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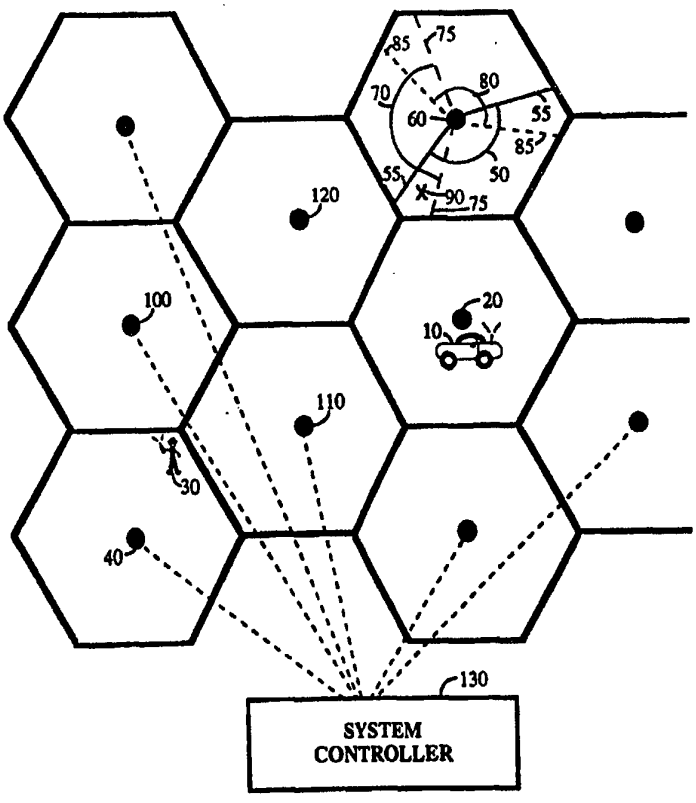
(54) Title: METHOD AND APPARATUS FOR REDUCING THE AVERAGE DOWNLINK TRANSMITTED POWER FROM BASE STATIONS DURING SOFT HANDOFF

(57) Abstract

A plurality of methods for achieving the soft or softer handoff process such that the performance of a system is improved. A first method is based on delaying the softer handoff process. A second method is based on reducing the power of transmissions from the sector having the weakest signal strength. A third method is based on eliminating transmissions from the sector having the weakest signal strength. A fourth method adds a new base station or sector only when the mobile unit is in need of additional power to operate properly. In all four methods, reverse link demodulation in each sector may continue with or without the transmission of the forward link. In all four methods the operation could be based on the signal strength of the reverse link signal or the forward link. It is also possible to combine two or more of these methods to create a hybrid method.



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Method and Apparatus for Reducing the Average Downlink Transmitted Power from Base Stations during Soft Handoff

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention is a Continuation-In-Part application of pending prior application Serial No. 08/144,901 filed on October 28, 1993 of Klein S. Gilhousen et al. for "METHOD AND APPARATUS FOR REDUCING THE AVERAGE TRANSMIT POWER OF A SECTORIZED BASE STATION" The present invention relates to communication systems, particularly to a plurality of methods for reducing the average transmit power from a sectorized base station.

II. Description of the Related Art

In a code division multiple access (CDMA) cellular telephone system, wireless local loop (WLL), satellite communication system such as GLOBALSTAR, or personal communications system (PCS), a common frequency band is used for communication with all base stations in a system. The common frequency band allows simultaneously communication between a mobile unit and more than one base station. Signals occupying the common frequency band are discriminated at the receiving station through the spread spectrum CDMA waveform properties based on the use of a high speed pseudonoise (PN) code. The high speed PN code is used to modulate signals transmitted from the base stations and the mobile units. Transmitter stations using different PN codes or PN codes that are offset in time produce signals that can be separately received at the receiving station.

In an exemplary CDMA system, each base station transmits a pilot signal having a common PN spreading code that is offset in code phase from the pilot signal of other base stations. During system operation, the mobile unit is provided with a list of code phase offsets corresponding to neighboring base stations surrounding the base station through which communication is established. The mobile unit is equipped with a searching element that allows the mobile unit to track the signal strength of the pilot signal from a group of base stations including the neighboring base stations.

A method and system for providing communication with the mobile unit through more than one base station during the handoff process are disclosed in U.S. Patent No. 5,267,261, issued November 30, 1993, entitled "MOBILE ASSISTED SOFT HANDOFF IN A CDMA CELLULAR TELEPHONE SYSTEM," assigned to the assignee of the present invention which is incorporated herein by this reference. Using this system, communication between the mobile unit and the end user is uninterrupted by the eventual handoff from an original base station to a subsequent base station. This type of handoff may be considered as a "soft" handoff in that communication with the subsequent base station is established before communication with the original base station is terminated. When the mobile unit is in communication with two base stations, a single signal for the end user is created from the signals from each base station by a cellular, WLL, GLOBALSTAR, or PCS controller.

Mobile unit assisted soft handoff operates based on the pilot signal strength of several sets of base stations as measured by the mobile unit. The Active Set is the set of base stations through which active communication is established. The Neighbor Set is a set of base stations surrounding an active base station comprising base stations that have a high probability of having a pilot signal strength of sufficient level to establish communication. The Candidate Set is a set of base stations having a pilot signal strength of sufficient level to establish communication.

When communications are initially established, a mobile unit communicates through a first base station and the Active Set contains only the first base station. The mobile unit monitors the pilot signal strength of the base stations of the Active Set, the Candidate Set, and the Neighbor Set. When a pilot signal of a base station in the Neighbor Set exceeds a predetermined threshold level, the base station is added to the Candidate Set and removed from the Neighbor Set at the mobile unit. The mobile unit communicates a message to the first base station identifying the new base station. A system controller decides whether to establish communication between the new base station and the mobile unit. Should the system controller decide to do so, the system controller sends a message to the new base station with identifying information about the mobile unit and a command to establish communications therewith. A message is also transmitted to the mobile unit through the first base station. The message identifies a new Active Set that includes the first and the new base stations. The mobile unit searches for the new base station transmitted information

signal and communication is established with the new base station without termination of communication through the first base station. This process can continue with additional base stations.

When the mobile unit is communicating through multiple base stations, it continues to monitor the signal strength of the base stations of the Active Set, the Candidate Set, and the Neighbor Set. Should the signal strength corresponding to a base station of the Active Set drop below a predetermined threshold for a predetermined period of time, the mobile unit generates and transmits a message to report the event. The system controller receives this message through at least one of the base stations with which the mobile unit is communicating. The controller may decide to terminate communications through the base station having a weak pilot signal strength.

The system controller upon deciding to terminate communications through a base station generates a message identifying a new Active Set of base stations. The new Active Set does not contain the base station through which communications are to be terminated. The base stations through which communication is established send the message to the mobile unit. The system controller also communicates information to the base station to terminate communications with the mobile unit. The mobile unit communications are thus routed only through base stations identified in the new Active Set.

Because the mobile unit is communicating with the end user though at least one base station at all times throughout the soft handoff processes, no interruption in communications occurs between the mobile unit and the end user. A soft handoff provides significant benefits in its inherent "make before break" communication over conventional "break before make" techniques employed in other cellular communication systems.

A typical cellular, WLL, GLOBALSTAR, or PCS system contains some base stations having multiple sectors. A multi-sectored base station comprises multiple independent transmit and receive antennas. The process of simultaneous communication with two sectors of the same base station is called softer handoff. The process of soft handoff and the process of softer handoff are the same from the mobile unit's perspective. However the base station operation in softer handoff is different from soft handoff. When a mobile unit is communicating with two sectors of the same base station, the demodulated data signals of both sectors are available for combination within the base station before the signals are passed to the

system controller. Because the two sectors of a common base station share circuitry and controlling functions, a variety of information is readily available to sectors of a common base station that is not available between independent base stations. Also two sectors of a common base station send the same power control information to a mobile unit (as discussed below). In satellite communication system such as GLOBALSTAR, most users will be in continuous softer handoff.

In a cellular, WLL, GLOBALSTAR, or PCS system, maximizing the capacity of the system in terms of the number of simultaneous telephone calls that can be handled is extremely important. System capacity in a spread spectrum system can be maximized if the transmitter power of each mobile unit is controlled such that each transmitted signal arrives at the base station receiver at the same level. In an actual system, each mobile unit may transmit the minimum signal level that produces a signal-to-noise ratio that allows acceptable data recovery. If a signal transmitted by a mobile unit arrives at the base station receiver at a power level that is too low, the bit-error-rate may be too high to permit high quality communications due to interference from the other mobile units. On the other hand, if the mobile unit transmitted signal is at a power level that is too high when received at the base station, communication with this particular mobile unit is acceptable but this high power signal acts as interference to other mobile units. This interference may adversely affect communications with other mobile units.

Path loss in the radio channel is defined as any degradation or loss suffered by a signal as it travels over-the-air and can be characterized by two separate phenomena: average path loss and fading. The forward link, i.e., the link from the base station to the mobile unit, typically but not necessarily operates on a different frequency than the reverse link, i.e., the link from the mobile unit to the base station. Nevertheless, because the forward and reverse link frequencies are within the same frequency band, a significant correlation exists between the average path loss of the two links. For example, a typically cellular system has one of its forward link channels centered about 882MHz paired with one of its reverse link channels centered about 837MHz. On the other hand, fading is an independent phenomenon for the forward link and reverse link and varies as a function of time. The characteristics of fading on the channel are the same, however, for both the forward and reverse link because the frequencies are within the

same frequency band. Therefore, the average of channel fading over time for both links is typically the same.

In an exemplary CDMA system, each mobile unit estimates the path loss of the forward link based on the total power at the input to the mobile unit. The total power is the sum of the power from all base stations operating on the same frequency assignment as perceived by the mobile unit. From the estimate of the average forward link path loss, the mobile unit sets the transmit level of the reverse link signal. Should the reverse link channel for one mobile unit suddenly improve compared to the forward link channel for the same mobile unit due to independent fading of the two channels, the signal as received at the base station from this mobile unit would increase in power. This increase in power causes additional interference to all signals sharing the same frequency assignment. Thus a rapid response of the mobile unit transmit power to the sudden improvement in the channel would improve system performance.

Mobile unit transmit power is also controlled by one or more base stations. Each base station with which the mobile unit is in communication measures the received signal strength from the mobile unit. The measured signal strength is compared to a desired signal strength level for that particular mobile unit. A power adjustment command is generated by each base station and sent to the mobile unit on the forward link. In response to the base station power adjustment command, the mobile unit increases or decreases the mobile unit transmit power by a predetermined amount. By this method, a rapid response to a change in the channel is effected and the average system performance is improved.

When a mobile unit is in communication with more than one base station, power adjustment commands are provided from each base station. The mobile unit acts upon these multiple base station power adjustment commands to avoid transmit power levels that may adversely interfere with other mobile unit communications and yet provide sufficient power to support communication from the mobile unit to at least one of the base stations. This power control mechanism is accomplished by having the mobile unit increase its transmit signal level only if every base station with which the mobile unit is in communication requests an increase in power level. The mobile unit decreases its transmit signal level if any base station with which the mobile unit is in communication requests that the power be decreased. A system for base station and mobile unit power control is disclosed in U.S. Patent No. 5,056,109 entitled "METHOD AND

APPARATUS FOR CONTROLLING TRANSMISSION POWER IN A CDMA CELLULAR MOBILE TELEPHONE SYSTEM," issued October 8, 1991, assigned to the Assignee of the present invention.

Base station diversity at the mobile unit is an important consideration in the soft handoff process. The power control method described above operates optimally when the mobile unit communicates with each base station through which communication is possible, typically between one to three base stations although a greater number is possible. In doing so, the mobile unit avoids inadvertently interfering with communications through a base station receiving the mobile unit's signal at an excessive level but unable to communicate a power adjustment command to the mobile unit because communication is not established therewith.

As a mobile unit moves toward the edge of the base station coverage area, the signal strength of the forward link signal at the mobile unit falls. Also as the mobile unit moves to the edge of the coverage area of the current base station, the mobile unit generally moves closer to the base station coverage area of other base stations. Thus as the mobile unit moves toward the edge of the base station coverage area, the signal level from the current base station falls while interference from other base stations increases. The falling signal level also means that the signals are more sensitive to thermal noise and the noise created by the receiving circuitry in the mobile unit. This situation may be aggravated by a mobile unit located within an area where two sectors of a common base station overlap.

In a case where a set of base stations is operating at near capacity, the mobile unit located at the edge of the base station coverage area and within the coverage area of two sectors of the same base station may experience a drop in signal-to-noise ratio such that the quality of communications is degraded. The softer handoff process provides information to the base station that can be used to improve this situation. The improvement can be created by decreasing the average power transmitted by each sector of a base station. By decreasing the average power transmitted by each sector of a base station, the interference to all mobile units is reduced. Thus the interference to the mobile units at the edge of the coverage area is also reduced causing an increase in the average signal-to-noise ratio of mobile units a the edge of the coverage area.

In a system having soft and softer handoff capabilities and having neighboring base stations at or near capacity, a given amount of base station

power is divided among the forward link signals such that each additional forward link signal transmitted from a base station decreases the power of other forward link signals. In a system operating at capacity, compare a base station having two sectors in which every mobile unit in the coverage area of the base station is in softer handoff mode to a base station having two sectors in which no mobile unit is in softer handoff mode. In the base station having every mobile unit in softer handoff, each forward link signal from each sector is transmitted at one-half of the power of each forward link signal from the base station having no mobile unit in softer handoff. Because, in the case where every mobile unit is in softer handoff, the signals from each sector are combined in the mobile unit, the signal-to-interference ratio after combining is equal to the no handoff case if and only if each mobile unit is well served by both sectors. However, in reality not every mobile unit in softer handoff in a sectorized base station is well served by each sector.

The present invention is a technique which could be used to reduced the number of signal transmitted by a sector. A fewer number of signals to be transmitted from a sector means more power available for the remaining signals. When the base station transmits higher power forward link signals, the signal-to-interference for mobile units operating at handoff boundaries or at the edge of the coverage area is improved. Alternatively, as the number of signals is reduced, the total base station transmitter power can decrease which also results in less interference power in the system. These techniques can be used to reduce the number of mobile units in soft and softer handoff.

It is therefore the object of the present invention to improve forward link signal-to-interference ratio by reducing ineffectual forward link transmissions to mobile units in soft or softer handoff, reducing the interference power to other mobiles and making more transmitter power available to all useful links to mobile units.

It is therefore the object of the present invention to provide a plurality of methods to decrease the transmission power from a base station.

It is another object of the present invention to provide a plurality of methods to provide an enhanced softer handoff process to improve the forward link performance.

SUMMARY OF THE INVENTION

The present invention defines a plurality of methods for performing the soft or softer handoff process such that the performance of a system is improved. A first method is based on delaying the softer handoff process. When the mobile unit informs a first sector through which it is communicating that a second sector from the same base station has a signal strength sufficient to support communications, the base station commands the second sector to find the mobile unit transmitted signal. The base station does not command the mobile unit to establish communication with the second sector until the reverse link signal received at the second sector exceeds a predetermined threshold. Delaying the softer handoff reduces the average number of mobile units in the soft handoff process and reduces the average total power transmitted by each sector thus reducing the total average interference to mobile units in the system.

A second method is based on reducing the power of transmissions from the sector having the weakest signal strength. When the mobile unit informs a first sector through which it is communicating that a second sector from the same base station has a signal strength sufficient to support communications, the base station commands the second sector to establish communication with the mobile unit. The base station also commands the mobile unit to establish communication with the second sector. After the mobile unit enters the softer handoff mode, the base station compares the reverse link signal strength from each of the sectors. The base station reduces the forward link transmission power for that mobile unit from the sector having the weakest reverse link signal strength indication. Reducing transmission power from the weaker sector reduces the average power transmitted from each sector and therefore reduces interference to mobile units in the system.

A third method is based on eliminating transmissions from the sector having the weakest signal strength. When the mobile unit informs a first sector through which it is communicating that a second sector from the same base station has a signal strength sufficient to support communications, the base station commands the second sector to establish communication with the mobile unit. The base station also commands the mobile unit to establish communication with the second sector. After the mobile unit enters the softer handoff mode, the base station monitors the reverse link signal strength from each of the sectors. If the reverse link signal strength from one sector falls below a predetermined threshold for more than a predetermined period of time, the base station discontinues

forward link transmissions from the sector having the weakest signal strength indication. Discontinuing transmissions from the weaker sector reduces the average power transmitted from each sector and therefore reduces interference to mobile units in the system.

A fourth method is based on providing the mobile unit with a desired operation aggregate signal strength. The mobile unit provides to the base station a signal strength measurement from every base station that is a member of the Active and Candidates sets. The base station ranks the power levels in order of descending magnitude. The power levels are then summed in order until the desired operation aggregate signal strength is exceeded. The base station returns an Active Set message to the mobile unit identifying each base station corresponding to a signal strength used to reach the desired operation aggregate signal strength.

In all four methods above, reverse link demodulation in each sector may continue with or without the transmission of the forward link thus this method does not adversely effect reverse link performance or power control. In all four methods the operation could be modified such that the mobile unit informs the base station of received power on the forward link. The forward link power measurements from the mobile unit could be used as the criteria instead of the reverse link measurements made at the base station. It is also possible to combine two or more of these methods to create a hybrid method.

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 and wherein:

Figure 1 is a diagram illustrating an exemplary base station coverage area structure;

Figure 2 is a block diagram illustrating an exemplary sectorized base station comprising multiple independent demodulation elements; and

Figure 3 is an exemplary representation of the coverage areas of three sectors of a sectorized base station.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 illustrates an exemplary base station coverage area structure. In such an exemplary structure, hexagonal base station coverage areas abut one another in a symmetrically tiled arrangement. Each mobile unit is located within the coverage area of one of the base stations. For example, mobile unit 10 is located within the coverage area of base station 20. In a code division multiple access (CDMA) cellular, wireless local loop (WLL), satellite communication system such as GLOBALSTAR, or personal communication (PCS) system, a common frequency band is used for communication with all base stations in a system allowing simultaneously communication between a mobile unit and more than one base station. Mobile unit 10 is located very close to base station 20 and therefore receives a large signal from base station 20 and relatively small signals from surrounding base stations. However mobile unit 30 is located in the coverage area of base station 40 but is close to the coverage area of base stations 100 and 110. Mobile unit 30 receives a relatively weak signal from base station 40 and similarly sized signals from base stations 100 and 110. Due to the decreased signal strength and the increased interference from neighboring base stations, mobile unit 30 has a lower overall signal to noise ratio with respect to base station 40 than mobile unit 10 has with respect to base station 20.

The exemplary base station coverage area structure illustrated in Figure 1 is highly idealized. In the actual cellular, WLL, GLOBALSTAR, or PCS environment, base station coverage areas may vary in size and in shape. Base station coverage areas may tend to overlap with coverage area boundaries defining coverage area shapes different from the ideal hexagon shape. Furthermore, base stations may also be sectored such as into three sectors, as is well known in the art. Base station 60 is shown as a three sectored base station. However base stations with a lesser or greater number of sectors are envisioned.

Base station 60 of Figure 1 represents an idealized three sectored base station. Base station 60 has three sectors, each of which covers more than 120 degrees of the base station coverage area. Sector 50, having a coverage area indicated by the unbroken lines 55, overlaps the coverage area of sector 70, having a coverage area indicated by the coarse dashed lines 75. Sector 50 also overlaps the sector 80, having a coverage area as indicated by the fine dashed lines 85. For example, location 90 as indicated by the X is located in both the coverage area of sector 50 and sector 70.

In general a base station is sectorized to reduce the total interference power to mobile units located within the coverage area of the base station while increasing the number of mobile units that can communicate through the base station. For example, sector 80 would not transmit a signal intended for a mobile unit at location 90 and thus no mobile unit located in sector 80 is significantly interfered with by the communication of a mobile unit at location 90 with base station 60.

However for a mobile unit positioned at location 90, the total interference has contributions from sectors 50 and 70 and from base stations 20 and 120. If the sum of the interference becomes too large, compared to the signal strength of the intended signal, communication between a mobile unit at location 90 and base station 60 may degrade. The present invention is a method for reducing the interference in such a case. In fact the present invention reduces the interference to all mobile units operating within a system of base stations.

The base stations 20, 40, 60, 100, and 120 shown in Figure 1 are controlled by system controller 130. Although Figure 1 shows only a subset of the connections between system controller 130 and the base stations, a connection between every base station and the system controller is implied. System controller 130 provides the control functions for each base station in the system. Among the control function is the coordination of the initiation and termination of soft handoff between base stations. When a mobile unit is in soft handoff between two or more base stations, a signal from the mobile unit is received at system controller 130 from each base station with which the mobile unit is in communication. System controller 130 performs the combination or selection of signals received from multiple base stations. System controller 130 also provides an interface to the public switch telephone network (PSTN) not shown.

Figure 2 illustrates an exemplary embodiment of a three sectored base station. In Figure 2, each of antennas 222A - 222C is the receive antenna for one sector and each of antennas 230A - 230C is the transmit antenna for one sector. Antenna 222A and antenna 230A correspond to a common coverage area and can ideally have the same antenna pattern. Likewise antennas 222B and 230B, and antennas 222C and 230C correspond to common coverage areas respectfully. Figure 2 represents a typical base station in that antennas 222A - 222C have overlapping coverage areas such that a single mobile unit signal may be present at more than one antenna at a time. Although only one receive antenna is shown for each sector,

typically two antennas are used for diversity with the receive signals combined for processing.

Figure 3 is a more realistic representation of the coverage areas of three sectors of a sectorized base station than base station 60 of Figure 1. Coverage area 300A, as represented by the finest line, corresponds to the coverage area of both antennas 222A and 230A. Coverage area 300B, as represented by the medium width line, corresponds to the coverage area of both antennas 222B and 230B. Coverage area 300C, as represented by the heaviest line, corresponds to the coverage area of both antennas 222C and 230C. The shape of the three coverage areas is the shape produced by standard directional dipole antenna. The edges of the coverage areas can be thought of as the location at which a mobile unit receives the minimum signal level to support communication through that sector. As a mobile unit moves into the sector, the signal strength increases. As a mobile unit moves past the edge of the sector, communication through that sector may degrade. A mobile unit operating in softer handoff mode is likely to be located in the overlapped region of two coverage areas.

Referring again to Figure 2, antennas 222A, 222B, and 222C supply the received signal to receive processings 224A, 224B, and 224C respectively. Receive processings 224A, 224B, and 224C process the RF signal and convert the signal to digital bits. Receive processings 224A, 224B, and 224C filter the digital bits and provide the resulting digital bits to interface port 226. Interface port 226 may connect any of the three incoming signal paths to any of the demodulation elements 204A - 204N under the control of controller 200 through interconnection 212.

Demodulation elements 204A - 204N are also controlled by controller 200 through interconnection 212. Controller 200 assigns demodulation elements 204A - 204N to one of the plurality of information signals from a single mobile unit from any one of the sectors. Demodulation elements 204A - 204N produce data bits 220A - 220N each representing an estimate of the data from the single mobile unit. Data bits 220A - 220N are combined in symbol combiner 208 to produce a single estimate of the data from the mobile unit. The output of symbol combiner 208 is aggregate soft decision data suitable for Viterbi decoding. Notice that symbol combiner 208 can combine signals from just one sector to produce an output or it can combine symbols from multiple sectors as selected by the interface port 226. Each one of demodulation elements 204A - 204N measures a signal strength estimation of the signal

that it is demodulating and provides the estimation to controller 200. A single power adjustment command is created from the estimated signal strengths independent of the sector through which the signal is received. Thus each sector in the base station transmits the same power adjustment command to a single mobile unit.

When symbol combiner 208 is combining signals from a mobile unit that is communicating through more than one sector, the mobile unit is in softer handoff. The base station may send the output of symbol combiner 208 to a decoder and then to a cellular, WLL, GLOBALSTAR, or PCS system controller. A system controller may receive decoded symbols from a common mobile unit from multiple base stations and produce a single output. This process is referred to as soft handoff.

Demodulation elements 204A - 204N also provide several output control signals to controller 200 through interconnection 212. The information passed to controller 200 includes an estimate of the signal strength of the signal assigned to a particular demodulator. Typically this information is not passed to the system controller. Therefore sectors of a common base station demodulating signals from a common mobile unit are much more intimately related than two base stations sending signals to a common system controller. The intimacy of the relationship of two sectors supporting a softer handoff mode with a single mobile unit provides the basis for the first three methods of the present invention.

In many applications, an actual base station also comprises at least one searcher element. The searcher element is also capable of demodulating a signal and is used to continually scan the time domain in search of available signals. The searcher element identifies a set of available signals and passes the information to the controller. The controller may use the set of available signals to assign or re-assign the demodulation elements to the most advantageous signals available. The placement of the searcher element is the same as the placement of the demodulating elements in Figure 2. As such the searcher elements may also be assigned to a signal from a plurality of sectors of a common base station. In the most general case, demodulation elements 204A - 204N can be assumed to comprise some elements that are capable of performing the searching function.

The transmit process shown in Figure 2 receives a message for a mobile unit from the end user through the system controller. The message can be sent on one or more of antennas 230A - 230C. Interface port 236 connects the message for the mobile unit to one of more of modulation

elements 234A - 234C as set by controller 200. Modulation elements 234A - 234C modulate the message for the mobile unit with the appropriate PN code. The modulated data from modulation elements 234A - 234C is passed to transmit processing 232A - 232C respectively. Transmits processings 232A - 232C convert the message to an RF frequency and transmit the signal at an appropriate signal level through antennas 230A - 230C respectively. Notice that interface port 236 and interface port 226 operate independently in that receiving a signal from a particular mobile unit through one of antennas 222A - 222C does not necessarily mean that the corresponding transmit antenna 230A - 230C is transmitting a signal to the particular mobile unit. Also note that the power adjustment commands sent through each antenna is the same, thus sector diversity in a common base station is not critical for the optimal power control performance.

The handoff process as described in U.S. Patent No. 5,056,109 referred to above, describes a process that is summarized in the following steps.

Normal operation of softer handoff:

1: Mobile unit is communicating with base station X through sector alpha antenna meaning base station X, sector alpha is identified as a member of the Active Set.

2: Mobile unit monitors the pilot signal from base station X, sector beta antenna and base station X, sector beta is identified as a member of the Neighbor Set. The pilot signal strength from base station X, sector beta antenna exceeds a predetermined threshold.

3: Mobile unit identifies base station X, sector beta as a member of the Candidate Set and informs base station X through sector alpha antenna.

4: Base station X establishes the availability of resources in sector beta.

5: Sector beta antenna begins to receive a reverse link signal from mobile unit.

6: Sector beta antenna begins to transmit a forward link signal to mobile unit.

7: Base station X through sector alpha antenna updates the mobile unit Active Set to identify base station X, sector beta.

8: Mobile unit establishes communication with base station X, sector beta antenna. Mobile unit combines the signals from sector alpha antenna and sector beta antenna.

9: Base station X combines the signals from mobile unit received through sector alpha antenna and sector beta antenna (softer handoff).

The first method to reduce the number of mobile units in the softer handoff mode is based on delaying the softer handoff process. The process inserts an additional step between steps 5 and 6 that we will label step 5.1. Step 5.1 adds the additional function as follows:

5.1: Determine the signal strength of the reverse link signal from the mobile unit. Pause the process at this step until the reverse link signal strength exceeds a predetermined threshold.

Step 5.1 delays the onset of softer handoff thus reducing the total number of forward link transmissions. Even while the forward link transmissions are delayed, the reverse link signal received by sector beta may be combined with the reverse link signal from sector alpha.

Referring again to Figure 3, suppose a mobile unit follows the path indicated the arrow. At point 302, the mobile unit enters the coverage area of sector 300B from sector 300A. At this point, sector 300B would be moved from the Neighbor Set to the Candidate Set. The mobile unit informs the base station of the new addition to the Candidate Set. If resources are available in sector 300B, sector 300B begins to receive the reverse link signal from the mobile unit. Sector 300B does not begin to transmit a signal and instead monitors the reverse link signal from the mobile unit. As the mobile unit moves further into sector 300B, the signal strength from the mobile unit as received by sector 300B increases. Suppose at point 304 the signal strength of the received signal exceeds the predetermined threshold of step 5.1. The process continues and sector 300B begins to transmit a forward link signal to the mobile unit. Sector 300A updates the mobile unit Active Set to include sector 300B.

Note that this method does not degrade the advantages of softer handoff and the make-before-break handoff process. In Figure 3, as the mobile unit continued to travel along the arrow, the mobile unit would be in a softer handoff state from point 304 until point 306. At point 306, communication with sector 300A can be terminated because the mobile unit is no longer within the coverage area of sector 300A. Without the addition of step 5.1, the mobile unit would be in softer handoff from point 302 to point 306.

This first method could be modified to achieve similar results by basing the delay on the signal strength of the forward link signal as measured at the mobile unit. The modified step 5.1 would be as follows:

5.1: Determine the signal strength of the pilot signal at the mobile unit from sector beta antenna. Pause the process at this step until the pilot signal strength exceeds a predetermined threshold.

The transfer of the pilot signal strength could automatically be transmitted from the mobile unit as part of the notification of a new entry in the Candidate Set. The mobile unit could transmit the signal strength periodically or mobile unit could respond to a request for the signal strength from the base station. The mobile unit could be aware of the threshold and notify the base station when the pilot signal strength exceeds the predetermined level.

No matter which variation of first method is used, the average transmission power from each sector is reduced. By delaying the forward link transmissions to the set of mobile units that are in the coverage area of a first sector and have not deeply penetrated the coverage area of a second sector, each mobile unit is subjected to a decrease amount of interference on the forward link. Notice that this method does not effect soft handoff (handoff between two independent base stations).

The second method involves reducing the power of the forward link transmission. The original steps 1 through 9 above would remain the same. An additional two steps would be added following step 9 as follows:

10: Determine the reverse link signal strength received through each sector antenna.

11: Reduce the power of the transmitted forward link signal by a predetermined amount from the sector antenna having the weakest reverse link signal.

Alternatively the same steps could be executed based on the forward link transmission power as follows:

10: Determine the forward link signal strength received from each sector at the mobile unit and provide this information to the base station.

11: Reduce the power of the transmitted forward link signal by a predetermined amount from the sector antenna having the weakest forward link signal as measured at the mobile unit.

No matter which variation of the second method is used, the average transmission power from each sector is reduced. By reducing the forward link transmissions to a set of mobile units that are in the coverage area of two sectors, each mobile unit in the two sectors is subjected to a decrease amount of interference on the forward link. Again this method does not effect soft handoff.

A potential unfavorable consequence to this method exists. The mobile unit may combine signals from two sectors based on the pilot signal strength from each of the sectors as received at the mobile unit. Therefore the mobile unit is assuming a fixed relationship between the strength of the pilot signal from a sector and the strength of the information signal intended specifically for the mobile unit. When the power of the transmitted information signal is reduced, the combination ratio will be unbalanced by some amount. The unbalance causes the combination process to operate with non-optimal performance. If the reduction ratio is small, for instance if the power intended for the mobile unit is reduced by about 3dB, this effect may be negligible. This problem could be fixed by having the base station inform the mobile unit of the relation between pilot signal strength and information signal strength. The mobile could respond to this information by appropriately modifying the combiner ratio to reflect the change.

A third method adds new steps 10 and 11 to the original steps 1 through 9 as follows:

10: Monitor the received reverse link signal at each sector antenna. When the reverse link signal falls below a threshold for a predetermined period of time at a sector antenna, inform the mobile unit to stop demodulating the forward link signal from the weak sector antenna.

11: Stop sending the forward link signal to the mobile unit from the weak sector antenna.

12: Return to step 5.

Alternatively the same steps could be executed based on the forward link transmission power as follows:

10: Determine the forward link signal strength level received from each sector antenna at the mobile unit and provide this information to the base station.

11: When the forward link signal from a sector antenna falls below a threshold for a predetermined period of time, inform the mobile unit to stop demodulating the forward link signal from the weak sector antenna.

12: Stop transmitting the forward link signal from the weak sector antenna.

No matter which variation of the third method is used, the average transmission power from a sector is reduced. By terminating the forward link transmissions to the set of mobile units in the coverage area of two sectors before signal strength would mandate termination, each mobile unit in both sectors is subjected to a decrease in interference power on the forward link. Notice that neither alternative to the third method requires the weak sector to discontinue demodulating the reverse link signal from the mobile unit. Again this method does not effect soft handoff.

The fourth method can be used in a manner similar to the first three methods to reduce the average transmission power from a base station. The advantage of the fourth method is that it is equally applicable to soft and softer handoff. In order to function optimally, a mobile unit must receive a desired operation aggregate signal strength. The desired operation aggregate signal strength is calculated as the sum the signal strengths of each signal being demodulated by a mobile unit. If more than the minimum aggregate signal strength is demodulated by a mobile unit, the additional power does not improve the link significantly. The additional power above the aggregate signal strength does however cause interference to other mobile units. The fourth method is based on eliminating the additional signal strength above the desired operation aggregate signal strength to each mobile unit.

The handoff process of the fourth method is summarized in the following steps.

1: Mobile unit is communicating with base station X through sector alpha antenna meaning base station X, sector alpha is identified as a member of the Active Set.

2: Mobile unit monitors the pilot signal from base station Y, sector beta antenna and base station Y, sector beta is identified as a member of the Neighbor Set. The pilot signal strength from base station Y, sector beta antenna exceeds a predetermined threshold.

3: Mobile unit identifies base station Y, sector beta as a member of the Candidate Set and informs base station X through sector alpha antenna. Mobile unit transmits the signal strength it perceives from base station X,

sector alpha, base station Y, sector beta, and any other base stations with which the mobile unit is in communication.

4: Base station X passes the signal strength information to the system controller. The system controller sums the signal strengths together in rank order beginning with the largest signal strength until all are summed together or until the desired operation aggregate signal strength is exceeded.

5: If base station Y, sector beta corresponds to one of the signal strengths used in the sum, the system controller designates a new Active Set comprising base station Y, sector beta.

6: Base station Y, sector beta antenna begins to transmit a forward link signal to mobile unit.

7: Base station X through sector alpha antenna updates the mobile unit Active Set to identify base station Y, sector beta.

8: Mobile unit establishes communication with base station Y, sector beta antenna. Mobile unit combines the signals from base station X, sector alpha antenna and base station Y, sector beta antenna.

9: System controller combines or selects between the signal received from base station X, sector alpha, base station Y, sector beta, and any other base station through which communication is established with the mobile unit.

In this manner, a new base station is only added to the Active Set if it is needed to provide the mobile unit with the desired operation aggregate signal strength for optimal performance. As with the other methods, reverse link demodulation in each sector or base station may continue with or without the transmission of the forward link.

When the fourth method as enumerated above does not add base station Y, sector beta in step 5, an alternative stimulus in addition to that listed in step 2 is needed to provide the stimulus to initiate the process at step 3. In the preferred embodiment, at least three different stimulus may exist. First, the mobile unit informs the base station whenever the signal strength of a member of the Candidate Set exceeds the signal strength of any member of the Active Set. Upon receiving such a message, the process resumes with step 3. Also the mobile unit may repeatedly send the base station a list of the signal strengths of the members of the Active Set as a power measurement report message. In the preferred embodiment, as the total aggregate power of the Active Set decreases, the power measurement report message is sent more often. When the total aggregate power falls below a threshold, the base station can request a Candidate and Active Set

signal strength measurement message in which the mobile unit informs the base station of the signal strength of each base station in the Active and Candidate Sets. Upon receiving such a message, the process resumes with step 4. Additionally the base station may request a Candidate and Active Set signal strength measurement message at any time due to some stimulus in the base station and the process may resume with step 4.

Using the fourth method, if a mobile unit in communication with a first and a second base stations enters the coverage area of a third base station, it provides the signal strength received from each of the three base stations to the system controller. If the signal strength of the new base station exceeds the signal strength of one of the two base stations with which communication is established and communication through two base stations is required to provide the mobile unit with the desired operation aggregate signal strength, the next Active Set message from the system controller designates the largest of the two previously active base stations and the new base station thus indicating that communication be terminated through a base station and established with another with the use of one message. In actual implementations the new base station's signal strength would need to exceed the currently active base station's signal strength by some reasonable gating amount. The system operates most effectively when the system is not 'ping ponging' communications between two base stations. The reasonable gating amount acts as hysteresis to prevent the ping pong situation.

There are many variations to the fourth method. The example above was described in terms of sectors of different base stations. The same method applies to sectors of a common base station and to unsectorized base stations. The functionality of the base station and system controller could be divided in many ways. An analogous method may be based on reverse link signal as perceived by the base stations or it could be based on other factors such as signal to noise ratio, frame erasure rate, and bit error rate. The fourth method may be elegantly coupled to one of the first three methods.

An analogous method could be used to remove a base station from the Active Set. Removing a base station from the Active Set as described in U.S. Patent No. 5,267,261 is also mobile unit assisted. The mobile unit monitors the signal strength of each base station through which communication is established. If the signal strength from a base station in the Active Set falls below a threshold for some period of time, the mobile unit informs the base stations through which it is communicating and at

least one base station responds by sending a new Active Set to the mobile unit which does not comprise the base station corresponding to the weak signal.

Applying the principles of the fourth method to the process of removing a base station from the Active Set is summarized in the following steps:

1: Mobile unit is communicating with base station X through sector alpha antenna and base station Y through sector beta antenna meaning base station X, sector alpha and base station Y, sector beta are identified as members of the Active Set.

2: Mobile unit transmits the signal strength it perceives from base station X, sector alpha, base station Y, sector beta, and any other base stations with which the mobile unit is in communication.

3: At least base station X passes the signal strength information to the system controller. The system controller sums the power levels together in rank order beginning with the largest signal strength until all are summed together or until the desired operation aggregate signal strength is exceeded.

4: If base station Y, sector beta does not correspond to one of the signal strengths used in the sum, the system controller designates a new Active Set that does not comprise base station Y, sector beta.

5: At least base station X, sector alpha antenna sends the mobile unit the new Active Set.

6: Base station Y, sector beta antenna terminates transmission of a forward link signal to mobile unit.

The fourth method as applied to removing a base station can also work from the same three variety of stimulus as described above for the process of adding a base station. For example, even if the signal strength received from base station Y, sector beta remains well above the communications threshold, it may be advantages to terminate communication through base station Y, sector beta if the mobile unit receives sufficient power from the other base stations with which it is in communication. Any time a list of the signal strengths of the members of the Active Set is sent from the mobile unit to the base station, the removal process of the fourth method may be executed. In the most efficient preferred embodiment, the addition and removal process of the fourth method are combined into one efficient process.

Each of the four methods defined herein may be combined with one or more of the other methods. Also there are many obvious variations of the embodiments of methods 1, 2, 3, and 4 including the simple rearrangement of steps within each method. The signal strength measurements made by the mobile units and base stations could be replaced by other criteria such as signal to noise ratio, frame erasure rate, and bit error rate. The previous example is based on the use of a pilot signal on the forward link. Signal strength measurements could be the measurement of signals other than a pilot signal whether or not the system comprises a pilot signal.

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.

WE CLAIM:

CLAIMS

1. In a spread spectrum communication system in which a mobile unit user communicates with another system user via at least one base station in a system of base stations as directed by a system controller, a method for directing communications between said mobile unit user and said system of base stations comprising the steps of:

communicating by said mobile unit with a first base station wherein said first base station has an entry on a first list in said mobile unit wherein said first list comprises an entry for each base station with which active communication is established;

measuring at said mobile unit signal strength transmitted by a second base station through which active communication is not established;

providing by said mobile unit to said system controller a measured signal strength of said first base station and said measured signal strength of said second base station; and

comparing at said system controller said measured signal strength of said first base station to a desired operating power and sending said mobile unit a new first list comprising said second base station if said measured signal strength of said first base station is less than said desired operating power and said mobile unit is not in communication with any other base station.

2. The method of claim 1 wherein each base station in said system of base stations transmits a pilot signal and wherein said measured signal strength of said second base station is a measurement of signal strength of said pilot signal transmitted by said second base station.

3. The method of claim 1 further comprising the steps of:

communicating by said mobile unit with a third base station wherein said third base station has an entry on said first list;

providing by said mobile unit to said system controller a measured signal strength of said third base station wherein said measured signal strength of said third base station is less than said measured signal strength of said first base station;

summing at said base station said measured signal strength of said first base station and said measured signal strength of said third base station; and

comparing said summed measured signal strength of said first and third base stations to said desired operating power and sending said mobile unit a new first list comprising an entry corresponding to said second base station if said summed measured signal strength of said first and third base stations is less than said desired operating power.

4. The method of claim 1 further comprising the steps of:

communicating by said mobile unit with a third base station wherein said third base station has an entry on said first list;

providing by said mobile unit to said system controller a measurement of signal strength of said third base station wherein said measured signal strength of said third base station is less than said measured signal strength of said first and second base stations; and

sending said mobile unit a new first list comprising an entry corresponding to said second base station if said measured signal strength of said first base station is less than said desired operating power.

5. The method of claim 4 wherein said measured signal strength of said third base station is less than said measured signal strength of said first and second base stations by a predetermined threshold amount.

6. The method of claim 4 further comprising the steps of:

summing at said system controller said measured signal strength of said first base station and said measured signal strength of said second base station; and

sending said mobile unit a new first list comprising an entry corresponding to said third base station only if said sum of said measured signal strengths of said first and second base stations is less than said desired operating power.

7. The method of claim 1 wherein said first base station and said second base stations are two different sectors of a common base station cell site.

8. The method of claim 1 wherein said first base station is a multisectored base station and wherein said measured signal strength of said first base station corresponds to a signal strength from a single sector thereof.

9. The method of claim 1 wherein said step of providing by said mobile unit to said system controller said measured signal strength of said first base station and said measured signal strength of said second base station is performed because said measured signal strength of said second base station exceeds said measured signal strength of said first base station.

10. The method of claim 1 wherein said step of providing by said mobile unit to said system controller said measured signal strength of said first base station and said measured signal strength of said second base station is performed periodically at a variable rate.

11. The method of claim 10 wherein said variable rate is a function of a rate at which of frame errors occur.

12. The method of claim 1 wherein said step of providing by said mobile unit to said system controller said measured signal strength of said first base station and said measured signal strength of said second base station is performed in response to a request from said system controller.

13. The method of claim 1 wherein said step of providing by said mobile unit to said system controller said measured signal strength of said first base station and said measured signal strength of said second base station is performed because said measured signal strength of said second base station exceeds a predetermined threshold.

14. The method of claim 1 further comprising the step of receiving and demodulating at said second base station an information signal transmitted by said mobile unit independent of whether said second base station has an entry on said first list or said new first list.

15. In a spread spectrum communication system in which a mobile unit user communicates with another system user via at least one base station in a system of base stations as directed by a system controller, a method for directing communications between said mobile unit user and said system of base stations comprising the steps of:

communicating by said mobile unit with a first base station wherein said first base station has an entry on a first list in said mobile unit wherein said first list comprises an entry for each base station with which active communication is established;

measuring at said mobile unit signal strength transmitted by a second base station;

comparing said measured signal strength of said second base station to a first predetermined level;

providing by said mobile unit to said system controller a measurement of signal strength of said first base station and said second base station if said measured signal strength of the second base station exceeds said first predetermined level; and

comparing at said system controller said measured signal strength of said first base station to a desired operating power and sending said mobile unit a new first list comprising said second base station if said measured signal strength of said first base station is less than said desired operating power and said mobile unit is not in communication with any other base station.

16. In a spread spectrum communication system in which a mobile unit user communicates with another system user via at least one base station in a system of base stations as directed by a system controller, a method for directing communications between said mobile unit user and said system of base stations comprising the steps of:

communicating by said mobile unit with a first base station wherein said first base station has an entry on a first list in said mobile unit wherein said first list comprises an entry for each base station with which active communication is established;

measuring at said mobile unit a communication quality index corresponding to a second base station wherein said second base station does not have an entry on said first list;

providing by said mobile unit to said system controller a measured quality index of said first base station and said measured quality index of said second base station; and

comparing at said system controller said measured quality index of said first base station to a desired operating index and sending said mobile unit a new first list comprising said second base station if said measured signal strength of said first base station does not meet said desired operating index.

17. The method of claim 16 wherein said measured quality index of said first and second base stations is a frame erasure rate.

18. The method of claim 16 wherein said measured quality index of said first and second base stations is a signal to noise ratio.

19. The method of claim 16 wherein said measured quality index of said first and second base stations is a bit error rate.

20. A method for improving the signal-to-interference ratio in a communication system having a set of base stations with at least one base station comprised of multiple sectors comprising the steps of:

establishing communication between a mobile unit and a first sector of said base station;

establishing communication between said mobile unit and a second sector of said base station;

measuring signal strength of a signal from said mobile unit received through said first sector;

measuring signal strength of a signal from said mobile unit received through said second sector;

comparing the signal strength of said signal from said mobile unit received through said first sector and the signal strength of said signal from said mobile unit received through said second sector to identify the sector receiving the weakest signal of said signals from said mobile unit received through said first and said second sector; and

reducing signal strength of a signal from said identified sector to said mobile unit.

21. A method for reducing interference in a communication system having a base station comprised of multiple sectors comprising the steps of:

receiving through a first sector antenna of said base station a first signal from a mobile unit;

receiving through a second sector antenna of said base station a second signal from said mobile unit;

transmitting through said first sector antenna a third signal to said mobile unit;

transmitting through said second sector antenna a fourth signal to said mobile unit;

measuring the signal strength of said first signal;

measuring the signal strength of said second signal wherein the signal strength of said second signal is less than the signal strength of said first signal; and

terminating the transmission of said fourth signal.

22. A method for reducing interference in a communication system having a base station comprised of multiple sectors comprising the steps of:

receiving through a first sector antenna of said base station a first signal from a mobile unit;

receiving through a second sector antenna of said base station a second signal from said mobile unit;

transmitting through said first sector antenna of said base station a third signal to said mobile unit;

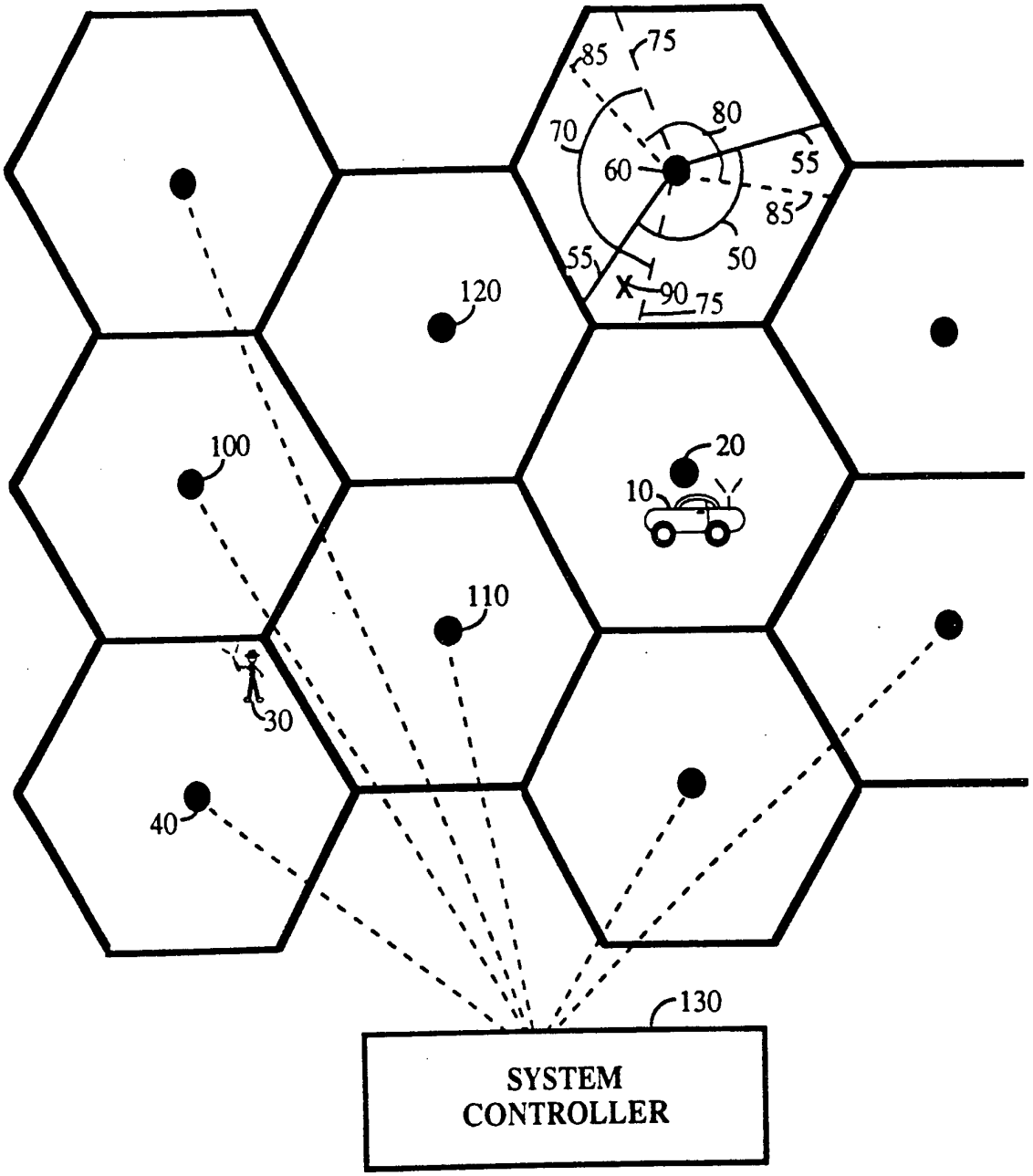
transmitting through said second sector antenna of said base station a fourth signal to said mobile unit;

measuring the signal strength of said third signal at said mobile unit;

measuring the signal strength of said fourth signal at said mobile unit wherein the signal strength of said fourth signal is less than the signal strength of said third signal;

providing by said mobile unit said signal strength of said third and fourth signals to said base station; and

terminating the transmission of said fourth signal.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80
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SYSTEM
CONTROLLER

FIG. 1

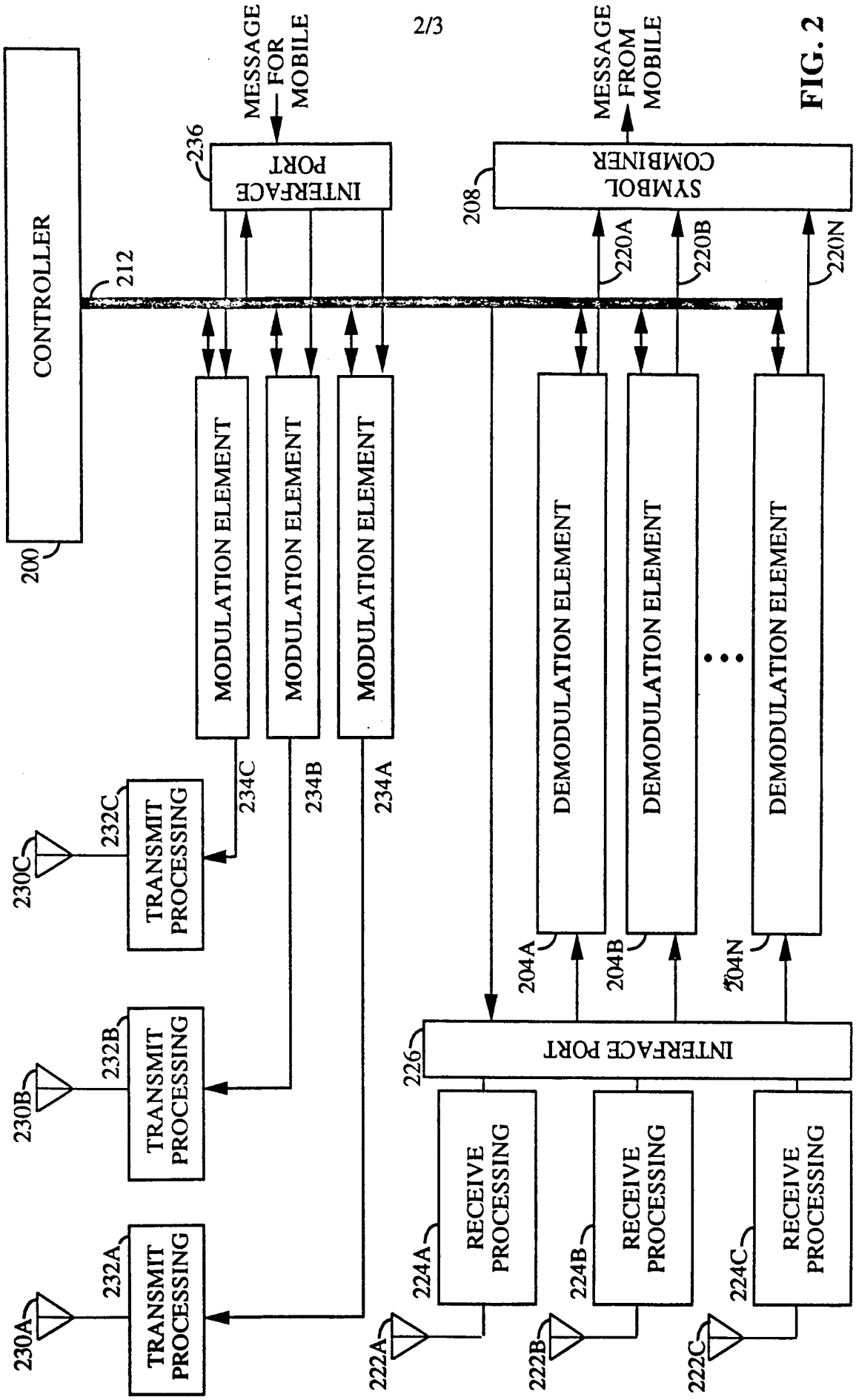
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FIG. 2

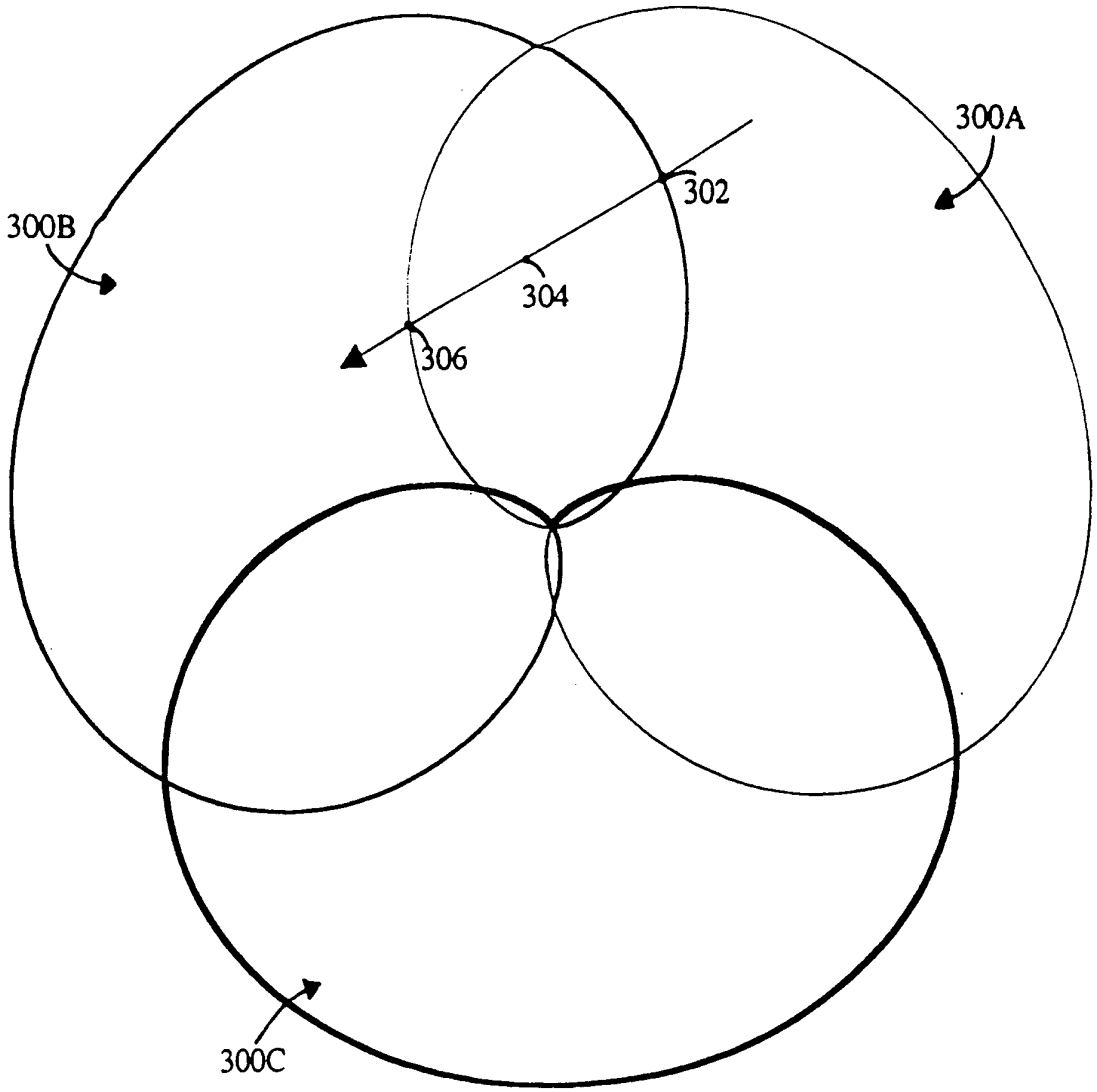

FIG. 3

INTERNATIONAL SEARCH REPORT

Intern al Application No
PCT/US 94/12459

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04Q7/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04Q H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	WO,A,93 11627 (MOTOROLA) 10 June 1993 see page 16, line 7 - page 17, line 8 see page 18, line 24 - page 19, line 15	21,22 1,2,7-19 20
Y A	42TH VEHICULAR TECHNOLOGY SOCIETY CONFERENCE, 10 May 1992, DENVER, US pages 823 - 826 ÖSTLING 'Handover with Simulcasting' see the whole document	1,2,7-19 20-22
Y A	WO,A,91 07020 (QUALCOMM) 16 May 1991 see page 6, line 9 - page 9, line 29	1,2,7-19 20-22
A	WO,A,92 17954 (PACTEL) 15 October 1992 see claims -/--	1,7,8, 15,22

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 February 1995	08. 03. 95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Janyszek, J-M

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INTERNATIONAL SEARCH REPORT

Intern al Application No
PCT/US 94/12459

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 532 485 (ERICSSON) 17 March 1993 see abstract	10
A	WO,A,93 07702 (QUALCOMM) 15 April 1993 see page 6, line 1 - page 8, line 17 see page 31, line 33 - page 32, line 21	11,12, 17-19

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intern al Application No
PCT/US 94/12459

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		BR-A-	9205587	27-09-94
		DE-T-	4294251	18-11-93
		FR-A-	2686202	16-07-93
		GB-A-	2267796	15-12-93
		JP-T-	6505613	23-06-94
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		AU-A-	6904191	31-05-91
		CN-A-	1051832	29-05-91
		EP-A-	0500775	02-09-92
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