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(54) **Title**: METHOD AND APPARATUS FOR DE-CENTRALIZED COORDINATED MULTI-POINT SCHEDULING WITH STATISTICAL PERFORMANCE OPTIMIZATION

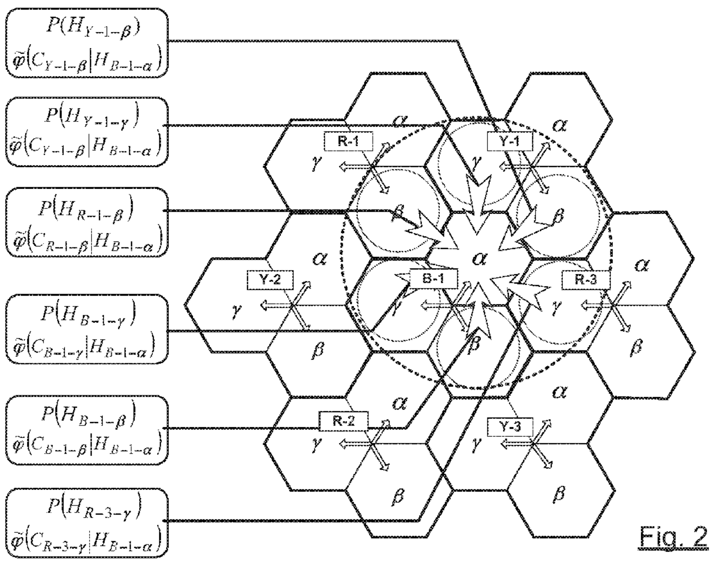

Fig. 2

(57) **Abstract**: The method provides a new approach of de-centralized coordinated scheduling in a wireless network, such as, for example, a LTE-Anetwork, by considering all likelihoods of resource allocation in neighbor cells and deriving decisions based on these statistics. Such a method thus relies on a novel de-centralized CS scheme with: new inter-node signaling to convey resource allocation statistics of cells in the cooperating set of cells, also called cluster, new algorithms to compute statistical performance metrics based on signaling in (i), and coordinated scheduling operated in individual nodes to allocate resource based on the statistical performance metrics.

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Method and apparatus for de-centralized coordinated multi-point scheduling with statistical performance optimization

1. Field of the invention

The invention relates to a method for scheduling user equipment in a wireless communications network, such as, for example, a Long Term Evolution-Advanced (LTE-A) network (as described in the series of standards Ts36.xxx release 10 and further issued by the third generation partnership program (3GPP)). More precisely, the invention relates to a method for scheduling user equipment, which allows mitigating the downlink interference between cells in a homogeneous or heterogeneous communications network.

2. Background

Wireless networks have witnessed the proliferation of smart communication terminals and drastic growth in the network traffic from data services. Operators have adopted Long Term Evolution-Advanced (LTE-A) for next generation wireless communication networks.

LTE-A can significantly enhance the spectrum efficiency and lift the performance bars for mobile subscribers. Nevertheless, its performance is limited by the interference leakage from neighbor cells, also known as inter-cell interference (ICI). Neighbor cells operating on the same spectrum actually generate ICI, which can degenerate user signal quality. The detrimental effect is especially significant to users on the cell edge, causing very poor service or even service disruption.

To mitigate the ICI, interference coordination technologies have been widely studied to coordinate the resource allocation between LTE cells such that severe interference can be avoided. Among the many techniques, which have been discussed, coordinated scheduling (CS) consists in mitigating ICI by coordinating resource allocation between cells. In general, there can be two types of interference coordination, namely, centralized scheduler and de-centralized CS. In centralized scheduling, cooperating cells send reports, e.g., user channel state information (CSI) and/or cell benefit metric associated with certain resource allocation, to a central controller. The latter then utilizes the global information to dictate resource usage of multiple cells to optimize the overall performance. Each cell then follows the resource allocation dictated by the centralized controller to perform user scheduling.

In de-centralized CS, there is no central unit to take charge of the cross-cell resource allocation. Instead, a coordination module residing in each node is responsible for coordinating with other nodes in the network, based on exchanged signaling between the nodes. Nodes may either be associated to local cells, or may be local control units, which are responsible for resource allocation for a number of inter-connecting cells. The signaling is transmitted over enhanced X2 interface or proprietary inter-node interface.

In 3GPP TR36.874, "Technical Specification Group Radio Access Network; Coordinated multi-point operation for LTE with non-ideal backhaul" and in "P-RANEV: CoMPWORKSTREAM BY NGMN ALLIANCE," NGMN RANEV project deliverable, CS schemes in either centralized architecture or via de-centralized coordination are evaluated.

A drawback of centralized scheduling is that it introduces a central controller, which is a new network element and thus implies to modify networks architecture.

De-centralized CS, as described by R. Agrawal et al.in "Centralized and Decentralized Coordinated Scheduling with Muting," *IEEE VTC Spring*, 2014,has less impact on the network architecture. It typically relies on the information of neighbor cell performance metrics (via inter-node signaling) to make mutual-beneficial decisions. Nevertheless, explicitly calculated performance metrics are known to be dependent on the resource usage of node-of-interest (where the de-centralized controller is sited) as well as resource usage in cooperating nodes, thus not suitable for de-centralized implementation.

One way to get around the problem is to assume resource allocation for cooperating nodes whereby the performance metric is forced to be a function of node-of-interest only. However, the so-obtained performance metrics could be biased if the assumptions differ from the real resource allocation in cooperating cells.

It would hence be desirable to provide a method for scheduling user equipment in a wireless communications network that would not show the drawbacks mentioned above. More precisely, it would be desirable to provide such a de-centralized coordinated scheduling method, which would not rely so heavily on the resource allocation in neighbor nodes.

3. Summary

According to an embodiment of the invention, a method for scheduling user equipment in an access node of a communication network comprising several access nodes, is provided, which comprises, for at least one of said nodes, called a node-of-interest, belonging to a cluster of cooperating nodes:

- sending to neighbor nodes in said cluster a likelihood of transmission state of said node-of-interest and receiving from said neighbor nodes in said cluster likelihoods of transmission state of said neighbor nodes;

- computing a statistical performance metric of said node-of-interest conditioned on its own likelihood of transmission state. Such a computing is based on the likelihoods of transmission states of the said neighbor nodes;
- computing a statistical performance metric of said node-of-interest conditioned on likelihoods of transmission state of said neighbor nodes in said cluster, called S2;
- sending to neighbor nodes in said cluster said statistical performance metric S2 and receiving from said neighbor nodes in said cluster corresponding statistical performance metrics of said neighbor nodes conditioned on said likelihood of transmission state of said node-of-interest ;
- determining a transmission state of said node-of-interest on the basis of said computed and received statistical performance metrics;
- scheduling user equipment served by said node-of-interest on the basis of said transmission state determined for said node-of-interest and on information relating to transmission states of said neighbor nodes in said cluster.

The method according to an embodiment of the invention thus relies on a novel and inventive approach of de-centralized coordinated scheduling in a wireless network, such as, for example, a LTE-A network (it must be noted that, although embodiments of the invention are described throughout this document in the context of LTE-A networks, the scope of the invention is not limited to this peculiar type of network and may find applications in any communication network where de-centralized coordination between cooperating nodes is of interest). Actually, such a method allows considering all likelihoods of resource allocation in neighbor cells and deriving decisions based on these statistics.

Such a method according to an embodiment of the invention thus relies on a novel de-centralized CS scheme with:

(i) new inter-node signaling to convey resource allocation statistics of cells in the cooperating set of cells, also called cluster,

(ii) new algorithms to compute statistical performance metrics based on signaling in (i), and

(iii) coordinated scheduling operated in individual nodes to allocate resource based on the statistical performance metrics.

According to such a method, resource coordination is performed to optimize the statistical performance metrics of cooperating nodes.

Although such a method is described from the point of view of a peculiar node in the cluster, called the node-of-interest, it must be understood that every node in the cluster of cooperating nodes becomes a node-of-interest at a certain point in time, and thus implements the method described here above and here after.

Hence, each cooperating node in the cluster implements algorithms to calculate the statistical performance metrics associated with the node itself (conditioned either on its own transmission state or the transmission state of neighbor cells), as well as algorithms to determine the resource allocation for the associated node with the statistical performance metrics calculated for the node-of-interest and those received from cooperating nodes.

Such a method for scheduling user equipment according to an embodiment of the invention allows enhanced de-centralized coordination, as compared to known prior art techniques, leading to improved interference management (for operators) and better user experience (for subscribers) while introducing minor impact to existing radio access network architecture. Actually, according to embodiments of the invention, no centralized controller is needed.

Moreover, as will be described in more details in the following parts of this document, such a method according to embodiments of the invention can be applied to a wide variety of scenarios including homogeneous networks and hybrid cloud Radio Access Network (C-RAN), etc.

According to a first embodiment, said method for scheduling comprises sending to said neighbor nodes in said cluster said transmission state determined for said node-of-interest and receiving from said neighbor nodes in said cluster corresponding transmission states determined by and for said neighbor nodes on the basis of computed and received statistical performance metrics, and said information relating to transmission states of said neighbor nodes in said cluster comprises said transmission states determined by and received from said neighbor nodes in said cluster.

Hence, scheduling user equipment may be implemented by accurately estimating user SINR (Signal Plus Interference to Noise Ratio) and scheduling priorities with explicit knowledge of cell cluster transmission states. Nevertheless, signaling of transmission state information is needed and this signaling is constrained by the end-to-end backhaul latency between cells in legacy networks.

According to a second alternate embodiment, said information relating to transmission states of said neighbor nodes in said cluster comprises said likelihoods of transmission state of said neighbor nodes in said cluster.

This alternate embodiment is not constrained by this additional backhaul latency, but only statistical likelihood information of neighbor cell transmission states is accessible for scheduling user equipment, which may impact the scheduling performance.

According to an embodiment of the invention, said transmission state determined for said node-of-interest maximizes a sum of the statistical performance metrics of said node-of-interest and of said neighbor nodes in said cluster.

Such a statistical performance-based approach allows optimizing resource coordination.

According to a further embodiment of the invention, such a method for scheduling also comprises a state expurgation mechanism allowing taking into account only the most probable transmission states of said nodes in said cluster, called survivor states. The most probable transmission states are evaluated based on the information on transmission states of the neighbor nodes received from the neighbor nodes.

Actually, to obtain the statistical performance metric of a node, the performance metric function needs to be evaluated over all possible transmission states of a number of cooperating nodes, which may lead to great computation complexity. Such a state expurgation mechanism relies on the hypothesis that node transmission states are not distributed uniformly, and allows achieving an accurate approximation of the statistical performance metric, while drastically reducing the computing complexity.

According to a particular embodiment, said state expurgation mechanism relies on a defined state-expurgation threshold, and said survivor states are the transmission states of said nodes in said cluster whose likelihood is above said threshold.

Such a threshold may be advantageously set according to the computation complexity, which is aimed at.

According to yet a further aspect, such a method also comprises setting a maximum number of survivor states. Hence, the computing complexity can be further reduced.

According to an embodiment of the invention, said communication network is a homogeneous network, and said nodes are base transceiver stations of said homogeneous network. For example, the communication network is a homogeneous LTE-A network, and the nodes are eNodeBs (for evolved NodeBs), which each manage several radio cells (also called macro cells), corresponding to sectors (each sector corresponding to one or several radio antennas pointing to the same direction) of a radio site.

In such a case, the method described above may be implemented at a radio site level or at a cell level, in order to either achieve de-centralized coordination between cooperating cells or between cooperating sites.

According to another embodiment of the invention, said communication network is a heterogeneous cloud radio access network comprising at least one macro cell and at least one small cell having at least partially overlapping coverage, and said nodes are central offices aggregating a base transceiver station of one of said macro cells, called a parent macro cell, and a baseband unit of one of said small cells having at least partially overlapping coverage with said parent macro cell, if any.

For example, the communication network is a hybrid C-RAN comprising macro-cells each associated to eNodeBs, and small cells whose coverage is overlapped with that of macrocells. Baseband units (BBUs) of small cells are positioned at a central office (CO), which is collocated with eNodeB of the parental macro cell. On the other hand, macro eNodeBs are inter-connected with legacy backhauls, and BBUs of macrocells are located at eNodeBs according to the conventional RAN architecture. In such a case, the method according to such an embodiment of the invention offers a de-centralized approach based on statistical performance metric, which can be applied to inter-site coordination in hybrid C-RAN.

The invention also concerns a computer program, in particular a computer program on or in an information medium or memory, suitable for implementing the method according to embodiments of the invention. This program can use any programming language, and be in the form of source code, object code, or of intermediate code between source code and object code such as in a partially compiled form, or in any other desirable form for implementing the configuration method according to the invention.

The information medium may be any entity or device capable of storing the programs. For example, the medium can comprise a storage means, such as a ROM, for example a CD ROM or a microelectronic circuit ROM, or else a magnetic recording means, for example a diskette (floppy disk) or a hard disk.

Moreover, the information medium may be a transmissible medium such as an electrical or optical signal, which may be conveyed via an electrical or optical cable, by radio or by other means. The program according to embodiments of the invention may in particular be downloaded from a network of Internet type.

The invention also concerns an access node, called a node-of-interest, belonging to a cluster of cooperating nodes of a communication network, said node-of-interest comprising:

- a sending unit for sending to neighbor nodes in said cluster a likelihood of transmission state of said node-of-interest;
- a receiving unit for receiving from said neighbor nodes in said cluster likelihoods of transmission state of said neighbor nodes;
- a computing unit for computing a statistical performance metric of said node-of-interest conditioned on its own likelihood of transmission state and a statistical performance metric of said node-of-interest conditioned on likelihoods of transmission state of said neighbor nodes in said cluster, called S2;

said sending unit also allowing sending to neighbor nodes in said cluster said statistical performance metric S2 and said receiving unit also allowing receiving from said neighbor nodes in said cluster corresponding statistical performance metrics of said neighbor nodes conditioned on said likelihood of transmission state of said node-of-interest ; and

- a deciding unit for determining a transmission state of said node-of-interest on the basis of said computed and received statistical performance metrics;
- a scheduling unit for scheduling user equipment served by said node-of-interest on the basis of said transmission state determined for said node-of-interest and on information relating to transmission states of said neighbor nodes in said cluster.

The invention further relates to a communication system comprising user equipment receiving and transmitting data from and to access nodes in a communication network,
said communication system comprising a cluster of cooperating nodes, comprising a node-of-interest and neighbor nodes,
said node-of-interest comprising:

- a sending unit for sending to said neighbor nodes a likelihood of transmission state of said node-of-interest;
- a receiving unit for receiving from said neighbor nodes likelihoods of transmission state of said neighbor nodes;
- a computing unit for computing a statistical performance metric of said node-of-interest conditioned on its own likelihood of transmission state and a statistical performance metric of said node-of-interest conditioned on likelihoods of transmission state of said neighbor nodes, called S2;

said sending unit also allowing sending to said neighbor nodes said statistical performance metric S2 and said receiving unit also allowing receiving from said neighbor nodes corresponding statistical performance metrics of said neighbor nodes conditioned on likelihoods of transmission state of their own neighbor nodes in said cluster; and

- a deciding unit for determining a transmission state of said node-of-interest on the basis of said computed and received statistical performance metrics;
- a scheduling unit for scheduling user equipment served by said node-of-interest on the basis of said transmission state determined for said node-of-interest and on information relating to transmission states of said neighbor nodes.

4. Brief description of the drawings

The invention can be better understood with reference to the following description and drawings, given by way of example and not limiting the scope of protection, and in which:

- Figure 1 illustrates inter-cell signaling according to a de-centralized Coordinated Scheduling method of the prior art;
- Figure 2 illustrates inter-cell signaling according to statistical coordinated multipoint scheduling based de-centralized coordination, according to an embodiment of the invention;
- Figure 3 shows the different steps of a method for scheduling in the homogeneous network of figure 2, according to an embodiment of the invention;
- Figure 4 illustrates a transmission state expurgation mechanism according to an embodiment of the invention;
- Figure 5 illustrates a known hybrid C-RAN architecture for a communication system comprising seven eNodeBs;
- Figure 6A and 6B respectively illustrate a cooperation cluster of dynamic eICIC according to the prior art and of enhanced eICIC according to an embodiment of the invention;
- Figure 7 illustrates a cluster of cells involved in performance metric calculation for a peculiar cell in the embodiment of figure 6B;
- Figure 8 shows the different steps of a method for scheduling in the hybrid C-RAN network of figure 5, according to an embodiment of the invention; and
- Figure 9 shows the structure of an access node implementing the methods of scheduling user equipment.

The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

5. Detailed description

Before the present invention is disclosed and described, it is to be understood that this invention is not limited to the particular structures, process steps, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular examples only and is not intended to be limiting. The same reference numerals in different drawings represent the same element. Numbers provided in flow charts and processes are provided for clarity in illustrating steps and operations and do not necessarily indicate a particular order or sequence.

a. Description of existing de-centralized CS (NSN)

Before presenting an embodiment of the invention, state-of-the-art de-centralized coordination method is first reviewed in relation to **Figure 1**, which shows a homogeneous network consisting of seven eNodeBs, denoted as *R-1, R-2, R-3, Y-1, Y-2, Y-3* and *B-1*, respectively. On **figure 1**, each eNodeB is illustrated by a set of three arrows with an angular spacing of 120°, along with a label showing its name. It is recalled that an eNodeB (for evolved Node B) plays the role of a base station in a mobile network implementing the LTE (for Long Term Evolution) or LTE Advanced standard. As such, eNodeBs behave as a gateway between the radio antennas and the core of the LTE network, also known as EPC (Evolved Packet Core).

There are 3 sectors (or cells) collocating in each eNodeB, labeled as α, β and γ. On **figure 1**, each sector, or cell is represented as a hexagon. For each eNodeB, one of the three arrows of the associated set of arrows points towards one of the three cells α, β and γ. Following notations are used throughout this document:

- $C_{B-1-\alpha}$ designates cell α of eNodeB *B-1*.
- $C_{B-1} = \{C_{B-1-\alpha}, C_{B-1-\beta}, C_{B-1-\gamma}\}$ are the co-sited cells of eNodeB *B-1*.
- $H_{B-1-\alpha}$ is the transmission state of cell-($B-1-\alpha$), with 0 indicating the cell is OFF and 1 indicating the cell is ON.
- $N(B-1-\alpha)$ designates the set of tier-1 neighbors of $C_{B-1-\alpha}$. It can be seen from Figure 1 that the neighbor set is:
  $N(B-1-\alpha) = \{C_{R-1-\beta}, C_{B-1-\beta}, C_{B-1-\gamma}, C_{R-3-\gamma}, C_{Y-1-\beta}, C_{Y-1-\gamma}\}$(1)

  The cells belonging to this neighbor set on **figure 1** are inside a dashed circle line.
- $\varphi(C_{B-1-\alpha} | H_{B-1-\alpha})$ is the performance metric of cell $C_{B-1-\alpha}$ conditioned on the transmission state hypothesis $H_{B-1-\alpha}$. For instance, it can be the proportional fair (PF) metric of $C_{B-1-\alpha}$.

In autonomous muting scheme, as described by R. Agrawal et al. in "Centralized and Decentralized Coordinated Scheduling with Muting," *IEEE VTC Spring*, 2014, each cell determines the transmission state to maximize the total performance metric of itself and its neighbors, given by:

$$H^*_{B-1-\alpha} = \arg\max_{H_{B-1-\alpha}} \left[\varphi\left(C_{B-1-\alpha} \middle| H_{B-1-\alpha}\right) + \sum_{c \in N(B-1-\alpha)} \varphi\left(c \middle| H_{B-1-\alpha}\right) \right]. \quad (2)$$

In equation (2), the first term on the right-hand-side (RHS) of the equation denotes the performance metric (PM) of cell $C_{B-1-\alpha}$ and the second term on the RHS is the performance metric of neighbor cells. Neighbor cell PMs can be obtained via inter-cell signaling, as illustrated by the arrows pointing towards cell $C_{B-1-\alpha}$ in **Figure 1**, and coming from cells$C_{Y-1-\gamma}$, $C_{Y-1-\beta}$, $C_{R-3-\gamma}$, $C_{B-1-\gamma}$, $C_{B-1-\beta}$ and $C_{R-1-\beta}$.

The inherent drawback with autonomous muting scheme is the difficulty in calculating the performance metric PM of a cell conditioned only on the transmission state of the cell-of-interest $C_{B-1-\alpha}$. For example, PM of cell $C_{B-1-\alpha}$ depends not only on $H_{B-1-\alpha}$, but also on the transmission states of neighbor cells $c \in N(B-1-\alpha)$. Hence, the explicit calculation of PM should be $\varphi\left(C_{B-1-\alpha} \middle| H_{B-1-\alpha}, H_{N(B-1-\alpha)}\right)$.

The issue with employing explicit PM value is that decision does not depend on the local cell transmission state only, which prohibits the de-centralized implementation. To circumvent the inherent problem, it is assumed in R. Agrawal et al., "Centralized and Decentralized Coordinated Scheduling with Muting," *IEEE VTC Spring*, 2014, that all other cells are ON except for the cell-of-interest $C_{B-1-\alpha}$ when calculating the PMs for the decision on $H_{B-1-\alpha}$. As a result, PM values in equation (2) are approximated as:

$$\varphi\left(C_{B-1-\alpha} \middle| H_{B-1-\alpha}\right) \approx \varphi\left(C_{B-1-\alpha} \middle| H_{B-1-\alpha}, H_{N(B-1-\alpha)}) = \mathbf{1}\right) \quad (3)$$

$$\varphi\left(c \middle| H_{B-1-\alpha}\right) \approx \varphi\left(c \middle| H_{B-1-\alpha}, H_{(c \cup N(c)) \setminus (B-1-\alpha)} = \mathbf{1}\right), \forall c \in N(B-1-\alpha). \quad (4)$$

Nevertheless, this assumption could be violated if other cells decide to mute in coming frames, which makes PM values used by cell $C_{B-1-\alpha}$ biased and the so-obtained decision becomes suboptimal.

b. <u>Proposed de-centralized CoMP with statistical performance optimization</u>

(i) Formulation of de-centralized coordination optimizing statistical performance

In an attempt to overcome the problem of employing both explicit PM values and biased PM in autonomous muting, an embodiment of the invention relies on a new performance metric and an innovative de-centralized resource coordination scheme with the newly defined PM. The new PM should satisfy the following two criteria:

- The performance metric is explicitly dependent on the transmission state of cell-of-interest only to allow for local decision made by the de-centralized controller.
- Neighbor cell transmission state should be implicitly accounted for in the performance metric whereby the de-centralized decision is made based on the likely transmission states of cooperating cells.

To this end, an embodiment of the invention introduces a statistical PM which is the expected cell performance metric conditioned only on the transmission state of the cell-of-interest by averaging over the transmission states of all other cells, given by

$$\widetilde{\varphi}\left(C_{B-1-\alpha}\middle|H_{B-1-\alpha}\right)=E_{H_{N(B-1-\alpha)}}\left[\varphi\left(C_{B-1-\alpha}\middle|H_{B-1-\alpha},H_{N(B-1-\alpha)}\right)\right] \quad (5)$$

$$\widetilde{\varphi}\left(c\middle|H_{B-1-\alpha}\right)=E\left[\varphi\left(c\middle|H_{B-1-\alpha},H_{(c\bigcup N(c))\backslash(B-1-\alpha)}\right)\right],\ \forall c\in N(B-1-\alpha) \quad (6)$$

In equation (6), the expectation is taken w.r.t. transmission states $H_{(c\bigcup N(c))\backslash(B-1-\alpha)}$, which is the joint transmission state of cell c and neighbors of c excluding cell-($B-1-\alpha$)

Correspondingly, transmission state of cell $C_{B-1-\alpha}$ is chosen to optimize the overall statistical performance metrics as:

$$H^{*}_{B-1-\alpha}=arg\max_{H_{B-1-\alpha}}\left[\widetilde{\varphi}\left(C_{B-1-\alpha}\middle|H_{B-1-\alpha}\right)+\sum_{c\in N(B-1-\alpha)}\widetilde{\varphi}\left(c\middle|H_{B-1-\alpha}\right)\right]. \quad (7)$$

In equation (7), $\widetilde{\varphi}\left(C_{B-1-\alpha}\middle|H_{B-1-\alpha}\right)$ is the cell-of-interest PM calculated over all likelihood of neighbor cell transmission states, given by:

$$\begin{aligned}\widetilde{\varphi}\left(C_{B-1-\alpha}\middle|H_{B-1-\alpha}\right)&=E_{H_{N(B-1-\alpha)}}\left[\varphi\left(C_{B-1-\alpha}\middle|H_{B-1-\alpha},H_{N(B-1-\alpha)}\right)\right]\\&=\sum\nolimits_{H_{N(B-1-\alpha)}}\varphi\left(C_{B-1-\alpha}\middle|H_{B-1-\alpha},H_{N(B-1-\alpha)}\right)\cdot P\left(H_{N(B-1-\alpha)}\right)\end{aligned}, \quad (8)$$

where $P\left(H_{N(B-1-\alpha)}\right)$ is the joint probability of transmission states for neighbor cells $c\in N(B-1-\alpha)$.

As each cell decides on the radio resource usage independently in de-centralized coordinated scheduling, the joint probability can be calculated by multiplying the transmission state likelihoods associated with each cell as:

$$P\left(H_{N(B-1-\alpha)}\right)=P\left(H_{R-1-\beta}\right)\ P\left(H_{B-1-\beta}\right)\ P\left(H_{B-1-\gamma}\right)\ P\left(H_{R-3-\gamma}\right)\ P\left(H_{Y-1-\beta}\right)\ P\left(H_{Y-1-\gamma}\right) \quad (9)$$

(ii) Signaling in support of an embodiment of the invention

New inter-cell signaling is needed to support the proposed scheme. **Figure 2** shows the coordination messages that cell $C_{B-1-\alpha}$ receives from cooperating cells, i.e., its tier-1 neighbors (i.e. cells located inside the dashed circle line on **figure 2**), which comprise two pieces of information of cell $c \in N(B-1-\alpha)$:

(S1) Cell transmission state likelihood $P(H_c = 0)$ and $P(H_c = 1)$.

(S2) Statistical performance metric $\tilde{\varphi}(c|H_{B-1-\alpha})$ conditioned on $H_{B-1-\alpha}$.

Such coordination messages are illustrated by the arrows pointing towards cell $C_{B-1-\alpha}$ in **Figure 2**, and coming from cells $C_{Y-1-\gamma}$, $C_{Y-1-\beta}$, $C_{R-3-\gamma}$, $C_{B-1-\gamma}$, $C_{B-1-\beta}$ and $C_{R-1-\beta}$.

Information (S1) is needed for cell $C_{B-1-\alpha}$ to calculate the statistical performance metric $\tilde{\varphi}(C_{B-1-\alpha}|H_{B-1-\alpha})$ according to equation (8), as well as the statistical PM to be sent to cooperating cells, e.g., $\tilde{\varphi}(C_{B-1-\alpha}|H_{R-1-\beta})$.

Information (S2) is used by the local coordinator in determining transmission state $H_{N(B-1-\alpha)}$ as in equation (7).

The following example pertaining to cell $C_{B-1-\gamma}$ illustrates the way neighbor cells can calculate information (S2).

$$\begin{aligned}\tilde{\varphi}(C_{B-1-\gamma}|H_{B-1-\alpha}) &= E_{H_{\overline{B-1-\alpha}}}\left[\varphi(C_{B-1-\gamma}|H_{B-1-\alpha}, H_{\overline{B-1-\alpha}})\right] \\ &= \sum\nolimits_{H_{\overline{B-1-\alpha}}} \varphi(C_{B-1-\gamma}|H_{B-1-\alpha}, H_{\overline{B-1-\alpha}}) \cdot P(H_{\overline{B-1-\alpha}})\end{aligned}, \quad (10)$$

where $\overline{B-1-\alpha} = (C_{B-1-\gamma} \cup N(B-1-\gamma)) \setminus C_{B-1-\alpha}$ is the complement set of cell $C_{B-1-\alpha}$. It can be seen in **Figure 2** that the complement set is given by

$$\overline{B-1-\alpha} = \{C_{R-1-\beta}, C_{Y-2-\alpha}, C_{Y-2-\beta}, C_{R-2-\beta}, C_{B-1-\beta}, C_{B-1-\gamma}\}. \quad (11)$$

(iii) Autonomous muting algorithm with statistical performance optimization

Figure 3 presents the statistical de-centralized coordination procedures for a three-cell cluster comprising Cell 1, Cell 2 and Cell 3.The one skilled in the art will easily extend the teachings of this example to a cluster comprising a greater number of cells.

- Cells exchange the likelihoods of transmission state, i.e., information (S1) (step 30);
- With information (S1) received from neighbor cells, each cell calculates the following performance metrics:
  - Statistical PM of the cell conditioned on its own transmission state, according to equation (8).
  - Statistical PM of the cell conditioned on neighbor cell transmission state, i.e., information (S2), following the principle of equation (10).

  Such operations are implemented in step 31 for Cell 1, step 32 for Cell 2 and step 33 for Cell 3.
- Cells exchange statistical PM values corresponding to information (S2) in step 34.

Based on statistical PM calculated and received from neighbor cells (note all these PMs are conditioned only on the transmission state of the local cell), each cell determines its transmission state resulting in the largest sum statistical PM. Such operations are implemented in step 35 for Cell 1, step 36 for Cell 2 and step 37 for Cell 3.

- There can be two alternative ways of performance coordinated scheduling with the transmission state determined in the previous step.
  - According to a first embodiment (Alt. 1), each cell schedule users given the transmission state determined from the previous step and the likelihoods of neighbor cell transmission states (i.e., information (S1)). Such operations are implemented in step 38 for Cell 1, step 39 for Cell 2 and step 40 for Cell 3.
  - According to a second embodiment (Alt. 2), cells exchange the transmission state they have selected (step 41) and then each cell schedules users according to the transmission states of itself as well as of neighbor cells (step 42 for Cell 1, step 43 for Cell 2 and step 44 for Cell 3).

In the second embodiment, LTE scheduler can accurately estimate user SINR (Signal to Interference plus Noise ratio) and scheduling priorities with explicit knowledge of cell cluster transmission states. Nevertheless, signaling of transmission state information is needed and this signaling is constrained by the end-to-end backhaul latency between cells in legacy networks.

The first embodiment is not constrained by this additional backhaul latency but only statistical likelihood information of neighbor cell transmission states is accessible to LTE scheduler, which may impact the scheduler performance.

Signaling (S1) can be obtained by calculating the relative frequency of cell transmission state within a time window. In this sense, it could be a long-term statistics and might not be updated in every coordination cycle. Therefore, it is not constrained by end-to-end backhaul latency.

(iv) Alternate embodiment of the invention

To obtain the statistical performance metric of a cell, the PM function must be evaluated over all possible transmission states of a number of cooperating cells. Therefore, the complexity is exponential w.r.t. the number of cells to marginalize over. For example, the complexity of calculating $\tilde{\varphi}\left(C_{B-1-\alpha} \middle| H_{B-1-\alpha}\right)$ is $O\left(2^{|N(B-1)|}\right)$. It is clear the computation load increases sharply w.r.t. the number of cells involved.

On the other hand, it should be noted that cell transmission states are not distributed uniformly, i.e., $P(H_c = 1) \neq P(H_c = 0), \forall c$. Therefore, some transmission states are associated with a much larger probability than others and these states are named as *survivors* hereafter. An accurate approximation of the statistical PM can then be obtained by marginalizing the PM function over these survivor states. The algorithm presented below allows to quickly obtain the survivor states with dominant probabilities, by expurgating all states whose probability is below a system-defined parameter ε.

Subroutines of computing dominant transmission states

$survivor = \phi, \quad P\_survivor = 1;$

Traverse all nodes in the cell cluster

Pick *c* from the cell cluster

len_child = 0;

FOR $ii = 1$ **TO** $length(survivor)$

$left\_child = [survivor(ii),\ \ 1], \quad P\_left\_child = P\_survivor(ii)\ \ P(H_c = 1)$

$right\_child = [survivor(ii),\ \ 0], \quad P\_right\_child = P\_survivor(ii)\ \ P(H_c = 0)$

IF $P\_left\_child < \varepsilon$

THEN discard*left_child*

ELSE *len_child* +=1, *survivor_child(len_child) = left_child,*

P_survivor_child(len_child) = P_left_child

IF $P\_right\_child < \varepsilon$

THEN discard*right_child*

ELSE *len_child* +=1, *survivor_child(len_child) = right_child,*

P_survivor_child(len_child) = P_right_child

END

survivor = survivor_child, *P_survivor = P_survivor_child*

END of cell traverse

Output dominant state *survivor* and the corresponding probability *P_survivor*

Figure 4 shows an example of locating *survivor* states for a four-cell cluster comprising cells a, b, c and d. The man skilled in the art will easily adapt this example to a cluster comprising any other number of cells. The transmission state likelihood associated with each cell is specified as in Table I. The state-expurgation threshold is set as $\varepsilon = 0.01$, whereby transmission state whose likelihood is above this threshold will be retained. Otherwise it will be discarded.

	a	b	c	d
$P(H_i = 1)$	0.95	0.95	0.9	0.9
$P(H_i = 0)$	0.05	0.05	0.1	0.1

Table I: cell transmission state probability

In **Figure 4**, a binary tree is used to represent all possible transmission states for a four-cell cluster. On each level, leaf nodes denote the composite transmission states of cells up to this level. It is stipulated the left child of each leaf node corresponds to the 'ON' status for the cell, while the right child is for the 'OFF' state. The likelihood of leaf nodes can be calculated by multiplying all probability figures associated with the paths from the top to the leaf node.

On each level, the probability of leaf nodes is compared against the expurgation threshold $\varepsilon = 0.01$. If the associated probability is below the threshold, the leaf node will be discarded, so are all the children of this node. Running the state expurgation routine over the binary tree in **Figure 4**, we can locate five survivor states (the five striped leaf nodes on the bottom of Figure 4). The cumulative probability of these five survivors is 0.97, hence they can be used to accurately calculate the statistical PM.

With the state expurgation mechanism, only the most probable transmission states of cooperating cells will be taken into account by resource coordination module. The advantage is that the computing complexity can be drastically reduced. In addition to using a state-expurgation threshold, it is also possible to set a maximum number on the survivor states for complexity reduction.

c. <u>De-centralized coordination in eICIC for hybrid C-RAN</u>

(i) State-of-art dynamic eICIC

The above-described de-centralized approach based on statistical PM can also be applied to inter-site coordination in hybrid Cloud RAN (or C-RAN for Radio Access Network). **Figure 5** shows a hybrid C-RAN system consisting of seven eNodeBs denoted as *R-1, R-2, R-3, Y-1, Y-2, Y-3* and *B-1*, respectively. Like in figure 1, each eNodeB is illustrated by a set of three arrows with an angular spacing of 120°, along with a label showing its name. There are three collocated macrocells in each eNodeB, labeled as α , β and γ. On **figure 5**, each macrocell is represented as a hexagon. For each eNodeB, one of the three arrows of the associated set of arrows points towards one of the three cells α , β and γ.

There are also a number of low-power small cell nodes (denoted by black triangles in **figure 5**) whose coverage is overlapped with that of macrocells. It is actually recalled that in heterogeneous or hybrid networks (HetNet), small cells are introduced, as a complement to macro cells. Such low power nodes (i.e. femto, pico, relay nodes) allow to significantly offload the traffic from macro cells, and to enhance the network coverage and throughput. However, macrocells and small cells share the same LTE spectrum, which allows increasing the spectral efficiency, but also gives rise to cross-tier interference in the downlink.

It must be noted that, throughout this document, the terms "small cell" designate any cell, which is smaller than a conventional macro cell served by a macro base station, as described in the LTE standard: for example, such a small cell may be a pico cell for in-building coverage, or a femto cell served by an access point, which is called a Home Node B (HeNB). More precisely, an heterogeneous network as described in this document usually comprises macro eNodes B (eNBs), which are deployed for initial coverage of the network by macro cells, and pico access nodes or HeNBs, which serve small cells, and are added to the network for capacity growth and better user experience.

Cloud RAN architecture is assumed by the small cell layer and black triangles in **Figure 5** stand for the antennas and remote radio heads (RRHs) of low-power nodes. Baseband units (BBUs) of small cells are detached from RRHs and are positioned at a central office (CO), which is collocated with eNodeB of the parental macrocell. Small cell RRHs are connected to CO via high-bandwidth, low-latency transport links which are named as fronthaul (solid curves linking a black triangle, i.e. a small cell RRH, to a macro eNodeB in **Figure 5**). Signals received by RRHs are filtered and digital samples are sent over fronthaul to CO for processing.

Since small cell CO is collocated with macro eNodeB, centralized scheduling can be implemented for co-sited macrocells and overlaid small cells. On the other hand, backhauls between macro eNodeBs (dashed lines linking macro eNodeBsin **Figure 5**) are non-ideal in terms of bandwidth and latency. This prevents joint scheduling of macrocells and small cell COs at different sites.

InJ. Wang et.al., "Enhanced Dynamic Inter-cell Interference Coordination Schemes for LTE-Advanced," *IEEE VTC Spring*, 2012, a dynamic eICIC (for enhanced Inter-Cell Interference Coordination) scheme is presented to jointly determine the almost blank sub-frame (ABS) patterns of co-sited macrocells. It is recalled that an ABS is characterized by minimum transmission, where just the most essential information required for the system is transmitted. By using so-called ABS, a base station thus reduces the interference to its surrounding neighbors. **Figure 6A** shows the cooperation cluster of dynamic eICIC for eNodeB-(*B-1*)(shown as the three hexagons located roughly inside the dashed circle line), which is confined to three co-sited macrocells (i.e., $C_{B-1-\alpha}$, $C_{B-1-\beta}$ and $C_{B-1-\gamma}$) and small cells aggregated at the same site.

Figure 6A hence corresponds to prior art. By denoting those (macro+small) cells as Q_{B-1} , dynamic eICIC scheme can be formulated as:

$$H_{B-1}^{*} = \underset{H_{B-1}}{\arg\max} \sum\nolimits_{c \in Q_{B-1}} \varphi(c|H_{B-1}) \qquad (12)$$

(ii) eICIC with statistical PM optimization

Two drawbacks are noted for the dynamic eICIC in the prior art:

- Transmission status H_{B-1}^{*} not only affects the performance of cells $c \in Q_{B-1}$, but also those in the coverage of neighbor (macro)-sites. Inter-sites cells subject to the interference of eNodeB-(*B-1*) are marked with circles in **Figure 6B**. To select $\boldsymbol{H_{B-1}^{*}}$ resulting in overall optimum performance, performance of these cells should also be taken into account.
- Explicit calculation of $\varphi(c|H_{B-1})$ is difficult, and in the implementation the approximation $\varphi(c|H_{B-1}) \approx \varphi(c|H_{B-1}, H_{N(B-1)} = \mathbf{1})$ is assumed. As discussed in previous sections, this approximation is biased and may compromise the performance.

According to an embodiment of the invention, eICIC for hybrid C-RAN is enhanced by taking into account performance of both macro and small cells in neighbor sites and employing statistical performance optimization. The new eICIC scheme then chooses the transmission state that optimizes the overall statistical performance of the cooperation cluster as:

$$H_{B-1}^{*} = \underset{H_{B-1}}{\arg\max} \sum\nolimits_{c \in Q_{B-1}} \tilde{\varphi}(c|H_{B-1}) + \sum\nolimits_{q \in Q_{N(B-1)}} \tilde{\varphi}(q|H_{B-1}). \qquad (13)$$

In equation (13), the first sum on the right hand side stands for the statistical PM of cells in the coverage of eNodeB-(*B-1*), and the second sum denotes the performance of cells in the coverage of neighbor sites.

(iii) Calculation of statistical PM for cells $c \in Q_{B-1}$

$$\begin{aligned}\tilde{\varphi}(c|H_{B-1}) &= E_{H_{N(B-1)}}\left[\varphi(c|H_{B-1}, H_{N(B-1)})\right] = \sum_{H_{N(B-1)}} \varphi(c|H_{B-1}, H_{N(B-1)}) \cdot P(H_{N(B-1)}) \\ &= \sum_{H_{N(B-1)}} \varphi(c|H_{B-1}, H_{Y-1}, H_{Y-2}, H_{Y-3}, H_{R-1}, H_{R-2}, H_{R-3}) \\ &\quad \cdot P(H_{Y-1}) \cdot P(H_{Y-2}) \cdot P(H_{Y-3}) \cdot P(H_{R-1}) \cdot P(H_{R-2}) \cdot P(H_{R-3})\end{aligned} \quad ,(14)$$

where the third equality is obtained by noting that tier-1 neighbor sites of eNodeB-(*B-1*) are $N(B-1) = \{Y-1, Y-2, Y-3, R-1, R-2, R-3\}$ and transmission state of each site is determined independently. It is also noted that performance of eNodeB-(*B-1*) is only affected by a subset of cells in the neighbor sites. For instance in site-(*Y-2*), cell $C_{Y-2-\alpha}$ and $C_{Y-2-\beta}$ are interfering with cells in eNodeB-(*B-1*), while cell $C_{Y-2-\gamma}$ causes little interference to cell *c and* is not considered. Based on this observation, the relevant neighbor site transmission states and the associated likelihoods in equation (14) can be defined as below.

$$H_{Y-1} \leftarrow \{H_{Y-1-\beta}, H_{Y-1-\gamma}\} \qquad P(H_{Y-1}) \leftarrow P(H_{Y-1-\beta}, H_{Y-1-\gamma}) \qquad (15)$$

$$H_{Y-2} \leftarrow \{H_{Y-2-\alpha}, H_{Y-2-\beta}\} \qquad P(H_{Y-2}) \leftarrow P(H_{Y-2-\alpha}, H_{Y-2-\beta}) \qquad (16)$$

$$H_{Y-3} \leftarrow \{H_{Y-3-\alpha}, H_{Y-3-\gamma}\} \qquad P(H_{Y-3}) \leftarrow P(H_{Y-3-\alpha}, H_{Y-3-\gamma}) \qquad (17)$$

$$H_{R-1} \leftarrow H_{R-1-\beta} \qquad P(H_{R-1}) \leftarrow P(H_{R-1-\beta}) \qquad (18)$$

$$H_{R-2} \leftarrow H_{R-2-\alpha} \qquad P(H_{R-2}) \leftarrow P(H_{R-2-\alpha}) \qquad (19)$$

$$H_{R-3} \leftarrow H_{R-3-\gamma} \qquad P(H_{R-3}) \leftarrow P(H_{R-3-\gamma}) \qquad (20)$$

(iv) Calculation of statistical PM for cells $c \in Q_{N(B-1)}$

An example of how to calculate the statistical performance for neighbor cells $Q_{R-3-\gamma}$ is presented below. Similarly, performance of these macro and small cells is determined by the resource usage of themselves as well as their tier-1 neighbors (located inside dashed circle line 70 in **Figure 7**).

The statistical PM of $Q_{R-3-\gamma}$ is then given by:

$$\tilde{\phi}\left(Q_{R-3-\gamma} \middle| H_{B-1}\right) = \quad \phi\left(Q_{R-3-\gamma} \middle| H_{B-1}, H_{Y-1-\beta}, H_{Y-3-\alpha}, H_{R-3}\right) \; P\left(H_{Y-1-\beta}\right) \; P\left(H_{Y-3-\alpha}\right) \; P\left(H_{R-3}\right). \qquad (21)$$

Such a calculation according to equation (21) must be operated for every neighbor cell of site-(*B-1*) $c \in Q_{N(B-1)}$, i.e. all cells marked with circles in **Figure 6B and 7.**

Figure 8 presents schematically the steps of the method for scheduling user equipment according to an embodiment of the invention in the context of eICIC for hybrid C-RAN with statistical performance optimization, when considering three sites, namely Site-R, Site-Y and Site-B. The one skilled in the art will easily extend the teachings of this example to a greater number of sites.

- Sites exchange the likelihoods of sites' transmission states (step 80);
- With information received from neighbor sites, each site calculates the following performance metrics:
  - Statistical PM of the site conditioned on its own transmission state.
  - Statistical PM of the site conditioned on neighbor sites' transmission state.

  Such operations are implemented in step 81 for Site-R, step 82 for Site-Y and step 83 for Site-B.
- Sites exchange statistical PM values with respect to different transmission state hypothesis in step 84.

Based on statistical PM calculated and received from neighbor sites, each site determines its transmission state resulting in the largest statistical sum PM. Such operations are implemented in step 85 for Site-R, step 86 for Site-Y and step 87 for Site-B.

- Each site then schedule users given the transmission state determined from the previous step and the likelihoods of neighbor sites transmission states. Such operations are implemented in step 88 for Site-R, step 89 for Site-Y and step 90 for Site-B.

Figure 9 shows the structure of an access node implementing the methods of scheduling user equipment as described above.

The access node shown on **figure 9**, also called a node-of-interest, comprises a sending unit Tx 91, which sends a likelihood of its own transmission state to neighbor nodes in a cluster of cooperating nodes of a communication network.

It also comprises a receiving unit 92, which receives from these neighbor nodes their own likelihoods of transmission state.

The access node of **figure 9** further comprises a computing unit µP 93 for computing a statistical performance metric of the node-of-interest conditioned on its own likelihood of transmission state and a statistical performance metric of the node-of-interest conditioned on likelihoods of transmission state of the neighbor nodes in the cluster, called S2.

The sending unit Tx 91 also allows sending to neighbor nodes in the cluster the statistical performance metric S2. Correspondingly, the receiving unit Rx 92 also allows receiving from the neighbor nodes in the cluster corresponding statistical performance metrics of the neighbor nodes conditioned on transmission state of node-of-interest .

In a particular embodiment (i.e., Alt.1 in Figure 3), the sending unit Tx 91 also allows sending to neighbor cells in the cluster the transmission state of said node-of-interest, the receiving unit Rx 92 also allows receiving from the neighbor nodes in the cluster the transmission state of neighbor nodes in the cluster.

The access node of figure 9 also comprises a deciding unit DEC 94 for determining a transmission state of said node-of-interest on the basis of said computed and received statistical performance metrics respectively received from the receiving unit Rx 92 and from the computing unit µP 93.

A scheduling unit SCH 95 allows scheduling user equipment served by the access node of figure 9 on the basis of the transmission state determined by the deciding unit DEC 94 and on information relating to transmission states of said neighbor nodes in said cluster.

In a particular embodiment, the deciding unit DEC 94 provides the sending unit Tx 91 with the transmission state it has determined for the node-of-interest, in order for the sending unit Tx 91 to send it to neighbor nodes.

Embodiments of the invention described above are directed to methods and apparatus to enhance de-centralized coordination between cooperating nodes (e.g., cells, sites, cluster of cells etc). A statistical performance-based approach is proposed to model the optimization object function for resource coordination. By doing this, the overall performance of the cooperation cluster can be described as a function of a local node transmission state which lends itself to de-centralized implementation.

The de-centralized coordination approach can be applied to the base stations in the homogenous networks to enable autonomous muting. It is also applicable to the central office (where macro and small cell BBUs are aggregated) in hybrid C-RAN systems to enable inter-site coordination. In both scenarios, new inter-site signaling including transmission state likelihood and statistical performance metric associated with neighbor nodes are defined.

CLAIMS

1. A method for scheduling user equipment in an access node of a communication network comprising several access nodes,

the method comprising, for at least one of said nodes, called a node-of-interest, belonging to a cluster of cooperating nodes:

- sending to neighbor nodes in said cluster a likelihood of transmission state of said node-of-interest and receiving from said neighbor nodes in said cluster likelihoods of transmission state of said neighbor nodes;
- computing a statistical performance metric of said node-of-interest conditioned on its own likelihood of transmission state;
- computing a statistical performance metric of said node-of-interest conditioned on likelihoods of transmission state of said neighbor nodes in said cluster, called S2;
- sending to neighbor nodes in said cluster said statistical performance metric S2 and receiving from said neighbor nodes in said cluster corresponding statistical performance metrics of said neighbor nodes conditioned on said likelihood of transmission state of said node-of-interest ;
- determining a transmission state of said node-of-interest on the basis of said computed and received statistical performance metrics;
- scheduling user equipment served by said node-of-interest on the basis of said transmission state determined for said node-of-interest and on information relating to transmission states of said neighbor nodes in said cluster.

2. The method of claim 1, wherein said information relating to transmission states of said neighbor nodes in said cluster comprises said likelihoods of transmission state of said neighbor nodes in said cluster.

3. The method of claim 1, wherein it also comprises sending to said neighbor nodes in said cluster said transmission state determined for said node-of-interest and receiving from said neighbor nodes in said cluster corresponding transmission states determined by and for said neighbor nodes on the basis of computed and received statistical performance metrics,

and wherein said information relating to transmission states of said neighbor nodes in said cluster comprises said transmission states determined by and received from said neighbor nodes in said cluster.

4. The method of claim 1, wherein said transmission state determined for said node-of-interest maximizes a sum of the statistical performance metrics of said node-of-interest and of said neighbor nodes in said cluster.

5. The method of any preceding claim, wherein it also comprises a state expurgation mechanism allowing taking into account only the most probable transmission states of said nodes in said cluster, called survivor states.

6. The method of claim 5, wherein said state expurgation mechanism relies on a defined state-expurgation threshold, and wherein said survivor states are the transmission states of said nodes in said cluster whose likelihood is above said threshold.

7. The method of claim 5 or 6, wherein it also comprises setting a maximum number of survivor states.

8. The method of any preceding claim, wherein said communication network is a homogeneous network, and wherein said nodes are base transceiver stations of said homogeneous network.

9. The method of any of claims 1 to 7, wherein said communication network is a heterogeneous cloud radio access network comprising at least one macro cell and at least one small cell having at least partially overlapping coverage, and wherein said nodes are central offices aggregating a base transceiver station of one of said macro cells, called a parent macro cell, and a baseband unit of one of said small cells having at least partially overlapping coverage with said parent macro cell, if any.

10. Computer program characterized in that it comprises program code instructions for the implementation of the method for scheduling user equipment of any of claims 1 to 9 when the program is executed by a processor.

11. Access node, called a node-of-interest, belonging to a cluster of cooperating nodes of a communication network,

said node-of-interest comprising:

- a sending unit for sending to neighbor nodes in said cluster a likelihood of transmission state of said node-of-interest;
- a receiving unit for receiving from said neighbor nodes in said cluster likelihoods of transmission state of said neighbor nodes;
- a computing unit for computing a statistical performance metric of said node-of-interest conditioned on its own likelihood of transmission state and a statistical

performance metric of said node-of-interest conditioned on likelihoods of transmission state of said neighbor nodes in said cluster, called S2;

said sending unit also allowing sending to neighbor nodes in said cluster said statistical performance metric S2 and said receiving unit also allowing receiving from said neighbor nodes in said cluster corresponding statistical performance metrics of said neighbor nodes conditioned on said likelihood of transmission state of said node-of-interest; and

- a deciding unit for determining a transmission state of said node-of-interest on the basis of said computed and received statistical performance metrics;
- a scheduling unit for scheduling user equipment served by said node-of-interest on the basis of said transmission state determined for said node-of-interest and on information relating to transmission states of said neighbor nodes in said cluster.

12. Communication system comprising user equipment receiving and transmitting data from and to access nodes in a communication network,

said communication system comprising a cluster of cooperating nodes, comprising a node-of-interest and neighbor nodes,

wherein said node-of-interest comprises:

- a sending unit for sending to said neighbor nodes a likelihood of transmission state of said node-of-interest;
- a receiving unit for receiving from said neighbor nodes likelihoods of transmission state of said neighbor nodes;
- a computing unit for computing a statistical performance metric of said node-of-interest conditioned on its own likelihood of transmission state and a statistical performance metric of said node-of-interest conditioned on likelihoods of transmission state of said neighbor nodes, called S2;

said sending unit also allowing sending to said neighbor nodes said statistical performance metric S2 and said receiving unit also allowing receiving from said neighbor nodes corresponding statistical performance metrics of said neighbor nodes conditioned on said likelihood of transmission state of said node-of-interest; and

- a deciding unit for determining a transmission state of said node-of-interest on the basis of said computed and received statistical performance metrics;
- a scheduling unit for scheduling user equipment served by said node-of-interest on the basis of said transmission state determined for said node-of-interest and on information relating to transmission states of said neighbor nodes.

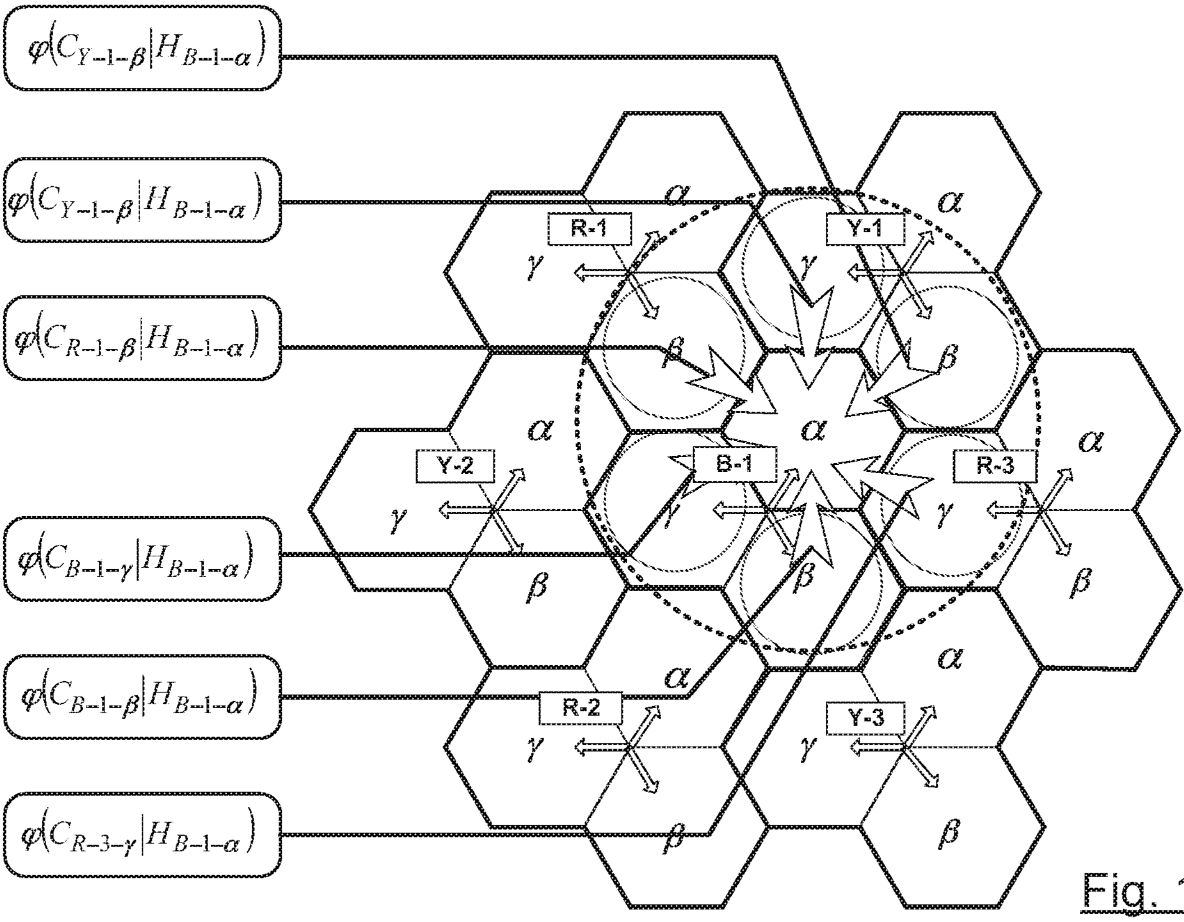
$\varphi(C_{Y-1-\beta}|H_{B-1-\alpha})$
$\varphi(C_{Y-1-\beta}|H_{B-1-\alpha})$
$\varphi(C_{R-1-\beta}|H_{B-1-\alpha})$
$\varphi(C_{B-1-\gamma}|H_{B-1-\alpha})$
$\varphi(C_{B-1-\beta}|H_{B-1-\alpha})$
$\varphi(C_{R-3-\gamma}|H_{B-1-\alpha})$
R-1
Y-1
Y-2
B-1
R-3
R-2
Y-3
α
β
γ

Fig. 1

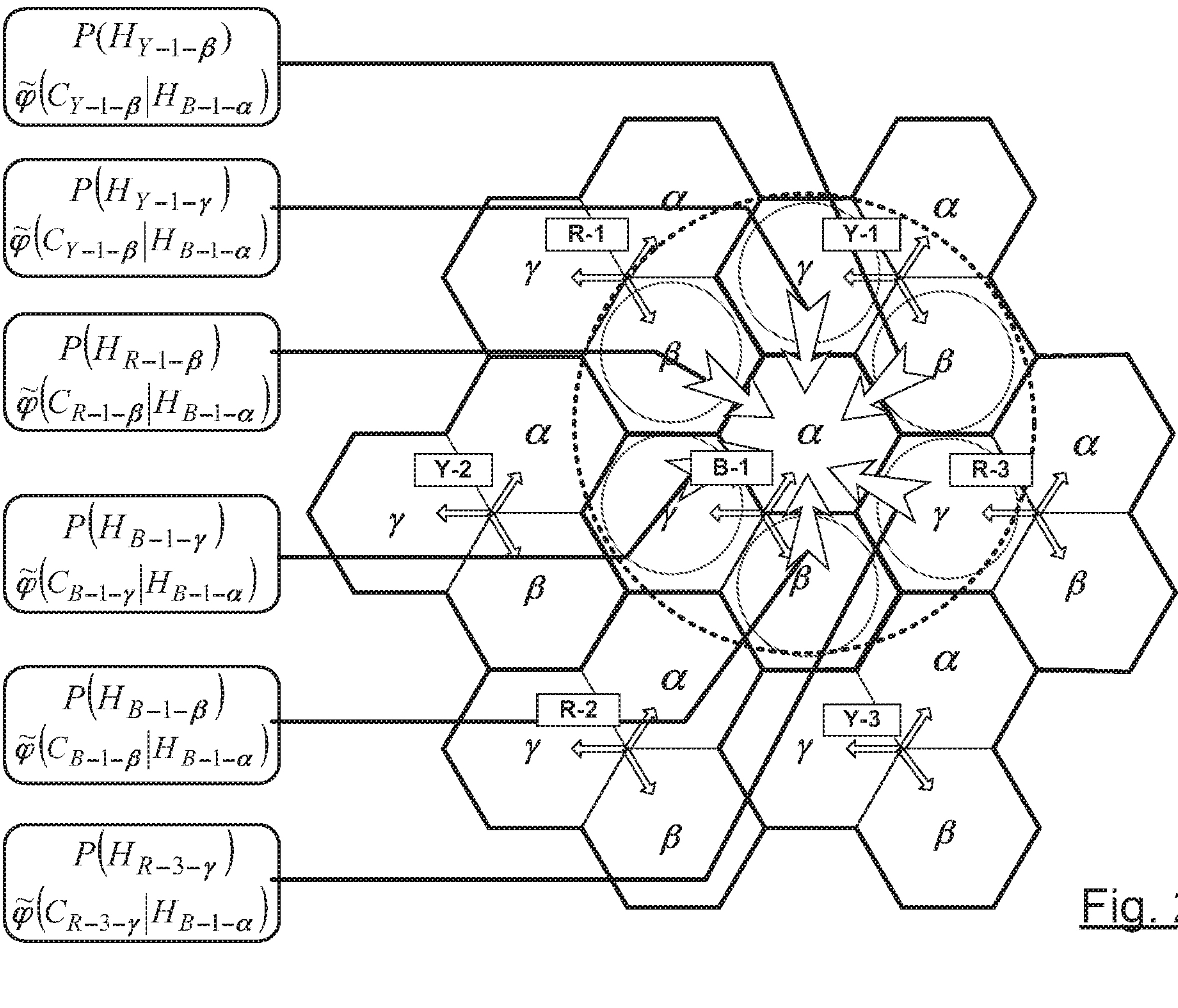
$P(H_{Y-1-\beta})$
$\tilde{\varphi}(C_{Y-1-\beta}|H_{B-1-\alpha})$
$P(H_{Y-1-\gamma})$
$\tilde{\varphi}(C_{Y-1-\beta}|H_{B-1-\alpha})$
$P(H_{R-1-\beta})$
$\tilde{\varphi}(C_{R-1-\beta}|H_{B-1-\alpha})$
$P(H_{B-1-\gamma})$
$\tilde{\varphi}(C_{B-1-\gamma}|H_{B-1-\alpha})$
$P(H_{B-1-\beta})$
$\tilde{\varphi}(C_{B-1-\beta}|H_{B-1-\alpha})$
$P(H_{R-3-\gamma})$
$\tilde{\varphi}(C_{R-3-\gamma}|H_{B-1-\alpha})$
R-1
Y-1
Y-2
B-1
R-3
R-2
Y-3
α
β
γ

Fig. 2

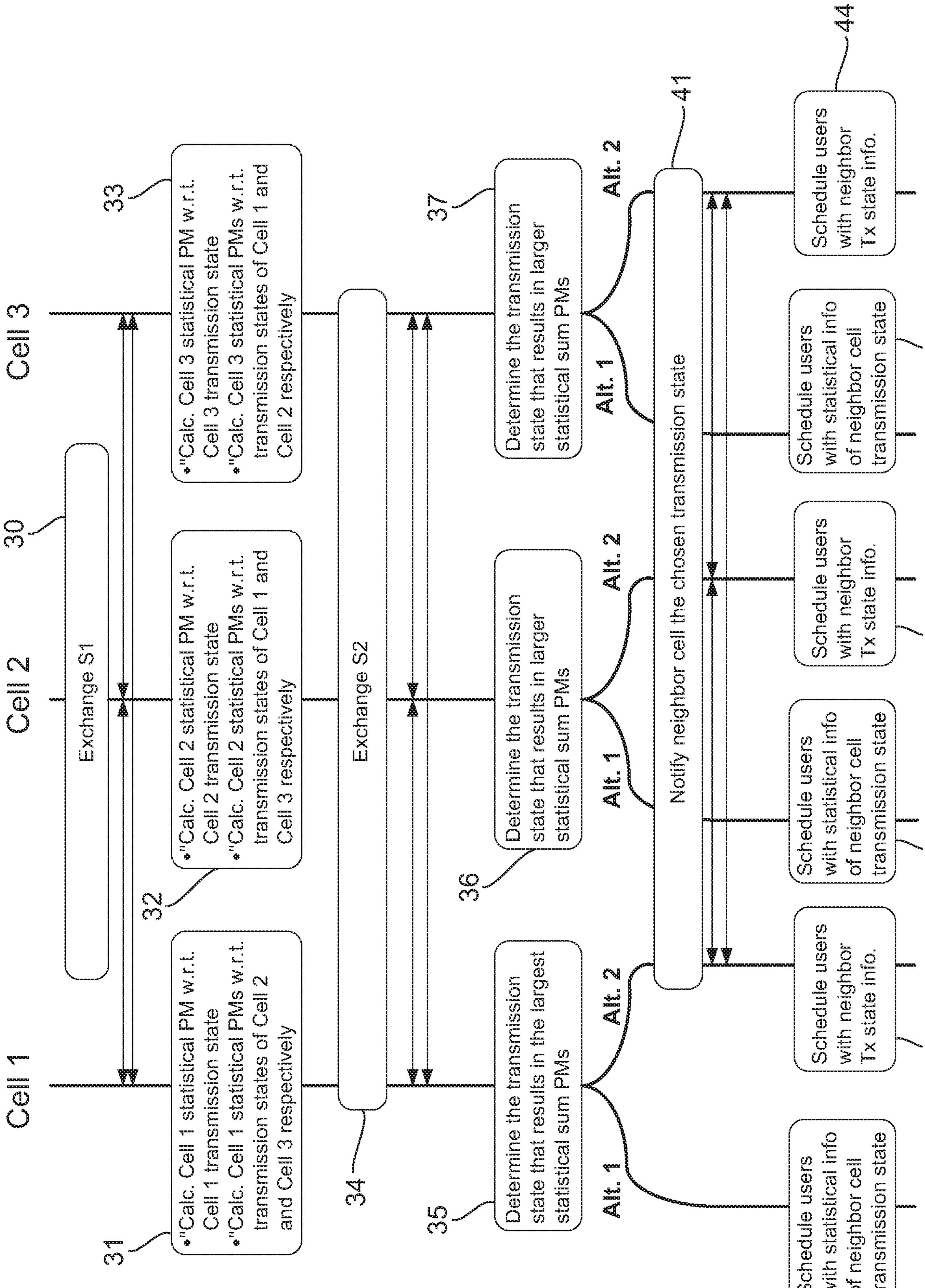
Cell 1
Cell 2
Cell 3
30
Exchange S1
31
•"Calc. Cell 1 statistical PM w.r.t. Cell 1 transmission state
•"Calc. Cell 1 statistical PMs w.r.t. transmission states of Cell 2 and Cell 3 respectively
32
•"Calc. Cell 2 statistical PM w.r.t. Cell 2 transmission state
•"Calc. Cell 2 statistical PMs w.r.t. transmission states of Cell 1 and Cell 3 respectively
33
•"Calc. Cell 3 statistical PM w.r.t. Cell 3 transmission state
•"Calc. Cell 3 statistical PMs w.r.t. transmission states of Cell 1 and Cell 2 respectively
34
Exchange S2
35
Determine the transmission state that results in the largest statistical sum PMs
36
Determine the transmission state that results in larger statistical sum PMs
37
Determine the transmission state that results in larger statistical sum PMs
Alt. 1
Alt. 2
41
Notify neighbor cell the chosen transmission state
38
Schedule users with statistical info of neighbor cell transmission state
42
Schedule users with neighbor Tx state info.
39
Schedule users with statistical info of neighbor cell transmission state
43
Schedule users with neighbor Tx state info.
40
Schedule users with statistical info of neighbor cell transmission state
44
Schedule users with neighbor Tx state info.

Fig. 3

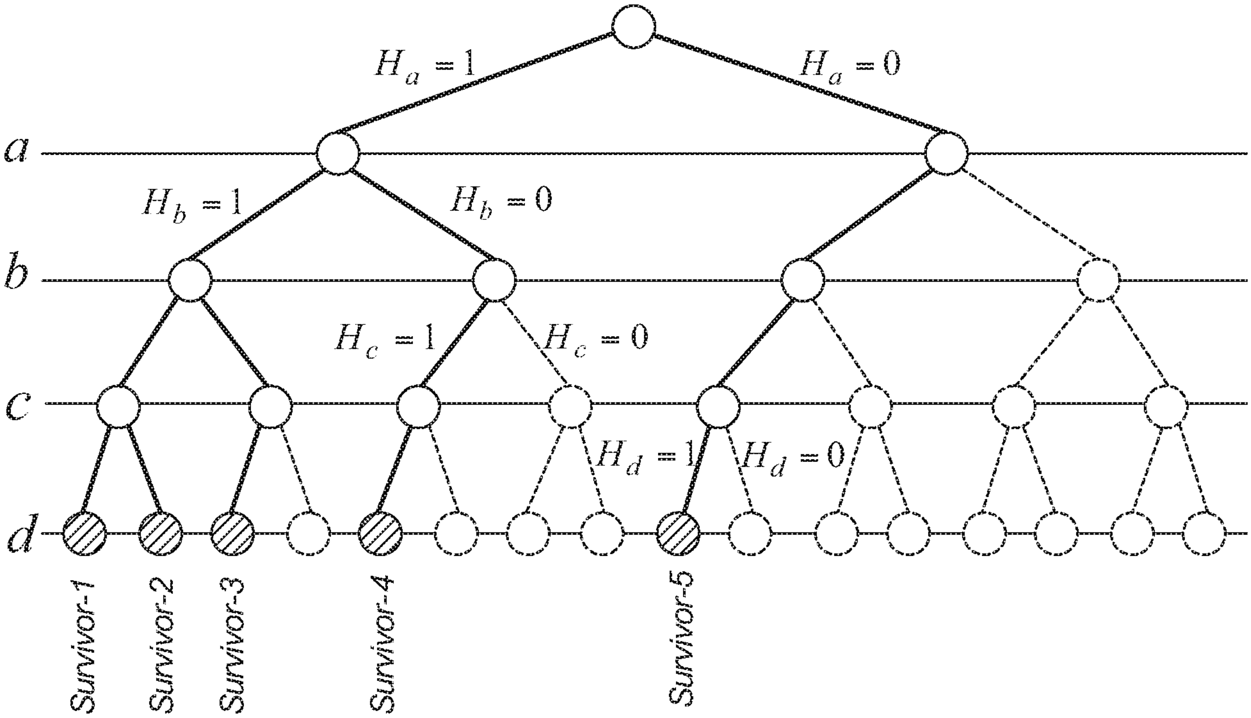
$H_a = 1$
$H_a = 0$
a
$H_b = 1$
$H_b = 0$
b
$H_c = 1$
$H_c = 0$
c
$H_d = 1$
$H_d = 0$
d
Survivor-1
Survivor-2
Survivor-3
Survivor-4
Survivor-5

Fig. 4

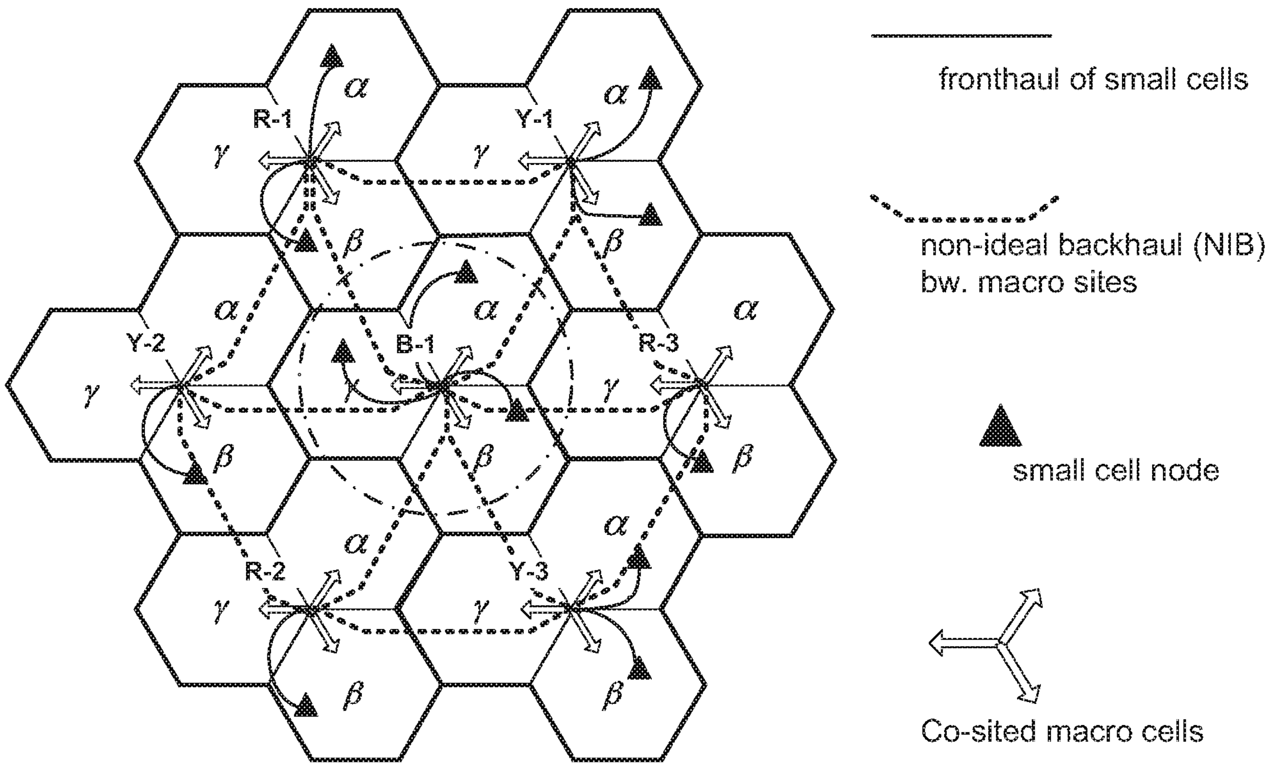
R-1
Y-1
Y-2
B-1
R-3
R-2
Y-3
α
β
γ
fronthaul of small cells
non-ideal backhaul (NIB)
bw. macro sites
small cell node
Co-sited macro cells

Fig. 5

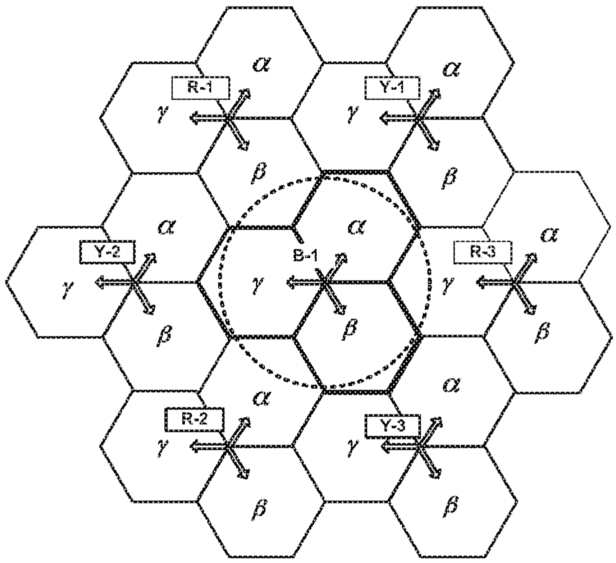

Fig. 6A

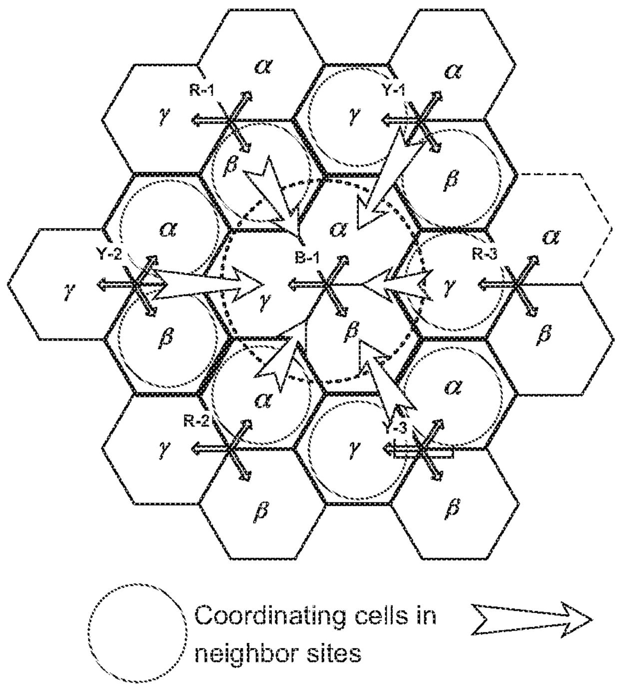

Fig. 6B

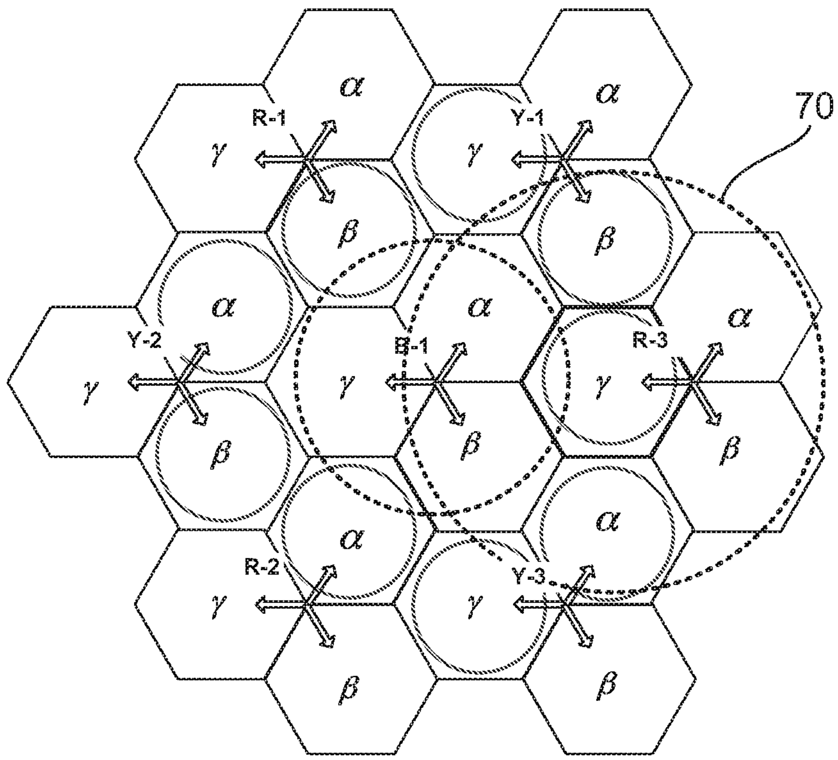

Fig. 7

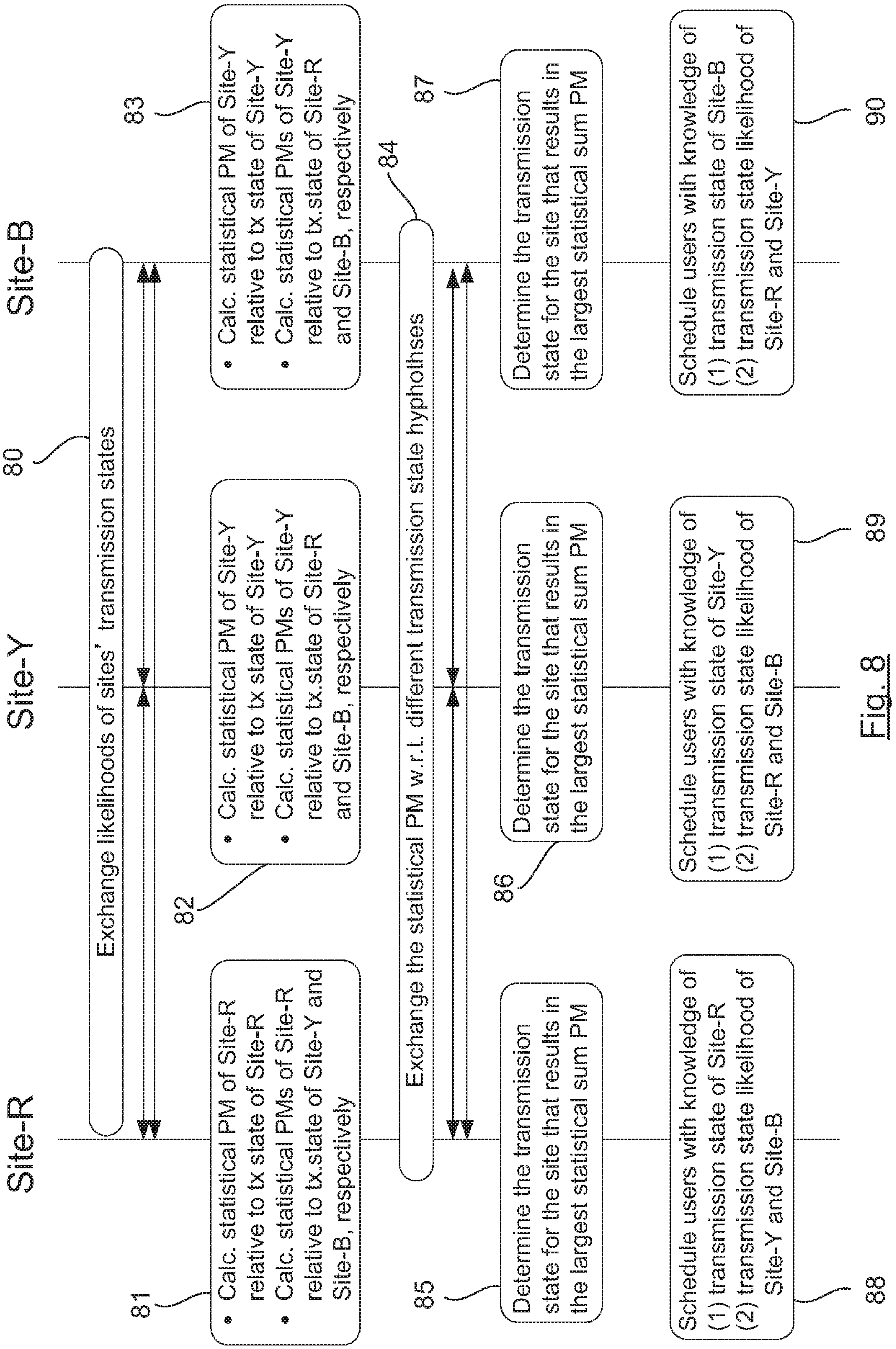
Site-R
Site-Y
Site-B
80
Exchange likelihoods of sites' transmission states
81
• Calc. statistical PM of Site-R relative to tx state of Site-R
• Calc. statistical PMs of Site-R relative to tx.state of Site-Y and Site-B, respectively
82
• Calc. statistical PM of Site-Y relative to tx state of Site-Y
• Calc. statistical PMs of Site-Y relative to tx.state of Site-R and Site-B, respectively
83
• Calc. statistical PM of Site-Y relative to tx state of Site-Y
• Calc. statistical PMs of Site-Y relative to tx.state of Site-R and Site-B, respectively
84
Exchange the statistical PM w.r.t. different transmission state hyphothses
85
Determine the transmission state for the site that results in the largest statistical sum PM
86
Determine the transmission state for the site that results in the largest statistical sum PM
87
Determine the transmission state for the site that results in the largest statistical sum PM
88
Schedule users with knowledge of (1) transmission state of Site-R (2) transmission state likelihood of Site-Y and Site-B
89
Schedule users with knowledge of (1) transmission state of Site-Y (2) transmission state likelihood of Site-R and Site-B
90
Schedule users with knowledge of (1) transmission state of Site-B (2) transmission state likelihood of Site-R and Site-Y

Fig. 8

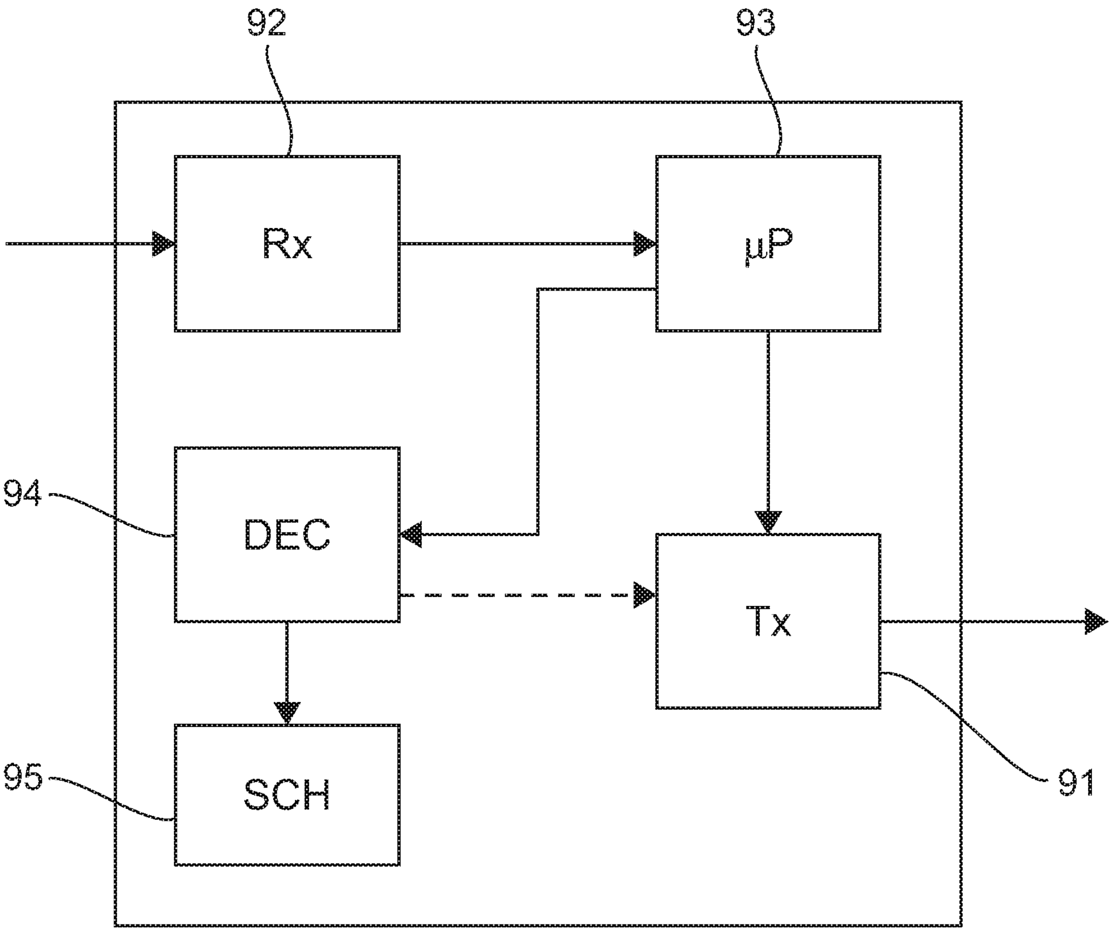

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No. **PCT/CN2014/081216**

A. CLASSIFICATION OF SUBJECT MATTER

H04W16/04 (2009.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W;H04Q

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

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

CNPAT,CNKI,WPI,EPODOC,3GPP:schedul+, neighbo?r, node, base station, BS, eNodeB, eNB, inter?cell interference, ICI, ICIC, coordinat+, de?centrali+, metric,information, send+, transmit+, performance

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2011090253 A1 (SAMSUNG ELECTRONICS CO.， LTD.) 28 July 2011 (2011-07-28) the whole document	1-12
A	WO 2014087454 A1 (NEC CORP.ET AL.) 12 June 2014 (2014-06-12) the whole document	1-12
A	CN 103297980 A (HUAWEI TECHNOLOGIES CO.，LTD.) 11 September 2013 (2013-09-11) the whole document	1-12

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 March 2015	**30 March 2015**

Name and mailing address of the ISA/CN	Authorized officer
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Facsimile No. **(86-10)62019451**	Telephone No. **(86-10)62413297**

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
WO 2011090253 A1	28 July 2011	KR 20110086470 A	28 July 2011
		JP 2011151779 A	04 August 2011
		US 2011183679 A1	28 July 2011
WO 2014087454 A1	12 June 2014	None	
CN 103297980 A	11 September 2013	WO 2013127310 A1	06 September 2013