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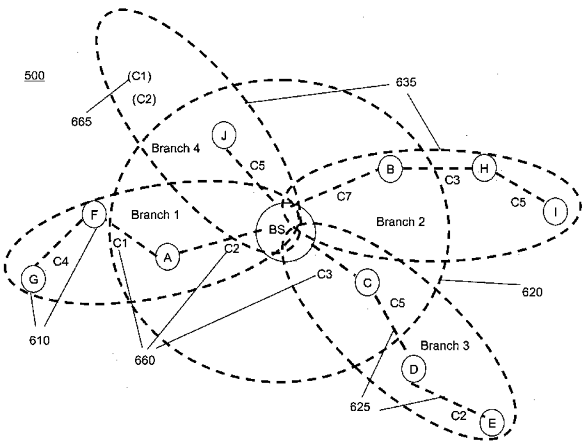
(54) **Title:** ASSIGNING CHANNELS WITHIN A MULTI-HOP NETWORK



(57) **Abstract:** The present invention relates to allocation of channels within a multi-hop wireless network having a base station together with a number of nodes, some of which will be outside the coverage range of the base station. The present invention provides a method of assigning channels within a centralised multi-hop wireless network (600) having a base station (BS) and number of nodes (610) coupled to the base station, wherein some of the nodes can be coupled to the base station using two or more connection hops (660) to one or more intermediate nodes; the method comprising: allocating a multi-hop connection branch (635) to each node within direct connection range (620) of the base station, each multi-hop connection branch capable of supporting connections to nodes beyond the direct connection range of the base station; allocating a channel set (320) to each multi-hop connection branch, each channel set comprising a sequence of channels (635) corresponding to a sequence of connection hops within the multi-hop connection branches; informing the nodes of each multi-hop connection branch of their respective allocated channel set (325, 330); each node within each multi-hop connection branch using one of the channels in the respective channel set for connecting to another node (335), the channel used being dependent on the number of hops the connection is from the base station.

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ASSIGNING CHANNELS WITHIN A MULTI-HOP NETWORK

Field of the Invention

The present invention relates to allocation of channels within a multi-hop wireless network having a base station together with a number of nodes, some of which will be outside the coverage range of the base station.

Background of the Invention

Multi-hop wireless networks involve implementing communication between a number of wireless devices and a gateway, base station or central node wherein some of the devices are outside the gateway's wireless or radio range. Communications between such devices and the gateway are enabled by utilising intermediate devices including the devices within range of the gateway and which act as relays. There may be two or more separate connections or hops with intermediate devices before reaching the gateway.

Multi-hop networks provide a cheaper alternative to installing additional gateways or base stations to cover the same area, however they are more complicated to implement. One of the problems with a multi-hop network is the rapid degradation of network performance as the number of hops increase. This is due to increased latency over a shared channel for which use is contended, such as in the well known CSMA/CA algorithm for example. One solution to this problem is to employ multiple channels over the network. However each wireless device or node then needs to determine which channel to use in order to minimise interference with other nodes which may be using the same channel elsewhere in the network. This increases the set-up time for the network and/or any changes to connections within it due to movement of the devices for example. Furthermore this requires a suitable scanning capability within each device.

US2003/058816 describes a system for allocating multiple channels to different links or hops within a multi-hop network. An access point or base station assigns different channels to different hops, so that nodes trying to communicate on the same link number or hop contend for access of the same channel. Thus for example all nodes within range of the base station but wanting to communicate on a link to a node outside this range (the second hop) will all be assigned the same channel to use.

WO02/078369 describes a system in which a channel manager for each node or wireless device scans all available channels before using this information to select a best channel. The channels are also allocated on a per hop basis.

"Impact of Interference and Channel Assignment on Blocking Probability in Wireless Networks" by Murtaza A. Zafer Eytan Modiano, in the CONFERENCE ON INFORMATION SCIENCES AND SYSTEMS, MARCH 17-19, 2004; available at http://web.mit.edu/murtaza/www/Research/CISS2004.pdf describes a system in which nodes scan all the available channels and exchange this information with other nodes so that the channels that is least used by neighbouring nodes is chosen as a link channel by each node.

US2005/208949 describes a method in which each node estimates traffic on virtual links on different channels to other nodes in order to determine a channel to use for that link.

Summary of the Invention

The present invention provides a method of assigning channels within a centralised multi-hop wireless network having a number of nodes or wireless devices including a central node or base station that might have a non-wireless connection to the Internet for example. Some of the nodes or wireless devices can be coupled to the central node over multiple connection hops, using intermediate nodes between the respective node and the base station effectively as relays. A first hop or connection is provided between the base station and one or more first nodes within range of the base station, then a second hop or connection is provided between the in-range or first nodes and second nodes outside the range of the base station but within range of the first nodes. Further third (fourth and so on) hops or connections may be made between the second and third (fourth) nodes even more distant from the base station, but within range of the second (third) nodes. Generally each first node will form a multi-hop or multi-connection branch through which second and third (and fourth or more) nodes communicate with the base station. Thus each first node will be capable of forming its own multi-hop connection branch in order to facilitate connection between second nodes and the base station using connections between itself and the base station (first hop) and between itself and one or more second nodes (second hop). Similarly one or more third nodes can be connected to the base station by additional connections (third hop) to one of the second nodes connected to the first node.

Each multi-hop connection branch may be an actual series of connected nodes or wireless devices which transfer data along the connections, some nodes acting as relays or intermediate nodes; or the branch may be a potential or virtual series of connected nodes. Each branch starts with a first node which is in direct connection range or wireless sensing range of the base station, and extends outside this direct connection range to other nodes using second, third, and so on hop connections.

The method of assigning or allocating channels to the various hops or connections between the wireless devices of one or more such multi-hop connection branches comprises allocating a multi-hop connection branch to each (first) node within direct connection range of the base station, each multi-hop connection branch capable of supporting connections to (second, third, and so on) nodes beyond the direct connection range of the base station. This can be achieved by simply allocating each first node with a unique branch identifier. The first nodes within each network can be determined using a multi-hop discovery procedure as known in the art, or by simply using a discovery procedure directed to identifying the in-range (first) nodes. The method then allocates a channel set to each multi-hop connection branch. Each channel set comprises a sequence of channels corresponding to a sequence of connections within a multi-hop connection branch from the base station. Where there are sufficient channels available within the network, the channels within the allocated channel sets can be different for respective hop in order to reduce interference. Similarly, within each channel set, the channels for adjacent hops will typically be different in order to reduce interference.

The allocation of channels in this way to the various connections of a multi-hop network reduces the set-up time for the network as each individual node does not need to scan all the available channels and then report back to the base station. The base station simply makes an allocation in a manner intended to reduce interference when the various multi-hop connection branches are all in use. Where there are sufficient channels, each hop of a branch is allocated a different channel from the same hop in other branches. Where there are insufficient channels, the number of times the same channel is used for the same hop is minimised. Typically even when using the same channel for the same hop for two or more branches, the interference will be low for bursty traffic – that is data exchange which is not periodic or occurs in bursts rather than (more or less) continuous and/or uniform. Similarly by not having adjacent connections within a multi-hop branch use the same channel, inference between connections supported by the same node is reduced.

Each allocated channel set is distributed to each (first, second, third, etc) node within the corresponding multi-hop connection branch. This distribution may be achieved by forwarding a corresponding channel set identifier to each node, for example using a common control channel. Each node within each multi-hop connection branch uses the respective forwarded channel set identifier to determine the appropriate channel set information from its own internal memory. For each connection the node is to establish with another node (eg second hop and third hop), it determines the appropriate channel from the channel set, (eg second or third channel within the channel set). Where there are multiple connections on the same hop (eg to two third nodes) the same channel is used.

In an alternative embodiment, the channel set itself rather than a channel set identifier may be forwarded to each node.

In order to determine the number of hops, and thus the appropriate channel from the forwarded channel set to use, each node may interrogate a hop parameter forwarded together with the channel set (or identifier) and which can be incremented by each node as it forwards the channel set to the next node within the multi-hop branch.

In another aspect there is provided a method of assigning channels within a centralised multi-hop wireless network having a base station and number of nodes coupled to the base station, wherein some of the nodes can be coupled to the base station using two or more connection hops to one or more intermediate nodes, and wherein multi-hop connection branches have been allocated to each node within direct connection range of the base station, and a channel set has been allocated to each multi-hop connection branch, each channel set comprising a sequence of channels corresponding to a sequence of connection hops within the multi-hop connection branches; the method comprising informing a newly in-range other node of the channel set of the multi-hop branch in response to determining that the other node requires more connection hops to the base station, and using one of the channels in the respective channel set for connecting to the other node, the channel used being dependent on the number of hops the connection is from the base station.

Alternatively or additionally, the method comprises receiving from a newly in-range other node the channel set of the multi-hop branch in response to determining that the other node requires fewer connection hops to the base station, and using one of the channels in the respective channel set for connecting to the other node, the channel used being dependent on the number of hops the connection is from the base station.

There is also provided a method of operating a wireless node within a centralised multi-hop wireless network having a base station and number of nodes coupled to the base station, wherein some of the nodes can be coupled to the base station using two or more connection hops to one or more intermediate nodes; the method comprising: monitoring for a newly in-range other node; informing a newly in-range other node of the channel set of the multi-hop branch in response to determining that the other node requires more connection hops to the base station, and using one of the channels in the respective channel set for connecting to the other node, the channel used being dependent on the number of hops the connection is from the base station.

There is also provided a method of operating a wireless node within a centralised multi-hop wireless network having a base station and number of nodes coupled to the base station, wherein some of the nodes can be coupled to the base station using two or more connection hops to one or more intermediate nodes; the method comprising: monitoring for a newly in-range other node; receiving from a newly in-range other node the channel set of the multi-hop branch in response to determining that the other node requires fewer connection hops to the base station, and using one of the channels in the respective channel set for connecting to the other node, the channel used being dependent on the number of hops the connection is from the base station.

The sequences of channels forming the various channel sets to be used by each branch can be generated in many ways as would be appreciated by those skilled in the art. In an embodiment, the channel sets are generated such that the channel assigned to each interface for a respective same hop is different. This may be achieved using a maximum length sequence generator in order to generate a first channel sequence or set, and then shifting the sequence left or right by one position for each additional set required. Unique channels for each hop may be provided in another set generated in a different way, for example manually, with additional sets being generated by shifting the sequence left or right by one position for each extra channel set.

Where more channel sets are required than there are channels available, then the additional channel sets may be arranged in order to minimise the occurrence of the same hop having the same channel on two or more channel sets. In an embodiment this is achieved by using a maximum length sequence generator to generate two or more channel sequences or sets, in order to populate two or more respective groups of channel sets. Each channel set group is then populated by shifting the respective first channel sequence by one position, left or right, for each extra channel set within the group up to a maximum of the number of available channels.

There are also provided a system, network, base station, and node or wireless device having means for implementing the above described methods. These means include but are not limited to processors and memory for executing software instructions corresponding to the method steps.

Brief Description of the Drawings

Embodiments will now be described with reference to the following drawings, by way of example only and without intending to be limiting, in which:

Figure 1 illustrates a multi-hop wireless network;

Figure 2 illustrates two known methods of allocating channels to the network of figure 1;

Figure 3 is a flow chart of a channel allocation method according to an embodiment;

Figure 4 illustrates a network discovery process for the network of figure 1;

Figure 5 illustrates the allocation of multi-hop branches to a network according to an embodiment;

Figure 6 illustrates a multi-hop network with channels allocated according to an embodiment;

Figure 7 illustrates generation of channel sets according to an embodiment;

Figures 8a and 8b show flow charts for operation of a base station and a node respectively in a multi-hop network according to an embodiment; and

Figure 9 shows flow chart for operation of a node when it receives a hello message from other neighbouring node.

Detailed Description

Referring to figure 1, a multi-hop wireless network 100 is shown and comprises a gateway, central node or base station 105 together with a number of wireless devices or nodes 110. The base station 105 has a limited sensing range or coverage area 120 which does not reach all of the nodes 110, and in particular nodes D and E. A series of connections or links 125 connect the nodes 110 to the base station 105 and in some cases to other nodes outside the base stations coverage area 120. Links or connections 125 between the base station 105 and first nodes A, B, C within its coverage area (in direct connection range) are known as first hop connections. Links between these first nodes (A, B, C) and second nodes (D) outside the coverage area 125 are known as second hop links or connections (eg C to D), and more distant links are known as third, fourth etc hop links. For example the link between node D and E is a third hop link, thus two further hops are required from node E to get to the base station 105, a second hop to node C and a first hop from there to the BS 105.

With appropriate hardware and software as would be understood by those skilled in the art, intermediate nodes such as C and D are able to pass packets between links to/from the base station on different hops in order to enable communication between the base station 105 and nodes 110 (D, E) outside its normal coverage area 125. Hence the term multi-hop network. However each node 110 needs to be able to determine which channels to use for which links, and as noted previously this may depend on the hop number of the link.

Figure 2a illustrates a single channel arrangement in which links on all hops share the same channel. A contention protocol such as CDMA/CA is used to allocate channel time amongst the nodes 110. Thus for example focusing on node D, channel 1 is used for both its hop to node C (network's second hop) and its hop to node E (third hop). Whilst this is a simple solution from a channel allocation perspective, it is not efficient and the network performance is downgraded as more nodes 110 are added to the network. This is exacerbated where addition multi-hop nodes are included as this then requires two or more connections to support this node, and therefore the channel requirements are increased to a greater degree.

Figure 2b illustrates a multiple channel arrangement for a multi-hop network in which channels are allocated on a per hop basis. Thus first hop links all use channel 3, second hop links all use channel 1, and third hop links all use channel 11. This reduces the contention load on each channel and reduces the delay between a distant node and the base station; however it does complicate the allocation of channels to each node. For example node D and node E will both need to be tuned to channel 11 in order to exchange packets, whilst node D and node C will both need to be tuned to channel 1. Therefore nodes will typically require two network interface cards or transceivers on different channels in order to support such a multi-hop network. In addition each node must know in advance which channels it must tune to in order to operate correctly within the network. Furthermore each pair of channels used by each node must be non-interfering given the proximity of the two network interfaces. Typically this is achieved by each node scanning the available network channels (eg 1-24) and allocating each a weight depending on the amount of interference detected and/or an estimate of traffic load on each. However nodes may not detect all sources of interference when scanning, especially when bursty traffic is being exchanged between other nodes. This may result in the selection of an unsuitable channel. Furthermore, a node will take sometime for each of its interfaces to scan all the available channels first before it could assign each interface to the suitable channel.

Figure 3 illustrates a method of allocating channels within a multi-hop network according to an embodiment. The method [300] initially performs a discovery procedure in order to determine the network architecture, that is which nodes are capable of being connected to which other nodes. This can be performed using any discovery algorithm known to the skilled person, and typically involves the nodes 110 and base station 105 exchanging "hello" control messages often on a dedicated control channel.

This process is illustrated in figure 4 which shows a network 400 similar to that of figure 1 and various possible or virtual links 430 between different nodes 410. The hello messages 431 typically include a sender's identifier 432 from the node that transmitted it (eg Hello-C) together with the received identifiers 433 of any nodes from which it has received hello messages – thus in the case of the hello message from node C (hello-C) to its neighbouring nodes A, B and D and the base station (BS) it transmits a hello message 431 with the identifiers BS, A B, and D. If the node had just arrived into the network and hadn't yet received any hello messages, then it would simply send its own identifier. Similarly node C receives hello messages from node B which includes the transmission identifier B together with the identifiers of other nodes which node B can "hear" – these include BS, A, and C as shown. Thus node C "knows" that its hello messages have been received by node B and therefore it can form a link with this node if required. Similarly node C can link with the base station and node D.

The hello messages 431 also include a "hops from base station" HBS parameter 434 which indicates how many hops (1-3) from the base station the hello message's transmitting node is. Because nodes A, B, and C are within range of the base station they will receive the base station's hello messages and so can set their "hops from base station" HBS parameter 434 at 1. Node D however will not receive base station hello messages but will receive a hello message from node C with a HBS parameter 434 of 1, node D will therefore be able to allocate itself a HBS parameter of 2 and include this in its hello messages. Similarly node E will have a HBS parameter of 3. Returning to figure 3, the information gathered from by each node's discovery procedure is then forwarded to the base station [310]. The base station uses this data to determine the network's current architecture as is known, and in particular to determine the in-range nodes (A, B, C).

In an alternative embodiment, the base station simply relies on hello messages or other communications received from in-range nodes (A, B, C) in order to determine and identify these in-range nodes. This speeds up allocation of channels as this modified method does not need to wait until the network topology is established – thus step 310 can be omitted. Thus the overhead to establish connections between the nodes is reduced as fewer packets have to be exchanged through the control channel, which is used for both the discovery and the setting up of connections between nodes as described in more detail below.

Each in-range node (A-C), that is each node within direct connection range of the base station is allocated a multi-hop connection branch as illustrated in figure 5. Here nodes A-J are shown notionally allocated to four branches 535. Each node within the base station's wireless range 520 is allocated its own branch – node A: branch 1, node B: branch 2, node C: branch 3, and node J: branch 4. Although branch 4 only has one node (J), this node is still allocated a multi-hop branch as the nodes may move with time and join different branches depending on which in-range nodes they can communicate with.

Referring again to figure 3, each multi-hop branch is allocated a channel set or sequence of channels [320]. A method of generating channel sets is described in more detail below, but each channel set includes a different sequence of channels corresponding to different hops from the base station – thus $S_i = \{C^i_j: j=1,2,3...\}$, where i is the channel set number and j is the hop number. Typically a maximum number of hops will be set j_{max}, so that for example where $j_{max} = 3$, each channel set will include a sequence of three channels – for example S_1={C3,C1,C11}, S_2={C2,C5,C8}, S_3={C9,C2,C7}, and so on for a maximum number of channel sets i_{max}. The channels within the sequence of channels correspond to equivalent hops within a multi-hop connection branch. Thus for example for channel set S_1, the first hop in a branch allocated this sequence of channels or channel set will have a link or connection on channel 3. Similarly, connections on the second hop will be on channel 1, and the third hop connections will be on channel 11.

Generally the same hop within each channel set will be allocated a different channel, such that each link within the same hop of the network will have a different channel. This reduces interference, especially with bursty traffic. Where there are insufficient network channels to ensure this, the occurrence of common channels within the channels ets on the same hop is minimised.

Where there are insufficient numbers of pre-determined channels sets, each branch is allocated a different one, however the channel sets may be re-allocated (eg allocated twice) if there are more branches than channels sets. In this situation the allocation of channels sets is arranged such that the repetition of channel sets is minimised – again this reduces interference and may provide quite acceptable performance especially for bursty traffic.

The channel sets or sequences of channels may be drawn from a predetermined store of these from within the base station, and each such channel set or sequence of channels will be associated with a respective identifier (eg S_1, S_2). Once each multi-hop branch 535 has been allocated a channel set, the identifier associated with the respective channel sets is forwarded to the first node in each multi-hop branch [325]. Each node includes a list of the channel sets together with their corresponding identifier so that it merely needs to receive the channel set identifier in order to tune its respective wireless interfaces. This reduces the signalling overhead required to implement the channel allocation method in this embodiment. In alternative embodiments, the entire channel set may be forwarded to the respective nodes. This avoids the need for the nodes to be pre-programmed with the channels sets.

Once the first node in each branch receives its respective channel set identifier, it forwards this on to the next node in the branch, and so on until all nodes in the branch have received the same channel set identifier. Distributing or informing the nodes of each multi-hop branch of the channel set identifier (or channel set itself in some embodiments) is achieved by forwarding a control message over the control channel from the base station to the first hop node in each branch, then the next hop node, and so on [330]. This control message 550 is illustrated in figure 5, and is passed from node to node down the chain of each multi-hop connection branch 535. The control message typically comprises a channel set number or identifier 554, and a hop number 556. Each node which receives the control message 550 increments the hop number 556 before passing the message to the next node down the chain. Thus each node can determine which hop its links to the other nodes are. For example the link between node A and the base station is hop 1, and the link between node A and node F is hop 2. Node A will receive the control message 550 with hop number 1 from the base station, increment this ($j = 2$), and transmit it to node F on the control channel. Node F will receive the control message from node A and will determine from this that its link to node A must use the second hop channel in the identified channel set for this branch, and the third hop channel in the same channel set for its link to node G. Node F then increments the hop number 556 ($j = 3$) before forwarding this to node G. A similar operation occurs on the nodes of the other multi-hop branches, but the channel set (identifier) will be different in each case.

Once the nodes have received these control messages, they will tune their wireless interfaces to the respective channels notified to them by the channel set identifier and hop number in the control message [335]. A network 600 is illustrated in figure 6 showing the allocated channels 760 used by each node following distribution of the control messages. For example in multi-hop branch 1, node A communicates with the base station (hop 1) on channel 2 (C2) and with node F (hop 2) on channel 1 (C1). Similarly node F communicates with node G (hop 3) on channel 4 (C4). In branch 4, although there is only one node (J) communicating with the base station (hop 1) on channel 5 (C5), further channels (C1, C2) 765 are available for further connections on hops 2 and 3 within this multi-hop branch or chain 735.

This channel assignment or allocation method is easy to set up, has a short multi-hop path set up time, and provides for minimal interference especially when used for bursty traffic as typically encountered in wireless internet access applications. There is no requirement for scanning of all channels by each node as in known arrangements. Furthermore, this method can be easily applied onto existing wireless devices without having to modify the network, MAC or Physical Layer.

As noted previously, the channel sets may be pre-programmed into the base station and the wireless devices or nodes, so that a channel set of sequence of channels identifier may be passed from the base station to the nodes to implement the channel allocation or assignment. Alternatively the entire channel set may be passed to respective nodes via a control channel. In a further alternative, the channel sets may be generated dynamically by the base station following discovery, and then passed to the nodes.

Figure 7 illustrates a standard maximum length sequence generator circuit which will be well known to those skilled in the art, but which in an embodiment can be used for generating channel sets. The or another maximum length sequence generator circuit may be used to provide the pre-programmed channel sets mentioned above, or for generating the sets on-the-fly or dynamically. The state of the shift registers are used to represent different channel numbers. For example a 3-stage shift register with generator polynomial g=[110], with initial state $[111]_2$=[7] can be used to represent channel 7. Table 1 below shows the output sequence for a first polynomial (#1).

K=3 stage shift register output in sequence
Polynomial #1 (n=1) = [1 0 1]

Binary state of shift register	Decimal value = channel number	Shift number, *m*
111	7	0
011	3	1
101	5	2
010	2	3
001	1	4
100	4	5
110	6	6

Table 1

The initial state is chosen from the number of available channels, and then the shift register is shifted by this number of channels (*m*) in order to obtain a full channel sequence. Once this first channel set is obtained, a further m-1 channel sets can be obtained simply by shifting the channel sequence by 1 position each time. For example for a first channel set of a sequence of 7 channels generated using the maximum length sequence generator – 7,3,5,2,1,4,6; the next 6 channel sets can be generated by shifting the channels 1 position to the left each time –second channel set 3,5,2,1,4,6,7; third channel set 5,2,1,4,6,7,3; ad so on. Where the number of channel sets exceeds the number of available channels, a second (or more) polynomial can be used to generate a first channel set of a second group (*n*=2) of channel sets. The same or a different initial channel can be used (eg $[111]_2=7$), however a different sequence of channels will be obtained at the output of the shift register. Table 2 shows a first channel sequence for this second group (*n*=2). The subsequent *m-1* channel sets are then obtained by shifting the channels one position to the left (or right) as before.

K=3 stage shift register output in sequence
Polynomial #2 (n=2) = [0 1 1]

Binary state of shift register	Decimal value = channel number	Shift number, *m*
111	7	0
011	3	1
001	1	2
100	4	3
010	2	4
101	5	5
110	6	6

Table 2

Although there is sometimes an overlap of common channels at the same position within the sequence (eg channel 7 in the first position, channel 3 in the second and channel 6 in the seventh position), for channels delivering bursty traffic, this minimal co-channel overlap is unlikely to be problematic.

A channel set can then be constructed from the sequence of any shift register output with a different initial shift number. For example,

$S_i =$ sequence of channels from *n*-th generator polynomial with initial shift *m*.

where channel set number is given by $i = (n-1)N_p + m$.

Thus, by specifying the channel set number i the channel sequence could be uniquely specified for each channel set for each branch from the base station.

Table 3 shows i=14 channel sets using m=7 available channels and n=2 polynomials.

$$i = (n-1)(2^K) + m$$
$$N_p = 2^K, K = 3$$

n	m	i	S_i
1	0	1	7, 3, 5, 2, 1, 4, 6
1	1	2	3, 5, 2, 1, 4, 6, 7
1	2	3	5, 2, 1, 4, 6, 7, 3
1	3	4	2, 1, 4, 6, 7, 3, 5
1	4	5	1, 4, 6, 7, 3, 5, 2
1	5	6	4, 6, 7, 3, 5, 2, 1
1	6	7	6, 7, 3, 5, 2, 1, 4
2	0	8	7, 3, 1, 4, 2, 5, 6
2	1	9	3, 1, 4, 2, 5, 6, 7
2	2	10	1, 4, 2, 5, 6, 7, 3
2	3	11	4, 2, 5, 6, 7, 3, 1
2	4	12	2, 5, 6, 7, 3, 1, 4
2	5	13	5, 6, 7, 3, 1, 4, 2
2	6	14	6, 7, 3, 1, 4, 2, 5

Table 3

The use of a maximum length sequence generator and subsequent shifting is a simple way to generate unique channel sets that have random and deterministic channel sequences. It also allows the length of the sequences to vary depending on number of available channels within wireless network. However alternative mechanisms for generating unique channel sets could alternatively be used as would now be appreciated by those skilled in the art, including manual determination.

Referring again to figure 6, branch 1 is using channel set S_1, branch 2 is using S_2, branch 3 is using S_3, and branch 4 is using S_4. Each channel set has a sequence of channels. The base station selects the channel sets in order to ensure that the channels allocated for common hops are different in each allocated channel set; or if this is not possible due to a limitation on the number of network channels available, that any repetition of channels within the same hop is minimised across the allocated channel sets. When there are say 20 network channels, then it is possible using the generator mechanism described with respect to figure 7 to generate 20 "uncorrelated" channel sets – that is channel sets which have different channels assigned to respective hops. Any extra channels sets will have the same channel allocated to a particular hop as another channel set. However for bursty traffic in particular, this will typically allow acceptable performance given that the traffic will typically not occur at the same time.

Figures 8a and 8b illustrate flow charts for the separate operation of the base station (105) and a wireless node (110) respectively. The base station method [800] of figure 8a initially participates in the discovery procedure by sending and receiving hello messages as previously described [805]. As noted previously, the base station need not receive discovery results from all the nodes in order to implement the channel assignments for the various branches of the network. The base station then allocates a multi-hop branch or chain to each node within its coverage are or sensing range [810]. This may be determined from the nodes with which it has managed to exchange hello messages. A different channel set is then allocated to each branch [815]. These may be drawn from a number of predetermined or pre-programmed channel sets, or the sets may be generated by the base station, for example using the arrangement of figure 7. The channel sets are allocated such that no two links between nodes on the same hop will have the same channel number in order to minimise interference over the network. Thus a unique channel set is allocated to each branch. However this may be replicated where there are many branches and not enough unique channel sets. Finally, the base station forwards control messages to each node within range together with its allocated channel set identifier [820]. In some cases the actual channel set may be sent. A hop number is included in the control message, and is initially set to 1 for each message/branch.

The node method [850] of figure 8b may initially participate in the discovery process by exchanging hello messages with other nodes and if in range with the base station. The node then sends it discovery results to the base station. As noted above however, this discovery phase is not required in all embodiments. The node receives a control message from the base station, possibly via other nodes [855]. The control message includes a channel set identifier for the node to use, together with a hop number. The node then sets or tunes its link with the preceding node (from which it has received the control message) to the channel in the identified channel set with the same hop number as that received [860]. The node then sets or tunes its link with the next node (to which it will forward the control message) to the channel in the identified channel set with the next hop number. Thus for example for a channel set of {3,6,1,8} and a received hop number of 2, the node will set its link with the previous node to channel 6, and its link with the next node to channel 1. The node then increments the hop number in the control message (to 3 say), and forwards the control message to the next node (if any) within the branch [865].

Referring again to figure 6, following the initial set-up of channels for the various hops within the multi-hop connection branches, the nodes (A-J) may move around and therefore may be required to form new connections. For example where node G moves out of range of node F and within range of node J, it will need to form a new connection with node J in order to communicate with the base station (BS). Nodes G and J will initially perform a discovery phase by exchanging hello messages as previously described. Following this, node J is configured to forward the channel set for the branch (branch 4) which node G has just joined. Node J will also forward the hop parameter (2 in this case) to node G, so that node G will be able to tune one of its wireless or network interfaces to the second hop channel (C2) within the channel set in order to form a connection with node J. Similarly, should a further node (eg node I) come within range of node G, node G will forward it the channel set for branch 4 together with its hop parameter (3) so that node I can tune to channel C1 in order to communicate with node G.

This method is illustrated in more detail in figure 9. The method [900] operates on each node and monitors for hello messages (431) from nodes it hasn't previously received such messages from [905]. Thus for example node J might receive a hello message from node G (Hello-G:3) without an entry corresponding to itself (J) as described with respect to figure 4. Similarly node G might receive a new hello message from node J without any record in that message from node J previously having received a corresponding message from node G. If it is determined that a hello message from a new node and been received [905Y], then the method [900] check the HBS parameter 434 associated with the sending node or wireless device [910]. As described previously with respect to figure 4, the HBS (434) or number of hops from the base station parameter is a parameter that can be allocated to each node depending on how many intermediate nodes are required for it to connect with the base station. In the example, node J will have an HBS of 1, and node G will have an HBS of 3 based on its previous connection with node F.

If the HBS parameter of the new node is higher than the HBS parameter of the node implementing the method [910Y], then the node sends the new node the channel set identifier for the multi-hop connection branch it is currently in, together with an incremented hop parameter [915], as previously described with respect to figure 5 and control message 550. The method then returns to monitor for new hello messages [905]. In the example, this would be the course of action for node J which has the lower HBS parameter and is closer to the base station than node G.

If however the HBS parameter of the new node is lower than that of the current node [910N], then the method awaits receipt of a channel set identifier and hop parameter from the other/new node [920]. The method then sets one of the node's network or wireless interface cards to the channel within the channel set corresponding to the hop parameter [925]. This enables the current node to communicate with the other node which will already be tuned to this channel. The current node can also tune another interface to the channel in the channel set corresponding to the incremented hop parameter. The method then returns to monitor for new hello messages [905]. In the example, this would be the course of action for node G which has the higher HBS parameter and is closer to the base station than node J.

In cases where the HBS parameters are equal [910 equal], no action is taken and the method returns to monitoring for new hello messages [905].

As with previous embodiments, instead of a channel set identifier coupled with pre-programmed channel sets, the channel sets themselves may be exchanged without the need for storage of the channel sets within each node.

The skilled person will recognise that the above-described apparatus and methods may be embodied as processor control code, for example on a carrier medium such as a disk, CD- or DVD-ROM, programmed memory such as read only memory (Firmware), or on a data carrier such as an optical or electrical signal carrier. For many applications embodiments of the invention will be implemented on a DSP (Digital Signal Processor), ASIC (Application Specific Integrated Circuit) or FPGA (Field Programmable Gate Array). Thus the code may comprise conventional programme code or microcode or, for example code for setting up or controlling an ASIC or FPGA. The code may also comprise code for dynamically configuring re-configurable apparatus such as re-programmable logic gate arrays. Similarly the code may comprise code for a hardware description language such as Verilog ™ or VHDL (Very high speed integrated circuit Hardware Description Language). As the skilled person will appreciate, the code may be distributed between a plurality of coupled components in communication with one another. Where appropriate, the embodiments may also be implemented using code running on a field-(re)programmable analogue array or similar device in order to configure analogue hardware.

The skilled person will also appreciate that the various embodiments and specific features described with respect to them could be freely combined with the other embodiments or their specifically described features in general accordance with the above teaching. The skilled person will also recognise that various alterations and modifications can be made to specific examples described without departing from the scope of the appended claims.

CLAIMS

1. A method of assigning channels within a centralised multi-hop wireless network having a base station and number of nodes coupled to the base station, wherein some of the nodes can be coupled to the base station using two or more connection hops to one or more intermediate nodes; the method comprising:

allocating a multi-hop connection branch to each node within direct connection range of the base station, each multi-hop connection branch capable of supporting connections to nodes beyond the direct connection range of the base station;

allocating a channel set to each multi-hop connection branch, each channel set comprising a sequence of channels corresponding to a sequence of connection hops within the multi-hop connection branches;

informing the nodes of each multi-hop connection branch of their respective allocated channel set;

each node within each multi-hop connection branch using one of the channels in the respective channel set for connecting to another node, the channel used being dependent on the number of hops the connection is from the base station.

2. A method according to claim 1, wherein each channel set comprises different channels allocated to respective hops.

3. A method according to claim 1 or 2, wherein informing the nodes of their respective channel sets comprises sending a respective channel set identifier to the first node in each multi-hop branch of nodes, and each node in each multi-hop branch forwarding the respective channel set identifier to the next node within the respective multi-hop branch.

4. A method according to claim 3, wherein each node stores a number of channel sets and corresponding channel set identifiers, and uses the received channel set identifier

to assign the channel for a connection with a previous node and/or a next node in the multi-hop branch.

5. A method according to claim 3 or 4, wherein each node within a multi-hop branch receives, increments then forwards a hop parameter together with the channel set identifier.

6. A method according to claim 1 or 2,. wherein informing the nodes of their respective channel sets comprises sending a respective channel set to the first node in each multi-hop branch of nodes, and each node in each multi-hop branch forwarding the respective channel set to the next node within the respective multi-hop branch.

7. A method according to any one preceding claim, wherein the channels for each channel set are generated using a maximum length sequence generator.

8. A method according to any one preceding claim, further comprising using a discovery procedure to determine only the connections between the base station and nodes within direct connection range of the base station prior to allocating the multi-hop branches.

9. A method according to any one preceding claim, wherein the connections between nodes are used for bursty traffic.

10. A method according to any one preceding claim, further comprising a said node within a said multi-hop connection branch informing a newly in-range other node of the channel set allocated to said multi-hop connection branch in response to determining that the other node requires more connection hops to the base station, and using one of the channels in the respective channel set for connecting to the other node, the channel used being dependent on the number of hops the connection is from the base station.

11. A method of operating a base station within a centralised multi-hop wireless network having a number of nodes coupled to the base station, wherein some of the nodes can be coupled to the base station using two or more connection hops to one or more intermediate nodes; the method comprising:

allocating a multi-hop connection branch to each node within direct connection range of the base station, each multi-hop connection branch capable of supporting connections to nodes beyond the direct connection range of the base station;

allocating a channel set to each multi-hop connection branch, each channel set comprising a sequence of channels corresponding to a sequence of connection hops within the multi-hop connection branches;

informing the nodes within direct connection range of each multi-hop connection branch of their respective allocated channel set.

12. A method of operating a wireless node within a centralised multi-hop wireless network having a base station and number of nodes coupled to the base station, wherein some of the nodes can be coupled to the base station using two or more connection hops to one or more intermediate nodes; the method comprising:

determining a channel set comprising a sequence of channels corresponding to a sequence of connections within a multi-hop connection branch from the base station;

determining the number of connection hops within the multi-hop branch to the base station;

using the determined channel set and the number of hops in order to assign one of the channels within the channel set to form a connection to another node.

13. A carrier medium for carrying processor code which when executed on a processor causes the processor to carry out the method according to any one preceding claim.

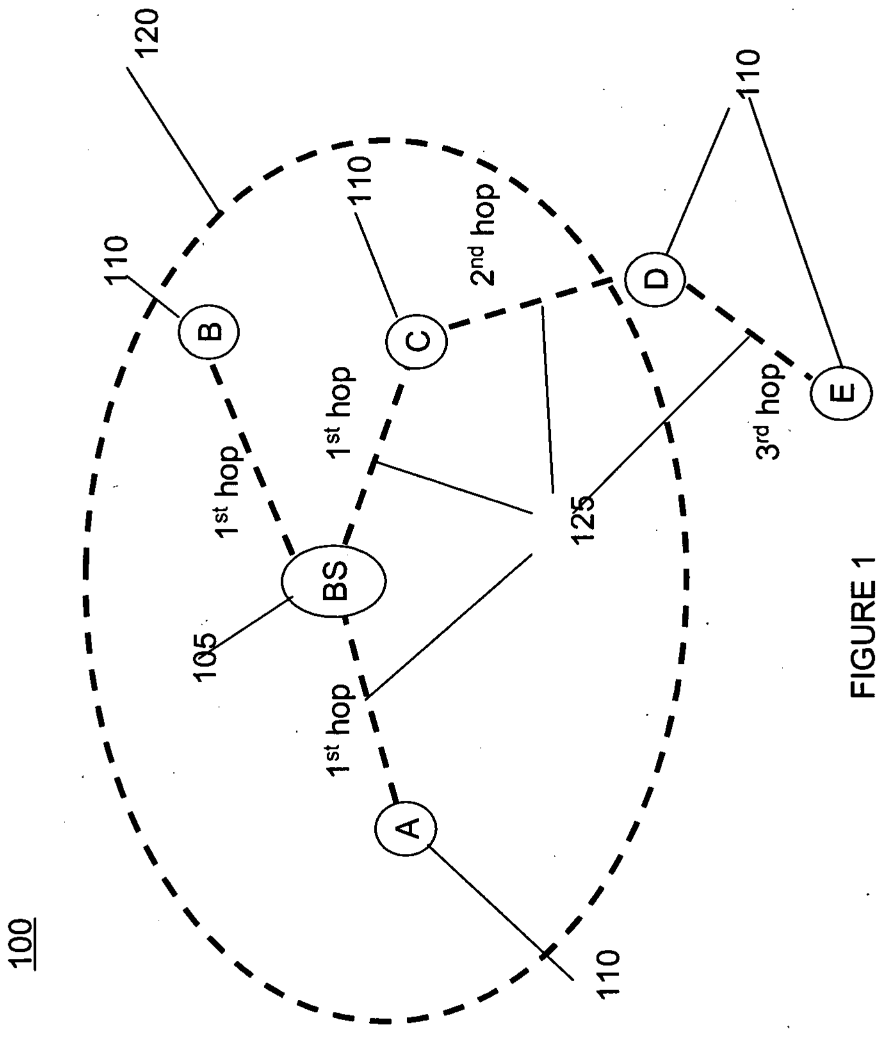
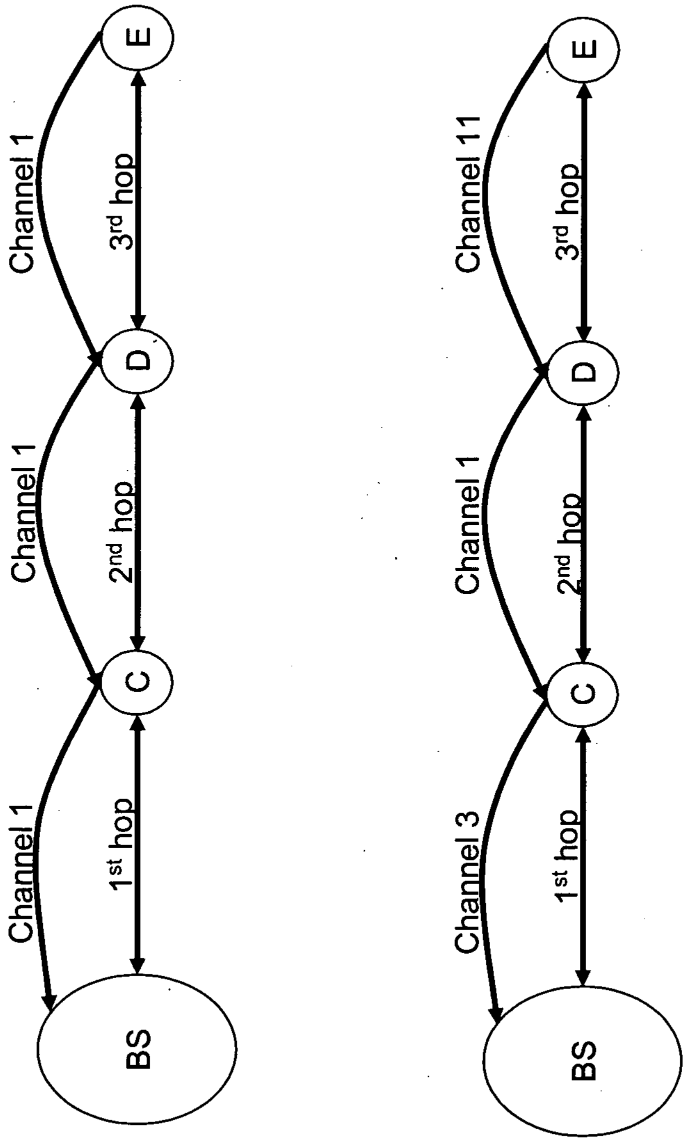

100
120
110
110
110
110
110
B
C
D
E
A
BS
105
1st hop
1st hop
1st hop
2nd hop
3rd hop
125

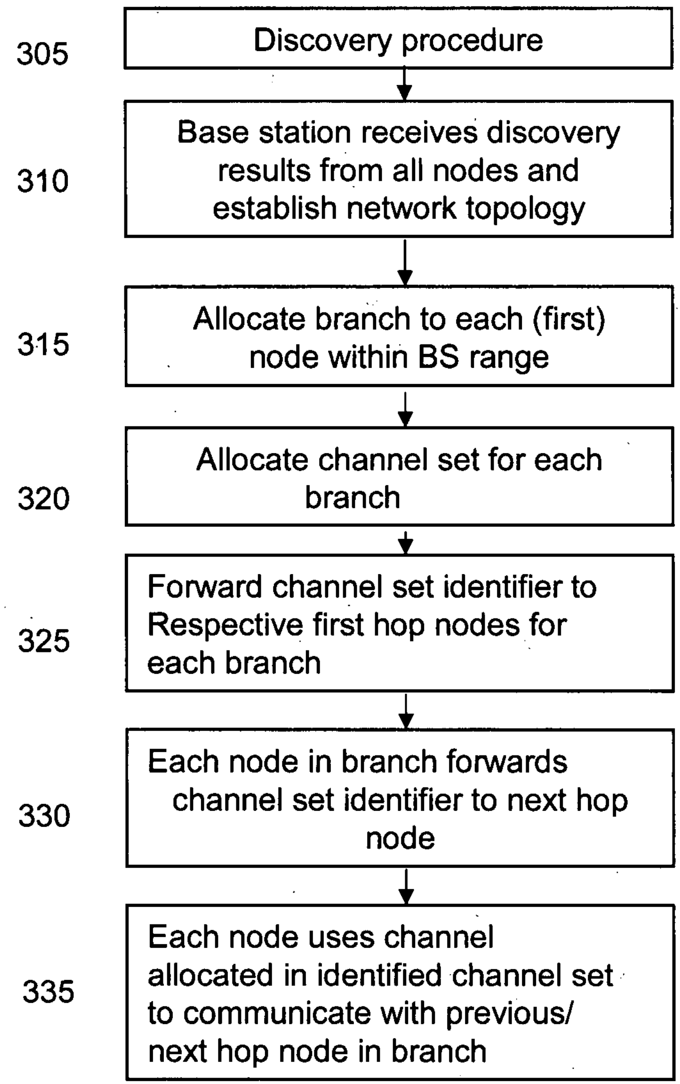
FIGURE 1



E
D
C
BS
Channel 1
Channel 1
Channel 1
3rd hop
2nd hop
1st hop
E
D
C
BS
Channel 11
Channel 1
Channel 3
3rd hop
2nd hop
1st hop

FIG 2B

300



305
Discovery procedure
310
Base station receives discovery results from all nodes and establish network topology
315
Allocate branch to each (first) node within BS range
320
Allocate channel set for each branch
325
Forward channel set identifier to Respective first hop nodes for each branch
330
Each node in branch forwards channel set identifier to next hop node
335
Each node uses channel allocated in identified channel set to communicate with previous/ next hop node in branch

FIG 3

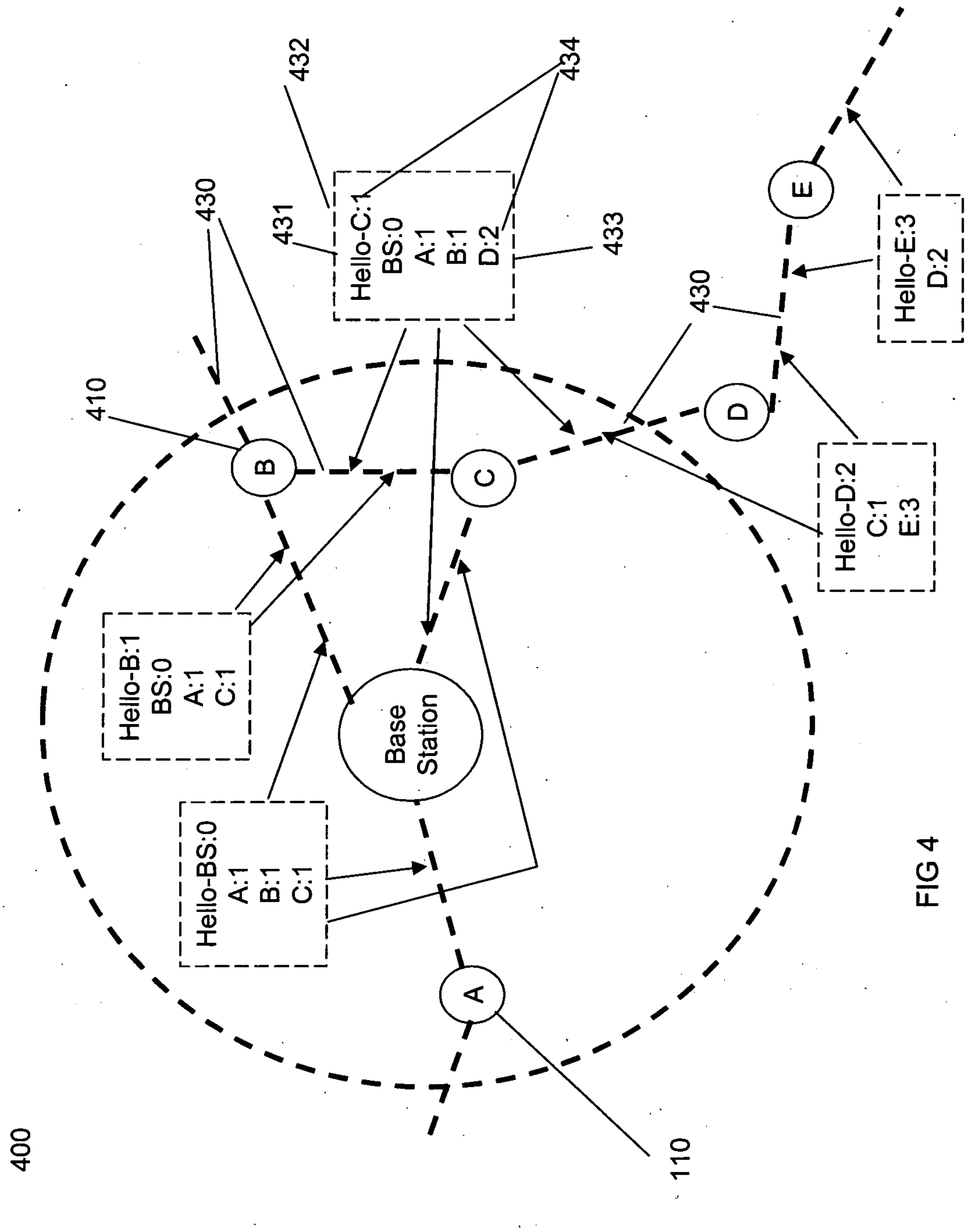

400
110
410
430
431
432
433
434
Hello-C:1
BS:0
A:1
B:1
D:2
Hello-B:1
BS:0
A:1
C:1
Hello-BS:0
A:1
B:1
C:1
Hello-D:2
C:1
E:3
Hello-E:3
D:2
Base Station
A
B
C
D
E

FIG 4

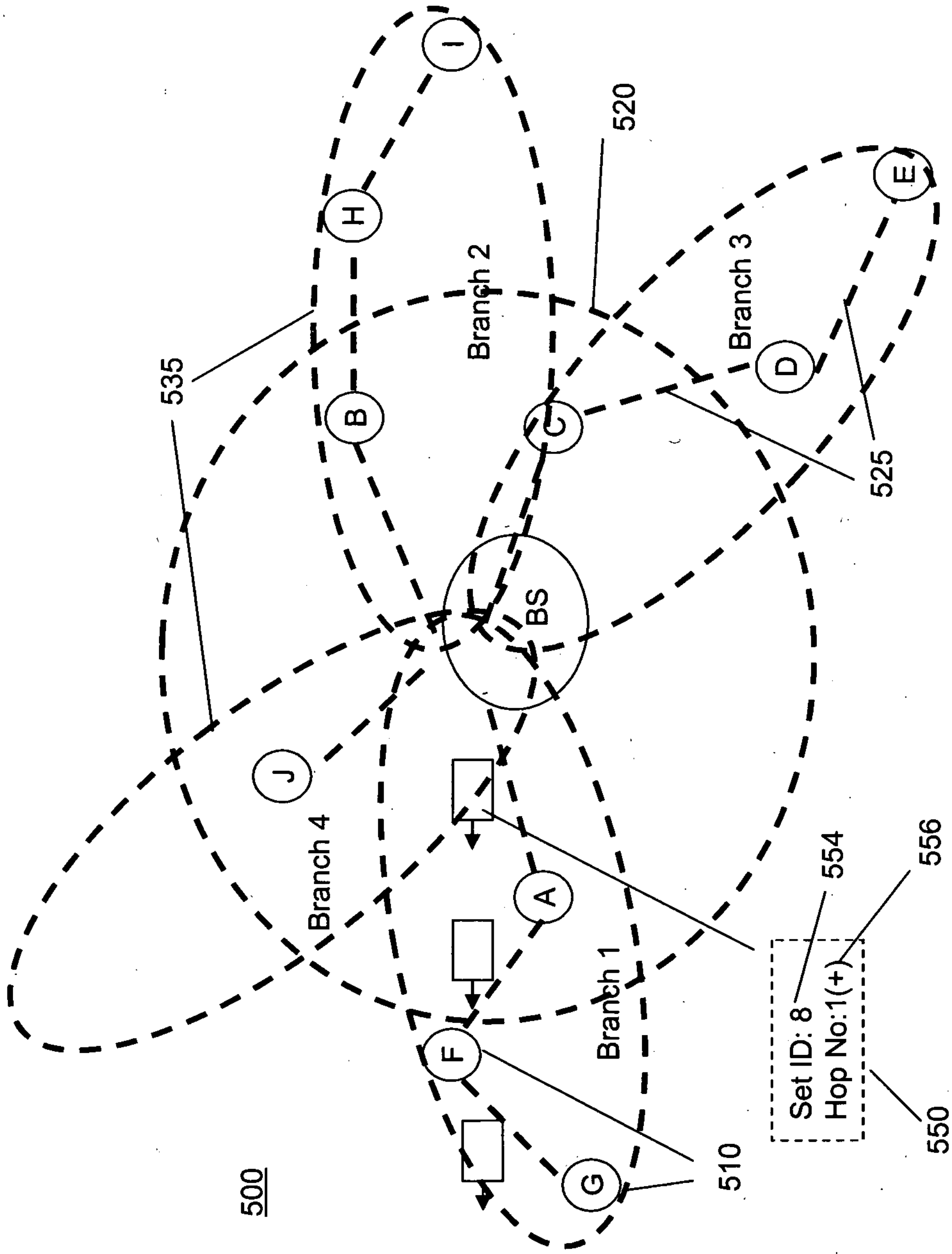

500
510
520
525
535
550
554
556
Set ID: 8
Hop No:1(+)
BS
A
B
C
D
E
F
G
H
I
J
Branch 1
Branch 2
Branch 3
Branch 4

FIG 5

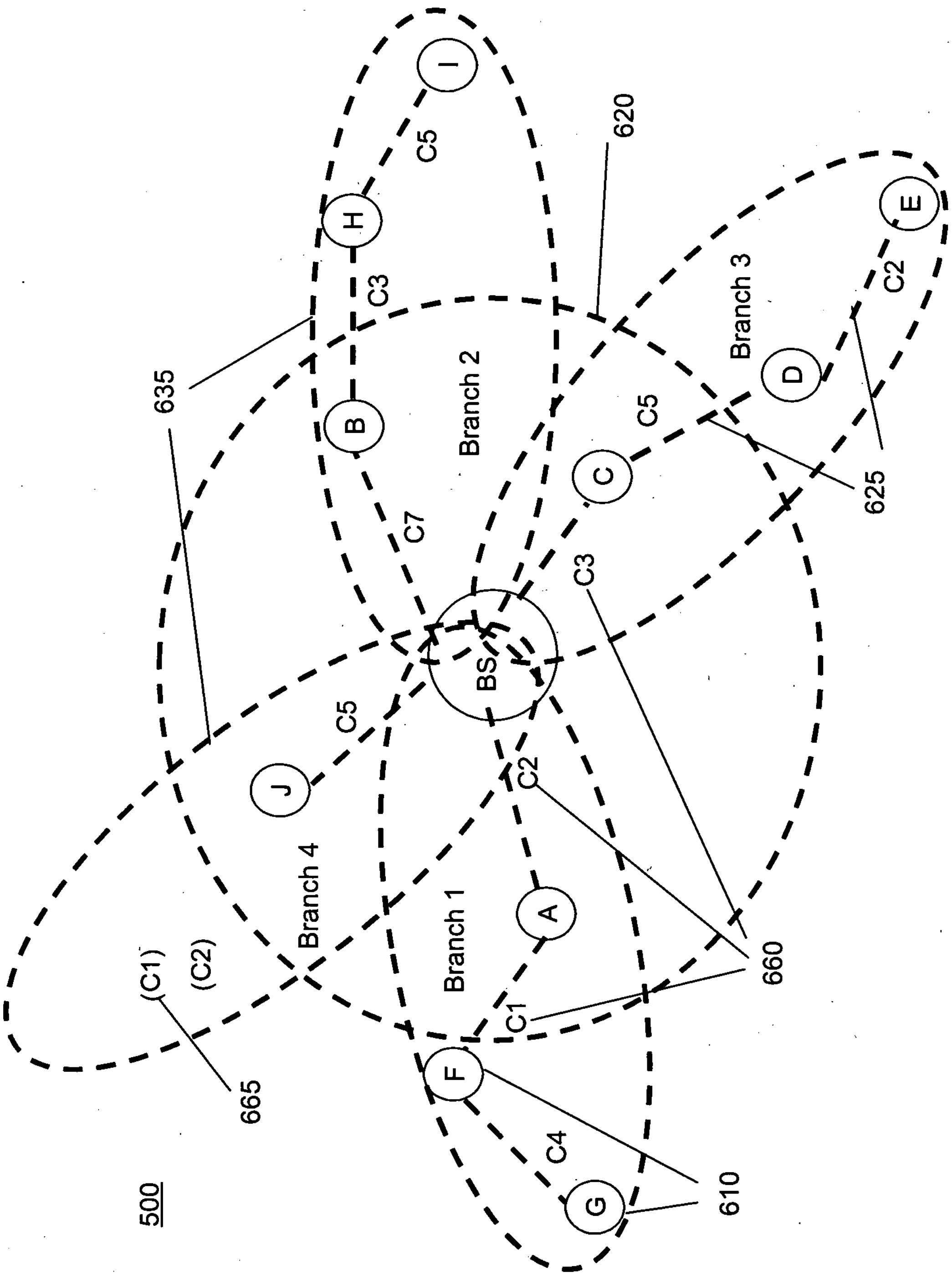

500
BS
A
B
C
D
E
F
G
H
I
J
Branch 1
Branch 2
Branch 3
Branch 4
C1
C2
C3
C4
C5
C7
(C1)
(C2)
610
620
625
635
660
665

FIG 6

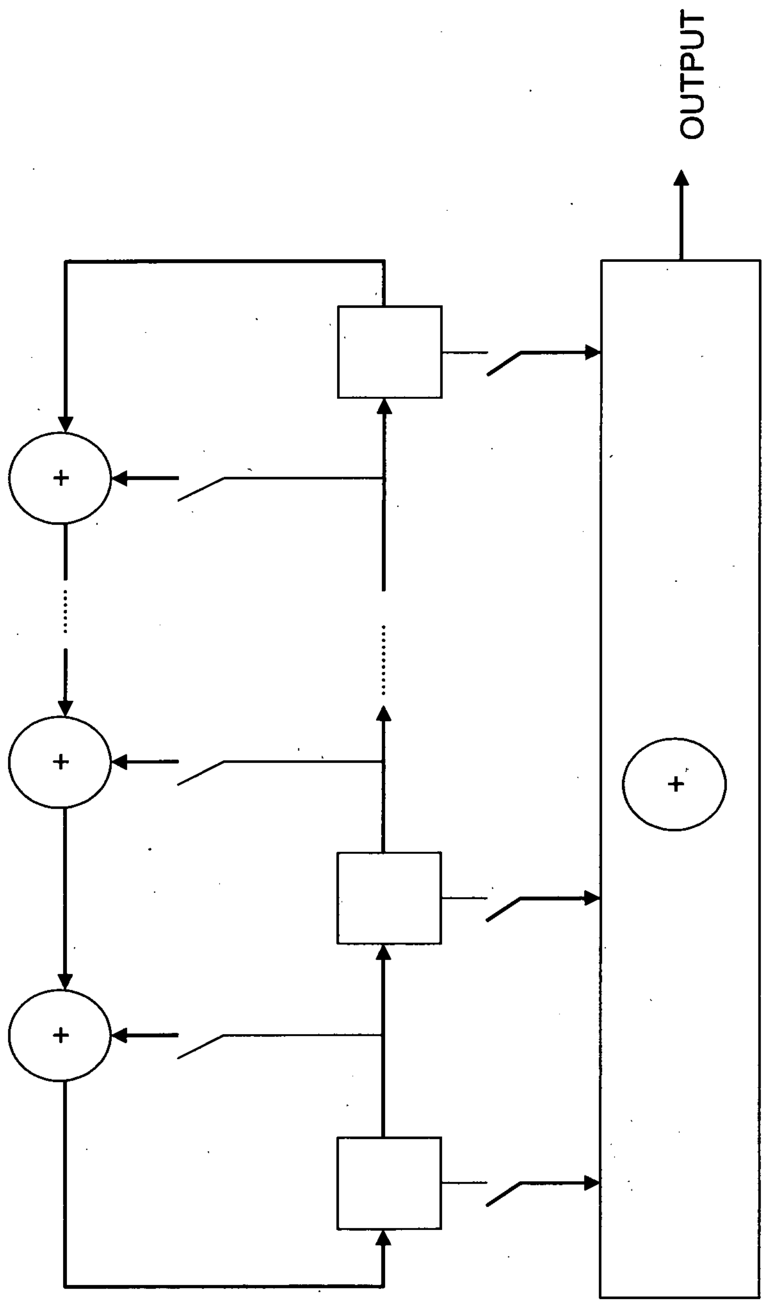


FIG 7

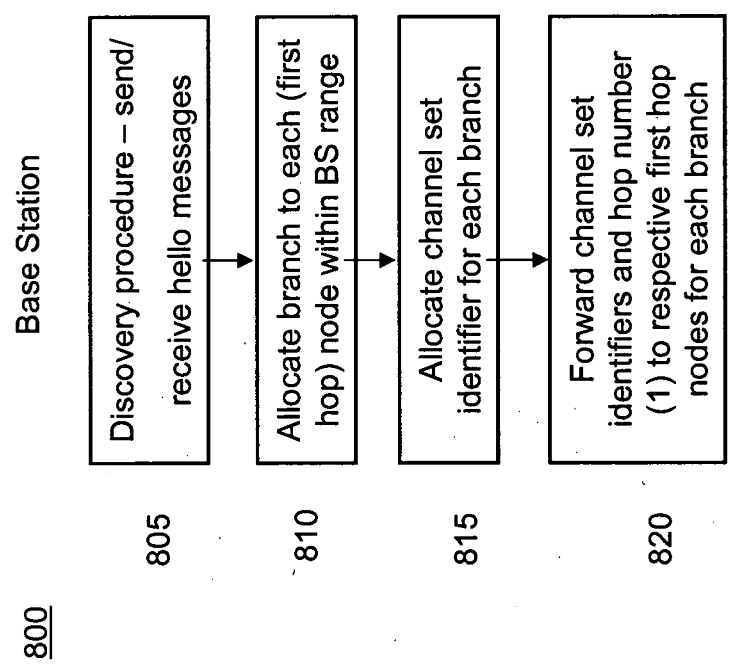

800
Base Station
805
Discovery procedure – send/ receive hello messages
810
Allocate branch to each (first hop) node within BS range
815
Allocate channel set identifier for each branch
820
Forward channel set identifiers and hop number (1) to respective first hop nodes for each branch

FIG 8A

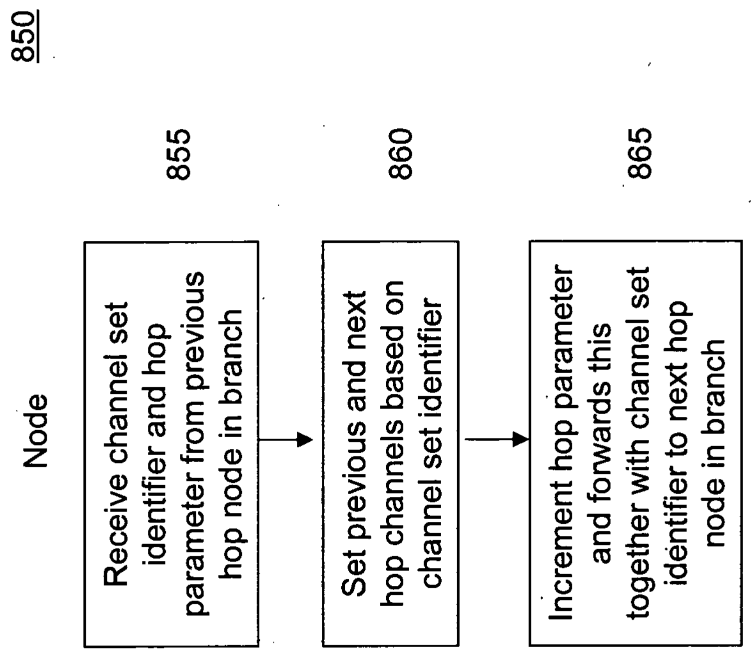

850
Node
855
Receive channel set identifier and hop parameter from previous hop node in branch
860
Set previous and next hop channels based on channel set identifier
865
Increment hop parameter and forwards this together with channel set identifier to next hop node in branch

FIG 8B

900

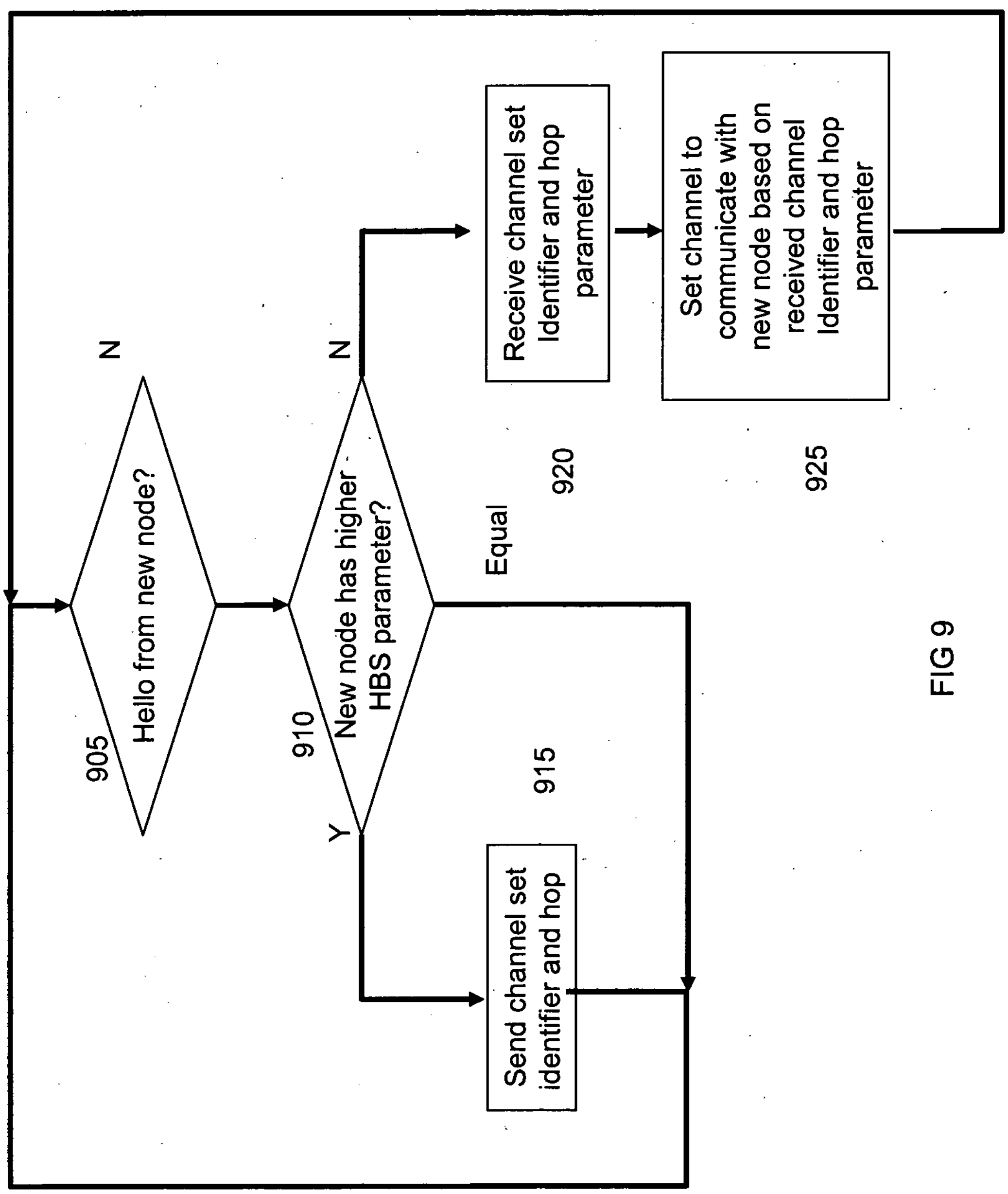

905
Hello from new node?
N
910
New node has higher HBS parameter?
N
Y
Equal
Receive channel set Identifier and hop parameter
920
Set channel to communicate with new node based on received channel Identifier and hop parameter
925
Send channel set identifier and hop
915

FIG 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2007/002906

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L12/56

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)
H04L

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

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

EPO-Internal, WPI Data, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/152291 A1 (AL-HARTHI SALEH [SA]) 14 July 2005 (2005-07-14) paragraphs [0012], [0014], [0016], [0019], [0021], [0022], [0024], [0030], [0036], [0039] figures 1-5	1-13
X	WO 2005/125108 A (AQUALIV AB [SE]; SEDELIUS HOERBERG JOHAN [SE]; JONSSON DENNIS [SE]; EH) 29 December 2005 (2005-12-29) page 5, line 28 - page 8, line 10 figures 1,2	1-13

-/--

[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 document but published on or after the international filing date

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 November 2007	21/11/2007

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

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

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2007/002906

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/058816 A1 (SHEARER DANIEL D M [US]) 27 March 2003 (2003-03-27) cited in the application paragraphs [0044] - [0046] paragraphs [0048] - [0053] paragraphs [0062] - [0067] paragraphs [0082], [0083] paragraphs [0092] - [0094] figures 1-3 -----	1-13

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2007/002906

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2005152291	A1	14-07-2005	NONE			
WO 2005125108	A	29-12-2005	AU	2005255856	A1	29-12-2005
			CA	2570891	A1	29-12-2005
			CA	2570923	A1	29-12-2005
			CA	2571146	A1	29-12-2005
			EP	1766892	A1	28-03-2007
			EP	1766594	A2	28-03-2007
			EP	1766872	A1	28-03-2007
			WO	2005125127	A1	29-12-2005
			WO	2005122710	A2	29-12-2005
US 2003058816	A1	27-03-2003	NONE			