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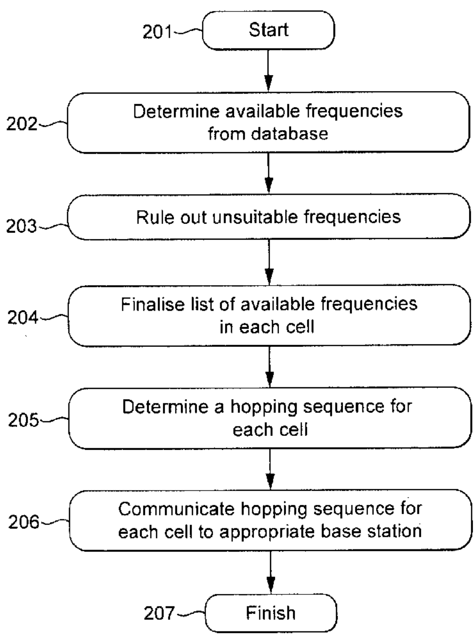

FIG. 2

(57) Abstract: A controller for a communication network, the communication network comprising a plurality of cells, each cell comprising a communication device and at least one terminal and each communication device being configured to communicate with the at least one terminal in its respective cell according to a frequency hopping sequence associated with that cell; and the controller being configured to: determine the frequency availability in each cell; determine a frequency hopping sequence for each cell in dependence on that frequency availability; and communicate the frequency hopping sequence for each cell to the communication device in that cell.

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FREQUENCY PLANNING

The present invention relates to assigning frequency hopping sequences to cells in a cellular communication network.

A wireless network may be configured to operate without having been specifically allocated any part of the electromagnetic spectrum. Such a network may be permitted to operate in so-called whitespace: a part of the spectrum that is made available for unlicensed or opportunistic access. Typically whitespace is found in the UHF TV band and spans 450MHz to 800MHz, depending on the country. A large amount of spectrum has been made available for unlicensed wireless systems in this frequency range.

A problem with operating in whitespace is that the available bandwidth is variable and cannot be guaranteed. These limitations are well-matched to the capabilities of machine-to-machine networks in which there is no human interaction. Machine-to-machine networks are typically tolerant of delays, dropped connections and high latency communications.

Any network operating in the UHF TV band has to be able to coexist with analogue and digital television broadcast transmitters. The density of the active television channels in any given location is relatively low (resulting in the availability of whitespace that can be used by unlicensed systems). The FCC has mandated that systems operating in the whitespace must reference a database that determines which channels may be used in any given location. This is intended to avoid interference with the TV transmissions and certain other incumbent systems such as wireless microphones.

For TV receivers (including those for digital TV (DTV)), there will inevitably be adjacent channels on which a strong transmission close to the TV receiver will interfere with TV reception. For example, the TV receivers may have image frequencies and poor adjacent channel rejection (ACR) on certain frequencies due to spurs on their local oscillators and limitations in their receive filters. These frequencies are often dependent on the specific receiver implementation and so are not amenable to being avoided through the database system.

Digital TV typically uses a channel bandwidth of 6 to 8 MHz. It also uses OFDM modulation in which the overall channel bandwidth is split into a large number of narrower channels (so-called sub-carriers), each of which is individually modulated. The system is designed so that, if a certain number of sub-carriers are subject to multipath fading, with the result that their signal-to-noise ratio is poor, the overall data can still be recovered. This is typically achieved by using interleaving and error correction codes, which mean that bit errors localised to a limited number of sub-carriers can be corrected. OFDM modulation can therefore achieve considerable robustness to multipath fading.

OFDM is only able to recover the transmitted data when the interferer is relatively narrowband compared with the bandwidth of the overall TV signal, such that a limited number of sub-carriers are affected. OFDM does not provide a similar performance benefit when the interferer occupies a relatively large proportion of the DTV channel bandwidth because in this case the error control coding may be incapable of correcting the bit errors due to the higher proportion of bits that may be corrupt. If the bandwidth of the transmitted signal from the terminal can be reduced to a small fraction of the DTV channel bandwidth, there is a lower chance of the DTV receiver being unable to decode the signal correctly. Another perspective on this is that the narrowband whitespace transmitter can be located much closer to the DTV receiver before causing noticeable degradation of the decoded DTV signal. This can be of particular benefit for mobile or portable whitespace devices whose exact location and antenna orientation cannot be easily constrained.

There is a potential issue with reducing the bandwidth occupied by the whitespace device's transmitter: transmitting on a narrow bandwidth channel makes the whitespace device sensitive to poor reception due to multipath fading. This is because the entire bandwidth could be in a long-term fade (lasting multiple frames), resulting in poor signal-to-noise ratio.

Both of these problems may be addressed using frequency hopping. Frequency hopping minimises the interference to TV reception, since no communication will be permanently causing interference to any given TV receiver. Frequency hopping also reduces the probability of the terminal being in a long-term fade. It provides a form of interleaving that enables more efficient error correction to be used.

The channels used for frequency hopping may be selected by the base station based upon information from the whitespace database on the available channels and associated power levels (which in turn are based upon the licensed spectrum use in the area). However, the whitespace database does not include information about every possible source of interference.

For example, a television transmitter may be intended to broadcast to only a particular coverage area, but may in fact leak into other nearby areas where the use of the frequencies in use by that transmitter are not prohibited in the whitespace database; major TV stations can be well above the thermal noise at distances of 100km. Although the signal from this transmitter may not be strong enough to be reliably received by television antennas in those nearby areas, it is often strong enough to cause severe interference to whitespace base stations in those areas, particularly if they have elevated antennas (which they may have in order to increase their own coverage area). On nominally free channels, reception is far more likely to be dominated by distant TV broadcasts rather than thermal noise, especially in rural regions. This interference can render many of the whitespace channels unusable or severely compromised.

Interference from other unlicensed whitespace networks can also be a problem as all whitespace networks compete for use of those frequencies the whitespace database marks as available.

Interference may also be caused by the unintended emissions of devices that are not part of a wireless network, e.g. spurious emissions from faulty electric drills.

Apart from all these interferers external to the network, there can also be problems for devices located close to the edge of cells. Neighbouring base stations are likely to have similar whitespace channel assignments. (As the distance between base stations increases, the assignments tend to change as the base stations are located in different TV service areas.) Therefore, if base stations pick their own frequency hopping sequences based on only the frequencies available in the whitespace database, the base stations of neighbouring cells are likely to make similar choices. If neighbouring cells use the same frequency hopping sequences then terminals at cell edges may receive multiple weak signals from both the base station for their own cell, and any neighbouring base stations in range, and have no way of distinguishing between them. Two neighbouring base stations may use the same frequencies on approximately one in ten frames. Each base station is surrounded by a number of others, typically around six, meaning interference is likely to occur somewhere within each cell around fifty percent of the time. This can result in a significant loss in capacity.

What is needed is a method and apparatus for reducing the impact of the various types of interference suffered by devices on cellular communication networks such as whitespace networks.

According to a first embodiment of the invention, there is provided a controller for a communication network, the communication network comprising a plurality of cells, each cell comprising a communication device and at least one terminal and each communication device being configured to communicate with the at least one terminal in its respective cell according to a frequency hopping sequence associated with that cell, the controller being configured to: determine the frequency availability in each cell; determine a frequency hopping sequence for each cell in dependence on that frequency availability; and communicate the frequency hopping sequence for each cell to the communication device in that cell.

The controller may be configured to determine and communicate new frequency hopping sequences at regular intervals.

The controller may be configured to determine and communicate new frequency hopping sequences in response to information received from one or more of the communication devices and/or terminals.

The controller may be configured to monitor the frequency availability in each cell on an ongoing basis and to determine and communicate new frequency hopping sequences in dependence on the results of that monitoring.

The controller may be configured to monitor the frequency availability in each cell by consulting an external database.

The controller may be configured to monitor the frequency availability in each cell by collecting information from the communication devices and/or terminals.

The controller may be configured to monitor the frequency availability in each cell by collecting information that includes one or more of: a number of missed acknowledgements (ACKs) in communications on a particular frequency in the cell since the last determination of the frequency hopping sequences; a number of cyclic redundancy check (CRC) failures in communications on a particular frequency in the cell since the last determination of the frequency hopping sequences; a received signal strength indicator (RSSI) measurement on a particular frequency in the cell since the last determination of the frequency hopping sequences; and a bit error rate (BER) measurement on a particular frequency in the cell since the last determination of the frequency hopping sequences.

The controller may be configured to determine a new frequency hopping sequence for a cell responsive to a determination that: the number of missed acknowledgements (ACKs) in communications on a particular frequency in that cell since the last determination of the frequency hopping sequences exceeds a predetermined number; and/or the number of cyclic redundancy check (CRC) failures in communications on a particular frequency in that cell since the last determination of the frequency hopping sequences exceeds a predetermined number; and/or the received signal strength indicator (RSSI) measurement on a particular frequency in a that cell since the last determination of the frequency hopping sequences is lower than a predetermined threshold level; and/or the bit error rate (BER) measurement on a particular frequency in that cell since the last determination of the frequency hopping sequences is higher than a predetermined threshold level.

The controller may be configured to determine the frequency hopping sequence for each cell to use all the frequencies available in that cell.

The controller may be configured to determine the frequency hopping sequence for each cell so as to minimise the length of time for which neighbouring cells will be using the same frequency at the same time.

The controller may be configured to determine the frequency hopping sequence for each cell so as to maximise the number of frequencies available in each cell that are used by the respective hoping sequence for that cell while minimising the length of time for which neighbouring cells will use the same frequency at the same time in accordance with their respective frequency hopping sequences.

The controller may be configured to determine the frequency hopping sequences for neighbouring cells by determining a frequency hopping sequence for one cell to comprise repeatedly cycling through a set of selected frequencies in a predetermined order and determining a frequency hopping sequence for a neighbouring cell to comprise repeatedly cycling through the same set of selected sequences in the same predetermined order, but with the neighbouring cell commencing said repeated cycling at a different frequency within the selected set from said one cell.

The controller may be configured to determine that: the frequency availability in the neighbouring cell is such that one or more additional frequencies are available to that neighbouring cell than to said one cell; determining the frequency hopping sequence for said one cell to use the set of selected sequences and the frequency hopping sequence for the neighbouring cell to use the same set of selected sequences together with the one or more additional frequencies; determining the frequency hopping sequence for said one cell to comprise repeatedly cycling through the set of selected sequences only for the time taken for the frequency hopping sequence of the neighbouring cell to complete one cycle of the set of selected sequences together with the one or more additional frequencies.

The controller may be configured to determine the predetermined order of the set of selected frequencies for said one cell by one of: arranging all of the available frequencies for that cell in a random order; arranging all of the available frequencies for that cell in ascending order; and arranging all of the available frequencies for that cell in descending order.

According to a second embodiment of the invention, there is provided a communication network comprising a plurality of cells, each cell comprising a communication device and at least one terminal, and wherein each communication device is configured to communicate with its respective terminal according to a frequency hopping sequence associated with its respective cell, and the communication network further comprising a controller as claimed in any preceding claim.

At least one of the communication devices may be configured to communicate the frequency hopping sequence for its respective cell to the at least one terminal in that cell by including in every frame transmitted to the at least one terminal an indication of that frequency hopping sequence.

The at least one of the communication devices may be configured to transmit the indication as a list of the frequencies in the frequency hopping sequence.

The at least one of the communication devices may be configured to transmit the indication as a frequency map in which a set bit indicates a frequency that forms part of the hopping sequence.

The at least one of the communication devices may be configured to transmit the indication as a seed for inputting into a pseudo random noise generator.

The at least one communication device may be configured to determine the seed to transmit as part of the indication in such a way that the chosen frequency for the nth frame may be calculated by: inputting the seed into a pseudo random noise generator; taking the nth value in the pseudo random noise sequence output; taking the modulo of that nth value using the number of bits set in the frequency map; and determining that the chosen frequency for the nth frame is the frequency having a position corresponding to that modulo value in the frequency map.

At least one of the communication devices may be configured to communicate the frequency hopping sequence for its respective cell to the at least one terminal in that cell by: including a list of the frequency hopping sequence only in particular frames transmitted at predetermined intervals; and in every other frame, including a periodicity of the hopping sequence and the frequency of the next frame.

The communication devices may be configured to include, in those other frames, the frequency that the next frame in which the frequency hopping sequence is listed will be on.

The frequency availability in each cell may depend upon one or more of: interference from licensed frequency use in the region covered by each cell; interference from licensed frequency use in regions within range of receivers located within each cell, but not within the region covered by each cell;

interference from neighbouring cells on the network; and interference from other unlicensed networks.

The communication network may be configured to operate in whitespace.

The communication network may be configured for machine-to-machine communication.

According to a third embodiment of the invention, there is provided a method for assigning frequency hopping sequences to cells in a communication network, the communication network comprising: a plurality of cells, each cell comprising a communication device and at least one terminal and each communication device being configured to communicate with the at least one terminal in its respective cell according to a frequency hopping sequence associated with that cell; and the method comprising: determining the frequency availability in each cell; determining a frequency hopping sequence for each cell in dependence on that frequency availability; and communicating the frequency hopping sequence for each cell to the communication device in that cell.

Aspects of the present invention will now be described by way of example with reference to the accompanying drawings. In the drawings:

Figure 1 shows an example of a machine-to-machine network;

Figure 2 shows an example of a process that may be implemented by a controller;

Figure 3 shows an example of a frame structure;

Figures 4(a) to 4(c) show examples of frequency hopping sequences in different frames;

Figure 5 shows an example of a controller; and

Figure 6 shows an example of a communication device.

The following description is presented to enable any person skilled in the art to make and use the system, and is provided in the context of a particular application. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art.

The general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

An aspect of the invention relates to using a central controller to gather information about frequency availability in each cell, and in dependence on that information assigning frequency hopping sequences to the cells in such a way as to reduce message failure caused by interference.

The communication network may be a wireless network comprising a number of cells. Preferably each cell contains a communication device, such as a base station, and one or more communication terminals with which the communication device is capable of communicating according to a frequency hopping communication sequence. The central controller gathers information relating to the frequency availability in each cell and uses this to determine appropriate frequency hopping sequences for each cell. These frequency hopping sequences are then communicated to the communication devices. The communication devices then suitably communicate the frequency hopping sequence appropriate to their respective cells to the terminals in the cell and subsequently use that hopping sequence in communicating with the terminals.

One or more embodiments of the invention will now be described with specific reference to a wireless network in which the communication devices are base stations. This is for the purposes of example only and it should be understood that the frequency hopping sequence allocation mechanism described herein may be implemented for, and communicated by, any suitable communication devices, irrespective of what particular role those devices play within the network. Also, one or more embodiments are described with specific reference to wireless networks in which the controller is an operations centre for the network. It should be understood that this is also for the purposes of example only and the frequency hopping sequence allocation mechanism described herein may be implemented by any suitable device (including, for example, a base station).

An example of a wireless network is shown in Figure 1. The network, shown generally at 104, comprises one or more base stations 105 that are each capable of communicating wirelessly with a number of terminals 106. Each base station may be arranged to communicate with terminals that are located within a particular geographical area or cell. The base stations transmit to and receive radio signals from the terminals. The terminals are suitably entities embedded or machines or similar that communicate with the base stations. Suitably the wireless network is arranged to operate in a master-slave mode where the base station is the master and the terminals are the slaves.

The base station controller 107 is a device that provides a single point of communication to the base stations and then distributes the information received to other network elements as required. That is, the network is based around a many-to-one communication model. The network may be arranged to communicate with a client-facing portion 101 via the internet 102. In this way a client may provide services to the terminals via the wireless network.

Other logical network elements shown in this example are:

- Core network. This routes traffic information between base stations and client networks.
- Billing system. This records utilisation levels and generates appropriate billing data.

- Authentication system. This holds terminal and base station authentication information.
- Location register. This retains the last known location of the terminals.
- Broadcast register. This retains information on group membership and can be used to store and process acknowledgements to broadcast messages.
- Operations and maintenance centre (OMC). This monitors the function of the network and raises alarms when errors are detected. It also manages frequency and code planning, load balancing and other operational aspects of the network.
- Whitespace database. This provides information on the available whitespace spectrum.
- Client information portal. This allows clients to determine data such as the status of associated terminals, levels of traffic etc.

In practice, many of the logical network elements may be implemented as databases running software and can be provided on a wide range of platforms. A number of network elements may be physically located within the same platform.

A network such as that shown in Figure 1 may be used for machine-to-machine communications, i.e. communications that do not involve human interaction. Machine-to-machine communications are well-matched to the limitations of operating in whitespace, in which the bandwidth available to the network may vary from one location to another and also from one time instant to the next. As the network does not have any specific part of the spectrum allocated to it, even unallocated parts of the spectrum may become unavailable, e.g. due to a device in the vicinity that is operating outside of the network but using the same part of the spectrum. Machines are able to tolerate the delays and breaks in communication that can result from these varying communication conditions. Services can be provided in non real-time; low latency is not important as long as data is reliably delivered.

In order to increase the number of messages that are reliably delivered, a central controller may be provided to make intelligent frequency hopping sequence allocations to cells using analysis of frequency availability information. A suitable process that may be performed by the controller is shown in Figure 2. The process commences in step 201. In step 202, the controller determines, for each and every cell, which frequencies are permitted for whitespace use. The controller may perform this step by accessing the whitespace database to rule out those frequencies reserved for licensed users. The controller may then determine what frequencies are otherwise excluded as being unsuitable (step 203). It may, for example, rule out as being unsuitable frequencies on which an unacceptably high level of interference has been found. In step 204 the controller produces a finalised list of frequencies that are available to each cell. The controller uses this list to generate a frequency hopping sequence for each cell (step 205), which is then communicated to the appropriate base station (step 206). The process finishes in step 207.

Interference on a particular frequency in a particular cell may be detected in a number of ways. For example, a received signal strength indicator (RSSI) may be monitored for communications on that frequency in that cell. If the RSSI drops below some predetermined threshold then an unacceptable level of interference may be determined to be present. Similarly, the bit error rate (BER) could be monitored and unacceptable interference could be determined to be present if it reaches a predetermined threshold. Communications between a base station and its associated terminals may contain cyclic redundancy checks (CRCs) in every frame. If more than a predetermined number of these fail within a predetermined time period or number of frames then, again, an unacceptable level of interference could be determined to be present. Communications could alternatively/also require acknowledgements (ACKs), if more than a predetermined proportion of ACKs are missed then this too could indicate an unacceptable level of interference.

Interference may be detected as above, or in other ways, by individual base stations and/or terminals, and the results conveyed to the controller.

Alternatively, raw data could be sent to the controller and the requisite analysis performed there. The majority of the analysis work should preferably be done by devices for which processing and/or electrical power is not particularly limited. For example a mains-powered device would be preferred to a battery powered device for this work.

The controller could also determine more specific information regarding the nature of the interference found in order to aid in optimising the frequency hopping sequence assignment. For example, if higher than average errors are reported on the same frame by neighbouring base stations it could be assumed that this is caused by interference between those base stations.

Once the controller has established which frequencies are available for use in each cell it can start to allocate frequency hopping sequences. It is preferable for the sequences to contain as many frequencies as possible to reduce the impact of fading etc, as discussed above. However, the sequences should also be generated so as to minimise the occasions on which neighbouring cells will be transmitting on the same frequency, as this can cause interference to the terminals in each cell (particularly those located near to a cell boundary). The controller may employ an algorithm to determine every possible frequency sequence across the cells of the network to analyse which arrangement will generate the least amount of overlap between neighbouring cells.

If the number of available frequencies is high, and the network relatively large, a computation such as the one described above can rapidly require an unworkable level of resource. A preferred option is for the available frequencies to be arranged in a predetermined order, with each cell starting its respective hopping sequence at a different frequency in the order from its neighbouring cells. The predetermined order might be random or worked out according to some rule. For example, the available frequencies might simply be organised into ascending or descending order. An example is shown in Figure 4(a). Cells 1 to 3 are neighbouring cells and frequencies 1 to 4 are available in each cell. Each cell is assigned a cyclic-sequence in which frequencies 1 to 4 are used in ascending order. However, each cell commences its respective sequence at a different offset from its neighbour, so that at any given time each cell is using a different frequency in the sequence from its neighbour. Simulations have shown that such offset, cyclic frequency hopping sequences functions very well, without the unfeasible computational burden associated with looking at all possible frequency hopping sequences across all cells.

Generating the sequences to simply comprise a list of available frequencies arranged in a predetermined order and then applying a respective offset for each cell works particularly well in networks arranged to operate in whitespace. This is because the frequencies available for use in whitespace are largely dictated by the frequencies that are already allocated to TV channels. Different TV transmitters may use different frequencies (which is why the spectrum available to whitespace networks is dependent on the location of that network); however, each TV transmitter is associated with a large geographical region. Typically, a transmitter may cover an area having a radius of around 50 miles. This means that neighbouring cells will largely have the same set of frequencies available to them. When this is the case, neighbouring cells can be prevented from overlapping in their frequency hopping sequences simply by applying an offset in each cell.

It will not always be the case that neighbouring cells have the same available frequencies, e.g. where neighbouring cells are located in different TV coverage areas. Often, one cell may have more frequencies available to it than its neighbour, which raises a potential problem that the two cells will eventually cycle round to be identical with each other, despite having commenced their cycles with different offsets. An example of such a situation is shown in Figure 4(b), in which frequencies 1 to 3 are available to cells 1 and 2, but frequency 4 is available only to cell 1. Consequently cell 1 cycles through frequencies 1 to 4, while cell 2 cycles through frequencies 1 to 3 with an offset. However, in this instance, the additional frequency in cell 1's hopping sequence means that the two cells inevitably end up using the same frequency for a time period illustrated by the dotted line 401. The overlap still occurs for a much lower percentage of the time than would be expected if the base stations chose their own frequency hopping sequences, but any overlap will nonetheless cause messages to clash. A solution to this problem would be for cell 1 to remove frequency 4 from its hopping sequence. However, this is not an ideal solution as it is preferred for the hopping sequence of each cell to make use of all the frequencies available to it.

A unique feature of machine-to-machine networks is their ability to tolerate delays caused by message clashes. In a machine-to-machine network, it is usually possible to simply resend data at a later time, with no ill effects, if the first transmission fails. Therefore, for those cells where they will, for some small percentage of the time, be operating on the same frequencies as one or more neighbouring cells, this is not necessarily as problematic as it may first appear. In addition, spreading codes may be implemented to minimise the number of packets lost as a consequence of frequency clashes (see below for more detail).

A preferred implementation, however, is to have the cell with fewer frequencies available to it cycle through those frequencies until its neighbouring cell, with more frequencies at its disposal, has finished one of its cycles. This scenario is illustrated in Figure 4(c). In this example, frequencies 1 to 3 are available to cells 1 and 2, but frequency 4 is available only to cell 1. In this example, the frequency hopping sequence of cell 2 has been extended so that the duration of one cycle matches the duration of one cycle of the frequency hopping sequence of cell 1. This is achieved by extending the set of frequencies through which cell 2 cycles to comprise the same number of frequencies as cell 1. Since four frequencies are not available in cell 2, this requires the first frequency of cell 2's set to be repeated. Another way to view this is that the frequency hopping sequence of cell 2 essentially comprises two different cycles, each with its own periodicity. In the first cycle, cell 2 cycles through frequencies 1 to 3 with its assigned offset. However, that cycle has a duration that is limited to the duration of the cycle of its neighbouring cell, cell 1. In other words, when cell 1 finishes its cycle, the cycle of cell 2 is essentially terminated and reset, so that it recommences its cycle from the beginning. An arrangement such as this may be advantageous in avoiding the overlapping frequencies of the arrangement shown in Figure 4(b).

Preferably the frequency hopping sequences are communicated to each base station, and the base stations pass the information on to any terminals in their cells. This communication is suitably achieved by the base station including information defining the sequence in each frame it transmits, so that a terminal can obtain the frequency hopping sequence by listening to only one frame.

The base station could inform terminals of the channels and hopping sequence to be used, and any changes, in a number of ways. A preferred embodiment is for the frequency hopping sequence to be communicated in every frame so that a terminal need only listen to one frame to obtain all the information about the frequency hopping sequence that it needs. One advantage of having each base station simply use an ascending or descending sequence of frequencies is that it can be particularly easily communicated to the terminals. For example, such a hopping sequence may be indicated simply by having a channel bitmap in every frame. For more complex sequences, it may be necessary for the base station to transmit the actual list of channels in the order in which hopping will occur. This can be transmitted in each frame, but with the risk that the resource requirement is high if there are a large number of channels.

An alternative for more complex hopping sequences is to transmit the full hopping sequence as part of a broadcast control channel frame transmitted by the base station to all the terminals in the cell at regular intervals. This frame could inform terminals of a forthcoming change to the channel assignment/hopping sequence in the cell, and page terminals if they are required to respond outside of their normal allocated slot, amongst other things. In every other frame, the base station may transmit the periodicity of the hopping sequence, the frequency of the next frame and optionally the frequency that the next broadcast control channel frame will be on. This approach allows for greater flexibility in the hopping sequences that can be adopted, but does mean that the terminals cannot gain complete knowledge of the hopping sequence from simply listening to one frame.

A further option is to transmit the hopping sequence as a combination of a 48-bit channel map (with a bit being set if that channel is in use in the base station), and a log2(n)-bit seed. In order to generate the sequence, a terminal may input the seed to a pseudo random noise generator. The chosen channel would then be the (MacFrame)'th value in the PRN sequence, modulo the number of bits set in the channel map. The base station might transmit the 48-bit channel map in a broadcast frame and the seed in every frame. This approach results in a relatively small amount of data being needed to characterise the hopping sequence, allowing it to be transmitted in each frame and hence ensuring devices can determine the future frequency usage from monitoring a single frame.

The network may use medium access control (MAC) to share the same radio resource between multiple terminals. An example of a suitable frame structure is shown in Figure 3. The frame (shown generally at 301) comprises time to ramp-up to full output power 302 (T_IFS), a synchronisation burst 303 (DL_SYNC), an information field providing the subsequent channel structure 304 (DL_FCH), a map of which information is intended for which terminal 305 (DL_MAP), a field to allow acknowledgement of previous uplink transmissions 306 (DL_ACK) and then the actual information to be sent to terminals 307 (DL_ALLOC). There is then a guard period for ramp-down of the downlink and ramp-up on the uplink 308 (T_SW), followed by the allocated uplink data transmissions 310 (UL_ALLOC) in parallel with channels set aside for uplink contended access 309 (UL_CA).

A suitable hopping rate for the downlink channels may be the frame rate, so that each frame is transmitted on a different frequency from the preceding frame. The frames for a network designed to operate in whitespace for machine-to-machine communication may be particularly long. In one example the frames may each be 2 seconds long, giving a frequency hop on the downlink every 2 seconds (which is 30 hops per minute).

The DL_FCH may include information to enable the terminals to determine the hopping sequence. The DL_FCH may include a list of the frequencies that are included in the sequence. One efficient way of communicating this information is by means of a channel map, with a bit being set if the channel is in use in the base station. The DL_FCH may also include a MAC Frame count (16-bit) enabling terminals to determine where the base station is in its hopping pattern.

The DL_MAP informs terminals as to whether there is any information for them in the frame and whether they have an uplink slot reserved for them to transmit information. It comprises a table of terminal identities, the number of slots that their information is spread over and the transmission mode and spreading factors used. All terminals monitoring the frame decode this field to determine whether they need to decode subsequent information. The length of the DL_MAP may be included as part of the DL_FCH. A terminal can determine the position of its assigned slots from the DL_MAP by adding up the number of slots allocated in prior rows in the table.

On the uplink the slots may be numbered from 0 to n on the first FDMA channel, then on the subsequent FDMA channel and so on. The terminal can determine how many slots there are each channel from the length of the frame available for the uplink (that remaining after completion of the downlink) divided by the length of each slot. If a terminal has data requiring multiple slots it would normally be given these consecutively on the same carrier as this both simplifies the terminal transmission and minimises the control information required to describe the slot location. However, it is possible to give the terminal multiple allocations on different carriers (so long as they are not simultaneous) to achieve frequency hopping on the uplink.

Due to the dynamic nature of the whitespace environment it may be necessary for the frequency hopping sequences to be updated from time to time. This may be done periodically. The controller could alternatively, or in addition, update the frequency hopping sequences in response to information received from a network device or devices. For example, if a predetermined threshold associated with a number of missed ACKs or failed CRCs, or an RSSI or BER level, is crossed, this could trigger a redetermination of frequency hopping sequences.

The communication links between the various components of the networks may be wired or wireless. The terminals may be located in fixed positions or mobile, roaming throughout and/or between cells.

Interference between network devices in neighbouring cells could also be reduced by the controller assigning different spreading codes for use in different cells. This can help to avoid complete packet loss in the event of direct frequency clashes between neighbouring cells. Preferably neighbouring cells are assigned orthogonal spreading codes.

An example of the functional blocks that may be comprised in a controller according to one embodiment of the invention are shown in Figure 5. The controller, shown generally at 501, comprises a communication unit 503 connected to an antenna 502 for transmitting and receiving messages. The controller might equally communicate the frequency hopping sequences to the communication devices via a wired connection. The controller further comprises an availability unit 504 for determining what frequencies are available in each cell, an analysis unit 505 for analysing which available frequencies should be avoided in the frequency hopping sequences, and a generation unit 506 for generating the frequency hopping sequences. The communication unit may effectively act as a central controller and may pass information between the other functional blocks.

An example of the functional blocks that may be comprised in a communication device according to one embodiment of the invention are shown in Figure 6. The communication device, shown generally at 601, comprises a communication unit 603 connected to an antenna 602 for transmitting and receiving messages. The communication device further comprises a storage unit 604 for storing its frequency hopping sequence and an analysis unit 605 for analysing the interference conditions in the cell. The communication unit may effectively act as a central controller and may pass information between the other functional blocks.

The apparatus in Figures 5 and 6 are shown illustratively as comprising a number of interconnected functional blocks. This is for illustrative purposes and is not intended to define a strict division between different parts of hardware on a chip. In practice, the communication device preferably uses a microprocessor acting under software control for implementing the methods described herein. In some embodiments, the algorithms may be performed wholly or partly in hardware.

The applicant hereby discloses in isolation each individual feature described herein and any combination of two or more such features, to the extent that such features or combinations are capable of being carried out based on the present specification as a whole in the light of the common general knowledge of a person skilled in the art, irrespective of whether such features or combinations of features solve any problems disclosed herein, and without limitation to the scope of the claims. The applicant indicates that aspects of the present invention may consist of any such individual feature or combination of features. In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention.

CLAIMS

1. A controller for a communication network, the communication network comprising:

a plurality of cells, each cell comprising a communication device and at least one terminal and each communication device being configured to communicate with the at least one terminal in its respective cell according to a frequency hopping sequence associated with that cell;

the controller being configured to:

determine the frequency availability in each cell;

determine a frequency hopping sequence for each cell in dependence on that frequency availability; and

communicate the frequency hopping sequence for each cell to the communication device in that cell.

2. A controller as claimed in claim 1, configured to determine and communicate new frequency hopping sequences at regular intervals.

3. A controller as claimed in claims 1 or 2, configured to determine and communicate new frequency hopping sequences in response to information received from one or more of the communication devices and/or terminals.

4. A controller as claimed in any preceding claim, configured to monitor the frequency availability in each cell on an ongoing basis and to determine and communicate new frequency hopping sequences in dependence on the results of that monitoring.

5. A controller as claimed in any preceding claim, configured to monitor the frequency availability in each cell by consulting an external database.

6. A controller as claimed in any preceding claim, configured to monitor the frequency availability in each cell by collecting information from the communication devices and/or terminals.

7. A controller as claimed in claim 6, configured to monitor the frequency availability in each cell by collecting information that includes one or more of:

a number of missed acknowledgements (ACKs) in communications on a particular frequency in the cell since the last determination of the frequency hopping sequences;

a number of cyclic redundancy check (CRC) failures in communications on a particular frequency in the cell since the last determination of the frequency hopping sequences;

a received signal strength indicator (RSSI) measurement on a particular frequency in the cell since the last determination of the frequency hopping sequences; and

a bit error rate (BER) measurement on a particular frequency in the cell since the last determination of the frequency hopping sequences.

8. A controller as claimed in any preceding claim, configured to determine a new frequency hopping sequence for a cell responsive to a determination that:

the number of missed acknowledgements (ACKs) in communications on a particular frequency in that cell since the last determination of the frequency hopping sequences exceeds a predetermined number; and/or

the number of cyclic redundancy check (CRC) failures in communications on a particular frequency in that cell since the last determination of the frequency hopping sequences exceeds a predetermined number; and/or

the received signal strength indicator (RSSI) measurement on a particular frequency in a that cell since the last determination of the frequency hopping sequences is lower than a predetermined threshold level; and/or

the bit error rate (BER) measurement on a particular frequency in that cell since the last determination of the frequency hopping sequences is higher than a predetermined threshold level.

9. A controller as claimed in any preceding claim, configured to determine the frequency hopping sequence for each cell to use all the frequencies available in that cell.

10. A controller as claimed in any preceding claim, configured to determine the frequency hopping sequence for each cell so as to minimise the length of time for which neighbouring cells will be using the same frequency at the same time.

11. A controller as claimed in any preceding claim, configured to determine the frequency hopping sequence for each cell so as to maximise the number of frequencies available in each cell that are used by the respective hoping sequence for that cell while minimising the length of time for which neighbouring cells will use the same frequency at the same time in accordance with their respective frequency hopping sequences.

12. A controller as claimed in any preceding claim, configured to determine the frequency hopping sequences for neighbouring cells by:

determining a frequency hopping sequence for one cell to comprise repeatedly cycling through a set of selected frequencies in a predetermined order; and

determining a frequency hopping sequence for a neighbouring cell to comprise repeatedly cycling through the same set of selected sequences in the same predetermined order, but with the neighbouring cell commencing said repeated cycling at a different frequency within the selected set from said one cell.

13. A controller as claimed in claim 12, configured to determine that:

the frequency availability in the neighbouring cell is such that one or more additional frequencies are available to that neighbouring cell than to said one cell;

determining the frequency hopping sequence for said one cell to use the set of selected sequences and the frequency hopping sequence for the neighbouring cell to use the same set of selected sequences together with the one or more additional frequencies;

determining the frequency hopping sequence for said one cell to comprise repeatedly cycling through the set of selected sequences only for the time taken for the frequency hopping sequence of the neighbouring cell to complete one cycle of the set of selected sequences together with the one or more additional frequencies.

14. A controller as claimed in claim 12 or 13, configured to determine the predetermined order of the set of selected frequencies for said one cell by one of:

arranging all of the available frequencies for that cell in a random order;

arranging all of the available frequencies for that cell in ascending order; and

arranging all of the available frequencies for that cell in descending order.

15. A communication network comprising a plurality of cells, each cell comprising a communication device and at least one terminal, and wherein each communication device is configured to communicate with its respective terminal according to a frequency hopping sequence associated with its respective cell, and the communication network further comprising a controller as claimed in any preceding claim.

16. A communication network as claimed in claim 15, wherein at least one of the communication devices is configured to communicate the frequency hopping sequence for its respective cell to the at least one terminal in that cell by including in every frame transmitted to the at least one terminal an indication of that frequency hopping sequence.

17. A communication network as claimed in claim 16, wherein the at least one of the communication devices is configured to transmit the indication as a list of the frequencies in the frequency hopping sequence.

18 A communication network as claimed in claim 16 or 17, wherein the at least one of the communication devices is configured to transmit the indication as a frequency map in which a set bit indicates a frequency that forms part of the hopping sequence.

19. A communication network as claimed in any of claims 16 to 18, wherein the at least one of the communication devices is configured to transmit the indication as a seed for inputting into a pseudo random noise generator.

20. A communication network as claimed in claims 18 and 19, wherein the at least one communication device is configured to determine the seed to transmit as part of the indication in such a way that the chosen frequency for the nth frame may be calculated by:

inputting the seed into a pseudo random noise generator;

taking the nth value in the pseudo random noise sequence output;

taking the modulo of that nth value using the number of bits set in the frequency map; and

determining that the chosen frequency for the nth frame is the frequency having a position corresponding to that modulo value in the frequency map.

21 A communication network as claimed in any of claims 15 to 19, wherein at least one of the communication devices is configured to communicate the frequency hopping sequence for its respective cell to the at least one terminal in that cell by:

including a list of the frequency hopping sequence only in particular frames transmitted at predetermined intervals; and

in every other frame, including a periodicity of the hopping sequence and the frequency of the next frame.

22. A communication network as claimed in claim 21, wherein the communication devices are configured to include, in those other frames, the frequency that the next frame in which the frequency hopping sequence is listed will be on.

23. A communication network as claimed in any of claims 15 to 22, wherein the frequency availability in each cell depends upon one or more of:

interference from licensed frequency use in the region covered by each cell;

interference from licensed frequency use in regions within range of receivers located within each cell, but not within the region covered by each cell;

interference from neighbouring cells on the network; and

interference from other unlicensed networks.

24. A communication network as claimed in any of claims 15 to 23, configured to operate in whitespace.

25. A communication network as claimed in any of claims 15 to 24, configured for machine-to-machine communication.

26. A method for assigning frequency hopping sequences to cells in a communication network, the communication network comprising:

a plurality of cells, each cell comprising a communication device and at least one terminal and each communication device being configured to communicate with the at least one terminal in its respective cell according to a frequency hopping sequence associated with that cell;

and the method comprising:

determining the frequency availability in each cell;

determining a frequency hopping sequence for each cell in dependence on that frequency availability; and

communicating the frequency hopping sequence for each cell to the communication device in that cell.

27. A controller substantially as herein described, with reference to the accompanying figures.

28. A communication network substantially as herein described, with reference to the accompanying figures.

29. A method substantially as herein described, with reference to the accompanying figures.

AMENDED CLAIMS
received by the International Bureau on 24 August 2012 (24.08.2012)

1. A controller for a communication network, the communication network comprising:

a plurality of cells, each cell comprising a communication device and at least one terminal and each communication device being configured to communicate with the at least one terminal in its respective cell according to a frequency hopping sequence associated with that cell;

the controller being configured to:

determine the frequency availability in each cell;

determine a frequency hopping sequence for each cell to comprise repeatedly cycling through a set of selected frequencies, the set of selected frequencies comprising, for each cell, frequencies available in that cell together with, for a cell which has a neighbouring cell with one or more frequencies available to, a repetition of one or more of the frequencies available in that cell so as to extend the duration of its frequency hopping cycle to equal that of its neighbouring cell; and

communicate the frequency hopping sequence for each cell to the communication device in that cell.

2. A controller as claimed in claim 1, configured to determine and communicate new frequency hopping sequences at regular intervals.

3. A controller as claimed in claims 1 or 2, configured to determine and communicate new frequency hopping sequences in response to information received from one or more of the communication devices and/or terminals.

4. A controller as claimed in any preceding claim, configured to monitor the frequency availability in each cell on an ongoing basis and to determine and communicate new frequency hopping sequences in dependence on the results of that monitoring.

5. A controller as claimed in any preceding claim, configured to monitor the frequency availability in each cell by consulting an external database.

6. A controller as claimed in any preceding claim, configured to monitor the frequency availability in each cell by collecting information from the communication devices and/or terminals.

7. A controller as claimed in claim 6, configured to monitor the frequency availability in each cell by collecting information that includes one or more of:

a number of missed acknowledgements (ACKs) in communications on a particular frequency in the cell since the last determination of the frequency hopping sequences;

a number of cyclic redundancy check (CRC) failures in communications on a particular frequency in the cell since the last determination of the frequency hopping sequences;

a received signal strength indicator (RSSI) measurement on a particular frequency in the cell since the last determination of the frequency hopping sequences; and

a bit error rate (BER) measurement on a particular frequency in the cell since the last determination of the frequency hopping sequences.

8. A controller as claimed in any preceding claim, configured to determine a new frequency hopping sequence for a cell responsive to a determination that:

the number of missed acknowledgements (ACKs) in communications on a particular frequency in that cell since the last determination of the frequency hopping sequences exceeds a predetermined number; and/or

the number of cyclic redundancy check (CRC) failures in communications on a particular frequency in that cell since the last determination of the frequency hopping sequences exceeds a predetermined number; and/or

the received signal strength indicator (RSSI) measurement on a particular frequency in a that cell since the last determination of the frequency hopping sequences is lower than a predetermined threshold level; and/or

the bit error rate (BER) measurement on a particular frequency in that cell since the last determination of the frequency hopping sequences is higher than a predetermined threshold level.

9. A controller as claimed in any preceding claim, configured to determine the frequency hopping sequence for each cell to use all the frequencies available in that cell.

10. A controller as claimed in any preceding claim, configured to determine the frequency hopping sequence for each cell so as to minimise the length of time for which neighbouring cells will be using the same frequency at the same time.

11. A controller as claimed in any preceding claim, configured to determine the frequency hopping sequence for each cell so as to maximise the number of frequencies available in each cell that are used by the respective hoping sequence for that cell while minimising the length of time for which neighbouring cells will use the same frequency at the same time in accordance with their respective frequency hopping sequences.

12. A controller as claimed in any preceding claim, configured to determine the frequency hopping sequences for neighbouring cells by:

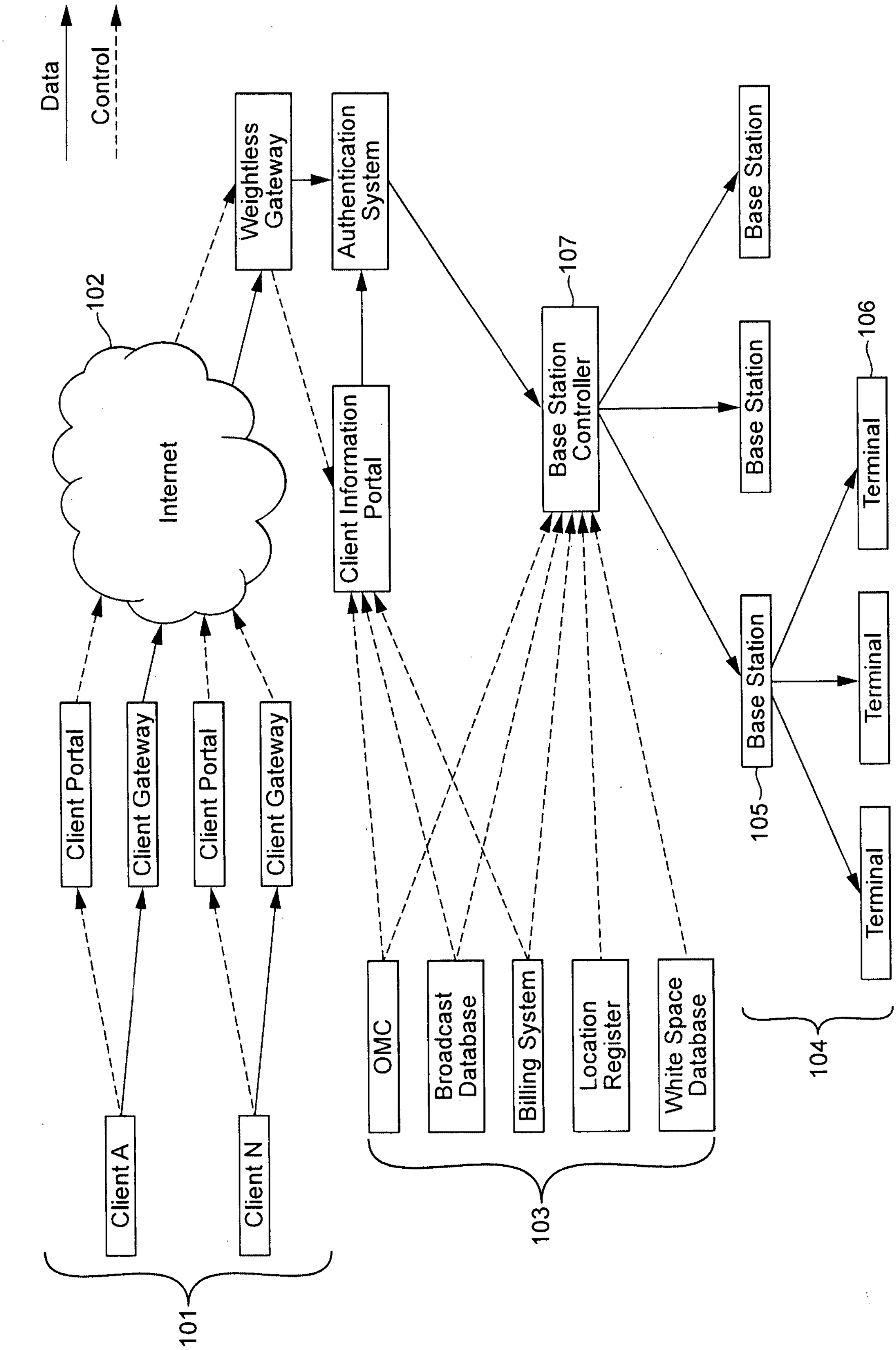
determining a frequency hopping sequence for one cell to comprise repeatedly cycling through the set of selected frequencies for that cell in a predetermined order; and

determining a frequency hopping sequence for a neighbouring cell to comprise repeatedly cycling through the same set of selected sequences in the same predetermined order, but with the neighbouring cell commencing said repeated cycling at a different frequency within the selected set from said one cell.

13. A controller as claimed in claim 12, configured to:

determine that the frequency availability in the neighbouring cell is such that one or more additional frequencies are available to that neighbouring cell than to said one cell;

determine the frequency hopping sequence for said one cell to use the set of selected sequences and the frequency hopping sequence for the neighbouring cell to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Authentication System
Internet
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Base Station Controller
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105
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Terminal
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104
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Client A
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OMC
Broadcast Database
Billing System
Location Register
White Space Database
103

FIG. 1

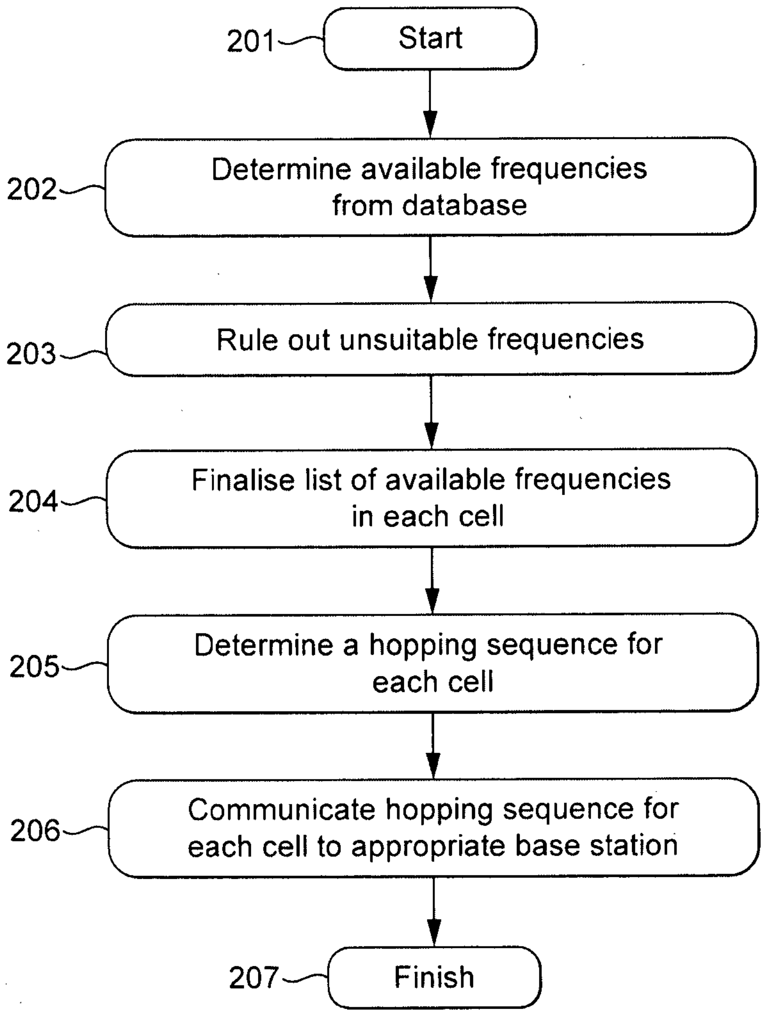
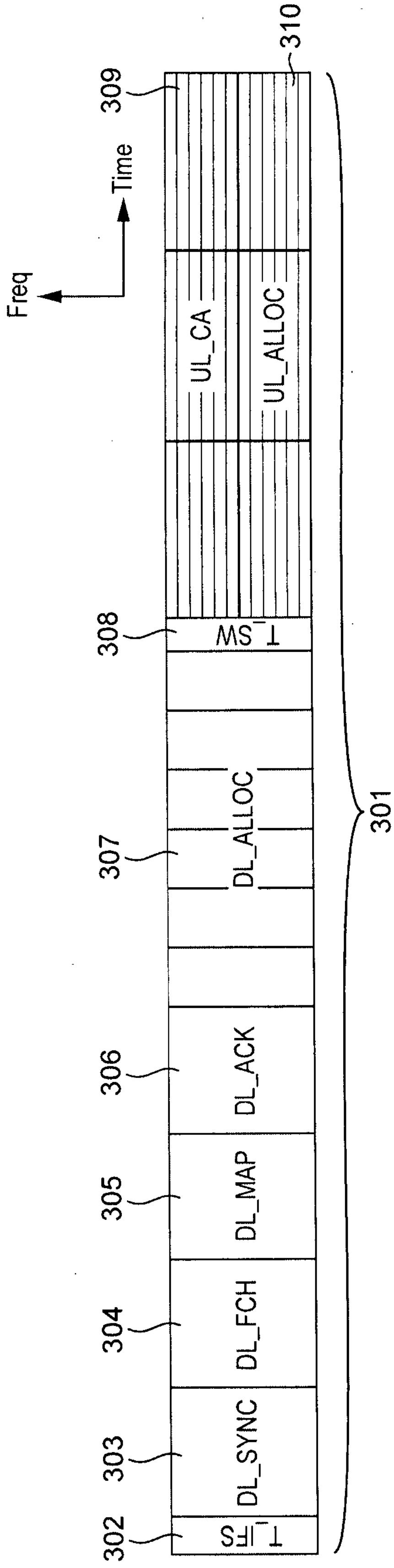

201
Start
202
Determine available frequencies from database
203
Rule out unsuitable frequencies
204
Finalise list of available frequencies in each cell
205
Determine a hopping sequence for each cell
206
Communicate hopping sequence for each cell to appropriate base station
207
Finish

FIG. 2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Freq
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UL_CA
UL_ALLOC
308
T_SW
307
DL_ALLOC
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DL_ACK
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DL_MAP
304
DL_FCH
303
DL_SYNC
302
T_IFS
301

FIG. 3

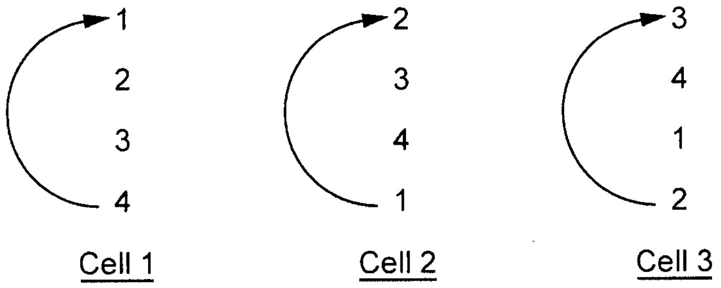
1
2
3
4
2
3
4
1
3
4
1
2
Cell 1
Cell 2
Cell 3

FIG. 4(a)

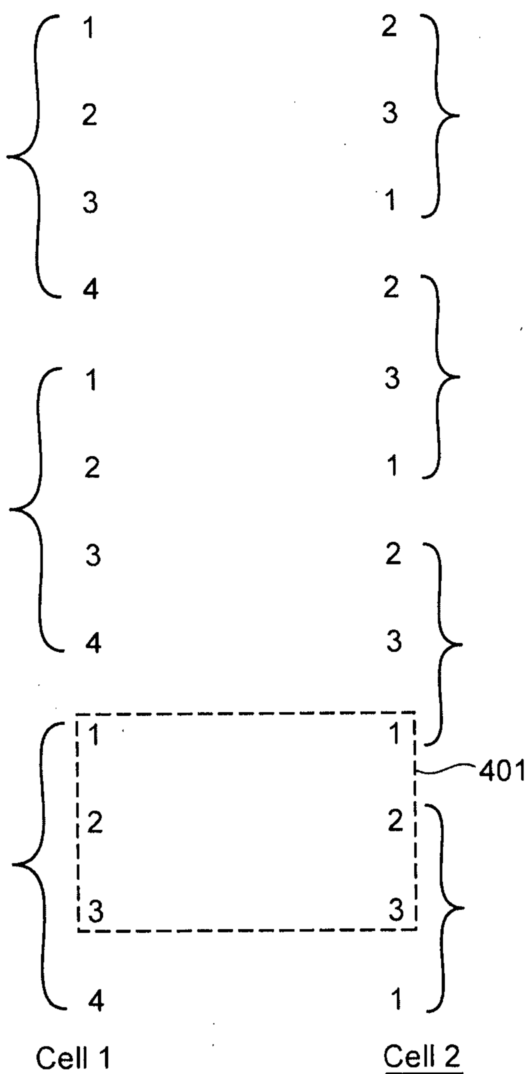
1
2
3
4
1
2
3
4
1
2
3
4
2
3
1
2
3
1
2
3
1
2
3
1
401
Cell 1
Cell 2

FIG. 4(b)

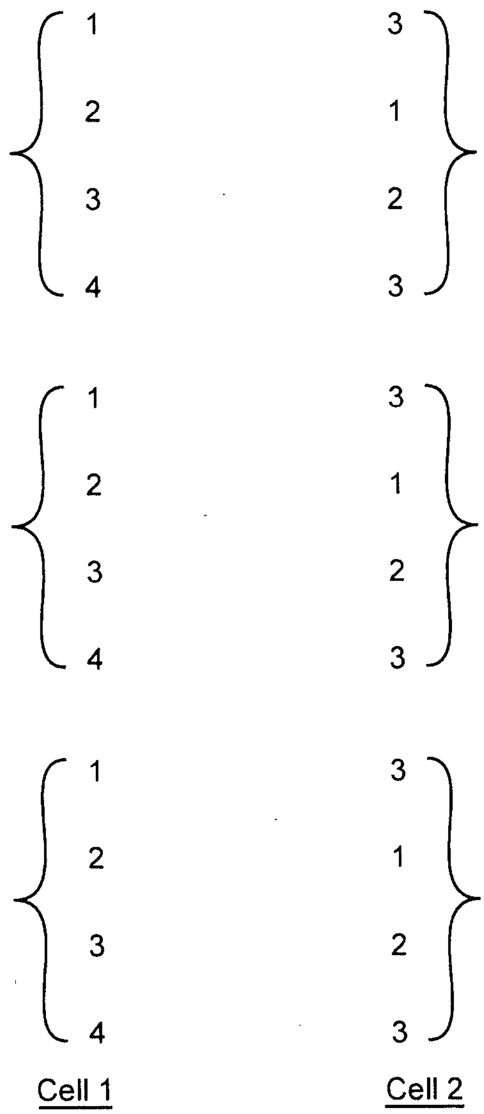

FIG. 4(c)

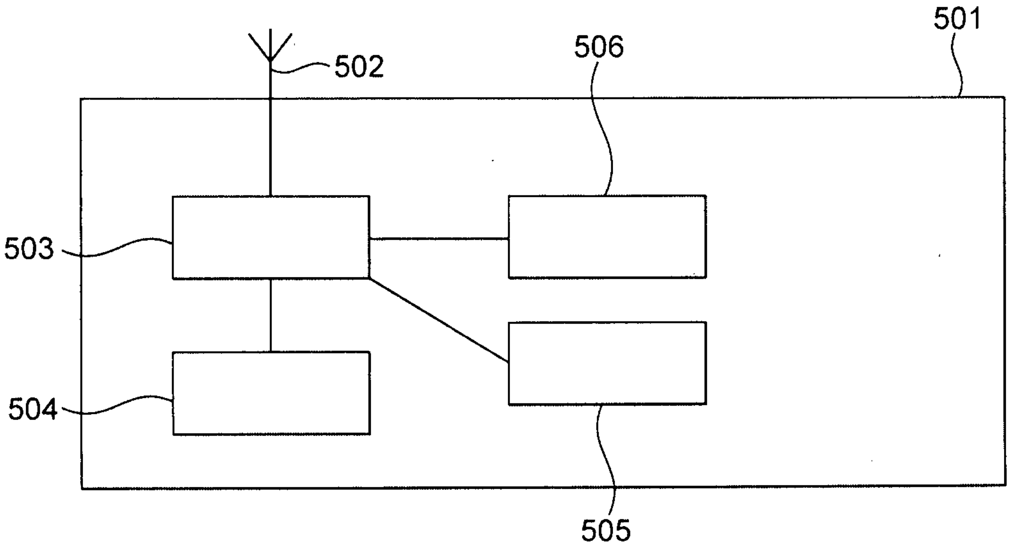

FIG. 5

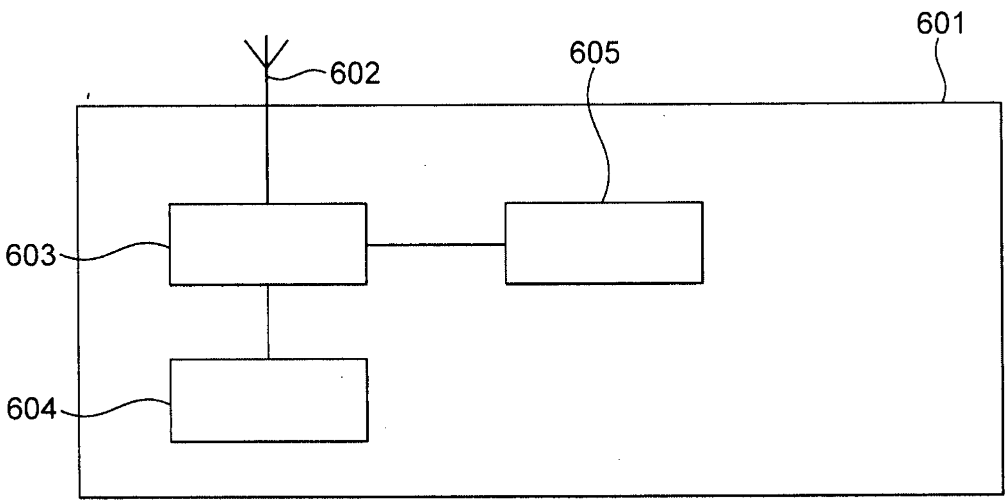

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/058429

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W16/14
ADD.

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)
H04W

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 850 611 A1 (ST MICROELECTRONICS INC [US]) 31 October 2007 (2007-10-31) paragraph [0001] - paragraph [0032] paragraph [0049] figures 1,3,4,7 -----	1-29
X	WENDONG HU ET AL: "COGNITIVE RADIOS FOR DYNAMIC SPECTRUM ACCESS -Dynamic Frequency Hopping Communities for Efficient IEEE 802.22 Operation", IEEE COMMUNICATIONS MAGAZINE, IEEE SERVICE CENTER, PISCATAWAY, US, vol. 44, no. 5, 1 May 2007 (2007-05-01), pages 80-87, XP011181061, ISSN: 0163-6804 the whole document ----- -/--	1-29

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

[X] 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 application or patent but published on or after the international filing date

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 June 2012	29/06/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Zembery, Peter

1

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2007/248076 A1 (JI BAOWEI [US] ET AL) 25 October 2007 (2007-10-25) paragraphs [0003], [0004], [0024] - paragraph [0034] -----	1-29
A	EP 1 717 962 A1 (LUCENT TECHNOLOGIES INC [US]) 2 November 2006 (2006-11-02) paragraph [0013] -----	1-29

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2012/058429

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 1850611 A1	31-10-2007	EP 1850611 A1 US 2007249341 A1	31-10-2007 25-10-2007
US 2007248076 A1	25-10-2007	KR 20070104282 A US 2007248076 A1	25-10-2007 25-10-2007
EP 1717962 A1	02-11-2006	DE 602005004757 T2 EP 1717962 A1 JP 2006311494 A KR 20060113345 A US 2006245470 A1	26-02-2009 02-11-2006 09-11-2006 02-11-2006 02-11-2006