CELLULAR MOBILE COMMUNICATION SYSTEM

FIELD OF THE INVENTION

The present invention relates to a cellular mobile communication system with radio base stations and mobile stations. The system comprises a number of cells which are arranged in two or more different layers or levels and the mobile station connections can be handed over from one cell to another. The system comprises means for monitoring and/or measuring at least one signal parameter of at least those cells not being in the uppermost layer and at least one threshold value is given for said signal parameter for at least each of said cells.

The system furthermore comprises means for controlling said handovers between different cells.

The invention also relates to a method for controlling handovers in a cellular mobile communication system wherein the cells are arranged in at least two different levels or layers.

A communication system of this kind comprises a number of base stations which generally are organized into a network. Each base station serves a geographical area which is called a cell. The geographical area can be said to be given by the radio propagation properties of the base station and of the surrounding radio base stations. The system furthermore comprises one or more mobile stations and when a mobile station moves, mobile connections can be handed over from one cell to another which is known as a handover. In this context however, a number of factors play an important role since it is of utmost importance that the most appropriate cell is selected when a handover is carried out, both under normal circumstances as under more or less extraordinary

circumstances. It is therefore extremely important that the cells are organized in the most suitable way.

STATE OF THE ART

A number of attempts have been done to provide a cellular mobile communication system with a cell structure which is appropriate.

One known system applies a so called "umbrella" cell treatment. Different cell layers, i.e. preference layers or priority layers, are in this case arranged according to the selection and placement of the radio base stations. Powerful base stations with high antennas then constitute so called umbrella cells whereas low-power base stations e.g. mounted at street level form so called "micro-cells" whereas furthermore so called "pico-cells" can be arranged which then e.g. may be mounted indoors. Thus there are either two or three different cell layers. In this case the normal cell selection mechanism, locating, is the mechanism responsible for providing the desired behaviour. However, no logic is dedicated to the purpose. The intention with the use of so called "umbrella" cells is to provide a safety net to the normal cell network by bridging coverage holes, providing spare capacity at call set up procedures and to have the function of rescue at radio disturbances etc. The purpose with micro-cells (in relation to umbrella cells or normal cells) is to provide the main capacity, particularly in high density traffic areas. The system with umbrella cells therefore direct traffic to the appropriate cells in the appropriate layer, in order to assure call continuity and to assure a successful call set up procedure. The cell structure with umbrella cells without dedicated logic however, does not work satisfactorily when base stations belonging to different layers are placed close to each other. The cell selection mechanism, locating, will then result in a number of unnecessary handovers such as from a micro-cell to an umbrella

cell even if the micro-cell provides radio conditions which are adequate. This is illustrated in Fig. 1 which shows two micro-cells under an umbrella cell. For the mobile station MS 1 the micro-cell C_A will provide the highest signal strength. Consequently that cell will carry the connection. The mobile station MS 2 will be in radio shade from both micro-cell base stations BS 1, BS 2. In this case the umbrella cell C_U fulfills its purpose and provides coverage where the micro-cells C_A, C_B fail to do so. However, for the mobile station MS 3, the micro-cell base station BS 2 is in line of sight and should therefore be able to carry the connection without problems. Nevertheless, the umbrella cell base station BS_U which also is in line of sight has a signal strength which is higher and will therefore take over the connection. Also at e.g. radio disturbances and call set up congestion connections may unnecessarily be taken over or upheld by the umbrella cell or may be generally upheld or taken over by less appropriate cells. This will lead to a waste of capacity which may lead to loss of connections etc. In other words, the occupation of less appropriate resources will increase. Moreover an efficient frequency planning and efficient dimensioning of the hard-ware is difficult. Furthermore the number of handovers is unnecessarily high which results in a high load on the switches and thus a non-negligible risk of loosing connections.

In another known system different cell layers are given different priorities and a priority has been given to handovers to the umbrella cell layer which is higher than the priority of handover due to a number of other radio network functions. Interactions with a number of radio network functions have been given different priorities. A higher layer has then been given a higher priority in case of radio disturbances and call set up congestion etc. Thus the passing between the layers is triggered by a number of different, extraordinary events such as e.g. congestion at call set up

and bad quality (high BER, Bit Error Rate). Also in this case connections are not always directed to the most adequate cell layer. Moreover coverage holes are not adequately covered.

GB-A-2 242 806 describes a cellular system comprising macro-, and micro-cells. Handovers are always effected via the macrocell layer in order to avoid unnecessary handovers from macrocell to microcell and back again. A handover to a lower layers is merely carried out when the link from the equipment to the base station associated with the underlying microcell has a quality which exceeds predefined criteria for a time interval that exceeds a predetermined time interval. Handover from a microcell to another microcell thus never occurs.
Thus, also in this case the "wrong" resource will be occupied to a great extent.

WO-A1-92/02105 discloses a cellular radio system. A handover-initiation system comprises means for determining the distance of a mobile station from the base station of a cell and means for measuring the signal strength to determine the path of a mobile station. With the use of the location determinating system it is possible, with the use of therein stored information and signal character on the estimated distance, to determine the location of a mobile station within a micro-cell. The system furthermore comprises means for storing information-pairs on location and signal character of said location and means to form a current pair comprising these parameters for a mobile station which is moving and means to compare stored parameters with current parameters. However, also in this case the wrong resources will be occupied leading to a non-efficient use of the resources and increasing the risk of loosing connections etc.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a cellular mobile communication system as initially referred to wherein the cells are organized into layers of preference in such a way that the system resources are used in an optimal way.

A further object of the invention is to provide a system through which it is at the same time assured that traffic is directed to the cells for which the network is dimensioned, that there is free capacity in the cells to provide spare capacity at call set up and to assure that there is free capacity in the cells for them to act as rescue cells at the same time to as to assure call continuity and successful call set up. It is also an object of the invention to direct connections to cells which confidently can take care of the connection and to bridge coverage holes. Still another object of the invention is to enable an efficient frequency planning and an efficient dimensioning of the hardware of the system. Still another object of the invention is to keep the number of handovers at a low level and to minimize the load on the switches as well as to minimize the risk of loosing connections.

These as well as other objects are achieved through a system of the above mentioned kind comprising controlling means which comprises a ranking arrangement which is based on a number of criteria.

One criterion is based on a comparison of the current monitored value of a signal parameter of the serving cell with the given threshold value for the serving cell and a second criterion is based on a comparison between a comparison of the current monitored value of a signal parameter of a neighbour cell with the given threshold value for that

neighbour cell. The handovers between cells are governed by the priority ranking arrangement in such a way that a systematic passing between cells or cell layers or levels is obtained, also for passing up and down between the layers.

It is also an object of the invention to provide a method for controlling the handover procedure in a cellular mobile communication system wherein the cells are arranged hierarchically in at least two different layers or levels so that the resources of the system are used in the optimal way and so that the traffic or the connections are directed to the appropriate cells in agreement with the dimensioning of the system etc.

These and other objects are achieved through a method wherein a priority ranking is carried out based on a number of criteria.

The method comprises the steps of:

- introducing a threshold value for the serving cell;
- introducing a threshold value for at least each cell not being in the uppermost layer;
- monitoring at least one signal connection parameter for the serving cell;
- monitoring at least one signal connection parameter for a number of neighbour cells;
- comparing the monitored current value of the signal parameter for the serving cell with the threshold value for serving cell;
- comparing the monitored value of the signal parameter for the neighbour cells with the threshold value for the respective cell;
- carrying out the handovers in agreement with the priority ranking arrangement in such a way that a systematic passing between cells or cell layers is obtained, also for passing up and down between cell

layers.

The method can particularly be modified to comprise any embodiment or any combination as further evaluated in relation to the system itself.

A number of advantageous embodiments are e.g. given by the features of the appended subclaims.

With the cellular system according to the invention connections will systematically be directed to a lower layer and at radio disturbances and call set up congestion among others there will be a systematic redirection of connections to cells that confidently can take care of them. Through the introduction of a threshold for each cell, a systematic way of passing between layers is obtained. The threshold can e.g. be for signal strength, path loss or both. Other signal parameters are also possible. Which signal parameter (I) is used, depends on the general handover strategy that the system applies. In a particular embodiment the so called Mobile Assisted HandOver strategy is used (MAHO). Then the mobile station performs signal strength (and/or other) measurements on radio energy transmitted from a number of neighbouring base stations. The mobile station transmits these measurements to the base station which delivers them to the unit responsible for the decision logic. However, also other handover strategies can be used such as NCHO (Network Controlled HandOver) wherein the mobile is passive, MCHO (Mobile Controlled HandOver) wherein the mobile both measures received signal strengths etc and takes decisions as to handover.

In a particular embodiment Time Division Multiple Access (TDMA) is used. With the system according to the invention the threshold is used for passing upwards as well as downwards, i.e. for passing to cells of a higher level of prefer-

ence as well as to cells of a lower level of preference, or having a lower priority. According to a particular embodiment the threshold is modified with the hysteresis which is added or subtracted according to the direction of movement. In the normal case, e.g. when no extraordinary events or simultaneous functions are demanded, one condition for passing to a higher layer is that if the signal strength (in this particular case) monitored from the cell currently serving the connection, i.e. the serving cell, decreases below the threshold for that particular cell (in an advantageous embodiment with hysteresis subtracted), the system extends the set of neighbour cells which are eligible for handover to cells in a higher hierarchical layer. However, the cells in the higher layer have a lower priority than cells in the current layer and in lower layers. A condition for passing to a lower layer is that if the signal strength monitored or measured for a neighbouring cell in a lower hierarchal layer increases above the threshold for that cell (in an advantageous embodiment with hysteresis added) that cell will be added to the set of neighbouring cells which are eligible for handover. This cell will have a higher priority than cells in the current layer or in higher layers.

In advantageous embodiments the interactions with other radio network functions are dealt with. Examples of other radio network functions are intra-cell handover, overlaid-underlaid sub-cell handover, extended range, directed retry, assignment to another cell, alarm handover etc. Particularly one or more of these or other radio network functions are given different priorities in relation to one another and to normal handover functions. This is particularly relevant when different radio network functions propose different types of actions simultaneously.

Particularly with the invention the mobile stations can systematically be directed to the lowest possible layer. This saves the capacity of the higher layers for extraordinary

events such as e.g. coverage gaps or call set up congestion etc.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will in the following be more fully described in a non-limiting way under reference to the accompanying drawings wherein :

Fig. 2 very schematically illustrates a mobile communication system,

Fig. 3 illustrates a flow diagram of the main flow in the locating procedure,

Fig. 4a illustrates a table for the ranking order in a two-layer structure wherein the serving cell is in the lowest layer and the signal strength for serving cell is under the threshold,

Fig. 4b illustrates a table for the structure of fig. 4a but wherein the serving cell is in the lowest layer and the signal strength of serving cell is over the threshold,

Fig. 4c illustrates a table for the structure of fig. 4a but wherein the serving cell is in a higher layer (forming an "umbrella"),

Fig. 5a illustrates a table for ranking order in a three-layer structure wherein serving cell is in the lowest layer and the signal-strength of the serving cell is under the threshold,

Fig. 5b is a table relating to the same structure as in Fig. 5a but wherein the signal strength of the serving cell is over the threshold,

Fig. 5c is a table relating to the same structure as in Fig. 5a but wherein serving cell is in the second layer and wherein the signal strength of serving cell is under the threshold,

Fig. 5d is a table relating to the same structure as in Fig. 5c but wherein the signal strength of the serving cell is over the threshold,

Fig. 5e is a table relating to the structure of Fig. 5a but wherein serving cell is in the 3rd or uppermost layer,

Fig. 6 illustrates how categories of handover candidates are ordered in a particular scenario.

DETAILED DESCRIPTION OF THE INVENTION

The cellular communication system comprises a cell structure wherein the cells are arranged in at least two layers in a hierarchical manner.

Fig 2 very schematically illustrates a cellular, mobile communication system, in this case the GSM-system. Fig 2 is merely shown for brief explanatory reasons, indicating very schematically a part of a mobile cellular system and it has of course in no way any limiting effect on the invention.

The Base Station System BSS comprises a number of Base Transceiver Stations BTSs wherein a group of BTSs is controlled by a Base Station Controller BSC and a number of Base Station Controllers BSCs are controlled by a Mobile Switching Centre MSC of the Switching System SS controlling calls to and from a network such as e.g. the Public Switched Telephone Network PSTN, the Public Land Mobile Network PLMN, the Packet Switched Public Data Network PSPDN, the Circuit

Switched Public Data Network, the Integrated Services Digital Network ISDN or any other network.

The Switching Center further comprises a Visitor Location Register VLR comprising a data Location Area, a Home Location Register HLR with data on subscribers etc. which however is not relevant for the present invention. OMC indicates an Operation and Maintenance Center OMC in a manner known per se. Dashed lines in the figure relate to information transmission and full lines relate to call connections and information transmission and dashed lines also relates to, in the case of boxes, alternative networks, alternative or optional functions (of the SS etc.).

According to the invention a threshold is introduced at least for each cell not being in the uppermost layer. This is one feature for the provision of a systematic way of passing between layers. The threshold can be for the signal strength or for path loss or for both or for any other parameter depending on the general handover strategy of the system (among others). In the embodiments described in the following merely these cases which relate to a signal strength threshold will be described. This is however by now means limitative and the treatment when e.g. a path loss threshold or another threshold or both is applied, is substantially identical.

The threshold is used for passing upwards as well as downwards in the cell hierarchy. According to advantageous embodiments the threshold for passing upwards and downwards is generally referred to as a threshold. It may however be modified with a hysteresis which is added or subtracted according to the direction of movement. In a generalized case the condition for passing upwards, i.e. from a lower layer to a higher layer is that if the signal strength measured from the cell currently serving the connection, i.e. the serving

cell, is below the threshold for that cell (particularly with a hysteresis subtracted) the system extends the set of neighbour cells which are eligible for handover to cells in a higher hierarchical layer. The cells in the higher layer will have a lower priority than cells in the current layer and in any lower layer. The corresponding condition for passing downwards, i.e. from a higher layer to a lower layer, that is if the signal strength measured from a neighbour cell in a lower hierarchical layer increases above the threshold for that cell (particularly with hysteresis added) that cell will be added to the set of neighbour cells which are eligible for handover. That cell will have a higher priority than cells in the current layer or in a higher layer.

Thus the cell structure can be said to be a hierarchical cell structure. Therethrough the locating function is affected and modified. The basic ranking is done over the different cell levels and a basic ranking list is formed. This list comprises a number of candidates and the list is organized depending on different conditions. The organization may be governed by a table and e.g. supplied as Permanent Exchange Data. The candidates in the list are also divided into categories which will be further discussed below.

In the following, some concepts are explained. Basic ranking means the ranking of cells based on signal strength and/or path loss criteria (or any other appropriate parameter). Locating relates to the procedure that, using measurement and parameter data, proposes the most appropriate connection. The output from the locating procedure is a list of possible candidates, the candidate list, for handover or assignment. Urgency refers to a condition requiring an urgent handover. Such is present if the transmission quality is too low, if Timing Advance (TA) is too large, if the time dispersion is too large or if any other criterion for extraordinary radio events is met depending on which physical measurements are

available for the radio connection. As to the umbrella cell concept, a cell may be defined as an umbrella cell. An umbrella cell is a cell in a network of large cells encompassing the normal network. However, this invention is based on a concept of hierarchical cells.

Generally there will be a great number of different requirements on the Base Station Controller BSC for the locating algorithm. The locating algorithm is here particularly defined as a collective term for cell and subcell selection, including all types of intra-cell change of channel. The locating function generally describes a functionality that comprises one of many functional components of the locating algorithm. In the following a handover generally describes a channel change between cells. In the following will be referred to the measured parameters or quantities. Those are quantities which are monitored in the (in a particular embodiment) MS, Mobile Station and in the BTS by a measuring device e.g. as specified in the GSM recommendations. When applying the Mobile Assisted Handover strategy MAHO, the quantities measured or monitored in the Mobile Station MS are transferred to the BSC over the air. Quantities measured or monitored in the Base Transceiver Station BTS are transferred to the BSC. However, the ways in which measurements are carried out, informed on etc. depend on the particular handover strategy that is used. In a particular embodiment, as will be further discussed later on, the measurements that are considered include uplink and downlink signal strength and uplink and downlink signal quality measurements. As already stated, there are of course a number of other alternatives. In the same embodiment reported quantities refers to quantities which are used in the MS, Mobile Station. The reported values are transferred from the MS to the BSC, Base Station Controller over air. Reports considered in the described embodiment include Timing Advance, TA, coming form the BTS. As in any known system,

filtering may be required. It may be necessary to smooth out stochastic variations etc. This will however not be further discussed.

In one embodiment, as in a number of known systems, cell and subcell evaluation may be performed together in a cycle which is completed at least within one SACCH (Slow Associated Control Channel) period, and repeated every SACCH period unless certain mechanisms prevent selection for a time interval. This however merely constitutes one example among many others.

As more thoroughly discussed later on, the cell selection is based on the ranking in the ranking list which it established. The ranking list is preferably established in the beginning of the cycle according to given basic principles. The final cell selection is obtained through reorganization of the list according to different principles which depend on the different criteria which will be further discussed later on. The locating function continuously monitors and evaluates the radio environment and suggest the most favourable cell (and/or subcell).

Based on a number of comparisons of measurements of measured and reported quantities a candidate list is produced. This candidate list comprises cells in order of preference. In an advantageous embodiment the signal quality and timing advance are continuously monitored and evaluated together with signal strength estimates (comprising possible filtering functions). The candidate list which is produced will e.g. in a known manner be sent to the call process handler to be used for channel allocation. Generally the locating comparison and the preparation of the candidate list according to the given prerequisites start immediately after the initiation of the locating algorithm.

Once the candidate list is received by the function handling the candidate list, the candidates are used in attempting to allocate the channel according to the information in each candidate entry. In the attempts, the candidates are used in the order they are placed in the list e.g. with one attempt for each candidate. If channel allocation to a particular candidate fails (e.g. in the case of a congestion), the candidate next in the list is to be used for the next attempt and so on until the channel has been allocated successfully or all candidates have been tried unsuccessfully. This is a procedure which generally is known per se which of course could be more or less modified but also completely exchanged through another procedure without departing from the scope of the invention.

Particularly, the interactions with other radio network functions such as intra-cell handover, overlaid-underlaid subcell handover, extended range, directed retry, assignment to another cell, alarm handover etc. will be discussed later on. This is particularly relevant when various radio network functions propose different types of actions at the same time. The cell candidates are according to the invention sorted into categories depending on a number of factors, in one embodiment on three factors, namely the layer, the ranking as compared to the serving cell and a measured parameter such as signal strength (or path loss or similar) compared to the threshold. Each combination of results from the evaluations of the radio network control functions is connected to a defined list of categories describing the precedence of the candidates in a so called "handover candidate list".

Fig. 3 illustrates in a general way the main flow of the locating procedure in one particular embodiment. Timing Advance TA reports and measurements are filtered in a wherein

among other things the Bit Error Rate is checked etc. In b the basic ranking is performed which is more thoroughly discussed later on. In c the hierarchical cell level evaluations are carried out, i.e. the evaluations as to if a cell is over/under a threshold etc.

Thereafter follows (d) the evaluations in relation to other Radio Network Functions, such as e.g. urgency conditions, overlaid/underlaid evaluation, intra-cell evaluation etc. These so called flags are introduced into the tables and constitute examples on conditions which can be controlled or modified.

Thereafter follows the organizing procedure which depends on a - d and wherein a candidate list is organized. Thereafter is proceeded e.g. as in any known system or Locating Flow.

In the particular described embodiment in the initiation procedure the Base Station Controller BSC block is initiated, the channel allocation process is initiated and the table(s) is/are read. The initiations are performed at activation of a locating individual or a cell, e.g. at handover at reception in the Base Station Controller BSC of a complete handover signal from the MS (Mobile Station) in the handover procedure. Among others the parameters layer, better/worse, over/under threshold are read. The initiation block furthermore comprises the so called CPH (Call Process Handler) process which handles the BSC (Base Station Controller) signalling, data structure, updating and processing the parameters, e.g. signal strengths etc. reports to the active locating instance. The procedures referred to are referred to in a simplified manner since most steps in the procedure correspond to the procedures that are carried out in known cellular mobile communications systems e.g. with conventional umbrella cells. E.g. filtering functions are carried out in a manner known per se etc. The basic ranking procedure will

be further discussed below in relation to two examples of establishing a priority table based on a hierarchical structure comprising two and three levels respectively.

In the locating procedure the measurement reports can e.g. be taken care of directly in the locating procedure itself or be placed in a buffer. However, preferably they are taken care of directly. Both urgency conditions and overlaid/underlaid evaluation and intracell evaluation are dealt with in a way similar to known cellular systems comprising umbrella cells. After the intracell evaluation follows an organizing procedure. This is different from known systems and will be further discussed and illustrated later on. The organizing procedure may comprise a grooming procedure whereafter the list is sent in a manner known per se, as well as the administration of the allocation reply is dealt with in any appropriate way.

In one embodiment the organizing procedure may e.g. comprise four procedures wherein cross-reference tables are built for cells in the parameter list, e.g. signal strength etc. to cells in the ranking list, cells in the parameter list to cells in the measurement value list, cells in the ranking list to cells in the parameter list and cells in the ranking list to cells in the measurement value list. This procedure is followed by the second procedure wherein each cell in the ranking list is fragmented according to three parameters, namely (as referred to above)

1 - layer,

2 - better or worse than serving cell and

3 - if it is over or under its own threshold. Thereafter the cells are sorted into a three-dimensional datastructure. The ranking list is stepped through in the ranking value order.

Table entries are found in any appropriate manner which generally is known per se.

Particularly relating to one embodiment the known umbrella cell concept can be said to be extended to a hierarchical cell structure. Therethrough it can be used to e.g. cover up holes in coverage from normal cells. According to one embodiment (which may or may not include a hysteresis threshold or a second threshold), the transitions between normal cells and "umbrella" cells are controlled by the threshold (the signal strength threshold I^{tr}) and the modified threshold, i.e. the signal strength threshold modified with hysteresis H^{tr}. In a particular embodiment these parameters (the first and the second thresholds) are defined for normal cells, i.e. not for cells forming so called "umbrellas". In this particular case this leads to a basic ranking list (among others referred to in Fig. 3) comprising 7 categories. This is illustrated in figs. 4a to 4c. For cells in level 1 (the lowest layer), in this embodiment so called normal cells, the signal strength is compared with the threshold value. In relation to the herein described embodiment "over" for serving cells means that the signal strength $I_0 \geq I_0^{tr} - H_0^{tr}$ and "under" for serving cells means that the signal strength $I_0 < I^{tr}_0 - H^{tr}_0$ whereas for neighbouring cells "over" means that the signal strength $I_i \geq I_i^{tr} + H_i^{tr}$ whereas "under" means that the signal strength $I_i < I_i^{tr} + H_i^{tr}$. The candidate list is organized depending on different conditions. This means that one or more categories which normally might be in the list can be removed from the list, and categories can be added etc. and the categories are arranged in a proper order according to the particular needs and requirements. The organisation as such is governed by a table as mentioned above. This table form permanent exchange data but it can also be changeable and possible to correct etc. The table comprises one part referred to as conditions. The conditions an e.g. be according to the following table, hereinafter referred to as Table A:

1 - Assignment Request arrived,
2 - AW-state (which means Assignment to worse cell),
3 - Excessive Timing Advance (TA) urgency,
4 - Bad Quality urgency,
5 - Overlaid-Underlaid subcell change,
6 - Intra-Cell handover.
(Table A)

Of course other conditions are also possible as well as there might be fewer or more conditions, depending on the particular needs and the particular requirements. The conditions can be true, indicated with a "1", false, indicated as "0" and finally they may be irrelevant, indicated as "-".
The table furthermore relates to different categories. In the tables illustrated in figs. 4a - 4c

s	- means serving cell,
1 bo	- better cell in layer one, SS (Signal Strength) over threshold,
1 bu	- better cell in layer 1, SS under threshold,
1 wo	- worse cell in layer 1, SS over threshold,
1 wu	- worse cell in layer 1, SS under threshold,
2 b	- better cell in layer 2,
2 w	- worse cell in layer 2.

The table in fig. 4a illustrates the serving cell in layer 1 (normal) wherein the signal strength is under the threshold. 24 different cases are illustrated. In the tables (Fig. 4a-4c) in referred to whether the serving cell has a signal strength which is over or under the threshold for the serving cell (se also Fig. 5a-5e).

The tables of Fig. 4 have been made up according to guidelines which have given a certain priority order between the different radio network functionalities. This priority order is given by the following table, hereinafter referred to as Table B:

1 - Normal Handover
2 - Timing Advance TA urgency
3 - Going to a lower layer
4 - Subcell change
5 - Intracell Handover
6 - BQ urgency
7 - Going to a higher layer
(Table B)

The table in Fig. 4b illustrates serving cell in layer one (normal) and the signal strength being over the threshold for 24 cases and finally the table in Fig. 4c illustrates the serving cell in layer 2 (which in this case relates to an "umbrella" cell) for 24 different cases. Particularly it is also possible to divide a number of cases into different cases for subcell change conditions which however will not be further discussed here.

The embodiment described above relates to a case with two cell layers or levels. Of course there can be more layers. In the following another embodiment will be described. In this case there are three different cell layers.

The hierarchical cells structure according to the invention can be applied to the umbrella cell functionality. An umbrella cell functionality provides a second level in a network comprising large cells which logically (and physically) are organized above the original cell network and works as a backup network therefor. In the present embodiment a third level is introduced which logically (and physically) is arranged below the original cell network and comprises small cells. In one embodiment this level forms a micro-cell network. Herein the first level or the lowest level (level 1) or the bottom level is called the micro-level and the second level or the middle level is called an normal or an original

level and the third level or the top level may be called a third or an upper level. Generally the intention with allocating mobiles in the hierarchical cell structure is to fill the lowest level first i.e. the mobile station should be served by a cell in the lowest possible level or layer because this level particularly has the highest capacity. This has as a consequence that the mobile station not always will be served by the best cell from e.g. a signal strength or a path loss point of view but by a cell which is good enough and in the lowest possible layer.

The invention particularly relating to the treatment with a threshold and with a system of tables as e.g. illustrated in Fig. 4, furthermore allows for any other strategy by changing the priorities as e.g. given by table B as referred to in the foregoing.
Moreover, the system comprising tables as e.g. in Fig. 4, allows for different strategies in different layers. In e.g. this way, traffic can be directed to any layer and not only to the lowest etc.

Of course the invention likewise relates to networks having more than two or three layers, but since the principle is the same independently of the number of layers only networks comprising a two and a three-layer structure will be more fully described herein.

A hierarchical cell structure according to the invention can be related both to the umbrella cell concept and to cells generally in different layers or levels. Through the introduction of the signal strength threshold I_0^{tr} or a threshold for upwards transition, below which a transition may occur, transitions to a logically higher level or layer is facilitated. A flag, in a manner know per se, indicating that a handover to a higher layer cell is allowed should be set when the signal strength in the serving normal cell falls below

I_0^{tr} -H_0^{tr}. The flag is e.g. be referred to as a Higher Level Change Allowed flag. A candidate list containing only better cells according to basic ranking should be sent if the flag is set (and if no other flags are set). If the list is empty however, i.e. no better cells exist; then the mobile station remains in the current cell i.e. in the serving cell. If however, after handover to a higher level cell, the signal strength from a lower layer cell again rises above the threshold, then this cell should not immediately (according to the particular embodiment) become part of the candidate list. The signal strength should preferably reach a level somewhat above I^{tr} or threshold I^{tr} + H^{tr} or a threshold for downwards transition in order to get a hysteresis effect which will prevent repeated handovers or so called "ping-pong handovers". When the signal strength from a lower level cell exceeds I^{tr} + H^{tr} a flag is set (in this particular embodiment). This flag can bee seen as a Lower Level Change Allowed. The candidate list is then sent containing the lower level cell exceeding I^{tr} + H^{tr}.

I^{tr} and H^{tr} here relate to cell parameters and the serving cell uses its own threshold values when evaluating I^{tr}-H^{tr} (I_0^{tr} - H_0^{tr}) (for a possible move to a higher level). When the serving cell evaluates neighbours it uses the threshold values corresponding to the neighbouring cells (I_i^{tr} + H_i^{tr}).

If a third level below the two other levels is introduced, the cells of that level shall generally be assured traffic in preference to all the other levels. This is achieved if the above reasoning is applied on the bottom level. In the following the bottom level is called level 1. For the provision of a candidate list a basic ranking is performed among all cells which fulfil a minimum criterion. After that a level oriented rearrangement is done. Any cell in the lower layer with a signal strength exceeding I_i^{tr}+H_i^{tr} (which refers to a preferred embodiment) will set a flag indicating Lower

Layer Change Allowed which will make the cell the top candidate in the candidate list. If there are more such cells the basic ranking result will be used at the ranking among themselves. If the Higher Layer Change Allowed flag is set, the assembling of the candidate list proceeds generally as follows: cells better than the serving cell, in the same or in a higher higher layer, may be candidates, cells in the same layer have priority over higher layer cells. Cells among the "better" cells above with a signal strength below the Higher Layer Change Allowed threshold, have a lower priority, (in case there are any at all). In the last category higher level cells have priority over lower level cells. This is due to the fact that going to a lower layer cell with a signal strength below the threshold for Higher Layer Change Allowed would immediately result in a transfer to a higher layer anyway. This saves two unnecessary handovers. If however an urgency flag is set simultaneously to the flag indicating Higher Layer Change Allowed, than also worse cells may be appended to the candidates list. The assembly to the candidates list is given by a table which implements the in the foregoing considered principle of priority. The table can be supplied as a permanent exchange data which allows tuning of the algorithm without changing the actual code. However, in an alternate embodiment the table is not permanent but can be changed e.g. by command. Of course it is possible to provide for means e.g. preventing handovers to lower layer cells under certain conditions, such as in the case of fast moving mobile stations etc. Moreover it is possible to add further cell types, e.g. indoor cells or pico-cells etc. Therethrough it can be necessary to introduce more levels in the cell ranking list.

The thresholds and hysteresis parameters can be set per BSC or per cell level or per MSC level or per system level.

In the case of three cell layers or levels, the basic ranking is made over the three cell levels. The candidates in the candidates list are as already discussed above divided into categories and the reported signal strength, the signal strength threshold and hysteresis and the cell level are used to set the categories for the neighbouring cells. Likewise, as already referred to, it does not have to be the signal strength but could also be the path-loss, the signal strength as well as the path-loss or any other convenient parameter.

In Figs. 5a - 5e tables are illustrated from which the candidate lists are formed as already mentioned above in relation to the embodiment comprising two cell layers. First a basic ranking is performed, advantageously among those cells which fulfil a minimum criterion of exceeding a threshold value of at least one given signal parameter.

Thereafter a hierarchical level evaluation is performed, i.e. a level-oriented rearrangement is done. This means that a candidate list is assembled governed by one or more tables. Examples of such tables are illustrated in Figs. 5a- 5e. These tables will in the following be explained. As above TA relates to Timing Advance and AW relates to Assignment to worse cell. In the tables, the number defines the layer, i.e. in this case three layers, layer 1, layer 2 and layer 3 wherein layer 1 is the lowest layer etc.

Better and worse is illustrated through b and w respectively whereas o and u means over and under the threshold respectively, plus or minus the hysteresis as the case may be, e.g. if an hysteresis is applied or not. If a hysteresis is applied, this may be dealt with by the locating function.

As in the embodiment relating to a hierarchical 2-layer structure, the table (Figures 5a - 5e) comprises a number of

conditions,
namely:

1 - Assignment request Arrived and AW (Assignment to worse cell) state,
2 - Assignment request Arrived and not AW-state,
3 - Excessive Timing Advance TA urgency,
4 - Bad quality urgency,
5 - Overlaid-Underlaid subcell change request,
6 - Intra-cell Handover request,
7,8 - Layer, wherein 00 indicates the lowest layer, 01 indicates the second layer, 10 indicates the third layer and finally 11 indicates the highest layer,
9 - Own cell signal strength under the threshold,
10 - Not used (but in this case indicated 0).

This table will hereinafter be referred to as Table C.

Table 5a relates to layer 1 under i.e. the own cell (serving cell) is in the lower layer (conditions 7 and 8) and the signal strength is under the threshold of that particular cell (condition 9). 32 different cases are indicated in the table.

Table 5b refers to layer 1 over, i.e. own cell is in the lower layer and the signal strength is over the threshold.

Table 5c relates to layer 2 under, i.e. the second layer wherein the own cell is in the second (in this case intermediate) layer and wherein the signal strength is under the threshold of that particular cell; i.e. $I_2 < I_2^{tr}$.

Table 5d relates to layer 2 over i.e. the second layer and a signal strength which exceeds the threshold ($I_2 > I_2^{tr}$).

Finally Table 5e relates to layer 3 over, which indicates

layer 3 own cell in upper layer in this case and a signal strength exceeding the threshold. Alternatively the threshold is not checked.

In the following two particular examples will be given on the interactions of the hierarchical cell structure with other network functions. Particularly the interactions with other network functions are given a priority yielding the sorted order in the priority table of the system both if e.g. the tables (such as Fig. 4 and Fig. 5) are based on the priority between the radio network functions or not.

In a first example the interaction with the intra-cell handover function will be described for a particular embodiment. Two or more radio network functions may make their propositions at the same time. In this case the intra-cell handover function proposes a change of channel within a cell at the same time as the hierarchical cell structure function proposes a handover to another cell either in a higher layer or in a lower. In this particular embodiment a handover to a higher layer has preference over an intra-cell handover (se Table B). However, an intra-cell handover has preference over e.g. a quality alarm handover. but of course e.g. a quality alarm handover may alternatively have preference over an intra-cell handover etc. This depends on the particular system needs and requirements.

When neighbour cells measurements have been received from the mobile, the corresponding cells are categorized according to the combination of three parameters, namely

1 - the hierarchical layer they belong to,
2 - their ranking as to if they are better or worse than the serving cell according to normal locating criteria and finally
3 - if the measured signal strength is above or below the

threshold for that cell. In this case, if three hierarchical layers are implemented, twelve categories are obtained.

Generally all possible situations and combinations of situations which are relevant to the various radio network controlled function evaluations are analyzed. Based thereon a unique sequence of cell categories are assigned to that particular combination of evaluation results. The sequencing of categories can e.g. be done in order to comply with a given priority list, such as e.g. the one given in table B. This sequence or candidate list, as already explained above thus represents the list of the handover candidates in the particular order of preference. Fig. 6 further explains how the different categories of cells can be arranged in order of priority in a list, e.g. the cases 6, 7, 8 in Fig. 4a. In Fig. 4a the two categories 2bo and 2bu form one single category 2b. For 2w the corresponding throwing together has been done for 2wo and 2wu. Furthermore, in Fig. 6 o/u (over/under) relates to the signal strength of the neighbour cell I_i being over/under the threshold value for that neighbour (or candidate) cell I_i^{tr}. The reason for this splitting up is to avoid unnecessary handover ping-pong effects (first going down a layer and directly thereafter having to go up to a higher layer again).

In the following an example will be considered wherein the structure comprises two cell layers and wherein the serving cell is in the lower layer. It is assumed that besides the normal locating the radio network evaluations have proposed three actions simultaneously, namely a bad quality alarm handover, handover to a higher hierarchical layer and an overlaid-underlaid subcell change. In this case a handover to a higher hierarchical layer has the highest priority whereas a bad quality alarm handover has the lowest priority. The highest priority of all is to remain in the lower layer, i.e. a normal better cell handover initiated by the normal

locating. With this combination of evaluation results, the candidate list of handover candidates as illustrated in fig. 6 is obtained. First a ranking by the locating function is performed wherein cells are denoted better and worse than the serving cell and thereafter the handover candidate list is established. As referred to above, above/below the threshold refers to the threshold for that particular cell. According to this list, the highest priority is to stay in the lower layer but only if a better cell appears which is illustrated in the first line. The second priority will be to go up to the upper layer which is illustrated in lines 2 and 3 of fig. 6. If going to a better cell will result in immediately going up to an upper layer or an "umbrella" cell which is the case if the signal strength of that cell is below the threshold, the first handover will not take place and instead there will be a handover directly to the upper cell or the "umbrella" which is illustrated on lines 1 and 4. The third priority will be to perform a subcell change which is illustrated on line 5. Finally, the lowest priority is to go to a cell which is ranked as worse than the cell currently serving the connection. Also in this case a cell in the lower layer has preference over a cell of the upper layer but not if a second handover to the upper layer would ensue which can be seen in lines 6 to 8 of fig. 6.

The advantageous embodiments invention applies to TDMA (Time Division Multiple Access) or FHMA (Frequency Hopping Multiple Access) or CDMA (Code Division Multiple Access). Moreover, the invention is not limited to any particular handover strategy but a number of different strategies can be used such as Mobile Assisted Handover strategy MAHO, Network Controlled Handover NCHO or Mobile Controlled Handover MCHO.

With the invention it is possible to apply a systematical approach upon designing hierarchical cell structures. Of course an arbitrary number of layers can be designed and the

detailed conditions for switching between layers can be controlled in terms of criteria for changing between layers as well as a detailed interplay with other radio network controlled functions.

Due among others to the fact that passing between layers is generally predictible, a systematical cell planning and dimensioning is possible. Furthermore it is possible to direct mobile stations to the lowest layer in a systematical way which, as already stated above, saves the capacity of the higher layers for e.g. coverage gaps or call setup congestion etc. Alternatively it is possible to direct mobile stations to any layer of preference.

With the invention it is among others thus intended to be able to direct the traffic to the cells for which the network or the Hierarchical Cellular System HCS actually is dimensioned and to ensure that there is free capacity in those cells which shall provide spare capacity at call set-up and which have the function of rescue cells.

Cells in a higher layer have priority at coverage holes and at radio disturbances to ensure call continuity. At call set-up congestion cells in a higher layer also have priority in order to ensure successful call set-up procedures.

The invention is of course not limited to the shown embodiments but can be varied in a number of ways within the scope of the claims.

Particularly the invention can be applied to generally every known standard, such as GSM, PDC, all PCS-standards, IS54, IS90, ADC, (D-)AMPS, DECT etc.

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CLAIMS

1. Cellular mobile communication system with a number of radio base stations (BS) and a number of mobile stations (MS), said system comprising a number of cells which are arranged in at least two different layers or levels wherein mobile stations (MS) can be handed over from one cell to another and comprising means for monitoring or measuring at least one signal connection parameter of at least those cells which are not in the uppermost layer and wherein at least one threshold value (I_o^{tr}, I_i^{tr}) for said at least one signal parameter is given for at least each cell (C_o, $C_{i,i-1,\ldots,n}$) not being in the uppermost layer, the system furthermore comprising controlling means for deciding on and controlling handover decisions,
c h a r a c t e r i z e d i n t h a t ,
the controlling means comprises a priority ranking arrangement based on a number of criteria of which a first criterion is based on a comparison of the current, monitored value (I_o) of a signal parameter (I_{ss}, $I_{p1,\ldots}$) of the serving cell with the given threshold value (I_o^{tr}) of the serving cell (C_o) or the cell currently serving a given connection, and a second criterion which is based on a comparison of the current, monitored value (I_i) of a signal parameter of a neighbour cell with the given threshold value (I_i^{tr}) for the same neighbour cell (C_i) wherein the handovers are governed by the priority ranking arrangement in such a way that a systematic passing between cells or cell layers or levels is obtained, also for passing up and down between cell layers.

2. System according to claim 1
c h a r a c t e r i z e d i n t h a t ,
the first criterion is used for deciding if a handover from

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a cell in a lower hierarchical layer to a cell in a higher hierarchical layer is to be considered.

3. System according to claim 2
characterized in that,
according to the first criterion a cell in a higher layer is eligible for handover if the current value of the monitored signal parameter value (I_o) of the serving cell (C_o) is less than the threshold value (I_o^{tr}) and/or the threshold value (I_o^{tr}) modified with a hysteresis (H_o^{tr}) for that cell.

4. System according to claim 3
characterized in that,
a cell in a higher hierarchical layer is eligible for handover if the current value of the monitored signal parameter (I_o) is smaller than the threshold value minus a hysteresis (H_o^{tr}).

5. System according to anyone of the preceding claims
characterized in that,
the second criterion is used for deciding if a handover from a higher hierarchical layer to a cell in a lower hierarchical layer is to be considered.

6. System according to claim 5
characterized in that,
according to the second criterion a cell (C_i) in a lower hierarchical layer is eligible for handover if the current monitored value on the monitored signal parameter (I_i) exceeds the threshold value (I_i^{tr}) of that cell and/or the threshold value (I_i^{tr}) modified with a hysteresis (H_i^{tr}).

7. System according to claim 6
characterized in that,
threshold value (I_i^{tr}) is modified in such a way that a hysteresis (H_i^{tr}) is added thereto.

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8. System according to anyone of the preceding claims
c h a r a c t e r i z e d i n t h a t ,
the cells (C_o, C_i) are sorted into categories based on a number of sorting criteria.

9. System according to claim 8
c h a r a c t e r i z e d i n t h a t ,
one sorting criterion comprises normal locating, i.e. the neighbouring cells (C_i) are ranked in comparison to the serving cell (C_0) e.g. if they are better or worse than that cell (C_0) for at least one monitored signal parameter (I_{ss}; $I_{p.l.}$).

10. System according to anyone of the preceding claims
c h a r a c t e r i z e d i n t h a t ,
the cells (C_i) are sorted into categories based on criteria relating both to the monitored signal parameter as compared to the monitored corresponding value of the serving cell (C_0) and to the monitored value of a cell (C_i) as compared to the threshold value of that same cell (C_i).

11. System according to anyone of the preceding claims
c h a r a c t e r i z e d i n t h a t ,
the cells are sorted into categories based on which layer they are in.

12. System according to anyone of claims 8 to 11
c h a r a c t e r i z e d i n t h a t ,
priority ranking arrangement comprises a number of criteria relating to a number of conditions.

13. System according to claim 12
c h a r a c t e r i z e d i n t h a t ,
the cells are arranged according to the sorting criteria depending on whether the conditions are fulfilled or not.

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14. System according to claim 12 or 13
characterized in that,
at least some of the conditions are so called alarm criteria such as e.g. bad quality urgency e.t.c.

15. System according to anyone of the preceding claims
characterized in that,
the priority ranking arrangement comprises an organizing table of cell categories which is sorted depending on a number of criteria.

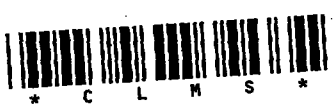
16. System according to claim 15
characterized in that,
the cells are sorted into the organizing table into categories which depend on at least the first and the second criteria and a number of conditions.

17. System according to claim 15 or 16
characterized in that,
a priority list or a handover candidate list is formed from the organizing table.

18. System according to anyone of the preceding claims
characterized in that,
the signal parameter is the signal strength.

19. System according to anyone of the preceding claims
characterized in that,
the signal parameter(s) is/are the pathloss or pathloss as well as signal strength.

20. System according to anyone of the preceding claims
characterized in that,
the cells are divided into two different layers.



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21. System according to anyone of claims 1 to 19 characterized in that, the cells are divided into three different layers, e.g. pico-cells, micro-cells and macro-cells.

22. System according to anyone of claims 1 to 19 characterized in that, the cells are divided into more than three layers.

23. System according to anyone of the preceding claims characterized in that, the handover strategy that is used is the Mobile Assisted Handover (MAHO) strategy.

24. System according to anyone of the preceding claims characterized in that, a threshold value (I_o^{tr}, I_i^{tr}) is given for cells also in the uppermost layer.

25. System according to anyone of the preceding claims characterized in that, cells in a higher layer form a so called "umbrella" for cells in a lower layer.

26. System according to anyone of the preceding claims characterized in that, interactions with other network functions are given a priority yielding the sorted order in the priority table of the system.

27. System according to anyone of the preceding claims characterized in that, for a particular network controlled function evaluation a unique sequence of cell categories is assigned to that combination of evaluation results.

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28. System according to anyone of the preceding claims characterized in that, Time Division Multiple Access (TDMA) or Frequency Division Multiple Access (FDMA) or Code Division Multiple Access (CDMA) is applied.

29. System according to anyone of the preceding claims characterized in that, it is a telephone communication system.

30. System according to anyone of the preceding claims characterized in that, the GSM standard is used.

31. System according to anyone of claims 1 to 29 characterized in that, e.g. the ADC, PDC or the DECT standard is used.

32. System according to anyone of claims 1 to 29 characterized in that, it is an ISDN-communication system.

33. Method for handing over connections between a mobile station and different cells in a cellular mobile communication system comprising a number of radio base stations and a number of mobile stations, the system comprising a number of cells which are arranged in at least two different layers or levels, the method comprising the following steps:

- introducing a threshold value for at least one signal parameter of the cell serving a given connection;
- introducing a threshold value for at least one signal parameter for at least each cell not being in

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the uppermost layer;

- monitoring the at least one signal parameter for the serving cell;
- monitoring the at least one signal parameter for a number of neighbour cells;
- comparing the monitored current value of the signal parameter for the serving cell with the threshold value for the serving cell;
- comparing the monitored value of the signal parameter for the neighbour cell with the threshold value for the respective cell;
- using the comparisons for carrying out the handovers in agreement with a given priority ranking order in such a way that a systematic passing between cells or cell layers is obtained, also for passing up and down between cell layers.

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FIG.1

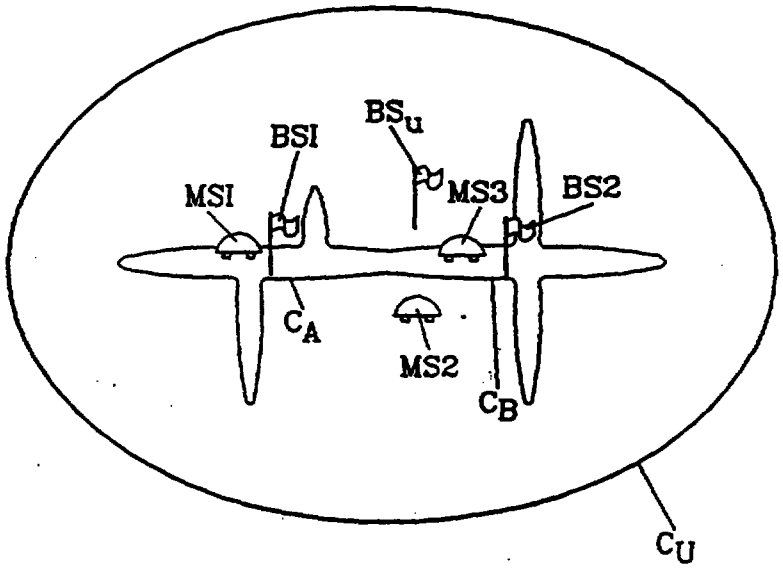
BSu
BSI
MSI
MS3
BS2
CA
MS2
CB
CU

FIG.2

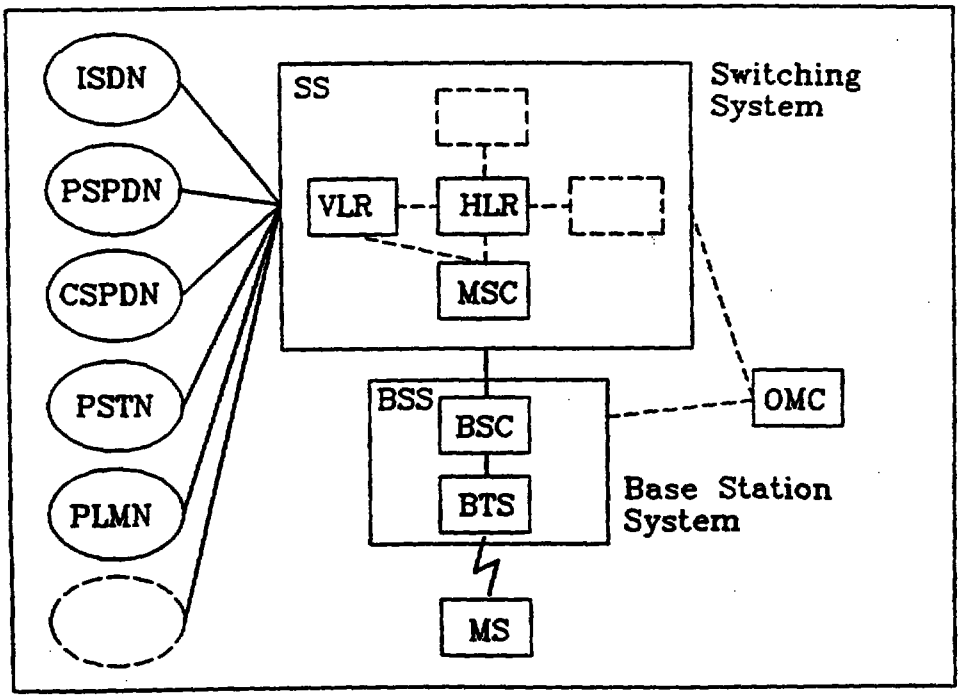
ISDN
PSPDN
CSPDN
PSTN
PLMN
SS
Switching System
VLR
HLR
MSC
BSS
BSC
BTS
Base Station System
OMC
MS

FIG.3

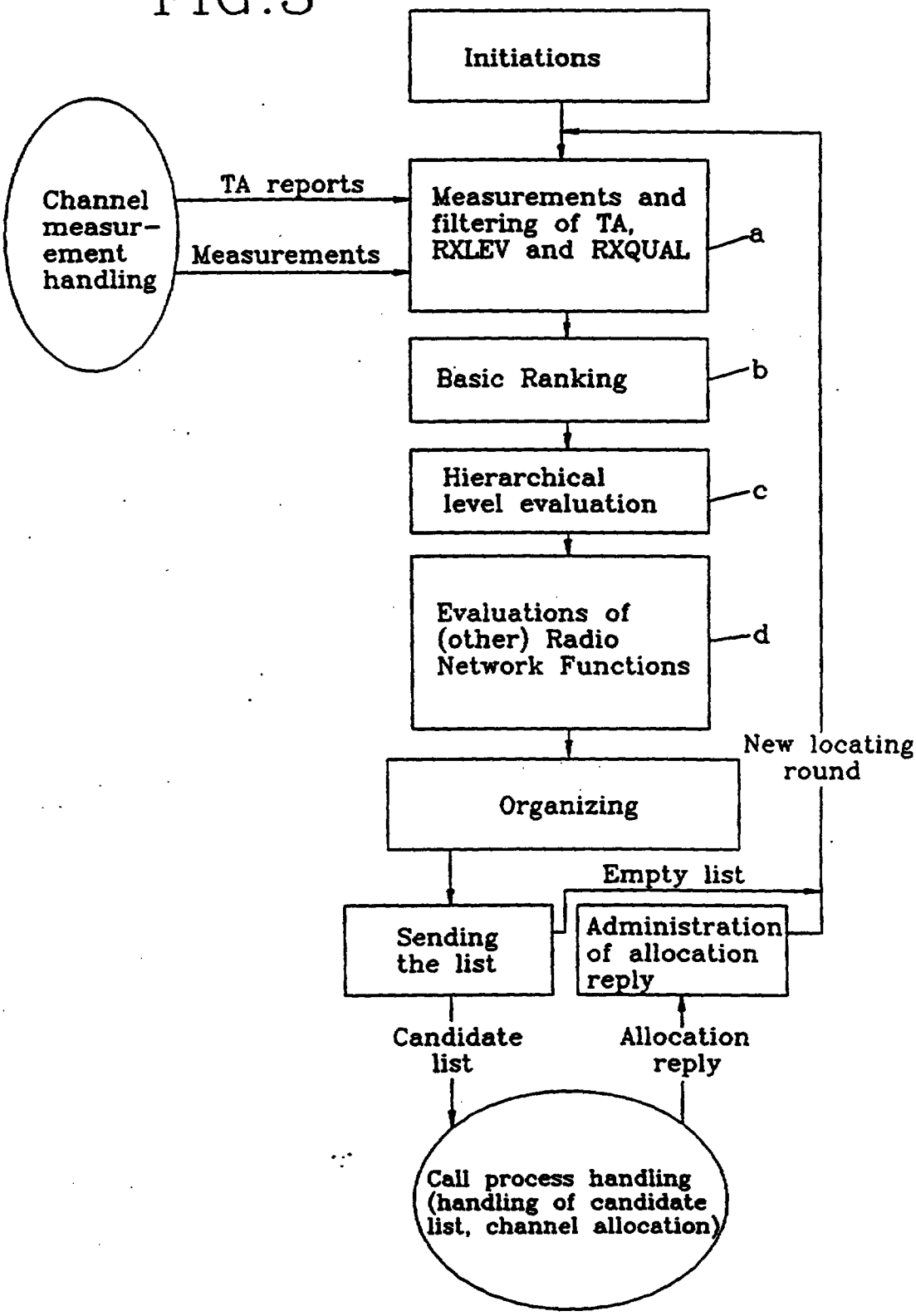
Initiations
Channel measur-ement handling
TA reports
Measurements
Measurements and filtering of TA, RXLEV and RXQUAL
a
Basic Ranking
b
Hierarchical level evaluation
c
Evaluations of (other) Radio Network Functions
d
New locating round
Organizing
Empty list
Sending the list
Administration of allocation reply
Candidate list
Allocation reply
Call process handling (handling of candidate list, channel allocation)

FIG. 4a

Case	Condition	Categories
	123456	
1	0–0000	1bo, 2b, 1bu;
2	0–0001	1bo, 2b, 1bu, s;
3	0–0010	1bo, 2b, 1bu, s;
4	0–0011	1bo, 2b, 1bu, s;
5	0–0100	1bo, 2b, 1bu, 1wo, 2w, 1wu;
6	0–0101	1bo, 2b, 1bu, s, 1wo, 2w, 1wu;
7	0–0110	1bo, 2b, 1bu, s, 1wo, 2w, 1wu;
8	0–0111	1bo, 2b, 1bu, s, 1wo, 2w, 1wu;
9	0–1000	1bo, 2b ,1bu, 1wo, 2w, 1wu;
10	0–1001	1bo, 2b, 1bu, 1wo, 2w, 1wu, s;
11	0–1010	1bo, 2b, 1bu, 1wo, 2w, 1wu, s;
12	0–1011	1bo, 2b, 1bu, 1wo, 2w, 1wu, s;
13	0–1100	1bo, 2b, 1bu, 1wo, 2w, 1wu;
14	0–1101	1bo, 2b, 1bu, 1wo, 2w, 1wu, s;
15	0–1110	1bo, 2b, 1bu, 1wo, 2w, 1wu, s;
16	0–1111	1bo, 2b, 1bu, 1wo, 2w, 1wu, s;
17	1000––	1bo, 2b, 1bu, s;
18	1001––	1bo, 2b, 1bu, s;
19	1010––	1bo, 2b, 1bu, s;
20	1011––	1bo, 2b, 1bu, s;
21	1100––	1bo, 2b, 1bu, s, 1wo, 2w, 1wu;
22	1101––	1bo, 2b, 1bu, s, 1wo, 2w, 1wu;
23	1110––	1bo, 2b, 1bu, 1wo, 2w, 1wu, s;
24	1111––	1bo, 2b, 1bu, 1wo, 2w, 1wu, s;

FIG. 4b

Case	Condition 123456	Categories
1	0–0000	1bo;
2	0–0001	1bo; s;
3	0–0010	1bo, s;
4	0–0011	1bo, s;
5	0–0100	1bo, 1wo, 2b, 2w, 1bu, 1wu;
6	0–0101	1bo, s, 1wo, 2b, 2w, 1bu, 1wu;
7	0–0110	1bo, s, 1wo, 2b, 2w, 1bu, 1wu;
8	0–0111	1bo, s, 1wo, 2b, 2w, 1bu, 1wu;
9	0–1000	1bo, 1wo, 2b, 2w, 1bu, 1wu;
10	0–1001	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
11	0–1010	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
12	0–1011	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
13	0–1100	1bo, 1wo, 2b, 2w, 1bu, 1wu;
14	0–1101	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
15	0–1110	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
16	0–1111	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
17	1000––	1bo, s, 1bu;
18	1001––	1bo, s, 2b, 1bu;
19	1010––	1bo, s, 2b, 1bu;
20	1011––	1bo, s, 2b, 1bu;
21	1100––	1bo, s, 1wo, 2b, 2w, 1bu, 1wu;
22	1101––	1bo, s, 1wo, 2b, 2w, 1bu, 1wu;
23	1110––	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
24	1111––	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;

FIG. 4c

Case	Condition 123456	Categories
1	0–0000	1bo, 1wo, 2b;
2	0–0001	1bo,1wo, 2b, s;
3	0–0010	1bo, 1wo, 2b, s;
4	0–0011	1bo, 1wo, 2b, s;
5	0–0100	1bo, 1wo, 2b, 2w, 1bu, 1wu;
6	0–0101	1bo, 1wo, 2b, s, 2w, 1bu, 1wu;
7	0–0110	1bo, 1wo, 2b, s, 2w, 1bu, 1wu;
8	0–0111	1bo, 1wo, 2b, s, 2w, 1bu, 1wu;
9	0–1000	1bo, 1wo, 2b, 2w, 1bu, 1wu;
10	0–1001	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
11	0–1010	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
12	0–1011	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
13	0–1100	1bo, 1wo, 2b ,2w, 1bu, 1wu;
14	0–1101	1bo, 1wo, 2b ,2w, 1bu, 1wu, s;
15	0–1110	1bo, 1wo, 2b ,2w, 1bu, 1wu, s;
16	0–1111	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
17	1000––	1bo, 1wo, 2b, s, 1bu, 1wu;
18	1001––	1bo, 1wo, 2b, s, 1bu, 1wu;
19	1010––	1bo, 1wo, 2b, s, 1bu, 1wu;
20	1011––	1bo, 1wo, 2b, s, 1bu, 1wu;
21	1100––	1bo, 1wo, 2b, s, 2w, 1bu, 1wu;
22	1101––	1bo, 1wo, 2b, s, 2w, 1bu, 1wu;
23	1110––	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;
24	1111––	1bo, 1wo, 2b, 2w, 1bu, 1wu, s;

FIG. 5a

Case	Condition	Categories
1	0000000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu;
2	1000000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s , 1wo, 2wo, 3wo, 3wu, 2wu, 1wu;
3	0100000010,	1bo, 2bo, 3bo, 3bu, 2bu ,1bu, s ;
4	0010000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu;
5	1010000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu, s;
6	0110000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s ;
7	0000100010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s ;
8	1000100010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s , 1wo, 2wo, 3wo, 3wu, 2wu, 1wu;
9	0100100010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu s ;
10	0010100010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu, s;
11	1010100010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu, s;
12	0110100010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s ;
13	0000010010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s ;
14	0010010010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu. s;
15	0000110010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s ;
16	0010110010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu. 1wu. s;
17	0001000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu;
18	1001000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s , 1wo, 2wo, 3wo, 3wu, 2wu, 1wu;
19	0101000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu;
20	0011000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu;
21	1011000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu. s;
22	0111000010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s ;
23	0001100010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s , 1wo, 2wo, 3wo, 3wu, 2wu, 1wu;
24	1001100010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s , 1wo, 2wo, 3wo, 3wu, 2wu, 1wu;
25	0101100010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s ;
26	0011100010,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu. s;

27 1011100010, 1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu, s;

28 0111100010, 1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s ;

29 0001010010, 1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s , 1wo, 2wo, 3wo, 3wu, 2wu, 1wu;

30 0011010010, 1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu, s;

31 0001110010, 1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s , 1wo, 2wo, 3wo, 3wu, 2wu, 1wu;

32 0011110010, 1bo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wo, 2wo, 3wo, 3wu, 2wu, 1wu, s;

FIG. 5b

Case	Condition	Categories
1	0000000000,	1bo;
2	1000000000,	1bo, s ,1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
3	0100000000,	1bo, s , 1bu;
4	0010000000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
5	1010000000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
6	0110000000,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s;
7	0000100000,	1bo, s ;
8	1000100000,	1bo, s , 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
9	0100100000,	1bo, s , 1bu;
10	0010100000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
11	1010100000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu. 2wu, 1bu, 1wu, s;
12	0110100000,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s;
13	0000010000,	1bo, s ;
14	0010010000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
15	0000110000,	1bo, s ;
16	0010110000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
17	0001000000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu. 2wu, 1bu, 1wu;
18	1001000000,	1bo, s , 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
19	0101000000,	1bo, s , 2bo, 3bo, 3bu, 2bu, 1bu;
20	0011000000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
21	1011000000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
22	0111000000,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s;
23	0001100000,	1bo, s , 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
24	1001100000,	1bo, s , 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
25	0101100000,	1bo, s , 2bo, 3bo, 3bu, 2bu, 1bu;
26	0011100000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;

27	1011100000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
28	0111100000,	1bo, 2bo, 3bo, 3bu, 2bu, 1bu, s;
29	0001010000,	1bo, s , 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
30	0011010000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
31	0001110000,	1bo, s , 1wo, 2bo, 2wo, 3bo 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
32	0011110000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo,3wu, 2bu, 2wu, 1bu, 1wu, s;

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FIG. 5c

Case	Condition	Categories
1	0000000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu,
2	1000000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s , 2wo, 3wo, 3wu, 2wu, 1bu, 1wu;
3	0100000110,	1bo, 1wo,2bo, 3bo, 3bu, 2bu, s , 1bu, 1wu;
4	0010000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu;
5	1010000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu, s;
6	0110000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wu, s;
7	0000100110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s ;
8	1000100110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s , 2wo, 3wo, 3wu, 2wu, 1bu, 1wu;
9	0100100110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s , 1bu, 1wu;
10	0010100110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu, s;
11	1010100110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu, s;
12	0110100110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wu, s;
13	0000010110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s ;
14	0010010110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu, s;
15	0000110110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s ;
16	0010110110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu, s;
17	0001000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu;
18	1001000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s , 2wo, 3wo, 3wu, 2wu, 1bu, 1wu;
19	0101000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s , 1bu, 1wu;
20	0011000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu;
21	1011000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu, s;
22	0111000110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wu, s;
23	0001100110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s , 2wo, 3wo, 3wu, 2wu, 1bu, 1wu;
24	1001100110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s , 2wo, 3wo, 3wu, 2wu, 1bu, 1wu;
25	0101100110,	1bo, 1wo, 2bo, 3bo, 3bu, s , 1bu, 1wu;
26	0011100110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu, s;

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27	1011100110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu, s;
28	0111100110	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wu, s;
29	0001010110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s , 2wo, 3wo, 3wu, 2wu, 1bu, 1wu;
30	0011010110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu, s;
31	0001110110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, s , 2wo, 3wo, 3wu, 2wu, 1bu, 1wu;
32	0011110110,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 2wo, 3wo, 3wu, 2wu, 1bu, 1wu, s;

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FIG. 5d

Case	Condition	Categories
1	0000000100,	1bo, 1wo, 2bo;
2	1000000100,	1bo, 1wo, 2bo, s , 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
3	0100000100,	1bo, 1wo, 2bo, s , 2bu, 1bu, 1wu;
4	0010000100,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
5	1010000100,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
6	0110000100,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wu, s;
7	0000100100,	1bo, 1wo, 2bo, s ;
8	1000100100,	1bo, 1wo, 2bo, s , 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
9	0100100100,	1bo, 1wo, 2bo, s , 2bu, 1bu, 1wu;
10	0010100100,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
11	1010100100,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
12	0110100100,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wu, s;
13	0000010100,	1bo, 1wo, 2bo, s;
14	0010010100,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
15	0000110100,	1bo, 1wo, 2bo, s ;
16	0010110100,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
17	0001000100,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
18	1001000100,	1bo, 1wo, 2bo, s , 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
19	0101000100,	1bo, 1wo, 2bo, s , 3bo, 3bu, 2bu, 1bu, 1wu;
20	0011000100,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
21	1011000100,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
22	0111000100,	1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wu, s;
23	0001100100,	1bo, 1wo, 2bo, s , 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
24	1001100100,	1bo, 1wo, 2bo, s , 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
25	0101100100,	1bo, 1wo, 2bo, s , 3bo, 3bu, 2bu, 1bu, 1wu;
26	0011100100,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;

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27 1011100100, 1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;

28 0111100100, 1bo, 1wo, 2bo, 3bo, 3bu, 2bu, 1bu, 1wu, s;

29 0001010100, 1bo, 1wo, 2bo, s , 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;

30 0011010100, 1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;

31 0001110100, 1bo, 1wo, 2bo, s , 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;

32 0011110100, 1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;

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FIG. 5e

Case	Condition	Categories
1	0000001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu;
2	1000001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s , 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
3	0100001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s , 2bu, 2wu, 1bu, 1wu;
4	0010001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
5	1010001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
6	0110001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 2bu, 2wu, 1bu, 1wu, s;
7	0000101000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s ;
8	1000101000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s , 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
9	0100101000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s , 2bu, 2wu, 1bu, 1wu;
10	0010101000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
11	1010101000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
12	0110101000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 2bu, 2wu, 1bu, 1wu, s;
13	0000011000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s ;
14	0010011000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
15	0000111000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s ;
16	0010111000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
17	0001001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
18	1001001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s , 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
19	0101001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s , 2bu, 2wu, 1bu, 1wu;
20	001001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo , 3wu, 2bu, 2wu, 1bu, 1wu;
21	1011001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;
22	0111001000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 2bu, 2wu, 1bu, 1wu, s;
23	0001101000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s , 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
24	1001101000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s , 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;
25	0101101000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s , 2bu, 2wu, 1bu, 1wu;
26	0011101000,	1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;

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27 1011101000, 1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;

28 0111101000, 1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 2bu, 2wu, 1bu, 1wu, s;

29 0001011000, 1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;

30 0011011000, 1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;

31 0001111000, 1bo, 1wo, 2bo, 2wo, 3bo, 3bu, s , 3wo, 3wu, 2bu, 2wu, 1bu, 1wu;

32 0011111000, 1bo, 1wo, 2bo, 2wo, 3bo, 3bu, 3wo, 3wu, 2bu, 2wu, 1bu, 1wu, s;

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FIG. 6

1	lower layer cells	better than serving cell	above the threshold	1bo
2	upper layer cells	better than serving cell	above the threshold	2bo
3	upper layer cells	better than serving cell	below the threshold	2bu
4	lower layer cells	better than serving cell	below the threshold	1bu
5	serving cell			s
6	lower layer cells	worse than serving cell	above the threshold	1wo
7	upper layer cells	worse than serving cell	above the threshold	2wo
8	upper layer cells	worse than serving cell	below the threshold	2wu
9	lower layer cells	worse than serving cell	below the threshold	1wu

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CLAIMS

1. Cellular mobile communication system with a number of radio base stations (BS) and a number of mobile stations (MS), said system comprising a number of cells which are arranged in at least two different layers or levels wherein mobile stations (MS) can be handed over from one cell to another and comprising means for monitoring or measuring at least one signal connection parameter of at least those cells which are not in the uppermost layer and wherein at least one threshold value (I_o^{tr}, I_i^{tr}) for said at least one signal parameter is given for at least each cell (C_o, $C_{i,i=1,\ldots,n}$) not being in the uppermost layer, the system furthermore comprising controlling means for deciding on and controlling handover decisions,
characterized in that,
the cells are arranged in a hierarchical structure and in that the controlling means comprises a priority ranking arrangement through which at least a basic ranking and hierarchical cell evaluations are performed which are based on a number of criteria of which a first criterion is based on a comparison of the current, monitored value (I_o) of a signal parameter (I_{ss}, $I_{pl,..}$) of the serving cell with the given threshold value (I_o^{tr}) of the serving cell (C_o) or the cell currently serving a given connection, and a second criterion which is based on a comparison of the current, monitored value (I_i) of a signal parameter of a neighbour cell with the given threshold value (I_i^{tr}) for the same neighbour cell (C_i), wherein via an organizing procedure using the results of at least the basic ranking and the hierarchical cell evaluations, e.g. using tables, a candidate list is provided which is used for channel allocation and/or cell selection in such a way that a systematic directing to or passing between cells or cell layers is obtained, also for

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passing up and down between cell layers wherein directing can be done to any layer.

2. System according to claim 1
c h a r a c t e r i z e d i n t h a t ,
the first criterion is used for deciding if a handover from a cell in a lower hierarchical layer to a cell in a higher hierarchical layer is to be considered.

3. System according to claim 2
c h a r a c t e r i z e d i n t h a t ,
according to the first criterion a cell in a higher layer is eligible for handover if the current value of the monitored signal parameter value (I_o) of the serving cell (C_o) is less than the threshold value (I_o^{tr}) and/or the threshold value (I_o^{tr}) modified with a hysteresis (H_o^{tr}) for that cell.

4. System according to claim 3
c h a r a c t e r i z e d i n t h a t ,
a cell in a higher hierarchical layer is eligible for handover if the current value of the monitored signal parameter (I_o) is smaller than the threshold value minus a hysteresis (H_o^{tr}).

5. System according to anyone of the preceding claims
c h a r a c t e r i z e d i n t h a t ,
the second criteria to used for deciding if a handover from a higher hierarchical layer to a cell in a lower hierarchical layer is to be considered.

6. System according to claim 5
c h a r a c t e r i z e d i n t h a t ,
according to the second criterion a cell (C_i) in a lower hierarchical layer is eligible for handover if the current monitored value on the monitored signal parameter (I_i) exceeds the threshold value (I_i^{tr}) of that cell and/or the

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threshold value (I_i^{tr}) modified with a hysteresis (H_i^{tr}).

7. System according to claim 6
c h a r a c t e r i z e d i n t h a t ,
threshold value (I_i^{tr}) is modified in such a way that a hysteresis (H_i^{tr}) is added thereto.

8. System according to anyone of the preceding claims
c h a r a c t e r i z e d i n t h a t ,
the cells (C_o, C_i) are sorted into categories based on a number of sorting criteria.

9. System according to claim 8
c h a r a c t e r i z e d i n t h a t ,
one sorting criterion comprises normal locating, i.e. the neighbouring cells (C_i) are ranked in comparison to the serving cell (C_0) e.g. if they are better or worse than that cell (C_0) for at least one monitored signal parameter (I_{ss}; $I_{p.l.}$).

10. System according to anyone of the preceding claims
c h a r a c t e r i z e d i n t h a t ,
the cells (C_i) are sorted into categories based on criteria relating both to the monitored signal parameter as compared to the monitored corresponding value of the serving cell (C_0) and to the monitored value of a cell (C_i) as compared to the threshold value of that same cell (C_i).

11. System according to anyone of the preceding claims
c h a r a c t e r i z e d i n t h a t ,
the cells are sorted into categories based on which layer they are in.

12. System according to anyone of claims 8 to 11
c h a r a c t e r i z e d i n t h a t ,
priority ranking arrangement comprises a number of criteria relating to a number of conditions and in that the cells are

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arranged according to the sorting criteria depending on whether the conditions are fulfilled or not.

13. System according to claim 12
characterized in that,
at least some of the conditions are so called alarm criteria such as e.g. bad quality urgency e.t.c.

14. System according to anyone of the preceding claims
characterized in that,
the priority ranking arrangement comprises an organizing table of cell categories which is sorted depending on a number of criteria.

15. System according to claim 14
characterized in that,
the cells are sorted into the organizing table into categories which depend on at least the first and the second criteria and a number of conditions.

16. System according to anyone of the preceding claims
characterized in that,
the signal parameter is the signal strength.

17. System according to anyone of the preceding claims
characterized in that,
the signal parameter(s) is/are the pathloss or pathloss as well as signal strength.

18. System according to anyone of the preceding claims
characterized in that,
the cells are divided into two different layers.

19. System according to anyone of claims 1 to 17
characterized in that,
the cells are divided into three different layers, e.g. pico-

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cells, micro-cells and macro-cells.

20. System according to anyone of claims 1 to 17 characterized in that, the cells are divided into more than three layers.

21. System according to anyone of the preceding claims characterized in that, the handover strategy that is used is the Mobile Assisted Handover (MAHO) strategy.

22. System according to anyone of the preceding claims characterized in that, a threshold value (I_o^{tr}, I_i^{tr}) is given for cells also in the uppermost layer.

23. System according to anyone of the preceding claims characterized in that, interactions with other network functions are given a priority yielding the sorting order in the priority table of the system.

24. System according to anyone of the preceding claims characterized in that, for a particular network controlled function evaluation, a unique sequence of cell categories is assigned to that combination of evaluation results.

25. System according to anyone of the preceding claims characterized in that, Time Division Multiple Access (TDMA) or Frequency Division Multiple Access (FDMA) or Code Division Multiple Access (CDMA) is applied.

26. System according to anyone of the preceding claims characterized in that,

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it is a telephone communication system.

27. System according to anyone of the preceding claims c h a r a c t e r i z e d i n t h a t , the GSM standard is used.

28. System according to anyone of claims 1 to 26 c h a r a c t e r i z e d i n t h a t , e. g. the ADC, PDC or the DECT standard is used.

29. System according to anyone of claims 1 to 26 c h a r a c t e r i z e d i n t h a t , it is an ISDN-communication system.

30. Method for handing over connections between a mobile station and different cells in a cellular mobile communication system comprising a number of radio base stations and a number of mobile stations, the system comprising a number of cells which are arranged in a hierarchical structure in at least two different layers or levels, the method comprising the following steps:

- introducing a threshold value for at least one signal parameter of the cell serving a given connection;
- introducing a threshold value for at least one signal parameter for at least each cell not being in the uppermost layer;
- monitoring the at least one signal parameter for the serving cell;
- monitoring the at least one signal parameter for a number of neighbour cells;
- comparing the monitored current value of the signal parameter for the serving cell with the threshold value for the serving cell;
- comparing the monitored value of the signal

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parameter for the neighbour cell with the threshold value for the respective cell;

- using the comparisons to provide a basic ranking list,
- carrying out hierarchical cell level evaluations comprising a level oriented reorganization relating to whether cells are over/under the respective threshold,
- carrying out an organizing procedure using a number of conditions, said organizing procedure e.g. being table-controlled to establish a candidate list,
- sending the cell candidate list to a call handling process so that channel allocation and/or cell selection is done in agreement with the given ranking order in such a way that a systematic passing between cell layers is obtained also for passing up and down or that mobile stations can be directed to any layer.

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(71) Applicant *(for all designated States except US)*: TELEFONAKTIEBOLAGET LM ERICSSON [SE/SE]; S-126 25 Stockholm (SE).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: FRISELL HÖGLIN, Anita [SE/SE]; Multrågatan 25, S-162 28 Vällingby (SE). FRIED, Tomas [SE/SE]; Mågavägen 25, S-161 53 Bromma (SE). BALCK, Kenneth [SE/SE]; Opphemsgatan 2, S-582 37 Linköping (SE).

(74) Agents: BERGENTALL, Annika et al.; Göteborgs Patentbyrå AB, P.O. Box 5005, S-402 21 Göteborg (SE).

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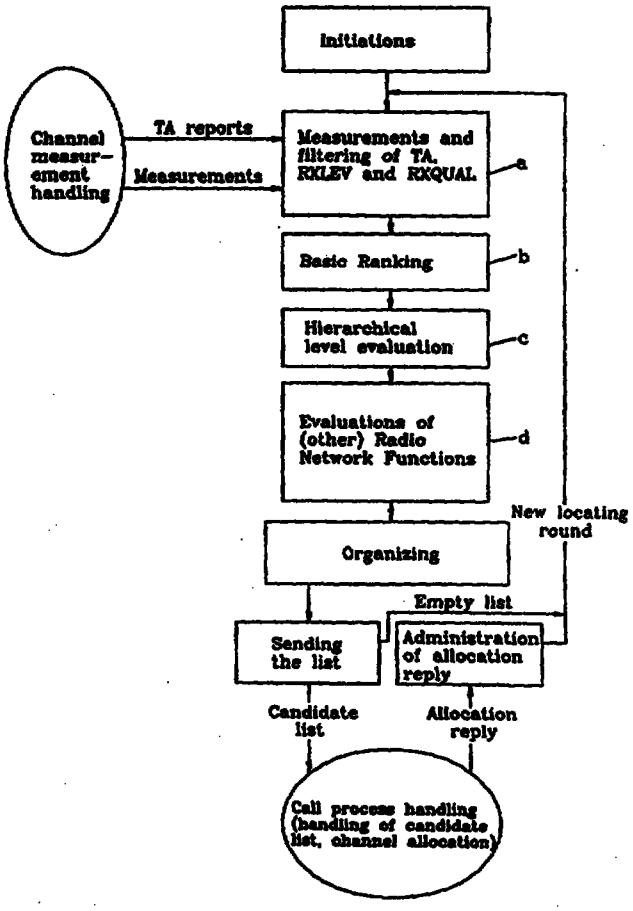
(54) Title: CELLULAR MOBILE COMMUNICATION SYSTEM

(57) Abstract

The present invention relates to a cellular mobile communication system comprising a number of radio base stations (BS) and a number of mobile stations (MS) wherein the system comprises a number of cells which are arranged in at least two different layers of preference. Connections carried on the communications system can be handed over from one cell to another and at least one signal parameter is measured or monitored. At least one threshold is given at least for each cell in the lower layers or at least one signal parameter. The system furthermore comprises means for deciding on and controlling handover decisions comprising a priority ranking arrangement based on a number of criteria of which one is based on a comparison between a monitored value (I_o) of a signal parameter with the threshold value (I_o^{tr}) of the serving cell and a second one is based on a comparison of the monitored value of a signal parameter (I_i) with the corresponding threshold value (I_i^{tr}) for a neighbour cell wherein handovers are governed by the priority ranking arrangement so that a systematic passing also up as well as down between layers is obtained.



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