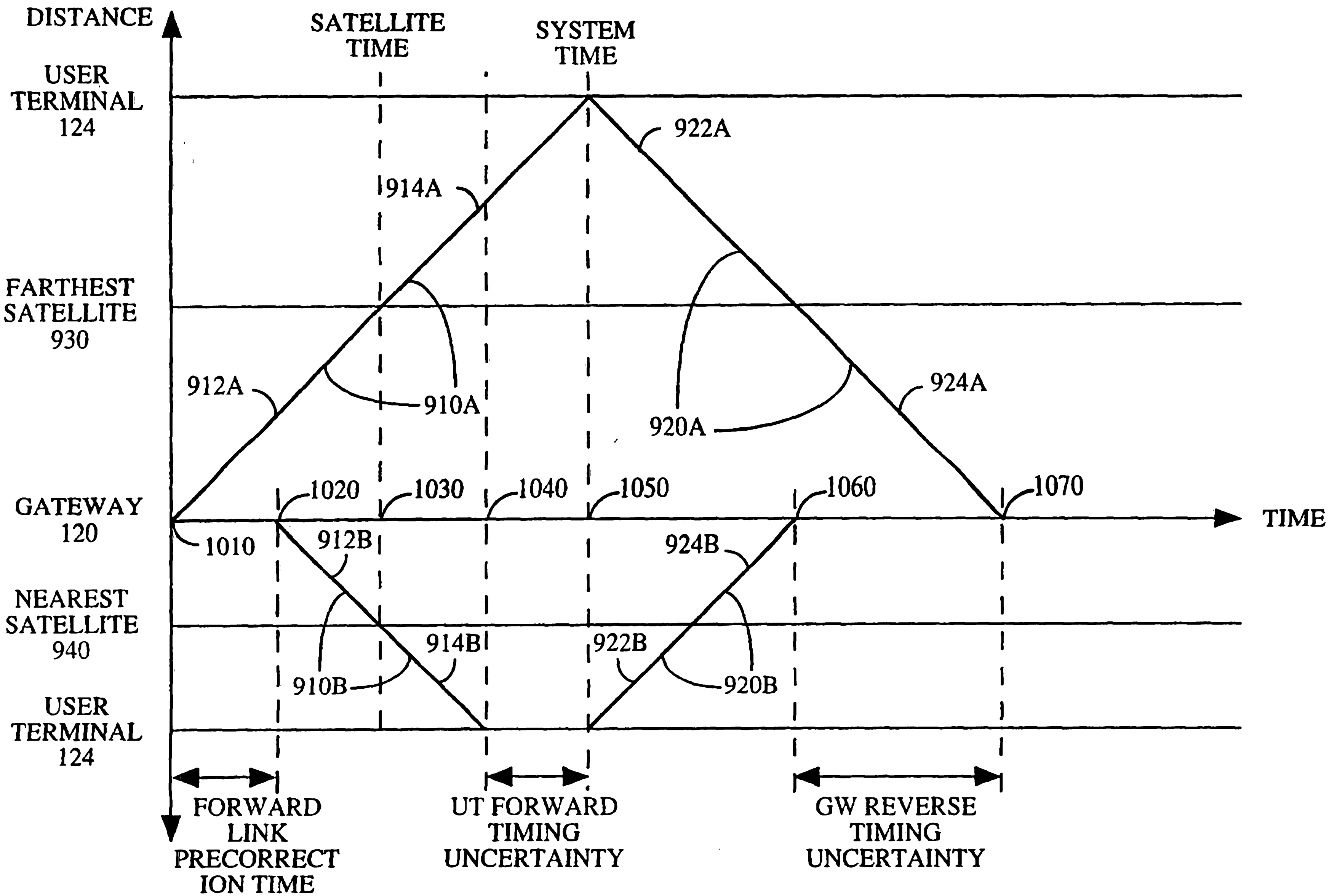
DISTANCE
SATELLITE TIME
SYSTEM TIME
USER TERMINAL 124
FARTHEST SATELLITE 930
GATEWAY 120
NEAREST SATELLITE 940
USER TERMINAL 124
TIME
914A
922A
912A
910A
920A
924A
1010
1020
1030
1040
1050
1060
1070
912B
924B
914B
922B
910B
920B
FORWARD LINK PRECORRECT ION TIME
UT FORWARD TIMING UNCERTAINTY
GW REVERSE TIMING UNCERTAINTY

FIG. 10

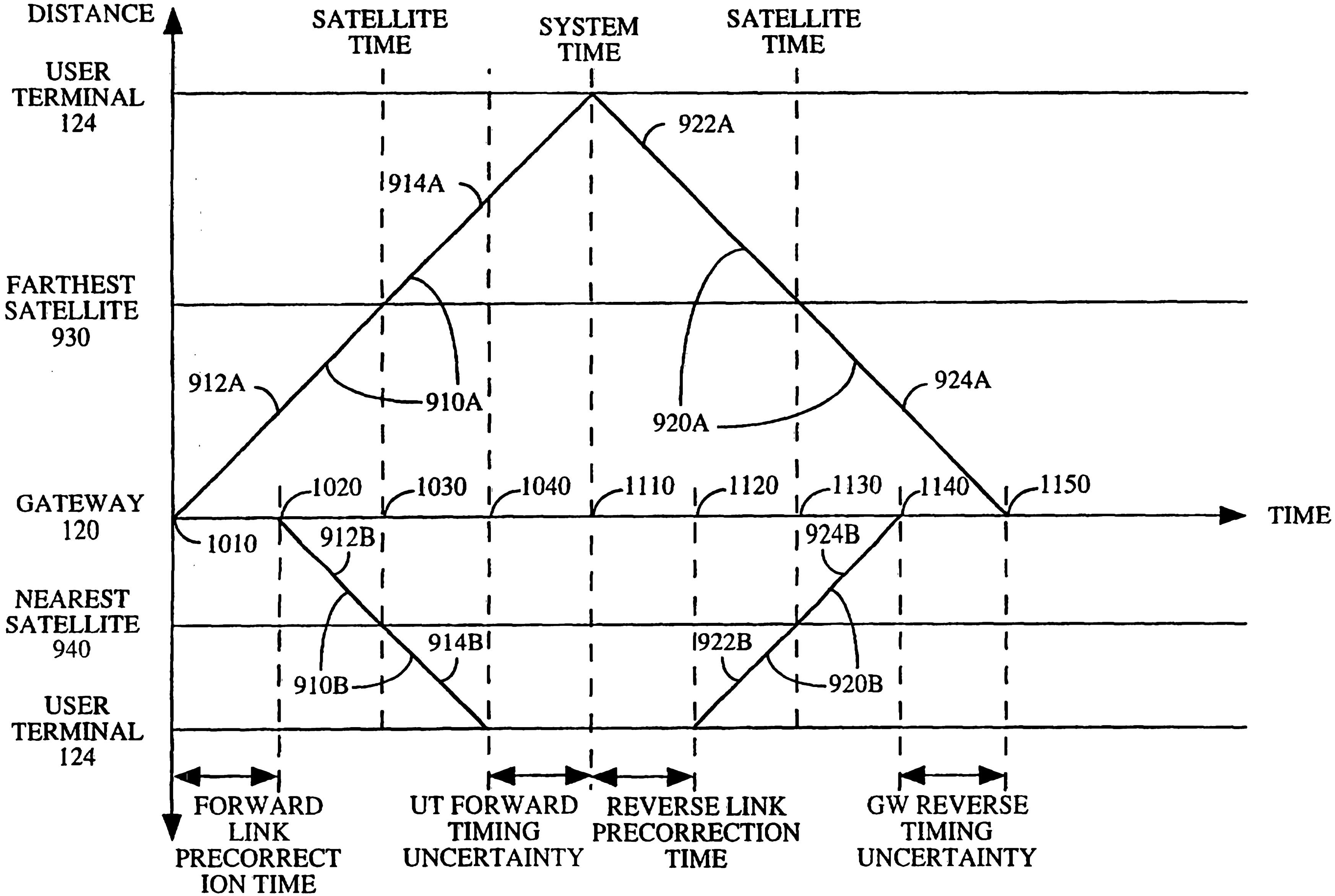
DISTANCE
USER TERMINAL 124
FARTHEST SATELLITE 930
GATEWAY 120
NEAREST SATELLITE 940
USER TERMINAL 124
SATELLITE TIME
SYSTEM TIME
SATELLITE TIME
TIME
914A
922A
912A
910A
920A
924A
1010
1020
1030
1040
1110
1120
1130
1140
1150
912B
924B
914B
922B
910B
920B
FORWARD LINK PRECORRECT ION TIME
UT FORWARD TIMING UNCERTAINTY
REVERSE LINK PRECORRECTION TIME
GW REVERSE TIMING UNCERTAINTY

FIG. 11

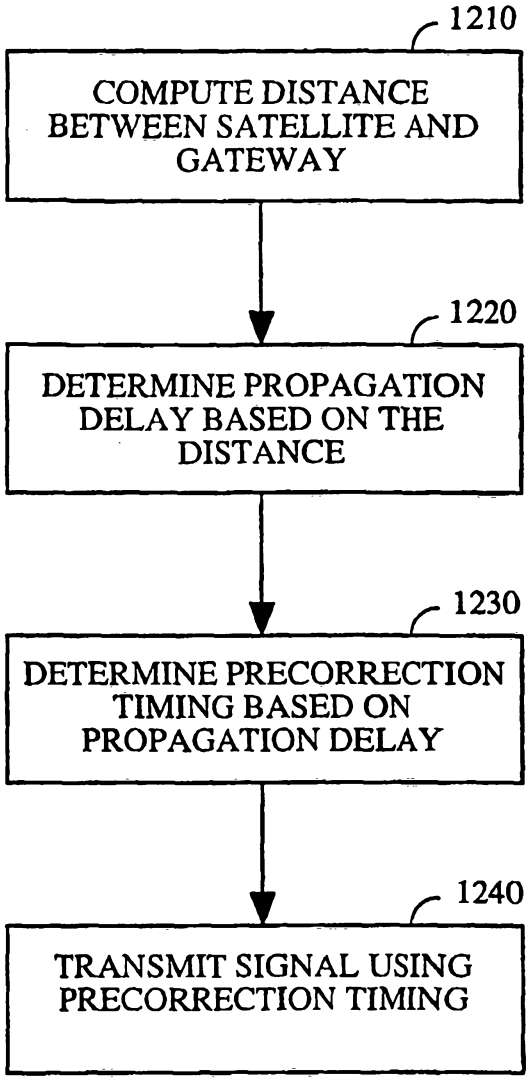
1210
COMPUTE DISTANCE BETWEEN SATELLITE AND GATEWAY
1220
DETERMINE PROPAGATION DELAY BASED ON THE DISTANCE
1230
DETERMINE PRECORRECTION TIMING BASED ON PROPAGATION DELAY
1240
TRANSMIT SIGNAL USING PRECORRECTION TIMING

FIG. 12

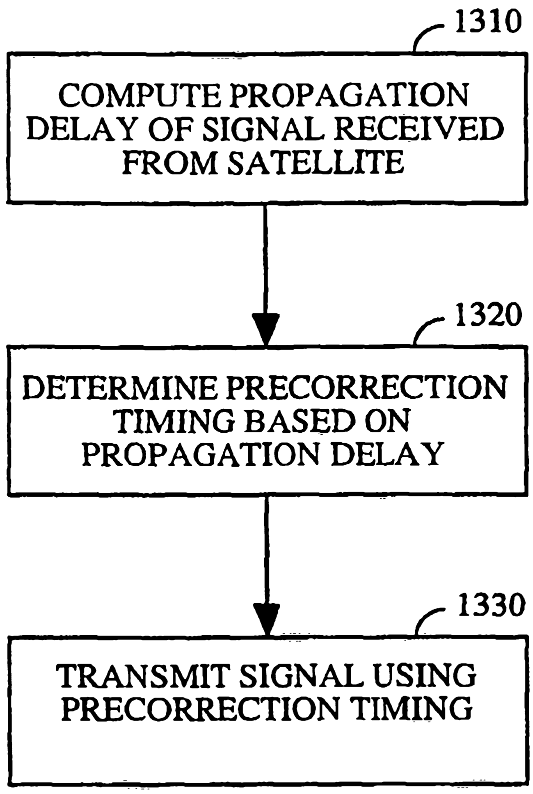
1310
COMPUTE PROPAGATION DELAY OF SIGNAL RECEIVED FROM SATELLITE
1320
DETERMINE PRECORRECTION TIMING BASED ON PROPAGATION DELAY
1330
TRANSMIT SIGNAL USING PRECORRECTION TIMING

FIG. 13