(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 December 2012 (27.12.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/175496 A1

(51) International Patent Classification:
H04W 72/08 (2009.01)

(21) International Application Number:
PCT/EP2012/061707

(22) International Filing Date:
19 June 2012 (19.06.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11171026.5 22 June 2011 (22.06.2011) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,

[Continued on next page]

(54) Title: INTERFERENCE COORDINATION BETWEEN BASE STATIONS

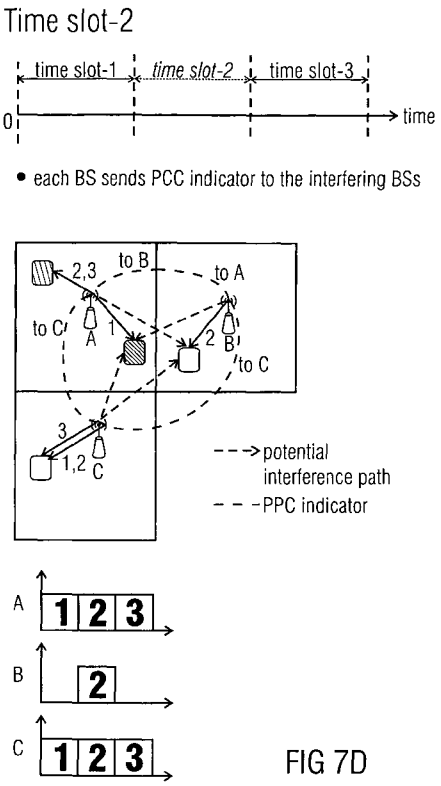


FIG 7D

(57) Abstract: A base station for communicating with a plurality of user equipments assigned to the base station comprises a receiver (10) for receiving, from a first one of a plurality of user equipments, one or more identifications (12) of further base stations interfering with the first user equipment in a transmission resource of a plurality of transmission resources, and for receiving, from a further base station, a primary resource indicator 14 indicating the primary transmission resource for the further base station, in which a further user equipment assigned to the further base station would suffer an interference from the base station. The base station further comprises a transmission resource allocator (16) for allocating a secondary transmission resource to the second user equipment from the set of available transmission resources, wherein the set of available transmission resources does not include the primary transmission resource indicated by the primary resource indicator (14).

WO 2012/175496 A1

TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

INTERFERENCE COORDINATION BETWEEN BASE STATIONS

Specification

The present invention is related to wireless transmission and, particularly, to wireless transmission between one or more base stations and user equipment such as mobile phones or other wireless terminals associated with these base stations.

Low-power small range BSs such as femto BSs are one of the important element of heterogeneous networks which promise high system performance in terms of capacity and coverage. However, because of its uncoordinated deployment, dynamic interference mitigation between such BSs becomes crucial in order to provide desired quality of service. The proposed method improves the cell edge capacity performance according to the dynamic interference environment of a BS in multi-user network deployments. With the proposed method, resources can be assigned to BSs in a full autonomous way. For the networks where BSs are controlled centrally, resources assignment can also be done by the combination of central and autonomous approaches.

A significant fraction of users served by a cellular network are located indoors; yet conventional macro-cellular networks may fail to deliver broadband experience to indoor users, due to severe wall penetration losses. Low-power bs such as femto BSs are one solution to this problem: wall penetration losses are largely mitigated, while the spatial reuse of radio resources is tremendously boosted, due to the small cell sizes 1-3]. However, such BSs are mostly deployed by end users locally without a coordination between each other. Unlike macrocell networks, in uncoordinated local area deployments, the operator cannot determine the locations of the neighboring BSs a priori. This causes an high interference between bs (co-channel interference) especially in networks where bs are densely deployed, such as within enterprises or residential complexes.

A frequency reuse technique, where interfering neighbors transmit data on different frequency resources (subbands), is widely used in local area networks to enhance the throughput of cell edge users. Access to the remaining subbands is restricted, so as not to interfere with neighboring bs. Thus, UEs located in the vicinity of two or more bs face less interference and enjoy better service quality. On the other hand, the trade-off of the frequency reuse is the decrease in the network's overall resource efficiency. Consequently, in order to increase the resource usage efficiency, BSs should use as many subbands as possible.

The vast variations of the interference conditions experienced by bs indicates the necessity of the dynamic frequency reuse approaches which aim at adopting the subband allocation to the observed interference conditions. In a distributed (autonomous) approach, each BS carries out the subband allocation on its own. In [4-8], distributed frequency reuse methods are studied, where each bs may access a predefined number of subbands, so they offer no leeway in subband number when interference conditions change. [9-11] propose a subband selection method depending on the interference environment of the BSs. However, these methods could cause an excessive signaling between BSs. In a centralized approach, subbands are assigned to bs by means of a central controller, which generally achieves more efficient resource utilization, at the expense of higher complexity at the central controller. Also, this approach needs an extra signaling between the controller and the BSs. In [12], a central entity assigns subbands according to the traffic demands of each bs, instead of the prevailing interference conditions. Therefore, under high traffic load situations where all bs require large bandwidth, this method may fail to assign sufficient resources to cell edge users. In [13-17] central resource assignment is applied based on graph theory which maps the interference conditions onto a graph (interference graph). In [13-15] resource utilization is not addressed; each UE (or BS as in [15]) is allocated same amount of resources independent of its interference environment. On the other hand, in [16] optimization in resource allocation is introduced but only applicable for macrocell networks. In [17], dynamic frequency reuse with high resource efficiency in random deployments is addressed. However, its efficiency decreases in multi-user deployments.

It is an object of the present invention to provide an improved concept of operating within a base station.

This object is achieved by a base station of claim 1, a method for operating a base station of claim 14 or a computer program of claim 15.

The present invention is based on the finding that, in order to achieve a high cell edge capacity, specific attention has to be paid to the allocation of the secondary transmission resources. Particularly, in order to perform a useful secondary transmission resource allocation, a receiver receives, from a first one of a plurality of user equipment, one or more identification of further base stations interfering with the first user equipment in a transmission resource of a plurality of transmission resources. Hence, all user equipments associated with the base station under consideration report the identifications of other base stations which provide interference to the user equipment associated with the base station under consideration.

Furthermore, the base station is configured for receiving, from one or more further base stations, a primary resource indicator indicating the primary transmission resource for the further base station, in which a further user equipment assigned to the further base station would suffer an interference from the base station under consideration. Stated differently, the base station under consideration receives the primary resource indicator from a different base station, where this different base station has been informed by the base station under consideration due to the transmission of identification of the other user equipment on the base station under consideration to the other base station.

The transmission resource allocator as included in the base station under consideration allocates a secondary transmission resource to the second user equipment from the set of available transmission resources, wherein the set of available transmission resources does not include the primary transmission resource indicated by the primary resource indicator. Stated differently, the transmission resource allocator makes sure that in the primary transmission resource of an neighboring base station, the base station under consideration does not transmit any information so that the user equipment in the neighboring base station is not interfered with by the transmission of the base station under consideration. The other transmission resources, i.e., the transmission resources not indicated by the primary transmission resource are free to be allocated to end user equipment associated with the base station under consideration or "served" by the base station under consideration in order to enhance the capacity of the mobile network.

In a further embodiment, the base station under consideration not only receives identification information on interfering base stations from the user equipment but also receives SINR measurements of the subbands from the user equipment served by the base station. Hence, the reception information received by the base station under consideration preferably comprises the identification information on interfering base stations and SINR information of subbands from the user equipment and primary subband indicator information from serving base stations of victim user equipment.

The output information provided by the base station in accordance with the present invention preferably comprises instructions to allocate resources to user equipment on the one hand and a primary subband indicator to interfering base stations on the other hand. The primary subband selection, i.e., the association of the transmission resources which are then signaled to neighboring base stations via the primary subband indicator can be performed in an autonomous way or, alternatively, in a centrally-controlled non-autonomous way.

Subsequently, preferred embodiments of the present invention are discussed in the context of the accompanying drawings in which:

Fig. 1 is a block diagram for illustrating a base station in accordance with an embodiment of the present invention;

Fig. 2 illustrates a mobile network consisting of several base stations and user equipment;

Figs. 3a to 3c illustrates a scenario in which the advantage of the present invention is visible;

Fig. 4 illustrates a transmission resource assignment for multi-user deployments;

Fig. 5 illustrates the scenario of Fig. 4 in the context of the measurements done by the user equipment;

Fig. 6a illustrates a preferred embodiment of the primary and secondary subband assignment process done autonomously;

Fig. 6b illustrates an overview of a subband assignment process in an embodiment done partly by the base station where the primary subbands are assigned by a central controller;

Fig. 7a illustrates an example of the present invention at time zero;

Fig. 7b illustrates an example of the present invention within a time slot-one;

Fig. 7c illustrates a transmission resource assignment at the base station at the end of time slot-one;

Fig. 7d illustrates the situation of the example within a time slot-two;

Fig. 7e illustrates a transmission resource assignment at the base station at the end of time slot-two/at the beginning of time slot-three;

Fig. 7f illustrates the example within time slot-three;

Fig. 8a illustrates the mean cell capacity of the inventive procedure compared to other procedures;

Fig. 8b illustrates the percentage of assigned recourses and of collisions over a number of time slots in order to show the high convergence of the preferred process;

Fig. 8c illustrates a CDF of the SINR for different procedures;

Fig. 8d illustrates the CDF of the user capacity for several implementations;

Fig. 9a illustrates an embodiment for calculating a transmission resource availability;

Fig. 9b illustrates an embodiment for performing the secondary assignment procedure;

Fig. 9c illustrates an embodiment for performing the primary assignment in an autonomous way; and

Fig. 10 illustrates a further embodiment for performing the secondary transmission resource assignment.

Fig. 1 illustrates a preferred embodiment of a base station for communicating with a plurality of user equipments assigned to the base station. The base station comprises a receiver 10 for receiving, from a first one of a plurality of user equipment, one or more identifications 12 of further base stations interfering with the first user equipment in a transmission resource of a plurality of transmission resources. When there are additional user equipments served by the base station, then, this base station also receives one or more identifications of further base stations interfering with this second user equipment in a transmission resource of a plurality of transmission resources. The receiver is additionally configured for receiving, from a further base station, a primary resource indicator 14 indicating the primary transmission resource for the further base station, in which a further user equipment assigned to the further base station would suffer an interference from the base station, i.e., the base station under consideration illustrated in Fig. 1. The base station furthermore comprises a transmission resource allocator 16 for allocating a secondary transmission resource to the second user equipment from the set of

available transmission resources, wherein the set of available transmission resources does not include the primary transmission resource indicated by the primary resource indicator 14.

The transmission resource allocator 16 is configured for allocating a primary transmission resource to the first user equipment as indicated by 18, wherein the primary transmission resource is different from the primary transmission resource indicated by the primary transmission resource indicator 14. Furthermore, the base station comprises a transmitter 20 for transmitting a primary transmission resource indicator 22 to a further base station, wherein the further base station is a base station causing an interference in the primary transmission resource at the first user equipment as determined by the one or more identifications 12 received by the receiver 10 from the first user equipment.

In a further embodiment, the receiver 10 is configured for receiving reception quality information 24 for a plurality of different transmission resources from the second user equipment. Furthermore, the transmission resource allocator 16 is configured to only allocate a secondary transmission resource to the second user equipment, for which the receiver 10 has received, from the second user equipment, a reception quality information indicating a reception quality above a predetermined reception quality threshold.

As illustrated in block 20 of Fig. 1, the transmitter performs a time slot-wise processing and the same is true for the receiver 10 and the transmission resource allocator 16. Hence, the receiver 10 is configured to receive the one or more identifications and a reception quality information (12, 24) in a first time slot, and the transmission resource allocator 16 is configured to allocate, based on the information received by the receiver 10, in a second time slot being later in time than the first time slot. Preferably, the second time slot is adjacent to the first time slot in time, but can also be a time slot which is not adjacent but is, for example, the second to next or third to next time slot. Furthermore, the receiver 10 is configured to receive the one or more identifications and the reception quality information 12, 24 in a first time slot, and the transmitter 20 is configured for transmitting the primary resource indicator 22 in a second time slot being later in time than the first time slot.

Hence, the receiver receives, in an embodiment, IDs from all user equipments served by the base station having the receiver, and, after allocation, the user equipments being allocated with the primary resources is treated such that the base stations interfering with this user equipment are provided with the primary resource indicator. The user equipments, however, that are allocated with a secondary transmission resource is not considered when the primary resource indicators are generated and sent. Therefore, the user equipment

having a secondary transmission resource reports the IDs of interfering base stations, but these interfering base stations do not receive a primary resource indicator.

As outlined later on, the transmission resource allocator 16 is configured to calculate an availability measure for each of the plurality of transmission resources based on individual reception quality information received from the user equipment served by the base station and to the transmission resource allocator 16 is configured to allocate the secondary transmission resource based on the availability measure for the specific transmission resource.

In a further embodiment, the transmission resource allocator 16 is configured to allocate the secondary transmission resource only to user equipment, for which a reception quality measure provided by the user equipment is above a predetermined reception quality measure threshold.

In a further embodiment, the transmission resource allocator 16 is additionally configured to perform a primary transmission resource allocation as well. This primary transmission resource allocation can be performed in a de-centralized autonomous way by the base station, but can also be performed in a centrally controlled way. In the latter case, the transmission resource allocator 16 is configured for receiving instructions 26 from a central controller so that the base station allocates the primary transmission resource 28 to a user equipment served by the base station in accordance with these instructions 26. On the other hand, the secondary transmission resource allocation indicated by 18 in Fig. 1 is performed by the transmission resource allocator 16 of the base station in a de-centralized distributed way.

In the embodiment, in which the transmission resource allocator 16 performs a primary transmission resource allocation 28 in a de-centralized way, the transmission resource allocator 16 is configured to perform the distributed procedure for the allocation of the primary transmission resource by only allocating a primary transmission resource not blocked by a primary transmission resource indicator 14 from a further base station as received by the receiver 10, and by selecting a transmission resource having an availability measure being higher than a minimum availability measure of the allocatable transmission resources.

Furthermore, the transmission resource allocator 16 is configured for re-allocating a primary transmission resource for a later time slot in case of receiving a primary resource indicator 14 for the allocated primary transmission resource, and wherein the at least one

secondary transmission resource 18 allocated in an earlier time slot is available for being selected as a primary transmission resource 28 for the later time slot.

Fig. 2 illustrates a scenario, in which the base station of Fig. 1 is located. Particularly, the base station of Fig. 1 is illustrated at base station 1 at 100 in Fig. 2. The further base station, from which the base station 100 receives the primary resource indicator PRI is indicated as further base station 3 or 103 in Fig. 2. Furthermore, the first one of the plurality of user equipment, from which the receiver of the base station 100 receives one or more identifications is indicated at 102. The "further base station" which is indicated to the base station 100 by the first user equipment 102 is indicated in Fig. 2 as the further base station 2 or 104. The primary transmission resource which the base station 100 assigns to the first user equipment 102 is signaled from the base station 100 to the further base station 104 via the primary resource indicator 105, since the further base station 104 results in an interference 106 at the first user equipment, where the first user equipment 102 is served by the base station 100. The other base station additionally served by the base station 100 is the second user equipment 107 that receives the secondary transmission resource signaled by the secondary resource allocation 108. The further base station 103 serves a further user equipment 108 and the first user equipment 108 receives interference by the base station 100 as illustrated at 109. Due to this, the further user equipment 108 provides the identification of the base station 100 to the further base station 103 as illustrated at 110. Due to this, the further base station 103 sends the primary resource indicator 111 to the base station 100.

Embodiments of the present invention address a distributed dynamic resource partitioning in wireless networks. The main objective is to protect user equipment (UEs) that are located near the cell boundary of two or more base stations (BSs) from detrimental downlink interference without causing a degradation in overall system performance. For this purpose, the present invention relates to a novel distributed dynamic frequency reuse (D-DFR) method. The method and the corresponding apparatus are advantageous in that they strike a balance between interference protection and spatial reuse of available resources and the present invention, i.e., the base station, the method of operating a base station and the corresponding computer program are well suited for randomly deployed wireless networks but can also be used for other non-randomly or semi-randomly deployed wireless networks.

In order to achieve an high cell edge capacity, a novel D-DFR method is developed. The main objective of D-DFR is to dynamically assign subbands to bs, so as to improve the capacity of cell-edge UEs, without causing a sharp decrease in the overall network

capacity. Instead of frequency resources, any other resources such as time, code, etc., can also be assigned to BSs with D-DFR for the same purpose. In this report, the focus will be on the assignment of subbands.

In D-DFR, each BS collects feedback from its UEs and the neighboring BSs. Based on these feedback, primary and secondary subbands are assigned for each BS. Primary subbands cannot be used by interfering neighbors. Thus, the UE to which a primary subband is allocated, faces low interference and enjoys higher capacities. For the sake of high resource utilization, in addition to the primary subband, the BS can use secondary subbands, depending on its interference conditions; however these subbands cannot be blocked at interfering neighboring BSs. Hence, the D-DFR offers the BS a greedy resource allocation limited by its interference environment.

The D-DFR is an iterative algorithm where the subbands assigned to the BSs are updated for the next time slot according to the feedback of the previous time slot. Fig. 6a shows an overview of the actions taken by a given BS, BS^b, for the networks without any central controller. During a time slot, of which duration is same for all UEs and BSs, a UE identifies the cell identities (IDs) of the interfering BSs and also measures the signal-to-interference-and-noise ratio (SINR) levels over each subband. Additionally, the serving BSs of the victim UEs, which face high interference from BS^b, inform BS^b about the primary subbands assigned by them. Upon receiving these feedback at the end of a time slot, BS^b assigns primary and secondary subbands that will be used during the next time slot.

Particularly, Fig. 6a illustrates an overview of the primary and secondary subband assignment process done autonomously by the base station under consideration. Here, victim UEs, such as user equipment 108 of Fig. 2, is the user equipment facing high interference from the base station under consideration. The interfering base station such as 104, on the other hand, is a base station which causes high interference (106 in Fig. 2) to the user equipment such as 102 in Fig. 2 served by the base station under consideration, i.e., base station 100.

Particularly, Fig. 6a additionally illustrates the time-slot wise processing. Illustrated is a first time slot 60a and a second time slot 60b, where the second time slot 60b is later in time than the first time slot 60a and is, particularly, adjacent in time to the first time slot 60a.

Particularly, Fig. 6a further illustrates the functionality of the transmission resource allocator 16. Steps performed by the transmission resource allocator 16 in the Fig. 6a embodiment are an identification 16a of available transmission resources or (component carriers equal to CCs) for transmission. Then, in this embodiment, a primary component carrier or transmission resource selection is performed as illustrated at 16b and in this embodiment a secondary component carrier selection is performed at 16c. The input into the process are the IDs of interfering base stations 12 and the signal to interference and noise ratios (SINRs) of the transmission resources (CCs) from the user equipment illustrated at 24 in Fig. 1 is an additional input, but not from user equipment but from base stations of victim user equipment is a primary resource indicator 14. The output of the procedure performed by the transmission resource allocator is the allocation of resources to user equipment 18, 28 and the transmission of a primary resource indicator 22 to interfering base stations.

Fig. 6b illustrates an overview of the subband assignment process done partly by the base station under consideration, i.e., base station 100 in Fig. 2. Primary subbands are assigned to base stations by a central controller as indicated by item 26 in Fig. 1 based on the feedback from base stations. Secondary subbands, however, are assigned autonomously by the base station under consideration as outlined by 16c in Fig. 6b.

Fig. 6b illustrates the subband assignment at BS_b for centrally controlled networks. In such cases, primary subbands are assigned to BSs by the central controller depending on the feedback sent from BSs. Secondary subbands, on the other hand, are assigned by BSs autonomously depending on the feedback from UEs and neighboring BS. Since the interfering environment of a BS does not change as frequently as UEs, the central controller does not need to update the primary subband assignment at each time slot. This way, signaling overhead decreases.

In order to inform the central controller on the current situation for the base station under consideration, i.e., BS_b, the transmission resource allocator is configured to forward, to the transmitter 20 of Fig. 1, the identifications of the interfering base stations which are transmitting to a central controller as illustrated at 61.

The present invention provides, in different embodiments, a plurality of advantages.

Each BS has a primary subband which is not used by its interfering neighbors. By allocating this subband to cell-edge UEs will increase the cell edge capacity, thus improves the fairness between the cell edge and cell center UEs.

- Dynamic resource assignment Primary and secondary subbands are updated based on the actual measurements done by UEs.
- Flexibility The number of assigned subbands depends on the interference conditions of each bs. bs facing low interference can use more subbands which increases the resource utilization.
- Less complexity Proposed method has modest signaling overhead and low complexity.
- Fast convergence By the wise selection of the subbands at the BSs, the network reaches a stable resource allocation in a short time.
- Both applicable to distributed and central approaches With D-DFR, subband assignment can be done in an autonomous way without need of a central controller. However, for the networks controlled by centrally, primary subbands can be assigned to BSs by a central controller. This makes the proposed method suitable for any kind of network deployments.
- High resource utilization for multi-user deployments Each user in the same cell experiences different interference conditions, hence, it is possible to allocate different subbands to different UEs according to interference they face. In addition to primary subband, with the allocation of secondary subbands, more subbands can be allocated to cell center UEs facing less interference. This increases the resoruce efficicency of the network.

Subsequently, the system model underlying the following considerations is discussed in more detail.

A downlink transmission in a wireless network based on 3GPP Long Term Evolution-Advanced (LTE-A) is considered. LTE-A is an evolved version of LTE with higher system performance targets [18]. Also, LTE-A is supposed to be backward compatible with LTE which means an LTE-A network should support an LTE UE. One of the important requirement for LTE-A is to support transmission bandwidth up to 100 MHz. Nevertheless, in LTE, maximum supported bandwidth is 20 MHz [19]. In order to achieve a high system bandwidth, carrier aggregation (CA) method is developed [20,21]. In CA, multiple blocks of LTE bandwidths, named as component carriers (CC), are combined to obtain a wider bandwidth. As each CC is compatible with LTE, both LTE and LTE-A UEs can be supported by an LTE-A network. As the bandwidth of LTE-A is composed of multiple CCs, each CC can be assumed as a subband where a BS transmits data over one or more subbands. For the rest of the report, subband and CC will be used interchangeably. It is worth to mention that a CC consists of resource blocks (RBs) which is the minimum

resource unit that can be allocated to a UE. A BS can allocate RBs of the same CC to UEs as long as each RB is allocated to only one UE in the same cell.

In the network, the BSs and UEs are assumed to be synchronized with each other. Each BS receives feedback of a previous time slot and makes decisions for the next time slot. During each time slot, the subbands used by BSs do not change. Changes in subband assignment are only done between time slots.

When, for example, Fig. 6a and the time slot 60a, 60b are considered, it is to be noted that, in an embodiment, the feedback from t_{n-1} is received at time 61. Then, at time 61, the subband assignment for t_n, i.e., for time slot 60a is performed. Then, at time 62, the feedback from time slot 60a is received and, at time 62, the subband assignment for the next time slot 60b is performed. Then, at time 63, the feedback from time slot 60b is received and the subband or component carrier assignment for the next time slot is performed.

Subsequently, the measurements done by the user equipment are discussed in more detail.
1) IDs of Interfering BSs: Owing to an uncoordinated deployment of BSs, it is impossible to know a priori the neighbors of a BS. Therefore, each UE discovers its interfering neighbors during operation. In D-DFR, each UE identifies its interfering BSs based on a pre-defined SINR threshold, γ_{th}, which specifies the minimum desired SINR for each UE.
In LTE-A, for each subband, UEs can distinguish the received signal strengths from different BSs with the help of BS-specific reference signals. The received signal strength observed by UE_m from BS_b is determined by

$$R_{m,b} = T_b G_{m,b} \quad (1)$$

where T_b is the BS transmit power and $G_{m,b}$ is the channel gain between BS_b and UE_m. This describes the combined effect of path loss and shadowing. The effect of fast fading is negligible since the measurement interval is long enough based on the UE's speed.

By knowing the received signal strength from all neighboring BSs, a UE can calculate the worst-case SINR by taking into account the interference from all neighboring BSs. Based on the received signal strengths from the serving BS_b, and from the set of all interfering BSs, I_m a UE_m experiences a worst case SINR of γ_{th}. If $\gamma < \gamma th$, then among I_m, the largest interfering BS is removed and γ_m is recalculated. This process continues until

$$\gamma_m = \frac{R_{m,b}}{\sum_{i \in \bar{I}_m} R_{m,i} + \eta} \geq \gamma_{\text{th}} \qquad (2)$$

where η accounts for thermal noise and $\bar{I}_m$ is the set of tolerable interfering neighbors defined by:

$$\bar{I}_m = I_m - I_{m,\text{rem}} \qquad (3)$$

where $I_{m,\text{rem}}$ is the set of removed interfering BSs, which must not use the same subband that is allocated to UE_m, so that it may achieve γ_{th}. All UEs report their interfering neighbors to their serving BSs when a change (such as the entrance of a BS in the network) is detected. When a BS allocates a primary subband p to UE_m, it informs the (potential) interfering BSs of UE_m via a primary subband indicator to prevent those interfering BSs from using p. Thus, the desired γ_{th} can be achieved for the UE_m. If a BS serves multiple UEs, then it should perform the same process for all UEs since each UE has distinct interfering BSs depending on its location.

As a final remark, increasing γ_{th} increases the number of the interfering BSs of a UE. This way, higher SINRs are achieved, but this is a traded-off with a reduced spatial reuse of subbands.

2) SINR Levels of Subbands: As stated above, a UE measures the received signal strengths from the serving BS and neighboring BSs over each subband. Therefore, it is possible for a UE to calculate the SINR levels of each subband. With SINR information over each subband, a BS identifies available subbands to allocate UEs for the next time slot. Subsequently, the availability of a subband is discussed.

In order to assign subbands autonomously, a BS needs a metric to compare the subbands. This way, it can select the most efficient ones in terms of desired performance criterion. For this purpose, a metric 'subband availability' is developed. The availability of a subband n, A_n, indicates how many UEs in a cell experiences an SINR higher than γ_{th} over n. However, if a given BS receives a primary subband indicator from its neighbor(s), the given BS cannot use the subband implied by the primary subband indicator in order to sustain the desired γ_{th} for the victim cell edge UEs. Therefore, the availability of indicated subband (banned subband) becomes 0 independent of SINR levels reported by UEs. Calculation of the availability of a subband n is given in the pseudo code of Fig. 9a.

M is the set of UEs of interest and $\gamma_{m,n}$ is the SINR level experienced by UE_m over n. If n is planned to be assigned as a secondary subband, all UEs in the cell constitute M . However, if it is planned to be assigned as a primary subband, then either all UEs or subset of UEs constitutes M . The selection of set of UEs to calculate a primary subband is explained in a detailed way in the following.

It is preferred to use a probability model within the subband assignment. Since the subband assignment at BSs are done in a distributed way according to the feedback of previous time slot, it is possible for a BS to make wrong decisions that cause a high interference on UEs. As the BSs learn their environment, the network reaches a stable point and the BSs do not need to change their subband assignments. However, it is desirable for a network to reach the stable point as fast as possible. Change in the subband assignment of a BS forces to change its neighbors' subband selection, hence increases the time to reach a stable point in the network. For instance, assume BS_A and BS_B which interfere each other. They allocate subband n to their UEs for the time slot t_f. Then, during the time slot t_f, UEs served by BS_A and BS_B face high interference. Therefore, for the next time slot, t_{f+1}, both BS_A and BS_B give up using n. However, during t_{f+1}, UEs measure low interference over n since both BSs do not use it. As a result, both BS_A and BS_B allocate n or the time slot t_{f+2}. This process continues until one of the BSs does not use n when other one decides to use it. For this purpose, in D-DFR, a BS can use a new subband that is not used during the previous time slot with a probability depending on its availability. By introducing a probability in the subband assignment, interfering BSs are prevented to use the same subband simultaneously. This way, the interference in the network decreases and the subband selection at BSs becomes stable in a shorter time. The probability of assigning the subband n is calculated as:

$$\mu(n)=\begin{cases} 0.5 & \text{if } |M|=1 \\ 1-\left(\dfrac{|M|-1}{|M|}\right)^{A_n} & \text{if } |M|>1 \end{cases} \qquad (4)$$

where A_n is the availability of n, M is the set of the UEs used for calculating the n's availability and the operator |.| indicates the cardinality of the given set. According to (4), probability of assigning a subband increases as its availability increases. This favors the selection of subbands that can be allocated to more users with an high SINR.

Subsequently, the assignment of a primary subband in a preferred embodiment is discussed in more detail.

Primary subband can be assigned centrally or autonomously. It is allocated to cell edge UEs and cannot be used by the interfering BSs. Therefore, a BS sends a primary subband indicator to the interfering BSs of the UEs to which a primary subband is allocated. Number of the primary subbands assigned to BSs is fixed and depending on the network conditions it can be adapted for each BS.

1) Central Assignment: After each BS receives the interfering BS IDs from the UEs, it sends these IDs to the central controller. Then, according to the received feedback, central controller assigns primary subbands to BSs. Detailed description of the central subband allocation can be found in [17].

2) Autonomous Assignment: In an autonomous primary subband allocation, the BS updates its primary subband assignment according to the feedback of the UEs to which the primary subband is allocated during the previous time slot. The primary subband selection algorithm is given in the following pseudo code where N' is the set of all subbands which are not assigned as a primary subband in the previous time slot, P is the set of primary subbands and p is the primary subband to be updated.

According to the pseudo code in Fig. 9c, the algorithm first calculates the availability of subbands. For this purpose, only the measurements of the set of UEs to which p is allocated during the previous time slot is used. As the cell edge UEs have the priority to use the primary subband, it is reasonable to update the primary subband assignment based on the measurements of UEs to which primary subband is allocated. Among N', the algorithm searches for a subband whose availability is higher than the primary subband, p. If there is such a subband, say n, then it is substituted for p in P with a probability of $\mu(n)$ as calulated in (4). If the probability criteria does not hold for n, then n is discarded from the subband set N' and the algorithm searches in N' for an another subband which has a higher availability than p. This process continues until the algorithm assigns a new primary subband or none of the subbands in N' has higher availability than A_p. If no subband substitutes for p as a primary subband, p remains as a primary subband for the next time slot. As a result, the primary subband assigned for the next time slot always has higher or equal availability than the primary subband assigned in previous time slot. This way, more cell edge UEs can experience high SINR, hence high capacity. The whole algorithm is repeated for each primary subband which is assigned during the previous time slot.

Subsequently, a preferred embodiment of the assignment of secondary subbands is discussed. After the primary subband assignment, as a next step, a BS searches for further subbands that it can allocate to UEs. Unlike the primary subband, the secondary subband cannot be banned at interfering BSs and it is only allocated to the UEs which measures SINR higher than γ_{th} over the secondary subband. Thus, as the availability of a subband increases, it can be allocated to more users. This increases the fairness between UEs. A BS can use as much subbands as it can depending on its interference environment. Nevertheless, in some situations, there can be a maximum limit on the number of subbands, N_{max}, that a BS can assign. This restricts the maximum number of secondary subbands that can be used. The secondary subband selection algorithm is given in the following pseudo code where N is the set of all subbands, S is the set of secondary subbands, P is the set of primary subbands and the operator $|.|$ indicates the cardinality of the given subband set.

According to the pseudo code in Fig. 9b, the algorithm first calculates the availability of subbands. For this purpose, unlike the primary subband assignment, the measurements of all UEs are taken into account. Before selecting any secondary subband, the BS discards the subbands having zero availability from the secondary subband set, S, because either these subbands are banned by the serving BSs of the victim UEs or all UEs in the cell experiences SINR lower than γ_{th} over these subbands. Therefore, such subbands cannot be used for the next time slot. The algorithm searches for a subband whose availability is higher than minAvail among the set of subbands which are not assigned as primary or secondary subbands, N'. If there is no limitation on the maximum number of assigned subbands, the BS can assign any subband as a secondary subband as long as its availability is greater than 0, which means $\text{minAvail} = 0$. If there is such a subband, say n, then the algorithm updates S by adding n to S with a probability of $\mu(n)$. n is discarded from the subband set N' and this process continues until none of the subbands in N' has higher availability than minAvail.

If there is a limitation on the maximum number of assigned subbands, same algorithm is followed as long as the total number of assigned subbands is smaller than N_{max}. When the number of assigned subbands reaches N_{max}, minAvail is set as the minimum availability of S, instead of 0. In other words, $\text{minAvail} = \min(A_S)$. Then, if there is a subband n in N', having availability higher than minAvail, the algorithm updates S by substituting n for the subband having the minimum availability in S with a probability of $\mu(n)$. It is clear that the updated secondary subbands set has always higher or equal availability than the secondary subband set assigned in the previous time slot.

As a final remark, in order to increase the resource utilization, different SINR threshold than γ_{th} can be used for the secondary subband assignment. During the calculation of the subband availability for secondary subband assignment, if a lower SINR threshold than γ_{th} is used, the availability of subbands increases. This, hence, increases the probability of assignment of more secondary subbands.

Subsequently, simulation results are discussed in the context of Figs. 8a to 8d.

1) Simulation Setup: In a simulator, a downlink transmission in a femtocell network is considered in [22]. The deployment of femtocells is modeled by a 5x5 grid, where a single floor building with 25 apartments, each having 10m x 10m area is used. BSs and UEs are randomly dropped within the apartment during each 'snapshot' of the simulation. The BS serves 4 UEs that are also located in the same apartment. The number of RBs per subband is set as 4. Thus, a BS can distribute a subband among 4 UEs. BS activation probability is set as 0.2 meaning one fifth of the apartments, on average, have one active BS. For the sake of simplicity, interference from the macrocell network is neglected, which may be accomplished by allocating different frequency bands to macro and femtocells. Even if co-channel macrocells are simulated, the trends in results will still remain the same. Parameters used in simulations are based on LTE specifications, but with bandwidth extension. They are summarized in Table 1 [22].

Table 1: Simulation Parameters

Parameter	Value
CC bandwidth	10 MHz
System bandwidth	40 MHz (4x10 MHz)
Traffic model	Full buffer
min. sep. between UE and BS	20 cm
BS antenna gain	0 dBi
Antenna Pattern	$A(\theta) = 0$ dB (omnidirectional)

(Horizontal)	
Interior path loss	$L = 127 + 30\log_{10} d$ [km], where d is the distance between UE and BS
Shadowing std. dev.	10 dB
max Tx power over a CC	20 dBm
Thermal Noise Density	$N_0 = -174$ dBm/Hz
UE Noise Figure	9 dB

For capacity calculations, the attenuated and truncated Shannon bound is used. It gives the capacity of a channel with link adaptation, which means the modulation and coding schemes are selected based on SINR. Given a specific $\gamma_{m,r}$, the spectral efficiency of UE_m on RB r in [bps/Hz] is calculated as [23]:

$$\bar{C}_{m,r} = \begin{cases} \bar{C}_{min} & \text{for } \gamma_{m,r} < \gamma_{min} \\ \alpha \log_2(1+\gamma_{m,r}) & \text{for } \gamma_{min} < \gamma_{m,r} < \gamma_{max} \\ \bar{C}_{max} & \text{for } \gamma_{m,r} > \gamma_{max} \end{cases} \qquad (5)$$

where α is the attenuation factor which represents implementation losses, γ_{min} and γ_{max} are the minimum and maximum SINRs used by the available modulation and coding schemes. Values of these parameters are given in Table 2 [23,24]. Given the set R_m of the RBs allocated to user UE^m, the capacity C_m of UE_m amounts to

$$C_m = \sum_{r \in R_m} B_r \bar{C}_{m,r} \qquad (6)$$

where B_r is the bandwidth of RB r.

Each snapshot of the simulator lasts after 10 time slots. During the snapshot, positions and shadowing values of BSs and UEs do not change. This is reasonable since in indoor

networks, the positions of users do not change drastically. The statistics, such as SINR and capacity, are calculated at the end of the 10^{th} time slot.

Table 2: Link to System Mapping Parameters.

Parameter	Value
$\overline{C}_{\min}$, $\overline{C}_{\max}$ [bps/Hz]	0, 4.4
α	0,6
$\gamma_{\min}$, $\gamma_{\max}$	-10, 19.5 dB

2) Results: In simulations, the D-DFR is compared with the fixed frequency reuse-2 and reuse-4 where a central controller assigns each BS 2 subbands and 1 subband respectively. For instance, for reuse-4, a BS identifies three most interfering neighbors according to the interference measured by its UEs. Then, the BS informs the central controller and the central controller assigns the BS a subband different than its interfering neighbors. For D-DFR, there is no central control over BSs; each BS assigns primary and secondary subbands autonomously. The SINR threshold, γ_{th}, is set to 5 dB and the number of primary subband per BS is set to 1. There is no limitation on the bandwidth that a BS can use which means $n_{\max} = 4$. At the beginning of each snapshot, BSs randomly assign one subband as a primary subband and then depending on feedback, they update their subband allocations during next time slots.

Figs. 8c and 8d show the cumulative distribution functions (CDFs) of SINR and user capacity, respectively. According to Fig. 8c, with D-DFR, nearly all UEs achieve an SINR exceeding 5 dB, which is the value of γ_{th}. As each bs uses one subband, with reuse-4, best SINR distribution is achieved. However, as it will be shown in the next figure, this is not translated into a higher capacity.

Fig. 8d compares the user capacity distributions of the three methods. Due to the Shannon bound in (5), spectral efficiencies cannot be further increased for SINR values exceeding 19.5 dB. Therefore, nearly 83% of the UEs experience a capacity of 11 Mbps for reuse-4 and nearly half of the UEs experience a capacity of 22 Mbps for reuse-2. It is seen from Fig. 8d that reuse-4 shows better performance than reuse-2 up to 11 Mbps. After this point to 22 Mbps, reuse-2 outperforms reuse-4 because of the double transmission bandwidth. Since each BS can only use one subband at reuse-4 method, the increased SINR cannot compensate the reduced resources utilization of the UEs facing less interference, thus

causing their capacity to decrease at this region. Consequently, by increasing the reuse factor, high cell edge performace is obtained but with a dramatic decrease in average cell capacity. With the D-DFR, high cell edge capacity similar to reuse-4 is achieved with a bearable decrease at high capacity regions. Only, between 11 and 22 Mbps, reuse-2 outperforms the D-DFR because of the more bandwidth allocated to reuse-2 UEs. On the other hand, in D-DFR, more subbands are assigned to the UEs that are exposed to low interference. Thus, D-DFR outperforms both reuse methods at capacities higher than 22 Mbps. Table 3 compares the cell edge capacity (defined as the 5% of the CDF of user capacity) and the average cell capacity performances of three methods. The resuts show that the D-DFR has best cell edge and average cell capacity performance. This indicates that with D-DFR, cell edge capacity is boosted without any degradation in average cell capacity which cannot be achieved by most frequency reuse methods.

Table 3: Performance of the Fixed Reuse and D-DFR

	Cell Edge Cap.	Average Cell Cap.
	[Mbps]	[Mbps]
Reuse-2	0.7	61.6
Reuse-4	3.6	40.3
D-DFR	3.9	72.3

Fig. 8b shows the percentage of the resources allocated to UEs and the percentage of these allocated resources which face SINR below -10 dB. According to the parameters given in Table 3, below -10 dB, spectral efficiency becomes 0. Therefore, the allocate resource facing SINR below -10 dB named as collision. Each measurements are done at the end of each time slot. Since each BS randomly assigns one subband as a primary subband for the first time slot, the percentage of the allocated resources is always 25%. Also, random subband assignment increases the percentage of collisions. Then, before the second time slot, UEs report their SINR measurements and IDs of interfering BSs to their BSs. Depending on the SINR values, BSs assign further subbands as secondary subbands during the second time slot and send a primary subband indicator to the interfering BSs. Assignment of the subbands based only on SINR levels, increases the number of used subbands and the collisions because BSs do not know their neighboring BSs yet. As can be seen in Fig. 5, during second time slot, percentage of the assigned resources and collisions increase up to 70% and 6.7% respectively. However, before the 3rd time slot, for the first time, BSs receive primary subband indicators from the serving BSs of victim UEs that

are sent at the begining of the second time slot. These primary subband indicators restric the interfering BSs to use their neighbors' primary subbands. Additionally, with the received SINR levels, BSs learn more about the subbands used by its interfering neighbors. Therefore, the percentage of the assigned resources and the collisions both decrease during the third time slot. After the third time slot, the percentage of the assigned resources increases with a decrease in the percentage of the collisions, as the BSs become more aware of their neighbors' decisions. Actually, only after the 4^{th} time slot, subband allocation becomes stable which is the another advantage of D-DFR.

Fig. 8a illustrates the performance evaluation as user capacity [Mbps] as a function of the mean cell capacity [Mbps]. Fig. 8a illustrates that the dynamic procedure in accordance with the present invention as illustrated at 81 outperforms the reuse-to scenario indicated at 82 and, of course, the reuse-one scenario indicated at 83.

The present invention provides the compromise between a fully central approach or a fully distributed approach. In the fully central approach, transmission resources are assigned by a central controller. The resource utilization is more efficient than in the distributed approach, but an extra signaling between the base stations and the controller is required. On the other hand, the distributed approach allows less complexity, since the transmission resources are assigned autonomously by the base stations.

Fig. 3c illustrates, together with Fig. 3a and Fig. 3b, the advantage of the present invention obtained by the distributed dynamic frequency reuse. Fig. 3c illustrates that the base station 100 has associated channel one as the primary transmission resource, base station two has associated channel two as the primary transmission resource and base station three has associated channel three as the primary transmission resource. Importantly, however, base station a is in the position to allocate a secondary transmission resource (secondary CC) for communicating with the user equipment 107, while the first user equipment 102 has the primary transmission resource. The potential interference path are indicated at 300. The multi-user deployment as illustrated in Fig. 3c is unique in that each user in the same cell experiences different interference conditions and this fact is advantageously used by the present invention. The transmission resource allocation is done according to the user equipment measurements for high resource utilization by allocating primary transmission resources and, importantly, secondary transmission resources as, for example, channel three for the communication between the base station 100 and the user equipment 107.

Regarding the transmission resource assignment for multi-user deployments, reference is made to Fig. 4. One rule of the preferred embodiment is that only one primary transmission

resource per base station is used. This results in a protected region. Furthermore, there are banned transmission resources. A base station cannot use the primary transmission resource of its neighbors. This guarantees minimum SINR of predefined SINR threshold for all cell-edge user equipment. The secondary transmission resources can be used by the neighbors. This increases resource efficiency, especially for the multi-user deployment. The secondary transmission resources are preferably allocated to the user equipment according to the SINR threshold. Fig. 4 particularly illustrates that base station A has, as the primary transmission resource, channel 1 and has allocated, as the secondary transmission resource, channel 3. On the other hand, the banned transmission resources are channel two for base station A, channel one for base station B and channel one and two for base station C.

Subsequently, reference is made to Fig. 5 in order to further illustrate the measurements to be performed by the user equipment. Specifically, the information to be provided by the user equipment are the identification information (IDs) of the interfering base stations. To this end, each user equipment can measure the received power from each base station in its vicinity. Then, each user equipment identifies the interfering base station IDs according to the predefined SINR threshold. Then, the base station receiving this information from the user equipment uses this information for sending the primary resource indicator to the interfering neighbors in order to make sure that the primary resource is only used by a certain base station and the user equipment, which is associated with this primary transmission resource, is not interfered with the neighboring base stations.

Furthermore, the SINR levels of each transmission resource are determined by each user equipment. The present invention advantageously uses the fact that each user equipment observes different SINR in different transmission resources. The SINR levels are reported to the serving base station and the serving base station then uses this information to find out which transmission resources are available for transmission. Fig. 5 illustrates that the PCC indicator 305 transmitted between the base stations results in banned transmission resources at each base station. Fig. 5 further illustrates that each user equipment which is located outside an interference region can use the third channel as the secondary transmission resource even though the neighboring base station C uses the third channel as its primary transmission resource.

Subsequently, a sequence of exemplary steps and actions, which could be performed when performing a channel allocation, are discussed with respect to Figs. 7a to 7f. At time zero, i.e., in the beginning of time slot-one, each base station could assign one CC (transmission resource) randomly. This results in the Fig. 7a example, in a situation in which base

stations A and C have channel three and base station B has channel two. During the first time slot, the user equipment makes measurements and identify the IDs of the interfering base stations and calculate SINR levels of each transmission resource. The potential interference paths are indicated in Fig. 7b. Then, at the end of time slot-one, the base station has received feedback of time slot-one. The base station then identifies the available transmission resources according to the SINR levels and updates the primary resource allocation (PCC) assignment and assigns secondary transmission resources if possible. This result, in the Fig. 7c example in a situation, in which base station A has channel one as the primary transmission resource, base station B has channel two at the primary transmission resource and base station C has 3 as the primary transmission resource. Hence, only a change for base station A is performed. Additionally, secondary transmission resources in the form of channels 2 and 3 are allocated for base station A and secondary transmission resources in the form of channels 1 and 2 are allocated for base station C.

Then, as illustrated in Fig. 7d, each base station sends the primary transmission resource indicator to the interfering base stations and this happens within time slot-two. However, the allocation of the channels remains the same within time slot-two as discussed in the context of Fig. 7c.

Then, as illustrated in Fig. 7e, the time slot-two is over and it is found out that a base station cannot use the transmission resources stated in the received transmission resource indicator indicating so-called banned transmission resources. These banned transmission resources are channel two for base station A, channel one for base station B and channels one and two for base station C. Therefore, the only secondary transmission resource remaining is channel three for base station A. Then, in time slot-three, this channel allocation is used as illustrated in Fig. 7f. It has been found out that, typically only after three to four iterations, a system reaches a stable resource allocation. The preferred algorithm can be considered to be a greedy resource allocation algorithm which is restricted by the neighbors.

In other words, the present invention can be seen as a method or a base station for dynamic frequency resource partitioning in order to mitigate interference in uncoordinated deployments in an autonomous way that neighboring base stations are assigned mutually different primary component carriers. The method or apparatus comprises means to inform adjacent cells on which primary component carriers are able to interference by means of inter-node signaling, so as to determine the resource allocation limitations for predefined SINR thresholds and user equipment and base station feedback. Additionally, the

method/apparatus further comprises means to determine further secondary component carrier allocation by base stations in order to maximize the overall network performance, without imposing excessive interference to primary component carriers of adjacent cells. In an embodiment, the primary component carrier selection is carried out by a centralized method while in a further embodiment the primary component carrier selection is carried by a distributed method, where primary component carriers are allocated successively by a p-persistent medium access protocol.

The present invention has several advantageous effects. One effect is the extension of soft frequency reuse concepts to heterogeneous networks where, particularly, a dynamic interference mitigation in uncoordinated deployment is obtained.

Furthermore, an autonomous transmission resource (CC) selection is performed. This is particularly useful in the context of the 3GPP work item "study inter-node signaling" needed for robust autonomous solutions, where each BTS node selects two user carrier(s) that maximizes the overall network performance (RAN3).

Furthermore, the present invention is compatible with LTE-A networks.

Additionally, a higher bandwidth utilization than known from the prior art is obtained and also some flexibility in the number of assigned transmission resources depending on the interference conditions and in the selection of secondary transmission resources.

The present invention results in a low signaling overhead and has shown a quick convergence to the stable resource allocation. It can also be applied to the central approach in order to increase the resource efficiency for multi-user deployment.

Fig. 10 illustrates a preferred procedure which is performed by the transmission resource allocator 16 of Fig. 1. In step 200, an availability measure for each of the plurality of transmission resources is calculated based on individual reception quality information received from the user equipment served by the base station.

In step 201, a number of allocatable secondary transmission resources is determined by removing, from the set of all transmission resources, transmission resources having zero availability, transmission resources being blocked by a primary transmission resource indicator received by the receiver and by removing the primary transmission resource allocated by the base station.

Then, in step 202 a search is performed for transmission resources having a higher availability than a minimum availability and the searches performed within the number of allocatable secondary transmission resources. Then, in step 203 a further search for a further transmission resource for the same user equipment or at least a further user equipment served by the base station is performed and the search and the further search are iteratively repeated 204 until a maximum number of allocatable secondary transmission resources is determined or all allocatable secondary transmission resources are determined. Hence, the maximum number of allocatable secondary transmission resources or all allocatable secondary transmission resources form the iteration termination criterion.

When, as illustrated in Fig. 10, item 205, the iteration termination criterion is fulfilled, the transmission resources found by the search step and the further search step are allocated to the at least one user equipment served by the base station as the secondary transmission resource are allocated to other user equipments served by the base station under consideration.

Although some aspects have been described in the context of an apparatus, it is clear that these aspects also represent a description of the corresponding method, where a block or device corresponds to a method step or a feature of a method step. Analogously, aspects described in the context of a method step also represent a description of a corresponding block or item or feature of a corresponding apparatus.

Depending on certain implementation requirements, embodiments of the invention can be implemented in hardware or in software. The implementation can be performed using a digital storage medium, for example a floppy disk, a DVD, a CD, a ROM, a PROM, an EPROM, an EEPROM or a FLASH memory, having electronically readable control signals stored thereon, which cooperate (or are capable of cooperating) with a programmable computer system such that the respective method is performed.

Some embodiments according to the invention comprise a non-transitory data carrier having electronically readable control signals, which are capable of cooperating with a programmable computer system, such that one of the methods described herein is performed.

Generally, embodiments of the present invention can be implemented as a computer program product with a program code, the program code being operative for performing one of the methods when the computer program product runs on a computer. The program code may for example be stored on a machine readable carrier.

Other embodiments comprise the computer program for performing one of the methods described herein, stored on a machine readable carrier.

In other words, an embodiment of the inventive method is, therefore, a computer program having a program code for performing one of the methods described herein, when the computer program runs on a computer.

A further embodiment of the inventive methods is, therefore, a data carrier (or a digital storage medium, or a computer-readable medium) comprising, recorded thereon, the computer program for performing one of the methods described herein.

A further embodiment of the inventive method is, therefore, a data stream or a sequence of signals representing the computer program for performing one of the methods described herein. The data stream or the sequence of signals may for example be configured to be transferred via a data communication connection, for example via the Internet.

A further embodiment comprises a processing means, for example a computer, or a programmable logic device, configured to or adapted to perform one of the methods described herein.

A further embodiment comprises a computer having installed thereon the computer program for performing one of the methods described herein.

In some embodiments, a programmable logic device (for example a field programmable gate array) may be used to perform some or all of the functionalities of the methods described herein. In some embodiments, a field programmable gate array may cooperate with a microprocessor in order to perform one of the methods described herein. Generally, the methods are preferably performed by any hardware apparatus.

The above described embodiments are merely illustrative for the principles of the present invention. It is understood that modifications and variations of the arrangements and the details described herein will be apparent to others skilled in the art. It is the intent, therefore, to be limited only by the scope of the impending patent claims and not by the specific details presented by way of description and explanation of the embodiments herein.

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Claims

1. Base station for communicating with a plurality of user equipments assigned to the base station, comprising:

a receiver (10) for receiving, from a first one of a plurality of user equipments, one or more identifications (12) of further base stations interfering with the first user equipment in a transmission resource of a plurality of transmission resources, and for receiving, from a further base station, a primary resource indicator (14) indicating the primary transmission resource for the further base station, in which a further user equipment assigned to the further base station would suffer an interference from the base station; and

a transmission resource allocator (16) for allocating a secondary transmission resource to the second user equipment from the set of available transmission resources, wherein the set of available transmission resources does not include the primary transmission resource indicated by the primary resource indicator 14.

2. Base station in accordance with claim 1, wherein the transmission resource allocator is configured for allocating a primary transmission resource to the first user equipment, the primary transmission resource being different from the primary transmission resource indicated by the primary transmission resource indicator,

wherein the base station further comprises a transmitter for transmitting a primary transmission resource indicator to a further base station, wherein the further base station is a base station causing an interference in the primary transmission resource at the first user equipment as determined by the one or more identifications (12) received by the receiver (10) from the first user equipment.

3. Base station in accordance with claim 1 or 2, in which the receiver is configured for receiving reception quality information (24) for a plurality of different transmission resources from the second user equipment,

wherein the transmission resource allocator is configured to only allocate a secondary transmission resource to the second user equipment, for which the receiver has received, from the second user equipment, a reception quality information indicating a reception quality above a predetermined reception quality threshold.

4. Base station in accordance with one of the preceding claims, in which the receiver (10) is configured to receive the one or more identifications and a reception quality information in a first time slot, and in which the transmission resource allocator is configured to allocate, based on information received by the receiver (10), in a second time slot being later in time than the first time slot.

5. Base station in accordance with claim 2, in which the receiver (10) is configured to receive the one or more identifications and the reception quality information in a first time slot, and in which the transmitter is configured for transmitting the primary transmission resource indicator in a second time slot being later in time than the first time slot.

6. Base station in accordance with one of the preceding claims, in which the transmission resource allocator (16) is configured to calculate (200) an availability measure for each of the plurality of transmission resources based on individual reception quality information received from the user equipment served by the base station and to allocate the secondary transmission resource based on the availability measure for the specific transmission resource.

7. Base station in accordance with one of the preceding claims, in which the transmission resource allocator (16) is configured to allocate the secondary transmission resource only to a user equipment, for which a reception quality measure provided by the user equipment is above a predetermined reception quality measure threshold.

8. Base station in accordance with one of the preceding claims, in which the transmission resource allocator (16) is configured to allocate as many secondary transmission resources as possible to the plurality of user equipments served by the base station or to allocate only a number of transmission resources bound by a predefined maximum number allocatable by the base stations.

9. Base station in accordance with claim 6, in which the transmission resource allocator (16) is configured to perform the following sequence of steps:

determine (201) a number of allocatable secondary transmission resources by removing, from the set of all transmission resources, transmission resources having zero availability, transmission resources being blocked by a primary transmission

resource indicator received by the receiver and the primary transmission resource allocated by the base station,

search (202) for a transmission resource having a higher availability than a minimum availability in the number of allocatable secondary transmission resources,

further search (203) for a further transmission resource for the same user equipment or at least a further user equipments served by the base station,

wherein the search step and the further search step are iteratively repeated (204) until a maximum number of allocatable secondary transmission resources is determined or all allocatable secondary transmission resources are determined, and

allocating (205) the transmission resources found by the search step and the further search step to at least one user equipment served by the base station as the secondary transmission resource.

10. Base station in accordance with one of claims 6 to 9,

in which the transmission resource allocator (16) is configured for calculating an availability for a specific transmission resource by accumulating the number of user equipments which are served by the base station and which report to the base station a reception quality information indicating the reception quality above a predetermined threshold for the specific transmission resource.

11. Base station in accordance with one of the preceding claims,

in which the transmission resource allocator (16) is configured for receiving instructions to allocate a primary transmission resource from a central controller so that the base station allocates the primary transmission resource to a user equipment served by the base station, and

in which the secondary transmission resource allocation is performed by the transmission resource allocator of the base station in a decentralized distributed way.

12. Base station in accordance with one of the preceding claims, in which the transmission resource allocator (10) is configure to perform a distributed procedure for the allocation of the primary transmission resource (28) by only allocating a primary transmission resource not blocked by a primary transmission resource indicator (14) from a further base station as received by the receiver (10), and by selecting a transmission resource having an availability measure being higher than a minimum availability measure of the allocatable transmission resources.

13. Base station in accordance with one of the preceding claims, in which the transmission resource allocator (16) is configured for reallocating a primary transmission resource for a later time slot in case of receiving a primary resource indicator (14) for the allocated primary transmission resource, and wherein the at least one secondary transmission resource (18) allocated in an earlier time slot is available for being selected as a primary transmission resource (28) for the later time slot.

14. Method of operating a base station for communicating with a plurality of user equipments assigned to the base station, comprising:

receiving (10), by the base station, from a first one of a plurality of user equipments one or more identifications of further base stations interfering with the first user equipment in a transmission resource of a plurality of transmission resources;

receiving, by the base station, from a further base station, a primary resource indicator indicating the primary transmission resource for the further base station, in which a further user equipment assigned to the further base station would suffer an interference from the base station; and

allocating (16), by the base station, a secondary transmission resource to the second user equipment from the set of available transmission resources, wherein the set of available transmission resources does not include the primary transmission resource indicated by the primary resource indicator.

15. Computer program for performing, when running on a processor, the method of claim 14.

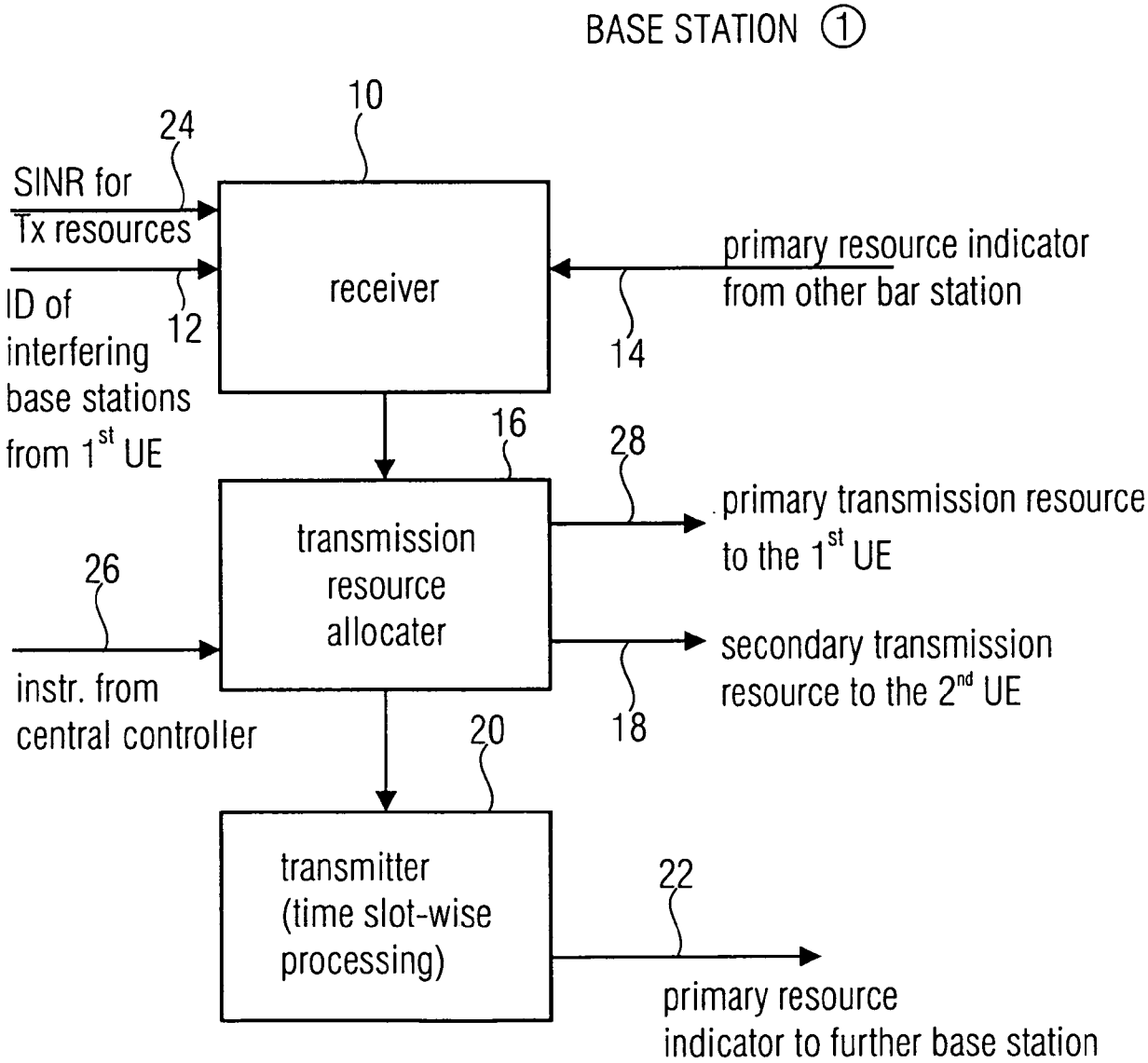

BASE STATION ①
10
24
SINR for
Tx resources
ID of
interfering
base stations
from 1st UE
12
receiver
primary resource indicator
from other bar station
14
16
28
transmission
resource
allocater
primary transmission resource
to the 1st UE
26
instr. from
central controller
secondary transmission
resource to the 2nd UE
18
20
transmitter
(time slot-wise
processing)
22
primary resource
indicator to further base station

FIG 1

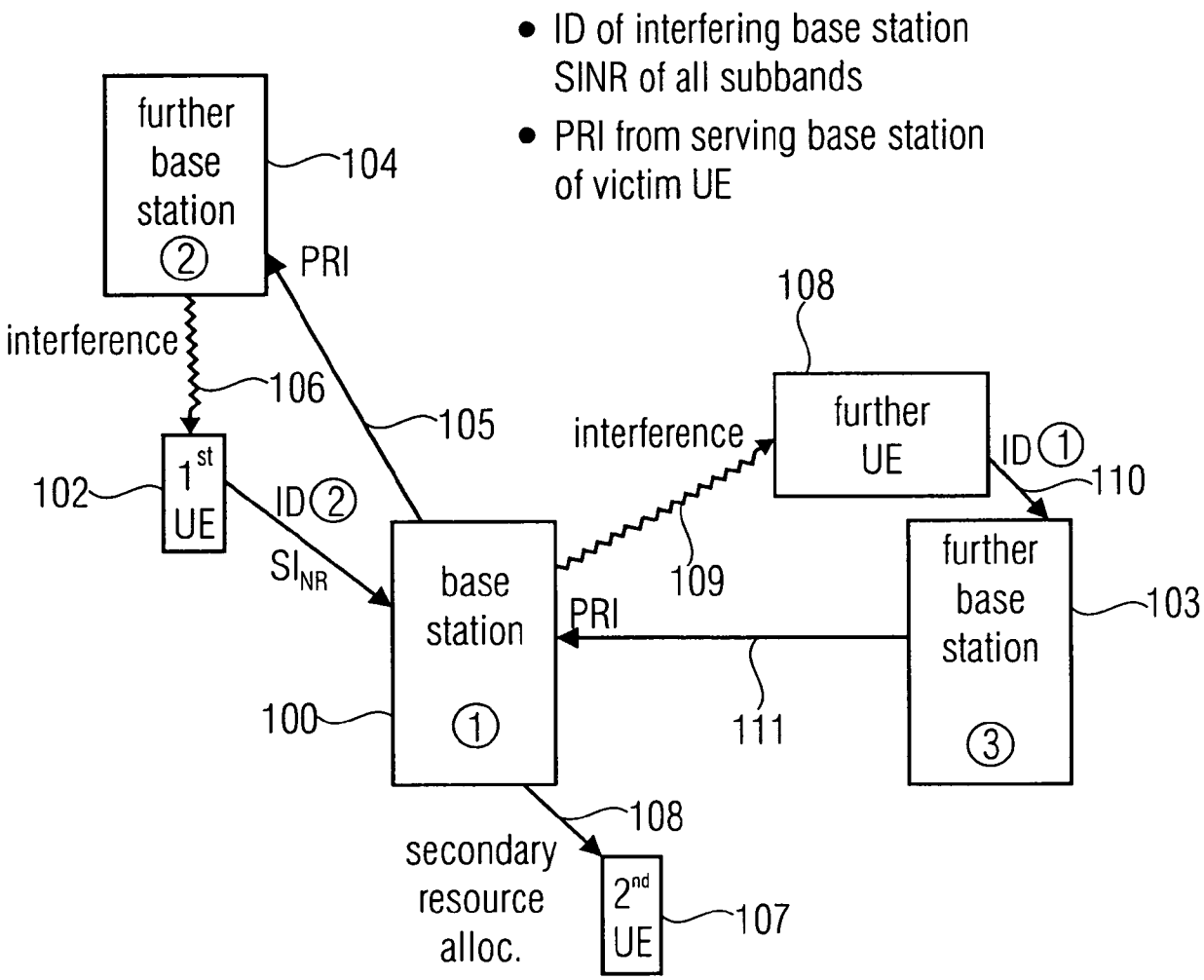

• ID of interfering base station SINR of all subbands
• PRI from serving base station of victim UE
further base station ②
104
PRI
interference
106
105
102
1st UE
ID ②
SINR
base station ①
100
108
further UE
interference
ID ①
110
109
further base station ③
103
PRI
111
108
secondary resource alloc.
2nd UE
107

FIG 2

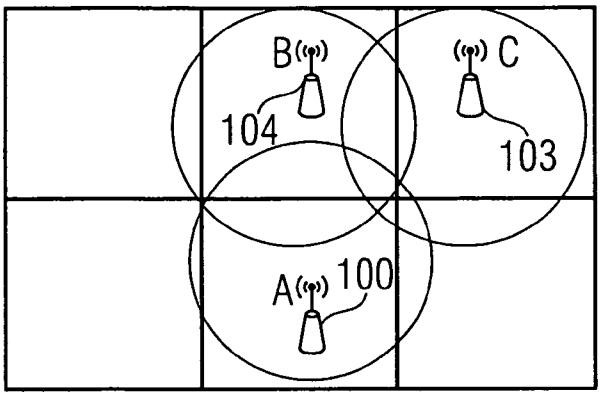


FIG 3A

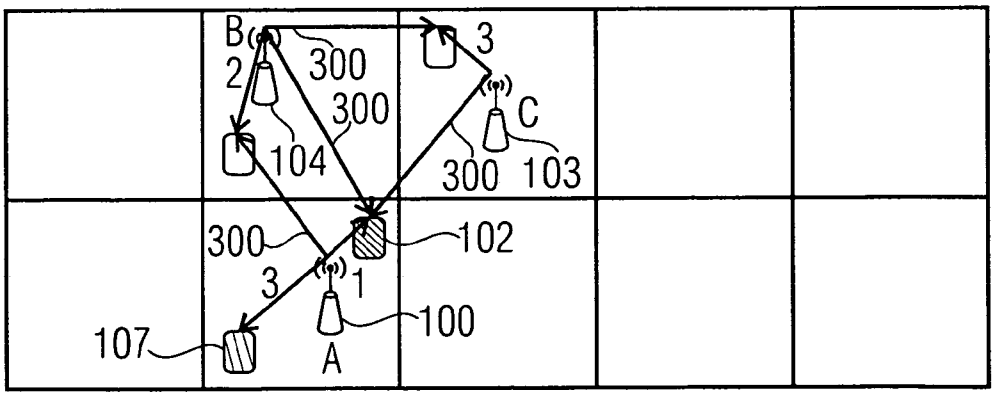


FIG 3B

→ potential interference path 300

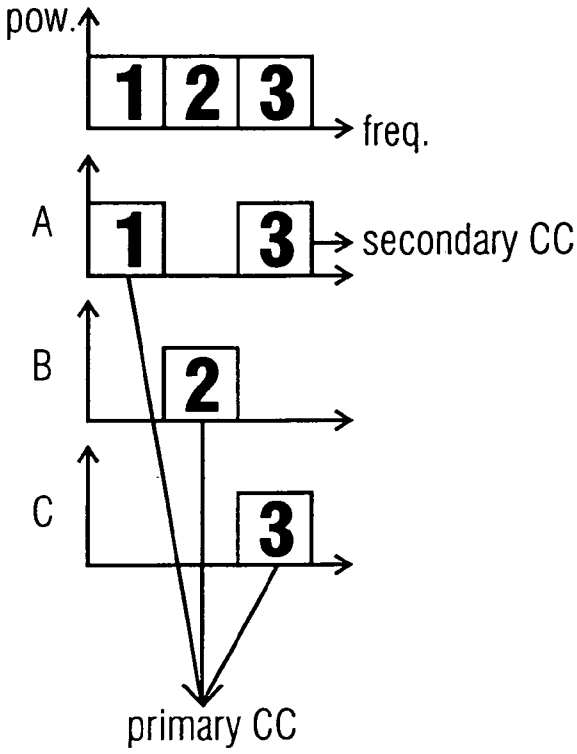


FIG 3C

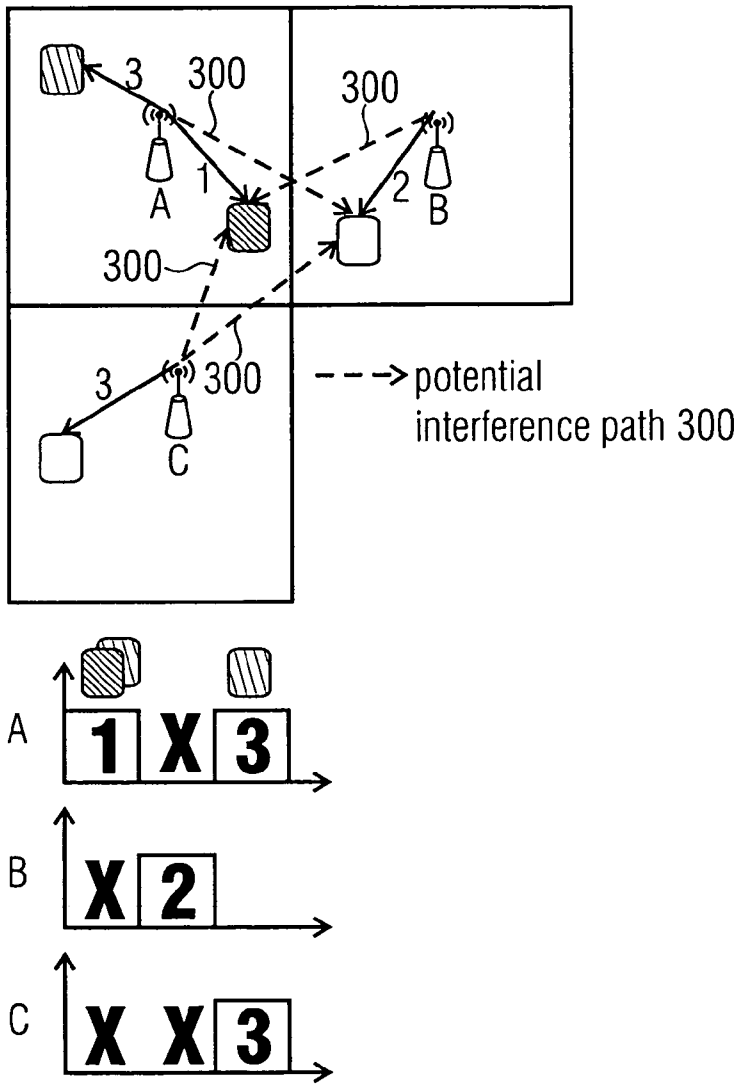
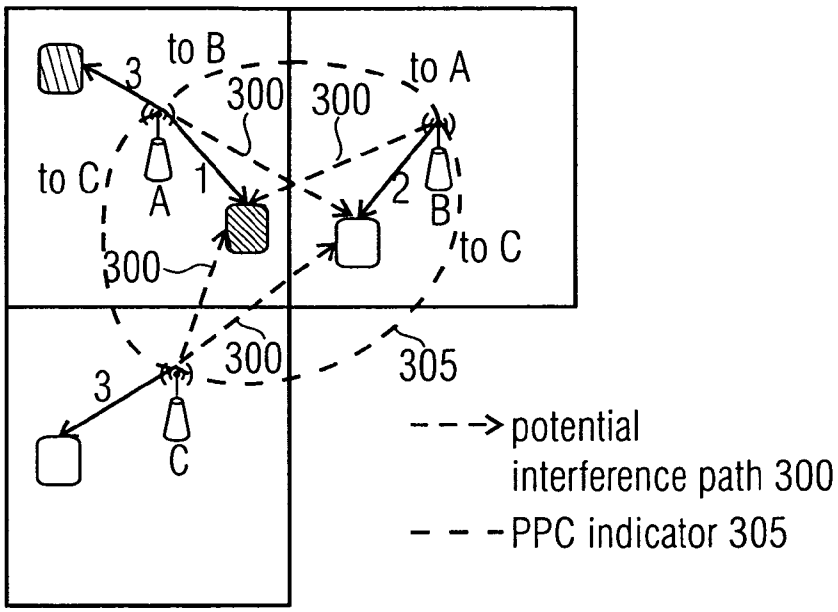

3
300
300
A
1
2
B
300
3
300
C
potential
interference path 300
A
1
X
3
B
X
2
C
X
X
3

FIG 4


to B
3
300
300
to A
to C
A
1
2
B
to C
300
300
305
3
C
potential interference path 300
PPC indicator 305

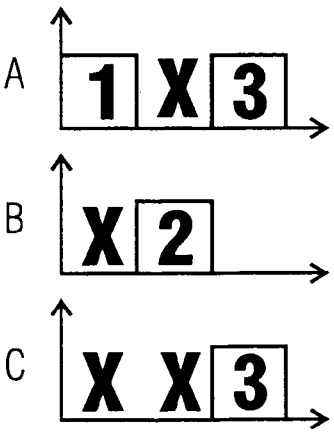

A
1 X 3
B
X 2
C
X X 3

FIG 5

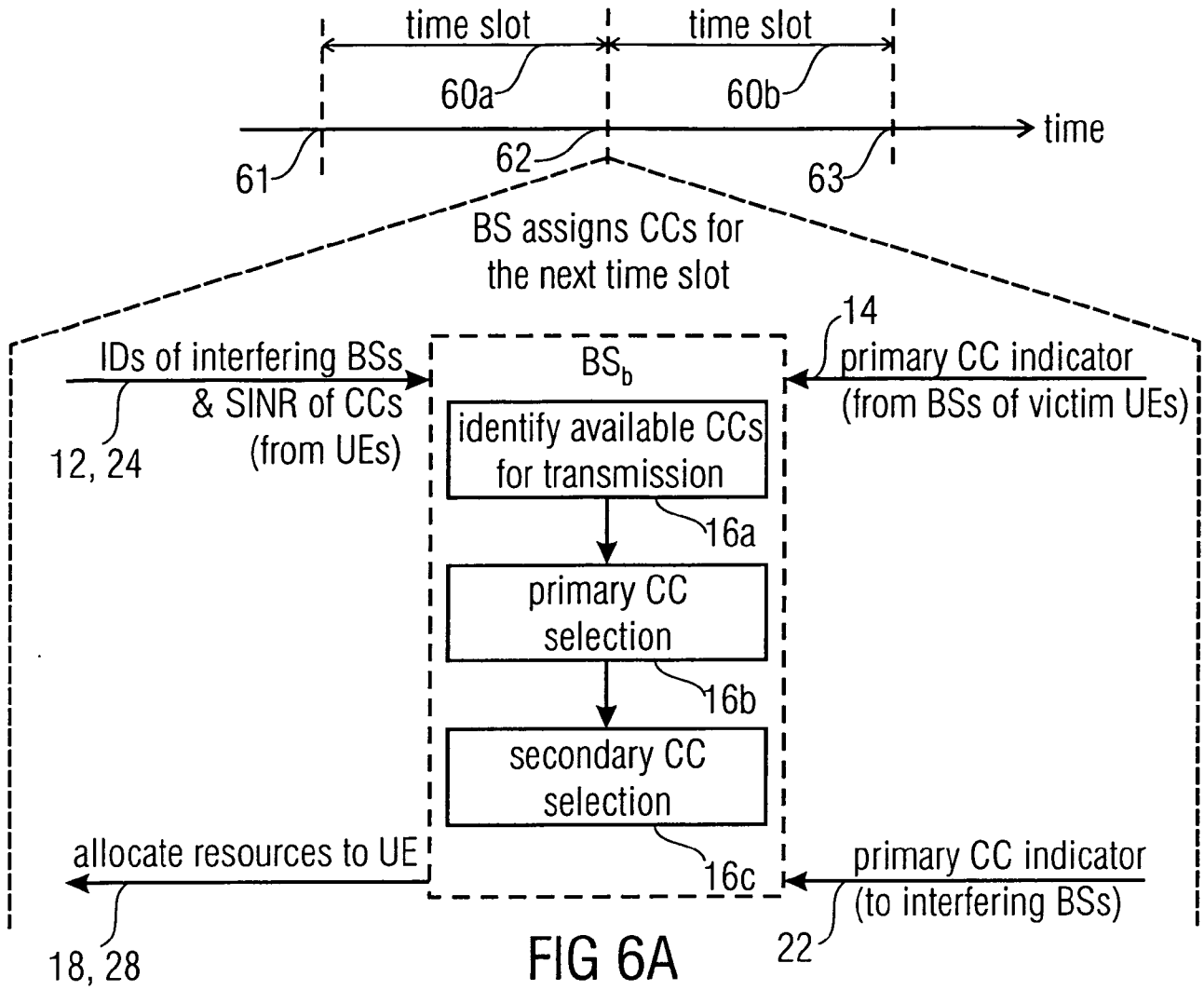

time slot
time slot
60a
60b
time
61
62
63
BS assigns CCs for the next time slot
14
IDs of interfering BSs & SINR of CCs (from UEs)
BS$_b$
primary CC indicator (from BSs of victim UEs)
12, 24
identify available CCs for transmission
16a
primary CC selection
16b
secondary CC selection
16c
allocate resources to UE
primary CC indicator (to interfering BSs)
18, 28
22

FIG 6A

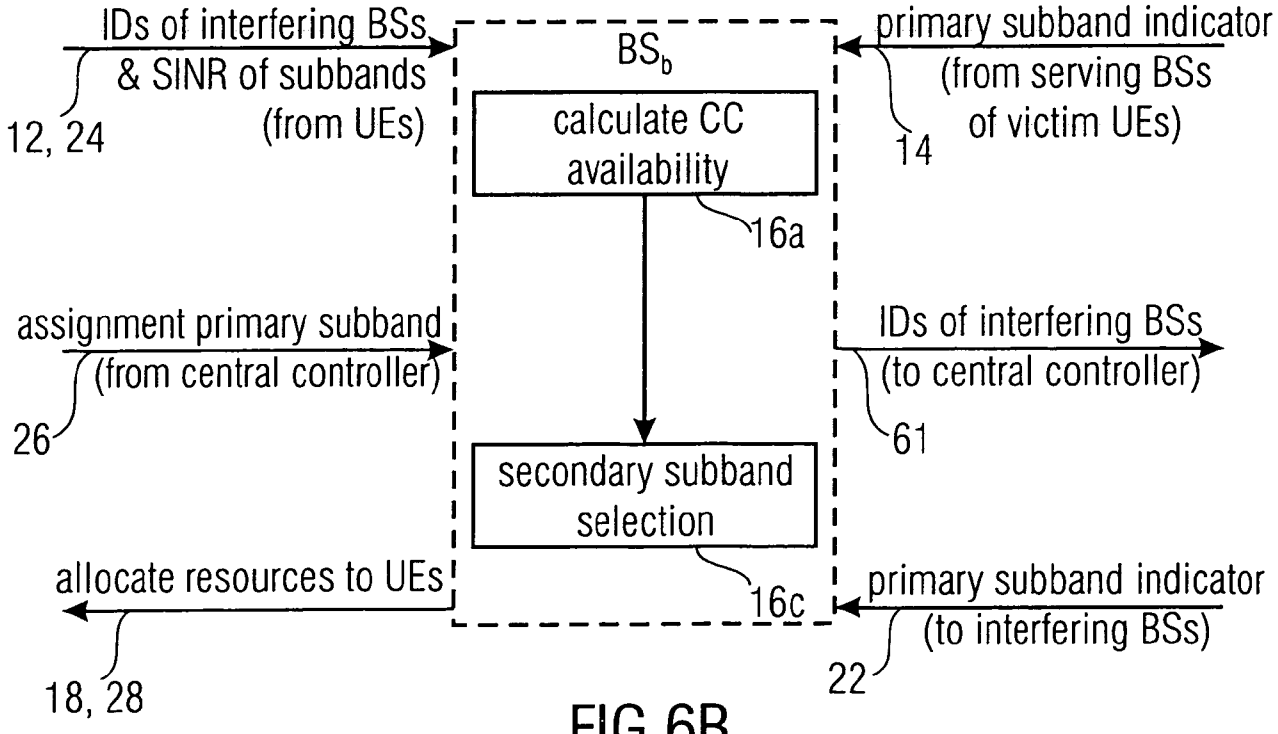
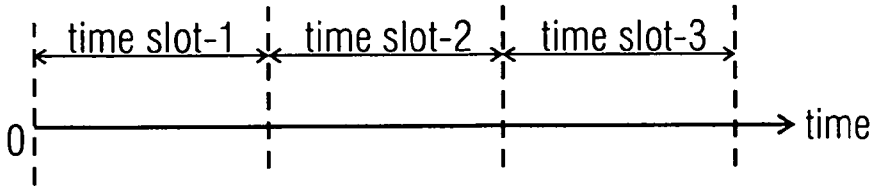

IDs of interfering BSs & SINR of subbands (from UEs)
BS$_b$
primary subband indicator (from serving BSs of victim UEs)
12, 24
calculate CC availability
16a
14
assignment primary subband (from central controller)
IDs of interfering BSs (to central controller)
26
61
secondary subband selection
16c
allocate resources to UEs
primary subband indicator (to interfering BSs)
18, 28
22

FIG 6B

At time o



- each BS assigns one CC randomly

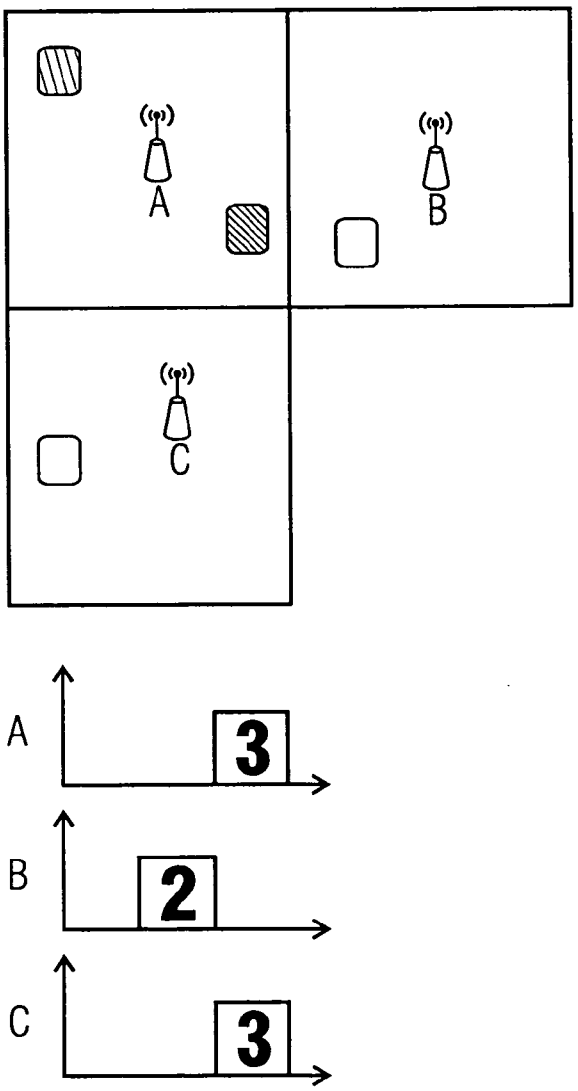
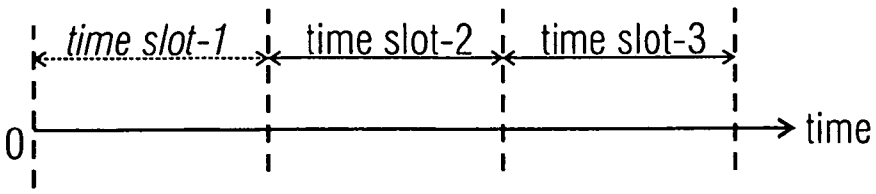
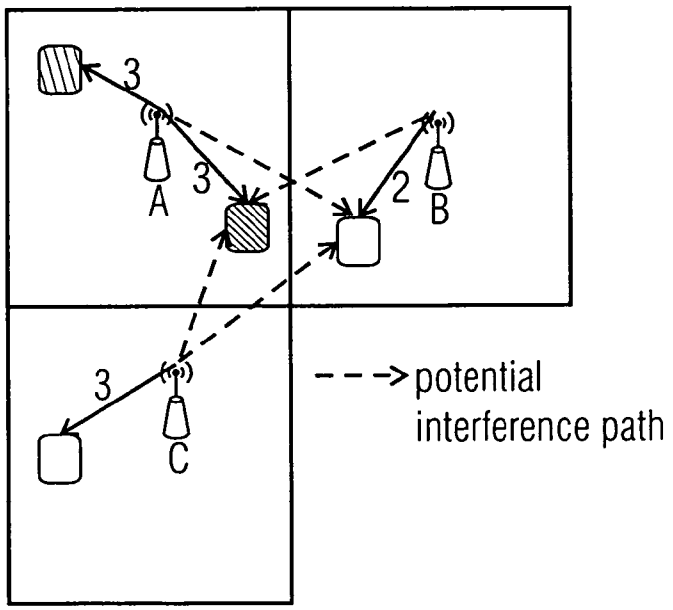


FIG 7A

Time slot-1



- **UEs make measurement:**
  - Identify IDs of interfering BSs
  - Calculate SINR levels of each CC



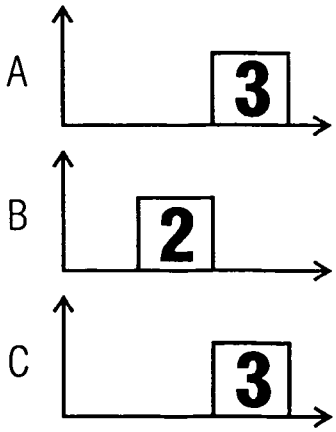
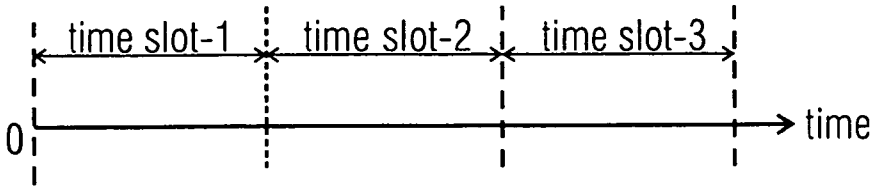
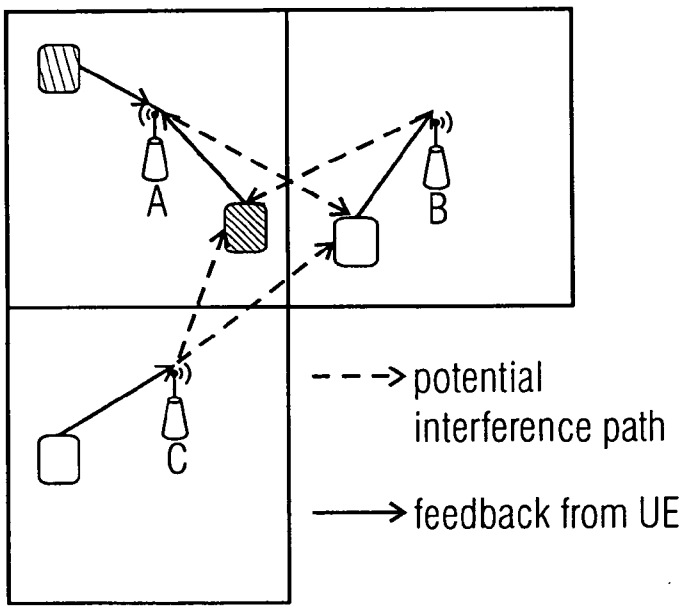


FIG 7B

CC Assignment at BS



- BS receives feedbacks of time slot-1
  -identifies available CCs according to SINR levels
  - updates PCC assignment
  - assigns SCC if possible



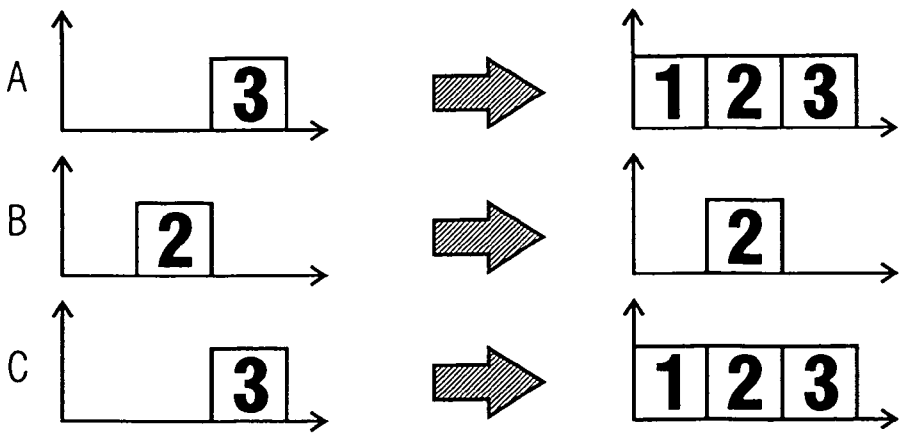
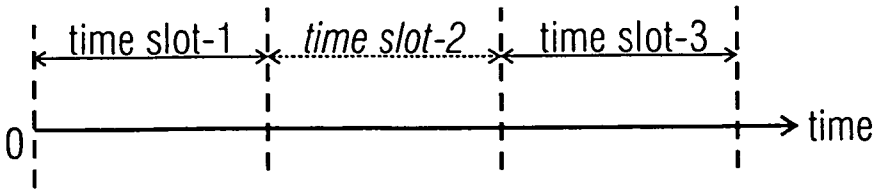
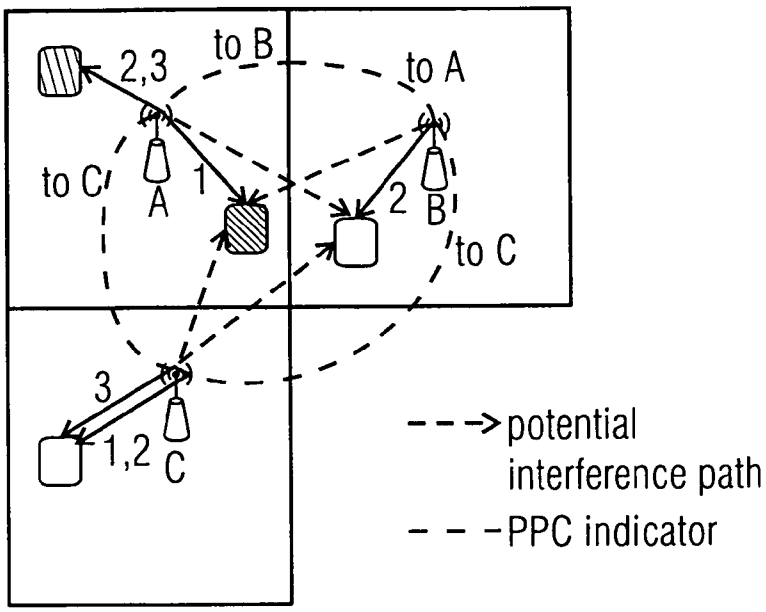


FIG 7C

Time slot-2



- each BS sends PCC indicator to the interfering BSs



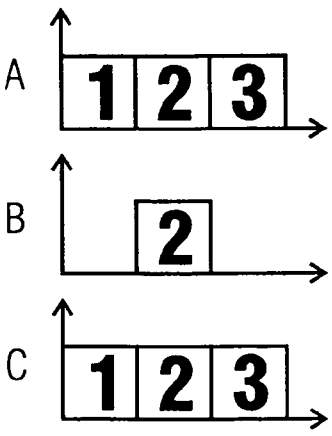
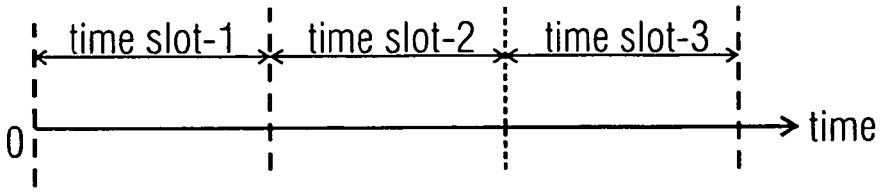
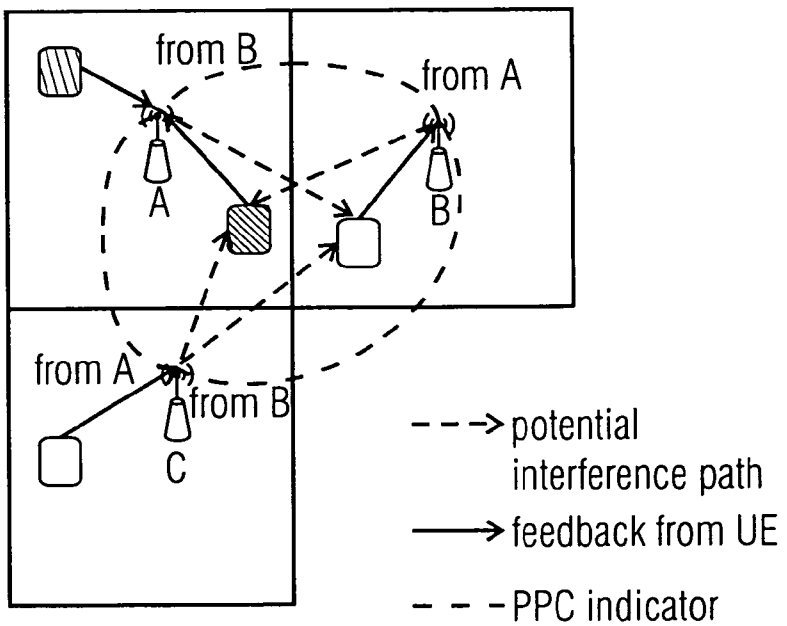


FIG 7D

CC Assignment at BS



- A BS cannot use the CCs stated in the received PCC indicator
  - **banned CCs**



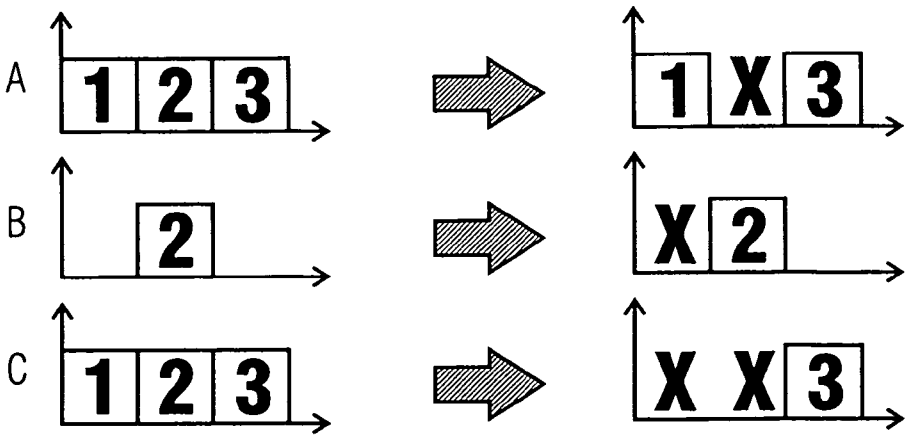
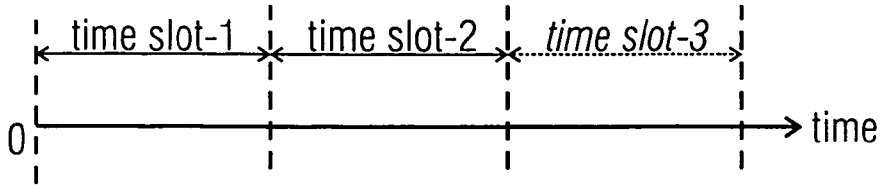
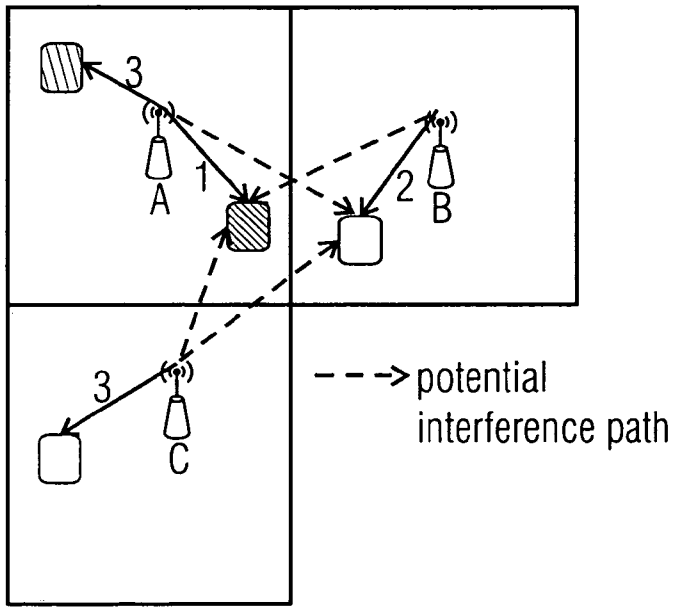


FIG 7E

Time slot-3



- after 3-4 iterations, a system rearches a stable resource allocation
- a greedy resource allocation, restricted by the neighbors



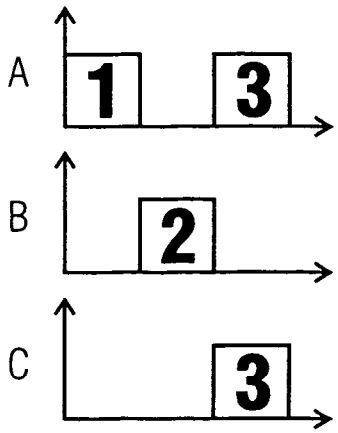
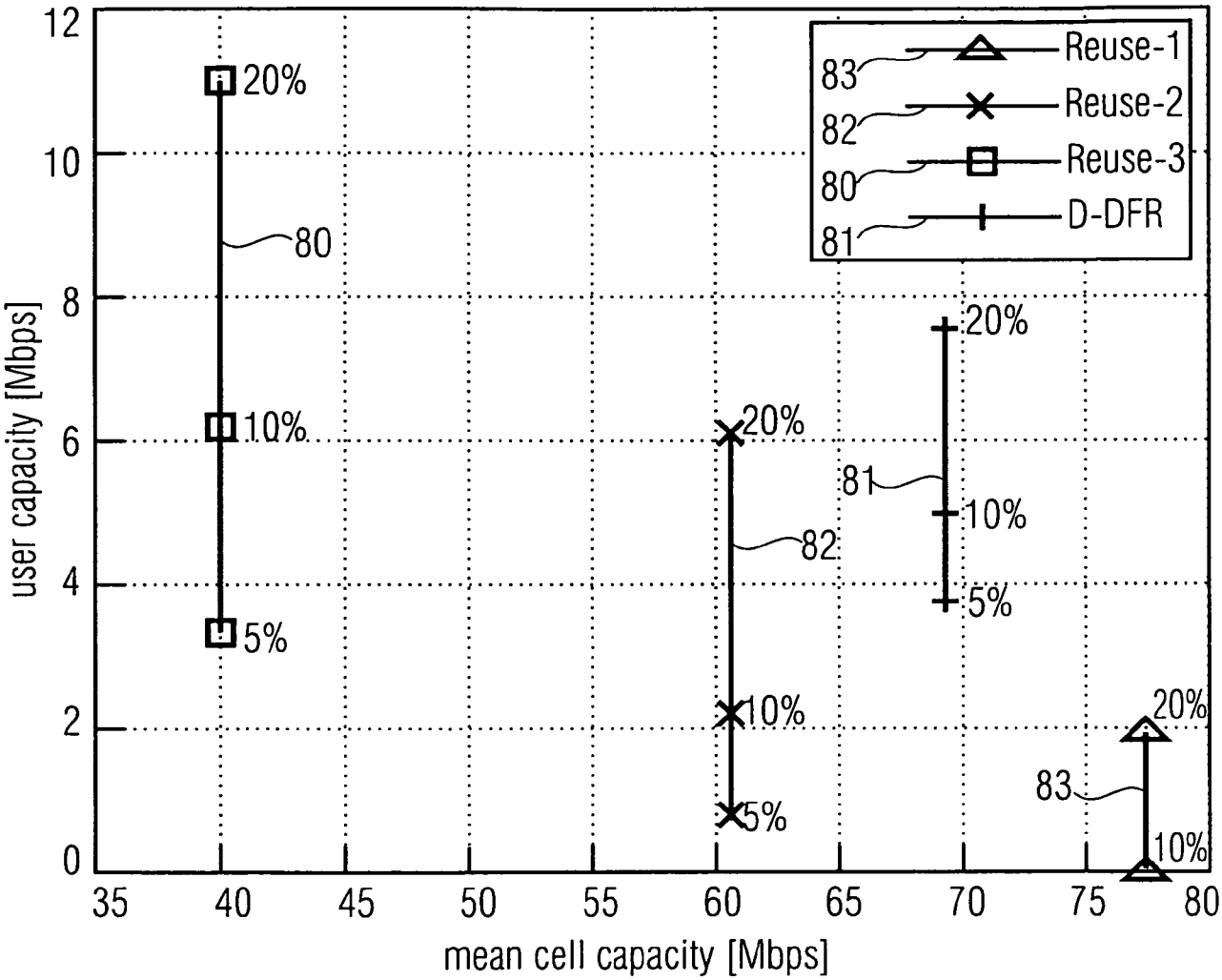


FIG 7F



- LTE-A femtocell network
- 5x5 grid
- activation rate = 0.2
- 4 CCs
- 4 UEs per BS
- Reuse-2 and Reuse-4 are central approaches

FIG 8A

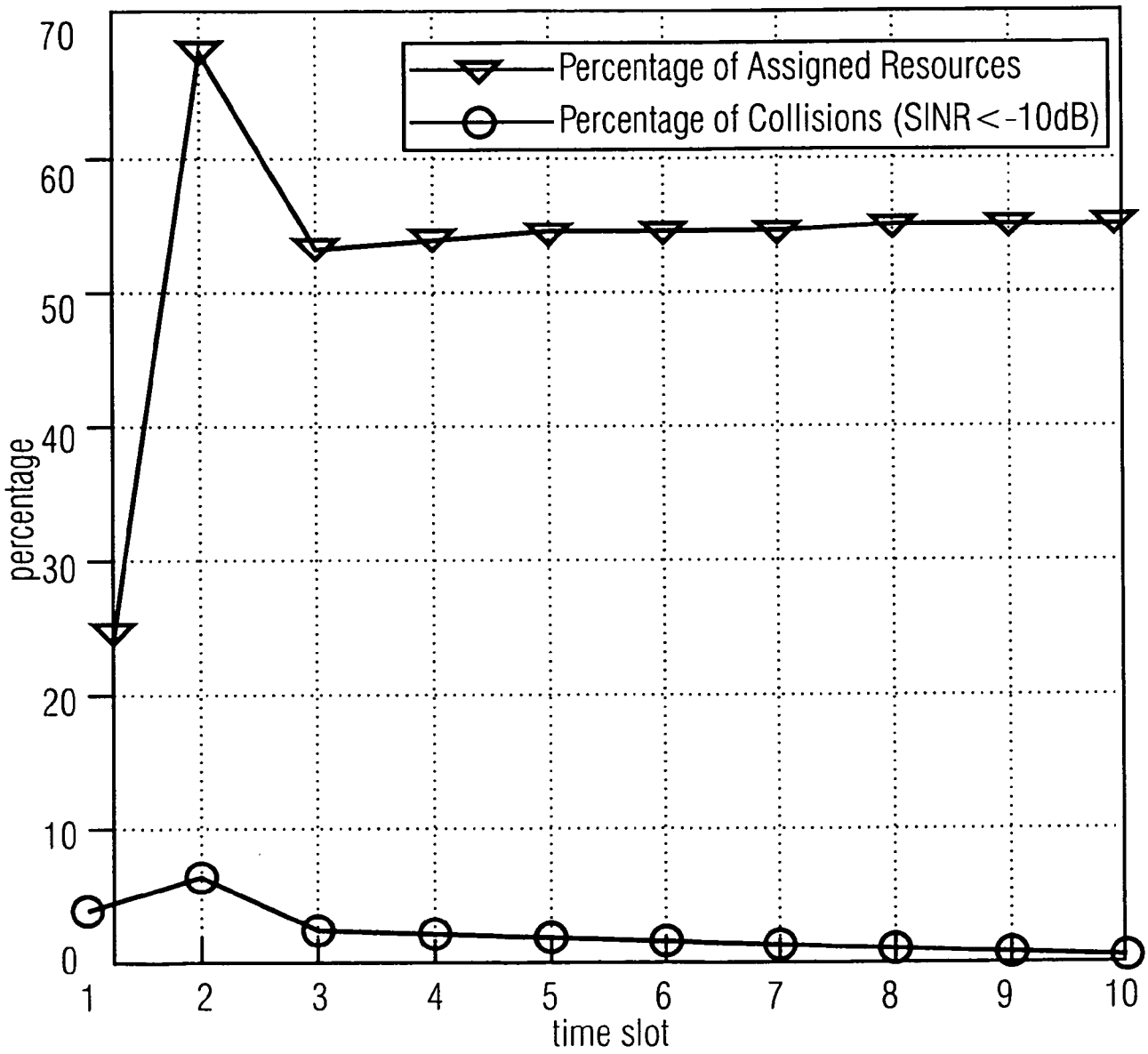
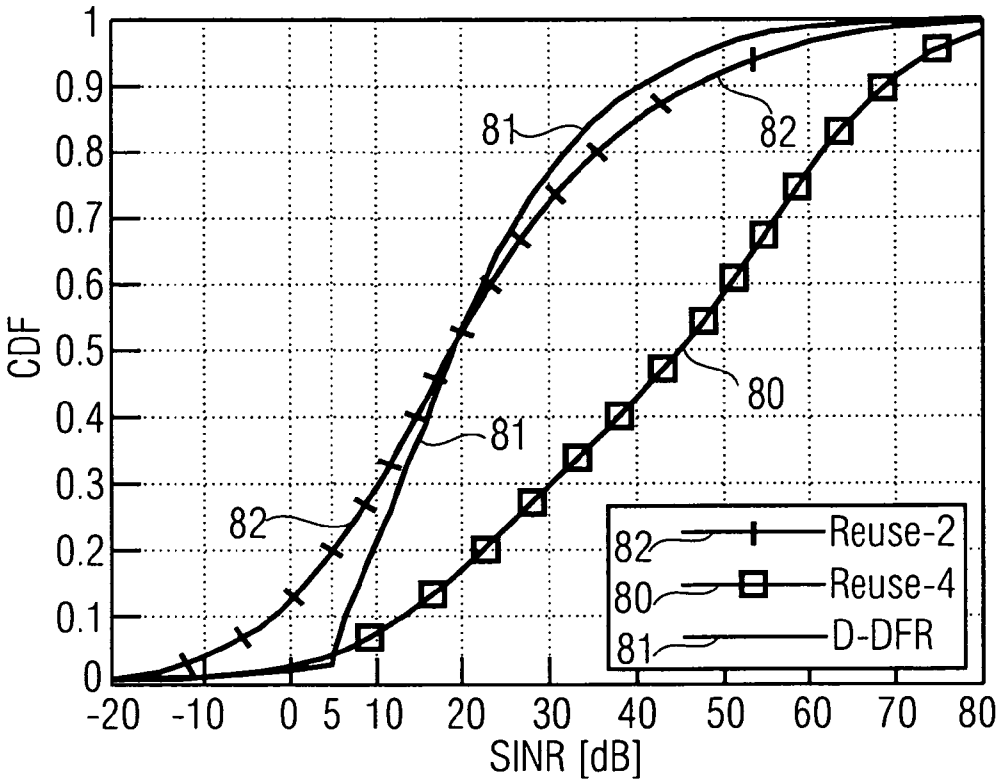

Percentage of Assigned Resources
Percentage of Collisions (SINR<-10dB)
percentage
time slot
0
10
20
30
40
50
60
70
1
2
3
4
5
6
7
8
9
10

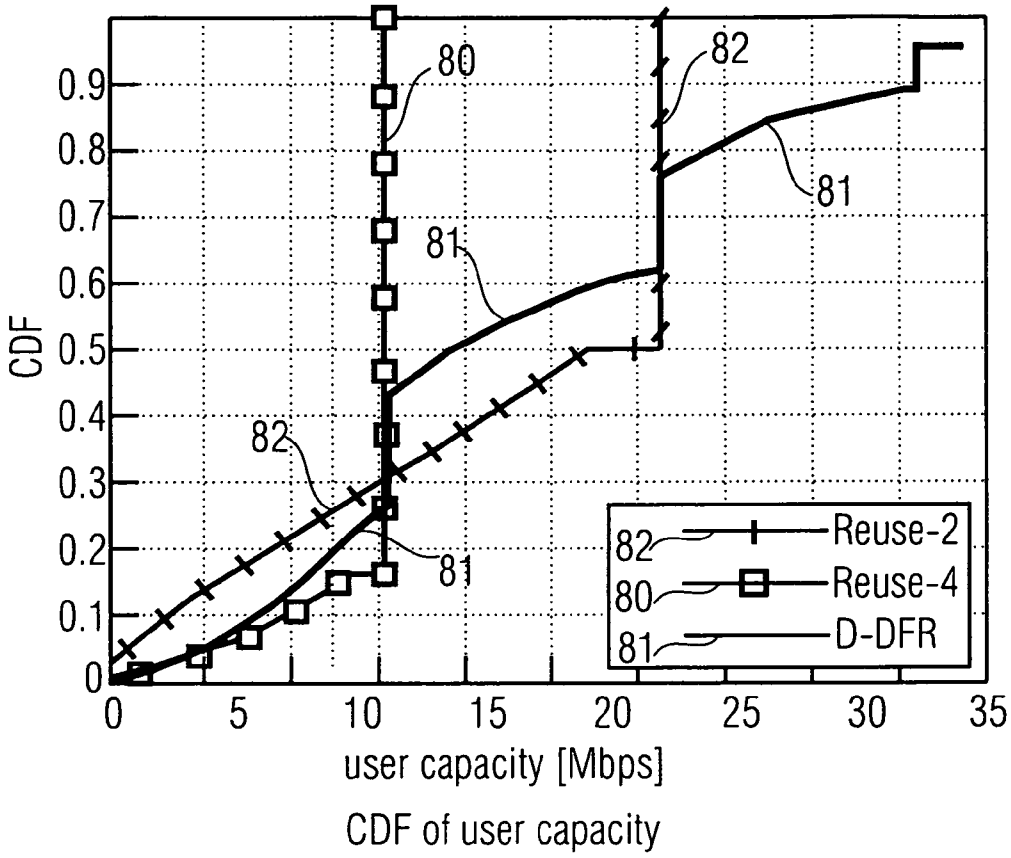
FIG 8B



CDF of SINR

CDFs of SINR and user capacity

FIG 8C



CDF of user capacity

FIG 8D

1: $A_n = 0$
2: **if** n is not banned by neighbor BSs **then**
3: **for** m $\in$ M **do**
4: **if** $\gamma_{m,n} \geq \gamma_{th}$ **then**
5: $A_n = A_n - 1$
6: **end if**
7: **end for**
8: **end if**

FIG 9A
(AVAILABILITY)

1: Calculate the availability of subband
2: $S = S - \{s \in S | A_s = 0\}$
3: $N' = N - (P + S)$
4: CALCULATE minAvail
5: **while** max $(A_{N'}) >$ minAvail **do**
6: $n. = \arg\max_{n \in N'} \{A_n\}$
7: $N' = N' - n$
8: with a probability $\mu(n)$ ⇨ UPDATE S
9: CALCULATE minAvail
10: **end while**

FIG 9B
(SECONDARY ASSIGNMENT)

1: calculate the availability of subbands
2: **while** max $(A_{N'}) > A_p$ **do**
3: $n = \arg\max_{n \in N'} (A_n)$
4: $N' = N' - n$
5: with a probability $\mu(n)$ ⇨ UPDATE P
6: **end while**

FIG 9C
(PRIMARY ASSIGNMENT)

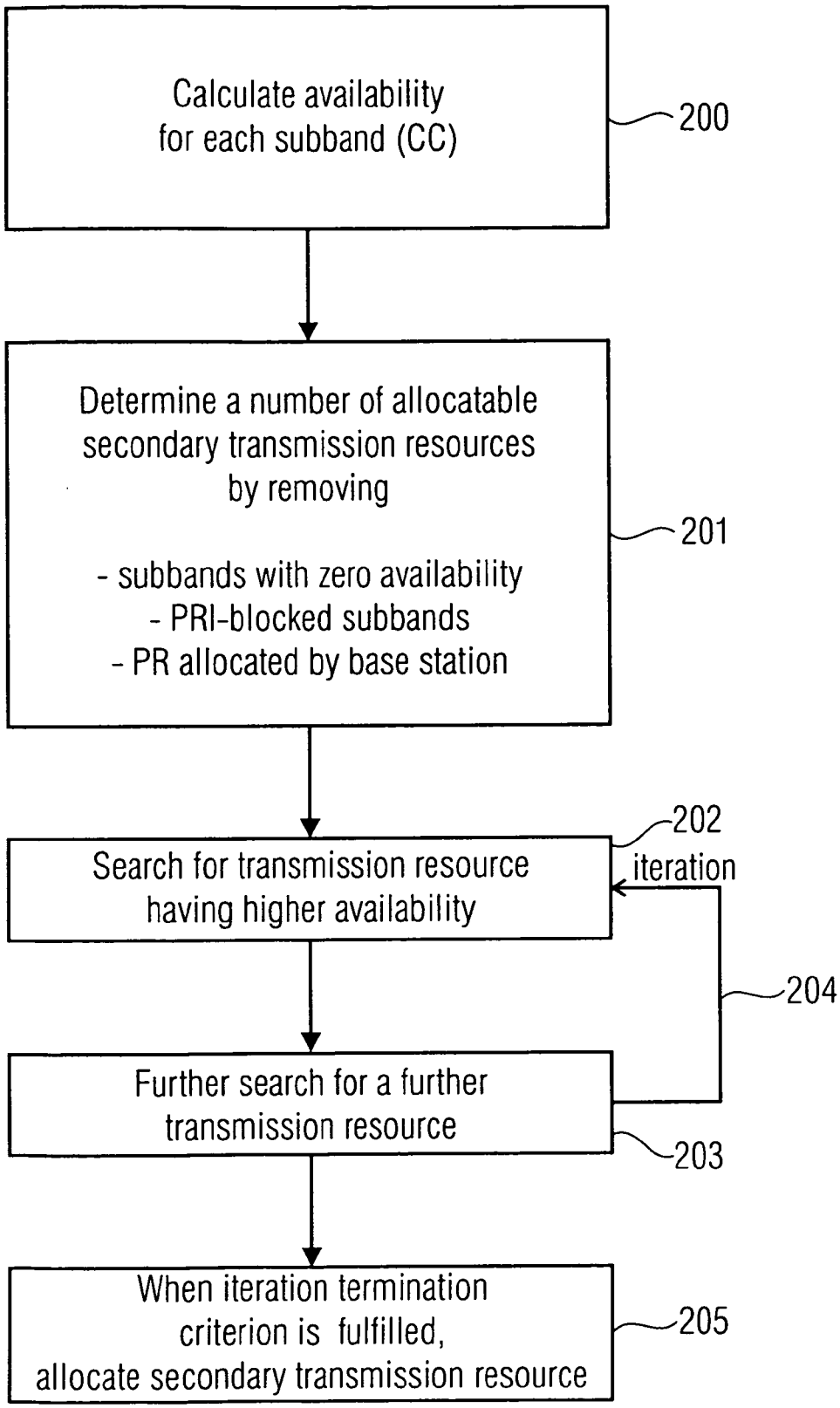

Calculate availability for each subband (CC)
200
Determine a number of allocatable secondary transmission resources by removing
- subbands with zero availability
- PRI-blocked subbands
- PR allocated by base station
201
202
Search for transmission resource having higher availability
iteration
204
Further search for a further transmission resource
203
When iteration termination criterion is fulfilled, allocate secondary transmission resource
205

FIG 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/061707

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W72/08
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2011/041981 A1 (HUAWEI TECH CO LTD [CN]; XIAO WEIMIN [US]; OTERI OGHENEKOME [US]; VAN) 14 April 2011 (2011-04-14)	1-5,7,8, 14,15
A	paragraph [0041] - paragraph [0043]; figure 1 paragraph [0053] - paragraph [0056] paragraph [0060] - paragraph [0069]; figures 4,5	6,9-13

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

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
21 August 2012	03/09/2012

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	SAMSUNG: "Flexible Fractional Frequency Reuse Approach", 3GPP DRAFT; R1-051341, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Seoul, Korea; 20051101, 1 November 2005 (2005-11-01), XP050100938, paragraph [0002]; figure 6 -----	1-15

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Information on patent family members

International application No
PCT/EP2012/061707

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