(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
8 November 2001 (08.11.2001)

PCT

(10) International Publication Number
WO 01/84760 A1

(51) International Patent Classification[7]: H04J 14/02, 14/00, H04B 7/185

(21) International Application Number: PCT/US01/06354

(22) International Filing Date: 28 February 2001 (28.02.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/561,372 28 April 2000 (28.04.2000) US

(71) Applicant: LGC WIRELESS, INC. [US/US]; 2540 Junction Avenue, San Jose, CA 95134-1902 (US).

(72) Inventors: WONG, Woon; Apartment 10, 1731 Warburton Avenue, Santa Clara, CA 95050 (US). SCHWARTZ, Adam, I.; 62 Union Avenue, Campbell, CA 95008 (US).

(74) Agent: ALBOSZTA, Marek; Suite 110, 45 Cabot Avenue, Santa Clara, CA 95051-6670 (US).

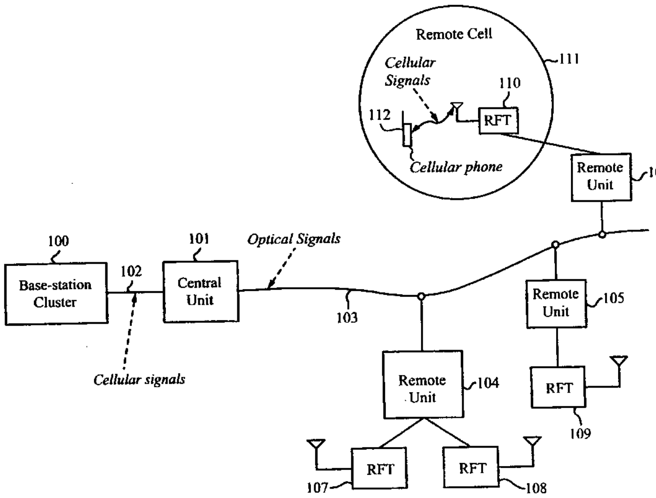
(81) Designated States *(national)*: AU, CA, CN, JP, MX.

(84) Designated States *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: A CELLULAR COMMUNICATIONS SYSTEM WITH CENTRALIZED CAPACITY RESOURCES USING DWDM FIBER OPTIC BACKBONE



(57) **Abstract:** This invention presents a cellular network in which base-stations (100) are placed at a centralized location and RF transceivers (107, 108, 109, 110) are located in remote cells (111). In such a system, the base-stations (100) serve the function of providing the cellular communication channels, while the RF transceivers (107, 108, 109, 110) provide the RF coverage for those channels. The base-stations (100) are in communication with the remote cells (11) via optical fibers (103), and dense wavelength division multiplexing (DWDM) (101) is advantageously employed to transmit information on the optical fibers (103). The cellular network of the present invention provides many advantages over the prior art cellular networks, notably in its efficiency, flexibility, cost-effectiveness, and the ability to dynamically manage the traffic capacity according to the traffic demand.

WO 01/84760 A1

PATENT APPLICATION

A CELLULAR COMMUNICATIONS SYSTEM WITH CENTRALIZED CAPACITY RESOURCES USING DWDM FIBER OPTIC BACKBONE

FIELD OF THE INVENTION

This invention relates generally to cellular communications systems. More particularly, it relates to systems and methods for de-coupling traffic capacity and RF coverage and using dense wavelength division multiplexing (DWDM) on optical fibers to distribute centralized traffic channel resources.

BACKGROUND ART

Cellular communications systems have become omnipresent, promising to deliver voice and data to every walk of modern life.

Conventional cellular networks employ an architecture which divides a geographical area into coverage areas called cells, and a base-station is placed at the center of each cell to serve the cellular traffic. Often, cells are further divided into sectors. The base-station is equipped with transmitters and receivers that provide the RF radio coverage in each sector; while a fixed number of cellular radio channels in the base-station assigned to each sector determines the traffic handling capacity. Hence, the RF coverage and the traffic capacity in each cell or cell sector are inherently coupled through the base-station. This adversely affects the efficiency and flexibility of the current cellular networks.

For example, it is difficult to design an efficient and cost-effective cellular network, not knowing future subscription volume and peak traffic density. Since one base-station must be installed in each cell in order just to provide the RF coverage, the cost for providing the traffic capacity, which may not be fully utilized in the years to come, and the associated operational expenses must be paid at the outset. Moreover, as the demand for cellular service increases within a particular area, the network must be re-engineered and more base-stations must be installed to meet the demand. This is costly and time consuming. All in all, the changing nature of traffic capacity demand makes it difficult for the current cellular networks to operate efficiently and to optimize both cost and grade-of-service.

Hence, as the demand for greater cellular service at ever lower cost increases, there is a need in the art for more efficient, flexible, cost-effective, and dynamic cellular networks.

With respect to this invention, the cellular channels serving calls within each sector are termed a cellular channel group. A cellular channel group may contain one or more cellular signals. It is common in the prior art to convert a single downlink cellular channel group from a cellular base-station to an optical signal characterized by a single optical carrier wavelength and transmit that optical signal over fiber optic cable to a single cell. In the cell, the optical signal is converted back to the original cellular signals that are transmitted into the cell. Similarly, a single uplink cellular channel group received from a single cell is converted to an optical signal characterized by a single optical carrier wavelength and transmitted over fiber optic cable back to the base-station. This method is limited to transmitting a single cellular channel group and can serve only a single cell or a single sector within a cell.

Also common in the prior art is the use of wave-division multiplexing (WDM) to transmit data groups across a fiber optic network. However, WDM technology has not yet been employed in cellular networks for the purpose of transmitting multiple cellular channel groups to multiple cells or cell-sectors.

OBJECTS AND ADVANTAGES

Accordingly it is a principal object of the present invention to provide a novel cellular architecture that de-couples the traffic channel resources from the RF coverage in a cellular network by placing base-stations at a centralized location and RF transceivers in remote cells. It is another object of the present invention to advantageously use optical fibers and wavelength division multiplexing (WDM) to transmit traffic channel resources between the centralized base-stations and the remote cells in such a network. It is a further advantage of the present invention to provide methods for distributing traffic channel resources according to the demand.

A primary advantage of the present invention is that by decoupling the traffic channel resources from the RF coverage, the cellular network becomes more efficient, adaptive, and cost-effective, in contrast to the passive and static nature of the prior art cellular networks. Another important advantage of the present invention is apparent in the use of optical fibers and dense wavelength division multiplexing (DWDM) to distribute centralized traffic channel resources to remote cells according to the demand. A further advantage of the present invention is that using DWDM allows fewer optical fibers to be implemented in this cellular network architecture, thus reducing the equipment cost. An additional advantage of the present invention is that as the demand for cellular service increases in a particular area, more capacity resources can be easily implemented without disrupting the overall operation of the entire network.

These and other objects and advantages will become apparent from the following description and accompanying drawings.

SUMMARY OF THE INVENTION

The present invention provides a cellular network in which base-stations are placed at a centralized location and RF transceivers are located in remote cells. The location of the base-stations may or may not physically overlap with any of the cell-sites. The key feature is that the base-stations are clustered together, as opposed to one base-station per cell structures in prior art cellular networks. In the cellular network of the present invention, the base-stations serve the function of providing cellular voice or data channels to handle the cellular traffic demand, while the remote RF transceivers provide the RF coverage for those channels in the remote cells. The base-stations are in communication with the remote units via optical fibers. WDM and/or DWDM may be advantageously employed to transmit multiple cellular channel groups through a relatively few number of optical fibers.

More specifically, a base-station cluster containing one or more base-stations, placed at a centralized location, is in communication with a central unit. The central unit is connected to one or more optical fibers. Connected at remote locations along the optical fibers are a plurality of remote units, each in communication with one or more remote RF transceivers positioned in remote cells. In the downlink route, the base-stations transmit downlink cellular channel groups, each containing one or more downlink cellular signals, to the central unit. The central unit converts each downlink cellular channel group to one downlink optical signal with distinct, predetermined downlink optical wavelength such that there is a one-to-one correspondence between each downlink cellular channel group and each downlink optical signal. The conversion from cellular signals to optical signals is typically accomplished by using the cellular signals within each cellular channel group to modulate an optical carrier signal at a specified optical wavelength. The central unit then uses DWDM to multiplex the downlink optical signals onto the optical fibers. The remote units de-multiplex the downlink optical signals delivered by the optical fibers and restore the original downlink cellular channel groups from the de-multiplexed downlink optical signals. The restored downlink cellular channel groups are then transmitted to the remote RF transceivers, which in turn broadcast the downlink cellular signals contained in these downlink cellular channel groups to cellular users in their respective cells. In the uplink route, uplink cellular signals are first received by the remote RF transceivers from the cellular users in their respective cells. These uplink cellular signals are then transmitted to the remote units from the remote RF transceivers. The remote units convert the uplink cellular signals to one or more uplink optical signals with distinct, predetermined uplink optical wavelengths and multiplex the uplink optical signals onto the optical fibers. The central unit in turn de-multiplexes the uplink optical signals delivered by the optical fibers and restores the original uplink cellular signals from the de-multiplexed uplink optical signals. The restored uplink cellular signals are subsequently transmitted to the centralized base-stations.

The selection of cellular signals contained in each cellular channel group can be chosen so as to efficiently transmit the cellular channels from the available base-station resources to remote cells or cell sectors based upon the cellular traffic demand in those remote cells and grade-of-service requirements. In addition, the use of DWDM provides a simple, efficient, economical, and elegant way to transmit optical signals over the optical fibers.

The "cellular signals" in the above description refer to any type of wireless communication signals. For example, common cellular signal formats include, but are not limited to, AMPS, GSM, TDMA, EDGE, and CDMA. Cellular signals are transmitted over the air as RF signals. However, cellular signals can be transmitted in other forms than RF signals in the cellular networks of this invention without departing from the principle and the scope of the invention.

A variety of cellular networks can be implemented according to the principle of the present invention, and various means and methods can be devised to transmit cellular signals between the centralized base-stations and remote cells in an efficient manner, as depicted in the drawings and the detailed description that follows.

The novel features of this invention, as well as the invention itself, will be best understood from the following drawings and detailed description.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** depicts an exemplary embodiment of a cellular network according to the present invention;

FIG. **2** illustrates how cellular signals are grouped and transmitted from a centralized base-station cluster to a central unit, and then converted to distinct optical signals at the central unit, according to an exemplary embodiment of the present invention;

FIGS. **3A-3C** show exemplary methods of the present invention for distributing centralized traffic channel resources to remote cells.

DETAILED DESCRIPTION

Although the following detailed description contains many specific details for the purposes of illustration, anyone of ordinary skill in the art will appreciate that many variations and alterations to the following details are within the scope of the invention. Accordingly, the exemplary embodiment of the invention described below is set forth without any loss of generality to, and without imposing limitations upon, the claimed invention.

FIG. **1** depicts an exemplary embodiment of a cellular network according to the present invention. By way of example to illustrate the principal concept and the topological structure of the cellular network architecture of the present invention, the exemplary cellular network includes a centralized base-station cluster **100** containing one or more base-stations, a central unit **101** connected the base-station cluster **100**, e.g., by one or more coaxial cables **12**, an optical fiber **103**, and remote units **104**, **105**, and **106**. The remote unit **104** is in turn connected to two remote RF transceivers **107** and **108**, the remote unit **105** is connected to one remote RF transceiver **109**, and the remote unit **106** is also connected to one remote RF transceiver

110. A remote cell **111** for which the remote RF transceiver **110** provides the RF coverage and a cellular phone **112** are shown for illustration purpose.

The cellular network in FIG. **1** operates as follows. In the downlink route, the base-station cluster **100** transmits downlink cellular signals in the form of RF signals via the cables **102** to the central unit **101**, where the downlink RF signals are converted to one or more downlink optical signals with distinct, predetermined downlink optical wavelengths. The conversion between RF signals to optical signals is typically accomplished by using the RF signals to modulate an optical carrier. The wavelength of the optical carrier determines the wavelength of the optical signal. The central unit **101** uses DWDM to multiplex the downlink optical signals onto the optical fiber **103.** By employing several wavelengths of light, typically separated by about 1 nanometer, DWDM allows many sets of optical signals to be transmitted on a single optic fiber cable. On the remote end, the remote units **104**, **105, 106** de-multiplex the downlink optical signals, for instance, by each selecting one or more downlink optical signals from the optical fiber **103**. The selection of the downlink optical signals from the optical fibers can be accomplished, for instance, by use of optical drop modules. Each remote unit restores a subset (where a subset is part or all of the set) of the original downlink RF signals from the selected downlink optical signals and transmits the restored downlink RF signals to its respective remote RF transceiver(s). The remote RF transceivers in turn broadcast these downlink RF signals to the cells they cover. In the uplink route, uplink RF signals are first received by the remote RF transceivers from the cellular users in their respective cells. These uplink RF signals are then transmitted to the remote units from the remote RF transceivers. The remote units convert the uplink RF signals to uplink optical signals with distinct, predetermined uplink optical wavelengths and multiplex the uplink optical signals to the optical fiber **103**. The addition of the uplink optical signals onto the optical fibers can be facilitated, for instance, by use of optical add modules. The central unit **101** in turn de-multiplexes the uplink optical signals delivered by the optical fiber **103** and restores the original uplink RF signals from the de-multiplexed uplink optical signals. The restored uplink RF signals are subsequently transmitted to the centralized base-station cluster **100** via the cables **102**.

The base-station cluster **100** generally includes one or more base-stations, each in direct connection with the central unit **101**. There can be a plurality of optical fibers connecting the central unit to the remote units. In such a case, the remote units may tap off from different optical fibers on the remote end, and each remote unit is in turn connected to one or more RF transceivers. Moreover, the optical fiber **13** can be configured to an optical fiber ring, extending from and terminating at the central unit **11**. The fiber ring links a plurality of remote units along its path, with each remote unit connected to one or more RF transceivers.

The connection between the base-station cluster **100** and the central unit **101** is generally served by using one or more coaxial cables, though other types of means for transmitting RF signals can also be utilized. Similarly, the connection between the remote units and their corresponding RF transceivers is typically provided by one or more coaxial cables.

Alternatively, a remote unit and its corresponding RF transceivers can be designed as one physical unit. Furthermore, the conversion between optical signals and RF signals on the remote end can be delegated to the RF transceivers, rather than being performed by the remote unit. This allows the connection between the remote unit and the RF transceivers to be optical. In such a case, the remote unit simply performs multiplexing/de-multiplexing function.

In general, the central unit and remote units may use various techniques of wavelength division multiplexing to multiplex/de-multiplex optical signals onto/from the optical fiber, though DWDM is most desirable, for it allows fewer number of optical fibers to be deployed. Other multiplexing techniques, such as frequency division multiplexing, can also be employed.

FIG. **2** provides a more detailed illustration of how cellular signals are grouped and converted to optical signals in a cellular network according to an exemplary embodiment of the present invention. A base-station cluster **200**, containing one or more base-stations, transmits downlink cellular signals to and receives uplink cellular signals from a central unit **201**. The connection between the base-station cluster **200** and the central unit **201** is typically provided by one or more coaxial cables and associated RF devices such as RF power combiners and RF switches. The base-stations are so configured that both downlink and uplink cellular signals are transmitted in Cellular Channel Groups, each comprising a plurality of cellular signals with distinct frequencies. For example, Cellular Channel Group-1 **202** contains downlink cellular signals with downlink frequencies $f_{1,1}$, $f_{1,2}$, …, $f_{1,m1}$ and uplink cellular signals with corresponding uplink frequencies $f_{1,1}'$, $f_{1,2}'$, …, $f_{1,m1}'$; Cellular Channel Group-2 **203** contains downlink cellular signals with downlink frequencies $f_{2,1}$, $f_{2,2}$, …, $f_{2,m2}$ and uplink cellular signals with corresponding uplink frequencies $f_{2,1}'$, $f_{2,2}'$, …, $f_{2,m2}'$; and Cellular Channel Group-n **204** contains downlink cellular signals with downlink frequencies $f_{n,1}$, $f_{n,2}$, …, $f_{n,mn}$ and uplink cellular signals with corresponding uplink frequencies $f_{n,1}'$, $f_{n,2}'$, …, $f_{n,mn}'$.

Upon being transmitted to the central unit **201**, the downlink cellular signals in Cellular Channel Group-1 are converted to a downlink optical signal with downlink wavelength λ_1, the downlink cellular signals in Cellular Channel Group-2 are converted to a downlink optical signal with downlink wavelength λ_2, and the downlink cellular signals in Cellular Channel Group-n are converted to a downlink optical signal with downlink wavelength λ_n. The downlink optical signals with downlink optical wavelengths λ_1, λ_2, …, λ_n are then multiplexed onto an optical fiber **205** to be transmitted to remote cells. In the uplink route, if a remote unit receives the downlink cellular signals contained in Cellular Channel Group-1, the uplink cellular signals it sends back to the base-stations have frequencies $f_{1,1}'$, $f_{1,2}'$, …, $f_{1,m1}'$, where the uplink frequency $f_{1,i}'$ has a predetermined relationship with the downlink frequency $f_{1,i}$. The remote unit converts these uplink cellular signals to an uplink optical signal with uplink wavelength λ_1', where λ_1' corresponds with the downlink wavelength λ_1 in a predetermined manner. Such a correspondence between downlink and uplink cellular signals as well as the one-to-one conversion between a Cellular Channel Group and an optical signal, as illustrated in FIG. **2**, pertain to all Cellular Channel Groups.

It is clear to those skilled in the art that FIG. **2** is for illustration purpose only. There are many ways to organize the cellular signals into cellular channel groups, as dictated by practical applications. A skilled artisan will know how to devise a grouping mechanism that is suitable for a given application.

FIGS. **3A-3C** depict three exemplary methods for allocating traffic channels according to the distribution of traffic demand in a cellular network of the present invention. By way of example, and without sacrificing the generality of the underlying principle of the present invention, a centralized base-station cluster **300**, a central unit **301**, an optical fiber **302**, and three remote units **303**, **30**, **305** are deployed in the exemplary cellular network. The remote units **303**, **304**, **305** are assigned to serve three remote cells **306**, **307**, **308** respectively, where each cell is outlined by a circle. FIG. **3A** pertains to a situation where the cellular traffic is light in the network. The base-station cluster **30** transmits a group of downlink cellular signals (contained in one cellular channel group) to the central unit **301**. The central unit converts these downlink cellular signals to a downlink optical signal with a downlink wavelength λ_1. The central unit **301** then transmits the downlink optical signal to the optical fiber **302**. The remote units are configured such that each receives the downlink optical signal with wavelength λ_1 from the optical fiber **302**. Accordingly, in the uplink route, each remote units converts uplink cellular signals from cellular users in its cell to an uplink optical signal with optical wavelength λ_1', and sends the uplink optical signal back to the optical fiber **302** to be transmitted to the central unit **301**. The central unit **301** in turn restores the original uplink cellular signals from the uplink optical signal with uplink optical wavelength λ_1' delivered by the optical fiber **302**. The restored uplink cellular signals are subsequently transmitted to the base-station cluster **300**.

In general, if a remote unit selects a downlink optical signal with downlink optical wavelength λ_i from an optical fiber, the uplink optical signal it sends back onto the optical fiber has an uplink wavelength λ_i', where λ_i and λ_i' have a predetermined relationship, and may also be equal under some special circumstances. For instance, if a downlink optical signal designated to and an uplink optical signal sent back by a remote unit do not travel on an optical fiber simultaneously, λ_i and λ_i' can be the same. Additionally, if the remote unit receives a downlink cellular signal with downlink frequency f_i, the uplink RF signal it sends back to the central unit has a predetermined frequency f_i'. And the downlink and uplink cellular signals characterized by these two frequencies are transmitted and routed in a predetermined fashion.

As the cellular traffic increases, the base-station cluster **300** is re-configured to transmit three groups of downlink Cellular signals (i.e., three cellular channel groups) to the central unit **301,** which in turn converts these downlink cellular signals to three optical signals with three distinct downlink optical wavelengths λ_1, λ_2, and λ_3, as shown in FIG. **3B**. The central unit **301** then multiplexes the three downlink optical signals onto the optical fiber **302,** e.g., by use of a WDM technique such as DWDM. On the remote end, each of the remote units is assigned one of the three downlink optical signals, thereby de-multiplexing the downlink optical signals delivered by the optical fiber **32**. By way of example, the remote unit **303** may be assigned the downlink optical signal with downlink optical wavelength λ_1; the remote unit **304** assigned the downlink optical signal with downlink optical wavelength λ_2; and the remote unit **305** has the downlink optical signal with downlink optical wavelength λ_3. Accordingly, the uplink optical signal sent back by the remote unit **303** has a predetermined uplink optical wavelength λ_1'; the uplink optical signal sent back by the remote unit **304** has a predetermined uplink optical wavelength λ_2'; and the uplink optical signal sent back by the remote unit **305** has a predetermined uplink optical wavelength λ_3'.

As the cellular traffic further increases, the base-station cluster **30** is re-configured to transmit nine groups of downlink cellular signals (i.e., nine cellular channel groups) to the central unit **301,** which in turn converts these downlink cellular signals to nine optical signals with nine distinct downlink optical wavelengths λ_1, λ_2,..., λ_9, as shown in FIG. **3C**. The central unit then multiplexes the nine downlink optical signals onto the optical fiber, e.g., by use of a WDM technique such as DWDM. On the remote end, the downlink optical signals delivered by the optical fiber are de-multiplexed and divided amongst the three remote units. For example, the remote unit **303** may be assigned the downlink optical signals with downlink optical wavelengths λ_1, λ_6, and λ_7; the remote unit **304** may be assigned the downlink optical signals with downlink optical wavelengths λ_2, λ_8, and λ_9; and the remote unit **305** has the downlink optical signals with downlink optical wavelengths λ_3, λ_4, and λ_5. In the embodiment depicted by FIG. **3C**, each remote cell is further divided to three sectors, and each sector is assigned a different optical wavelength. Accordingly, the uplink optical signals sent back by the remote unit **303** have predetermined uplink optical wavelength λ_1', λ_6', λ_7'; the uplink optical signals sent back by the remote unit **304** have predetermined uplink optical wavelength λ_2', λ_8', λ_9'; and the uplink optical signals sent back by the remote unit **305** have predetermined uplink optical wavelength λ_3', λ_4', λ_5'. The net result is that groups of cellular signals can be transmitted to and from the centralized base-stations to individual cells or sectors according to the optical wavelength assigned to each cell or sector.

In the above embodiments, the selection of the downlink optical signals from the optical fibers can be accomplished, for instance, by use of optical drop modules. similarly, the addition of the uplink optical signals onto the optical fibers can be facilitated, for instance, by use of optical add modules.

It should be clear that the exemplary embodiments described in FIGS. **3A-3C** are provided to illustrate the capability of the present invention for distributing the traffic channel resources according to the demand. The remote units can be configured and programmed in a variety of ways to de-multiplex downlink optical signals and multiplex uplink optical signals, so as to effectively distribute the traffic channel resources. Moreover, the use of DWDM provides a simple, effective and economical way (since it allows fewer fibers to be deployed) to multiplex optical signals onto an optical fiber. A skilled artisan will know how best to utilize DWDM and arrange the remote units according to the traffic capacity and demand for a given application.

All in all, the cellular network architecture of the present invention allows the configuration of a cellular network to be altered in various ways to best suit a given application.

In the above description of the invention, the term cellular signals signifies any type of wireless communication signals. For example, common cellular signal formats include, but are not limited to, AMPS, GSM, TDMA, EDGE, and CDMA. Cellular signals are transmitted over the air as RF signals. However, cellular signals can be transmitted in forms other than RF in the cellular networks of this invention without departing from the principle and the scope of this invention.

The RF signals have frequencies typically in the range of 100 MHz to 10 GHz. The wavelengths of optical signals transmitted on the optical fibers can range from 10,000 nm to 100 nm, and the commonly utilized wavelengths are centered at 850 nm, 1330nm and 1550 nm.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions, and alternations can be made herein without departing from the principle and the scope of the invention. Accordingly, the scope of the present invention should be determined by the following claims and their legal equivalents.

CLAIMS

What is claimed is:

1. A cellular communications system comprising:
   a) a base-station cluster, containing one or more base-stations;
   b) a central unit connected to said base-station cluster; and
   c) a signal transfer means connected between said base-station cluster and said central unit, wherein said central unit transmits two or more downlink cellular channel groups, each containing one or more cellular signals, from said base-station cluster to one or more remote units located in one or more remote cells of said cellular communications system.

2. The cellular communications system of claim 1 wherein said central unit is connected to said one or more remote units by one or more optical fibers.

3. The cellular communication system of claim 2 wherein said central unit converts said two or more downlink cellular channel groups transmitted from said base-station cluster to two or more downlink optical signals with downlink optical wavelengths such that said downlink cellular channel groups and downlink optical wavelengths are in a one-to-one correspondence, wherein said downlink optical signals are multiplexed onto said one or more optical fibers, and wherein said one or more remote units de-multiplex said downlink optical signals delivered by said one or more optical fibers and restore said two or more downlink cellular channel groups from said de-multiplexed downlink optical signals.

4. The cellular communications system of claim 3 wherein said central unit uses wavelength division

multiplexing (WDM) to multiplex said downlink optical signals onto said one or more optical fibers, and wherein said one or more remote units use wavelength division multiplexing to de-multiplex said downlink optical signals from said one or more optical fibers.

5. The cellular communications system of claim 4 wherein said wavelength division multiplexing comprises dense wavelength division multiplexing (DWDM).

6. The cellular communication system of claim 3 wherein said central unit uses frequency division multiplexing to modulate said downlink cellular signals onto said two or more downlink optical signals transmitted onto one or more optical fibers, and wherein said one or more remote units de-multiplexes said downlink optical signals from said one or more optical fibers by reversing said frequency multiplexing.

7. The cellular communication system of claim 3 wherein said one or more remote units convert uplink cellular signals transmitted from said one or more remote cells to uplink optical signals with uplink optical wavelengths and multiplex said uplink optical signals onto said one or more optical fibers, wherein said uplink optical wavelengths correspond with said downlink optical wavelengths of said downlink optical signals received by said one or more remote units, and wherein said central unit de-multiplexes said uplink optical signals from said one or more optical fibers and restores said uplink cellular signals from said de-multiplexed uplink optical signals.

8. The communication system of claim 7 wherein said one or more remote units use wavelength division multiplexing to multiplex said uplink optical signals onto said one or more optical fibers, and

wherein said central unit uses wavelength division multiplexing to de-multiplex said uplink optical signals from said one or more optical fibers.

9. The communications system of claim 8 wherein said wavelength division multiplexing comprises dense wavelength division multiplexing (DWDM).

10. The communication system of claim 7 wherein said one or more remote units use frequency division multiplexing to modulate said uplink cellular signals onto one or more optical signals transmitted onto said one or more optical fibers, and wherein said central unit de-multiplexes said uplink optical signals from said one or more optical fibers by reversing said frequency multiplexing.

11. The cellular communications system of claim 1 further comprising one or more RF transceivers connected to each of said one or more remote units.

12. The cellular communications system of claim 1 said cellular signals comprises RF signals.

13. A cellular communication system comprising:

a) a base-station cluster at a centralized location, containing one or more base-stations;

b) a central unit in communication with said base-station cluster;

c) one or more remote units;

d) one or more RF transceivers in communication with each of said one or more remote units; and

e) one or more optical fibers;

wherein:

a) said central unit converts two or more downlink cellular channel groups, each containing one or more downlink cellular signals, transmitted by said base-station cluster to two or more downlink optical signals with downlink optical wavelengths in a one-to-one correspondence with said downlink cellular channel groups and multiplexes said downlink optical signals onto said one or more optical fibers;

b) each of said one or more remote units de-multiplexes said downlink optical signals from said one or more optical fibers, restores a subset of said downlink cellular channel groups from said de-multiplexed downlink optical signals, and transmits said restored downlink cellular channel groups to said one or more RF transceivers;

c) each of said one or more remote units converts uplink cellular signals from said one or more RF transceivers to one or more uplink optical signals with uplink optical wavelengths and multiplexes said one or more uplink optical signals onto said one or more optical fibers, wherein said uplink optical wavelengths are in correspondence said downlink optical wavelengths; and

d) said central unit de-multiplexes said uplink optical signals from said one or more optical fibers, restores said uplink cellular signals from said de-multiplexed uplink optical signals and transmits said restored uplink cellular signals in uplink cellular channel groups to said base-station cluster, wherein said uplink cellular channel groups are in correspondence with said downlink cellular channel groups.

14. The communication system of claim 13 wherein wavelength division multiplexing is used to transmit said downlink and uplink optical signals on said one or more optical fibers.

15. The cellular communications system of claim 14 wherein said wavelength division multiplexing comprises dense wavelength division multiplexing (DWDM).

16. The communication system of claim 13 wherein frequency division multiplexing is used to modulate said downlink cellular signals and uplink cellular signals onto one or

more optical signals transmitted onto said one or more optical fibers.

17. The cellular communications system of claim 13 wherein said one or more optical fibers comprises an optical fiber ring, wherein said optical fiber ring extends from and terminates at said central unit, and wherein said one or more remote units are connected to said optical fiber ring.

18. A method of cellular communication, comprising the steps of:
   a) transmitting two or more downlink cellular channel groups from a base-station cluster placed at a centralized location;
   b) converting said two or more downlink cellular channel groups transmitted by said base-station cluster to two or more downlink optical signals with downlink optical wavelengths in a one-to-one correspondence with said downlink cellular channel groups;
   c) multiplexing said downlink optical signals to one or more optical fibers;
   d) de-multiplexing said downlink optical signals delivered by said one or more optical fibers;
   e) restoring said downlink cellular channel groups from said de-multiplexed downlink optical signals; and
   f) transmitting said restored downlink cellular channel groups to two or more remote RF transceivers.

19. The method of claim 18 wherein said steps c) and d) use dense wavelength division multiplexing (DWDM).

20. The method of claim 18 wherein said steps c) and d) uses frequency division multiplexing.

21. The method of claim 18 wherein said steps b) and c) are carried out by a central unit in communication with said base-station cluster, wherein said central unit is connected to said one or more optical fibers.

22. The method of claim 18 wherein said steps d), e) and f) are carried out by one or more remote units in communication with said two or more RF transceivers, wherein said one or more remote units are connected to said one or more optical fibers.

23. The method of claim 22 further comprising the steps of:
    a) said one or more remote units convert uplink cellular signals received by said remote RF transceivers to one or more uplink optical signals with uplink optical wavelengths, wherein said uplink optical wavelengths correspond with said downlink optical wavelengths of said downlink optical signals received by said one or more remote units;
    b) multiplexing said uplink optical signals onto said one or more optical fibers;
    c) de-multiplexing said uplink optical signals delivered by said one or more optical fibers and restoring said uplink cellular signals from said de-multiplexed uplink optical signals; and
    d) transmitting said restored uplink cellular signals in uplink cellular channel groups to said base-station cluster, wherein said uplink cellular channel groups are in correspondence with said downlink cellular channel groups.

24. The method of claim 23 wherein said steps b) and c) uses dense wavelength division multiplexing (DWDM).

25. The method of claim 23 wherein said steps b) and c) uses frequency division multiplexing.

26. The method of claim 23 wherein said steps c) and d) are carried out by a central unit in communication with said base-station cluster, wherein said central unit is connected to said one or more optical fibers.

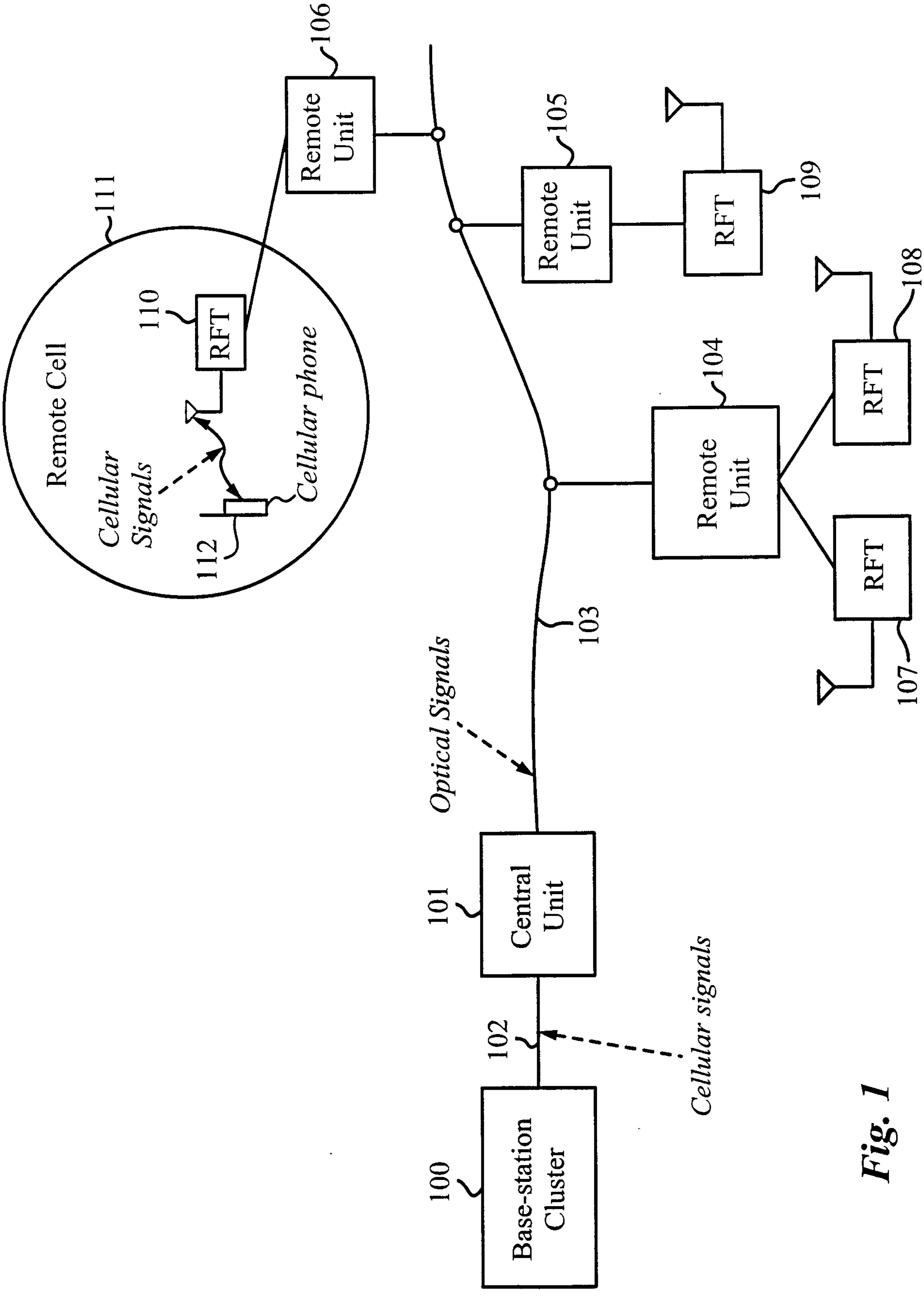

Remote Cell
111
110
RFT
Cellular Signals
Cellular phone
112
Remote Unit
106
Remote Unit
105
RFT
109
Remote Unit
104
RFT
108
RFT
107
103
Optical Signals
Central Unit
101
102
Cellular signals
Base-station Cluster
100

Fig. 1

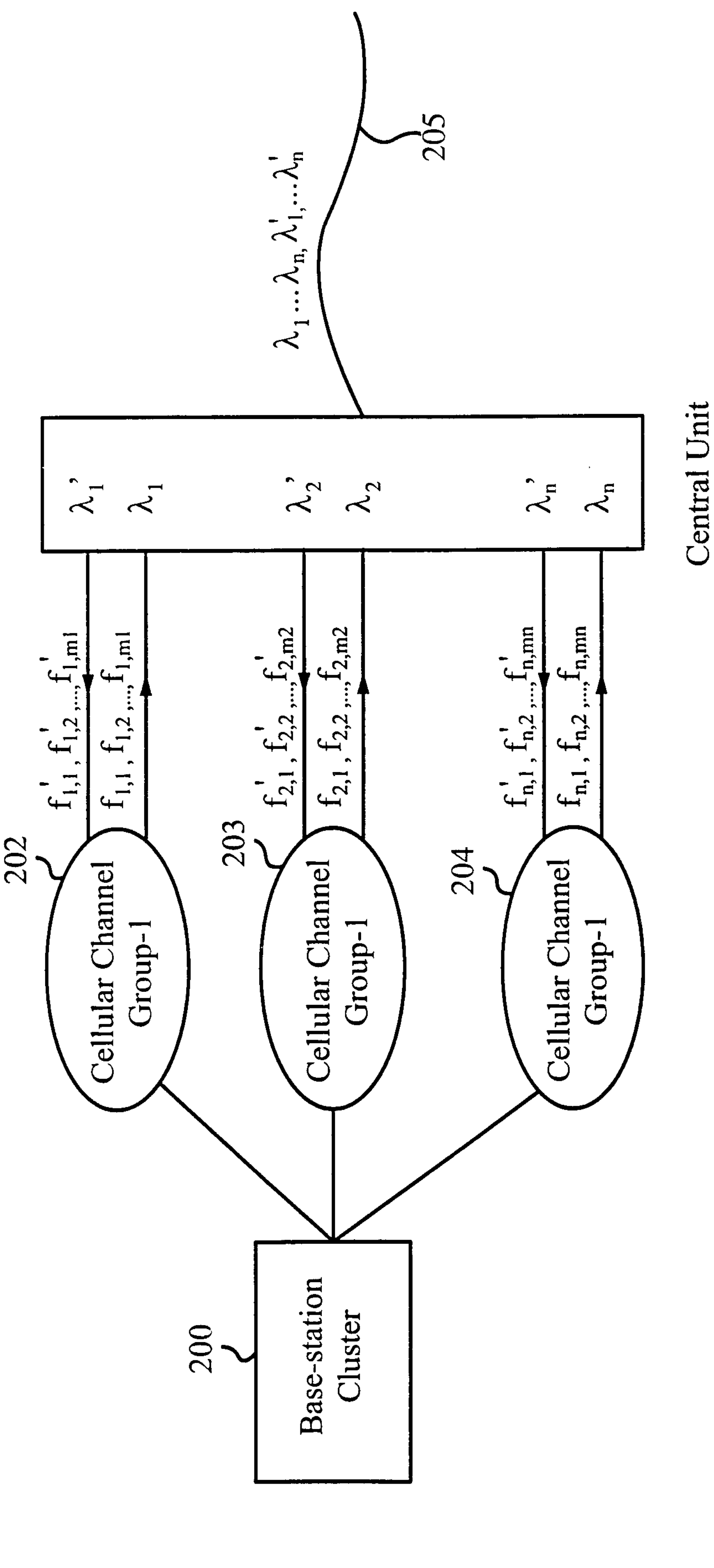
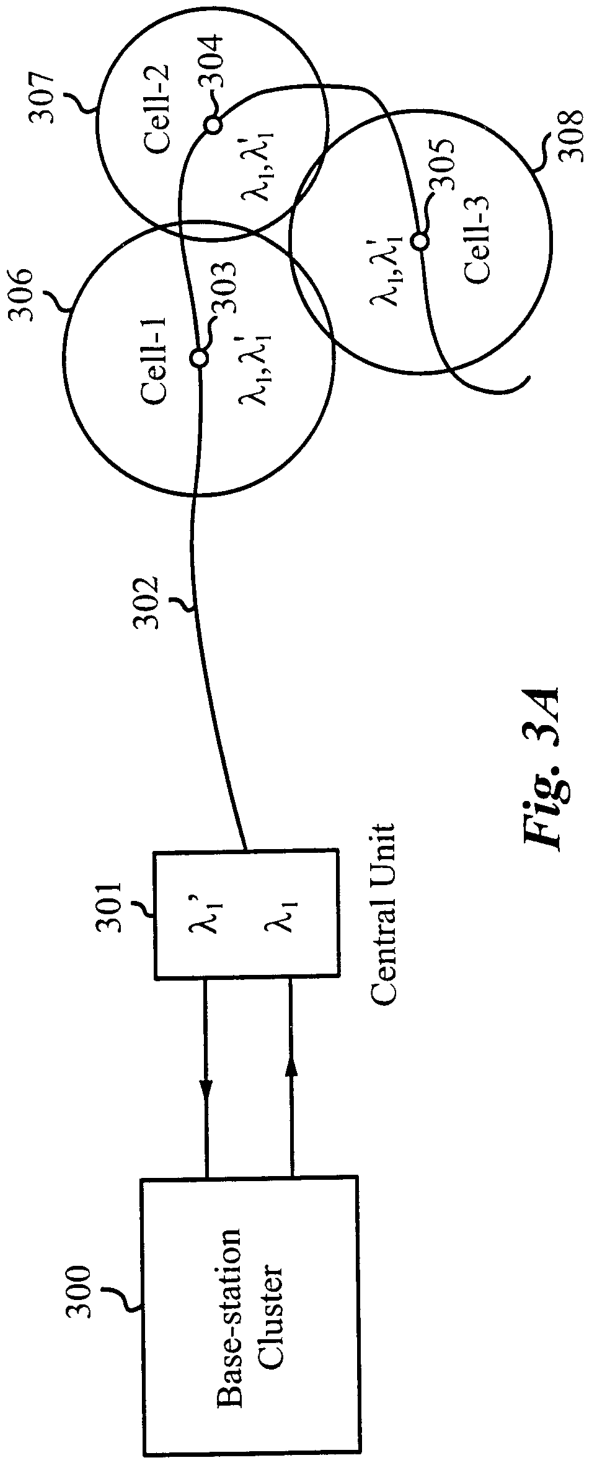

205
λ1…λn, λ'1,…λ'n
Central Unit
λ'1
λ1
λ'2
λ2
λ'n
λn
f'1,1, f'1,2,…, f'1,m1
f1,1, f1,2,…, f1,m1
f'2,1, f'2,2,…, f'2,m2
f2,1, f2,2,…, f2,m2
f'n,1, f'n,2,…, f'n,mn
fn,1, fn,2,…, fn,mn
202
Cellular Channel Group-1
203
Cellular Channel Group-1
204
Cellular Channel Group-1
200
Base-station Cluster

Fig. 2



307
Cell-2
304
λ1,λ'1
308
305
Cell-3
λ1,λ'1
306
Cell-1
303
λ1,λ'1
302
301
λ'1
λ1
Central Unit
300
Base-station
Cluster

Fig. 3A

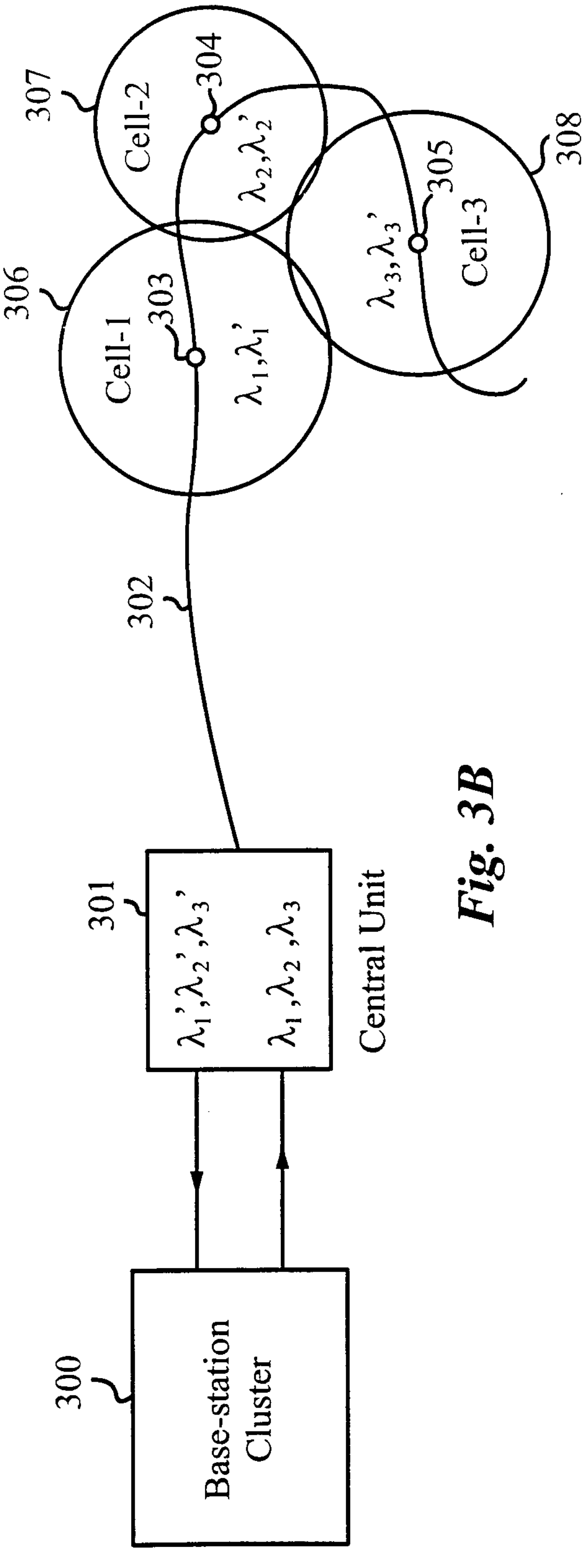

307
Cell-2
304
λ_2,λ_2'
308
305
Cell-3
λ_3,λ_3'
306
Cell-1
303
λ_1,λ_1'
302
301
$\lambda_1',\lambda_2',\lambda_3'$
$\lambda_1,\lambda_2,\lambda_3$
Central Unit
300
Base-station Cluster

Fig. 3B

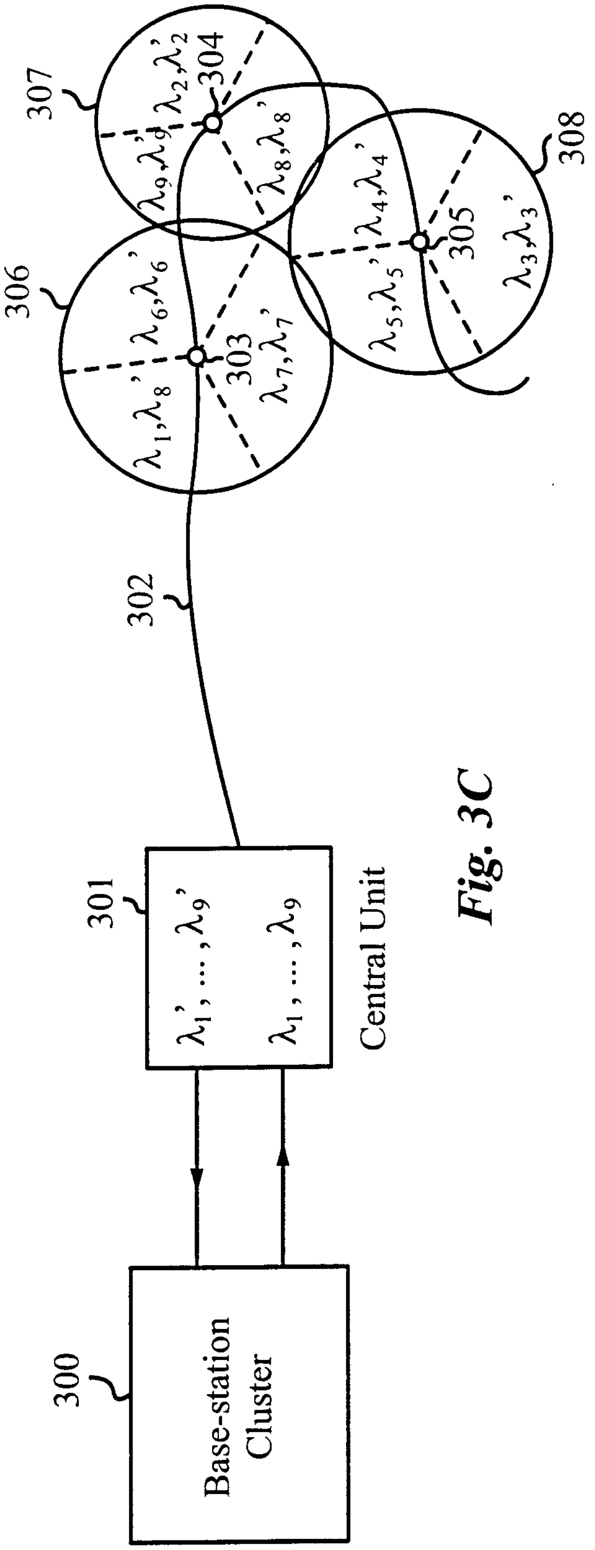

300
Base-station Cluster
301
λ'1, ..., λ'9
λ1, ..., λ9
Central Unit
302
303
304
305
306
307
308
λ1,λ8'
λ6,λ6'
λ7,λ7'
λ9,λ9'
λ2,λ2'
λ8,λ8'
λ4,λ4'
λ5,λ5'
λ3,λ3'

Fig. 3C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/06354

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) :H04J 14/02, 14/00; H04B 7/185
US CL : 359/132, 117, 145; 455/431
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)
U.S. : 359/132, 117, 145; 455/431

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST, WEST, base station

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,969,837 A (FARBER et al) 19 October 1999, Figs. 1 and 2, col. 3, lines 30-67, col. 4, lines 1-54.	1-26
X	US 5,682,256 A (MOTLEY et al) 28 October 1997, Fig. 1, col. 2, lines 30-67, cols. 3-4, lines 1-67.	1-26
X	US 6,055,425 A (SINIVAARA) 25 April 2000, Figs. 3 and 4, col. 2, lines 4-67, col. 3, lines 1-42.	1-26

☐ Further documents are listed in the continuation of Box C. ☐ See patent family 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 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
14 MAY 2001	10 OCT 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer LESLIE PASCAL Telephone No. (703) 305-4700