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BASE STATION HANDOVER IN A HYBRID GSM/CDMA NETWORK

FIELD OF THE INVENTION

5 The present invention relates generally to wireless telecommunications, and specifically to advanced cellular telephone networks.

BACKGROUND OF THE INVENTION

10 The Global System for Mobile (GSM) telecommunications is used in cellular telephone networks in many countries around the world. GSM offers a useful range of network services and standards. Existing GSM networks are based on time-division multiple access (TDMA) digital communications technology. In a TDMA-based cellular network, each mobile subscriber unit communicates with only a single base station at any given time. When a
15 subscriber moves from one cell to another, a "hard handover" takes place, in which the base station with which the subscriber has been communicating breaks off its link with the subscriber, and a new base station takes over.

 Code-division multiple access (CDMA) is an improved digital communications technology, which affords more efficient use of radio
20 bandwidth than TDMA, as well as a more reliable, fade-free link between cellular telephone subscribers and base stations. The leading CDMA standard is IS-95, promulgated by the Telecommunications Industry Association (TIA). This standard provides "soft handover" (or "handoff") capability, wherein in moving from one cell to another, the subscriber unit is temporarily in contact
25 with two or more base stations at the same time. This soft handover, which is made possible by the code-division approach, decreases the likelihood of a loss of connection, which can happen frequently in hard handovers.

 PCT patent application PCT/US96/20764, which is incorporated herein by reference, describes a wireless telecommunications system that uses a
30 CDMA air interface (i.e., basic RF communications protocols) to implement GSM network services and protocols. Using this system, at least some of the TDMA base stations (BSSs) and subscriber units of an existing GSM network would be replaced or supplemented by corresponding CDMA equipment.

CDMA BSSs in this system are adapted to communicate with GSM mobile switching centers (MSCs) via a standard GSM A-interface. The core of GSM network services is thus maintained, and the changeover from TDMA to CDMA is transparent to users.

5 Hybrid cellular communications networks, incorporating both GSM and CDMA elements, are also described in PCT patent publications WO 95/24771 and WO 96/21999, and in an article by Tscha, et al., entitled "A Subscriber Signaling Gateway between CDMA Mobile Station and GSM Mobile Switching Center," in Proceedings of the 2nd International Conference on Universal
10 Personal Communications, Ottawa (1993), pp. 181-185, which are incorporated herein by reference. None of these publications deals with specific issues of how to perform efficient handovers of subscriber units between different base stations in such hybrid networks.

 PCT patent application PCT/US97/00926, which is also incorporated
15 herein by reference, describes methods of intersystem handover between CDMA and TDMA BSSs in a hybrid GSM/CDMA telecommunications system. A GSM/TDMA BSS generates pilot beacon signals in accordance with CDMA technology. During a telephone call, a subscriber unit detects the pilot signals and notifies a base station controller that the signals have been detected. The
20 subscriber unit is then handed over from the CDMA to the TDMA BSS without interrupting the call.

SUMMARY OF THE INVENTION

 It is an object of the present invention to provide methods and apparatus
25 for use in a mixed TDMA/CDMA cellular communications network.

 It is a further object of some aspects of the present invention to provide improved methods and apparatus enabling handover of a subscriber unit between TDMA and CDMA base stations without interrupting communications.

30 In preferred embodiments of the present invention, a mixed GSM/CDMA cellular communications system includes both TDMA and CDMA base stations, jointly controlled by a mobile switching center (MSC).

Systems of this type are described generally in the above-mentioned PCT patent applications, which are incorporated herein by reference. A subscriber unit in the network, also referred to herein as a mobile station (MS), is capable of communicating with both types of base stations, by appropriately switching
5 between TDMA and CDMA air interfaces, while preferably using GSM network protocols over both types of interface. It is a feature of preferred embodiments of the present invention that the communications system may be based on an existing GSM/TDMA infrastructure, with the addition of CDMA BSSs, and with substantially no other modification to the existing infrastructure.

10 In order to determine when a handover should take place, a MS in communication with a current base station of one type (CDMA or TDMA) monitors RF signals originating from another base station, which may be a base station of the other type (TDMA or CDMA, respectively). A message sequence between the current base station and the MS enables the MS to acquire
15 appropriate synchronization information with regard to the new base station, and report back on this information to the current base station. The information is used by the system to enable the MS to establish an air interface with the new base station, whereupon the handover takes place without substantially interrupting communications between the MS and the network.

20 In the context of the present patent application, such handovers between base stations are referred to as "mobile-assisted handovers." Mobile-assisted handover is used in GSM and in CDMA systems known in the art, wherein a mobile station measures and reports on the strength of signals received from a base station transceiver in a neighboring cell before being handed over to that
25 cell. In hybrid GSM/CDMA systems that have been proposed to date, however, mobile stations are presumed to be capable of receiving signals from either a CDMA or a TDMA base station at any given time (or a CDMA beacon associated with a TDMA base station, as in the above-mentioned PCT patent application PCT/US97/00926), but not both, and are therefore not capable of
30 providing this type of assistance. The provision of mobile-assistance in accordance with the principles of the present invention enables handovers to be conducted more smoothly and reliably than would otherwise be possible.

In some preferred embodiments of the present invention, the MS switches between TDMA and CDMA operation in the course of a telephone call, according to instructions received from the base station with which the unit is in communication. Before the handover is to take place, the MS receives signals from both TDMA and CDMA base stations, and reports back to the base station regarding the signals it is receiving. The information thus reported is reported back to and used by the BSC to initiate the handover. Preferably, the MS comprises a single radio transceiver, and therefore, at any given moment the MS can communicate with either the TDMA or CDMA base station, but not both. (In accordance with the principles of IS-95, however, as described hereinabove, the unit can communicate with more than one CDMA base station at once.) It is noted further that each GSM/TDMA base station has its own synchronization clock, to which the MSs in communication therewith are synchronized, while the CDMA base stations are mutually synchronized to a real time of day. Therefore, in switching between the TDMA and CDMA stations, the MS in each case acquires and synchronizes its operation to the appropriate clock signal without substantially interrupting the telephone call.

In some of these preferred embodiments, the MS is in communication with a CDMA base station, when it is determined that the unit may be handed over to a GSM/TDMA base station. CDMA transmission by the MS transceiver is interrupted temporarily, during which time the unit performs a GSM neighbor scan, generally in accordance with GSM standards, to acquire and synchronize to the TDMA base station. Preferably, the CDMA transmission is interrupted for a single frame, typically 20 msec long, creating an idle time slot in accordance with the IS95 standard. After the TDMA base station is identified, and suitable messages have been exchanged, a traffic channel between the base station is opened, and the MS is switched to the TDMA base station while interruption of a telephone call being conducted by the MS is substantially minimized.

In others of these preferred embodiments, the MS is in communication with a TDMA base station, when it is determined that the unit may be handed over to a CDMA base station. In order to synchronize with the CDMA station, the MS acquires the time of day, preferably by receiving an accurate time of day

from the TDMA base station, wherein the GSM network is provided with equipment necessary to generate and broadcast the time of day. Preferably, the network includes a cell broadcast system (CBS), in accordance with the GSM standard, which is used to receive the time of day, provided, for example, by the Global Positioning System (GPS) or received from one or more of the CDMA base stations, and broadcast it through the network to the MSs. Alternatively, the MS temporarily interrupts TDMA reception in order to acquire and synchronize to the time of day of the CDMA station. Thus, although a certain degradation of the signal may result from the TDMA time slot(s) lost in this fashion, the mobile-assisted handover from TDMA to CDMA is generally more reliable and less disturbing to a user of the MS than would otherwise be possible.

Although preferred embodiments are described herein with reference to MSs having a single transceiver for TDMA and CDMA use, it will be appreciated that the principles of the present invention may similarly be applied using subscriber units and system hardware of other types, and particularly using a subscriber unit having separate or only partially integrated TDMA and CDMA transceivers.

There is therefore provided, in accordance with a preferred embodiment of the present invention, in a mobile wireless telecommunications system, which includes base stations of a first type operating according to a first air interface, and base stations of a second type operating according to a second air interface, a method for handing over a mobile station in the system from a first base station, which is of the first type, to a second base station, which is of the second type, including:

- establishing a communications link over the first air interface between the mobile station and the first base station;

- receiving data from the mobile station responsive to a signal received by the mobile station over the second air interface from the second base station, substantially without breaking the communications link with the first base station; and

- handing over the mobile station from the first to the second base station responsive to the data received therefrom.

Preferably, receiving the data includes receiving a measurement of signal strength, and handing over the mobile station includes comparing measurements of signal strengths from the first and second base stations and handing over the mobile station responsive to the comparison. Preferably, receiving the data includes applying a weighting factor to the measurement of signal strength, wherein applying the weighting factor includes varying the factor according to a network condition in the system. Further preferably, applying the weighting factor includes transmitting a weighting factor over the communications link to the mobile station, which applies the weighting factor to the measurement.

Preferably, receiving the data includes receiving an identification of the second base station based on decoding by the mobile station of the signal received over the second air interface.

In a preferred embodiment, transmitting from the first base station to the mobile station a list of frequencies of base stations of the second type in the system, such that the mobile station seeks to receive the signal at a frequency in the list.

Preferably, handing over the mobile station includes transmitting a handover command from the first base station.

Preferably, establishing the communications link and receiving the data responsive to the signal include establishing the link and receiving the signal at the mobile station using a single RF transceiver in the mobile station.

In a preferred embodiment, one of the first and second air interfaces includes a TDMA interface, and the other of the interfaces includes a CDMA interface, wherein the TDMA interface preferably includes a GSM interface, and wherein the CDMA interface is configured to convey GSM network messages. Preferably, the CDMA interface is based on an IS-95 standard.

Preferably, establishing the communications link includes using a single radio resource management protocol layer to manage the first air interface, and wherein handing over the mobile station includes using the single radio resource management protocol layer to manage the second air interface.

Further preferably, receiving the data from the mobile station includes defining an area of overlap between a first region served by the first air

interface and a second region served by the second air interface, and triggering the mobile station to receive the data when the mobile station is in the area of overlap.

In a preferred embodiment, the first air interface includes a CDMA interface, and wherein the second air interface includes a GSM/TDMA interface, and receiving data from the mobile station includes gating the mobile station to interrupt a CDMA communications link so as to receive and decode a GSM/TDMA signal. Preferably, gating the mobile station includes interrupting CDMA communications for the duration of an IS-95 frame, wherein receiving the data includes receiving an identification of the second base station based on decoding of GSM frequency correction and synchronization channels of the signal by the mobile station.

In another preferred embodiment, the first air interface includes a GSM/TDMA interface, and the second air interface includes a CDMA interface, and receiving the data from the mobile station includes controlling the mobile station to interrupt the communications link so as to receive and decode a CDMA signal.

Preferably, receiving the data includes conveying time of day information through the GSM/TDMA interface. Further preferably, conveying the time of day information includes broadcasting time of day information through the system using a GSM cell broadcast service, wherein broadcasting the time of day information includes receiving a time of day and an associated GSM frame number from a transceiver in communication with a base station of the first type in the system. Preferably, the mobile station decodes a sync channel of the CDMA signal so as to derive the time or day.

Alternatively or additionally, receiving the data includes conveying a GSM cell broadcast service message to the mobile station to initiate a search by the mobile station for a signal from a base station of the second type. Preferably, conveying the GSM cell broadcast service message to the mobile station includes conveying the message so as to be received by the mobile station while the mobile station is operating in a dedicated mode.

Preferably, receiving the data from the mobile station includes receiving an identification of a CDMA pilot beam decoded by the mobile station. Further

preferably, the method includes mapping the second base station as a GSM base station so as to control the handover.

Preferably, controlling the mobile station includes controlling the mobile station to receive the CDMA signal during a first TDMA time slot and to
5 decode the signal during a subsequent TDMA time slot while communicating with the base station over the TDMA interface so as to generate the data to be received by the base station.

There is further provided, in accordance with a preferred embodiment of the present invention, a method for conveying time of day information to a
10 mobile station in a GSM wireless telecommunications system, including:

inputting the time of day information to the system; and
broadcasting the information to the mobile station over the system.

Preferably, the GSM wireless telecommunications system includes a cell broadcast system, and broadcasting the time of day information includes
15 broadcasting the information over the cell broadcast system. Preferably, broadcasting the time of day information includes broadcasting a message so as to be received by the mobile station while the station is operating in a dedicated mode.

Further preferably, broadcasting the time of day information includes
20 receiving a time of day and an associated GSM frame number from a transceiver in communication with the system, and the method includes synchronizing the mobile station to a CDMA transmission signal using the time of day information.

In a preferred embodiment, the method includes determining a location
25 of the mobile station responsive to a transmission thereby of the time of day information to a plurality of base stations in the system.

Preferably, inputting the time of day includes opening a data call from a transceiver having the time of day information to the cell broadcast center, wherein opening the data call preferably includes receiving time of day
30 information from a GPS device. Alternatively, opening the data call includes receiving time of day information from a CDMA cell associated with the GSM system.

There is further provided, in accordance with a preferred embodiment of the present invention, in a GSM mobile wireless telecommunications system, which includes a first base station subsystem and a second base station subsystem, at least one of which subsystems operates according to a CDMA air interface, a method for handing over a mobile station in the system from first to the second base station subsystem, including:

mapping the at least one of the first and second subsystems that operates according to the CDMA air interface as a GSM/TDMA subsystem;

establishing a communications link between the mobile station and the first base station subsystem, so that the mobile station receives a first signal from the first base station subsystem;

receiving data from the mobile station responsive to a second signal received by the mobile station from the second base station subsystem, substantially without breaking the communications link with the first base station subsystem;

comparing the strengths of the first and second signals, substantially as though both the first and second base station subsystems were GSM/TDMA subsystems; and

handing over the mobile station from the first to the second base station subsystem responsive to comparison of the signal strengths.

Preferably, mapping the at least one of the subsystems that operates according to the CDMA air interface includes assigning to the subsystem a GSM frequency and location.

Further preferably, establishing the communications link and handing over the mobile station include conveying messages between the first and second subsystems and a mobile switching center in the system via a GSM A-interface. Preferably, both the first and second base station subsystems operate according to the CDMA air interface, wherein handing over the mobile station includes conveying a new IS-95 long code through the A-interface, substantially without violating A-interface protocols.

Preferably, receiving the data from the mobile station includes applying a weighting factor to the second signal, and wherein comparing the strengths of the signals includes comparing the weighted signal, wherein applying the

weighting factor includes conveying the weighting factor to the mobile station, which applies the weighting factor to the second signal. Preferably, applying the weighting factor includes varying the factor according to a network condition in the system.

5 There is also provided, in accordance with a preferred embodiment of the present invention, wireless communications apparatus, for use in a mobile telecommunications system, including:

 a base station of a first type which transmits and receives a first signal according to a first air interface;

10 a base station of a second type which transmits and receives a second signal according to a second air interface; and

 a mobile station, which receives the second signal over the second air interface from the base station of the second type while maintaining a communication link over the first air interface with the base station of the first type, and which transmits data to the base station of the first type responsive to the second signal so that the mobile station is handed over from the first to the second base station responsive to the transmitted data.

 Preferably, the data transmitted by the mobile station includes a measurement of signal strength, such that the mobile station is handed over responsive to a comparison of signal strengths of the first and second signals. Preferably, a weighting factor is applied to the measurement of signal strength, wherein the weighting factor is varied according to a network condition in the system. Preferably, the weighting factor is transmitted over the communications link to the mobile station, which applies the weighting factor to the measurement.

 Further preferably, the mobile station decodes the second signal to determine an identification of the base station of the second type.

 Preferably, the base station of the first type transmits to the mobile station a list of frequencies of mobile stations of the second type in the system, such that the mobile station seeks to receive the second signal at a frequency in the list.

Preferably, the base station of the first type transmits a handover command to the mobile station, whereby the mobile station is handed over from the first to the second base station.

Further preferably, the mobile station includes a single RF transceiver
5 which communicates with both the base stations of the first and second types.

In a preferred embodiment, one of the first and second air interfaces includes a TDMA interface, and the other of the interfaces includes a CDMA interface., wherein the TDMA interface preferably includes a GSM interface, and wherein the CDMA interface is configured to convey GSM network
10 messages. Preferably, the CDMA interface is based on an IS-95 standard. Further preferably, the mobile station uses a single radio resource management protocol layer to manage both the first and second air interfaces.

Preferably, the base station triggers the mobile station to receive the second signal over the second air interface when the mobile station is in an area
15 of overlap between a first region served by the first air interface and a second region served by the second air interface

In a preferred embodiment, the first air interface includes a CDMA interface, and the second air interface includes a GSM/TDMA interface, and the base station of the first type gates the mobile station to interrupt the
20 communications link so as to receive and decode a GSM signal.

Preferably, the mobile station interrupts the link for the duration of an IS-95 frame.

Further preferably, the mobile station processes the second signal to decode GSM frequency correction and synchronization channels of the signal.

25 In another preferred embodiment, the first air interface includes a GSM/TDMA interface, and the second air interface includes a CDMA interface, and the base station of the first type controls the mobile station to interrupt the communications link so as to receive and decode a CDMA signal.

Preferably, the base station of the first type conveys time of day
30 information to the mobile station through the GSM/TDMA interface. Preferably, the apparatus includes a GSM cell broadcast center, which conveys the time of day information through the system to the mobile station using a GSM cell broadcast service, wherein the cell broadcast center receives the time

of day information and an associated GSM frame number from a transceiver in communication with a base station of the first type in the system.

Alternative or additionally, the mobile station decodes a synchronization channel of the CDMA signal so as to derive the time of day.

5 Preferably, the GSM cell broadcast center conveys a cell broadcast service message to the mobile station to initiate a search by the mobile station for the second signal, wherein the mobile station receives the cell broadcast service message while the mobile station is operating in a dedicated mode.

10 Alternatively or additionally, the mobile station processes the CDMA signal to identify a CDMA pilot beam.

Preferably, the mobile station receives the CDMA signal during a first TDMA time slot and processes the signal during a subsequent TDMA time slot while communicating with the base station over the TDMA interface so as to generate the data for transmission to the base station.

15 There is further provided, in accordance with a preferred embodiment of the present invention, apparatus for conveying time of day information to a mobile station in a GSM wireless telecommunications system, including a cell broadcast center, which broadcasts the information to the mobile station using a GSM cell broadcast system.

20 Preferably, the apparatus includes a transceiver in communication with the system, which transmits a time of day and an associated GSM frame number to the cell broadcast center, wherein the transceiver opens a data call through the system to the cell broadcast center so as to convey the time of day and the associated frame number thereto.

25 Preferably, the mobile station is synchronized to a CDMA transmission signal using the time of day information.

Further preferably, the mobile station receives the information from the cell broadcast system while operating in a dedicated mode.

30 There is moreover provided, in accordance with a preferred embodiment of the present invention, apparatus for inputting time of day information to a communications controller in a wireless telecommunications system, including:

a clock signal receiver, which receives the time of day information from a clock source; and

a radio transceiver, which receives the time of day information from the clock signal receiver, and which opens a data call through the system to the communications controller so as to convey the information thereto.

Preferably, the communications controller includes a GSM cell broadcast center, wherein the radio transceiver receives a GSM frame number from a base station in the system, and conveys the frame number to the cell broadcast center together with the time of day information.

Preferably, the clock signal receiver includes a radio receiver which receives the time of day information from a CDMA communications cell, wherein the radio transceiver includes the radio receiver.

Alternatively, the clock signal receiver includes a GPS device.

There is additionally provided, in accordance with a preferred embodiment of the present invention, apparatus for mobile wireless telecommunications in a GSM telecommunications system, including:

a mobile station; and

first and second base station subsystems, transmitting first and second signals to the mobile station, at least one of which is a CDMA signal, and both of which subsystems are mapped in the GSM system as GSM base station subsystems,

wherein the mobile station is handed over from the first to the second subsystem responsive to a comparison of the strengths of the first and second signals received by the mobile station, substantially as though both the first and second base station subsystems operated according to a GSM/TDMA air interface.

Preferably, the subsystem transmitting the CDMA signal is assigned a GSM frequency and location in the system. Further preferably, messages are conveyed between the first and second subsystems and a mobile switching center in the system via a GSM A-interface, wherein both the first and second signals include CDMA signals. Preferably, a new IS-95 long code is conveyed through the A-interface from the second to the first subsystem in order to hand over the mobile station, substantially without violating A-interface protocols.

Preferably, the mobile station applies a weighting factor to the second signal before the signal strengths are compared.

There is further provided, in accordance with a preferred embodiment of the present invention, a mobile station for use in a wireless telecommunications system including CDMA and TDMA base stations, including:

5 a single mobile radio transceiver, which communicates with the CDMA and TDMA base stations;

a modem unit, which encodes signals for transmission by the mobile transceiver and decodes signals received thereby, such that the signals are CDMA-encoded for communication with the CDMA base station and TDMA-encoded for communication with the TDMA base station; and

10 terminal equipment, through which a user of the mobile station communicates with the modem unit.

Preferably, the modem unit encodes the signals in accordance with GSM radio interface layer protocols.

15 Further preferably, the mobile station receives and processes a signal from one of the CDMA and TDMA base stations substantially without breaking a communications link existing between the mobile station and the other one of the CDMA and TDMA base stations.

There is also provided, in accordance with a preferred embodiment of the present invention, a method for conveying messages to a plurality of mobile stations operating in a dedicated mode in a GSM wireless telecommunications system including a cell broadcast service, including:

20 broadcasting the messages to the mobile stations over the cell broadcast service; and

25 receiving the messages at the mobile stations substantially without interrupting the dedicated mode operation of the mobile stations.

There is additionally provided, in accordance with a preferred embodiment of the present invention, apparatus for mobile wireless telecommunications in a GSM telecommunications system, including:

30 a cell broadcast center, which broadcasts messages over a cell broadcast system; and

a mobile station, which receives the messages while communicating in a dedicated mode, substantially without interrupting the dedicated mode communications.

The present invention will be more fully understood from the following detailed description of the preferred embodiments thereof, taken together with the drawings in which:

5 **BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1 is a schematic block diagram of a hybrid GSM/CDMA cellular communications system, in accordance with a preferred embodiment of the present invention;

10 Fig. 2A is a schematic block diagram illustrating communications protocols between a mobile station and base station subsystems in the system of Fig. 1, in accordance with a preferred embodiment of the present invention;

Fig. 2B is a schematic block diagram of a hybrid GSM/CDMA mobile station, in accordance with a preferred embodiment of the present invention;

15 Figs. 3A and 3B are schematic block diagrams illustrating communications protocol stacks between elements of the system of Fig. 1, in accordance with a preferred embodiment of the present invention;

Fig. 4A is a schematic block diagram illustrating handover of a mobile station from a CDMA base station to a GSM base station in the system of Fig. 1, in accordance with a preferred embodiment of the present invention;

20 Fig. 4B is a schematic block diagram illustrating signal flow associated with the handover of Fig. 4A, in accordance with a preferred embodiment of the present invention;

25 Fig. 5 is a schematic block diagram illustrating signal flow associated with provision of time of day information in the system of Fig. 1, in accordance with a preferred embodiment of the present invention;

Fig. 6 is a schematic illustration showing cells in a hybrid GSM/CDMA cellular communications system, useful in understanding a method for handover of a mobile station from a GSM base station to a CDMA base station, in accordance with a preferred embodiment of the present invention;

30 Fig. 7 is a schematic block diagram illustrating signal flow associated with a handover from a GSM base station to a CDMA base station, in accordance with a preferred embodiment of the present invention;

Fig. 8 is a schematic block diagram illustrating handover of a mobile station between CDMA base stations in a hybrid GSM/CDMA cellular communications system, in accordance with a preferred embodiment of the present invention; and

Fig. 9 is a schematic illustration showing signal flow associated with the handover of Fig. 8, in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is now made to Fig. 1, which is a schematic block diagram of a hybrid GSM/CDMA cellular communications system 20, in accordance with a preferred embodiment of the present invention. System 20 is built around a public land mobile network (PLMN) 22, which is based on the GSM communications standard, as described hereinabove. Infrastructure for such networks already exists and is in wide use in many countries, and the present invention has the advantage of enabling gradual introduction of CDMA service in conjunction with such a network without requiring major changes to the existing infrastructure. PLMN 22 comprises at least one mobile-services switching center (MSC) 24, or possibly a number of such centers (although only one MSC is shown here for clarity of illustration), which controls network operations within a geographical area. Among other functions, MSC 24 is responsible for location registration of subscriber units and handover of subscriber units between base stations, as well as linking PLMN 22 to a public switched telephone network (PSTN) and/or packet data network (PDN) 48. The PLMN also comprises a network management center (NMC) 26 and a cell broadcast center (CBC) 28. These functions are described further hereinbelow.

System 20 includes a plurality of mobile stations (MS) 40, which communicate with PLMN 22 via a plurality of base station subsystems (BSS) 30 and 32 over a wireless RF link in one or more of the accepted cellular communications frequencies. MS 40, which is also known as a subscriber unit, is capable of communicating with both GSM BSS 30, using a substantially standard GSM TDMA signaling protocol, and CDMA BSS 32, using CDMA-

based communication methods described hereinbelow. Additionally, although in standard GSM systems, mobile stations can typically receive broadcasts from CBC 28 only in idle mode, MS 40 is capable of receiving such broadcasts during a call through BSS 30, as will be described further hereinbelow. Although for
5 the sake of clarity, only one each of MS 40, GSM BSS 30 and CDMA BSS 32 is shown in Fig. 1, it will be understood that in actuality, system 20 typically comprises a plurality of each of these system elements.

Both GSM BSS 30 and CDMA BSS 32 communicate with and are controlled by MSC 24. Communications between GSM BSS 30 and MSC 24 are
10 substantially in accordance with GSM standards. CDMA BSS 32 is modified relative to the IS95 CDMA standard so as to communicate with PLMN 22 in accordance with GSM standards, and particularly so as to communicate with MSC 24 via the GSM standard A-interface, as further described hereinbelow with reference to Figs. 3A and 3B. BSS 32 also communicates with CBC 28, so as
15 to receive messages to be broadcast over the air, and comprises a radio operation and maintenance center (OMC-R) 38. The OMC-R communicates with NMC 26 over a GSM-standard Q3 interface, preferably using an information model based on the GSM 12.XX series of specifications, which are incorporated herein by reference. Optionally, BSS 32 may be linked to a general
20 packet data service (GPRS) 50, such as has been proposed by the European Telecommunications Standards Institute (ETSI). Alternatively or additionally, BSS 32 may be coupled for transmission of packet data directly to PSTN/PDN 48 (although such a connection is, for the sake of simplicity, not shown in Fig. 1), preferably with a link to the Internet therethrough.

25 Communications between CDMA BSS 32 and MS 40 are built on a CDMA "air interface," which is preferably generally in accordance with the IS95 standard for CDMA communications. BSS 32 is built around a base station controller (BSC) 34, which controls and communicates with a number of base station transceivers (BTS) 36. Each BTS transmits RF signals to and receives RF
30 signals from MS 40 when the MS is within a geographical area, or cell, served by the particular BTS. When during a telephone call, the MS moves from the cell of one CDMA BTS 36 to another, a "soft handover" (or handoff) between the BTSs takes place, as is known in the CDMA art.

There may also be regions of service of system 20, however, which do not have CDMA coverage (i.e., there is no CDMA BTS 36 in such a region), or in which coverage is weak or congested. If MS 40 moves into such a region during a telephone call, the MS is handed over from the CDMA BTS to a BTS associated with GSM BSS 30 without interrupting the call. Similarly, if MS 40 moves from a region served only by GSM BSS 30 into the cell of CDMA BTS 36 during a call, the MS is preferably handed over from the GSM to the CDMA BSS. Methods for performing such handovers between CDMA and GSM/TDMA service and vice versa, as well as between one CMDA BSS 32 and another, are described further hereinbelow. By virtue of such methods and of the architecture of system 20, as shown in Fig. 1, MS 40 receives the benefits of CDMA service in those regions served by system 20 in which the service has been implemented, without losing service in TDMA regions. Transitions between CDMA and TDMA regions are substantially transparent to users of MS 40, because higher-level GSM network protocols are observed throughout the system, and only the lower-level RF air interface is changed during the transition.

Fig. 2A is a block diagram that schematically illustrates communications protocol stacks between MS 40 and BSSs 30 and 32, in accordance with a preferred embodiment of the present invention. MS 40 communicates with GSM BSS 30 over a GSM Um interface, which is based on a standard TDMA air interface, so that substantially no modification is required to BSS 30 or to GSM Layer 1 and Layer 2 standard interface protocols in order to accommodate MS 40. MS 40 communicates with CDMA BSS 32 over a CDMA Um interface, based on a CDMA IS-95 air interface with certain modifications. Subscriber units known in the art are capable of operating over either a GSM Um or a CDMA Um interface, but not both.

In order to sustain both of these interfaces, MS 40 comprises mobile equipment (ME) 42 (Fig. 1), which must include either two radio transceivers, one configured for TDMA operation and one for CDMA, or a single transceiver which can dynamically switch between TDMA and CDMA. The ME includes mobile termination (MT), which supports terminal equipment (TE) 46 for voice

and/or data input and output. In addition, MS 40 comprises a subscriber identity module (SIM) 44, in accordance with GSM standards.

Fig. 2B is a schematic block diagram illustrating MS 40 comprising a single radio transceiver in ME 42, in accordance with a preferred embodiment of the present invention. MS 40 is built around a modem unit 59, including a DSP core 60 capable of generating and processing both TDMA and CDMA signals. Preferably, core 60 comprises an ASIC device, including stand-alone CDMA transmission/reception processing, which is supported by GSM timing logic 64 and a GSM hardware accelerator (or DSP) 62, as well as having a port for SIM 44. Core 60 receives input and delivers output to TE 46. In this case, TE 46 is represented as an audio microphone and speaker, and core 60 performs D/A and A/D conversion, as well as vocoding functions on the audio signals, as are known in the art. Either GSM or CDMA vocoding is applied, depending on whether MS 40 is in contact with GSM BSS 30 or CDMA BSS 32. Core 60 may, additionally or alternatively, be configured to work with TE 46 providing digital data input/output, such as a fax device.

Core 60 outputs digital data, which may be in either TDMA or CDMA format, to a mixed-signal output device 66. Device 66 processes and converts the data to analog baseband form, for input to RF transmitter 68. A duplexer 70 conveys the resultant RF signals via antenna to the GSM or CDMA base station, as appropriate. Signals received from the base station are passed by duplexer 70 through an RF receiver 72 and a mixed-signal input device 74, which performs baseband conversion and AGC functions, to core 60. Preferably, transmitter 68, receiver 72 and mixed-signal devices 66 and 74 are controlled by core 60.

RF transmission and reception by MS 40 are preferably at frequencies in the GSM 900 or 1800 MHz band, for compatibility with existing GSM equipment, particularly BSS 30. Assuming that MS 40 includes only the single transceiver shown in Fig. 2B, operating in the GSM band, CDMA equipment in system 20 must be appropriately configured to operate in this frequency range, as well.

Returning to Fig. 2A, whether MS 40 physically includes one transceiver or two, it must support dual air interface Layers 1 and 2 in its protocol stack, for

operation vis-a-vis GSM BSS 30 and CDMA BSS 32, respectively. The CDMA air interface between MS 40 and CDMA BSS 32 comprises CDMA Layer 1, which operates on a standard IS-95 protocol, and GSM-CDMA Layer 2, in which IS-95 operation is modified to accommodate the needs of GSM network services. Layer 2 supports transmission of frames between MS 40 and BSS 30 or 32. GSM-CDMA Layer 2 includes functionality, such as message ordering, priority and fragmentation, and suspension and resumption of communications, which is normally supported by the standard GSM Layer 2, but not by CDMA IS-95. Vis-a-vis GSM BSS 30, air interface Layers 1 and 2 are in accordance with GSM standards, substantially without modification.

Standard GSM protocols include a third Radio Interface Layer (RIL3), including three sub-layers, above GSM Layer 1 and Layer 2. The lowest of these three RIL3 sub-layers is a Radio Resource (RR) management layer, which supports Mobile Management (MM) and Connection Management (CM) sub-layers above it. The RIL3 sub-layers in GSM BSS 30 are substantially unchanged with respect to the GSM standard, and the GSM MM and CM sub-layers are likewise maintained substantially without change in MS 40. The CM sub-layer supports signaling for call processing, as well as GSM supplementary services and short message service (SMS). The MM sub-layer supports signaling required for locating MS 40, authentication and encryption key management.

In order to support the MM and CM layers, a GSM-CDMA RR layer is introduced in the MS 40 and BSS 32 protocol stacks. The GSM-CDMA RR layer, which manages radio resources and maintains radio links between MS 40 and BSSs 30 and 32, is "aware" of the existence of the dual GSM and CDMA lower layers (Layers 1 and 2) in the MS 40 protocol stack. It invokes the appropriate lower layers in the MS stack to communicate with either the standard RIL3-RR layer over the GSM Um interface or the GSM-CDMA RR layer of BSS 32 over the CDMA Um interface, depending on instructions it receives from the BSS with which it is in communication. The MM and CM layers are not processed by BSS 32, but are rather relayed through between MS 40 and MSC 24 for processing in a manner substantially transparent to the CDMA air interface layers below. The RR layer in the MS stack also controls the handover between

the corresponding air interfaces defined in Layers 1 and 2 and assists in cell selection for the handover, under instructions from MSC 24 and the BSSs.

Regardless of which of the air interfaces is in use, the GSM-CDMA RR layer supports the standard GSM RIL3-MM and CM layers above it. The RR layer preferably offers complete radio resource management functionality as defined by GSM specifications 04.07 and 04.08, which are incorporated herein by reference. Although a "RR" layer *per se* is not defined by the CDMA IS-95 standard, the GSM-CDMA RR layer described herein maintains full IS-95 radio resource functionality, as well.

In accordance with GSM standards, the functionality of the RR layer includes both idle mode operation and dedicated mode services (i.e., services performed during a telephone conversation). The idle mode operation of the RR layer includes automatic cell selection and idle handover between GSM and CDMA cells, as well as between pairs of CDMA cells and pairs of GSM cells, with cell change indication as specified by the GSM standard. The RR layer in idle mode also performs broadcast channel processing, as specified by GSM and CDMA standards, and establishment of RR connections.

In dedicated mode, the RR layer performs the following services:

- Routing services, service request, transfer of messages, and substantially all other functions specified by GSM standards.
- Change of dedicated channels (handover), including hard handovers as described hereinbelow and CDMA-to-CDMA soft and "softer" handovers.
- Mode settings for the RR channel, including transmission mode, type of channel and coding/ decoding/transcoding mode.
- MS parameters management based on IS-95 specifications.
- MS classmark management based on GSM specifications.

It will be understood by those skilled in the art that the above features of the RR layer are listed only by way of a summary, and that additional details and features may be added based on published GSM and CDMA specifications.

Fig. 3A is a block diagram that schematically illustrates protocol stacks used in signaling interfaces between MS 40, CDMA BSS 32 and GSM MSC 24, in

accordance with a preferred embodiment of the present invention. These interfaces enable MS 40 to communicate with GSM MSC 24 over a CDMA air interface. Operation of these interfaces, and particularly message flow through these interfaces, is described in greater detail in the above-mentioned PCT patent application PCT/US96/20764 and incorporated herein by reference. When MS 40 is in communication with MSC 24 via GSM BSS 30, the protocol stacks are in accordance with GSM standards, substantially without modification.

As noted hereinabove, MS 40 exchanges signals with CDMA BSS 32 over the CDMA Um interface, wherein the MS and BSS protocol stacks are modified to include the GSM-CDMA RR layer and Layer 2. In Fig. 3A, a relay layer is shown explicitly in the BSS 32 protocol stack, for conveying RIL3-CM and MM signaling between MS 40 and MSC 24, largely without processing by BSS 32. Other layers involved in the Um interface were described hereinabove with reference to Fig. 2A.

CDMA BSS 32 communicates with GSM MSC 24 over a standard, substantially unmodified GSM A-interface. This interface is based on the GSM SS7 and BSS Application Part (BSSAP) protocols, as are known in the art, preferably in accordance with the GSM 08.08 standard. BSSAP supports procedures between MSC 24 and BSS 32 that require interpretation and processing of information related to single calls and resource management, as well as transfer of call control and mobility management messages between MSC 24 and MS 40. BSS 32 translates CDMA Layer 1 and GSM-CDMA Layer 2 and RR protocols exchanged between the BSS and MS 40 into appropriate SS7 and BSSAP protocols for transmission to MSC 24, and vice versa.

Because CDMA BSC 34 communicates with GSM MSC 24 using the standard A-interface, substantially no modifications are required in the core GSM MSC in order to enable the addition of CDMA BSS 32 to GSM system 20. Furthermore, MSC 24 need not be aware that there is any difference in identity between GSM/TDMA BSS 30 and CDMA BSS 32, since both communicate with the MSC in a substantially identical manner over the A-interface. Preferably, cells associated with BTSs 36 of BSS 32 are mapped by MSC 24 in substantially the same manner as GSM/TDMA cells, and are thus assigned GSM absolute

radio frequency channel number (ARFCN) and base station identity code (BSIC) values, in accordance with the GSM standard. From the point of view of MSC 24, a handover between GSM BSS 30 and CDMA BSS 32, or even between two different CDMA BSSs, is no different from a handover between two GSM
5 BSSs in a conventional GSM/TDMA-based system. The BSIC of the CDMA cells is assigned so as to be distinguishable within system 20 from conventional GSM cells.

Fig. 3B is a block diagram that schematically illustrates protocol stacks involved in conveying voice data between MS 40 and MSC 24 via CDMA BSS
10 32, in accordance with a preferred embodiment of the present invention. Voice data between MS 40 and BSS 32 are coded and decoded by a CDMA vocoder, which may comprise any of the standard IS-95 vocoder protocols known in the art. BSS 32 translates CDMA Layer 1 into GSM E1 TDMA signals, and converts the CDMA vocoded data into PCM A-law companded voice data, in accordance
15 with the requirements of the A-interface standard. MSC 24 thus transmits and receives voice data to and from MS 40 via BSS 32 substantially without regard to the fact that the data between the BSS and the MS are CDMA-encoded, as though MS 40 were operating in GSM/TDMA mode.

Fig. 4A is a schematic block diagram showing details of system 20, useful
20 in understanding a method for mobile-assisted handover of MS 40 from CDMA BSS 32 to GSM BSS 30, in accordance with a preferred embodiment of the present invention. Unlike Fig. 1, BSS 30 is shown here in detail to include a BSC 77 and a plurality of BTSs 78 and 80. Fig. 4A illustrates the handover of MS 40 from one of the BTSs associated with BSS 32, labeled here BTS 76, to BTS 78 of
25 BSS 30. BSS 32 also includes GSM-CDMA BSC 34 and BTSs 36, as described with reference to Fig. 1.

The handover from CDMA BTS 76 to TDMA BTS 78 is preferably initiated by BSS 32 when it is determined that MS 40 is in a location in which such a handover might be desirable. This situation may arise when the signal
30 received from BTS 76 is weak, or when MS 40 is known to be reaching the edge of a CDMA coverage area, or when traffic on CDMA channels is heavy. Alternatively, BSS 32 may instruct MS 40 to seek a signal from BTS 78 (or other GSM BTSs) from time to time independently of any specific pressure to do so.

Fig. 4B is a schematic signal flow diagram, illustrating signals conveyed between MS 40, BSSs 30 and 32 and MSC 24 in the handover process of Fig. 4A, in accordance with a preferred embodiment of the present invention. BSC 34 instructs MS 40 to begin a gated search for neighboring GSM BTSs, wherein for
5 brief periods, MS 40 interrupts its communications with BTS 76 to search for and receive TDMA signals. Preferably, MS 40 is operating on the IS95 standard, which enables CDMA transmission to be idle for the duration of a 20 msec frame, during which the GSM TDMA neighbor scan can take place without substantially interrupting CDMA voice communications. Alternatively, such
10 an idle period may also be introduced under other CDMA standards, as well. Further alternatively, as noted hereinabove, MS 40 may comprise separate TDMA and CDMA transceivers that can be used simultaneously for this purpose.

Preferably, BSC 34 provides MS 40 with a list of the frequencies of
15 neighboring GSM TDMA cells, such as those associated with BTSs 78 and 80. Such a list is useful in reducing the time needed to search for and find BTS 78, since MS 40 will search only at the frequencies of the cells on the list. The list is updated as MS 40 moves from one cell to another and is maintained during handovers between TDMA and CDMA base stations.

20 When MS 40 receives a signal at the frequency of BTS 78, it attempts to decode the GSM frequency correction (FCCH) and synchronization (SCH) channels in the signal. This decoding may take several of the gated CDMA idle periods to complete. Once decoding is successfully accomplished, MS 40 determines the power level of the TDMA signal and reports it to BSS 32
25 together with the GSM cell identity. Based on this information, the BSS determines whether and when a handover is to take place. At an appropriate time, BSS 32 initiates a handover request to MSC 24. MSC 24 conveys the handover request to GSM BSS 30, which acknowledges the request. GSM BSS 30 then conveys a handover command via MSC 24 and CDMA BSS 32 to MS 40,
30 and GSM BSS 30 opens a new traffic channel (TCH) with the MS. At this point the handover is complete, and MS 40 switches over to BTS 78.

The decision to initiate the handover may take place whenever the signal from GSM BTS 78 becomes stronger than that of CDMA BTS 76, but preferably

other criteria are applied. For example, since CDMA channels typically offer better transmission quality than GSM channels, the handover is preferably initiated only when the GSM signal is stronger than the CDMA signal by some predetermined weighting factor. The factor may be preprogrammed in system 20, or it may be set by a user of MS 40. It may also be adjusted dynamically in response to such parameters as the geographical location of the MS and the relative amounts of traffic on the CDMA and TDMA channels in the system.

Fig. 5 is a schematic block diagram showing signal flow in system 20 (Fig. 1) associated with providing the time of day to relevant GSM BSCs and BTSs in the system, in accordance with a preferred embodiment of the present invention. Ordinarily, GSM BSSs in system 20 would not be informed of the time of day, since this information is not required by the GSM standard. On the other hand, the IS-95 standard requires that CDMA base stations be synchronized, since such synchronization is necessary for identification and decoding of the signals and for soft handover between cells. Therefore, for mobile-assisted handover of MS 40 from TDMA BTS 78 to CDMA 76 (as shown in Fig. 4A, but with the direction of the handover arrow reversed), it is necessary that the time of day be provided by system 20.

The method of Fig. 5 allows the time of day to be provided in system 20 without the necessity of hardware or software changes in MSC 24 or in GSM BSS 30 or BTSs 78 and 80, by using CBC 28, which is a standard part of PLMN 22, to broadcast the time of day over the system. Ordinary, CBC 28 provides a cell broadcast service (CBS) in accordance with GSM interface standards 03.41 and 03.49, enabling general short messages to be broadcast unacknowledged to defined geographical areas within system 20. The messages are received by MS 40 while it is in standby, or idle, mode (i.e., when the MS is not involved in a telephone call). For the purpose of providing time of day information, however, MS 40 is preferably capable of receiving CBS messages not only when it is in an idle mode, as prescribed by GSM standards, but also when the MS is in a dedicated mode, i.e., during a telephone call. The use of the CBS to provide time-of-day information to MS 40 is desirable particularly when the MS includes only a single radio transmitter and receiver, as shown in Fig. 2B; when

dual radios are used, one for CDMA and the other for TDMA, the CDMA radio can receive the time of day while the TDMA radio is in use in a telephone call.

In a preferred embodiment of the present invention, CBS messages are also used to initiate a search by MS 40 for neighboring cells, as described above
5 with reference to Fig. 4B.

A special MS 90, which is equipped with a GPS (global positioning system) receiver 91, is located in one or more of the GSM/TDMA cells of system 20 in which the time of day is needed. In Fig. 5, MS 90 receives the time of day from receiver 91 and associates the time with an identification of the
10 concurrent TDMA frame number, based on synchronization signals transmitted by BTS 78, in accordance with the GSM standard. Alternatively, MS 90 may be configured to receive the time of day from a CDMA BSS, in which case GPS receiver 91 is not required. MS 90 opens a data call via BTS 78, BSC 77, MSC 24 and PSTN/PDN 48 to CBC 28, and sends to the CBC the cell identification and
15 correspondence of the current time of day and frame number. Alternatively, MS 90 may convey the information by any other suitable method, such as using the GSM SMS. CBC 28 then transmits this information over the CBS to the cell, so that MS 40 receives the time of day even when it is operating in GSM/TDMA mode. Therefore, when MS 40 is to be handed over to CDMA BTS 76, there is
20 no need to acquire synchronization/time of day information from the CDMA BTS, and the handover can proceed more rapidly and smoothly.

Introducing the time of day into system 20 also has benefits for the GSM portion of the system in itself, without connection to CDMA handover. For example, MS 40 can transmit its time of day to different GSM BTSs 78 and 80,
25 and the timing delay from the MS to each of the BTSs can be measured and used to determine the location of the MS.

Fig. 6 is a schematic map of overlapping GSM/TDMA cells 92 and CDMA cells 94 in network 20, illustrating aspects of mobile-assisted handover from GSM BTS 78 to CDMA BTS 76, in accordance with a preferred
30 embodiment of the present invention. An operator of system 20 will recognize that when MS 40 is located in any of cells 1-5 shown in Fig. 6, a TDMA/CDMA handover may take place. Therefore, CBC 28 will broadcast a CBS message to

all dual-mode (GSM/CDMA) MSs in these cells, including the following information and instructions:

- MS to begin search for CDMA signals (search trigger).
- Frequencies of CDMA BTSs in overlapping and neighboring cells.
- 5 • GSM mapping of CDMA cells 94, according to GSM MSC 24.
- Identification of the time of day with the current TDMA frame number, preferably as derived from MS 90, although other methods may also be used to supply the time of day.
- Optionally, the factor by which the CDMA signal strength is to be
10 multiplied for comparison with the TDMA signal, as described hereinabove.

There is no need for such a message to be broadcast in cells 6-10. Furthermore, it will be understood that only the dual-mode MSs are programmed to receive and interpret this message, while ordinary GSM/TDMA MSs will ignore it.

- 15 The CBS message triggers and enables the dual-mode MSs to gather and provide information to GSM BSS 30 and MSC 24 for assistance in making the handover to one of the CDMA BSSs, unlike hybrid GSM/CDMA systems that have been suggested in the prior art.

Fig. 7 is a block diagram illustrating signal flow in system 20 associated
20 with a mobile-assisted handover from BTS 78 to BTS 76, in accordance with a preferred embodiment of the present invention. As noted above with reference to Fig. 6, the handover begins with the transmission of the search trigger and other information. The search trigger is transmitted periodically by BTS 78 whenever MS 40 is in one of GSM cells 1-5 (Fig. 6), or in response to some other
25 preprogrammed condition.

Upon receiving the trigger, MS 40 switches off its TDMA traffic with BTS 78 and tunes its receiver to an appropriate CDMA frequency for a short period, preferably for about 5 msec. Then, after the MS has resumed communicating with BTS 78, it attempts to decode any CDMA signal it received in order to
30 identify a pilot beam of the BTS whose transmission it has received, say from BTS 76. As noted above, BTS 76 is mapped in system 20 as though it were a conventional GSM/TDMA BTS. MS 40 therefore transmits a report message

back to GSM BTS 78 indicating the power of the signal it received from BTS 76 (optionally multiplied by the relative CDMA/TDMA weighting factor mentioned above), together with the GSM system map identification of BTS 76. From the point of view of GSM BSS 30 and MSC 24, there is no substantial
5 difference between the message transmitted by MS 40 in this case and the message that would be transmitted as the result of an ordinary GSM neighbor scan.

This process of measurement and reporting goes on until BSS 30 determines that MS 40 should be handed over to BTS 76. At this point, BSS 30
10 conveys a message to MSC 24 indicating that the handover is required. MSC 24 passes a handover request on to BSS 32, which sends an acknowledgment back via MSC 24 to BSS 30. GSM BSS 30 then gives a handover command to MS 40, and a traffic channel is opened between MS 40 and CDMA BTS 76, completing the handover.

15 The process described above thus allows mobile-assisted handover from GSM/TDMA BSS 30 to CDMA BSS 32 with high speed and reliability, and with minimal interruption to service in the middle of a call during which the handover takes place. For the purposes of this handover, GSM cells in system
20 receive time of day information, and the CDMA cells are mapped into the GSM system, at minimal hardware expense and substantially without the necessity of reprogramming existing GSM system elements.

A similar TDMA-CDMA handover process may be carried out even in the absence of time-of-day information at GSM BSS 30. In this case, after MS 40 has acquired a pilot channel signal associated with BTS 76, it must tune in to
25 and decode the CDMA sync channel of the BTS in order to derive the time of day. This operation takes about 300 msec, creating a noticeable but still tolerable interruption in voice service during a call. Further alternatively, a similar handover process can be performed using a MS having two transceivers, one for TDMA and the other for CDMA, as described hereinabove.

30 Fig. 8 is a schematic block diagram illustrating handover between two different CDMA BSSs 101 and 103 within system 20, in accordance with a preferred embodiment of the present invention. BSS 101 comprises a BSC 102 and a plurality of BTSs 106 and 108; and BSS 103 comprises a BSC 104 and a

plurality of BTSs 110 and 112. BSSs 101 and 103 are substantially similar to and interchangeable with BSS 32, shown in Fig. 1 and described hereinabove, and communicate with GSM MSC 24 via the GSM A-interface. MS 40 is shown in the figure in the midst of a handover from BTS 108 to BTS 110, under the control of MSC 24. Although the handover takes place between two CDMA BSSs, from the point of view of the system, it is a handover between two GSM BSSs, wherein BTSs 108 and 110 are respectively mapped by MSC 24 as GSM cells.

Fig. 9 is a schematic diagram illustrating signal flow between the elements of system 20 shown in Fig. 8 in the course of the handover, in accordance with a preferred embodiment of the present invention. The handover is triggered when MS 40 reports to BSS 101 that it is receiving a signal from BTS 110 with a higher power level than that of BTS 108. BSS 101 then sends a standard GSM handover-required message to MSC 24, specifying the GSM cell identity of BTS 110 as the new cell assignment desired for the handover. MSC 24 sends a handover request to BSS 103, which responds by sending to the MSC an acknowledgment that encapsulates a RIL3-RR handover command message, which is passed back to BSS 101. Thus, all of the messages sent between BSSs 101 and 103 comply with A-interface requirements, and CDMA parameters associated with IS95 are mapped to corresponding GSM parameters, for example, identification of vocoder type 13K QCELP in CDMA to GSM full rate vocoder. The handover request, acknowledge and command are passed on by MSC 24 substantially without change.

After receiving the handover command, old BSS 101 sends the RR handover command message to MS 40 so as to effect the handover to new BSS 103. The message to MS 40 includes:

- A new long code mask, in accordance with CDMA standards
- Nominal power level parameters
- Frame offset
- Code channel
- Layer 2 acknowledgment numbering
- Forward traffic channel power control parameters

- Number of preamble
- New band class and frequency.

Although preferred embodiments are described hereinabove with reference to a particular hybrid GSM/CDMA system, it will be appreciated that the principles of the present invention may similarly be applied to effect mobile-assisted handovers in other hybrid communication systems, as well. Moreover, although the preferred embodiments make reference to specific TDMA- and CDMA-based communications standards, those skilled in the art will appreciate that the methods and principles described hereinabove may also be used in conjunction with other methods of data encoding and signal modulation. The scope of the present invention encompasses not only the complete systems and communications processes described hereinabove, but also various innovative elements of these systems and processes, as well as combinations and sub-combinations thereof.

It will thus be appreciated that the preferred embodiments described above are cited by way of example, and the full scope of the invention is limited only by the claims.

WE CLAIM:

CLAIMS

1. In a mobile wireless telecommunications system, which includes base stations of a first type operating according to a first air interface, and base stations of a second type operating according to a second air interface, a method for handing over a mobile station in the system from a first base station, which is of the first type, to a second base station, which is of the second type, comprising:

establishing a communications link over the first air interface between the mobile station and the first base station;

receiving data from the mobile station responsive to a signal received by the mobile station over the second air interface from the second base station, substantially without breaking the communications link with the first base station, wherein receiving the data comprises receiving a measurement of signal strength, by applying a weighting factor to the measurement of signal strength and varying the weighting factor according to a network condition in the system; and

handing over the mobile station from the first to the second base station responsive to the data received therefrom, wherein handing over the mobile station comprises comparing measurements of signal strengths from the first and second base stations and handing over the mobile station responsive to the comparison.

2. A method according to claim 1, wherein applying the weighting factor comprises transmitting a weighting factor over the communications link to the mobile station, which applies the weighting factor to the measurement.

3. In a mobile wireless telecommunications system, which includes base stations of a first type operating according to a first air interface, and base stations of a second type operating according to a second air interface, a method for handing over a mobile station in the system from a first base station, which is of the first type, to a second base station, which is of the second type, comprising:

establishing a communications link over the first air interface between the mobile station and the first base station;

receiving data from the mobile station responsive to a signal received by the mobile station over the second air interface from the second base station, substantially

without breaking the communications link with the first base station, wherein receiving the data comprises receiving an identification of the second base station based on decoding by the mobile station of the signal received over the second air interface; and

handing over the mobile station from the first to the second base station responsive to the data received therefrom.

4. In a mobile wireless telecommunications system, which includes base stations of a first type operating according to a first air interface, and base stations of a second type operating according to a second air interface, a method for handing over a mobile station in the system from a first base station, which is of the first type, to a second base station, which is of the second type, comprising:

establishing a communications link over the first air interface between the mobile station and the first base station;

receiving data from the mobile station responsive to a signal received by the mobile station over the second air interface from the second base station, substantially without breaking the communications link with the first base station; and

handing over the mobile station from the first to the second base station responsive to the data received therefrom;

wherein establishing the communications link and receiving the data responsive to the signal comprise establishing the link and receiving the signal at the mobile station using a single RF transceiver in the mobile station.

5. In a mobile wireless telecommunications system, which includes base stations of a first type operating according to a first air interface, and base stations of a second type operating according to a second air interface, a method for handing over a mobile station in the system from a first base station, which is of the first type, to a second base station, which is of the second type, comprising:

establishing a communications link over the first air interface between the mobile station and the first base station;

receiving data from the mobile station responsive to a signal received by the mobile station over the second air interface from the second base station, substantially without breaking the communications link with the first base station; and

handing over the mobile station from the first to the second base station responsive to the data received therefrom;

wherein one of the first and second air interfaces comprises a TDMA interface, and the other of the interfaces comprises a CDMA interface.

6. A method according to claim 5, wherein the TDMA interface comprises a GSM interface, and wherein the CDMA interface is configured to convey GSM network messages.

7. A method according to claim 5, wherein the CDMA interface is based on an IS-95 standard.

8. A method according to claim 5, wherein establishing the communications link comprises using a single radio resource management protocol layer to manage the first air interface, and wherein handing over the mobile station comprises using the single radio resource management protocol layer to manage the second air interface.

9. In a mobile wireless telecommunications system, which includes base stations of a first type operating according to a first air interface, and base stations of a second type operating according to a second air interface, a method for handing over a mobile station in the system from a first base station, which is of the first type, to a second base station, which is of the second type, comprising:

establishing a communications link over the first air interface between the mobile station and the first base station;

receiving data from the mobile station responsive to a signal received by the mobile station over the second air interface from the second base station, substantially without breaking the communications link with the first base station, wherein receiving the data comprises defining an area of overlap between a first region served by the first air interface and a second region served by the second air interface, and triggering the mobile station to receive the data when the mobile station is in the area of overlap; and

handing over the mobile station from the first to the second base station responsive to the data received therefrom.

10. In a mobile wireless telecommunications system, which includes base stations of a first type operating according to a first air interface, and base stations of a second type operating according to a second air interface, a method for handing over a mobile station in the system from a first base station, which is of the first type, to a second base station, which is of the second type, comprising:

establishing a communications link over the first air interface between the mobile station and the first base station;

receiving data from the mobile station responsive to a signal received by the mobile station over the second air interface from the second base station, substantially without breaking the communications link with the first base station; and

handing over the mobile station from the first to the second base station responsive to the data received therefrom;

wherein the first air interface comprises a CDMA interface, and wherein the second air interface comprises a GSM/TDMA interface, and wherein receiving data from the mobile station comprises gating the mobile station to interrupt a CDMA communications link so as to receive and decode a GSM/TDMA signal.

11. A method according to claim 10, wherein gating the mobile station comprises interrupting CDMA communications for the duration of an IS-95 frame.

12. A method according to claim 10, wherein receiving the data comprises receiving an identification of the second base station based on decoding of GSM frequency correction and synchronization channels of the signal by the mobile station.

13. In a mobile wireless telecommunications system, which includes base stations of a first type operating according to a first air interface, and base stations of a second type operating according to a second air interface, a method for handing over a mobile station in the system from a first base station, which is of the first type, to a second base station, which is of the second type, comprising:

establishing a communications link over the first air interface between the mobile station and the first base station;

receiving data from the mobile station responsive to a signal received by the mobile station over the second air interface from the second base station, substantially without breaking the communications link with the first base station; and

handing over the mobile station from the first to the second base station responsive to the data received therefrom;

wherein the first air interface comprises a GSM/TDMA interface, and the second air interface comprises a CDMA interface, and wherein receiving the data from the mobile station comprises controlling the mobile station to interrupt the communications link so as to receive and decode a CDMA signal.

14. A method according to claim 13, wherein receiving the data comprises conveying time of day information through the GSM/TDMA interface.

15. A method according to claim 14, wherein conveying the time of day information comprises broadcasting time of day information through the system using a GSM cell broadcast service.

16. A method according to claim 15, wherein broadcasting the time of day information comprises receiving a time of day and an associated GSM frame number from a transceiver in communication with a base station of the first type in the system.

17. A method according to claim 14, wherein the mobile station decodes a sync channel of the CDMA signal so as to derive the time of day.

18. A method according to claim 13, wherein receiving the data comprises conveying a GSM cell broadcast service message to the mobile station to initiate a search by the mobile station for a signal from a base station of the second type.

19. A method according to claim 18, wherein conveying the GSM cell broadcast service message to the mobile station comprises conveying the message so as to be received by the mobile station while the mobile station is operating in a dedicated mode.

20. A method according to claim 13, wherein receiving the data from the mobile station comprises receiving an identification of a CDMA pilot beam decoded by the mobile station.

21. A method according to claim 13, and comprising mapping the second base station as a GSM base station so as to control the handover.

22. A method according to claim 13, wherein controlling the mobile station comprises controlling the mobile station to receive the CDMA signal during a first TDMA time slot and to decode the signal during a subsequent TDMA time slot while communicating with the base station over the TDMA interface so as to generate the data to be received by the base station.

23. Wireless communications apparatus, for use in a mobile telecommunications system, comprising:

- a base station of a first type which transmits and receives a first signal according to a first air interface;

- a base station of a second type which transmits and receives a second signal according to a second air interface; and

- a mobile station, which receives the second signal over the second air interface from the base station of the second type while maintaining a communication link over the first air interface with the base station of the first type, and which transmits data to the base station of the first type responsive to the second signal so that the mobile station is handed over from the first to the second base station responsive to the transmitted data;

- wherein the data transmitted by the mobile station comprises a measurement of signal strength, to which a weighting factor is applied and varied according to a network condition in the system, such that the mobile station is handed over responsive to a comparison of signal strengths of the first and second signals.

24. Wireless communications apparatus, for use in a mobile telecommunications system, comprising:

- a base station of a first type which transmits and receives a first signal according to a first air interface;

a base station of a second type which transmits and receives a second signal according to a second air interface; and

a mobile station, which receives the second signal over the second air interface from the base station of the second type while maintaining a communication link over the first air interface with the base station of the first type, and which transmits data to the base station of the first type responsive to the second signal so that the mobile station is handed over from the first to the second base station responsive to the transmitted data;

wherein the data transmitted by the mobile station comprises a measurement of signal strength, to which a weighting factor is applied and transmitted over the communications link to the mobile station, which applies the weighting factor to the measurement, such that the mobile station is handed over responsive to a comparison of signal strengths of the first and second signals.

25. Wireless communications apparatus, for use in a mobile telecommunications system, comprising:

a base station of a first type which transmits and receives a first signal according to a first air interface;

a base station of a second type which transmits and receives a second signal according to a second air interface; and

a mobile station, which receives the second signal over the second air interface from the base station of the second type while maintaining a communication link over the first air interface with the base station of the first type, and which transmits data to the base station of the first type responsive to the second signal so that the mobile station is handed over from the first to the second base station responsive to the transmitted data;

wherein the mobile station decodes the second signal to determine an identification of the base station of the second type.

26. Wireless communications apparatus, for use in a mobile telecommunications system, comprising:

a base station of a first type which transmits and receives a first signal according to a first air interface;

a base station of a second type which transmits and receives a second signal according to a second air interface; and

a mobile station, which receives the second signal over the second air interface from the base station of the second type while maintaining a communication link over the first air interface with the base station of the first type, and which transmits data to the base station of the first type responsive to the second signal so that the mobile station is handed over from the first to the second base station responsive to the transmitted data;

wherein the mobile station comprises a single RF transceiver which communicates with both the base stations of the first and second types.

27. Wireless communications apparatus, for use in a mobile telecommunications system, comprising:

a base station of a first type which transmits and receives a first signal according to a first air interface;

a base station of a second type which transmits and receives a second signal according to a second air interface; and

a mobile station, which receives the second signal over the second air interface from the base station of the second type while maintaining a communication link over the first air interface with the base station of the first type, and which transmits data to the base station of the first type responsive to the second signal so that the mobile station is handed over from the first to the second base station responsive to the transmitted data;

wherein one of the first and second air interfaces comprises a TDMA interface, and the other of the interfaces comprises a CDMA interface.

28. Apparatus according to claim 27, wherein the TDMA interface comprises a GSM interface, and wherein the CDMA interface is configured to convey GSM network messages.

29. Apparatus according to claim 27, wherein the CDMA interface is based on an IS-95 standard.

30. Apparatus according to claim 27, wherein the mobile station uses a single radio resource management protocol layer to manage both the first and second air interfaces.

31. Wireless communications apparatus, for use in a mobile telecommunications system, comprising:

- a base station of a first type which transmits and receives a first signal according to a first air interface;

- a base station of a second type which transmits and receives a second signal according to a second air interface; and

- a mobile station, which receives the second signal over the second air interface from the base station of the second type while maintaining a communication link over the first air interface with the base station of the first type, and which transmits data to the base station of the first type responsive to the second signal so that the mobile station is handed over from the first to the second base station responsive to the transmitted data;

- wherein the base station triggers the mobile station to receive the second signal over the second air interface when the mobile station is in an area of overlap between a first region served by the first air interface and a second region served by the second air interface.

32. Wireless communications apparatus, for use in a mobile telecommunications system, comprising:

- a base station of a first type which transmits and receives a first signal according to a first air interface;

- a base station of a second type which transmits and receives a second signal according to a second air interface; and

- a mobile station, which receives the second signal over the second air interface from the base station of the second type while maintaining a communication link over the first air interface with the base station of the first type, and which transmits data to the base station of the first type responsive to the second signal so that the mobile station is handed over from the first to the second base station responsive to the transmitted data;

- wherein the first air interface comprises a CDMA interface, and wherein the second air interface comprises a GSM/TDMA interface, and wherein the base station of the first type gates the mobile station to interrupt the communications link so as to receive and decode a GSM signal.

33. Apparatus according to claim 32, wherein the mobile station interrupts the link for the duration of an IS-95 frame.

34. Apparatus according to claim 32, wherein the mobile station processes the second signal to decode GSM frequency correction and synchronization channels of the signal.

35. Wireless communications apparatus, for use in a mobile telecommunications system, comprising:

- a base station of a first type which transmits and receives a first signal according to a first air interface;

- a base station of a second type which transmits and receives a second signal according to a second air interface; and

- a mobile station, which receives the second signal over the second air interface from the base station of the second type while maintaining a communication link over the first air interface with the base station of the first type, and which transmits data to the base station of the first type responsive to the second signal so that the mobile station is handed over from the first to the second base station responsive to the transmitted data;

- wherein the first air interface comprises a GSM/TDMA interface, and the second air interface comprises a CDMA interface, and wherein the base station of the first type controls the mobile station to interrupt the communications link so as to receive and decode a CDMA signal.

36. Apparatus according to claim 35, wherein the base station of the first type conveys time of day information to the mobile station through the GSM/TDMA interface.

37. Apparatus according to claim 36, and comprising a GSM cell broadcast center, which conveys the time of day information through the system to the mobile station using a GSM cell broadcast service.

38. Apparatus according to claim 37, wherein the cell broadcast center receives the time of day information and an associated GSM frame number from a transceiver in communication with a base station of the first type in the system.

39. Apparatus according to claim 36, wherein the mobile station decodes a synchronization channel of the CDMA signal so as to derive the time of day.

40. Apparatus according to claim 35, and comprising a GSM cell broadcast center, which conveys a cell broadcast service message to the mobile station to initiate a search by the mobile station for the second signal.

41. Apparatus according to claim 40, wherein the mobile station receives the cell broadcast service message while the mobile station is operating in a dedicated mode.

42. Apparatus according to claim 35, wherein the mobile station processes the CDMA signal to identify a CDMA pilot beam.

43. Apparatus according to claim 35, wherein the mobile station receives the CDMA signal during a first TDMA time slot and processes the signal during a subsequent TDMA time slot while communicating with the base station over the TDMA interface so as to generate the data for transmission to the base station.