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(54) **Title:** METHOD AND APPARATUS FOR DETERMINING NETWORK CLUSTERS FOR WIRELESS BACKHAUL NETWORKS

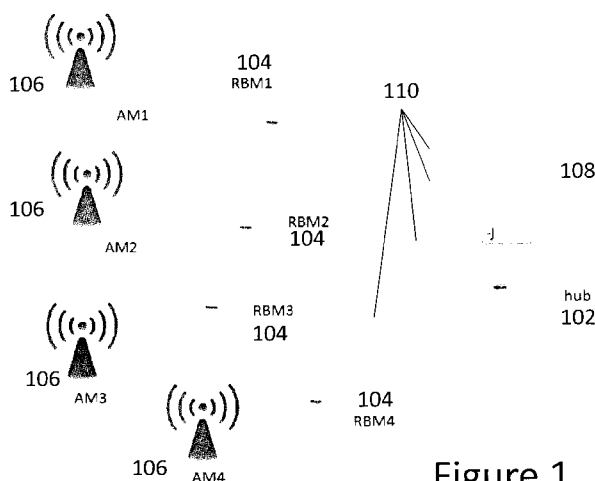


Figure 1

(57) **Abstract:** Practical methods and apparatuses are provided for determining network clusters in wireless backhaul networks comprising a plurality of hubs (102) and Remote Backhaul Modules (RBM) (104) based on link quality value (LQV) metrics. From an input LQV table of LQV values for each hub-RBM link (110), the link quality values are first ranked. Clusters are then identified from all the possible links based on the order of the highest link quality value to the lowest link quality value, any constraints on the number of RBMs per cluster, and clustering each RBM only once. Links with strong link quality values are chosen to optimize the LQV metric. LQV based clustering achieves a higher average LQV, e.g., average spectrum efficiency or weighted sum spectrum efficiency, for the entire backhaul network compared to the geographic location based clustering. The method is straightforward to implement and has low computational complexity.

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METHOD AND APPARATUS FOR DETERMINING NETWORK CLUSTERS FOR WIRELESS BACKHAUL NETWORKS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from United States Provisional patent application serial No. 61/503,336, filed June 30, 2011, entitled “Method and Apparatus for Determining Network Clusters for Wireless Backhaul Networks”, which is incorporated herein by reference in its entirety.

[0002] This application is related to International Patent Application No. PCT/CA2011/001020

and to United States Patent application No. 13/230,368, both of which were filed September 12, 2011, entitled “System and Method for Co-Channel Interference Measurement And Managed Adaptive Resource Allocation for Wireless Backhaul”, claiming priority from United States Provisional patent application No. 61/382,217, filed September 13, 2010; this application is also related to United State Patent application No. 13/463,478, entitled “Interference Mitigation with Scheduling and Dynamic Power Spectrum Allocation for Wireless Networks”, filed May 3, 2012 claiming priority from United States Provisional patent applications No. 61/483,417, filed May 6, 2011 and No. 61/506,895, filed 12 July 2011; all these applications are incorporated herein by reference in their entirety.

TECHNICAL FIELD

[0003] This invention relates to wireless systems with point-to-multipoint transmissions. It is particularly related to wireless backhaul networks, and methods and apparatus for resource allocation in such networks, for improved performance and data rate.

BACKGROUND

[0004] Wireless backhaul networks are deployed to carry the traffic between a wireless access network and the core network. For example, as described in the above referenced related co-pending applications, a wireless backhaul network may comprise a plurality of hubs, each connected to the wired core network, via Ethernet. Each hub serves multiple remote backhaul modules (RBM), in a point to multipoint configuration, using a wireless channel. Each RBM is deployed close to an access network base station, such as a small cell

base station, and connected to the base station via a cable. The hubs are deployed at the locations where wired high capacity access to the core network is available, e.g. at a fiber point-of-presence.

[0005] In a wireless backhaul network, the term cluster refers to a number of RBMs and their respective serving hub. Methods and apparatus are required for determining which RBMs are served by each hub, i.e. for determining network clustering, to optimize or improve network performance. In particular, for non line-of-sight (NLOS) wireless backhaul networks it is desirable to have systems and methods for network clustering that overcome the limitations of conventional geographic location based network clustering.

[0006] Wireless backhaul networks can have different carrier frequency reuse factors. Interference is generated when multiple transmitters use the same carrier frequency. The data rate of any wireless link between a transmitter and a receiver, i.e. a hub-RBM link, in the network is directly related to the signal to interference and noise power ratio (SINR) in the system. It is desirable to have a clustering strategy that can utilize the SINR information to determine the clustering outcomes and thus to improve the average network data rate.

[0007] Hubs and RBMs are deployed at fixed locations, and hubs are located at elevated locations with sufficient height above obstacles or other environmental clutter. For example, in an urban area, hubs may be positioned on a tall building or a rooftop, above the clutter. Each RBMs is typically co-located with an access network base station, e.g. for a small cell base station, on a utility pole, sidewall of a building or other location below the roofline. Thus, typically there is not a direct line of sight between an RBM and a hub.

[0008] Based on empirical measurements, wireless channels of the backhaul network have relatively longer coherence time than those of the access network. The strongest one or two electromagnetic propagation paths between a hub and a RBM remain stationary because the environment at a sufficient height above the ground typically changes very little over time. That is, the wireless channel between any hub and RBM changes only when the environment changes significantly, such as when there is new construction, or a change of season in an area with trees. This fact motivates the use of directional antennas with fixed beam patterns for both hubs and RBMs in the backhaul network. Use of directional beam-forming antennas would be a promising enhancement to the performance for the backhaul system. In this application, the focus is on fixed beam patterns for both hubs and RBMs.

[0009] For point to multipoint coverage, any hub antenna may cover multiple RBM locations. A fixed hub pattern is used to cover a particular angle range. For example, similar

to the access network, a cell, which defines the 360 degree coverage of the neighborhood around the center, can be divided into three 120 degree equally spaced sectors. In such an arrangement, each hub is deployed to cover one 120 degree sector with a fixed antenna pattern and three hub modules are co-located at the center of the cell.

[0010] An RBM antenna in the backhaul network needs to have a narrow beam width and steer its main lobe to the strongest angle of departure (AoD) direction between the hub and the RBM. Due to the narrow beam width of the RBM antenna and sufficient height of hub and RBM antennas, the power delay profile of the multi-path channel between the hub and the RBM confines most of the power in the first tap. This is different from wireless access networks where the height of mobile user antennas is low and omni-directional antennas are used for the mobile users. The frequency response of the channel in the backhaul network may have much less variability than that in the access network. The entire bandwidth may be divided into a number of frequency bins and be accessed by different hub-RBM links on a per-bin basis. The frequency domain modulation scheme can be either orthogonal frequency division multiple access (OFDMA), frequency division multiple access (FDMA) or single carrier modulation (if the number of bins is one). Based on the property of the power delay profile of the channel, the average channel gain in a pre-defined frequency bin in the frequency domain is a good representation of the channel response in this bin. The above referenced US patent application No. 13/230,368, for example, discloses methods for managing resource allocation using clustering or grouping of links, based on co-channel interference metrics obtained from measurements of relative path loss or signal strength for each link.

[0011] Conventionally, in network planning, geographic location based clustering is used for wireless network clustering, i.e. using an algorithm based on the geographic position, or location index, of each transmitter and receiver module. However, such an approach may not be optimum for NLOS wireless backhaul links and is computationally complex.

[0012] For NLOS links having a similar hub-RBM separation distance, the effects of environmental clutter such as buildings or trees, referred to as shadow fading or log normal shadowing, may be quite different, and significantly affect relative path loss and signal strength. Geographic location based clustering does not account for these factors or e.g. use SINR information to improve network performance. Consequently, improved or alternative methods for network clustering are required for NLOS wireless backhaul networks.

[0013] An object of the present invention is to provide improved or alternative methods and apparatus for determining network clustering, for improved network performance in point-to-multipoint wireless networks and particularly for wireless backhaul solutions comprising fixed or stationary nodes with directional antennas, including small cell NLOS backhaul networks.

SUMMARY OF INVENTION

[0014] The present invention seeks to eliminate, or at least mitigate, disadvantages of known methods and apparatus, or at least provide an alternative.

[0015] The present invention provides methods and apparatus for clustering links in a wireless backhaul network based on link quality metrics for each hub-RBM link, referred to as "link quality based clustering". In a network comprising a plurality of hub-RBM links, network clustering comprises determining which Remote Backhaul Modules (RBMs) are served by a hub, to allow scheduling of resources based on said clustering of links to provide an increased network performance, for example an increased average link quality value.

[0016] According to one aspect of the invention, there is provided a method for determining network clusters in a wireless backhaul network comprising a plurality of hubs and a plurality of Remote Backhaul Modules (RBM), comprising: for each of a plurality of hub-RBM links, obtaining an input link quality value; ranking said input link quality values; and from the highest to lowest link quality values, satisfying constraints with respect to a maximum number of RBM per hub, and clustering each RBM only once, identifying each hub-RBM cluster from the ranked LQV values.

[0017] Preferably in embodiments of the present invention, the LQV is a weighted LQV, wherein weights comprise the weighted data rate of each link.

[0018] In preferred embodiments, the method comprises:

- i. ranking link quality values of hub-RBM links for each of a plurality of candidate hub-RBM links, i.e. for multiple candidate RBM locations, and choosing the maximum value(s) of these link quality values to obtain an input link quality table; and
- ii. reshaping the link quality table into a vector in a column-wise order and ranking link quality values of the link quality tables, and then

- iii. from the highest to the lowest link quality links, identifying each hub-RBM cluster by excluding each RBM from being clustered more than once and by satisfying a maximum number of RBM per cluster constraint.

[0019] The link quality table vector comprises two dimensions corresponding to the hub index (hub ID) and the RBM index (RBM ID) wherein: for the t^{th} position in the reordered LQV vector, the RBM ID and hub ID are computed as

$$RBM\ ID(t) = mod\left(\frac{\pi^{-1}(t) - 1}{NM}\right) + 1$$

$$hub\ ID(t) = floor\left(\frac{\pi^{-1}(t) - 1}{NM}\right) + 1.$$

[0020] The step of ranking link quality values of hub-RBM links may comprises ranking link quality values of multiple candidate site locations for each RBM, and providing a link quality table vector that comprises three dimensions, corresponding to the hub index, RBM index and location index.

[0021] The step of obtaining or determining the link quality values for each hub-RBM link may comprises any one of:

- a) obtaining a data rate of each link; or
- b) obtaining a weighted data rate of each link wherein weights are assigned based on traffic conditions of the links; or
- c) obtaining a SINR value of each link; or
- d) obtaining an average SINR across frequency bins of each link; or
- e) obtaining an average channel gain across frequency bins of each link; or
- f) obtaining the inverse of the distance of each link.

[0022] Obtaining the link quality values may comprise measuring said link quality values for each of the plurality of hub-RBM links, for example measuring a SINR value for each link, or computing link quality values for each of a plurality of hub-RBM links from network parameters.

[0023] Where it is not feasible to measure SINR values, for example, these may be approximated as the SINR values for each bin using:

$$SINR_{ij} = \frac{G_{ij}[j \rightarrow i]g_{ij}P}{N_{ij} + \sum_{l \neq i} G_{lj}[j \rightarrow i]g_{lj}P}.$$

where the path loss and shadowing gain between hub i and RBM j in a linear scale is

denoted by g_{ij} ; the noise power is denoted by N_{ij} ; the combined transmit and receive antenna gain is denoted by $G_{ij}[j \rightarrow i]$ assuming the mainlobe of the RBM j 's antenna is steered towards hub i .; and the transmit power of all hubs is denoted by P .

[0024] Thus a method and apparatus are provided for determining which RBMs are served by each hub in a wireless backhaul network. In particular, when LQV is defined as the SINR value of each link, methods according to embodiments of the invention use SINR information for determining the clustering outcomes and thus improve the average network data rate. Based on simulations, the method is demonstrated to provide improved performance relative to conventional geographic location based clustering.

[0025] Also provided is a metric that defines LQV as the weighted data rate of each link where weights can be assigned based on traffic conditions of the links; the data rate of each link; the average SINR across frequency bins of each link; the average channel gains across frequency bins of each link; or the inverse of the distance of each link.

[0026] For example, a weight based on data traffic condition of each hub and RBM link is assigned. When LQV is defined as the weighted data rate of each hub and RBM link, the proposed clustering strategy can achieve good quality of service across the backhaul network. When LQV is defined as the data rate of each link, the clustering strategy simply maximizes the average data rate of the network.

[0027] Another aspect of the invention provides apparatus in a wireless backhaul network comprising a processor and instructions, e.g. in a control node, for implementing the method steps of any one of the method claims.

[0028] Yet another aspect of the invention provides a computer readable medium storing instructions which when executed in a processor perform the method steps of any one of the method claims.

[0029] Additionally, there is provided a method for managing resource allocation for a plurality of radio links in a wireless network, comprising: clustering of links based on a link quality value (LQV) of each link, and scheduling resources to links based on said clustering of links to provide an increased average link quality value of the network.

[0030] Thus, methods, apparatus and metrics according to aspects of the present invention makes use of the link quality value (LQV) information, and advantageously a weighted LQV, of the hub-RBM links for determining clustering for improved network performance.

[0031] The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description, taken in conjunction with the accompanying drawings, of preferred embodiments of the invention, which description is by way of example only.

BRIEF DESCRIPTION OF DRAWINGS

[0032] FIG. 1 shows an example of a cluster model for a backhaul network in which a cluster comprises one hub and four RBMs, and each RBM is co-located with an access module (AM);

[0033] FIG. 2 shows a schematic diagram of a wireless backhaul interference network comprising 21 hubs and 84 RBMs with the frequency use factor = 1;

[0034] FIG. 3 shows a schematic diagram of a wireless backhaul interference network comprising 57 hubs and 228 RBMs with the frequency use factor = 1;

[0035] FIG. 4 shows a schematic diagram of a wireless backhaul interference network comprising 111 hubs and 444 RBMs with the frequency use factor = 1;

[0036] FIG. 5 shows a table that summarizes the system parameters of the wireless backhaul network used to evaluate the performance of methods according to embodiments of the invention;

[0037] FIG. 6 shows a table that summarizes the modulation and coding format and the corresponding SINR target values of the wireless backhaul network;

[0038] FIG. 7 shows a flow chart representing steps of a method according to an embodiment of the invention, for determining clusters in the backhaul network;

[0039] FIG. 8 shows a simulation schematic that plots the average spectrum efficiency of the downlink of the backhaul network for different realizations of the channel; and

[0040] FIG. 9 shows a simulation schematic for the clustering gain in terms of spectrum efficiency as the number of hubs increases (21, 57 and 111 hubs).

DESCRIPTION OF PREFERRED EMBODIMENTS

[0041] FIG. 1 shows a schematic diagram representing an example of a cluster in a point-to-multipoint wireless backhaul network 100 comprising one hub module 102 serving four RBMs 104. Each RBM 104 is co-located with an access module (AM) 106, such as a small cell base station, with a wired connection, e.g. an Ethernet cable. The hub module 102 has a

separate directional antenna 108 and RBMs each have integrated directional antenna that is directed towards the hub. Unlike a multi-hop architecture, there is only one hop from each RBM to a respective hub to carry the traffic. It is also different from the relay system where the access links and relay links share the same radio frequency band. The backhaul network operates at a different frequency band from that of the access network.

[0042] FIG. 2 show a schematic diagram representing a wireless backhaul network comprising 21 hubs, each serving a plurality of RBMs. As indicated schematically for the central node in FIG. 2, in each cell, the circle indicating the “hub” comprises 3 hub modules. Each hub module has an antenna oriented to serve a 120 degree sector with four RBMs. FIG.s 3 and 4 are schematic diagrams representing networks of different network sizes comprising 57 hubs to 111 hubs respectively. In each, the frequency reuse factor is one.

[0043] Parameters used for the system simulations are listed in the table shown in FIG. 5. FIG. 6 lists the SINR target in dB, for different modulation and coding formats.

[0044] In a wireless backhaul network comprising a plurality of nodes comprising hubs and RBMs, a method for determining network clusters according to an embodiment of the present invention, determines which RBMs are served by a particular hub based on obtaining a link quality value metric for each hub-RBM link, ranking the links based on the link quality value, and determining hub-RBM clusters from a highest to lowest ranking of the link quality values. The clustering method takes into account any constraints on the maximum number of RBMs per cluster and clusters each RBM only once, i.e. each RBM belongs to only one cluster. A link quality value based method for determining the clustering outcomes can provide an increased average link quality value, or e.g. an increased average network data rate.

[0045] The clustering method according to the embodiment determines the RBM antenna orientation directions. On each bin, the initial power assigned to all hubs is set to the maximum allowable power. The LQV metric used for determining clusters is based on the combined link quality values of all bins calculated based on the initial power. On each bin, the link quality for each hub and RBM link is determined assuming the RBM steers its main lobe to maximize the overall link quality value of this link.

[0046] Thus, the method comprises obtaining link quality values for each of a plurality of hub-RBM links, either by measurement or computation from network parameters, and from the input link quality values for each hub-RBM link, performing “link quality based clustering” steps comprising:

- i. Ranking link quality values of each of the plurality of hub-RBM links, or for each of multiple RBM candidate site locations, and choosing the maximum of these link quality values to obtain an input link quality table.
- ii. Reshaping the link quality table into a vector in a column-wise order and ranking link quality values of the link quality tables.
- iii. From the highest to the lowest link quality links, identifying each hub-RBM cluster by excluding the scenario of an RBM being clustered more than once and by satisfying a maximum number of RBM per cluster constraint.

[0047] FIG. 7 shows the flow chart representing steps of the clustering method, which comprise: picking the maximum LQV of the candidate locations, forming a two dimensional LQV table, reshaping the table into an array, ranking the LQV array from highest to lowest, then, from the highest to the lowest identifying each hub-RBM cluster satisfying constraints including excluding an RBM being clustered more than once and a maximum number of RBM per cluster.

[0048] Thus, if there are N hubs and each cluster has M RBMs, the total number of RBMs is NM . For the link between hub i and RBM j at its k^{th} candidate location, the LQV is denoted by LQV_{ijk} . The LQVs are further processed so that $LQV_{ij} = \max_k LQV_{ijk}$. A two dimensional LQV table is formed. The two dimensional table of LQV (of a size $N \times NM$) is then reshaped into a vector (array) and the LQVs of the vector are ranked. The reshape function performs the operation in a column-wise order. The ranking operation is denoted by a permutation π , which reorders the LQVs from the highest to the lowest. The inverse permutation of π is denoted by π^{-1} , which maps the index of the reordered LQVs to the index of the reshaped LQVs. Therefore, the first RBM ID and hub ID in the reordered LQV vector are respectively:

$$RBM\ ID\ (1) = \text{mod} \left(\frac{\pi^{-1}(1) - 1}{NM} \right) + 1$$

$$hub\ ID\ (1) = \text{floor} \left(\frac{\pi^{-1}(1) - 1}{NM} \right) + 1.$$

Equation 1

For the t^{th} position in the reordered LQV vector, the RBM ID and hub ID are computed as

$$RBM\ ID(t) = \text{mod}\left(\frac{\pi^{-1}(t) - 1}{NM}\right) + 1$$

$$hub\ ID(t) = \text{floor}\left(\frac{\pi^{-1}(t) - 1}{NM}\right) + 1.$$

Equation 2

[0049] Initially, the clusters have RBM counts equal to 0. The set of identified RBMs for each cluster is denoted by β_i for the i^{th} hub/cluster. The sets β_i are initialized to be empty sets. Starting with $t = 1$, thus the first search position in the reordered LQV vector is 1. The first identified RBM ID is stored in a set denoted by Ω (the set of all identified RBMs).

$RBM\ ID(1)$ is added to the set $\beta_{hub\ ID(1)}$. The RBM count for $hub\ ID(1)$ is updated to be 1.

[0050] The clustering process continues from the second element in the reshaped LQV vector ($t = 2$), searching elements one by one. If $hub\ ID(t)$'s RBM count does not reach M and $RBM\ ID(t)$ has not been identified in the search process (i.e., $RBM\ ID(t)$ does not appear in the set Ω), $RBM\ ID(t)$ is added to the set $\beta_{hub\ ID(t)}$ and the RBM count of $hub\ ID(t)$ increases by 1. Then, $RBM\ ID(t)$ is added to the set Ω . Otherwise, no operations are done for β_i , Ω and the RBM counts of each hub. The process is continued until the set Ω has a size NM .

[0051] For performance evaluation, the averaged SINR across the frequency bins for each link was used as the LQV metric. The simulation results are summarized in the following two paragraphs, with reference to FIGs. 8 and 9, which compare the SINR based clustering of the present embodiment with conventional geographic location based clustering. FIG. 8 shows a simulation schematic that plots the average spectrum efficiency of the downlink of the backhaul network for different realizations of the channel. FIG. 9 shows the clustering gain in terms of spectrum efficiency as the number of hubs increases (21, 57 and 111 hubs).

[0052] In FIG. 8, the average spectrum efficiency with the clustering method of the embodiment outperforms the average spectrum efficiency based on geographic location based clustering method by about 1.19 bps/Hz. This simulation was performed for the topology with 21 hubs and 84 RBMs. This translates to around 34% of the spectrum efficiency gain considering that the average spectrum efficiency with the geographic based clustering is about 3.5 bps/Hz.

[0053] As the number of hubs increases, the spectrum efficiency gain decreases slightly. However, the percentage gain is still approximately 35%.

[0054] The LQV may be defined as one of a) the SINR value of each link; b) the data rate of each link; c) the weighted data rate of each link; d) the average SINR across frequency bins of each link; e) the average channel gains across frequency bins of each link or e) the inverse of the distance of each link. Advantageously, when the LQV is a weighted LQV value, e.g. a weighted data rate of each link, weights are assigned based on traffic conditions of the links.

[0055] The method may comprise approximating the input LQV table based on assigned weights of all links, noise powers, path losses, shadowing losses and transmit/receive antenna gains if it is not feasible to measure directly the LQV values between any hub and RBM (with the best RBM steering).

[0056] The path loss and shadowing gain between hub i and RBM j in a linear scale is denoted by g_{ij} . The noise power is denoted by N_{ij} . The combined transmit and receive antenna gain is denoted by $G_{ij}[j \rightarrow i]$ assuming the mainlobe of the RBM j 's antenna is steered towards hub i . The transmit power of all hubs is denoted by P . For example, when the SINR value of any hub-RBM link cannot be directly measured, the SINR values for each bin can be approximated using the following formula:

$$SINR_{ij} = \frac{G_{ij}[j \rightarrow i]g_{ij}P}{N_{ij} + \sum_{l \neq i} G_{lj}[j \rightarrow l]g_{lj}P}$$

Equation 3

[0057] Thus, for example, the LQV metric can be defined as the average SINR of all frequency bins of each link. Shadowing and path loss information are measured based on the methods disclosed in copending United States Patent application No. 13/230,368. Combined with the antenna gains, the SINR values of each hub-RBM link can be computed according to the equation 3 above, and used as the input data to the clustering method.

[0058] Thus, a method is provided for managing resource allocation for a plurality of radio links in a wireless network, comprising clustering of links based on a link quality value (LQV) of each link, and scheduling resources to links based on said clustering of links, e.g. to provide an increased average link quality value of the network and improved average network data rate.

[0059] In practice, the procedure for determining the clusters is part of the practice of optimizing the system performance, i.e. in terms of quality of service, e.g. throughput. In the above referenced copending United State Patent application No. 13/463,478 a joint hub power allocation and scheduling method is disclosed to enhance the average network throughput given a pre-determined clustering strategy. This method can be combined with the clustering method disclosed herein to further improve the average network throughput after clustering. This method also presents a practical framework to realize the basic clustering feature of the managed resource allocation (MARA) for a backhaul network as disclosed in the above referenced copending United States Patent application No. 13/230,368.

[0060] Since the method for determining network clusters uses a link quality ranking criterion to sort the link quality values of the links and identify clusters based on the ranking, it thus has low computational complexity. It does not require exhaustively searching the space of all possible hub-RBM cluster assignments.

[0061] Several link quality value metrics are defined and may be used to perform clustering. Advantageously, a weight based on data traffic condition of each hub and RBM link is assigned. When LQV is defined as the weighted data rate of each hub and RBM link, the proposed clustering strategy can achieve good quality of service across the backhaul network. When LQV is defined as the data rate of each link, the clustering strategy simply maximizes the average data rate of the network.

[0062] The proposed method can be applied when there are multiple candidate locations for each RBM. In this case, the input LQV table has three dimensions corresponding to the hub index, RBM index, and location index. The output of the proposed method includes the best locations of RBMs over the candidate locations and the resulting clusters.

In summary, methods according to embodiments of the invention provide for clustering of links in a wireless backhaul network based on determining the input link quality values, ranking of link quality values, and from the highest to the lowest link quality values, identifying each hub-RBM cluster to satisfy constraints with respect to clustering each RBM only once and a maximum number of RBM per hub. Link quality value metrics are defined that may be measured in an active network, or alternatively where measurement is not feasible, computed or simulated based on network parameters. Thus, a network planning computer program can be written to implement the method to determine network clusters to improve performance in an active network or for network design and planning purposes.

Thus the backhaul network may comprise apparatus comprising a processor and program instructions, e.g. in a control node of the network, for performing the method steps, based on input link quality values that are measured or calculated as described above to determine the network clusters. The output of the program may be displayed in a visual representation based on which the installers can configure the clusters, e.g. for improved performance, such as improved data rate or average link quality value of the network.

INDUSTRIAL APPLICABILITY

[0063] Methods and apparatus according to embodiments of the invention have application to determining network clusters, each comprising a hub and a plurality of RBMs, for improving performance of wireless backhaul networks and in particular for increasing data rates of NLOS wireless backhaul networks.

[0064] LQV based clustering can achieve a higher average LQV, e.g., average spectrum efficiency or weighted sum spectrum efficiency, for the entire backhaul network compared to the geographic location based clustering. LQV based clustering chooses the links with strong link quality values to optimize the LQV metric, and may additionally take into account a location index. The proposed method is straightforward to implement in practice and has low computational complexity.

[0065] Although embodiments of the invention have been described and illustrated in detail, it is to be clearly understood that the same is by way of illustration and example only and not to be taken by way of limitation, the scope of the present invention being limited only by the appended claims.

CLAIMS

1. A method for determining network clusters in a wireless backhaul network comprising a plurality of hubs (102) and a plurality of Remote Backhaul Modules (RBM) (104), comprising the steps of:

for each of a plurality of hub-RBM links (110), obtaining an input link quality value (LQV);

ranking said input link quality values; and

from the highest to lowest link quality values, and satisfying constraints with respect to a maximum number of RBM per hub, and clustering each RBM only once, identifying each hub-RBM cluster from the ranked LQV values.

2. A method according to claim 1 where link quality values are weighted and wherein weights are assigned based on traffic conditions of each link.

3. A method according to claim 1 or claim 2, wherein ranking said input link quality values comprises:

i. ranking link quality values of hub-RBM links for each candidate location of an RBM and choosing the maximum value(s) of these link quality values to obtain an input link quality table;

ii. reshaping the link quality table into a vector in a column-wise order and ranking link quality values of the link quality tables.

and wherein identifying each hub-RBM cluster comprises:

iii. from the highest to the lowest link quality links, identifying each hub-RBM cluster by excluding each RBM from being clustered more than once and by satisfying a maximum number of RBM per cluster constraint

4. A method according to claim 3 wherein the link quality table vector comprises two dimensions corresponding to a hub index (hub ID) and an RBM index (RBM ID) wherein: for the t^{th} position in the reordered LQV vector, the RBM ID and hub ID are computed as

$$RBM\ ID(t) = \text{mod}\left(\frac{\pi^{-1}(t) - 1}{NM}\right) + 1$$

$$hub\ ID(t) = \text{floor}\left(\frac{\pi^{-1}(t) - 1}{NM}\right) + 1.$$

5. A method according to claim 3 wherein the step of ranking link quality values of hub-RBM links comprises ranking link quality values of multiple candidate site locations for each RBM, and wherein the link quality table vector comprises three dimensions corresponding to the hub index, RBM index and location index.

6. A method according to any one of claims 1 to 5 wherein the step of obtaining the link quality values for each hub-RBM link comprises any one of:

obtaining a data rate of each link; or

obtaining a weighted data rate of each link wherein weights are assigned based on traffic conditions of the links; or

obtaining a SINR value of each link; or

obtaining an average SINR across frequency bins of each link; or

obtaining an average channel gain across frequency bins of each link; or

obtaining the inverse of the distance of each link.

7. A method according to claim 6 wherein obtaining the link quality values comprises measuring said link quality values for each of the plurality of hub-RBM links.

8. A method according to claim 6 wherein obtaining the link quality values comprises computing said link quality values for each of a plurality of hub-RBM links from network parameters.

9. A method according to claim 6 wherein the link quality values are approximated as the SINR values for each bin using :

$$SINR_{ij} = \frac{G_{ij}[j \rightarrow i]g_{ij}P}{N_{ij} + \sum_{l \neq i} G_{lj}[j \rightarrow l]g_{lj}P}.$$

where the path loss and shadowing gain between hub i and RBM j in a linear scale is denoted by g_{ij} ; the noise power is denoted by N_{ij} ; the combined transmit and receive

antenna gain is denoted by $G_{ij}[j \rightarrow i]$ assuming the mainlobe of the RBM j 's antenna is steered towards hub i .; and the transmit power of all hubs is denoted by P .

10. A method for managing resource allocation for a plurality of radio links in a wireless backhaul network comprising a plurality of hubs and RBMs, comprising:

clustering of links based on a link quality value (LQV) of each link, and

scheduling resources to links based on said clustering of links to provide an increased average link quality value of the network.

11. A method according to claim 10 further comprising managing power allocation and scheduling for interference mitigation in the network based on said network clusters.

12. Apparatus in a wireless backhaul network comprising a processor and instructions for implementing the method steps of any one of method claims 1 to 11.

13. A computer readable medium storing instructions which when executed in a processor perform the method steps of any one of method claims 1 to 11.

14. A link quality metric for a method according to any one of claims 1 to 11 for determining network clustering of hub-RBM links in a wireless backhaul network, comprising any one of:

a) a data rate of each link; or

b) a weighted data rate of each link wherein weights are assigned based on traffic conditions of the links; or

c) a SINR value of each link; or

d) an average SINR across frequency bins of each link; or

e) an average channel gain across frequency bins of each link; or

f) an inverse of the distance of each link.

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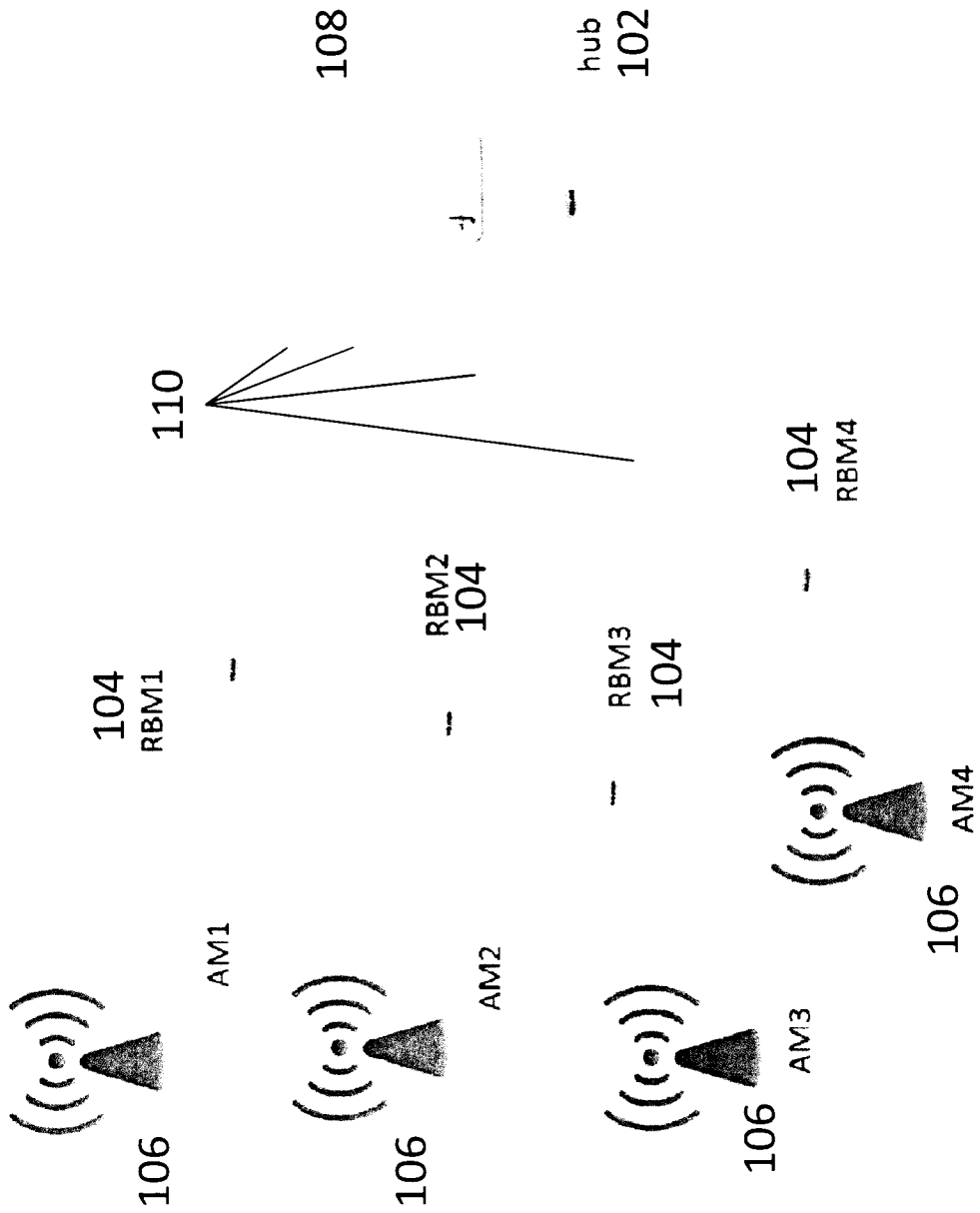


Figure 1

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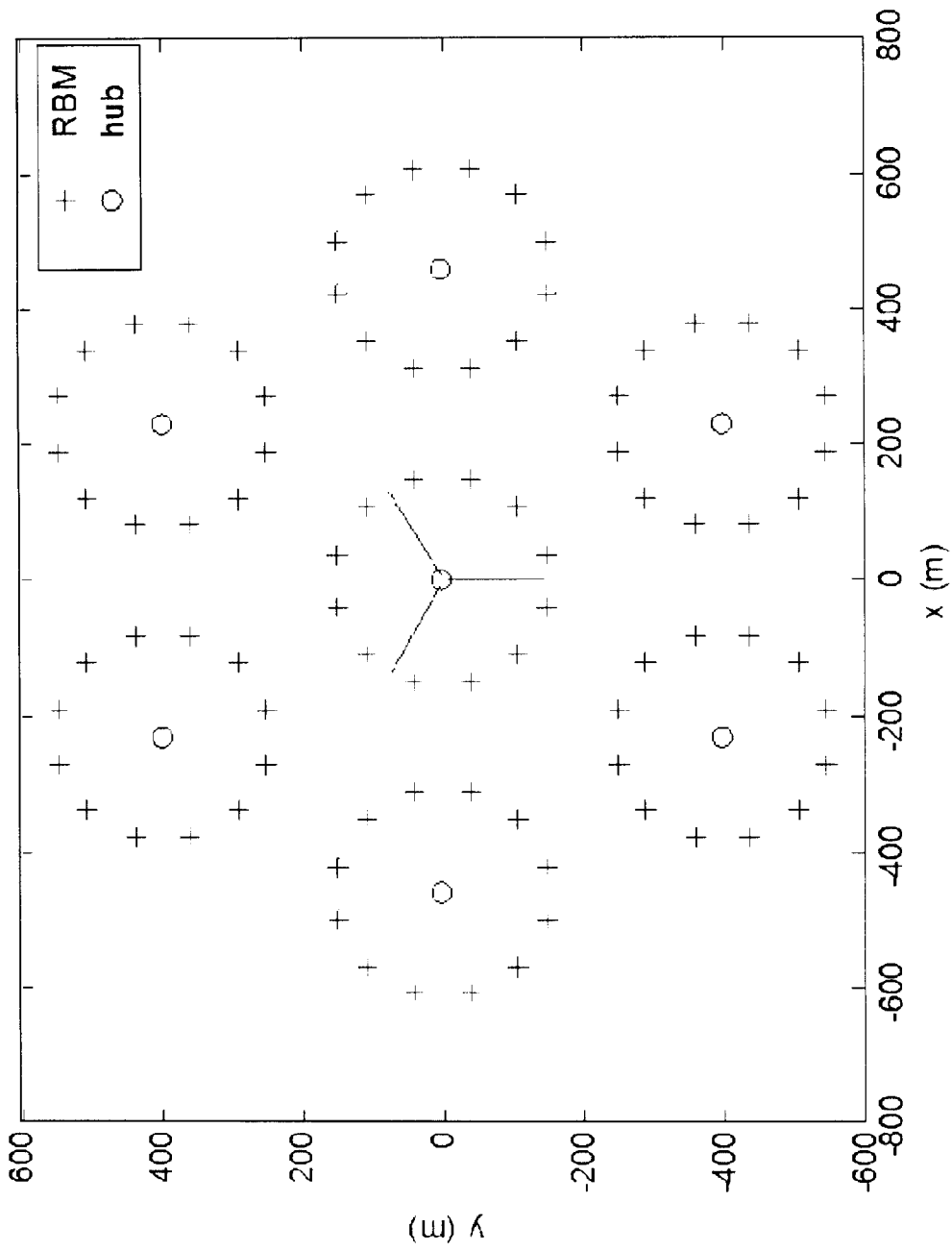


Figure 2

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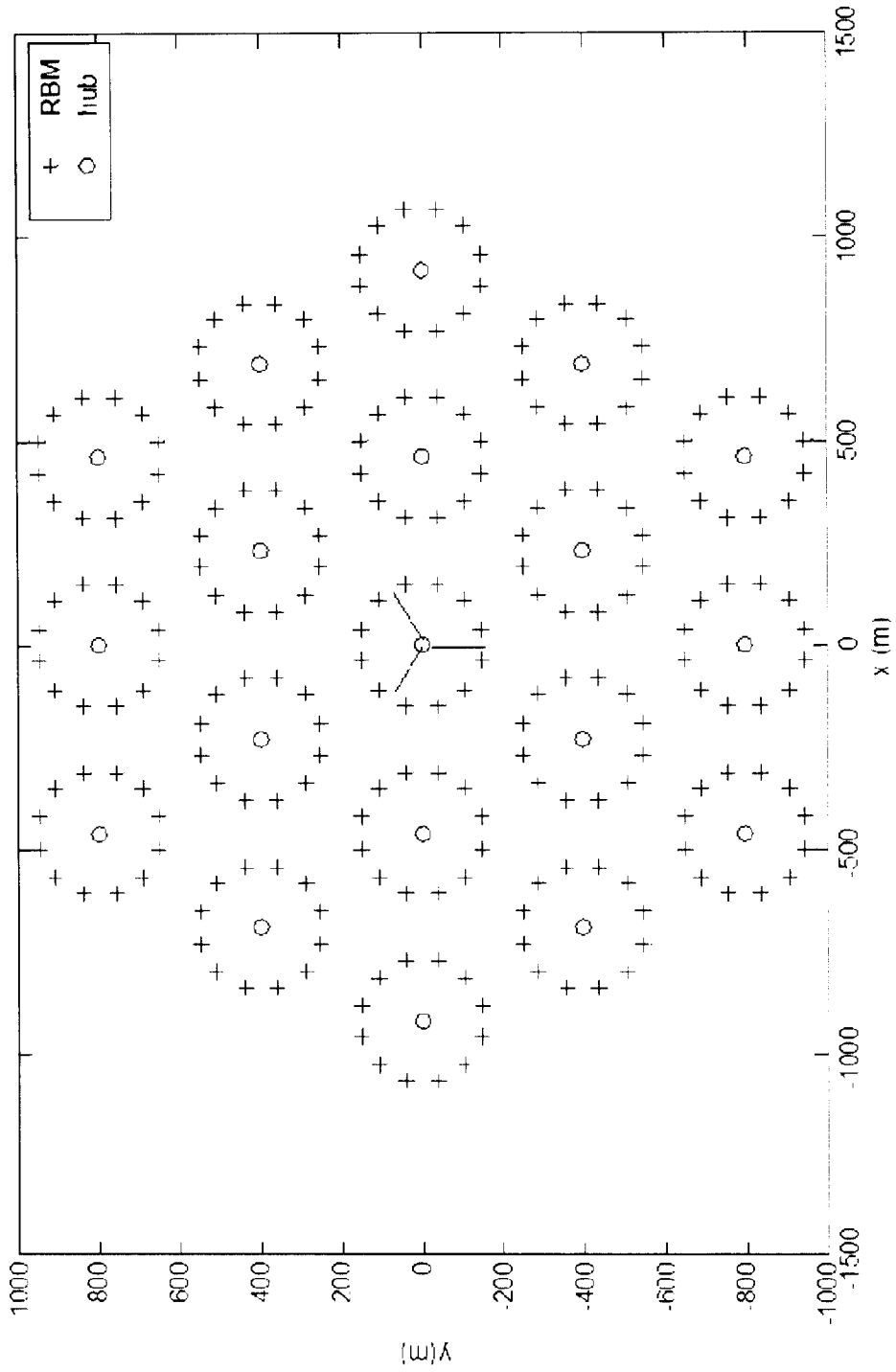


Figure 3

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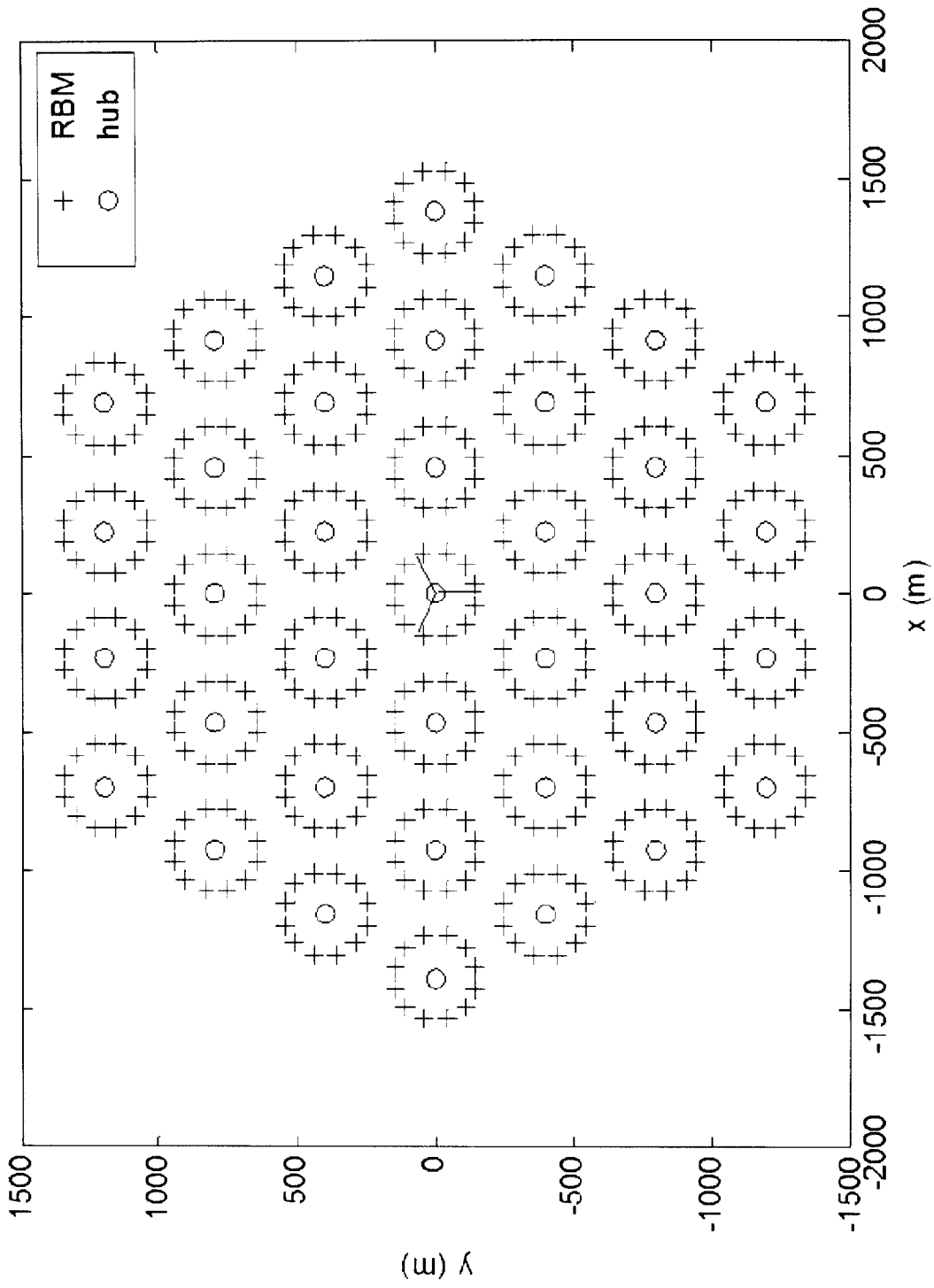


Figure 4

Topology	3 sector per cell
Number of hubs	21, 57, 111
Frequency reuse	1
Number of RBMs per hub	4
Channel bandwidth	10 MHz
Hub max TX power per subcarrier	-32.7 dBw
Noise power per subcarrier	-158.6 dBw
Channel model	Stanford University Interim Model 3
Number of frequency bins	1
Hub antenna 3dB beamwidth (one-sided)	45 degree
RBM antenna 3dB beamwidth (one-sided)	22.5 degree
Number of candidate locations per RBM	1

Figure 5

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Modulation and coding format	SINR target (dB)
QPSK $\frac{3}{4}$	7
16QAM $\frac{1}{2}$	11
16QAM $\frac{3}{4}$	14
64QAM $\frac{2}{3}$	19
64QAM $\frac{3}{4}$	21
64QAM $\frac{5}{6}$	23
256QAM $\frac{6}{8}$	26
256QAM $\frac{7}{8}$	30

Figure 6

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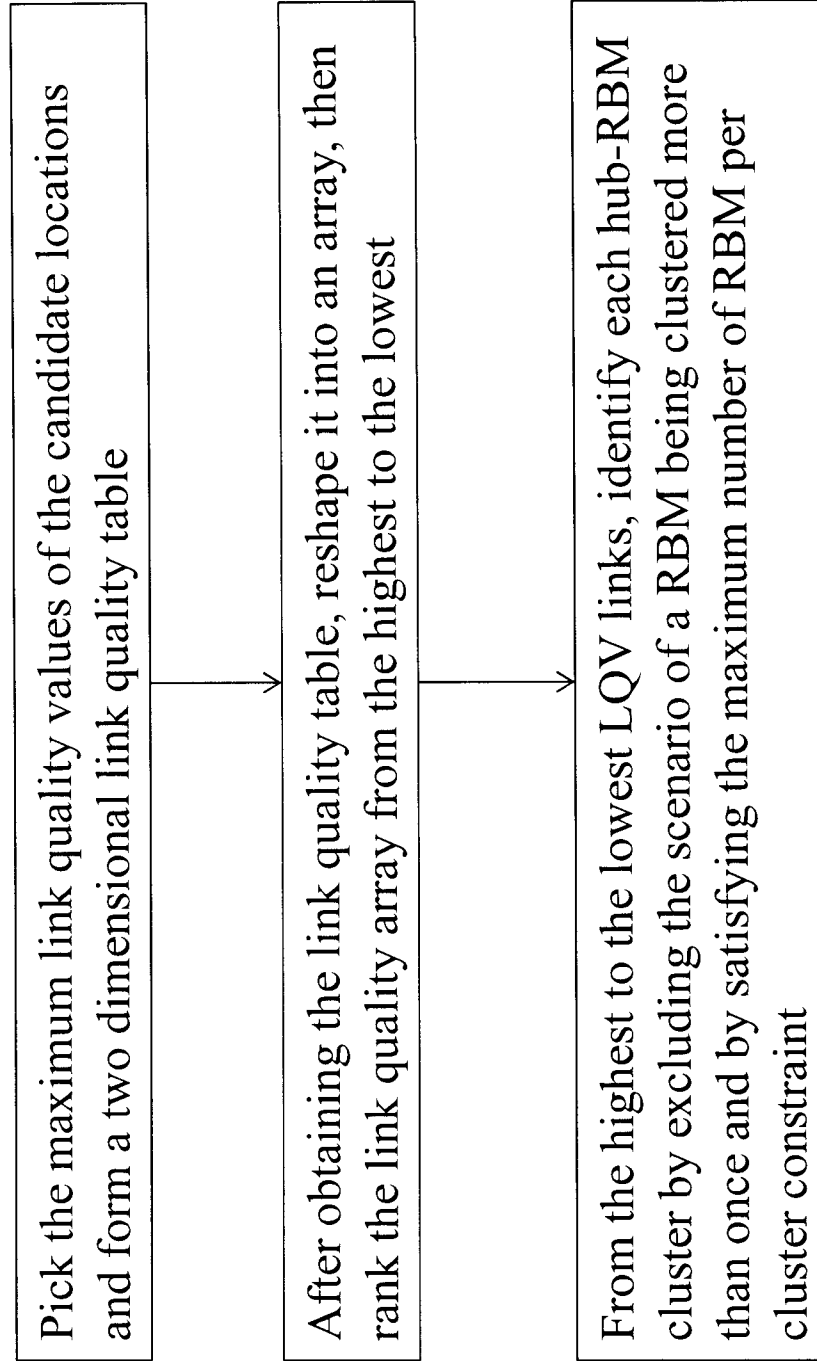


Figure 7

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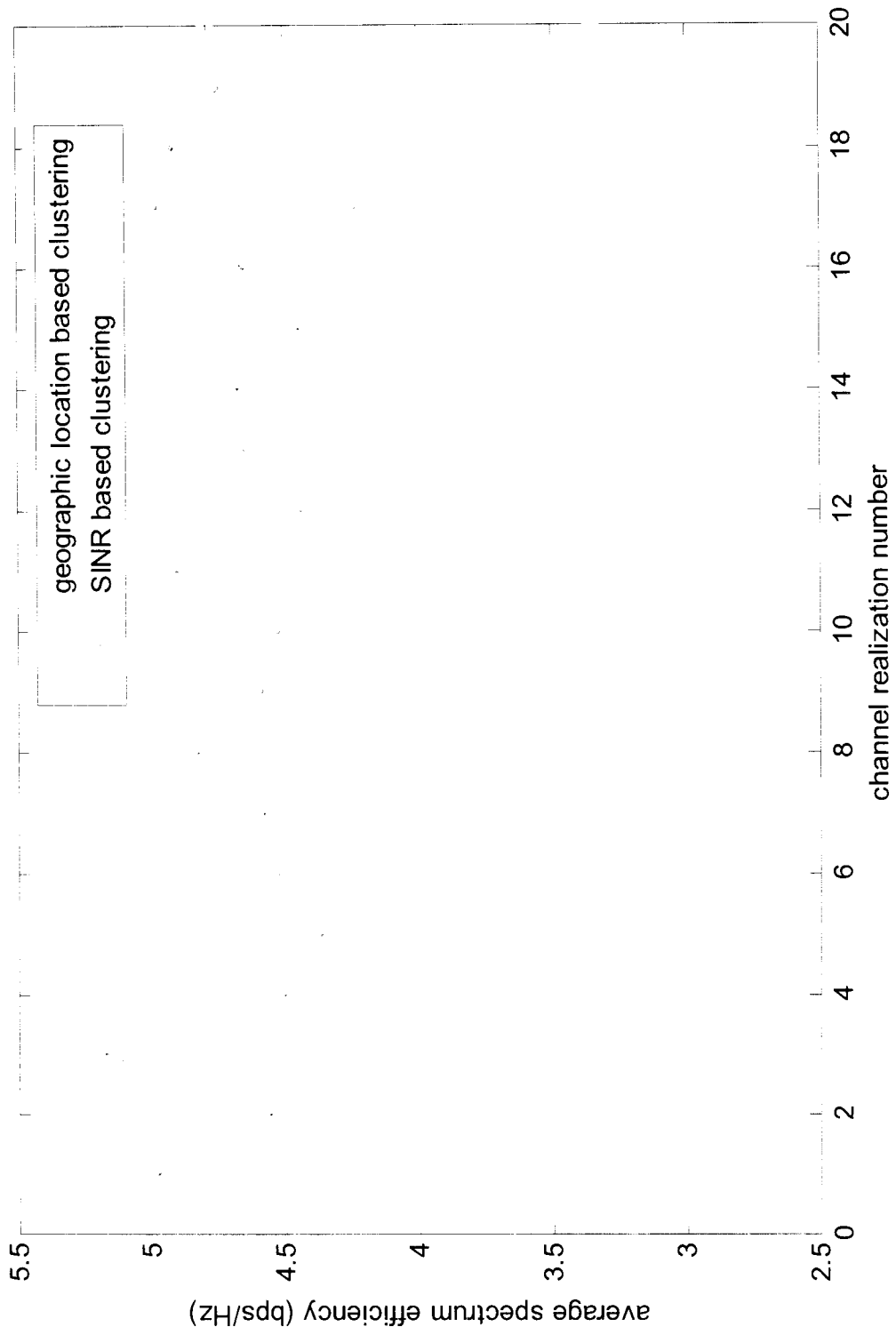


Figure 8

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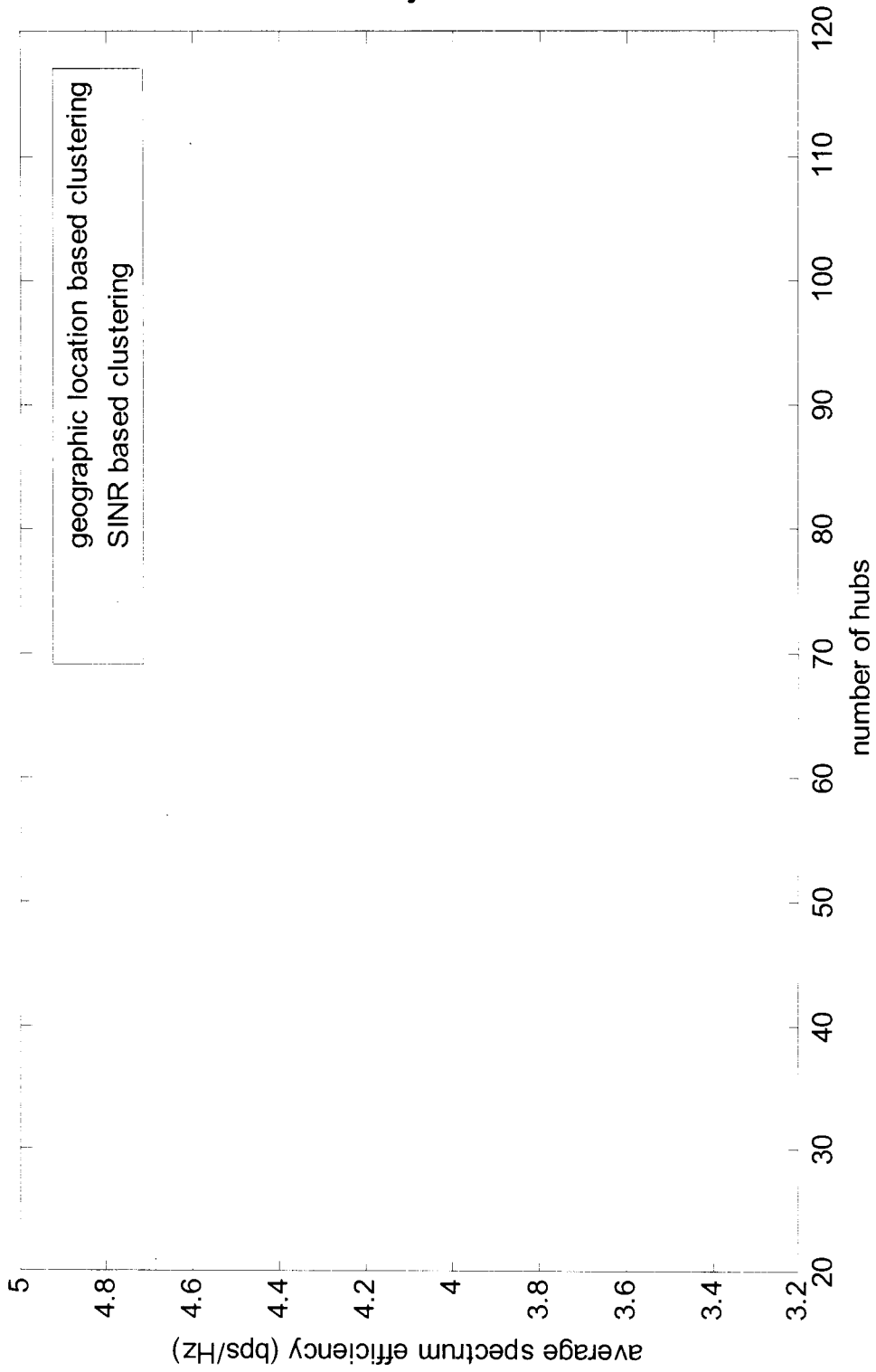


Figure 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2012/000621

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **H04W 40/00** (2009.01) , **H04W 24/00** (2009.01)

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)

IPC(2009.01): H04W 40/00 ; H04W 24/00

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

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

Database: Canadian Patent Database (CPD), TotalPatent

Keywords: wireless backhaul network, RBM (remote backhaul modules), LQV (link quality value), data rate, SINR (signal to interference and noise power ratio), channel gain, spectrum efficiency

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/0197603A1 (Ji et al.) 06 August 2009 (06-08-2009) * paragraphs 0007, 0008, 0020, 0027, 0031-0054, 0074, 0080, 0083, 0088, 0100, 0130; Figs. 1, 3 *	1-9 and 12-14
A	US 2011/0222455A1 (Hou et al.) 15 September 2011 (2011-09-15) *the whole document*	1
A	US 7,729,257B2 (Kodialam et al.) 01 June 2010 (2010-06-01) * the whole document*	1, 6, and 14

 Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents :	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search

October 10, 2012

Date of mailing of the international search report

04 December 2012 (04-12-2012)

Name and mailing address of the ISA/CA
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Facsimile No.: 001-819-953-2476

Authorized officer

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Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons :

1. Claim Nos. :
because they relate to subject matter not required to be searched by this Authority, namely :

2. Claim Nos. :
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically :

3. Claim Nos. :
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows :

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos. :
4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos. :
claims 1-9 and 12-14

- Remark on Protest** The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2012/000621

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
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		CA2712662A1	06 August 2009 (06-08-2009)
		CN101933371A	29 December 2010 (29-12-2010)
		EP2238793A1	13 October 2010 (13-10-2010)
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		JP2011511558A	07 April 2011 (07-04-2011)
		KR20100114109A	22 October 2010 (22-10-2010)
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		RU2010136650A	20 March 2012 (20-03-2012)
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		EP1999669A2	10 December 2008 (10-12-2008)
		JP2009532940A	10 September 2009 (10-09-2009)
		KR20080114772A	31 December 2008 (31-12-2008)
		US2007237081A1	11 October 2007 (11-10-2007)
		WO2007126610A2	08 November 2007 (08-11-2007)
		WO2007126610A3	21 February 2008 (21-02-2008)