(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 2 798 896 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
17.10.2018 Bulletin 2018/42

(21) Application number: **11811354.7**

(22) Date of filing: **29.12.2011**

(51) Int Cl.:
H04W 72/12 *(2009.01)*

(86) International application number:
PCT/EP2011/074266

(87) International publication number:
WO 2013/097904 (04.07.2013 Gazette 2013/27)

(54) **SCHEDULING ALGORITHM FOR WIRELESS COMMUNICATION NETWORKS**
PLANNUNGSALGORITHMUS FÜR DRAHTLOSE KOMMUNIKATIONSNETZE
ALGORITHME D'ORDONNANCEMENT POUR RÉSEAUX DE COMMUNICATIONS SANS FIL

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(43) Date of publication of application:
05.11.2014 Bulletin 2014/45

(73) Proprietor: **Telecom Italia S.p.A.**
20123 Milano (IT)

(72) Inventors:
- **ACCONGIAGIOCO, Giovanni**
  I-88900 Crotone (KR) (IT)
- **ANDREOZZI, Matteo Maria**
  I-56122 Pisa (IT)
- **CARETTI, Marco**
  I-10148 Torino (IT)
- **FANTINI, Roberto**
  I-10148 Torino (IT)
- **MIGLIORINI, Daniele**
  I-56122 Pisa (IT)
- **SABELLA, Dario**
  I-10148 Torino (IT)
- **STEA, Giovanni**
  I-56122 Pisa (IT)

(74) Representative: **Maccalli, Marco et al**
Maccalli & Pezzoli S.r.l.
Via Settembrini, 40
20124 Milano (IT)

(56) References cited:
WO-A1-2011/085817
WO-A2-2008/103979
US-A1- 2009 296 595
US-A1- 2010 195 614
US-A1- 2010 306 613
US-A1- 2011 090 808
US-A1- 2011 170 642

- **ALCATEL-LUCENT: "Comparison of CSI Feedback Schemes", 3GPP DRAFT; R1-092310, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, no. Los Angeles, USA; 20090624, 24 June 2009 (2009-06-24), XP050350842, [retrieved on 2009-06-24]**
- **TIAN LAN ET AL: "Resource Allocation and Performance Study for LTE Networks Integrated with Femtocells", GLOBECOM 2010, 2010 IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, IEEE, PISCATAWAY, NJ, USA, 6 December 2010 (2010-12-06), pages 1-6, XP031846737, DOI: 10.1109/GLOCOM.2010.5684197 ISBN: 978-1-4244-5636-9**

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 2 798 896 B1

Printed by Jouve, 75001 PARIS (FR)

Description

Background of the invention

Field of the invention

[0001] The present invention generally relates to wireless communications networks, such as cellular networks. More particularly, the present invention relates to resources allocation on wireless communication networks, such as OFDMA wideband wireless communication networks making use of a Distributed Antenna System through Frequency Domain Packet Scheduling.

Overview of the related art

[0002] Evolution of wideband wireless communication networks has experienced a significant growth in terms of spread and performance, and has recently brought to new-generation cellular systems (generally referred to as fourth generation or 4G cellular wireless systems), such as WiMAX ("Worldwide Interoperability for Microwave Access") - *i.e.* a communication technology for wirelessly delivering high-speed Internet service to large geographical areas, LTE ("Long Term Evolution") and LTE-Advanced, which are designed to meet needs for high-speed data and media transport as well as high-quality voice and video communications support into the next decade.

[0003] As known, such new-generation cellular systems make use of some advanced techniques, such as OFDM ("Orthogonal Frequency Division Multiplex") signal transmission scheme - based on using multiple sub-carriers closely-spaced in the frequency domain such that adjacent sub-carriers are orthogonal to each other, and the associated OFDMA "Orthogonal Frequency-Division Multiple Access" access scheme, relying on the use of the OFDM signal transmission scheme and according to which individual (or groups of) sub-carriers (*i.e.* elementary resource allocations, generally referred to as "Physical Resource Blocks") are assigned, based on scheduling decisions, to different users, so as to support differentiated Quality of Service (QoS), *i.e.* to control data rate and error probability individually for each user.

[0004] An extension of such OFDMA-based wireless communication networks is to consider the implementation thereof within Distributed Antenna Systems, which, originally introduced to simply cover dead spots in indoor wireless communications networks, have been recently identified as providing potential advantages in outdoor wireless communications networks (to such an extent that many cellular service providers and/or system manufacturers may also consider replacing legacy cellular systems with distributed antenna systems or adopting them in the forthcoming 4G wireless communications networks).

[0005] Each Distributed Antenna System (in the following DAS system or DAS, for the sake of conciseness) substantially comprises a network of spatially separated radio-transmitting remote units - *e.g.* antennas - covering a corresponding geographic area, and a common central unit (or eNodeB), for accomplishing processing and managing operations, to which each remote unit is connected through a proper transport medium (*e.g.* optical fibers, dedicated wires, or exclusive radio-frequency links). Each remote unit is configured for receiving a digital base-band signal from the central unit, and, after digital to analog conversion, filtering and amplifying operations, for transmitting the corresponding radio-frequency signal to user equipments (*e.g.,* user terminals, such as cellular phones) of subscribers/users requiring services in the same network cell (*e.g.,* voice call). In this way, being the radio-frequency signal to be transmitted by the central unit radiated by several remote units located remote from the central unit, better defined cell coverage and extended cell coverage (thus, fewer coverage holes), simplified maintenance (as DAS system can reduce the required number of central units within a target service area) and higher signal-to-interference-plus-noise ratio (SINR) are obtained with respect to a non DAS system.

[0006] Presently, a number of works are known wherein solutions providing for scheduling schemes are disclosed.

[0007] In Ping Gong, Ke Yu, Yumei Wang, "Radio resource allocation for multiuser OFDMA distributed antenna systems", IEEE International Conference on Network Infrastructure and Digital Content, 2009, the authors face the problem of assigning transmitting power and logic sub-bands to a plurality of users served in DAS modality, in downlink direction. The problem of allocation is formulated as problem of mixed integer-linear optimization, and heuristic algorithms are calculated that approximate the optimum solution.

[0008] In Joonil Choi, Illsoo Sohn, Sungjin Kim and Kwang Bok Lee, "Efficient Uplink User Selection Algorithm in Distributed Antenna Systems", IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications, 2007, the authors describe a scheme for assigning users to antennas.

[0009] In W. Xu, Z. He, K. Niu, "Opportunistic Packet Scheduling in OFDM Distributed Antenna Systems", WiCOM'09 Proceedings of the 5th International Conference on Wireless communications, networking and mobile computing, 2009, the authors investigate an OFDM system with distributed antennas for allocating power and sub-bands in such a way to minimize packet losses.

[0010] In B. Yang, Y. Tang, "Heuristic Resource Allocation for Multiuser OFDM Distributed Antenna System with

Fairness Constraints", Proceedings of ICCTA 2009, the authors face the problem of maximizing the amount of traffic transmitted under some constraints in an OFDM system with DAS. In this respect, the authors propose heuristic algorithms for allocating sub-carriers to the users, with the constraints that an antenna can serve only one user on a sub-carrier and that each user has a predefined granted minimum rate.

[0011] In Lisha Ling, Tan Wang, Ying Wang, Cong Shi, "Schemes of Power Allocation and Antenna Port Selection in OFDM Distributed Antenna Systems", Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd, the authors propose a power allocation and antenna port selection heuristic algorithm on OFDM-DAS systems.

[0012] In Marsch P., Khattak S., Fettweis G., "A Framework for Determining Realistic Capacity Bounds for Distributed Antenna Systems", Information Theory Workshop, 2006. ITW '06 Chengdu. IEEE, the authors propose a framework for evaluation of uplink capacity bounds of DAS systems through link-level simulations.

[0013] In Jun Zhang, Andrews J., "Distributed Antenna Systems with Randomness Wireless Communications", IEEE Transactions, 2008, the authors evaluate performance, by simulating a realistic channel, of single-cell and multi-cell DAS systems by comparing two known transmitting techniques (*i.e.* MRT, or "Maximum Ratio Transmission", and ST, or "Selection Transmission"), verifying that the single-cell MRT technique provides better performance whereas the multi-cell ST technique provides lower outage probability. Moreover, the authors study how the geometric or random arrangements of the remote units affect the system performance.

[0014] In Zhu, H., Karachontzitis, S., Toumpakaris, D., "Low-complexity resource allocation and its application to distributed antenna systems", Wireless Communications, IEEE 2010, the authors evaluate, through link-level simulations, performance increase in case of resource allocation based on frequency chunk (logical band) in single-cell systems and DAS systems, by comparing two known transmitting techniques (*i.e.* MRT, or "Maximum Ratio Transmission", and ZFB, or "Zero Forcing Beamforming").

[0015] In Peng Shang, Guangxi Zhu, Li Tan, Gang Su, Tan Li, "Transmit Antenna Selection for the distributed MIMO Systems", 2009 International Conference on Networks Security, Wireless Communications and Trusted Computing, the authors face the problem of the selection of the transmitting antenna as a two-level optimization problem: the first level selects the cluster of antennas for the service of a determined user, whereas the second level selects which antennas of the cluster are to be used for the user.

[0016] In Alexei Gorokhov, Dhananjay A. Gore, and Arogyaswami J. Paulraj, "Receive Antenna Selection for MIMO Spatial Multiplexing: Theory and Algorithms", IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 51, NO. 11, NOVEMBER 2003, the authors illustrate different algorithms, described for MIMO systems and applicable to DAS systems, for the selection of the receiving antennas in the uplink direction.

[0017] US2011170642 relates to an apparatus comprising: a receiver configured to receive a channel quality indication matrix; a processor configured to repeat, until the channel quality indication matrix is empty except for selected scheduling results, the following procedure: selecting a column of the channel quality indication matrix having the smallest number of non-zero channel quality indicators; searching for a largest channel quality indicator in the selected column of the channel quality indication matrix; selecting the searched largest channel quality indicator as a scheduling result, and emptying the column and row of the channel quality indication matrix corresponding to the selected scheduling result except for the selected scheduling result.

[0018] WO2011085817 provides an improved solution for generating and compressing uplink channel feedback information in a communication system. The solution comprises determining, at a user terminal, information related to a condition of at least one channel between the user terminal and at least one communication point of a co-operative multi-point transmission network, and generating feedback information comprising, for each reporting sub-band, a channel condition of a predetermined resource block and at least one differential channel condition of at least one other resource block within the same reporting sub-band. The generated feedback information may be communicated to a control node of the co-operative multipoint communication network.

Summary of invention

[0019] The Applicant has recognized that none of the above-referenced works discloses scheduling algorithms for concurrent activation of different remote units and concurrent allocation of same available time-frequency resources to the different activated remote units (thereby allowing the use of spatial multiplexing techniques), while taking into account throughput maximization (herein intended as maximization of the average rate of successful data or data packets delivery over a communication channel) and mutual interference among the activated remote units. Moreover, the Applicant has identified that in Ping Gong, Ke Yu, Yumei

[0020] Wang work each user is assumed to be connected to a single remote unit, to receive only one data stream (thereby disallowing the use of spatial multiplexing techniques based on multiple remote units), and to occupy exclusively a whole logic sub-band, whereas neither finite size of the user buffers nor allocation criterion aimed to obtain maximum throughput are considered. Furthermore, in the referenced work the entity that manage the scheduling is assumed to know physical parameters (*e.g.,* noise power on each logic sub-band), which actually are not reported by the users in

LTE-Advanced.

[0021] Instead, as far as Joonil Choi, Illsoo Sohn, Sungjin Kim and Kwang Bok Lee work and Alexei Gorokhov, Dhananjay A. Gore, and Arogyaswami J. Paulraj work are concerned, according to the Applicant the described algorithms do not allow allocation of resources to users, but simply establish a user-antenna connection based on features of the physical layer (thus prescinding from the concept of frame or amount of data the user has to transmit).

[0022] The Applicant has also found that in W. Xu, Z. He, K. Niu work the overall power is allocated to the antenna having maximum gain (thus no reference to concurrent selection of multiple antennas is made), similarly to Lisha Ling, Tan Wang, Ying Wang, Cong Shi work, wherein power maximization is achieved by selecting the best antenna for each user (thus, without considering spatial multiplexing and interference issues), and to B. Yang, Y. Tang work, wherein the user having rate closest to a required minimum rate is selected and associated with the antenna and the sub-carrier having maximum gain (regardless of buffer status of the selected user in terms of amount of data within it).

[0023] Moreover, the Applicant has identified that in Peng Shang, Guangxi Zhu, Li Tan, Gang Su, Tan Li work the possibility of spatial multiplexing is not considered, as well as finite size of the buffers. Moreover, in the referenced work the service choice is based exclusively on features of the physical layer not explicitly reported by users in LTE-Advanced.

[0024] As mentioned above, many cellular service providers and/or system manufacturers may consider adopting DAS systems in the forthcoming 4G wireless communications networks, such as LTE-Advanced, thus the Applicant has tackled the problem of devising a solution suitable to provide a new simple and effective scheduling procedure for concurrent activation of different remote units and concurrent allocation of same available physical resource blocks to the different concurrently activated remote units, while considering throughput maximization and mutual interference among the activated remote units.

[0025] In doing so, the Applicant has paid particular attention to develop a scheduling procedure that can be easily adapted to further implementations of the wireless communication networks that, although not necessarily provided with DAS systems, are to be considered as being affected by the same common issue as scheduling concurrent activation of different remote units for concurrent resource allocation thereon. For example, another possible key enhancement feature of LTE-Advanced may be bandwidth extension via carrier aggregation to support deployment bandwidth up to 100 MHz, which could allow achieving peak target data rates higher than 1 Gbps in the downlink and 500 Mbps in the uplink. Attractiveness of carrier aggregation comes from the fact that it allows operators/providers to deploy a system by aggregating several smaller contiguous or non-contiguous carriers while providing backward compatibility to legacy users. In fact, since LTE-Advanced has to provide spectrum compatibility to legacy users, support for wider bandwidth in LTE-Advanced can be provided through aggregation of multiple carriers, wherein each carrier may appear as LTE carrier to legacy users while LTE-Advanced users would be able to transmit and receive on several carriers simultaneously (and according to one of the three possible aggregation scenarios, namely "Intra-band Contiguous", "Intra-band Non-Contiguous" and "Inter-band Non-Contiguous").

[0026] The invention is set out in the appended set of claims. The embodiments and/ or examples of the following description which are not covered by the appended claims are considered as not being part of the present invention.

[0027] One or more aspects of the solution according to specific embodiments of the invention are set out in the independent claims, with advantageous features of the same solution that are indicated in the dependent claims, whose wording is enclosed herein *verbatim* by reference (with any advantageous feature being provided with reference to a specific aspect of the solution according to an embodiment of the invention that applies *mutatis mutandis* to any other aspect).

[0028] More specifically, the solution according to one or more embodiments of the present invention relates to a method for scheduling resources allocation within a wireless communications network comprising at least one network cell, the at least one network cell comprising a central unit providing coverage over the network cell and managing at least one transmission frame for putting into communication the central unit with at least one corresponding user equipment within the network cell. The method comprises
retrieving input parameters, said input parameters comprising, for each user equipment, a channel quality parameter indicative of a measured/estimated channel quality based on actual network cell conditions;
applying a de-contextualization function to each channel quality parameter for obtaining a corresponding atomic channel quality parameter indicative of the channel quality de-contextualized from the actual network cell conditions;
performing a scheduling algorithm for providing a binary allocation matrix indicative of each scheduled physical resource block, transmission frame and user equipment, and
applying a contextualization function to said allocation matrix for obtaining indication of transport block size to be used by the scheduled transmission frame for transport blocks transmissions from or towards each scheduled user equipment, wherein said performing a scheduling algorithm may comprise reiterating the scheduling algorithm until all the atomic channel quality parameters have been zeroed, and said scheduling algorithm may comprise, for each iteration:

> for each user equipment, masking the atomic channel quality parameters by a current buffer status variable indicative of the current status of the user equipment buffer;

scheduling the user equipment, transmission frame and physical resource block whose masked atomic channel quality parameter has maximum value;
upon each scheduling, updating the allocation matrix by setting the element of the allocation matrix corresponding to the scheduled user equipment, transmission frame and physical resource block at a first value indicative of the scheduling;
updating the current buffer status variable of the scheduled user equipment according to said scheduling;
zeroing the atomic channel quality parameters related to the scheduled transmission frame for the scheduled physical resource block, and
updating each atomic channel quality parameter different from zero corresponding to the scheduled physical resource block.

[0029] Preferably, although not necessarily, said masking the atomic channel quality parameters comprises replacing each atomic channel quality parameter by the minimum value between the atomic channel quality parameter itself and the current buffer status variable.

[0030] Advantageously, said updating each atomic channel quality parameter different from zero corresponding to the scheduled physical resource block comprises applying to it a penalization factor indicative of the interference that would occur if the transmission frame of the current scheduling decision was transmitted, and penalizing each atomic channel quality parameter different from zero by means of the determined penalization factor.

[0031] The input parameters may further comprise a buffer size parameter indicative of an amount of data that is buffered for each user equipment, and said updating the current buffer status variable may comprise decreasing each value of the current buffer status variable, initially set at the buffer size parameter, by actual amount of data already served to the corresponding user equipment buffer, with said actual amount of data that takes into account mutual interference among the transmission frames by means of the respective penalization factor.

[0032] The input parameters may further comprise a number of active transmission frames for each user equipment. In this respect, the method may further comprise
after said updating the allocation matrix, updating the number of active transmission frames for the scheduled user equipment, and
after said zeroing the atomic channel quality parameters related to the scheduled transmission frame for the scheduled physical resource block, zeroing all the atomic channel quality parameters related to the scheduled user equipment in case the corresponding number of active transmission frames is zero.

[0033] According to a non-limiting embodiment, the contextualization function is zero when no mutual interference between the transmission frames is present, constant when each transmission frame is supposed to induce a constant interference factor to all the other transmission frames, and proximity-based when each transmission frame is supposed to induce a constant interference factor to the neighboring transmission frames.

[0034] In the uplink case, said channel quality parameter is an uplink channel quality parameter denoting the uplink channel quality evaluated in respect of the at least one user equipment and by the central unit in respect of the transmission frame, whereas said buffer status parameter is an uplink buffer status parameter comprised, together with the uplink channel quality parameter, with a buffer status report available at the remote unit. In the downlink case, said channel quality parameter is a feedback downlink channel quality parameter denoting the downlink channel quality evaluated by each user equipment, whereas said buffer status parameter is a downlink buffer status parameter.

[0035] Another aspect of the solution according to an embodiment of the present invention relates to a computer program loadable into at least one internal memory of a computer system with input units and output units as well as with processing units, the computer program comprising executable software adapted to carry out the method phases of above, alone or in combination, when running in the computer system.

[0036] A further aspect of the solution according to embodiments of the present invention relates to a wireless communications network comprising at least one network cell, the at least one network cell comprising a central unit providing coverage over the network cell and managing at least one transmission frame for putting into communication the central unit with at least one corresponding user equipment within the network cell. The base station comprises a scheduler unit for retrieving input parameters, said input parameters comprising, for each user equipment, a channel quality parameter indicative of a measured/estimated channel quality based on actual network cell conditions;
applying a de-contextualization function to each channel quality parameter for obtaining a corresponding atomic channel quality parameter indicative of the channel quality de-contextualized from the actual network cell conditions;
performing a scheduling algorithm for providing a binary allocation matrix indicative of each scheduled physical resource block, transmission frame and user equipment, and
applying a contextualization function to said allocation matrix for obtaining indication of transport block size to be used by the scheduled transmission frame for transport blocks transmissions from or towards each scheduled user equipment.

[0037] Without departing from the scope of the invention, the wireless communications may a cellular communication network compliant with Long Term Evolution (LTE) Advanced standard adopting Single Carrier Frequency Division

Multiple Access scheme for uplink transmission and Orthogonal Frequency Division Multiplexing Modulation Access scheme for downlink transmission, LTE or Wi-max standards.

[0038] The wireless communications network may further comprise at least one remote unit implementing a distributed antenna system for physically transmitting the at least one transmission frame, each remote unit of the distributed antenna system being coupled with the central unit through a transport medium comprising optical fibers, dedicated wires, and/or exclusive radio-frequency links, and being coupleable with each user equipment concurrently by radio links.

[0039] Additionally or alternatively, each transmission frame may be transmitted on a separate frequency band through carrier aggregation approach.

[0040] Thanks to the present invention, available physical resource blocks are allocated to a set of concurrently activated remote units such as to have maximum throughput and minimal interference (due to concurrent activation of multiple remote units on the same time-frequency resources). Hence, the proposed procedure is able to use spatial multiplexing technique, thereby profiting by advantages of frequency selective scheduling. Moreover, although the present invention will be described with reference to wireless communication networks provided with DAS systems, it may also be applied to other wireless communication networks configurations (also unprovided with DAS systems, such as those based on carrier aggregation) that can be demonstrated as having reference, in terms of general problem formulation, to the one herein exemplarily illustrated.

Brief description of the annexed drawings

[0041] These and other features and advantages of the present invention will be made apparent by the following description of some exemplary and non limitative embodiments thereof; for its better intelligibility, the following description should be read making reference to the attached drawings, wherein:

Figure 1 schematically shows a wireless communications network portion wherein the solution according to one or more embodiments of the present invention may be applied;

Figure 2 schematically shows a high-level scheme of a scheduling procedure according to the principles of the present invention;

Figure 3 schematically shows a flow chart illustrating a sequence of operations of a scheduling algorithm of the scheduling procedure according to an embodiment of the present invention, and

Figure 4 schematically shows a flow chart illustrating a sequence of operations of a scheduling algorithm of the scheduling procedure according to another embodiment of the present invention.

Detailed description of preferred embodiments of the invention

[0042] With particular reference to the figures, **Figure 1** shows a (portion of a) wireless communications network **100** wherein the solution according to one or more embodiments of the present invention may be applied. The wireless communication network **100** may comprise a plurality of fixed-location Central Units (CUs), such as the CU **105,** which in general accomplishes to processing and managing, *e.g.* scheduling operations (as will be better discussed in the following); one or more CUs, such as the CU **105,** provide for (radio/cable) coverage over a geographic area, also referred to as network cell, such as the (*e.g.* hexagonal-shaped) network cell **110,** for allowing each *i-th* User Equipment (in the following UE or UE_i, with i=1,2, ...N, N=7 in the example at issue) within the network cell (such as one among the UE_is $\mathbf{UE_1}$-$\mathbf{UE_7}$ - *e.g.,* mobile phone - within the network cell **110**) to receive a required service (*e.g.,* a phone call). In the exemplary but not limiting embodiment described, the wireless communication network **100** is a cellular communication network (or briefly cellular network), compliant with the forthcoming Long Term Evolution (LTE) Advanced protocol standardized by the Third Generation Partnership Project (3GPP) Universal Mobile Telecommunications System (UMTS), wherein Single Carrier Frequency Division Multiple Access (SC-FDMA) scheme for uplink transmission (*i.e.,* transmission path from the UE_is) and Orthogonal Frequency Division Multiplexing Modulation Access (OFDMA) scheme for downlink transmission (*i.e.,* transmission path towards the UE_is) are used. As known, the OFDMA and the SC-FDMA schemes allow different number of sub-carriers to be assigned to different UE_is, and hence supporting differentiated Quality of Service (QoS), *i.e.* controlling data rate and error probability individually for each UE_i.

[0043] As known, the CU **105** is generally configured for managing one or more transmission frames (*i.e.,* data structures, containing both user data and control data, that form the signal to be radio-frequency transmitted) for putting into communication the CU **105** with one or more corresponding UE_is within the network cell 110. In the exemplary, not limiting, embodiment visible in the figure, the cellular network **100** also comprises a number j=1, 2,...M (with M=3 in the disclosed example) of radio-transmitting Remote Units (RUs or RU_js - *e.g.* antennas, as illustrated in the figure for the RU_js $\mathbf{RU_1}$-$\mathbf{RU_3}$ - which implement a Distributed Antenna System (or DAS system or DAS) generally configured for transmitting several independent transmission frames thereby making communication between the CU **105** and one, some, or all the UE_is within the network cell **110** more efficient (however, as will be best described in the following, the principles of the present invention may be equivalently applied to a system, *e.g.* exploiting carrier aggregation approach, in which the transmission frames are mainly transmitted by the central unit, on predefined carriers, instead of the remote units). The RU_js represent intermediate stations between the CU **105** and one or more UE_is within the network cell **110** (*e.g.,* by radiating the *e.g.* radio-frequency signal to be transmitted from the CU **105** to a selected UE_i from different RU_js), and are separated in space, *i.e.* distributed within the network cell **110** such as to provide coverage over the same geographical area (*i.e.* the network cell **110** itself) as a single RU does in a conventional implementation.

[0044] Advantageously, each RU_j is connected to the CU **105** through a proper transport medium - *e.g.* optical fibers (as herein assumed and exemplarily illustrated by solid lines), dedicated wires, or exclusive radio-frequency links. Thus, according to well known principle of DAS systems, each RU_j is configured for receiving a digital base-band signal from the CU **105,** and, after carrying out proper digital to analog conversion, filtering and amplifying operations, for transmitting the corresponding radio-frequency signal to the UE_is (hence, to subscribers/users) requiring services in the network cell **110.**

[0045] For the sake of completeness, as well known by those having ordinary skill in the art, the CUs, such as the CU **105,** are generally part of a Radio Access Network (not depicted), which is generally communicably coupled with a E-UTRAN ("Evolved-UMTS Terrestrial Radio Access Network", not shown), the latter in turn being typically coupled with other networks, such as Internet and/or public switched telephone networks (not illustrated).

[0046] According to an embodiment of the present invention, the CU **105** (typically, through a scheduler unit, or scheduler, thereof, not shown) is configured for implementing a scheduling procedure aimed to handle concurrent activation of different RU_js for allocation of same radio resources thereto, while optimizing and maximizing network cell throughput through exploitation of parameters already available in LTE-Advanced standard, such as mutual interference among the activated RU_js.

[0047] Turning now to **Figure 2,** the latter schematically shows a high-level scheme of a scheduling procedure **200** according to the principles of the present invention.

[0048] As previously discussed, the object of the scheduling procedure **200** is throughput maximization of the network cell by properly and concurrently activating a set of RU_js to which available physical radio resource blocks can be allocated with minimal mutual interference.

[0049] It should be understood that the term "radio resources" may have specific meaning according to the technology used for the cellular network (for example, the technology used for modulation and coding scheme for implementing transmissions over channels or links); for the cellular network herein exemplarily disclosed, such term should be generically construed as, and thus referred in the following as, radio "Physical Resource Blocks", *i.e.,* groups of elementary resource allocations, such as transport carriers (*e.g.* sub-carriers), assigned by the CU scheduler for data transmission purposes (*e.g.,* a physical resource block for LTE-Advanced may comprise a group of 12 sub-carriers when the sub-carrier bandwidth is 15 kHz or a group of 24 sub-carriers when the sub-carrier bandwidth is 7.5 kHz).

[0050] In the exemplary disclosed embodiment, the scheduling procedure **200** is run within the CU at each TTI ("Transmission Time Interval", *i.e* the signal time on the air interface - *e.g.,* 1 TTI=lms), and generally comprises a scheduling algorithm outputting an allocation matrix indicative of UE_is-RD_js allocation scheduling decisions (*i.e.,* of each scheduled physical resource block, RU_j and UE_i), and preliminary operations for allowing the scheduling decisions to be taken as correctly and reliably as possible (as will be described shortly).

[0051] In the exemplary disclosed embodiment, the scheduling procedure **200** prepares/retrieves (*e.g.* receives) input parameters (block **205**) indicative of a status of the UE_is within the network cell and that, according to the last release 10 LTE standard, come from the UE_is - such as in case of downlink transmission, to which reference will be made hereinafter for the sake of description ease only - or are generated/estimated therefor (for instance by the CU or the RU_js by any proper measurement/estimation method, *e.g.* RSSI measurement) - such as in case of uplink transmission. Advantageously, such input parameters comprise:

- Channel Quality Indicator (or *CQI(i,j)*) parameter, also referred to as channel quality parameter in the following), *i.e.* a measure/estimation of communication channels quality of each RU_j for communicating to each UE_i making use of performance metric (such as signal-to-noise ratio (SNR), signal-to-interference plus noise ratio (SINR), and indicating a suitable data rate (typically a Modulation and Coding Scheme (MCS) value) for downlink transmissions. As known, such measure/estimation is conditioned by actual, current network cell conditions (*e.g.,* signal interference among actually active RU_js) during the measure/estimation. In the present, not limiting implementation, it will be assumed that *CQI(i,j)* as a whole comprises, resident in the CU, an array of possible, discrete CQI values (in the following, *CQI_val*) that can be assigned to the measures/estimations of communication channels quality (and expressed as the number of bytes allocable for each physical resource block), and, resident in each UE_i, a corresponding CQI indexes matrix (in the following, *CQI_ind(i,j)*) that each UE_i report to the CU for communicating the position, within the array of CQI values, of the value *CQI_val* that best approximates the measure/estimation of the channels quality for all the RU_js made by the considered UE_i.

- UE$_i$s information, *i.e.* the information referring to each *i-th* UE$_i$ in terms of
  buffer size parameter q_i, *i.e.* amount of data that is buffered at the CU for each *i-th* UE$_i$ for downlink (or at the UE$_i$ for uplink) transmissions (in the uplink, such parameter is made available to the CU by Buffer Status Reporting provided in both LTE and LTE-Advanced standards); and
  spatial layer L_i, *i.e.* the number of active layers for each *i-th* UE$_i$ (it should be noted that, in case of carrier aggregation approach, the number of active transmission frames would be considered instead of the number of active layers).

- Physical Resource Block (or PRB$_k$), *i.e.* each *k-th* group of elementary resource allocations, such as transport carriers (*e.g.* sub-carriers), assigned by CU scheduler for data transmission purposes to a UE$_i$.

- Frame Size *FS(j)*, *i.e.* the size, expressed in PRB$_k$s, of the frequency space that each *j-th* RU$_j$ has at disposal for signal transmission.

[0052] According to the present invention, the channel quality parameters are recognized to be "contextualized", *i.e.* the measure/estimation of the reported *CQI(i,j))* parameters refer to the activation of a determined set of RU$_j$s, in the following active set, on a determined PRB$_k$.

[0053] In this respect, according to the present invention, the scheduling procedure **200** makes use of a proper de-contextualization function *g, e.g.* resident in the CU and defined as a function able to transform each *CQI(i,j))* parameter measure/estimation computed for each *i-th* UE$_i$ (uplink case), or reported by the *i-th* UE$_i$ (downlink case), for a considered RU$_j$ in a corresponding "atomic" measure/estimation, *i.e.* a measure/estimation not conditioned, not correlated, *i.e.* de-contextualized, from the active set which the considered RU$_j$ belonged to during *CQI(i,j))* parameter measurement/estimation, and a contextualization function *f*, *e.g.* resident in the CU as well and defined as a function able to modify the expected amount of bits for the *k-th* PRB$_k$ for each UE$_i$ according to the made scheduling decisions and specifically according to the active sets scheduled by the scheduler for each UE$_i$ (*i.e.,* the contextualization function *f* accomplishes a logically inverse operation with respect to the de-contextualization function *g*). As should be easily understood, the contextualization function *f*, and the de-contextualization function g are not limiting for the present invention, as they can be expressed by any mathematic formula or model according to specific and contingent criteria. By way of example only, the contextualization function *f* may be:

- "Zero", indicating that the mutual interference between the RUs is zero;
- "Constant", indicating that each RU$_j$ is supposed to induce a constant interference to all the other RU$_j$s (*e.g.,* interference factor equal to 1, meaning that the current *CQI_ind* of the de-contextualized CQI index matrix has to be decreased by 1, and the number of bytes for PRB$_k$ has to be accordingly estimated by using the array of values *CQI_val* in TBS);
- "Proximity-based", indicating that each RU$_j$ is supposed to induce a constant interference to the neighboring RU$_j$s only, and a null interference on the non-neighboring RU$_j$s.

[0054] Upon reception of the input parameters of above, the scheduling procedure **200** initializes (*e.g.,* at the value of the buffer size parameter q$_i$) a current buffer status variable B_i indicative of the current status of each UE buffer (block **210**), and then computes an "Atomic CQI Matrix", hereinafter *aCOI(i,j,k)* matrix (block **215**), *i.e.* a matrix of "atomic $CQI_{i,j,k}$" elements, or $aCOI_{i,j,k}$ elements, obtained by applying to the $CQI_{i,j,k}$ elements (in turn derived from *CQI_val* array and *CQI_ind(i,j)* index table) the de-contextualization function g and the information about the network cell features, and indicative of the channel quality de-contextualized from the active set according to which the feedback parameter had been calculated/estimated (*e.g.,* the active set related to five previous executions of the scheduling procedure, 5ms in the considered example).

[0055] In other words, the $aCQI_{i,j,k}$ elements of the *αCQI(i,j,k)* matrix represent the amount of bits that can be transmitted for each *k-th* PRB$_k$, *i.e.* the number of bits for each *k-th* PRB$_k$ to be transmitted to each *i-th* UE$_i$ if only the *j-th* RU$_j$ should be active on the *k-th* PRB$_k$, thus the values of the $aCQI_{i,j,k}$ elements are not depending on the active set according to which they had been previously measured/estimated, as opposed to the $CQI_{i,j,k}$ elements (from which the $aCQI_{i,j,k}$ elements are derived) that are intrinsically conditioned by the determined allocation configuration of the activated set of RU$_j$s.

[0056] Then, at block **220**, the scheduling procedure **200** performs a scheduling algorithm (described below) that reiterates until the *aCQI(i,j,k)* matrix is totally zeroed (*i.e.,* all $aCQI_{i,j,k}$ elements thereof are zero), and provides (block **225**) the scheduling decisions in terms of a binary allocation matrix *T(i,j,k)* indicative of the scheduled UE$_i$s, RU$_j$s and PRB$_k$s, *i.e.* of each *k-th* PRB$_k$ allocated for each *j-th* RU$_j$ towards each *i-th* UE$_i$, without any indication of transport block size to be used by the scheduled RU for transport blocks transmissions from or towards each scheduled UE$_i$ (information that instead will be provided by applying the contextualization function *f* to the allocation matrix *T(i,j,k)*).

[0057] With reference to **Figure 3,** it schematically shows a flow chart illustrating a sequence of operations of a scheduling algorithm **320** according to an embodiment of the present invention. The scheduling algorithm **320** starts at the black start circle, and then reaches the block **325,** wherein the $\alpha COI(i,j,k)$ matrix is "masked" by using current buffer status variable B_i of the corresponding *i-th* UE$_i$s (*e.g.* by replacing, for each *k-th* PRB$_k$, each $aCQI_{i,j,k}$ element of the *aCQI(i,j,k)* matrix by the minimum between *CQI_val[COI_ind(i,j)]* and B_i, thereby avoiding wasting radio resources as allocation of more radio resources than those requested to transmit all data of the *i-th* UE$_i$ buffer is prevented (*i.e.*, there is no transmission capacity overestimation for the *i-th* UE$_i$), then the $aCQI_{i,j,k}$ element of the *aCQI(i,j,k)* matrix having maximum *CQI_val* is determined (thus, the *i-th* UE$_i$, *j-th* RU$_j$ and *k-th* PRB$_k$ whose corresponding masked $aCQI_{i,j,k}$ element has maximum value are scheduled).

[0058] At block **330** the scheduling algorithm **320** updates the allocation matrix *T(i,j,k)* (for example, by associating a "1" value for each scheduled UE$_i$, RU$_j$ and PRB$_k$) and, if necessary, also updates the number of layers L_i in use for the *i-th* UE$_i$, *e.g.* in case the latter had received services on at least one layer.

[0059] The scheduling algorithm **320** then updates (block **335**) the current buffer status variable B_i of all the *i-th* UE$_i$s; by way of example only, this can be achieved by decreasing the value of each current buffer status variable B_i (*e.g.* initially set at the corresponding buffer size parameter q_i, see initialization step of above) by actual amount of data already served to the corresponding UE buffer, said actual amount of data taking into account possible mutual spatial interference among the RU$_j$s by means of a corresponding penalization factor.

[0060] Then, the column of the *aCQI(i,j,k)* matrix related to the *j-th* RU$_j$ on the *k-th* PRB$_k$ is zeroed and, if necessary (*e.g.* layers run out), the remaining of the row of the *i-th* UE$_i$ is zeroed as well (block **340**).

[0061] At block **345** the scheduling algorithm **320** applies (by means of the contextualization function *f*) the interference model for updating the not-zeroed $aCQI_{i,j,k}$ elements of the *aCQI(i,j,k)* matrix that will be used for the following, new active set. In an embodiment of the present invention, this is achieved by determining a penalization factor *P* indicative of the interference that would occur if the *j-th* RU$_j$ of the active set determined by the current scheduling decision transmitted (or, equivalently, if the transmission frame was transmitted), and updating the current $aCQI_{i,j,k}$ elements by penalizing them (by means of the determined penalization factor *P*) taking into account both its own interference and the interference induced on the RU$_j$s activated before it (in other words, the penalization factor is indicative of the difference between the *COI(i,j)* parameters of the previous reporting and the *CQI(i,j)* parameters that would be hypothetically calculated upon considering the active set determined by the current scheduling decision).

[0062] In this way, the updated $aCQI_{i,j,k}$ elements form a new, updated, current *aCQI(i,j,k)* matrix for a new UE$_i$, RU$_j$, PRB$_k$ scheduling, until all the possible UE$_i$s, RU$_j$s, PRB$_k$s to be scheduled have ended; as exemplarily illustrated in the figure, the scheduling algorithm **320** achieves this by checking at the decision block **350** whether all the $aCQI_{i,j,k}$ elements of the *aCQI(i,j,k)* matrix have been zeroed, denoting that all the possible UE$_i$s, RU$_j$s, PRB$_k$s have been examined, or not. In the affirmative case, exit branch **Y** of the decision block **350,** the scheduling algorithm **320** ends to the double end black circle (and causes the scheduling procedure ending, as the latter provides the allocation matrix *T(i,j,k)* indicative of the allocation of all the *k-th* PRB$_k$s on (one or more) RU$_j$s towards (one or more) UE$_i$s), whereas in the negative case, exit branch **N** of the decision block **350,** the scheduling algorithm **320** reiterates the steps above discussed of the blocks **325-350** until the all the $aCQI_{i,j,k}$ elements of the *aCQI(i,j,k)* matrix have been zeroed.

[0063] For the sake of completeness and clarity, in the following a practical, numeric operation example of the scheduling algorithm **320** will be proposed and briefly discussed. In this respect, let be considered the exemplary and not limiting scenario illustrated in the tables below, namely a "General Configuration" table comprising the number of involved UE$_i$s, the number of involved RU$_j$s, the number of considered PRB$_k$s and the number of layers L_i, the array of possible (*e.g.,* discrete) values *CQI_val,* the index table *CQI_ind(i,j)* comprising, for each *i-th* UE$_i$/*j-th* RU$_j$ pair, the index referring to the corresponding associated *CQI_val* estimate/measure, the penalization factor *P* given by the values that the contextualization function *f* takes according to the configuration of the active set, and the current buffer status variable B_i (initially supposed as being equal to the value of the buffer size parameter q_i of the *i-th* UE$_i$).

General Configuration

Number of UE$_i$s	2
Number of RU$_j$s	3
Number of PRB$_k$s	2
Number of Layers	2

CQI_val[CQI_ind(i,j)]

0	6	15	25	39	50	63	72	80	93

CQI_ind(i,j)

	RU_1	RU_2	RU_3
UE_1	6	2	9
UE_2	4	8	3

Penalization Factor

(RU_1,RU_2,RU_3) Configuration	$P=f(RU_1,RU_2,RU_3)=\{P_1,P_2,P_3\}$
(0,0,1)	{0,0,0}
(0,1,0)	{0,0,0}
(1,0,0)	{0,0,0}
(0,1,1)	{0,2,2}
(1,1,0)	{2,2,0}
(1,0,1)	{1,0,1}
(1,1,1)	{3,4,3}

B_i

	q_i
UE_1	93
UE_2	130

[0064] For the sake of description simplicity, let be supposed that the de-contextualization function *g* has already been applied, thus with the indexes *CQI_ind(i,j)* and the values *CQI_val* which the indexes *CQI_ind(i,j)* point to that are atomic already. Under this assumption, for the two *k-th* PRB_ks to be allocated, the *aCQI(i,j,k)* matrix derived from the *CQI_val* table and the index table *CQI_ind(i,j)* is the following (shown as two distinct tables each one for a corresponding *k-th* PRB_k to be allocated):

aCQI(i,j,k=1)

	RU_1	RU_2	RU_3
UE_1	63	15	93
UE_2	39	80	25

aCQI(i,j,k=2)

	RU_1	RU_2	RU_3
UE_1	63	15	93
UE_2	39	80	25

[0065] In order to avoid wasting radio resources, the *aCQI(i,j,k)* matrix is obtained after masking operation thereof, *i.e.* replacing of each *CQI_val[CQI_ind(i,j)]* (*i.e.* each value of the $aCQI_{i,j,k}$ element of the *aCQI(i,j,k)* matrix) by the minimum value between *CQI_val[CQI_ind(i,j)]* and the current buffer status variable B_i (initially assumed as being equal to the value of the corresponding q_i parameter). In the case at issue, as all the q_i parameters of the UEs have values at most equal to, or even higher than each $aCQI_{i,j,k}$ element, the resulting *aCQI(i,j,k)* matrix after masking operation is the same as that of above.

[0066] In such condition, the $aCQI_{i,j,k}$ element of the $aCQI(i,j,k)$ matrix having maximum CQI_val (93, in the example at issue) is that corresponding to UE_1,RU_3,PRB_1 ($i=1,j=3,k=1$). The allocation matrix $T(i,j,k)$ is updated ($T_{1,3,1}$ equal to 1, denoting that the PRB_1 is allocated on the RU_3 for data transmission to the UE_1).

[0067] As the maximum CQI_val also corresponds to the maximum value as possible of CQI_val, thus the RU_3 was not yet transmitting to the UE_1. The layer L_1 referred to UE_1 is decreased by one unit (L_1=1).

[0068] Then, the scheduling algorithm updates the current buffer status variable B_i according to the current status of the $aCQI(i,j,k)$ matrix, *i.e.* by considering the maximum between 0 (indicating no available buffer size is provided for handling data, *i.e.* full buffer) and the remaining available buffer size (obtained by decreasing the data till that moment provided from the buffer size parameter q_i), namely:

- B_1=max(0, q_1-$T_{1,3,1}$*$CQI\_val[CQI\_ind_{1,3}]$=93-93)=0
- B_2=max(0, q_2)=130

[0069] Then, $aCQI_{1,3,1}$=$aCQI_{2,3,1}$ is zeroed (as the PRB_1 has been allocated on the RU_3 for data transmission to the UE_1, and hence allocation of the PRB_1 itself on the RU_3 for data transmission to the UE_2 is avoided), whereas no zeroing of the row of the UE_1 is performed as the layers are not saturated.

[0070] Then, for each $aCQI_{i,j,k}$ element to be updated, the penalization factor P is calculated/retrieved for the active set comprising the scheduled RU and the RU corresponding to the $aCQI_{i,j,k}$ element to be updated, and interference model is then applied for updating.

$$aCQI_{1,1,1}$$

$$\left\{\begin{array}{l} P=f(1,0,1)=\{1,0,1\}=\{P_1,P_2,P_3\} \\ aCQI_{1,1,1}=\max(0,CQI\_val[CQI\_ind_{1,1}-P_1]+T_{1,3,1}*CQI\_val[CQI\_ind_{1,3} \\ -P_3]-T_{1,3,1}*CQI\_val[CQI\_ind_{1,3}-P_2])=\max(0,\ 50+80-93)=27 \end{array}\right\}$$

$$aCQI_{1,2,1}$$

$$\left\{\begin{array}{l} P=f(0,1,1)=\{0,2,2\}=\{P_1,P_2,P_3\} \\ aCQI_{1,2,1}=\max(0,CQI\_val[CQI\_ind_{1,2}-P_2]+T_{1,3,1}*CQI\_val[CQI\_ind_{1,3} \\ -P_3]-T_{1,3,1}*CQI\_val[CQI\_ind_{1,3}-P_1])=\max(0,\ 0+72-93)=0 \end{array}\right\}$$

$$aCQI_{2,1,1}$$

$$\left\{\begin{array}{l} P=f(1,0,1)=\{1,0,1\}=\{P_1,P_2,P_3\} \\ aCQI_{2,1,1}=\max(0,CQI\_val[CQI\_ind_{2,1}-P_1]+T_{1,3,1}*CQI\_val[CQI\_ind_{1,3} \\ -P_3]-T_{1,3,1}*CQI\_val[CQI\_ind_{1,3}-P_2])=\max(0,\ 25+80-93)=12 \end{array}\right\}$$

$$aCQI_{2,2,1}$$

$$\left\{\begin{array}{l} P=f(0,1,1)=\{0,2,2\}=\{P_1,P_2,P_3\} \\ aCQI_{2,2,1}=\max(0,CQI\_val[CQI\_ind_{2,2}-P_2]+T_{1,3,1}*CQI\_val[CQI\_ind_{1,3} \\ -P_3]-T_{1,3,1}*CQI\_val[CQI\_ind_{1,3}-P_1])=\max(0,\ 63+72-93)=42 \end{array}\right\}$$

[0071] Thus, the updated $aCQI(i,j,k)$ matrix is the following:

aCQI(i,j,k=1)

	RU_1	RU_2	RU_3
UE_1	37	0	0
UE_2	12	42	0

aCQI(i,j,k=2)

	RU_1	RU_2	RU_3
UE_1	63	15	93
UE_2	39	80	25

[0072] As the *aCQI(i,j,k)* matrix is not yet zeroed, the scheduling algorithm is reiterated for a new scheduling decision.

[0073] In this case, the $aCQI_{i,j,k}$ element of the ACM matrix having maximum *CQI_val* (*i.e.* 80, after masking of the *aCQI(i,j,k)* matrix with the current buffer status variable, as before) is that corresponding to UE_2,RU_2,PRB_2 ($i=2$,$j=2$,$k=2$). The allocation matrix *T(i,j,k)* is updated ($T_{2,2,2}$ equal to 1, denoting that the PRB_2 is allocated on the RU_2 for data transmission to the UE_2).

[0074] The layer L_2 referred to UE_2 is decreased by one unit (L_2=1).

[0075] As before, the scheduling algorithm then updates the current buffer status variable B_i, namely:

- B_1=0 (as before)
- $B_2=\max(0,\ q_2-T_{2,2,2}*CQI\_VAL[CQI_{2,2}])=\max(0,130-80)=50$

[0076] Then, $aCQI_{2,2,2}=aCQI_{1,2,2}$ is zeroed (as the PRB_2 has been allocated on the RU_2 for data transmission to the UE_2, and hence allocation of the PRB_2 itself on the RU_2 for data transmission to the UE_1 is avoided), whereas no zeroing of the row of the UE_2 is performed as the layers are not saturated.

[0077] Then, for each $aCQI_{i,j,k}$ element to be updated, the corresponding penalization factor *P* is calculated/retrieved, and interference model is hence applied for updating:

$$aCQI_{1,1,2}$$

$$\left\{\begin{array}{l} P=f(1,1,0)=\{2,2,0\}=\{P_1,P_2,P_3\} \\ aCQI_{1,1,2}=\max(0,CQI\_val[CQI\_ind_{1,1}-P_1]+T_{2,2,2}*CQI\_val[CQI\_ind_{2,2} \\ -P_2]-T_{2,2,2}*CQI\_val[CQI\_ind_{2,2}-P_3])=\max(0,\ 39+63-80)=22 \end{array}\right\}$$

$$aCQI_{2,1,1}$$

$$\left\{\begin{array}{l} P=f(1,1,0)=\{2,2,0\}=\{P_1,P_2,P_3\} \\ aCQI_{2,1,1}=\max(0,CQI\_val[CQI\_ind_{2,1}-P_1]+T_{2,2,2}*CQI\_val[CQI\_ind_{2,2} \\ -P_2]-T_{2,2,2}*CQI\_val[CQI\_ind_{2,2}-P_3])=\max(0,\ 15+63-80)=0 \end{array}\right\}$$

$$aCQI_{1,3,1}$$

$$\left\{\begin{array}{l} P{=}f(0,1,1){=}\{0,2,2\}{=}\{P_1,P_2,P_3\} \\ aCQI_{1,3,1}{=}\max(0,CQI\_val[CQI\_ind_{1,3}-P_3]+T_{2,2,2}{*}CQI\_val[CQI\_ind_{2,2} \\ -P_2]-T_{2,2,2}{*}CQI\_val[CQI\_ind_{2,2}-P_1]){=}\max(0,\ 72+63-80){=}55 \end{array}\right\}$$

$$aCQI_{2,3,1}$$

$$\left\{\begin{array}{l} P{=}f(0,1,1){=}\{0,2,2\}{=}\{P_1,P_2,P_3\} \\ aCQI_{2,3,1}{=}\max(0,CQI\_val[CQI\_ind_{2,3}-P_3]+T_{2,2,2}{*}CQI\_val[CQI\_ind_{2,2} \\ -P_2]-T_{2,2,2}{*}CQI\_val[CQI\_ind_{2,2}-P_1]){=}\max(0,\ 6+63-80){=}0 \end{array}\right\}$$

[0078] Thus, the updated *aCQI(i,j,k)* matrix is the following:

aCQI(i,j,k=1)

	RU_1	RU_2	RU_3
UE_1	37	0	0
UE_2	12	42	0

aCQI(i,j,k=2)

	RU_1	RU_2	RU_3
UE_1	22	0	55
UE_2	0	0	0

[0079] As the updated *aCQI(i,j,k)* matrix is not yet zeroed, the scheduling algorithm is reiterated for a new scheduling decision.

[0080] In this case, the $aCQI_{i,j,k}$ element of the *aCQI(i,j,k)* matrix having maximum *CQI_val* (*i.e.* 42, after masking of the *aCQI(i,j,k)* matrix with the current buffer status variable) is that corresponding to UE_2,RU_2,PRB_1 ($i=2, j=2, k=1$). The allocation matrix *T(i,j,k)* is updated ($T_{2,2,1}$ equal to 1), whereas the layer L_2 referred to UE_2 is unchanged as RU_2 already transmits to UE_2.

[0081] Then, the scheduling algorithm updates the current buffer status variable B_i according to the current status of the *aCQI(i,j,k)* matrix. In this case, the buffer B_1 does not empty, as RU_2 spatially interferes with the RU_3 on the PRB_1 - thus, with penalization factor equal to $P_3=2$ (P=*f*(0,1,1)={0,2,2,2}={P_1,P_2,P_3}), namely:

- $B_1=\max(0,\ q_1-T_{1,3,1}{*}CQI\_val[CQI\_ind_{1,3}-P_3])=\max(0,93-72)=21$, whereas the buffer B_2 can be calculated as usual:
- $B_2=\max(0,\ q_2-T_{2,2,1}{*}CQI\_va[CQI\_ind_{2,2}-P_2])=\max(0,130-80-63)=0$.

[0082] Then, $aCQI_{2,2,1}=aCQI_{1,2,1}$ is zeroed, the penalization factors are calculated/retrieved and interference model is hence applied for updating the $aCQI_{i,j,k}$ elements of the *aCQI(i,j,k)* matrix. The resulting matrix is the following:

aCQI(i,j,k=1)

	RU_1	RU_2	RU_3
UE_1	0	0	0
UE_2	0	0	0

$aCQI(ij,k=2)$

	RU$_1$	RU$_2$	RU$_3$
UE$_1$	22	0	55
UE$_2$	0	0	0

[0083] As the updated $aCQI(i,j,k)$ matrix is not yet zeroed, the scheduling algorithm is reiterated for another scheduling decision.

[0084] In this case, the $aCQI_{i,j,k}$ element of the $aCQI(i,j,k)$ matrix having maximum CQI_val (*i.e.* 55, after masking of the $aCQI(i,j,k)$ matrix with the current buffer status) is that corresponding to UE$_1$,RU$_3$,PRB$_2$ ($i=1,j=3,k=2$). The allocation matrix $T(i,j,k)$ is updated ($T_{1,3,2}$ equal to 1), whereas the layer L_2 referred to UE$_2$ is unchanged as the RU$_3$ already transmitted to UE$_1$.

[0085] Then, the scheduling algorithm updates the current buffer status variable B_i. In this case, the buffer B_2 does not empty, as RU$_2$ interferes with the RU$_3$ on the PRB$_2$ (thus, with penalization factor equal to 2), namely:

- B_2= max(0, 130-80-63)=0.

whereas the buffer B_1 is

- B_1=max(0, 93-72-72)=0.

[0086] Then, $aCQI_{1,3,2}$=$aCQI_{2,3,2}$ is zeroed, the penalization factors are calculated/retrieved and interference model is hence applied for updating the $aCQI_{i,j,k}$ elements of the $\alpha CQI(i,j,k)$ matrix. At this point, the matrix is empty and the scheduling algorithm ends and provides the allocation matrix illustrated below:

$T(i,j,k=1)$

	RU$_1$	RU$_2$	RU$_3$
UE$_1$	0	0	1
UE$_2$	0	1	0

$T(i,j,k=2)$

	RU$_1$	RU$_2$	RU$_3$
UE$_1$	0	0	1
UE$_2$	0	1	0

[0087] **Figure 4** schematically shows a flow chart illustrating a sequence of operations of a scheduling algorithm **420** of the scheduling procedure according to another embodiment of the present invention.

[0088] The scheduling algorithm **420** starts at the black start circle, then reaches the decision block **425**, wherein a test is executed for checking whether the $aCQI(i,j,k)$ matrix has at least one index triple (i,j,k) such that the corresponding $aCQI_{i,j,k}$ element is different from zero. In the affirmative case, exit branch **Y** of the decision block **425,** the scheduling algorithm **420** starts a scheduling cycle for scheduling the UE$_i$, RU$_j$ and PRB$_k$ whose current buffer status variable B_i has minimum value; more particularly, during each scheduling cycle, the scheduling algorithm **420** selects an index triple (i,j,k), updates (block **430**) the corresponding $T_{i,j,k}$ element of the allocation matrix $T(i,j,k)$ (*e.g.*, by setting it at "1"), and calculates (block **435**) the current buffer status variable B_i (*e.g.*, through the $aCQI(i,j,k)$ matrix and the penalization factor like before) by assuming that the $aCQI_{i,j,k}$ element corresponding to the selected index triple (i,j,k) is used for transmission.

[0089] Then, the scheduling algorithm **420** reaches the decision block **440,** wherein a test is executed for checking whether the selected index triple (i,j,k) is the best choice (for scheduling). In order to check that, any proper criterion may be used, such as throughput maximization and the like; in such case, the decision block **440** is configured for checking minimum B_i, *e.g.*, by comparing the value B_i corresponding to the selected index triple (i,j,k) with the value B_i corresponding to the (saved) index triple (i,j,k) that during a previous scheduling cycle has been identified as having minimum B_i (as before, computing/updating of the current buffer status variable B_i of the scheduled UE comprises decreasing the buffer size parameter q_i of the scheduled UE by actual amount of data already served to the corresponding user equipment buffer, said actual amount of data taking into account mutual interference among the active set by means of the corresponding penalization factor).

[0090] In the affirmative case, exit branch **Y** of the decision block **440,** at block **445** the scheduling algorithm **420** saves the *(i,j,k)* index triple - and stores the corresponding new *aCQI(i,j,k)* matrix configuration - that, by said comparison, has been found as determining the lowest value of B_i (in fact, as B_i represents data in queue to the *i-th UE,* low values of B_i correspond to high data transmission, whereas high values of B_i correspond to low data transmission), thereby reaching the block **450** (wherein the $T_{i,j,k}$ element of the allocation matrix *T(i,j,k)* is set at *e.g.* "0" and the value $T_{i,j,k}$=0 is saved); otherwise, exit branch **N** of the decision block **440,** the scheduling algorithm directly jumps to block **450.**

[0091] The operations of the blocks **430-450** are reiterated as long as the scheduling cycle has not selected all the other index triples *(i,j,k)* and compared the values B_i thereof with the current maximum value B_i. In this respect, at the decision block **455** the scheduling algorithm **420** checks whether all the index triples *(i,j,k)* have been considered (index triples *(i,j,k)* ended). In the affirmative case, exit branch **Y** of the decision block **455,** the scheduling algorithm **420** sets at 1 the $T_{i,j,k}$ element of the allocation matrix *T(i,j,k)* corresponding to the index triple *(i,j,k)* that has determined the lowest value of B_i (block **460**) - and, as before, updates the number of active layers for the scheduled UE - whereas in the negative case, exit branch **N** of the decision block **455,** the scheduling algorithm **420** returns to block **430** for a new iterations of the scheduling cycle until all the available index triples *(i,j,k)* have been considered.

[0092] Thus, after all the iterations of the scheduling cycle, the scheduled *i-th* UE, *j-th* RU, and *k-th* PRB are available at block **460.** At this point, in a similar manner as the scheduling algorithm of above, the scheduling algorithm **420** updates the *aCQI(i,j,k)* matrix (block **465**), *e.g.* by zeroing the $aCQI_{i,j,k}$ elements related to the scheduled RU for the scheduled PRB (*i.e.,* the column of the *aCQI(i,j,k)* matrix related to the scheduled RU on the scheduled PRB_k), by updating the $aCQI_{i,j,k}$ elements (different from zero) of each not-scheduled UE_i, RU_j and PRB_k, and, if necessary (layers ended for the scheduled UE_i), by zeroing the row of the *aCQI(i,j,k)* matrix related to the scheduled UE_i. As before, the updating of the each $aCOI_{i,j,k}$ element comprises applying to it a penalization factor *P* indicative of the interference that would occur if the *j-th* RU_j of the active set determined by the current scheduling decision transmitted, and updating the current $aCQI_{i,j,k}$ elements by penalizing them (by means of the determined penalization factor *P*) taking into account both its own interference and the interference induced on the RU_js activated before it.

[0093] The updated *aCQI(i,j,k)* matrix is hence used for data transmission, and forms the new basis for the next scheduling decision. In this respect, the scheduling algorithm **420** is reiterated until the *aCQI(i,j,k)* matrix has been zeroed (in fact, as visible in the figure, the scheduling algorithm **420** from block **465** returns to block **425,** and hence ends to the double end circle once the *aCQI(i,j,k)* matrix has been zeroed (exit branch **N** of the decision block **425**).

[0094] A practical example of the scheduling algorithm above discussed is herein disclosed.

[0095] Let be considered the same scenario assumed for illustrating the scheduling algorithm of the previous embodiment, but differently from the latter, the values of the buffers are those critical (q_1=85; q_2=143). The steps of the scheduling algorithm **420** are herein briefly illustrated.

[0096] First, starting from B_1=0, B_2=0, the following matrix is obtained:

$T_{1,1,1}$=1

	B_i
UE_1	63
UE_2	0

$T_{1,2,1}$=1

	B_i
UE_1	15
UE_2	0

$T_{1,3,1}$=1

	B_i
UE_1	85
UE_2	0

$T_{1,1,2}=1$

	B_i
UE_1	63
UE_2	0

$T_{1,2,2}=1$

	B_i
UE_1	15
UE_2	0

$T_{1,3,2}=1$

	B_i
UE_1	85
UE_2	0

$T_{2,1,1}=1$

	B_i
UE_1	0
UE_2	39

$T_{2,2,1}=1$

	B_i
UE_1	0
UE_2	80

$T_{2,3,1}=1$

	B_i
UE_1	0
UE_2	25

$T_{2,1,2}=1$

	B_i
UE_1	0
UE_2	39

$T_{2,2,2}$=1

	B_i
UE_1	0
UE_2	80

$T_{2,3,2}$=1

	B_i
UE_1	0
UE_2	25

[0097] The best configuration is $T_{1,3,1}$=1, hence the PRB_1 is assigned, the corresponding row of the $aCQI_{1,3,1}$ element is deleted and B_1=85, B_2=0 are considered:

$T_{1,1,1}$=1

	B_i
UE_1	85
UE_2	0

$T_{1,2,1}$=1

	B_i
UE_1	72
UE_2	0

$T_{1,2,1}$=1

	B_i
UE_1	85
UE_2	0

$T_{1,2,2}$=1

	B_i
UE_1	85
UE_2	0

$T_{1,3,2}$=1

	B_i
UE_1	85
UE_2	0

$T_{2,1,1}$=1

	B_i
UE_1	80
UE_2	25

$T_{2,2,1}$=1

	B_i
UE_1	72
UE_2	63

$T_{2,1,2}$=1

	B_i
UE_1	85
UE_2	39

$T_{2,2,2}$=1

	B_i
UE_1	85
UE_2	80

$T_{2,3,2}$=1

	B_i
UE_1	85
UE_2	25

[0098] The best configuration is $T_{2,2,2}$=1, hence the PRB_1 is assigned, the corresponding row of the $aCQI_{2,2,2}$ element is deleted and B_1=85, B_2=80 are considered:

$T_{1,1,1}$=1

	B_i
UE_1	85
UE_2	80

$T_{1,2,1}$=1

	B_i
UE_1	72
UE_2	80

$T_{1,1,2}$=1

	B_i
UE_1	85
UE_2	63

$T_{1,3,2}$=1

	B_i
UE_1	85
UE_2	63

$T_{2,1,1}$=1

	B_i
UE_1	80
UE_2	105

$T_{2,2,1}$=1

	B_t
UE_1	72
UE_2	143

$T_{2,1,2}$=1

	B_i
UE_1	85
UE_2	78

$T_{2,3,2}$=1

	B_i
UE_1	85
UE_2	69

[0099] The best configuration is $T_{2,2,1}$=1, hence the PRB_1 is assigned, the corresponding row of the $aCQI_{2,2,1}$ element is deleted and B_1=72, B_2=143 are considered:

$T_{1,1,1}$=1

	B_i
UE_1	85
UE_2	119

$T_{1,1,2}=1$

	B_i
UE$_1$	85
UE$_2$	126

$T_{1,3,2}=1$

	B_i
UE$_1$	85
UE$_2$	126

$T_{2,1,1}=1$

	B_i
UE$_1$	63
UE$_2$	125

$T_{2,1,2}=1$

	B_i
UE$_1$	72
UE$_2$	141

$T_{2,3,2}=1$

	B_i
UE$_1$	72
UE$_2$	132

[0100] As no better configuration has been found, the scheduling algorithm ends. Therefore, the buffers of UE$_1$ and UE$_1$ can be emptied down to the values of, respectively:

$$q_1=85-72=13$$

$$q_2=143-143=0$$

[0101] Naturally, in order to satisfy local and specific requirements, a person skilled in the art may apply to the solution described above many logical and/or physical modifications and alterations. More specifically, although the present invention has been described with a certain degree of particularity with reference to preferred embodiments thereof, it should be understood that various omissions, substitutions and changes in the form and details as well as other embodiments are possible. In particular, different embodiments of the invention may even be practiced without the specific details set forth in the preceding description for providing a more thorough understanding thereof; on the contrary, well-known features may have been omitted or simplified in order not to encumber the description with unnecessary details. Moreover, it is expressly intended that specific elements and/or method steps described in connection with any disclosed embodiment of the invention may be incorporated in any other embodiment as a matter of general design choice.

[0102] For example, the solution according to an embodiment of the invention lends itself to be implemented through an equivalent method (by using similar steps, removing some steps being not essential, or adding further optional steps); moreover, the steps may be performed in different order, concurrently or in an interleaved way (at least partly).

[0103] Moreover, although the common principles of the scheduling algorithms of the present invention have been described as applying to wireless communication networks comprising DAS systems, this should not be construed limitatively; in fact, the described scheduling algorithms may be conceptually used, without substantial changes and without departing from the scope of the present invention, to many other communication networks configurations that, although unprovided with the DAS system, involve similar problem formulations in terms of resource allocation. In this respect, the Applicant has also investigated communication networks implementing carrier aggregation, and (as will be briefly described in the following) has found that the latter has to be considered as a particular sub-case of the (generic) DAS problem herein disclosed, which makes the scheduling algorithms developed for communication network provided with DAS systems fully applicable to carrier aggregation context as well.

[0104] In fact, as briefly discussed in the introductory part of the present description, carrier aggregation for achieving bandwidth extension is a key enhancement feature of LTE-Advanced.

[0105] By using a similar notation of that of above, in LTE-Advanced each UE report its perceived downlink channel state to eNodeB scheduler as the $CQI_{i,j}$ value, which determines the Transmission Block Size (TBS) that the eNodeB should use, *i.e.,* indirectly, the number of bits per PRB.

[0106] A single UE_i may receive transmissions from different RU_js on a same time-frequency resource. In fact, such transmissions are spatially separated, and can therefore be reconstructed at the UE_i with a sufficiently high probability. In this respect, each UE_i is able to decode simultaneously a maximum number of spatially separated layers (that may be smaller or larger than the number of RU_js that can target it at a given TTI), whereas the number of layers that the channel may support simultaneously changes over time (and is estimated by the UE_i and reported to the eNodeB scheduler as a Rank Indicator, or RI). Hence, at a given TTI, the UE_i may receive up to RI spatially separated layers.

[0107] The scheduler coordinates j=1,2,... M distributed RU_js, hence builds up to M frames. Each RU_j transmits a frame of k=1,2,...B_j PRB_ks. The network cell provides service for i=1,2,...N UE_is, and let be denoted by q_i the backlog (physically queued at the eNodeB) destined to UE_i ("UE backlog", to be distinguished from idle and backlogged UE_is accordingly). Each UE_i can receive data from up to k_i RU_js simultaneously, wherein k_i represents the RI reported by the UE_i. Let be denoted by $K=\sum_{i=1}^{N} k_i$ the total number of exploitable layers at a given time, by $CQI_{i,j}$ the number of bytes that the *j-th* RU_j will put in a PRB_k destined to the *i-th* UE_i, and by $x_{i,j}$ the number of PRB_ks allocated by *j-th* RU_j to the *i-th* UE_i. Let be also assumed that the TBS increases linearly with the number of PRBs employed to compute it, so that $CQI_{i,j} * x_{i,j}$ the overall number of bytes that the *i-th* UE_i receives from the *j-th* RU_j.

[0108] Under the assumptions of above, the object of computing, on each TTI, the resource allocation that ensures optimal throughput can be formulated as follows:

$$\max \sum_{i=1}^{N} \sum_{j=1}^{M} \left(CQI_{i,j} \cdot x_{i,j} - p_{i,j} \right)$$

s.t.

$$\sum_{j=1}^{M} \left(CQI_{i,j} \cdot x_{i,j} - p_{i,j} \right) \le q_i \qquad \forall i \qquad (i)$$

$$p_{i,j} \le CQI_{i,j} - 1 \qquad \forall i,j \qquad (ii)$$

$$\sum_{i=1}^{N} x_{i,j} \le B_j \qquad \forall j \qquad (iii)$$

$$\sum_{j=1}^{M} b_{i,j} \le k_i \qquad \forall i \qquad (iv)$$

$$x_{i,j} \ge b_{i,j} \qquad \forall i,j \qquad (v)$$

$$x_{i,j} \leq b_{i,j} \cdot B \qquad \forall i,j \quad (vi)$$

$$b_{i,j} \in [0,1],\ p_{i,j}, x_{i,j} \in Z' \qquad \forall i,j \quad (vii)$$

[0109] The following modeling variables are introduced:

- $p_{i,j}$: the padding received by the *i-th* UE$_i$ from the *j-th* RU$_j$, due to the fact that PRB$_k$s contain a fixed number of bytes. Obviously, padding has to be discounted from objective function, in order to avoid entire frames being allocated to idle UE$_i$s with high CQI$_{i,j}$.
- $b_{i,j}$: a binary variable stating that *j-th* RU$_j$ is serving the *i-th* UE$_i$.

[0110] Constraint (i) ensures that each UE$_i$ receives no more PRB$_k$s than needed to clear its backlog, whereas constraint (ii) prevents the scheduler to allocate entire PRB$_k$s of padding. On the other hand, constraint (iii) enforces the limit on the frame length for each RU$_j$. Constraint (iv) relates to the maximum number of simultaneous layers, whereas constraints (v-vi) force $x_{i,j}$ to be positive if $b_{i,j}$=1, and null otherwise. B is a constant such that $B \geq B_j \forall j$, so that constraint (vi) is inactive when $b_{i,j}$=1.

[0111] In a carrier aggregation enabled cell, LTE UE$_i$s may receive transmissions on different carriers on different time-frequency resource, while LTE-Advanced UE$_i$s may receive transmission on multiple carriers during the same TTI.

[0112] An LTE-Advanced UE$_i$ can decode simultaneously data from all of the available carriers at a given TTI. The scheduler coordinates M carriers, hence builds M frames. On each carrier j a frame of B_j PRBs is transmitted. The cell provides service for i=1,2, N UE$_i$s, and let q_i denote the backlog (physically queued at the eNodeB) destined to the *i-th* UE$_i$. An LTE-Advanced UE$_i$ can receive data from all RU$_j$s simultaneously. Let be denoted by $K = \sum_{i=1}^{N} k_i$ the total number of exploitable carriers at a given time, by CQI$_{i,j}$ the number of bytes that the eNodeB will put in a PRB$_k$ of carrier j destined to the *i-th* UE$_i$, and by $x_{i,j}$ the number of PRB$_k$s allocated on carrier j to the *i-th* UE$_i$. Let be also assumed that the TBS increases linearly with the number of PRB$_k$s employed to compute it, so that $CQI_{i,j} * x_{i,j}$ is the overall number of bytes that the *i-th* UE$_i$ receives on carrier j.

[0113] Under definitions and assumptions of above, the carrier aggregation-aware version of the optimal-throughput problem can be formulated as follows:

$$\max \sum_{i=1}^{N} \sum_{j=1}^{M} \left(CQI_{i,j} \cdot x_{i,j} - p_{i,j} \right)$$

s.t.

$$\sum_{j=1}^{M} \left(CQI_{i,j} \cdot x_{i,j} - p_{i,j} \right) \leq q_i \qquad \forall i \quad (i)$$

$$p_{i,j} \leq CQI_{i,j} - 1 \qquad \forall i,j \quad (ii)$$

$$\sum_{i=1}^{N} x_{i,j} \leq B_j \qquad \forall j \quad (iii)$$

$$\sum_{j=1}^{M} b_{i,j} \leq k_i \qquad \forall i \quad (iv)$$

$$x_{i,j} \geq b_{i,j} \qquad \forall i,j \quad (v)$$

$$x_{i,j} \leq b_{i,j} \cdot B \qquad \forall i,j \quad (vi)$$

$$b_{i,j} \in [0,1], \; p_{i,j}, x_{i,j} \in Z^{+} \qquad \forall i,j \quad (vii)$$

[0114] The following modeling variables are introduced:

- $p_{i,j}$: the padding received by the *i-th* UE$_i$ on carrier *j*, due to the fact that PRB$_k$s contain a fixed number of bytes. Obviously, padding has to be discounted from the objective function, in order to avoid entire frames being allocated to idle UE$_i$s with high $CQI_{i,j}$.
- $b_{i,j}$: a binary variable stating that carrier *j* carries data for the *i-th* UE$_i$.

[0115] Constraint (i) ensures that each UE$_i$ receives no more PRB$_k$s than needed to clear its backlog, whereas constraint (ii) prevents the scheduler to allocate entire PRB$_k$s of padding. On the other hand, constraint (iii) enforces the limit on the frame length for each carrier. Constraint (iv) relates to the maximum number of simultaneous carriers, whereas constraints (v-vi) force $x_{i,j}$ to be positive if $b_{i,j}$=1, and null otherwise. *B* is a constant such that $B \geq B_j \forall j$, so that constraint (vi) is inactive when $b_{i,j}$=1.

[0116] Therefore, as visible by comparing the analytic formulations of above, the DAS-aware throughput maximization problem substantially matches the carrier aggregation-aware throughput maximization problem, thus any man skilled in the art could easily adapt the scheduling algorithms above described for the DAS system context to carrier aggregation context (hence, to any other similar context).

[0117] Although the described scheduling algorithms have been considered as substantially operating in downlink direction, this should not be understood in a restricting way. In fact, the scheduling algorithms according to the invention may be equivalently applied in the uplink direction; in this respect, in an alternative embodiment, not shown, said CQIs reported by the UEs are replaced by the channel estimation performed by eNodeB for the UEs, and the buffer size parameters in downlink transmission are replaced by the buffer size parameters in uplink transmission, available at the eNodeB thanks to the reporting of the BSR (Buffer Status Report) provided by the LTE and LTE-Advanced standards.

[0118] Moreover, nothing prevents from implementing the scheduling algorithm in such a way that the scheduling decision is based on both uplink and downlink feedback information, or any combination thereof.

[0119] In addition, analogous considerations apply if the wireless communication network has a different structure or comprises equivalent components, or it has other operating features. In any case, any component thereof may be separated into several elements, or two or more components may be combined into a single element; in addition, each component may be replicated for supporting the execution of the corresponding operations in parallel. It should also be noted that any interaction between different components generally does not need to be continuous (unless otherwise indicated), and it may be both direct and indirect through one or more intermediaries.

[0120] Moreover, although for the present invention explicit reference has been made to wireless communication network based on the LTE-Advanced standard, it should be understood that it is not in the intentions of the Applicant to be limited to the implementation of any particular wireless communication system architecture or protocol. In this respect, it is also possible to provide that, with suitable simple modifications, the present link scheduling algorithm may be applied also to other open or proprietary communication protocols, for example, WiMAX, among them.

Claims

1. A method (**200**) for scheduling resources allocation within a wireless communications network (**100**) comprising at least one network cell (**110**), the at least one network cell comprising a central unit (**105**) providing coverage over the at least one network cell and managing at least one transmission frame for putting into communication the central unit with at least one corresponding user equipment (**UE$_1$-UE$_7$**) within the network cell, the method comprising the following steps carried out by the central unit (**105**); retrieving (**205**) input parameters, said input parameters comprising, for each user equipment, a channel quality parameter indicative of a channel quality measured or estimated based on actual network cell conditions,
applying (**215**) a de-contextualization function to each channel quality parameter for obtaining a corresponding atomic channel quality parameter, wherein said atomic channel quality parameter is not correlated to the actual network cell conditions,
performing a scheduling algorithm providing (**220,320**) a binary allocation matrix indicative of each scheduled physical resource block, transmission frame and user equipment based on said atomic channel quality parameters, and
applying a contextualization function to said allocation matrix for obtaining indication of transport block size to be used by the scheduled transmission frame for transport blocks transmissions from or towards each scheduled user equipment, wherein said performing (220, 320) a scheduling algorithm comprises reiterating the scheduling algorithm

until all the atomic channel quality parameters have been zeroed, said scheduling algorithm comprising, for each iteration:

for each user equipment, masking (**325**) the atomic channel quality parameters by a current buffer status variable indicative of the current status of the user equipment buffer;
scheduling the user equipment, transmission frame and physical resource block whose masked atomic channel quality parameter has maximum value;
upon each scheduling, updating (**330**) the allocation matrix by setting an element of the allocation matrix corresponding to the scheduled user equipment, transmission frame and physical resource block at a first value indicative of the scheduling;
updating (**335**) the current buffer status variable of the scheduled user equipment according to said scheduling;
zeroing (**340**) the atomic channel quality parameters related to the scheduled transmission frame for the scheduled physical resource block, and
updating (**345**) each atomic channel quality parameter different from zero corresponding to the scheduled physical resource block.

2. The method according to Claim 1, wherein said masking (**325**) the atomic channel quality parameters comprises replacing each atomic channel quality parameter by the minimum value between the atomic channel quality parameter itself and the current buffer status variable.

3. The method according to Claim 2, wherein said updating each atomic channel quality parameter different from zero corresponding to the scheduled physical resource block comprises applying to it a penalization factor indicative of the interference that would occur if the transmission frame of the current scheduling decision was transmitted, and penalizing each atomic channel quality parameter different from zero by means of the determined penalization factor.

4. The method according to Claim 3, wherein the input parameters further comprise a buffer size parameter indicative of an amount of data that is buffered for each user equipment, and wherein said updating the current buffer status variable comprises decreasing each value of the current buffer status variable, initially set at the buffer size parameter, by actual amount of data already served to the corresponding user equipment buffer, said actual amount of data taking into account mutual interference among the transmission frames by means of the respective penalization factor.

5. The method according to any Claim from 2 to 3, wherein the input parameters further comprise a number of active transmission frames for each user equipment, and wherein the method further comprises
after said updating the allocation matrix, updating the number of active transmission frames for the scheduled user equipment, and
after said zeroing the atomic channel quality parameters related to the scheduled transmission frame for the scheduled physical resource block, zeroing all the atomic channel quality parameters related to the scheduled user equipment in case the corresponding number of active transmission frames is zero.

6. The method according to any Claim from 3 to 5, wherein the contextualization function is zero when no mutual interference between the transmission frames is present, constant when each transmission frame is supposed to induce a constant interference factor to all the other transmission frames, and proximity-based when each transmission frame is supposed to induce a constant interference factor to the neighboring transmission frames.

7. The method according to any Claim from 4 to 6, wherein said channel quality parameter is an uplink channel quality parameter denoting the uplink channel quality evaluated in respect of the at least one user equipment and by the central unit in respect of the transmission frame, said buffer status parameter being an uplink buffer status parameter comprised, together with the uplink channel quality parameter, with a buffer status report available at the remote unit.

8. The method according to any Claim from 4 to 6, wherein said channel quality parameter is a feedback downlink channel quality parameter denoting the downlink channel quality evaluated by each user equipment, said buffer status parameter being a downlink buffer status parameter.

9. A computer program loadable into at least one internal memory of a computer system (**100**) with input units and output units as well as with processing units, the computer program comprising executable software adapted to carry out the method phases according to any of the preceding Claims, alone or in combination, when running in the computer system.

10. A wireless communications network (**100**) comprising at least one network cell (**110**), the at least one network cell comprising a central unit (**105**) providing coverage over the network cell and managing at least one transmission frame for putting into communication the central unit with at least one corresponding user equipment (**UE_1-UE_7**) within the at least one network cell, the central unit comprising a scheduler unit configured for

retrieving (**205**) input parameters, wherein said input parameters comprise, for each user equipment, a channel quality parameter indicative of a channel quality measured or estimated based on actual network cell conditions,

applying (**215**) a de-contextualization function to each channel quality parameter for obtaining a corresponding atomic channel quality parameter, wherein said atomic channel quality parameter is not correlated to the actual network cell conditions, wherein

said performing a scheduling algorithm providing (**320**) a binary allocation matrix indicative of each scheduled physical resource block, transmission frame and user equipment based on said atomic channel quality parameters, and

applying a contextualization function to said allocation matrix for obtaining indication of transport block size to be used by the scheduled transmission frame for transport blocks transmissions from or towards each scheduled user equipment,

wherein said performing a scheduling algorithm comprises

reiterating the scheduling algorithm until all the atomic channel quality parameters have been zeroed, said scheduling algorithm comprising, for each iteration:

> for each user equipment, masking (325) the atomic channel quality parameters by a current buffer status variable indicative of the current status of the user equipment buffer;
>
> scheduling the user equipment, transmission frame and physical resource block whose masked atomic channel quality parameter has maximum value;
>
> upon each scheduling, updating (330) the allocation matrix by setting an element of the allocation matrix corresponding to the scheduled user equipment, transmission frame and physical resource block at a first value indicative of the scheduling;
>
> updating (335) the current buffer status variable of the scheduled user equipment according to said scheduling;
>
> zeroing (340) the atomic channel quality parameters related to the scheduled transmission frame for the scheduled physical resource block, and f
>
> updating (345) each atomic channel quality parameter different from zero corresponding to the scheduled physical resource block.

11. The wireless communications network according to Claim 10, wherein the wireless communication network is a cellular communication network compliant with Long Term Evolution, LTE, Advanced standard adopting Single Carrier Frequency Division Multiple Access scheme for uplink transmission and Orthogonal Frequency Division Multiplexing Modulation Access scheme for downlink transmission, LTE or Wi-max standards.

12. The wireless communications network according to Claim 10 or 11, further comprising at least one remote unit (**RU_1,RU_2,RU_3**) implementing a distributed antenna system for physically transmitting the at least one transmission frame, each remote unit of the distributed antenna system being coupled with the central unit through a transport medium comprising optical fibers, dedicated wires, and/or exclusive radio-frequency links, and being coupleable with each user equipment concurrently by radio links.

13. The wireless communication network according to Claim 10 or 11, wherein, each transmission frame is transmitted on a separate frequency band through carrier aggregation approach.

Patentansprüche

1. Verfahren (200) zum Festlegen einer Ressourcenzuordnung innerhalb eines drahtlosen Kommunikationsnetzes (100), das mindestens eine Netzzelle (110) umfasst, wobei die mindestens eine Netzzelle eine zentrale Einheit (105) umfasst, die eine Abdeckung über die mindestens eine Netzzelle bereitstellt und mindestens einen Sendeframe verwaltet, der die zentrale Einheit mit mindestens einer entsprechenden Benutzervorrichtung (UE_1-UE_7) innerhalb der Netzzelle in Kommunikation setzt, das Verfahren umfassend: die folgenden, durch die zentrale Einheit (105) ausgeführten Schritte:

> Abrufen (205) von Eingangsparametern, wobei die Eingangsparameter für jede Benutzervorrichtung einen Kanalqualitätsparameter umfassen, der eine Kanalqualität angibt, die auf Grundlage von tatsächlichen Netz-

zellenbedingungen gemessen oder geschätzt wird,
Anwenden (215) einer Entkontextualisierungsfunktion auf jeden Kanalqualitätsparameter zum Erhalten eines entsprechenden atomischen Kanalqualitätsparameters, wobei der atomische Kanalqualitätsparameter nicht mit den tatsächlichen Netzzellenbedingungen zusammenhängt,
Durchführen eines Festlegungsalgorithmus zur Bereitstellung (220, 320) einer binären Zuordnungsmatrix, die jeden festgelegten physikalischen Ressourcenblock, jeden Sendeframe und jede Benutzervorrichtung auf Grundlage der atomischen Kanalqualitätsparametern angibt, und
Anwenden einer Kontextualisierungsfunktion auf die Zuordnungsmatrix zum Erhalten der Angabe der Transportblockgröße, die durch den festgelegten Sendeframe für Transportblocksendungen von oder an jede festgelegte Benutzervorrichtung zu verwenden ist,
wobei das Durchführen (220, 320) eines Festlegungsalgorithmus die Wiederholung des Festlegungsalgorithmus umfasst, bis alle atomischen Kanalqualitätsparameter genullt wurden, wobei der Festlegungsalgorithmus für jede Wiederholung umfasst:

Maskieren (325), für jede Benutzervorrichtung, der atomischen Kanalqualitätsparameter durch eine aktuelle Pufferstatusvariable, die den aktuellen Status des Benutzervorrichtungspuffers angibt;
Festlegen der Benutzervorrichtung, des Sendeframes und des physikalischen Ressourcenblocks, dessen maskierter atomischer Kanalqualitätsparameter einen Maximalwert aufweist;
Aktualisieren (330), bei jeder Festlegung, der Zuordnungsmatrix durch Einstellen eines Elements der Zuordnungsmatrix, entsprechend der festgelegten Benutzervorrichtung, dem Sendeframe und dem physikalischen Ressourcenblock, zu einem ersten Wert, der die Festlegung angibt;
Aktualisieren (335) der aktuellen Pufferstatusvariable der festgelegten Benutzervorrichtung gemäß der Festlegung;
Nullen (340) der atomischen Kanalqualitätsparameter, die mit dem festgelegten Sendeframe zusammenhängen, für den festgelegten physikalischen Ressourcenblock, und
Aktualisieren (345) jedes atomischen Kanalqualitätsparameters, der sich von Null unterscheidet, entsprechend dem festgelegten physikalischen Ressourcenblock.

2. Verfahren nach Anspruch 1, wobei das Maskieren (325) der atomischen Kanalqualitätsparameter das Ersetzen jedes atomischen Kanalqualitätsparameters durch den Minimalwert zwischen dem atomischen Kanalqualitätsparameter selbst und der aktuellen Pufferstatusvariable umfasst.

3. Verfahren nach Anspruch 2, wobei das Aktualisieren jedes atomischen Kanalqualitätsparameters, der sich von Null unterscheidet, entsprechend dem festgelegten physikalischen Ressourcenblock, dessen Anwendung auf einen Pönalisierungsfaktor umfasst, der eine Interferenz angibt, die auftreten würde, wenn der Sendeframe der aktuellen Festlegungsentscheidung senden würde, und Pönalisieren jedes atomischen Kanalqualitätsparameters, der sich von Null unterscheidet, mittels des bestimmten Pönalisierungsfaktors.

4. Verfahren nach Anspruch 3, wobei die Eingangsparameter ferner einen Puffergrößenparameter umfassen, der eine Datenmenge angibt, die für jede Benutzervorrichtung gepuffert wird, und wobei das Aktualisieren der aktuellen Pufferstatusvariable ein Verringern jedes Werts der aktuellen Pufferstatusvariable, die anfänglich auf den Puffergrößenparameter gesetzt ist, um die tatsächliche Menge der Daten, die bereits an den entsprechenden Benutzervorrichtungspuffer zugestellt wurden, umfasst, wobei die tatsächliche Menge der Daten gegenseitige Interferenzen zwischen den Sendeframes mittels des jeweiligen Pönalisierungsfaktors in Betracht ziehen.

5. Verfahren nach einem der Ansprüche 2 bis 3, wobei die Eingangsparameter ferner eine Anzahl aktiver Sendeframes für jede Benutzervorrichtung umfassen und wobei das Verfahren ferner umfasst:

nach dem Aktualisieren der Zuordnungsmatrix, Aktualisieren der Anzahl aktiver Sendeframes für die festgelegte Benutzervorrichtung, und
nach dem Nullen der atomischen Kanalqualitätsparameter, die mit dem festgelegten Sendeframe für den festgelegten physikalischen Ressourcenblock zusammenhängen, Nullen aller atomischen Kanalqualitätsparameter, die mit der festgelegten Benutzervorrichtung verbunden sind, falls die entsprechende Anzahl aktiver Sendeframes Null ist.

6. Verfahren nach einem der Ansprüche 3 bis 5, wobei die Kontextualisierungsfunktion Null ist, wenn keine gegenseitige Interferenz zwischen den Sendeframes vorliegt, konstant, wenn jeder Sendeframe einen konstanten Störfaktor auf alle anderen Sendeframes einleiten soll, und nähebasiert, wenn jeder Sendeframe einen konstanten Störfaktor auf die benachbarten Sendeframes einleiten soll.

7. Verfahren nach einem der Ansprüche 4 bis 6, wobei der Kanalqualitätsparameter ein Uplink-Kanalqualitätsparameter ist, der die Uplink-Kanalqualität benennt, die bezüglich der mindestens einen Benutzervorrichtung und durch die zentrale Einheit bezüglich der Sendeframes bewertet wird, wobei der Pufferstatusparameter ein Uplink-Pufferstatusparameter ist, der zusammen mit dem Uplink-Kanalqualitätsparameter in einem Pufferstatusbericht enthalten ist, der an der externen Einheit verfügbar ist.

8. Verfahren nach einem der Ansprüche 4 bis 6, wobei der Kanalqualitätsparameter ein Feedback-Downlink-Kanalqualitätsparameter ist, der die Downlink-Kanalqualität angibt, die durch jede Benutzervorrichtung bewertet wird, wobei der Pufferstatusparameter ein Downlink-Pufferstatusparameter ist.

9. Computerprogramm, das in mindestens einen internen Speicher eines Computersystems (100) mit Eingabeeinheiten und Ausgabeeinheiten sowie mit Verarbeitungseinheiten geladen werden kann, wobei das Computerprogramm ausführbare Software umfasst, die angepasst ist, die Verfahrensphasen nach einem der vorhergehenden Ansprüche alleine oder in Kombination auszuführen, wenn es in dem Computersystem läuft.

10. Drahtloses Kommunikationsnetz (100), umfassend mindestens eine Netzzelle (110), wobei die mindestens eine Netzzelle eine zentrale Einheit (105) umfasst, die eine Abdeckung über die Netzzelle bereitstellt und mindestens einen Sendeframe verwaltet, um die zentrale Einheit mit mindestens einer entsprechenden Benutzervorrichtung (UE_1-UE_7) innerhalb der mindestens einen Netzzelle in Kommunikation zu setzen, wobei die zentrale Einheit eine Festlegungseinheit umfasst, die zum Abrufen (205) von Eingangsparametern konfiguriert ist, wobei die Eingangsparameter für jede Benutzervorrichtung einen Kanalqualitätsparameter umfassen, der eine Kanalqualität angibt, die auf Grundlage von tatsächlichen Netzzellenbedingungen gemessen oder geschätzt wird,
Anwenden (215) einer Entkontextualisierungsfunktion auf jeden Kanalqualitätsparameter zum Erhalten eines entsprechenden atomischen Kanalqualitätsparameters, wobei der atomische Kanalqualitätsparameter nicht mit den tatsächlichen Netzzellenbedingungen zusammenhängt, wobei das Durchführen eines Festlegungsalgorithmus eine binäre Zuordnungsmatrix bereitstellt (320), die jeden festgelegten physikalischen Ressourcenblock, jeden Sendeframe und jede Benutzervorrichtung auf Grundlage der atomischen Kanalqualitätsparameter angibt, und
Anwenden einer Kontextualisierungsfunktion auf die Zuordnungsmatrix zum Erhalten der Angabe der Transportblockgröße, die durch den festgelegten Sendeframe für Transportblocksendungen von oder an jede festgelegte Benutzervorrichtung zu verwenden ist, wobei das Durchführen eines Festlegungsalgorithmus die Wiederholung des Festlegungsalgorithmus umfasst, bis alle atomischen Kanalqualitätsparameter genullt wurden, wobei der Festlegungsalgorithmus für jede Wiederholung umfasst:

Maskieren (325), für jede Benutzervorrichtung, der atomischen Kanalqualitätsparameter durch eine aktuelle Pufferstatusvariable, die den aktuellen Status des Benutzervorrichtungspuffers angibt;
Festlegen der Benutzervorrichtung, des Sendeframes und des physikalischen Ressourcenblocks, dessen maskierter atomischer Kanalqualitätsparameter einen Maximalwert aufweist;
Aktualisieren (330), bei jeder Festlegung, der Zuordnungsmatrix durch Einstellen eines Elements der Zuordnungsmatrix, entsprechend der festgelegten Benutzervorrichtung, dem Sendeframe und dem physikalischen Ressourcenblock zu einem ersten Wert, der die Festlegung angibt;
Aktualisieren (335) der aktuellen Pufferstatusvariable der festgelegten Benutzervorrichtung gemäß der Festlegung;
Nullen (340) der atomischen Kanalqualitätsparameter, die mit dem festgelegten Sendeframe zusammenhängen, für den festgelegten physikalischen Ressourcenblock, und
Aktualisieren (345) jedes atomischen Kanalqualitätsparameters, der sich von Null unterscheidet, entsprechend dem festgelegten physikalischen Ressourcenblock.

11. Drahtloses Kommunikationsnetz nach Anspruch 10, wobei das drahtlose Kommunikationsnetz ein Handykommunikationsnetz ist, das dem fortgeschrittenen "Long Term Evolution"-, LTE, Advanced Standard entspricht, der ein "Single Carrier Frequency Division Multiple Access"-Schema für die Uplink-Sendung und ein "Orthogonal Frequency Division Multiplexing Modulation Access"-Schema für die Downlink-Sendung, LTE- oder Wi-max-Standards übernimmt.

12. Drahtloses Kommunikationsnetz nach Anspruch 10 oder 11, ferner umfassend mindestens eine externe Einheit (RU_1, RU_2, RU_3), die ein verteiltes Antennensystem umsetzt, um physikalisch den mindestens einen Sendeframe zu übermitteln, wobei jede externe Einheit des verteilten Antennensystems mit der zentralen Einheit über ein Trans-

portmittel verbunden ist, das optische Fasern, zugeordnete Drähte und/oder ausschließliche Funkfrequenzverbindungen umfasst, und mit jeder Benutzervorrichtung gleichzeitig über Funkverbindungen verbindbar ist.

13. Drahtloses Kommunikationsnetz nach Anspruch 10 oder 11, wobei jeder Sendeframe über einen Trägeraggregationsansatz auf einem separaten Frequenzband gesendet wird.

Revendications

1. Procédé (**200**) de planification d'affectation de ressources dans un réseau de communication sans fil (**100**) comprenant au moins une cellule de réseau (**110**), la au moins une cellule de réseau comprenant une unité centrale (**105**) assurant une couverture sur la au moins une cellule de réseau et gérant au moins une trame de transmission pour mettre en communication l'unité centrale avec au moins un équipement utilisateur correspondant (**UE_1-UE_7**) à l'intérieur de la cellule de réseau, le procédé comprenant les étapes suivantes réalisées par l'unité centrale (**105**) :

> récupération (**205**) de paramètres d'entrée, lesdits paramètres d'entrée comprenant, pour chaque équipement utilisateur, un paramètre de qualité de canal représentatif d'une qualité de canal mesurée ou estimée sur la base des conditions réelles de la cellule de réseau,
> application (**215**) d'une fonction de décontextualisation à chaque paramètre de qualité de canal pour obtenir un paramètre de qualité de canal atomique correspondant, dans laquelle ledit paramètre de qualité de canal atomique n'est pas corrélé aux conditions réelles de la cellule de réseau,
> exécution d'un algorithme de planification pour fournir (**220, 320**) une matrice d'affectation binaire représentative de chaque bloc de ressources physiques planifiées, trame de transmission et équipement utilisateur sur la base desdits paramètres de qualité de canal atomique, et
> application d'une fonction de contextualisation à ladite matrice d'affectation pour obtenir une indication de la taille du bloc de transport à utiliser par la trame de transmission planifiée pour transporter des transmissions de blocs à partir de chaque équipement utilisateur planifié ou vers celui-ci,
> dans lequel ladite exécution (**220, 320**) d'un algorithme de planification comprend la réitération de l'algorithme de planification jusqu'à la mise à zéro de tous les paramètres de qualité de canal atomique, ledit algorithme de planification comprenant, pour chaque itération :
>
> > pour chaque équipement utilisateur, le masquage (**325**) des paramètres de qualité de canal atomique par une variable de l'état actuel du tampon, représentative de l'état actuel du tampon de l'équipement utilisateur ;
> > la planification de l'équipement utilisateur, de la trame de transmission et du bloc de ressources physiques dont le paramètre de qualité de canal atomique masqué a une valeur maximale ;
> > au cours de chaque planification, la mise à jour (**330**) de la matrice d'affectation en réglant un élément de la matrice d'affectation correspondant à l'équipement utilisateur planifié, à la trame de transmission et au bloc de ressources physiques, à une première valeur représentative de la planification ;
> > la mise à jour (**335**) de la variable de l'état actuel du tampon de l'équipement utilisateur planifié selon ladite planification ;
> > la mise à zéro (**340**) des paramètres de qualité de canal atomique associés à la trame de transmission planifiée pour le bloc de ressources physiques planifié, et
> > la mise à jour (**345**) de chaque paramètre de qualité de canal atomique différent de zéro, correspondant au bloc de ressources physiques planifié.

2. Procédé selon la Revendication 1, dans lequel ledit masquage (**325**) des paramètres de qualité de canal atomique comprend le remplacement de chaque paramètre de qualité de canal atomique par la valeur minimale entre le paramètre de qualité de canal atomique lui-même et la variable de l'état actuel du tampon.

3. Procédé selon la Revendication 2, dans lequel ladite mise à jour de chaque paramètre de qualité de canal atomique différent de zéro correspondant au bloc de ressources physiques planifié comprend l'application à celui-ci d'un facteur de pénalisation représentatif de l'interférence qui se produirait si la trame de transmission de la décision de planification actuelle avait été transmise, et la pénalisation de chaque paramètre de qualité de canal atomique différent de zéro, au moyen du facteur de pénalisation déterminé.

4. Procédé selon la Revendication 3, dans lequel les paramètres d'entrée comprennent, en outre, un paramètre de taille de tampon représentatif d'une quantité de données qui est tamponnée pour chaque équipement utilisateur, et dans lequel ladite mise à jour de la variable de l'état actuel du tampon comprend la diminution de chaque valeur de la variable de l'état actuel du tampon, initialement réglée au paramètre de taille du tampon, de la quantité réelle de données déjà fournies au tampon de l'équipement utilisateur correspondant, ladite quantité réelle de données prenant en compte une interférence mutuelle parmi les trames de transmission, au moyen du facteur de pénalisation respectif.

5. Procédé selon l'une quelconque des Revendications 2 à 3, dans lequel les paramètres d'entrée comprennent, en outre, plusieurs trames de transmission actives pour chaque équipement utilisateur, et dans lequel le procédé comprend, en outre,
après ladite mise à jour de la matrice d'affectation, la mise à jour de plusieurs trames de transmission actives pour l'équipement utilisateur planifié, et
après ladite mise à zéro des paramètres de qualité de canal atomique associé à la trame de transmission planifiée pour le bloc de ressources physiques planifié, la mise à zéro de tous les paramètres de qualité de canal atomique associés à l'équipement utilisateur planifié, dans le cas où le nombre correspondant de trames de transmission actives est égal à zéro.

6. Procédé selon l'une quelconque des Revendications 3 à 5, dans lequel la fonction de contextualisation est égale à zéro lorsqu'il n'existe aucune interférence mutuelle entre les trames de transmission, constante lorsque chaque trame de transmission est supposée induire un facteur d'interférence constant pour toutes les autres trames de transmission, et basée sur la proximité, lorsque chaque trame de transmission est supposée induire un facteur d'interférence constant pour les trames de transmission voisines.

7. Procédé selon l'une quelconque des Revendications 4 à 6, dans lequel ledit paramètre de qualité de canal est un paramètre de qualité de canal sur la liaison montante indiquant la qualité du canal sur la liaison montante par rapport au le au moins un équipement utilisateur et par l'unité centrale par rapport à la trame de transmission, ledit paramètre d'état de tampon étant un paramètre d'état de tampon sur la liaison montante comprenant, avec le paramètre de qualité de canal sur la liaison montante, un rapport d'état de tampon disponible à l'unité distante.

8. Procédé selon l'une quelconque des Revendications 4 à 6, dans lequel ledit paramètre de qualité de canal est un paramètre de qualité de canal sur la liaison descendante en rétroaction indiquant la qualité du canal sur la liaison descendante, évaluée par chaque équipement utilisateur, ledit paramètre d'état de tampon étant un paramètre d'état de tampon sur la liaison descendante.

9. Programme informatique pouvant être chargé dans au moins une mémoire interne d'un système informatique (100) avec des unités d'entrée et des unités de sortie, ainsi qu'avec des unités de traitement, le programme informatique comprenant un logiciel exécutable conçu pour réaliser les phases du procédé selon l'une quelconque des Revendications précédentes, seule ou en combinaison, lorsqu'il tourne dans le système informatique.

10. Réseau de communication sans fil (**100**) comprenant au moins une cellule de réseau (**110**), la au moins une cellule de réseau comprenant une unité centrale (**105**) assurant une couverture sur la cellule de réseau et gérant au moins une trame de transmission pour mettre en communication l'unité centrale avec au moins un équipement utilisateur correspondant (**UE_1-UE_7**) à l'intérieur de la au moins une cellule de réseau, l'unité centrale comprenant une unité de planification configurée pour
récupérer (**205**) les paramètres d'entrée, dans lesquels lesdits paramètres d'entrée comprennent, pour chaque équipement utilisateur, un paramètre de qualité de canal représentatif d'une qualité de canal mesurée ou estimée sur la base des conditions réelles de la cellule de réseau,
appliquer (**215**) une fonction de décontextualisation à chaque paramètre de qualité de canal pour obtenir un paramètre de qualité de canal atomique correspondant, dans laquelle opération, ledit paramètre de qualité de canal atomique n'est pas corrélé aux conditions réelles de la cellule de réseau,
dans laquelle :

> ladite exécution d'un algorithme de planification fourni (**320**) une matrice d'affectation binaire représentative de chaque bloc de ressources physiques planifiées, trame de transmission et équipement utilisateur sur la base desdits paramètres de qualité de canal atomique, et
> appliquer une fonction de contextualisation à ladite matrice d'affectation pour obtenir une indication de la taille du bloc de transport à utiliser par la trame de transmission planifiée pour transporter des transmissions de blocs à partir de chaque équipement utilisateur planifié ou vers celui-ci,
> dans lequel ladite exécution d'un algorithme de planification comprend la réitération de l'algorithme de planification jusqu'à la mise à zéro de tous les paramètres de qualité de canal atomique, ledit algorithme de planification

comprenant, pour chaque itération :

pour chaque équipement utilisateur, le masquage (**325**) des paramètres de qualité de canal atomique par une variable d'état actuel de tampon représentative de l'état actuel du tampon de l'équipement utilisateur ;
la planification de l'équipement utilisateur, de la trame de transmission et du bloc de ressources physiques dont le paramètre de qualité de canal atomique masqué a une valeur maximale ;
au cours de chaque planification, la mise à jour (**330**) de la matrice d'affectation en réglant un élément de la matrice d'affectation correspondant à l'équipement utilisateur planifié, à la trame de transmission et au bloc de ressources physiques, à une première valeur représentative de la planification ;
la mise à jour (**335**) de la variable de l'état actuel du tampon de l'équipement utilisateur planifié selon ladite planification ;
la mise à zéro (**340**) des paramètres de qualité de canal atomique associés à la trame de transmission planifiée pour le bloc de ressources physiques planifié, et
la mise à jour (**345**) de chaque paramètre de qualité de canal atomique différent de zéro, correspondant au bloc de ressources physiques planifié.

11. Réseau de communication sans fil selon la Revendication 10, dans lequel le réseau de communication sans fil est un réseau de communication cellulaire conforme à la norme d'Évolution à long terme avancée (LTE-A), adoptant un système d'Accès multiple à répartition en fréquence unique, pour la transmission sur la liaison montante, et un système d'Accès multiple par répartition en fréquence orthogonale, pour la transmission sur la liaison descendante, à la norme LTE ou à la norme Wi-max.

12. Réseau de communication sans fil selon la Revendication 10 ou 11, comprenant, en outre, au moins une unité distante ($\mathbf{RU_1}$, $\mathbf{RU_2}$, $\mathbf{RU_3}$) pour mettre en oeuvre un système réseau d'antennes distribuées pour transmettre physiquement la au moins une trame de transmission, chaque unité distante du système réseau d'antennes distribuées étant couplée avec l'unité centrale par un support de transport comprenant des fibres optiques, des fils dédiés, et / ou des liaisons radio-fréquence exclusives, et pouvant être couplée avec chaque équipement utilisateur parallèlement à des liaisons radio.

13. Réseau de communication sans fil selon la Revendication 10 ou 11, dans lequel chaque trame de transmission est transmise sur une bande de fréquences séparée par une approche d'agrégation de porteuses.

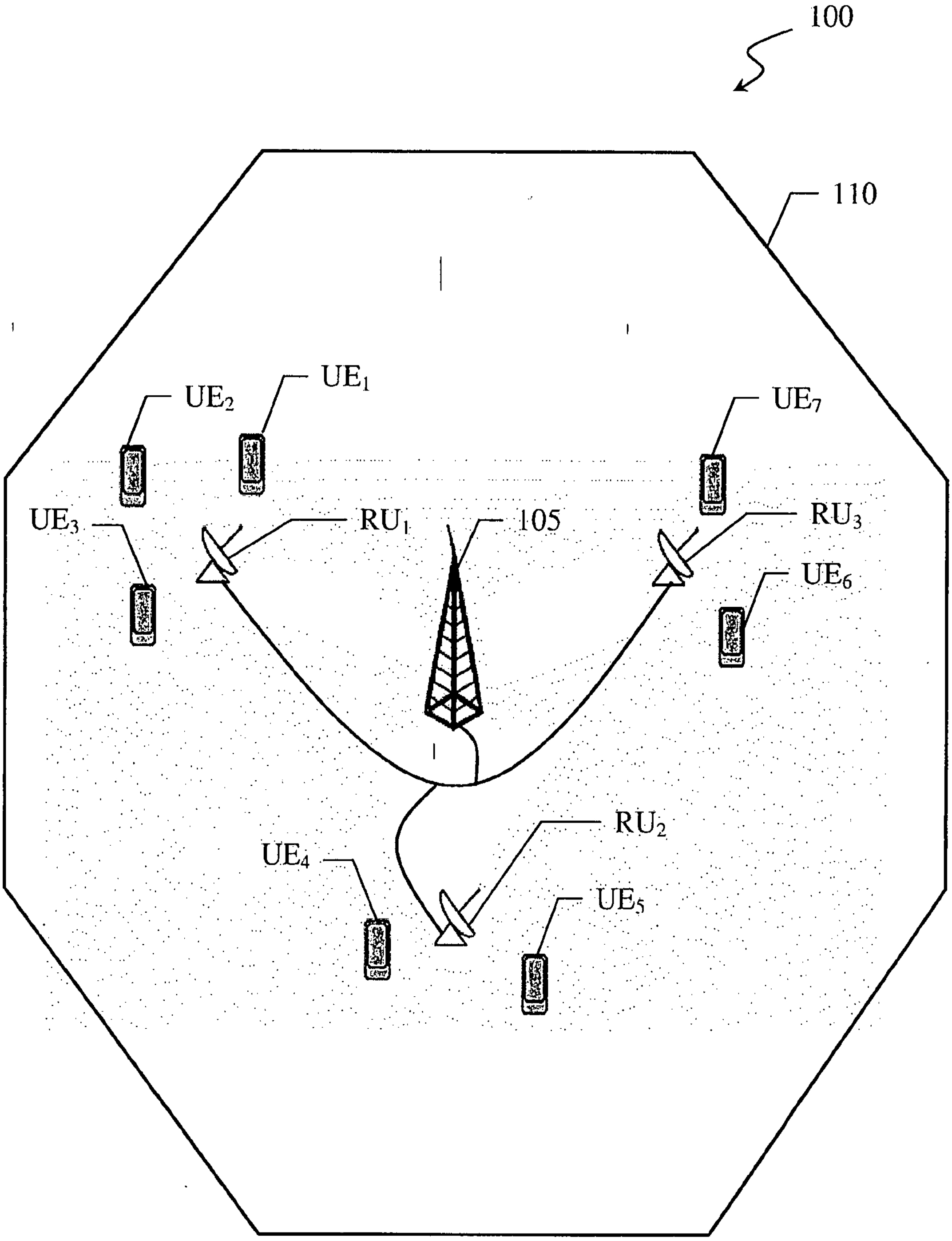

FIG.1

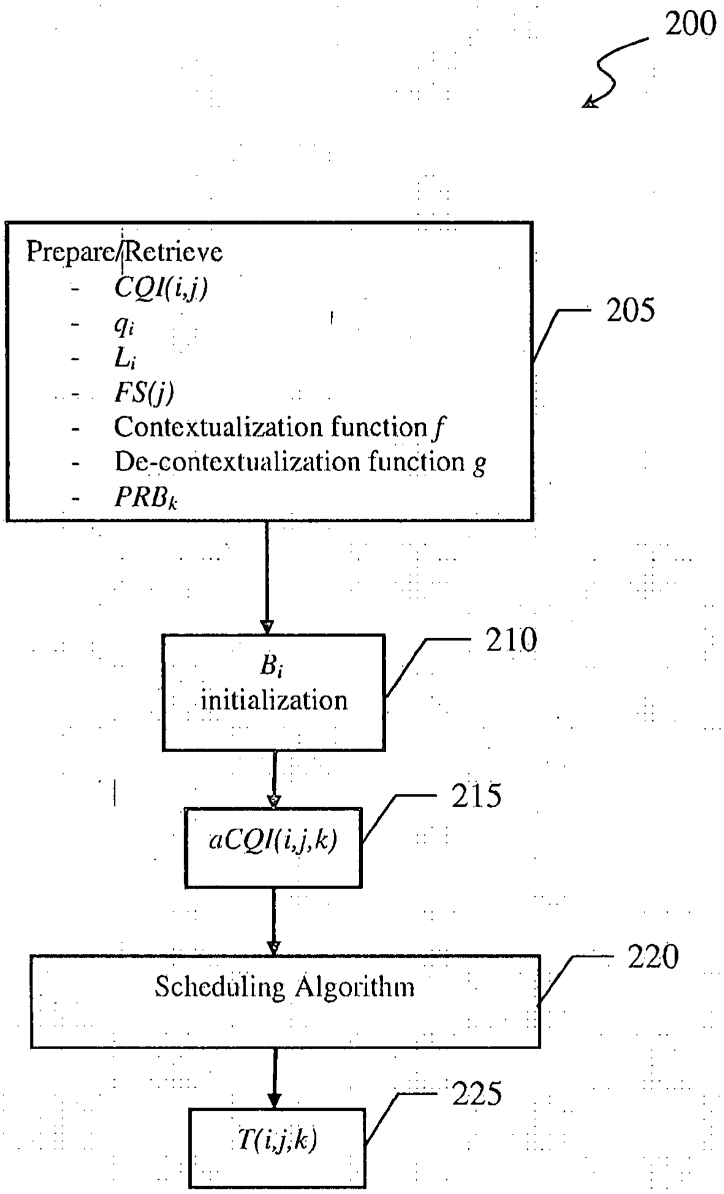
200
Prepare/Retrieve
- CQI(i,j)
- q_i
- L_i
- FS(j)
- Contextualization function f
- De-contextualization function g
- PRB_k
205
B_i
initialization
210
aCQI(i,j,k)
215
Scheduling Algorithm
220
T(i,j,k)
225

FIG.2

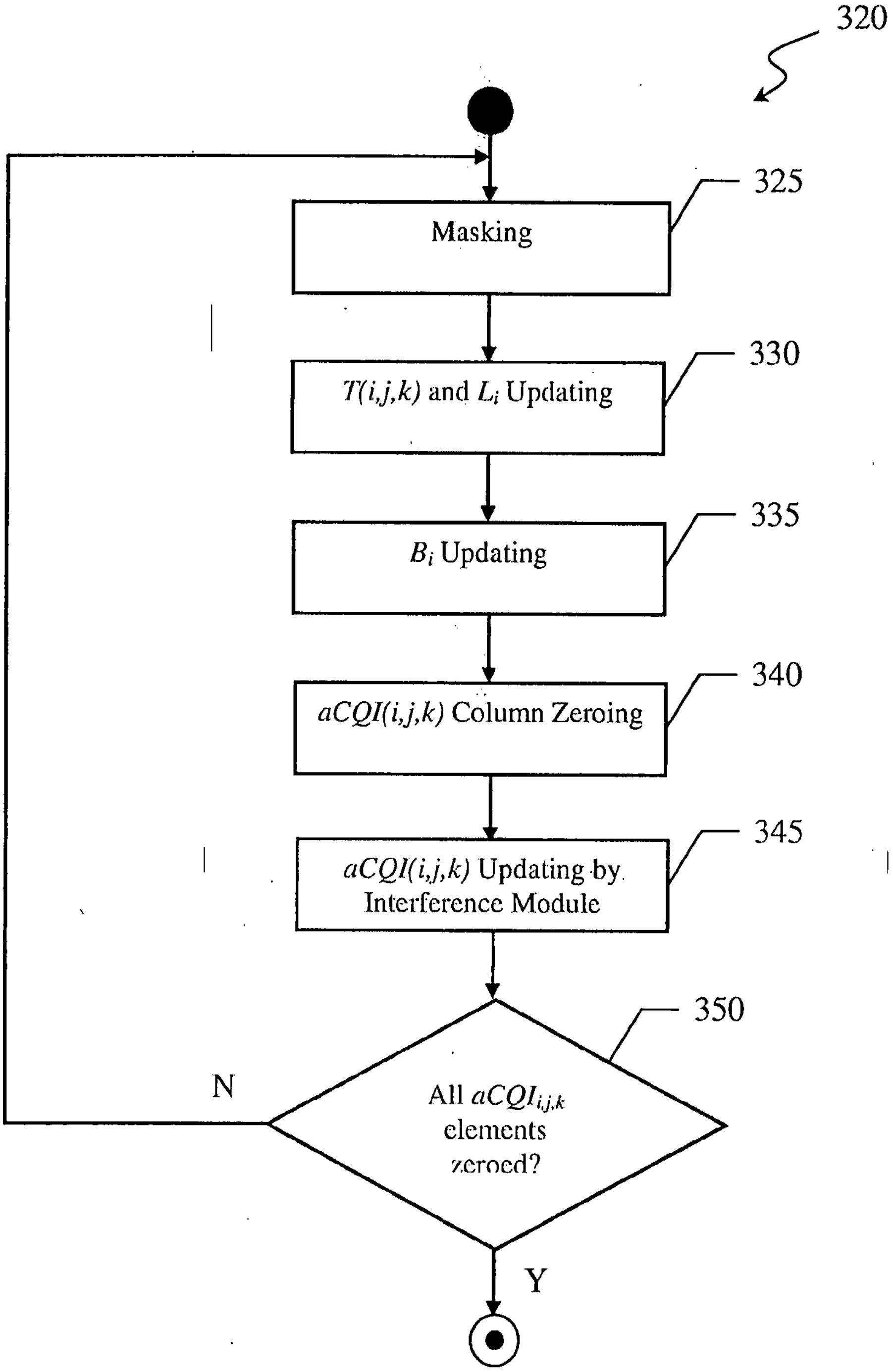
320
325
Masking
330
T(i,j,k) and Li Updating
335
Bi Updating
340
aCQI(i,j,k) Column Zeroing
345
aCQI(i,j,k) Updating by Interference Module
350
All aCQIi,j,k elements zeroed?
N
Y

FIG.3

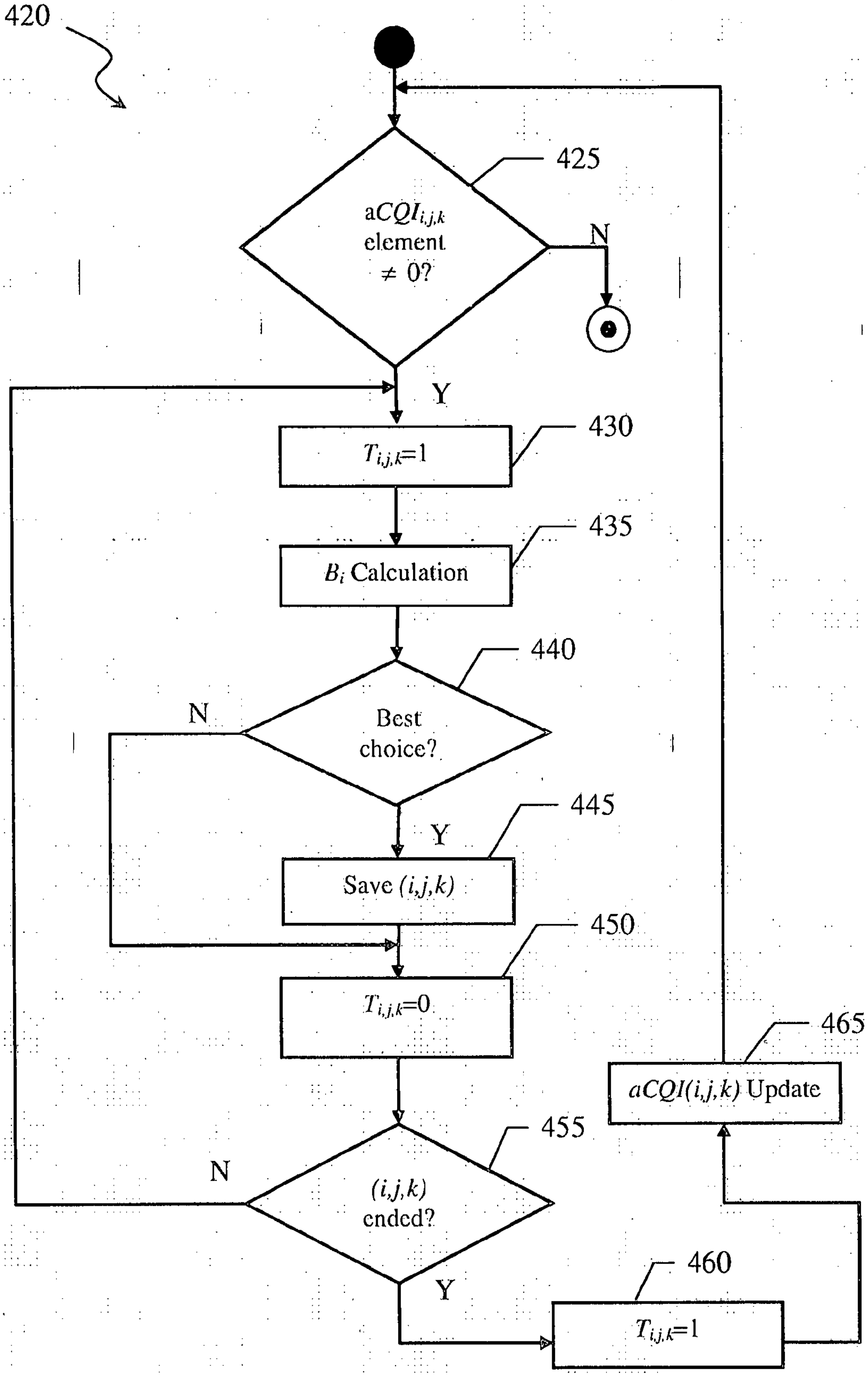
420
425
$aCQI_{i,j,k}$ element ≠ 0?
N
Y
430
$T_{i,j,k}$=1
435
B_i Calculation
440
Best choice?
N
Y
445
Save (i,j,k)
450
$T_{i,j,k}$=0
455
(i,j,k) ended?
N
Y
460
$T_{i,j,k}$=1
465
aCQI(i,j,k) Update

FIG.4

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 2011170642 A **[0017]**
- WO 2011085817 A **[0018]**

Non-patent literature cited in the description

- **PING GONG ; KE YU ; YUMEI WANG.** Radio resource allocation for multiuser OFDMA distributed antenna systems. *IEEE International Conference on Network Infrastructure and Digital Content,* 2009 **[0007]**
- **JOONIL CHOI ; ILLSOO SOHN ; SUNGJIN KIM ; KWANG BOK LEE.** Efficient Uplink User Selection Algorithm in Distributed Antenna Systems. *IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications,* 2007 **[0008]**
- **W. XU ; Z. HE ; K. NIU.** Opportunistic Packet Scheduling in OFDM Distributed Antenna Systems. *WiCOM'09 Proceedings of the 5th International Conference on Wireless communications, networking and mobile computing,* 2009 **[0009]**
- **B. YANG ; Y. TANG.** Heuristic Resource Allocation for Multiuser OFDM Distributed Antenna System with Fairness Constraints. *Proceedings of ICCTA,* 2009 **[0010]**
- Schemes of Power Allocation and Antenna Port Selection in OFDM Distributed Antenna Systems. **LISHA LING ; TAN WANG ; YING WANG ; CONG SHI.** Vehicular Technology Conference Fall (VTC 2010-Fall. IEEE, 2010 **[0011]**
- A Framework for Determining Realistic Capacity Bounds for Distributed Antenna Systems. **MARSCH P. ; KHATTAK S. ; FETTWEIS G.** Information Theory Workshop, 2006. ITW '06 Chengdu. IEEE, 2006 **[0012]**
- **JUN ZHANG ; ANDREWS J.** Distributed Antenna Systems with Randomness Wireless Communications. *IEEE Transactions,* 2008 **[0013]**
- Low-complexity resource allocation and its application to distributed antenna systems. **ZHU, H. ; KARACHONTZITIS, S. ; TOUMPAKARIS, D.** Wireless Communications. IEEE, 2010 **[0014]**
- **PENG SHANG ; GUANGXI ZHU ; LI TAN ; GANG SU ; TAN LI.** Transmit Antenna Selection for the distributed MIMO Systems. *International Conference on Networks Security,* 2009 **[0015]**
- **ALEXEI GOROKHOV ; DHANANJAY A. GORE ; AROGYASWAMI J. PAULRAJ.** Receive Antenna Selection for MIMO Spatial Multiplexing: Theory and Algorithms. *IEEE TRANSACTIONS ON SIGNAL PROCESSING,* November 2003, vol. 51 (11 **[0016]**