In a cellular telephone system a system for directing communications between a mobile user and cell-sites as a mobile user changes cell-site service areas. The mobile user includes an apparatus for, while in communication with another system user via one cell-site, determining a transition of the mobile user from the cell-site service area to the service area of another cell-site. The system includes circuitry responsive to the indication for coupling communications between the mobile user and the other system user via the new cell-site while the mobile user also remains in communication with the system user via the first cell-site. The system further includes apparatus responsive to the coupling of the communications between the mobile user and the other system user via the new cell-site for terminating the communications between the mobile user and another system user via cell-site with communications continuing between the mobile user and the system user via the new cell-site.
FIG. 4
METHOD AND SYSTEM FOR PROVIDING A SOFT HANDOFF IN COMMUNICATIONS IN A CDMA CELLULAR TELEPHONE SYSTEM

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates to cellular telephone systems. More specifically, the present invention relates to a novel and improved system for controlling handoff in communications of cell-site stations with a mobile unit in a code division multiple access (CDMA) cellular telephone system.

II. Description of the Related Art

The use of code division multiple access (CDMA) modulation techniques is but one of several techniques for facilitating communications in which a large number of system users are present. Although other techniques such as time division multiple access (TDMA), frequency division multiple access (FDMA) and AM modulation schemes such as amplitude companded single sideband (ACSSB) are known, CDMA has significant advantages over these other modulation techniques.

The use of CDMA techniques in a multiple access communication system is disclosed in U.S. patent application Ser. No. 06/921,261, filed Oct. 17, 1996, entitled "SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS", now U.S. Pat. No. 4,901,307 assigned to the Assignee of the present invention, the disclosure thereof incorporated by reference.

In the just mentioned patent, a multiple access technique is disclosed where a large number of mobile telephone system users, each having a transceiver, communicate through satellite repeaters or terrestrial base stations (also known as cell-site stations, or for short, cell-sites) using code division multiple access (CDMA) spread spectrum communication signals. In using CDMA communications, the frequency spectrum can be reused multiple times thus permitting an increase in system user capacity. The use of CDMA techniques results in a much higher spectral efficiency than can be achieved using other multiple access techniques.

In the conventional cellular telephone systems the available frequency band is divided into channels typically 30 KHz in bandwidth while analog FM modulation techniques are used. The system service area is divided geographically into cells of varying size. The available frequency channels are divided into sets with each set usually containing an equal number of channels. The frequency sets are assigned to cells in such a way as to minimize the possibility of co-channel interference. For example, consider a system in which there are seven frequency sets and the cells are equal size hexagons. A frequency set used in one cell will not be used in the six nearest or surrounding neighbors of that cell. Furthermore, the frequency set in one cell will not be used in the twelve nearest neighbors of that cell.

In the conventional cellular telephone system, the handoff scheme implemented is intended to allow a call to continue when a mobile telephone crosses the boundary between two cells. The handoff from one cell to another is initiated when the cell-site receiver handling the call notices that the received signal strength from the mobile telephone falls below a predetermined threshold value. A low signal strength indication implies that the mobile telephone must be near the cell border. When the signal level falls below the predetermined threshold value, the cell-site asks system controller to determine whether a neighboring cell-site receives the mobile telephone signal with better signal strength than the current cell-site.

The system controller in response to the current cell-site inquiry sends messages to the neighboring cell-sites with a handoff request. The cell-site neighboring the current cell-site employs special scanning receivers which look for the signal from the mobile unit on the specified channel. Should one of the neighboring cell-sites report an adequate signal level to the system controller, then a handoff will be attempted.

Handoff is then initiated when an idle channel from the channel set used in the new cell-site is selected. A control message is sent to the mobile telephone commanding it to switch from the current channel to the new channel. At the same time, the system controller switches the call from the first cell-site to the second cell-site.

In the conventional system a call will be discontinued if the handoff to the new cell-site is unsuccessful. There are many reasons that a failure in handoff may occur. Handoff can fail if there is no idle channel available in the neighboring cell for communicating the call. Handoff can also fail if another cell-site reports hearing the mobile telephone in question, when in fact this cell-site actually hears a different mobile unit using the same channel in a completely different cell. This reporting error will result in the call being switched to a wrong cell, typically one in which signal strength is insufficient to maintain communications. Furthermore should the mobile telephone fail to hear the command to switch channels, the handoff will fail. Actual operating experience indicates that handoff failures occur frequently which questions the reliability of the system.

Another common problem in the conventional telephone system occurs when the mobile telephone is near the border between two cells. In this situation the signal level tends to fluctuate at both cell-sites. This signal level fluctuation results in a ping-ponging situation in which repeated requests are made to hand the call back and forth between the two cell-sites. Such additional unnecessary handoff requests increase the possibility of the mobile unit incorrectly hearing the channel switch command or fail in hearing the command at all. Furthermore, the ping-ponging situation raises the possibility that the call will be discontinued if it is unnecessarily transferred to a cell in which all channels are currently in use and thus unavailable for accepting the handoff.

It is therefore an object of the present invention to provide in a cellular telephone system improvements in call handoff between cell-sites and thus provide greater service reliability.

SUMMARY OF THE INVENTION

In a CDMA cellular telephone system, the same frequency band is used for all cells. The CDMA waveform properties that provide processing gain are also used to discriminate between signals that occupy the same frequency band. A mobile telephone or unit thus need not switch frequencies when handoff of the call is made from one cell-site to another. Furthermore, the probability that the call will be discontinued if the handoff command is received in error is substantially reduced.

In a CDMA cellular telephone system, each cell-site has a plurality of modulator-demodulator units or
spread spectrum modems. Each modem consists of a digital spread spectrum transmit modulator, at least one digital spread spectrum data receiver and a searcher receiver. Each modem at the cell-site is assigned to a mobile unit as needed to facilitate communications with the assigned mobile unit. Therefore in many instances many modems are available for use while other ones may be active in communicating with respective mobile units. In the present invention a handoff scheme is employed for a CDMA cellular telephone system in which a new cell-site modem is assigned to a mobile unit while the old cell-site continues to service the call. When the mobile unit is located in the transition region between the two cell-sites, the call can be switched back and forth between cell-sites as signal strength dictates. Since the mobile unit is always communicating through at least one cell-site, no disrupting effects to the mobile unit or in service will occur.

When mobile unit communications are firmly established with the new cell-site, e.g. the mobile unit is well within the new cell, the old cell-site continues servicing the call. The just described handoff techniques can be considered as a "soft" handoff in communications between cell-sites with the mobile unit. The soft handoff is in essence a make-before-break switching function. In contrast, conventional cellular telephone systems can be considered as providing a break-before-make switching function.

In a CDMA cellular telephone system of the present invention, a soft handoff technique is implemented which also permits the mobile unit to initiate a handoff. The mobile unit is also permitted to determine the best new cell-site to which communications are to be transferred from an old cell-site. Although it is preferred that the mobile unit initiate the handoff request and determine the new cell-site, handoff process decisions may be made as in the conventional cellular telephone system. As discussed previously with respect to conventional systems, the cell-site determines when a handoff may be appropriate and, via the system controller, request neighboring cells to search for the mobile unit signal. The cell-site receiving the strongest signal as determined by the system controller then accepts the handoff.

In the CDMA cellular telephone system, each cell-site transmits a "pilot carrier" signal. This pilot signal is used by the mobile units to obtain initial system synchronization and to provide robust time, frequency and phase tracking of the cell-site transmitted signals.

Each cell-site also transmits a "setup" channel comprised of spread spectrum modulated information, such as cell-site identification, system timing, mobile paging information and various other control signals. The pilot signal transmitted by each cell-site is of the same spreading code but with a different code phase offset. Phase offset allows the pilot signals to be distinguished from one another resulting in distinguishment between cell-sites from which they originate. Use of the same pilot signal code allows the mobile unit to find system timing synchronization by a single search through all pilot signal code phases. The strongest pilot signal, as determined by a correlation process for each code phase, is readily identifiable. The identified pilot signal corresponds to the pilot signal transmitted by the nearest cell-site.

Upon acquisition of the strongest pilot signal, i.e. initial synchronization of the mobile unit with the strongest pilot signal, the mobile unit searches for the appropriate setup channel of that cell-site. The setup channel is transmitted by the cell-site using one of a plurality of different predetermined spread spectrum codes. In an exemplary embodiment of the present invention, twenty-one different codes are used. However, it should be understood that more or less codes could be used in the setup channel as determined by system parameters. The mobile unit then begins a search through all of the different codes used in the setup channel.

When the mobile unit identifies the appropriate setup code for that cell-site, system information is received and processed. The mobile unit further monitors the setup channel for control messages. One such control message would indicate a call is waiting for transfer to this mobile unit.

The mobile unit continues to scan the received pilot carrier signal code at the code offsets corresponding to neighboring cell-site transmitted pilot signals. This scanning is done in order to determine if the pilot signal emanating from neighboring cells is becoming stronger than the pilot signal first determined to be strongest. If, while in this call inactive mode, a neighbor cell-site pilot signal becomes stronger than that of the initial cell-site transmitted pilot signal, the mobile unit will acquire the stronger pilot signal and corresponding setup channel of the new cell-site.

When a call is initiated, a pseudonoise (PN) code address is determined for use during the course of this call. The code address may be either assigned by the cell-site or be determined by prearrangement based upon the identity of the mobile unit. After a call is initiated the mobile unit continues to scan the pilot signal transmitted by cell-sites located in neighboring cells. Pilot signal scanning continues in order to determine if one of the neighboring cell-site transmitted pilot signals becomes stronger than the pilot signal transmitted by the cell-site the mobile unit is in communication with. When the pilot signal transmitted by a cell-site located in a neighboring cell becomes stronger than the pilot signal transmitted by a cell-site in the current cell, it is an indication to the mobile unit that a new cell has been entered and that a handoff should be initiated. In response to this pilot signal strength determination, the mobile unit generates and transmits a control message to the cell-site presently servicing the call. This control message, indicative that a new cell-site transmitted pilot signal is now stronger than the current cell-site transmitted pilot signal, is provided to the system controller. The control message further contains information identifying the new cell-site and PN code. The control message as relayed to the system controller is interpreted that a handoff in mobile unit communications to the identified new cell-site is to begin.

The system controller now begins the handoff process. It should be understood that during handoff the PN code address of the particular mobile unit which is to undergo the handoff process need not change. The system controller begins the handoff by assisting in the assignment of a modem located in the new cell-site to the call. This modem is given the PN address associated with the call in communications between the mobile unit and the current cell-site modem. The new cell-site modem assigned to service the call searches for and receives the mobile unit transmitted signal. The cell-site modem also begins transmitting an outbound signal to the mobile unit. The mobile unit searches for this outbound signal in accordance with the signal and setup channel information provided by the new cell-site.
When the new cell-site modem transmitted signal is acquired, the mobile unit switches over to listening to this signal. The mobile unit then transmits a control message indicating that handoff is complete. The control message is provided by either or both of the old and new cell-site modems to the system controller. In response to this control message the system controller switches the call over to the new cell-site modem alone while discontinuing the call through the old cell-site modem. The old cell-site modem then enters a pool of idle modems available for reassignment.

As an additional improvement, the handoff process can introduce a second mode of operation. This second mode is referred to herein as the cell-site diversity mode. The subject matter on the cell-site diversity mode is further disclosed in copending U.S. patent application entitled "DIVERSITY RECEIVER IN A CDMA CELLULAR TELEPHONE SYSTEM", Ser. No. 07/432,552, filed Nov. 7, 1989, by the inventors hereof and assigned to the Assignee of the present invention.

In the cell-site diversity mode the call is allowed to linger in the in-between state as described above with reference to the call being processed by two cell-sites. In the exemplary embodiment described herein with reference to the mobile telephone of the present invention, a total of three demodulator processors or receivers are utilized. One of the receivers is used for the scanning function, while the two other receivers are used as a two channel diversity receiver. During operation in a single cell, the scanning receiver attempts to find the cell-site transmitted signal travelling upon multiple paths to the mobile unit. These multipath signals are typically caused by reflections of the signals from terrain, buildings and other signals obstructions. When two or more such reflections are found, the two receivers are assigned to the two strongest paths. The scanning receiver continues to evaluate the multiple paths to keep the two receivers synchronized with signals on the two strongest paths as path conditions change.

In the cell-site diversity mode, the strongest two paths from each cell-site is determined by the search receiver. The two receivers are assigned to demodulate the signals on the strongest two paths of the four paths available from the original cell-site and from the new cell-site. The data demodulation process uses information from both of these receivers in a diversity combining operation. The result of this diversity combining operation is a greatly improved resistance to deleterious fading that may occur in the multi-path cellular telephone environment.

Although different types of diversity combining techniques are known in the art, the present invention uses diversity combining to significantly advance the quality and reliability of communications in a mobile cellular telephone system. In the present invention a form of maximal ratio combining is utilized. The signal-to-noise ratio is determined for both paths being combined with the contributions from the two paths weighted accordingly. Combining is coherent since pilot signal demodulation allows the phase of each path to be determined.

In the path from the mobile unit to the two cell-sites, path diversity reception is also obtained by having both cell-sites demodulate the mobile unit transmitted signals. Both cell-sites forward their demodulated data signals to the system controller along with an indication of signal quality for each cell-site receiver. The system controller then combines the two versions of the mobile unit signal and selects the signal with the best quality indication. It should be understood that it is possible to transmit the undecoded or even the undemodulated signals to the system controller in order to allow a better diversity combining process to be utilized.

The handoff process in the cell diversity mode is initiated as previously discussed. The mobile unit determines that a neighboring cell-site transmitted signal is of a signal strength great enough to allow good quality demodulation of the signal. The mobile unit transmits a control message to the current cell-site indicating the identity of this new cell-site and a request for the cell diversity mode. The cell-site then relays the cell-site identity and request to the system controller.

The system controller responds by connecting the call to a modem in the new cell-site. The system controller then performs diversity combining of the signals received by the two cell-sites while the mobile unit performs diversity combining of the signals received from the two cell-sites. The cell diversity mode continues as long as signals received from both cell-sites are of a level sufficient to permit good quality demodulation.

The mobile unit continues to search for signals transmitted from other cell-sites. If a third cell-site transmitted signal becomes stronger than one of the original two cell-site signals, the control message is then transmitted by the mobile unit via at least one current cell-site to the system controller. The control message indicates the identity of this cell-site and a request for handoff. The system controller then discontinues the call being communicated via the weakest cell-site signal of the three while providing the call through the two strongest cell-sites. Should the mobile units be equipped with additional receivers, such as three receivers, a triple cell-site-diversity mode may be implemented.

The cell-site diversity mode is terminated when the mobile unit determines that only one cell-site is providing adequate signals for quality demodulation. The mobile unit then sends a control message indicative of the cell-site to remain in communication upon termination of the cell-site diversity mode. The cell-site diversity mode may also be terminated by the system controller if the system were to become overloaded with an insufficient number of modems available to support all mobile unit requests for this mode of operation. The cell-site diversity mode as discussed is implemented by decision being made at the mobile unit to operate in the cell-site diversity mode. However, it should be understood that the cell-site diversity mode can be implemented with the decisions for operation in this mode being made at the system controller.

The present invention provides a substantial improvement over present cellular telephone systems with respect to mobile unit handoff. The make-before-break handoff mechanism of the present invention is a significant improvement in overall system reliability with lower service disruption. The implementation of a cell-site diversity mode provides further improvements over conventional cellular telephone systems by providing additional system reliability and quality in communications.

BRIEF DESCRIPTION OF THE DRAWINGS

The features 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 correspond throughout and wherein:
FIG. 1 is a schematic overview of an exemplary CDMA cellular telephone system in accordance with the present invention;

FIG. 2 is a block diagram of a mobile unit telephone configured for CDMA communications in a CDMA cellular telephone system;

FIG. 3 is a block diagram of a cell-site equipment in a CDMA cellular telephone system; and

FIG. 4 is a block diagram of a mobile telephone switching office equipment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An exemplary telephone system in which the present invention is embodied is illustrated in FIG. 1. The system illustrated in FIG. 1 utilizes CDMA modulation techniques in communication between the system mobile units or mobile telephones, and the cell-sites. Cellular systems in large cities may have hundreds of cell-site stations serving hundreds of thousands of mobile telephones. The use of CDMA techniques readily facilitates increases in user capacity in systems of this size as compared to conventional FM modulation cellular systems.

In FIG. 1, system controller and switch 10, also referred to as mobile telephone switching office (MTSO), typically includes interface and processing circuitry for providing system control to the cell-sites. Controller 10 also controls the routing of telephone calls from the public switched telephone network (PSTN) to the appropriate cell-site for transmission to the appropriate mobile unit. Controller 10 also controls the routing of calls from the mobile units, via at least one cell-site to the PSTN. Controller 10 may direct calls between mobile users via the appropriate cell-site stations since such mobile units do not typically communicate directly with one another.

Controller 10 may be coupled to the cell-sites by various means such as dedicated telephone lines, optical fiber links or by microwave communication links. In FIG. 1, three such exemplary cell-sites, 12, 14 and 16 along with an exemplary mobile unit 18, which includes a cellular telephone, are illustrated. Arrows 20a-20b define the possible communication link between cell-site 12 and mobile unit 18. Arrows 22a-22b define the possible communication link between cell-site 14 and mobile unit 18. Similarly, arrows 24a-24b define the possible communication link between cell-site 16 and mobile unit 18.

The cell-site service areas or cells are designed in geographic shapes such that the mobile unit will normally be closest to one cell-site. When the mobile unit is idle, i.e., no calls in progress, the mobile unit constantly monitors the pilot signal transmissions from each nearby cell-site. As illustrated in FIG. 1 the pilot signals are respectively transmitted to mobile unit 18 by cell-sites 12, 14 and 16 respectively upon communication links 20b, 22b and 24b. The mobile unit then determines which cell it is in by comparing pilot signal strength transmitted from these particular cell-sites.

In the example illustrated in FIG. 1, mobile unit 18 may be considered closest to cell-site 16. When mobile unit 18 initiates a call, a control message is transmitted to the nearest cell-site, cell-site 16. Cell-site 16 upon receiving the call request message, signals system controller 10 and transfers the call number. System controller 10 then connects the call through the PSTN to the intended recipient.

Should a call be initiated within the PSTN, controller 10 transmits the call information to all the cell-sites in the area. The cell-sites in return transmit a paging message to the intended recipient mobile unit. When the mobile unit hears a page message, it responds with a control message that is transmitted to the nearest cell-site. This control message signals the system controller that this particular cell-site is in communication with the mobile unit. Controller 10 then routes the call through this cell-site to the mobile unit.

Should mobile unit 18 move out of the coverage area of the initial cell-site, cell-site 16, an attempt is made to continue the call by routing the call through another cell-site. In the handoff process there are two different methods of initiating the handoff of the call or routing through another cell-site.

The first method, called the cell-site initiated handoff, is similar to the handoff method employed in the original first generation analog cellular telephone systems currently in use. In the cell-site initiated handoff method, the initial cell-site, cell-site 16, notices that the signal transmitted by mobile unit 18 has fallen below a certain threshold level. Cell-site 16 then transmits a handoff request to system controller 10. Controller 10 relays the request to all neighboring cell-sites, 14, 12 of cell-site 16. The controller transmitted request includes information relating to the channel, including the PN code sequence used by mobile unit 18. Cell-sites 12 and 14 tune a receiver to the channel being used by the mobile unit and measure the signal strength, typically using digital techniques. If one of cell-sites 12 and 14 receives a stronger signal than the initial cell-site reported signal strength, then a handoff is made to this cell-site.

The second method of initiating a handoff is called the mobile initiated handoff. The mobile unit is equipped with a search receiver which is used to scan the pilot signal transmission of neighboring cell-sites 12 and 14, in addition to performing other functions. If a pilot signal of cell-sites 12 and 14 is found to be stronger than the pilot signal of cell-site 16, mobile unit 18 transmits a control message to the current cell-site, cell-site 16. This control message contains information identifying the cell-site of greater signal strength in addition to information requesting a handoff to this cell-site. Cell-site 16 transfers this control message to controller 10.

The mobile initiated handoff method has various advantages over the cell-site initiated handoff method. The mobile unit becomes aware of changes in paths between itself and the various neighboring cell-sites much sooner and with less effort than the cell-sites are capable of doing. However, to perform a mobile initiated handoff each mobile unit must be provided with a searching receiver to perform the scanning function. However, in the exemplary embodiment described herein of a mobile unit CDMA communications capability, the search receiver has additional functions which require its presence.

FIG. 2 illustrates in block diagram form an exemplary mobile unit. The mobile unit includes an antenna 30 which is coupled through diplexer 32 to analog receiver 34 and transmit power amplifier 36. Antenna 30 and diplexer 32 are of standard design and permit simultaneous transmission and reception through a single antenna. Antenna 30 collects transmitted signals and provides them through diplexer 32 to analog receiver 34. Receiver 34 receives the RF frequency signals from diplexer 32 which are typically in the 850 MHz fre-
quency band for amplification and frequency downconversion to an IF frequency. This frequency translation process is accomplished using a frequency synthesizer of standard design which permits the receiver to be tuned to any of the frequencies within the receive frequency band of the overall cellular telephone frequency band.

The IF signal is then passed through a surface acoustic wave (SAW) bandpass filter which in the preferred embodiment is approximately 1.25 MHz in bandwidth. The characteristics of the SAW filter are chosen to match the waveform of the signal transmitted by the cell-site which has been direct sequence spread spectrum modulated by a PN sequence clocked at a predetermined rate, which in the preferred embodiment is 1.25 MHz. This clock rate is chosen to be an integer multiple of a number of common data rates such as 16 Kbps, 9.6 Kbps, and 4.8 Kbps.

Receiver 44 also performs a power control function for adjusting the transmit power of the mobile unit. Receiver 44 generates an analog power control signal that is provided to transmit power control circuitry 38. The control and operation of the mobile unit power control feature is disclosed in a pending U.S. patent application entitled "METHOD AND APPARATUS FOR CONTROLLING TRANSMISSION POWER IN A CDMA CELLULAR MOBILE TELEPHONE SYSTEM", Ser. No. 07/433,031, filed Nov. 7, 1989, now U.S. Pat. No. 5,056,019, by the inventors hereof assigned to the Assignee of the present invention.

Receiver 34 is also provided with an analog to digital (A/D) converter (not shown) for converting the IF signal to a digital signal with conversion occurring at a 9.216 MHz clock rate in the preferred embodiment which is exactly eight times the PN chip rate. The digitized signal is provided to each of two or more signal processors or data receivers, one of which is a searcher receiver with the remainder being data receivers.

In FIG. 2, the digitized signal output from receiver 34 is provided to digital data receivers 40 and 42 and to a searcher receiver 44. It should be understood that an inexpensive, low performance mobile unit might have only a single data receiver while higher performance units may have two or more to allow diversity reception.

The digitized IF signal may contain the signals of many on-going calls together with the pilot carriers transmitted by the current and all neighboring cell-sites. The function of the receivers 40 and 42 are to correlate the IF samples with the proper PN sequence. This correlation process provides a property that is well-known in the art as "processing gain" which enhances the signal-to-interference ratio of a signal matching the proper PN sequence while not enhancing other signals. Correlation output is then synchronously detected using the pilot carrier from the closest cell-site as a carrier phase reference. The result of this detection process is a sequence of encoded data symbols.

A property of the PN sequence as used in the present invention is that discrimination is provided against multi-path signals. When the signal arrives at the mobile receiver after travelling upon more than one path there will be a difference in the reception time of each multi-path propagation of the signal. This reception time difference corresponds to the difference in distance divided by the speed of light. If this time difference exceeds one microsecond, then the correlation process will discriminate against one of the paths. The receiver can choose whether to track and receive the earlier or later path. If two receivers are provided, such as receivers 40 and 42, then two independent paths can be tracked and in parallel.

Searcher receiver 44, under control of control processor 46 is for continuously scanning the time domain, around the nominal time of a received pilot signal of the cell-site, for other multi-path pilot signals from the same cell-site and for other cell-site transmitted pilot signals. Receiver 44 will measure the strength of any reception of a desired waveform at times other than the nominal time. Receiver 44 compares signal strength in the received signals. Receiver 44 provides a signal strength signal to control processor 46 indicative of the strongest signals.

Processor 46 provides control signals to digital data receivers 40 and 42 for each to process a different one of the strongest signals. On occasion another cell-site transmitted pilot signal is of greater signal strength than the current cell-site signal strength. Control processor 46 then would generate a control message for transmission to the system controller via the current cell-site requesting a transfer of the call, to the cell-site corresponding to the stronger pilot signal. Receivers 40 and 42 may therefore handle calls through two different cell-sites.

The outputs of receivers 40 and 42 are provided to a diversity combiner and decoder circuitry 48. The diversity combiner circuitry contained within circuitry 48 simply adjusts the timing of the two streams of received signals into alignment and adds them together. This addition process may be proceeded by multiplying the two streams by a number corresponding to the relative signal strengths of the two streams. This operation can be considered a maximal ratio diversity combiner. The resulting combined signal stream is then decoded using a forward stream error detection decoder also contained within circuitry 48.

In the exemplary embodiment convolutional encoding is utilized. The convolutional encoding has a constraint length 9 and a code rate 1 3, i.e. three encoded symbols are produced and transmitted for every information bit to be transmitted. The optimum decoder for this type of code is of the soft decision Viterbi algorithm decoder design. The resulting decoded information bits are passed to the user digital baseband circuitry 50.

Baseband circuitry 50 typically includes a digital vocoder (not shown). Baseband circuitry 50 further serves as an interface with a handset or any other type of peripheral device. Baseband circuitry 50 accommodates a variety of different vocoder designs. Baseband circuitry 50 provides output information signals to the user in accordance with the information provided thereto from circuitry 48.

User analog voice signals typically provided through a handset are provided as an input to baseband circuitry 50. Baseband circuitry 50 includes an analog to digital (A/D) converter (not shown) which converts the analog signal to digital form. The digital signal is provided to the digital vocoder where it is encoded. The vocoder output is provided to a forward error correction encoding circuit (not shown) for error correction. This voice digitized encoded signal is output from baseband circuitry 50 to transmit modulator 52.

Transmit modulator 52 modulates the encoded signal on a PN carrier signal whose PN sequence is chosen according to the assigned address function for the call. The PN sequence is determined by control processor 46.
from call setup information that is transmitted by the cell-site and decoded receivers 40 and 42. In the alternative, control processor 46 may determine the PN sequence through pre-arrangement with the cell-site. Control processor 46 provides the PN sequence information to transmit modulator 52 and to receivers 40 and 42 for call decoding.

The output of transmit modulator 52 is provided to transmit power control circuitry 38. Signal transmission power is controlled by the analog power control signal provided from receiver 34. Furthermore, control bits are transmitted by the cell-sites in the form power adjustment commands which are processed by data receivers 40 and 42. The power adjustment command is used by control processor 46 in setting the power level in mobile unit transmission. In response to power control commands control processor 46 generates a digital power control signal that is provided to circuitry 38. Further information on the interrelationship of the receivers 40 and 42, control processor 46 and transmit power control 38 are also further described in the above-mentioned copending patent application.

The output of transmit modulator 52 is amplified by power amplifier circuitry 36. Circuitry 36 amplifies and converts the IF signal to an RF frequency by mixing with a frequency synthesizer output signal which tunes the signal to the proper output frequency. Circuitry 36 includes an amplifier which amplifies the power to a final output level. The intended transmission signal is output from circuitry 36 to diplexer 32. Diplexer 32 couples the signal to antenna 30 for transmission to the cell-sites.

Control processor 46 is also capable of generating control messages such as cell-diversity mode requests and cell-site communication termination commands. These commands are provided to transmit modulator 52 for transmission. Control processor 46 is responsive to the data received from data receivers 40, 42 and search receiver 44 for making decisions relative to handoff and diversity combining.

FIG. 3 illustrates in block diagram form an exemplary embodiment of the cell-site equipment. At the cell-site, two receiver systems are utilized with each having a separate antenna and analog receiver for space diversity reception. In each of the receiver systems the signals are processed identically until the signals undergo a diversity combination process. The elements within the dashed lines correspond to elements corresponding to the communications between the cell-site and one mobile unit. The output of the analog receivers are also provided to other elements used in communications with other mobile units.

In FIG. 3, the first receiver system is comprised of antenna 60, analog receiver 62, search receiver 64 and digital data receiver 66. This receiver system may also include an optional digital data receiver 68. The second receiver system includes antenna 70, analog receiver 72, search receiver 64 and digital data receiver 66. Also utilized in signal processing and control for handoff and diversity is cell-site control processor 78. Both receiver systems are coupled to diversity combiner and decoder circuitry 80. Digital link 82 is utilized to communicate signals to and from the MTSO (FIG. 4) with cell-site transmit modulator 84 and circuitry 80 under the control of control processor 78.

Signals received on antenna 60 are provided to analog receiver 62. Received signals amplified by an ampli-
than one cell-site with nominally the same information. closed herein.

or more cell-sites to diversity combiner 104 or the cor-

signal from one cell-site may be of better quality than

inbound link from the mobile unit to the cell-sites, the 1. In a cellular telephone system in which a mobile

is in the handoff process with the call processed by two bodiment herein, but is to be accorded the widest scope

ates teardown on loss of signal. The cell-site communi-

ates for assignment of digital data receivers and modulators

service area. the vocoders at the MTSO. Furthermore, system con-

The output from circuitry 88 is provided to antenna 92 40

transmit-modulators at the cell-site. Circuitry 88 further

puts of transmit modulator 84 with the output of other 30

provides to transmit power control circuitry 86 where 25

the data for transmission to the intended recipient mo-

spectrum modulates, according to a predetermined

spread function as assigned by control processor 78,

transmit modulator 84 spread spectrum modulates, according to a predetermined

signals are transmitted from vocoder 106 to digital

A multiplicity of serial coupled diversity combiners and vocoders are provided in parallel, nominally, one for each call to be processed. Diversity combiner 104 compares the signal quality indicators accompanying the information bits from the two or more cell-site sig-

Diversity combiner 104 selects the bits corre-

frame-by-frame basis of the information for output to

Vocoder 106 converts the format of the digitized

voice signal to standard 64 Kbps PCM telephone for-

any other standard format. The resultant signals are transmitted from vocoder 106 to digital

Vocoder 106 converts the format of the digitized
diversity combiner as determined by a signal

responding diversity combiner as determined by a sig-

from system control processor 100. When the sys-

system is not in the cell-diversity mode, diversity combiner

may be either bypassed or fed the same information

on each input port.

Voice signals coming from the PSTN intended for

the mobile unit are provided to digital switch 108. Under the control of system control proces-

sor 100, the call is routed to the PSTN.

Digital switch 102 under system control processor control directs the encoded data to the cell-

if the mobile unit is in a handoff mode communicat-

ing to multiple cell-sites or in a cell diversity mode,

digital switch 102 routes the calls to the appropriate cell-sites for transmission by the appropriate cell-site

transmitter to the intended recipient mobile unit. How-

ever, if the mobile unit is communicating with only a single cell-site or not in a cell diversity mode, the signal

is directed only to a single cell-site.

System control processor 100 provides control over
digital switches 102 and 108 for routing data to and from the MTSO. System control processor 100 also
determines the assignment of calls to the cell-sites and to the vocoders at the MTSO. Furthermore, system con-
trol processor 100 communicates with each cell-site control processor about the assignment of particular calls between the MTSO and cell-site, and the assign-

ment of PN codes for the calls. It should be further understood that as illustrated in FIG. 4 digital switches

102 and 108 are illustrated as two separate switches, however, this function may be performed by a single

physical switching unit.

The previous description of the preferred embodi-

ments are provided to enable any person skilled in the

art to make or use the present invention. Various modifi-
cations 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 pre-

sent invention is not intended to be limited to the em-

bodiment herein, but is to be accorded the widest scope
consistent with the principles as novel features dis-

closed herein.

We claim:

1. In a cellular telephone system in which a mobile

system user and another system user communicate user

information signals therebetween via at least one of a

plurality of geographically separated cell-sites each
defining a respective geographic service area, a system

for directing communications between said mobile sys-
means for, while said mobile system user is in a service
area of one cell-site and communicating user
information signals with another system user via
said cell-site, determining a transition of said
mobile system user from said one cell-site service
area to a service area of another cell-site, and
for providing a handoff request identifying said
transition.

1. The system of claim 1 wherein each cell-site transmits
a pilot signal indicative of said transmitting cell-site,
said means for determining comprising:
scanning receiver means located at said mobile sys-
tem user and said another system user via said at least
one of said plurality of cell-sites as said mobile system
user changes cell-site service areas, comprising:
means for, while said mobile system user is in a ser-
vice area of one cell-site and communicating user
information signals with another system user via
said cell-site, determining a transition of said
mobile system user from said one cell-site service
area to a service area of another cell-site, and
for providing a handoff request identifying said
transition.

2. The system of claim 1 wherein each cell-site transmits
a pilot signal indicative of said transmitting cell-site,
said means for determining comprising:
scanning receiver means located at said mobile sys-
tem user for when said mobile system user is in a
transition from said one cell-site service area to said
another cell-site service area, receiving said cell-site
transmitted pilot signals, measuring signal
strength of each received pilot signal, comparing
pilot signal strength measurements, and providing
a signal strength signal indicative of a received
pilot signal of greatest measured signal strength
and cell-site of origin; and
processing means located at said mobile system user
for receiving said signal strength signal and for,
when said signal strength signal changes from indic-
sating said one cell-site transmitted pilot signal is of
a greater signal strength than said another cell-site
transmitted pilot signal to indicating said another
cell-site transmitted pilot signal is of a signal
strength greater than said one cell-site transmitted
pilot signal, generating said handoff request.

3. The system of claim 2 wherein each mobile system
user communicates said handoff request to said one
cell-site for coupling to a system controller, wherein
said system controller comprises said means for cou-
ping, and said means for coupling comprises:

4. The system of claim 3 wherein said means for ter-
minating comprises:
said processing means being further responsive to
said communication of user information signals
between said mobile system user and said another
system user via said another cell-site for generating
a handoff complete command, said mobile system
user communicating said handoff complete
command to said system controller via at least one
of said one cell-site and said another cell-site;
said system processing means being further respon-
sive to said handoff complete command for gener-
ating a second switch command; and
said switching means being further responsive to said
second switch command for decoupling communic-
ation of said user information signals between said
mobile system user and said another system user
via said one cell-site.

5. In a cellular radio communication system, a
method for handing off communications between a
mobile system user and another system user from one
cell to another cell comprising the steps of:
directing by a system controller a relay of user infor-
mation signals between a mobile system user and
another system user through one cell-site;
determining, by said mobile system user while said
mobile system user and said another system user
are communicating said user information signals
through said one cell-site, a transition of said mo-
obile system user from a service area of said one
cell-site to a service area of another cell-site;
generating, by said mobile user in response to said
transition determination, a first control signal iden-
tifying said another cell-site;
communicating said first control signal from said
mobile system user through said one cell-site to
d said system controller;
directing, by said system controller in response to
said first control signal, a communication of said
user information signals between said mobile sys-
tem user and said another system user through said
another cell-site concurrently with said communica-
tion of said user information signals between said
mobile system user and said another system user
through said one cell-site.

6. The method of claim 5 further comprising the steps
of:
generating, by said mobile system user in response to
said communication of said user information signals
between said another system user and said mobile
system user via said another cell-site, a second
control signal;
communicating said second control signal from said
mobile system user to said system controller via at
least one of said one cell-site and said another cell-
site; and
terminating by said system controller a directing of
said user information signals to said one cell-site.

7. The method of claim 5 wherein said user informa-
tion signals communicated by said mobile system user,
said one cell-site and said another cell-site are spread
spectrum modulated according to predetermined
spreading codes.

9. In a cellular radio telephone system in which mo-
bile users are capable of initiating and receiving calls to
and from other mobile users and users in a public tele-
phone system wherein said calls are relayed through at
least one of a plurality of cell-sites under the control of
a system controller, each of said calls comprised of user
information signals which are spread spectrum modu-
lated according to a different predetermined user infor-
mation signal spreading code as communicated between
said at least one cell-site and a corresponding mobile
user, and wherein each call transmits a pilot signal
that is spread spectrum modulated according to a pilot
signal spreading code common to all cell-sites and each
cell-site pilot signal is of a predetermined level with
respect to a neighboring cell-site pilot signal, a
method for directing the relay of communications
between a mobile user and another user through said
cell-sites as mobile user changes service areas of
said cell-sites, said method comprising the steps of:
communicating user information signals between a
mobile user and another user through a first cell-
site;
transmitting a pilot signal by each of said first cell-site
and a second cell-site;
receiving at said mobile user said first and second
cell-site transmitted pilot signals;
determining at said mobile user relative pilot signal
strength of said pilot signals as received at said
mobile user;
generating, at said mobile user in response to said
determination of relative pilot signal strength, a
handoff request when said second cell-site trans-
mitted pilot signal is of a predetermined level with
respect to said first cell-site transmitted pilot signal;
communicating said handoff request to said system
controller via said first cell-site;
assigning by said system controller said second cell-
site to relay said communication of user informa-
tion signals between said mobile user and said an-
other user; and
communicating said user information signals between
said mobile user and said another user through said
second cell-site wherein said mobile user and said
another user concurrently communicate through
both said first and second cell-sites.

10. The method of claim 9 further comprising the
steps of:
detecting at said mobile user said communication of
said user information signals as relayed through
said second cell-site;
generating a handoff complete command at said mo-
bile user in response to said detection of said sec-
cond cell-site relayed communication of said user
information signals;
transmitting said handoff complete command to at
least one of said first and second cell-sites; and
terminating in response to said handoff complete
command said communication of user information
between said mobile user and said another system
user through said first cell-site.

11. The method of claim 9 further comprising the
steps of:
generating a cell-diversity mode request at said first
cell-site;
relaying said cell-diversity mode request to said mo-
bile user; and
wherein said mobile user is responsive to said cell-
diversity mode request for maintaining communi-
cation with said another user through said first and
second cell-sites.

12. The method of claim 9 wherein the step of com-
municating said user information signals through said
first cell-site comprises the steps of:
receiving at said system controller an another user
information signal from said another user;
coupling said another user information signal from
said system controller to said first cell-site;
receiving at said first cell-site from said system con-
troller said another user information signal;
modulating at said first cell-site said another user
information signal according to a predetermined
another user information signal spreading code so
as to provide a first spread spectrum signal;
transmitting by said first cell-site said first spread
spectrum signal;
receiving at said mobile user said first spread spec-
trum signal;
desparking, at said mobile user according to said
predetermined another user information signal
spreading code, said received first spread spectrum
signal so as to provide said another user informa-
tion signal to said mobile user;
modulating, at said mobile user, a mobile user infor-
mation signal spreading code to a predetermined
mobile user information signal spreading code so as to
provide a second spread spectrum signal;
transmitting by said mobile user said second spread
spectrum signal;
receiving at said first cell-site said second spectrum
signal;
desparking, at said first cell-site according to said
predetermined mobile user information signal
spreading code, said received second spread spec-
trum signal so as to provide said mobile user informa-
tion signal;
coupling said mobile user information signal to said
system controller from said first cell-site;
receiving at said system controller said mobile user
information signal from said first cell-site; and
providing said mobile user information signal from
said system controller to said another user.

13. The method of claim 9 wherein the step of deter-
mining relative pilot signal strength comprises the steps
of:
measuring pilot signal strength of said received pilot
signals at said mobile user;
comparing at said mobile user said pilot signal
strength measurements; and
identifying one of said pilot signals of greatest signal
strength.

14. The method of claim 9 wherein the step of com-
municating said handoff request comprises the steps of:
transmitting said handoff request to said first cell-site;
and
relaying by said first cell-site said handoff request to
said system controller.

15. The method of claim 9 wherein the step of assign-
ing said second cell-site to said communication of user
information signals comprises the steps of:
determining from said handoff request an identifica-
tion of said second cell-site;
between said mobile user and said another user; and
selecting at said second cell-site one of a plurality of
modems at said second cell-site for communication
of said user information signals between said mobile
user and said another user.

16. The method of claim 12 wherein the step of com-
municating said user information signals through said
second cell-site comprises the steps of:
coupling said another user information signal from
said system controller to said second cell-site;
receiving at said second cell-site from said system
controller said another user information signal;
modulating at said second cell-site said another user
information signal according to said another user
information signal spreading code so as to provide
a third spread spectrum signal;
transmitting by said second cell-site said third spread
spectrum signal;
receiving at said mobile user said third spread spec-
trum signal;
despreading, at said mobile user according to said
another user information signal spreading code, said
received third spread spectrum signal;
combining said despread first and third spread spec-
trum signals so as to provide said another user
information signal to said mobile user;
receiving at said second cell-site said second spread
spectrum signal;
despreading, at said second cell-site according to said
mobile user information signal spreading code, said
second cell-site received second spread spectrum
signal so as to provide at said second cell-site said
mobile user information signal;
coupling said mobile user information signal to said
system controller from said second cell-site;
receiving at said system controller said mobile user
information signals from said second cell-site;
combining said at said system controller said mobile
user information signals received from each of said
first and second cell-sites; and
providing said combined mobile user information
signals from said system controller to said another
user.

17. The method of claim 10 wherein the step of termi-
nating said communication of user information signals
between said mobile user and said another user through said
first cell-site comprises the steps of:
relaying by said at least one of said first and second
cell-sites said handoff complete command to said
system controller;
decoupling by said system controller a communica-
tion of said user information signals between said
another user and said first cell-site;
discontinuing by said first cell-site a communication
of said user information signals from said another
user to said mobile user;
generating a termination command at said first cell-
site;
transmitting said termination command to said mobile
user; and
discontinuing by said mobile user a communication of
said user information signals from said mobile user to
said first cell-site.

18. In a mobile radio telephone system in which mo-
obile users are capable of initiating and receiving calls
comprised of information signals to and from other
mobile users and users in a public telephone system
wherein said calls are relayed through at least one of a
plurality of cell-sites under the control of a system con-
troller and wherein each cell-site has a corresponding
service area, a system for directing the relay of commun-
ications between a mobile user and another user
through said cell-sites as said mobile user changes cell-
site service areas, said system comprising:
means at each cell-site of a plurality of cell-sites for
generating and transmitting a pilot signal indicative of
each cell-site of origin;
means at said system controller for, receiving a user
information signal from a user intended for a mo-
obile user and coupling said user information signal
to a first cell-site;
means at said first cell-site for, receiving said user
information signal from said system controller,
spread spectrum modulating said user information
signals according to a first predetermined user
information signal spreading code and transmitting
said spread spectrum modulated user information
signal to an intended recipient mobile user;
means at said mobile user for receiving and despreading
said first cell-site transmitted spread spectrum
modulated user information signal according to said
first spreading code so as to provide a first resultan-
t user information signal to said mobile user;
means at said mobile user for spread spectrum modu-
lating a mobile user information signal intended for
said user according to a second spreading code and
transmitting said spread spectrum modulated mo-
bile user information signal to said first cell-site;
means at said mobile user for, receiving said pilot
signals transmitted by said first cell-site and a sec-
cord cell site, determining relative pilot signal
strength of each received pilot signal, generating a
handoff request when said second cell-site trans-
mitted pilot signal is of a predetermined level with
respect to said first cell-site transmitted pilot signal,
and transmitting said handoff request to said first

19. In a mobile radio telephone system in which mo-
obile users are capable of initiating and receiving calls
through said second cell-site an assignment of
said second cell-site in communicating said user
information signals between said mobile user and
said another user; and
selecting at said second cell-site one of a plurality of
modems at said second cell-site for communication
of said user information signals between said mobile
user and said another user.

20. The method of claim 16 wherein the step of termi-
nating said communication of user information signals
between said mobile user and said another user through
said cell-sites comprises the steps of:
coupling said another user information signal from
said system controller to said second cell-site;
receiving at said second cell-site from said system
controller said another user information signal;
modulating at said second cell-site said another user
information signal according to said another user
information signal spreading code so as to provide
a third spread spectrum signal;
transmitting by said second cell-site said third spread
spectrum signal;
receiving at said mobile user said third spread spec-
trum signal;
despreading, at said mobile user according to said
another user information signal spreading code, said
received third spread spectrum signal;
combining said despread first and third spread spec-
trum signals so as to provide said another user
information signal to said mobile user;
receiving at said second cell-site said second spread
spectrum signal;
despreading, at said second cell-site according to said
mobile user information signal spreading code, said
second cell-site received second spread spectrum
signal so as to provide at said second cell-site said
mobile user information signal;
coupling said mobile user information signal to said
system controller from said second cell-site;
receiving at said system controller said mobile user
information signals from said second cell-site;
combining said at said system controller said mobile
user information signals received from each of said
first and second cell-sites; and
providing said combined mobile user information
signals from said system controller to said another
user.
said means at said mobile user for receiving and despreading said first cell-site transmitted spread spectrum modulated user information signal further for receiving and despreading said second cell-site transmitted spread spectrum modulated user information signal according to said first spreading code so as to provide a second resultant user information signal, combining said first and second resultant user information signals so as to provide a combined user information signal to said second spreading code so as to provide a second resultant mobile user information signal, and for coupling said second resultant mobile user information signal to said system controller; and
said means at said second cell-site for receiving said second resultant mobile user information signal from said first cell-site further for receiving said second resultant mobile user information signal from said second cell-site, combining said first and second resultant mobile user information signals so as to provide a combined mobile user information signal, and for coupling said combined mobile user information signal to said user in place of said first resultant mobile user information signal, and wherein said mobile user contemporaneously communicates with said user through both said first and second cell-sites.

19. The system of claim 18 further comprising:
said means at said mobile user for generating said handoff request further for detecting a coupling of communications between said user and said user, generating a handoff complete command and transmitting said handoff complete command to at least one of said first and second cell-sites;
said means at said first and second cell-sites for receiving, despreading and coupling said first and second resultant mobile user information signals to said system controller further for receiving and coupling said handoff complete command to said system controller;
said means at said system controller for receiving and combining said first and second resultant mobile user information signals from said first and second cell-sites further for receiving said handoff complete command from said at least one of said first and second cell-sites and responsive thereto for coupling only said second resultant mobile user information signal to said user; and
said means at said system controller for coupling said user information signal to said first and second cell-sites responsive to said received handoff command for decoupling said user information signal to said first cell-site.

20. The system of claim 18 wherein each cell-site spread spectrum modulates each pilot signal according to a pilot signal spreading code common to all cell-sites and cell-site each pilot signal is of a different predetermined code phase with respect to each neighboring cell-site pilot signal.

21. In a cellular radio telephone system in which mobile users are capable of initiating and receiving calls to and from other mobile users and users in a public telephone system wherein said calls are relayed through at least one of a plurality of cell-sites under the control of a system controller, each of said calls comprised of information signals which are spread spectrum modulated according to a different predetermined information signal spreading code as communicated between a user and a corresponding mobile user via at least one cell-site, and wherein each cell-site transmits a pilot signal that is spread spectrum modulated according to a pilot signal spreading code common to all cell-sites and each cell-site pilot signal is of a different predetermined code phase with respect to a neighboring cell-site pilot signal, a method for directing the relay of communications between a mobile user and another user through said cell-sites as said mobile user changes service areas of said cell-sites, said method comprising the steps of:

communicating user information signals between a mobile user and another user through a first cell-site;
determining at said first cell-site signal strength of said user information signals as received at said first cell-site from said mobile user;
generating, at said first cell-site in response to said determination of signal strength, a handoff request when said signal strength fall below a predetermined level;
communicating said handoff request to said system controller;
assigning by said system controller each cell-site of a plurality of cell-sites neighboring said first cell-site to determine signal strength of said user information signals as received at said each respective neighboring cell-site from said mobile user;
determining at each respective neighboring cell-site signal strength of said user information signals as received at said each respective neighboring cell-site from said mobile user and reporting to said system controller by each respective neighboring cell-site signal strength of said user information signals as received at said each respective neighboring cell-site from said mobile user;
communicating said user information signals between said mobile user and said another user through at least one of said neighboring cell-sites wherein said mobile user and said another user concurrently communicates through both said first cell-site and said at least one of said neighboring cell-sites.

22. The method of claim 21 further comprising the steps of:
detecting said communication of said user information signals through said at least one of said neighboring cell-sites; and
terminating said communication of user information signals between said mobile user and said another system user through said first cell-site.

23. The method of claim 21 further comprising the steps of:
generating a cell-diversity mode request at said first cell-site;
relaying said cell-diversity mode request to said mobile user; and
wherein said mobile user is responsive to said cell-diversity mode request for maintaining communication with said another user through said first cell-site and said at least one of said neighboring cell-sites.