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(54) Title: A METHOD FOR SCHEDULING USERS IN A CELLULAR ENVIRONMENT FOR APPLYING PARETO OPTIMAL POWER CONTROL, SCHEDULER AND WIRELESS COMMUNICATION NETWORK

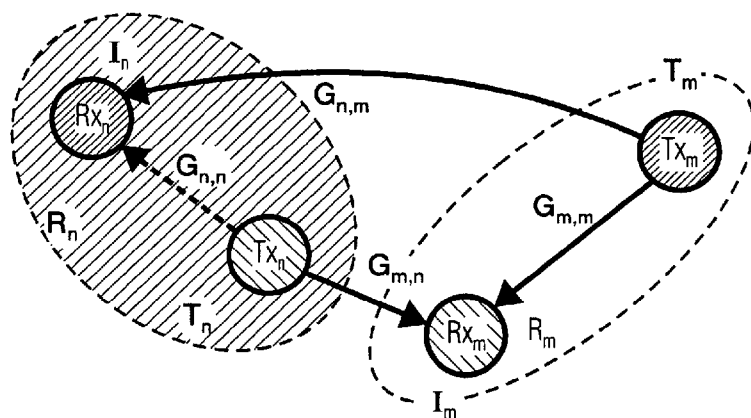


FIG 2A

(57) Abstract: An approach for scheduling users (MS_1 - MS_S) in a cellular environment such that a Pareto optimal power control can be applied, wherein in each cell (C_1 - C_3) of the cellular environment there are a plurality of user, comprises scheduling users (MS_1 - MS_S) such that a number of groups of interfering users from different cells (C_1 - C_3) which fulfill a feasibility condition for the Pareto optimal power control is maximized.



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A Method for Scheduling Users in a Cellular Environment for Applying Pareto Optimal Power Control, Scheduler and Wireless Communication Network

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Description

Embodiments of the invention relate to the field of wireless communication networks, more specifically to approaches for joint scheduling and power control in a cellular environment, in particular to the scheduling of users such that Pareto optimal power control (POPC) can be directly applied.

When considering scheduling and power control in the uplink of a cellular orthogonal frequency division multiple access (OFDMA) system, uplink power control is an important aspect and is particularly relevant for cellular networks. Fig. 1 is a schematic representation of a portion of such a cellular network comprising two base stations Rx_1 and Rx_2 receiving on the uplink connection signals from mobile stations or mobile users Tx_1 and Tx_2 . Mobile stations Tx_1 communicate with base station Rx_1 , while mobile station Tx_2 communicates with base station Rx_2 . As shown in Fig. 1, several transmissions occur concurrently so that interference may occur. In the example shown in Fig. 1 the transmission signal transmitted by mobile station Tx_2 for communicating with the associated base station Rx_2 is also received at the base station Rx_1 as an interference transmission I_{21} . Interference may severely effect the attainable spectral efficiency in the network. Therefore, for avoiding negative effects on the spectral efficiency scheduling and power control in the uplink connections between the transmitters and the receivers are important aspects. It is noted that the same applies for a downlink connection in such a network in which a transmission occurs from the respective base stations to the associated users, wherein a transmission from a base station may also be received as an interference communication at other mobile stations. When considering Fig. 1, in the down link scenario the base stations would be in the transmitters Tx_1 , Tx_2 and the mobile stations would be the receivers Rx_1 and Rx_2 .

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For addressing the problem of interference in wireless communication systems, either in the uplink connection or in the downlink connection, in general, scheduling and power control are separated, i.e. one approach is used for scheduling, and another approach is used for power control. However, this not only generates additional scheduling complexity but also may reduce the optimality of the solution (see, for example, T. ElBatt and A. Ephremides, "Joint Scheduling and Power Control for Wireless ad hoc Networks," *IEEE Transactions on Wireless Communications*, vol. 3, no. 1, pp. 74 – 85, 2004).

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Scheduling in OFDMA networks in the uplink and downlink is described in X. Wang, G. B. Giannakis, and Y. Yu, "Channel-Adaptive Optimal OFDMA Scheduling," in *Proc. of 41st Annual Conference on Information Sciences and Systems CISS*, Baltimore, MD, USA, March 2007, pp. 536–541, where an on-line algorithm based on the water-filling solution is proposed. While this approach delivers an optimal resource block allocation (RB allocation), the throughput fairness among the users is not considered. A computationally efficient power control mechanism is described in D. Kivanc, G. Li, and H. Liu, "Computationally Efficient Bandwidth Allocation and Power Control for OFDMA," *IEEE Transactions on Wireless Communications*, vol. 2, no. 6, pp. 1150 – 1158, 2003, where the problem of minimizing target power is described. However, the joint subcarrier and power allocation is split into two stages, thus disregarding the dependence between the two. In addition, two greedy allocation algorithms are suggested, so that the fairness consideration is reduced to a minimum rate constraint.

A further known approach is the so-called multi-carrier proportional fair (PF) scheduling, which is described in H. Kim, K. Kim, Y. Han, and S. Yun, "A Proportional Fair Scheduling for Multicarrier Transmission Systems," in *Proc. of 60th Vehicular Technology Conference, VTC*, vol. 1, Sep. 2004, pp. 409–413. Multi-carrier PF scheduling is based on a generic PF scheduling metric, the maximization of the sum of logarithmic average user rates. Although performance gains over round-robin schedulers are achieved, the high algorithm complexity makes it unsuitable for fourth generation (4G) OFDMA systems. In R. Kwan, C. Leung, and J. Zhang, "Proportional fair multiuser scheduling in LTE," *IEEE Signal Processing Letters*, vol. 16, no. 6, pp. 461–464, Jun 2009 a lower complexity suboptimal proportional fair scheduler (PFS) is described, where subcarriers are scheduled sequentially. However, this causes large sum throughput losses, especially when the user signal-to-interference-plus-noise ratio (SINR) distribution is irregular, which is generally the case in cellular networks. In M. Khedr, I. El-Rube, Y. Hanafy, and H. Abou-Zeid, "Subcarrier opportunistic proportional fair scheduling for OFDMA systems," in *Proc. of 4th International Conference on Internet ICI*, Tashkent, Sep. 2008, pp. 1–5, subcarrier opportunistic PF scheduling is described, where a subcarrier is assigned to the user with the best weighted response relative to the average response of the other users on the subcarrier. While this scheme provides reasonable capacity-fairness gains, it is only suitable for the downlink and would require to be modified appropriately for the uplink.

The above-described approaches known in the art deal with scheduling, which are separate from power control approaches. For example, power control for OFDM networks involves a fractional power control (FPC) scheme as, for example, described in A. Rao, "Reverse Link Power Control for Managing Inter-Cell Interference in Orthogonal Multiple Access

Systems,” in *Proc of Vehicular Technology Conference (VTC)*, Oct. 2007, pp. 1837 – 1841. This scheme offers a slight adaptation to conventional power control to trade off spectral efficiency and cell-edge bit rate. However, many users will not achieve their SINR targets, so that user throughput will suffer. An extension to FPC is described in Z. Li, Y. Wang, and D. Yang, “A Novel Power Control Scheme in OFDMA Uplink,” in *Proc. of International Conference on Signal Processing (ICSP)*, 2008, pp. 2880 –2883, where the power control expression takes into account interference caused to neighboring cells. While this achieves a modest capacity increase, the mean level of interference to other cells is not reduced, rather only the variance is. In L. K. Tee, C. van Rensburg, and J.-A. Tsai, “Uplink Power Control for an OFDMA Mobile Cellular System,” in *Proc. of the Vehicular Technology Conference*, Baltimore, MD, Sep./Oct. 2007, on the other hand, a closed-loop power control is described which offers significant gains in the user throughput and transmit power, however these are achieved for very low SINRs only, whereas almost no benefits can be seen in the high SINR range.

It is an object of the invention to provide an improved approach for controlling in a wireless communication system interference through adjusting the transmit power, whilst maximizing the spectral efficiency.

This object is achieved by a method of claim 1, a scheduler of claim 14, and a wireless network of claim 15.

Embodiments of the invention provide a method for scheduling users in a cellular environment such that a Pareto optimal power control can be applied, wherein in each cell of the cellular environment there are a plurality of user, the method comprising:

scheduling users such that a number of groups of interfering users from different cells which fulfill a feasibility condition for the Pareto optimal power control is maximized.

Embodiments of the invention provide a scheduler for a wireless network having a plurality of cells, each including a plurality of users, the scheduler being configured to schedule the users in accordance with embodiments of the invention.

Embodiments of the invention provide a wireless network comprising a plurality of cells, each including a plurality of users, and a scheduler in accordance with embodiments of the invention.

Yet another embodiment of the invention provides a computer program product comprising a program including instructions stored by a computer readable medium, the instructions executing a method in accordance with embodiments of the invention when running the program on a computer.

In accordance with an embodiment scheduling comprises iterating through combinations of users in the cells, and allocating resource blocks to the users such that the combinations fulfilling the feasibility condition are scheduled as interferers.

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In accordance with an embodiment scheduling comprises searching all combinations of users, each combination including one user in a neighboring cell, adding to a set of candidates each combination which fulfills the feasibility condition, and allocating the users until all users in the set of candidates have been allocated, wherein allocating starts with users being part in the fewest combinations. Scheduling the users may be repeated until all users in the set of candidates have been scheduled.

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In accordance with an embodiment, in case there are users which are not part of any combination fulfilling the feasibility condition, scheduling further comprises deactivating for each user one link, adapting a SINR target for each user to maintain system spectral efficiency, adding each combination of users which fulfills a modified feasibility condition to a further set of candidates, and allocating the users until all users in the further set of candidates have been allocated, wherein the allocation starts with a user being part in the fewest combinations. Deactivating, adapting, adding and allocating may be repeated for users not part of any combination fulfilling the modified feasibility condition until all links to users in neighboring cells have been deactivated.

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In accordance with an embodiment for a three cell scenario the feasibility condition is as follows:

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$$F_{12}F_{21} + F_{13}F_{31} + F_{23}F_{32} + F_{12}F_{23}F_{31} + F_{13}F_{21}F_{32} < 1$$

where

$$F_{ij} = \frac{\gamma_i^* G_{j,v_i}}{G_{i,v_i}} \quad \text{are the elements of the interference matrix } \mathbf{F},$$

γ_i^* is the target SINR of user i , and

G_{j,v_i} is the path gain between user j and the BS v_i of MS i .

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In accordance with an embodiment the method further comprises switching off the links to users in neighboring cells, in case of one or more users in a cell that cannot form a combination fulfilling the feasibility condition. The links may be switched off over a plurality of consecutive time slots, wherein the SINR target of the remaining links is changed for maintaining the system spectral efficiency. The SINR target of the remaining links may be changed as follows:

$$\gamma_{(i),up}^* = \frac{\prod_{j=1}^K (1 + \gamma_j^*)}{1 + \gamma_{(2),up}^*} - 1,$$

where $\gamma_{(i),up}^*$ represents the updated SINR target of the i^{th} remaining link.

In accordance with an embodiment the method may further comprise grouping three cells with coinciding beam patterns to form a cluster shielded from neighboring sectors' interference, applying the scheduling the these three cells, and tessellating the clusters over the cell environment, thereby applying the scheduling separately to each cluster.

In accordance with an embodiment for each combination fulfilling the feasibility condition the method comprises calculating the Pareto optimal power allocation and assigning it to the users.

Embodiments of the invention provide an approach for obtaining an optimal power control for users or mobile stations in a cellular environment using Pareto optimal power control, i.e. adjusting the transmit power such that an achieved SINR of a receiver cannot be increased without reducing the SINR of another receiver. Pareto optimal power control (POPC) is described in A. Goldsmith, *Wireless Communications* University Press, 2005. In accordance with Pareto scheduling multiple interfering users in neighboring cells are scheduled such that the number of groups of interferers which fulfill a feasibility condition for Pareto optimal power control is maximized. After applying the Pareto optimal power control each user or mobile station in each group will achieve its SINR target with Pareto optimal transmit power. Thus, embodiments of the invention address the issues of scheduling a power control in the uplink of a cellular OFDM system, however, in accordance with further embodiments, the inventive approach can also be implemented in the downlink.

The above-described known approaches for solving the resource and power allocation problems separate a resource allocation problem and the power location problem in an attempt and solve them separately as an optimization problem. Even most "joint" solutions

to the problems provide separate stages for resource, power and rate allocations (see, for example, the publications of T. ElBatt, X. Wang and D. Kivanc mentioned above). Hence, these approaches reduce the optimality of the solutions provided. Contrary thereto, the inventive approach, by combining two allocation stages, allows to schedule users such that the power control stage becomes simply a power assignment procedure, rather than needing to calculate the necessary transmission powers based on an optimal resource allocation. Further, by increasing the applicability of POPC in the network, the users and system target spectral efficiencies will be met with Pareto optimal transmit powers.

In accordance with the embodiments of the invention, Pareto optimal scheduling (POS) is presented, which is a novel scheduling mechanism based on Pareto optimal power control (POPC). Mobile stations (MSs) are scheduled based on path gains and signal-to-interference-plus-noise ratio (SINR) targets such that the conditions for POPC are fulfilled. Further, users are scheduled in such a manner that the number of concurrently transmitting MSs is maximized. In accordance with further embodiments, a stepwise removal (SR) algorithm is provided for a situation where links do not meet the conditions for POPC. In such a case, the links are removed in order for other MSs to achieve their SINR targets, while the targets of the other (remaining) MSs updated to prevent losses in system spectral efficiency caused by the link removals.

Embodiments of the invention are applicable for cellular networks as well as for heterogeneous networks composed of micro, pico and femto-cells.

Embodiments of the invention are advantageous as they provide for a possibility to optimize the interference coordination such that the system spectral efficiency is maximized which allows to more efficiently use the spectral resources and, therefore, to also reduce the costs per transmitted bit. Also, embodiments of the invention are advantageous as the issues of scheduling and power control are solved jointly and simultaneously such that a loss of solution optimality due to a separation of these steps is avoided. In addition, the power usage of the system is minimized due to POPC. Further, all scheduled users (i.e. users that have been assigned RBs and that have not been removed through SR) achieve the SINR targets, and hence also the spectral efficiency target is achieved. Further, an enhanced sum-rate through increase in spatial reuse is achieved as well as a boost in cell-edge user throughput since all users achieve the SINR targets. Also energy efficiency is significantly improved through power control.

Scheduling may take place either in the respective base stations communicating with each other via a backbone network or in an entity at a higher level in the network, for example in the base station of the macro-cell.

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Embodiments of the invention will now be described with regard to the accompanying drawings in which:

Fig. 1 is a schematic representation of a portion of a cellular network;

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Fig. 2 shows a schematic representation of a communication system, wherein Fig. 2(a) depicts a schematic representation of two transmitters, and wherein Fig. 2(b) and Fig. 2(c) depict the strengths of a receive signal, a noise signal and an interference signal at two receivers;

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Fig. 3 shows a schematic representation of a three-cell network (Fig. 3(a)) and the available resource blocks (Fig. 3(b));

Fig. 4 shows an example of a SR algorithm with SINR target updates over multiple time slots;

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Fig. 5 shows a three-cell system similar to the one in Fig. 3(a);

Fig. 6 depicts a sectorized cellular network with a three-cell scheduler being tessellated over its cells;

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Fig. 7 shows a graph depicting the range of values for c and d in Eq. (4) for which all eigenvalues of F are within the unit circle;

Fig. 8 shows the POS algorithm in accordance with an embodiment of the invention;

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Fig. 9 shows a graph of the spectral efficiency results for various power allocation techniques for varying SINR targets and inter-site distances (ISDs); and

Fig. 10 shows a graph of the system power usage results for the various power control techniques.

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Pareto optimal scheduling (POS) focuses on scheduling users such that Pareto optimal power control (POPC) is applied in a way that the system spectral efficiency and energy consumption are optimized. The inventive approach relies on POPC described in A. Goldsmith, *Wireless Communications* University Press, 2005, for which all users achieve the SINR targets and the total transmit power of the mobile stations (MSs) is minimized. In accordance with POPC the transmit power is adjusted such that a certain SINR is achieved at the receiver on each link.

Fig. 2 shows a schematic representation of a communication system. Fig. 2(a) depicts a schematic representation of two transmitters Tx_n and Tx_m transmitting signals. Further, two receivers Rx_n and Rx_m are shown receiving from the transmitters respective signals. In Fig. 2(a) the transmitter Tx_n serves the transmitter Rx_n via a channel having a channel gain $G_{n,n}$. Likewise, the transmitters Tx_m serves the receiver Rx_m via a further channel having a channel gain $G_{m,m}$. However, the respective receivers are also subjected to interference in that receiver Rx_n receives a signal from the transmitter Tx_m , via an interference channel having a channel gain $G_{n,m}$. Likewise receiver Rx_m receives a signal from the transmitter Tx_n via an interference channel having a channel gain $G_{m,n}$. The transmit powers of the respective transmitters are denoted as T_n and T_m , respectively, and the received power or rather the power level of the signal received at the respective receivers is denoted R_n and R_m , respectively. The SINR at receiver Rx_n is calculated as follows:

$$\gamma_n = \frac{R_n}{I_n + N_0}$$

In accordance with G. J. Foschini and Z. Miljanic, "A Simple Distributed Autonomous Power Control Algorithm and Its Convergence," *IEEE Transactions on Vehicular Technology*, vol. 42, no. 4, pp. 641–646, Nov. 1993, for a Pareto optimum power control the power at a transmitter is updated as follows:

$$T_m(k) = \frac{\Gamma_m}{\gamma_m(k-1)} T_m(k-1)$$

where:

Γ_m : SINR target

$\gamma_m(k)$: achieved SINR

However, increasing the transmit power on one link induces interferences to the other link as is shown in Figs. 2(b) and (c). In Fig. 2 (b) the received power 100 ($R_n(k)$) at a time instance k is indicated. Also the noise signal 102 (N_0) and the interference signal 104 (I_n) at

time instance k are shown. In Fig. 2(c) the received power 200 at receiver Rx_m at instance k , the noise signal 202 (N_0) and the interference signal 204 at the receiver Rx_m is shown at time instance k . The distance between the transmitter Tx_n and the receiver Rx_m is smaller than a distance between the transmitter Tx_m and the receiver Rx_n . The distance between the transceiver Tx_n and the receiver Rx_n is shorter than a distance between the transmitter Tx_m and the receiver Rx_m . The power received at receiver Rx_n is higher than the power received at receive Rx_m (see Fig. 2(b) and Fig. 2(c)). The noise remains substantially unchanged. Further, the interference signal at the receiver Rx_n is smaller than the interference signal 204 at the receiver Rx_m .

In case it is determined that a desired SINR is not achieved at the receiver Rx_m the transmitter Tx_m may be controlled to increase its transmit power as is shown at 200' in Fig. 2(c). However, this yields a higher interference signal at the receiver Rx_n as is shown at 104' in Fig. 2(b). Further, in case the transmit power of the transmitter Tx_n is increased as is shown at 100' in Fig. 2(b), for example for obtaining a desired SINR at the receiver Rx_n this also increases the interference at the receiver Rx_m as is shown at 200'. Thus, Pareto optimal power control is a non-trivial task.

In accordance with the inventive approach, users are scheduled in such a manner that each MS only has a single interferer in each neighboring cell (i.e. the same RBs (resource blocks) are assigned to a single MS in each cell) such that POPC can be applied directly to each group of MSs. For allowing POPC to be applied to a group of interfering MSs, the following condition must hold:

$$\mathbf{P}^* = (\mathbf{I} - \mathbf{F})^{-1} \mathbf{u} \quad \text{iff} \quad \rho_F < 1, \quad (1)$$

where $\mathbf{P}^*$ is the Pareto optimum power vector, $\mathbf{I}$ is the identity matrix, $\mathbf{u}$ is the vector of noise power scaled by the SINR targets and channel gains, $\mathbf{F}$ is the interference matrix, and ρ_F is the Perron-Frobenius (i.e., maximum absolute) eigenvalue of $\mathbf{F}$. If a group of MSs interfering with each other can fulfill the condition in Eq. (1), then POPC is utilized and each MS is allocated in optimum transmit power. To be able to schedule users in this way, the condition set forth in Eq. (1) needs to be formulated such that the network can directly utilize available information, i.e., path gains and SINR targets. After a derivation, the feasibility condition can be formulated as follows:

$$F_{12}F_{21} + F_{13}F_{31} + F_{23}F_{32} + F_{12}F_{23}F_{31} + F_{13}F_{21}F_{32} < 1, \quad (2)$$

where

$F_{ij} = \frac{\gamma_i^* G_{j,v_i}}{G_{i,v_i}}$ are the elements of the interference matrix $\mathbf{F}$,

γ_i^* is the target SINR of MS i , and
 G_{j,v_i} is the path gain between MS j and the BS v_i of MS i .

- 5 Thus, the feasibility condition is expressed in terms of path gains and SINR targets, and the users can be scheduled accordingly.

To utilize Eq. (2) the scheduler needs to be aware of both the desired link and interfering link gains of the MSs in the system. Each of the MSs can estimate its path gains to its own
 10 and neighboring BSs using the reference signals in the downlink, and can report back to the BS on uplink control channels. The BSs in question can then share this information among each other over the network backbone, for example, the X2 interface in LTE. The information may either be passed to a higher architecture level (for example, the Serving Gateway (S-GW)/Mobility Management Entity (MME) in LTE) or to a single nominal BS
 15 so that the appropriate MS groups can be calculated according to Eq. (2) and the scheduling commands can be signaled to the individual BSs.

An example for the combination of power control, scheduling and resource partitioning in accordance with embodiments of the invention will be described in the following on the
 20 basis of Fig. 3, in which Fig. 3(a) shows a schematic representation of a three-cell network and Fig. 3(b) shows the available resource blocks (RBs), more specifically five different frequencies or frequency bands that may be allocated to the respective users. In Fig. 3(a) three-cells C_1 to C_3 are shown each comprising a respective base station BS_1 to BS_3 . Each of the cells C_1 to C_3 comprises five mobile stations. During scheduling appropriate user
 25 pairs are determined so that all links may coexist, i.e. a desired SINR target is met. In POS, when there are multiple users per cell (see cells C_1 to C_3 of Fig. 3(a)), the MSs must be scheduled such that the number of groups of interferers fulfilling the condition (2) is maximized. This is done by iterating through all combinations of MSs in the cells, and allocating the RBs such that the combinations of MSs fulfilling the condition are scheduled as
 30 interferers. If it is possible to schedule all users in the system such that for each group of the interferers the condition (2) is fulfilled, then with POPC every user (MS) will achieve its target SINR and the total system power will be minimized.

An example of such a scheduling instance is shown in Fig. 3(a), and in each cell the same
 35 resource blocks RBs are assigned to each MS in a group (and, clearly, a different set of RBs is assigned for each group). Then, after POPC is applied, each MS in each group will

achieve its SINR target with Pareto optimal transmit power. For example, in Fig. 3(a) in each cell C_1 to C_3 a resource block is assigned only once, as can be seen from the respective numbers 1 to 5 assigned to the respective mobile stations in the cells C_1 to C_3 .

- 5 The above-described scheduling process may comprise swapping the RB assignment between two users in one cell, which may result in a different interference condition in adjacent cells so as to meet the condition (2). For example, in Fig. 3(a) initially resource block 3 might have been assigned to mobile station MS_1 , and resource block 1 might have been assigned to mobile station MS_2 . However, this assignment did not fulfill condition (2) so
- 10 that during the scheduling process in cell C_1 the resource blocks 1 and 3 were swapped so that mobile station MS_1 has assigned thereto resource block 1 (instead of resource block 3), and mobile station MS_2 has assigned thereto resource block 3 instead of resource block 1) so that for the allocation depicted in Fig. 3(a) condition (2) is fulfilled.
- 15 However, there may be situations in which, due to the position of some MS_s , for example at a cell-edge, these users may not be able to form a group of interferers that satisfies the condition for POPC. In this case, one or more links need to be switched off in order to allow potential interferers to be scheduled and to achieve the desired SINR targets. Fig. 3(a) shows an example for such a link removal or switching off of a link because the group of
- 20 mobile stations having allocated therewith resource block 4, namely mobile stations MS_3 to MS_5 do not form a group of interferers that satisfies the above-mentioned feasibility condition for POPC. Thus, in accordance with a stepwise removal (SR) algorithm in accordance with an embodiment of the invention, one or more links of the mobile station MS_3 to the base stations BS_1 to BS_3 are removed and, therefore, in Fig. 3(a) mobile station
- 25 MS_3 is shown with a dotted circle. Removing one or more links for the mobile station allows the other two mobile stations MS_4 and MS_5 to achieve their SINR targets (updated).

Turning off any link may harm the system spectral efficiency so that in accordance with an embodiment the SINR targets of the interferers will be updated to “cover” the removed

30 spectral efficiency from the excluded link. By this mechanism, POPC can still be applied, with one or multiple links, if needed, removed, so that the spectral efficiency is maintained and that minimum transmit power usage is ensured.

An example of the SR algorithm is shown in Fig. 4 with SINR target updates over multiple

35 time slots. As is shown in Fig. 4, over multiple time slots S_1 to S_3 for a mobile station each of the three links is removed once, as is shown by the dashed arrow having the ‘x’. At the same time, the SINR targets (and consequently the spectral efficiency) of the two remaining links are augmented as is indicated by larger, bold arrows. By this approach, in each

time slot and over all time slots (in the example shown over three time slots) the spectral efficiency S_{sys} is maintained. Furthermore, over three time slots each individual MS can achieve its target spectral efficiency, because the two inflated transmissions compensate for the loss of the removed transmission. Hence, both the system and the individual spectral efficiencies are maintained through the SINR target updates in the SR algorithm, while the link removals in each slot allow for scheduling of the other two users.

An example of an algorithm for combined power control, scheduling and resource partitioning in accordance with the embodiments of the invention will now be described with regard to Fig. 5 showing a three-cell system as in Fig. 3(a). The first step of the algorithm is a resource allocation step in which resource blocks are assigned to the respective users. In Fig. 5 the same resource is assigned to mobile stations MS_1 to MS_3 in the respective cells C_1 to C_3 . In the power control step it is determined as to whether condition (2) is fulfilled for the group of mobile station MS_1 to MS_3 . In case it is determined that $\rho_F \geq 1$, then at least one of the links in the group does not achieve the desired SINR target. It is assumed in Fig. 5 that the links associated with mobile station MS_1 are removed and that only then the remaining mobile stations in the group achieve the desired SINR target, i.e. $\rho_F < 1$. Therefore, Fig. 5 shows mobile station MS_1 crossed out. The algorithm then returns to resource allocation step and a new set of mobile stations is selected so that the group now includes mobile station MS_2 to MS_4 .

As described above, the POS scheduling approach is for a three-cell system, however, realistic scenarios comprise more than three cells. One option would be to derive the feasibility condition (2) for a larger number of cells and therefore apply the POS approach to a larger network, however, E. Jury, "A simplified stability criterion for linear discrete systems," Proceedings of the IRE, vol. 50, no. 6, pp. 1493-1500, 1962 indicates that the feasibility conditions for even a four-cell scenario are excessively complex so that the just-mentioned extension to larger networks is not practical. In accordance with embodiments of the invention this problem is solved by an approach tessellating the three-cell POS over a network of any dimension. This is described with regard to Fig. 6 depicting a sectorized cellular network where a three-cell scheduler is tessellated over the cells in such a manner that three neighboring sectors/cells with interfering beams are grouped so that POS can be applied. In the sectorized cellular network of Fig. 6 universal frequency reuse is applied, and the different numbers in the respective cells indicate which BS is serving the cells. By grouping three cells with coinciding beam patterns (see the shaded cells in Fig. 6) POS can be applied to these three cells, and the cluster will be relatively shielded from neighboring sectors' interference due to the nature of the beam pattern. This clustering is then tessellated over the network such that POS can be applied separately in each of these clusters

without overly excessive co-channel interference (CCI) from the surrounding cells thereby allowing the MSs to achieve the transmission requirements.

In the following a detailed embodiment of the inventive approach will be described. In Pareto optimal power allocation, given a feasible link allocation, *i.e.*, $\rho_F < 1$, a vector $\mathbf{P}^* = (\mathbf{I} - \mathbf{F})^{-1} \mathbf{u}$ can be found such that all users achieve their SINR requirements with minimal power. This is a highly desirable result which, depending on the locations of the interfering MSs, may not always be feasible. Hence, by scheduling the users purposefully in such a manner as to maximize the number of feasible $\mathbf{F}$ matrices (in principle, there can be as many $\mathbf{F}$ matrices as there are RBs in the system), the system spectral efficiency can be maximized. A scheduler in accordance with embodiments of the invention allowing for this will now be described.

Since for a particular grouping of MSs (on the same RB(s) in different cells) to be feasible $\rho_F < 1$, it follows the modulus of all eigenvalues λ_i of $\mathbf{F}$ must also be less than unity, *i.e.*, $|\lambda_i| < 1, \forall i = 1, \dots, K$. In other words, all eigenvalues must lie within the unit circle.

In E. Jury, "A simplified stability criterion for linear discrete systems," Proceedings of the IRE, vol. 50, no. 6, pp. 1493-1500, 1962, a simplified analytic test of stability of linear discrete systems is described. The test also yields the necessary and sufficient conditions for any real polynomial to have all its roots inside the unit circle. Hence, this test can be directly applied to the characteristic function $f_F(\lambda)$ of the matrix $\mathbf{F}$, whose roots are the eigenvalues of $\mathbf{F}$, and thus need to lie within the unit circle. The characteristic function of $\mathbf{F}$, f_F , can be expressed as follows:

$$\text{Given } \mathbf{F} = \begin{bmatrix} 0 & F_{12} & F_{13} \\ F_{21} & 0 & F_{23} \\ F_{31} & F_{32} & 0 \end{bmatrix}$$

$$f_{\mathbf{F}_3}(\lambda) = \det(\mathbf{F} - \lambda \mathbf{I}) = 0$$

$$= -\lambda^3 + \lambda(F_{12}F_{21} + F_{13}F_{31} + F_{23}F_{32}) + F_{12}F_{23}F_{31} + F_{13}F_{21}F_{32} \quad (3)$$

$$= \lambda^3 + c\lambda + d \quad (4)$$

$$\begin{aligned} \text{Hence } c &= -F_{12}F_{21} - F_{13}F_{31} - F_{23}F_{32} \\ d &= -F_{12}F_{23}F_{31} - F_{13}F_{21}F_{32} \end{aligned}$$

In E. Jury, "A simplified stability criterion for linear discrete systems," Proceedings of the IRE, vol. 50, no. 6, pp. 1493-1500, 1962, the stability constraints for a polynomial of order $K=3$ are given as:

$$\begin{aligned}
 f(z) &= a_3 z^3 + a_2 z^2 + a_1 z + a_0, \quad a_3 > 0 \\
 1) \quad &|a_0| < a_3 \\
 2) \quad &a_0^2 - a_3^2 < a_0 a_2 - a_1 a_3 \\
 3) \quad &a_0 + a_1 + a_2 + a_3 > 0, a_0 - a_1 + a_2 - a_3 < 0
 \end{aligned} \tag{5}$$

In E. Jury, "A simplified stability criterion for linear discrete systems," Proceedings of the IRE, vol. 50, no. 6, pp. 1493-1500, 1962, the stability constraints are for a polynomial of degree n to have all its n roots within the unit circle, which is a necessary condition for the stability of linear discrete systems. However, in accordance with the inventive approach the stability of the polynomial is not an issue, rather it is to be ensured that the roots, which are the eigenvalues of $\mathbf{F}$, lie within the unit circle so that $\mathbf{F}$ becomes feasible.

The above conditions can now be applied to the characteristic function $f_{\mathbf{F}_3}(\lambda)$

$$\begin{aligned}
 f_{\mathbf{F}_3}(\lambda) &= \lambda^3 + c\lambda + d \\
 a_3 &= 1, a_2 = 0, a_1 = c, a_0 = d, \\
 1) \quad &|d| < 1 \\
 2) \quad &d^2 - 1 < c \rightarrow c > 1 - d^2 \\
 3) \quad &d + c + 1 > 0 \rightarrow c > -d - 1, \\
 &d - c - 1 < 0 \rightarrow c > d - 1
 \end{aligned} \tag{6}$$

which describes the ranges of c and d for which $\mathbf{F}$ is feasible. These are shown in Fig. 7 by the dotted lines and the enclosed area. In Fig. 7 the enclosed area depicts the range of values for c and d in Eq. (4) for which all eigenvalues of $\mathbf{F}$ are within the unit circle. Due to the nature of c , $d < 0$, the area B within the dotted lines 1, 2 and 3 denotes a specific feasibility area. However, since $F_{i,j} > 0, \forall i, j$, it is clear that both $c, d < 0$, and hence the feasible area is substantially reduced (from the area A to the area B in Fig. 7), and the constraints are reduced to only a single one, such that the **feasibility condition** becomes:

$$\begin{aligned}
 3) \quad &c > -d - 1 \\
 &-F_{12}F_{21} - F_{13}F_{31} - F_{23}F_{32} > F_{12}F_{23}F_{31} + F_{13}F_{21}F_{32} - 1 \\
 &\text{So, } \rho_{\mathbf{F}} < 1 \text{ if:} \\
 &F_{12}F_{21} + F_{13}F_{31} + F_{23}F_{32} + F_{12}F_{23}F_{31} + F_{13}F_{21}F_{32} < 1
 \end{aligned} \tag{7}$$

So, a group of MSs, one in each cell (in the three-cell scenario), is feasible iff the condition in Eq. (7) is fulfilled. This is dependent on the individual desired and interfering path gains, along with the SINR targets of the users. Therefore, a scheduler may make use of this condition to schedule users such that the number of feasible groups of MSs is maximized, hence also maximizing the spectral efficiency of the system.

In both POPC and the Foschini-Miljanic algorithm (an iterative implementation of POPC and described in G. Foschini, Z. Miljanic, "A Simple Distributed Autonomous Power Control Algorithm and Its Convergence," IEEE Transactions on Vehicular Technology, vol. 42, no. 4, pp. 641-646, Nov. 1993), if $\rho_F \not\leq 1$ then no solution is available, and hence $\mathbf{P} \rightarrow 0$ or $\mathbf{P} \rightarrow (P_{max}, \dots, P_{max})^T$, respectively. In these cases, either none of the links will transmit, or transmit with (most-likely) too much power, and hence these solutions are suboptimal.

To address this problem is to successively remove single links from the group of interfering MSs, until a $\mathbf{F}$ is achieved with $\rho_F < 1$. At each step, the link is removed that is causing the largest interference to the other users, *i.e.*, the column of $\mathbf{F}$ with the largest sum (both the column and the corresponding row are removed from $\mathbf{F}$). However, turning off one of the links will harm the system spectral efficiency, and hence, in accordance with embodiments, an update function is provided to amend the SINR targets of the remaining links such that the system spectral efficiency does not suffer:

$$\gamma_{(1),up}^* = \frac{\prod_{j=1}^K (1 + \gamma_j^*)}{1 + \gamma_{(2),up}^*} - 1, \quad (8)$$

where $\gamma_{(i),up}^*$ represents the updated SINR target of the i^{th} remaining link. Since Eq. (8) has infinite solutions, an additional condition on $\gamma_{(1),up}^*$ and $\gamma_{(2),up}^*$ such as a power minimization

$$\text{Solve (8) s.t.} \quad \min \{ \gamma_{(1),up}^* + \gamma_{(2),up}^* \}, \quad (9)$$

or an equal absolute SINR increase

$$\text{Solve (8) s.t.} \quad \gamma_{(1),up}^* - \gamma_{(1)}^* = \gamma_{(2),up}^* - \gamma_{(2)}^*, \quad (10)$$

is necessary. Finally, when two links have been removed and only a single link remains,

$$\gamma_{(1),up}^* = \prod_j^K (1 + \gamma_j^*) - 1 \quad (11)$$

and $\mathbf{F} = 0$, $\rho_F = 0$, and $\mathbf{P} = \mathbf{u} = \frac{n\gamma_{(1),up}^*}{G_{1,v_1}}$.

5

Through this form of link removal, the system spectral efficiency can be maintained while maximizing the number of transmitting users according to the feasibility constraint ρ_F . Furthermore, it prevents the explosion of transmit powers that results from the Foschini-Miljanic algorithm, and the annihilation of links caused by POPC.

10

In the case that the scheduler is unable to find feasible groups for particular MSs (due to *e.g.*, location at cell-edge), the SR algorithm will turn off one of the links in a group of MSs, resulting in a feasibility matrix $\mathbf{F}$ of size $K-1 \times K-1$, in the three-cell case 2×2 :

15

$$\mathbf{F} = \begin{bmatrix} 0 & F_{12} \\ F_{21} & 0 \end{bmatrix} \quad (12)$$

Hence, the characteristic function is given by

20

$$\begin{aligned} f_{\mathbb{F}_2}(\lambda) &= \det(\mathbf{F} - \lambda \mathbf{I}) \\ &= \lambda^2 - F_{12}F_{21} = 0 \\ &= \lambda^2 + c \\ c &= -F_{12}F_{21} \end{aligned} \quad (13)$$

25

Again from E. Jury, "A simplified stability criterion for linear discrete systems," Proceedings of the IRE, vol. 50, no. 6, pp. 1493-1500, 1962, the stability constraints for a polynomial of order $K-1=2$ are

$$\begin{aligned} f(z) &= a_2 z^2 + a_1 z + a_0, \quad a_2 > 0 \\ 1) \quad &|a_0| < a_2 \\ 2) \quad &a_0 + a_1 + a_2 > 0, \quad a_0 - a_1 + a_2 > 0 \end{aligned} \quad (14)$$

30

Applying these conditions to the $f_{\mathbb{F}_2}(\lambda)$ yields

$$\begin{aligned}
f_{\mathbf{r}_2}(\lambda) &= \lambda^2 + c \\
a_2 &= 1, a_1 = 0, a_0 = c, \\
1) \quad &|c| < 1 \\
2) \quad &c + 1 > 0 \rightarrow 1 > -c,
\end{aligned} \tag{15}$$

and hence the **feasibility condition** is given by

$$\begin{aligned}
5 \quad &2) \quad \begin{matrix} 1 > -c \\ 1 > F_{12}F_{21} \end{matrix} \quad \text{So, } \rho_F < 1 \text{ if : } F_{12}F_{21} < 1
\end{aligned} \tag{16}$$

The goal of the scheduler is to maximize the “MS-groups” for which the feasible condition in (7) is satisfied, and the Pareto optimal power control can be applied. This is opposed to a random scheduler in which the assignment of RBs, and hence also the MS-groups, is performed in an arbitrary fashion. An embodiment of the POS algorithm is shown in Fig. 8 and will now be described.

The scheduling algorithm is split into three allocation stages, corresponding to the number of cells considered (in this embodiment three) and hence the number of stepwise removals (plus 1) that are possible.

In the first round of grouping, the scheduler searches through all combinations of three MSs (*i.e.*, one in each cell), and adds each group to the set of candidates S that fulfils the feasibility condition (7). Since it is possible for certain MSs to be part of multiple feasible groups, and some MSs to not be part of any, to maximize the number of feasible combinations, those MSs with the fewest feasible combinations will be scheduled first, before scheduling other groups and removing the possible partners. Hence, the MSs with the least feasible groups is scheduled first along with the two feasible partners that have the least feasible groups, and so on until all MSs in S have been scheduled/grouped. This completes the first round of grouping.

In the second round, the MSs that have not been scheduled yet, *i.e.*, those that did not make up any feasible combination in the first round grouping, are to be assigned. Because it is not possible to schedule any of these users in groups of 3 (as otherwise they would have been already scheduled in the first round), in this round groups will be allocated with one link deactivated. Furthermore, as in the stepwise removal algorithm described above the SINR targets are increased according to Eq. (8) to maintain the system spectral efficiency. Thus, similar as in the first round, the set S now denotes all “MS-pairs” that satisfy Eq.

(16), and are hence feasible for allocation. Again, the MS(s) with the fewest number of feasible combinations are scheduled first, and to complete each group a MS is selected from the unscheduled cell that has either no feasible combinations, or at least the fewest of those in that cell remaining to be scheduled. This is done until all MSs in D have been
 5 scheduled, completing the second round of grouping.

Finally, in the third round of grouping, where MS-groups with two deactivated links are scheduled, the scheduling becomes rather simple. The basic premise is that the activated link in each group should have the best path gain, so as to minimize its transmit power, and
 10 hence that of the group. Therefore, each of the remaining groups is constructed using the MS with the best path gain, and the MS in each of the two remaining cells with the worst path loss, until all MSs have been scheduled. The SINR target is also updated, such that the system spectral efficiency can be maintained.

15 In the power allocation stage, $\mathbf{F}$ and $\mathbf{u}$ are constructed for each MS-group (these are of course sized accordingly for those groups allocated in the second or third round of grouping) and the Pareto optimal power allocation is calculated and assigned. The power of each MS is limited by the system's given maximum transmit power, which may reduce the optimality of some solutions, however is unavoidable. Through this scheduler, the system
 20 will attain the desired spectral efficiency, and if not, minimize the losses incurred.

Fig. 9 shows the spectral efficiency results for the various power allocation techniques (random scheduling is used for all the power allocation techniques except POS) for varying SINR targets and inter-site distances (ISDs). As can be seen, POPC, the Foschini-Miljanic
 25 algorithm, open-loop power control and maximum power systems are constant for the various ISDs. The maximum power performance is constant over all SINR targets, and since the Foschini-Miljanic algorithm converges to this when the groupings are infeasible, it is clear why its performance is bounded. The Pareto optimal allocation suffers significantly from the random grouping, as the number of feasible groups disappears very rapidly with
 30 increasing SINR. Furthermore, the upper bound in Fig. 9 simply denotes the Shannon capacity of the given SINR target, *i.e.*, the attainable spectral efficiency if all MSs can be optimally scheduled.

The ISD is however a significant factor in the performance of the SR algorithm and POS as
 35 described in the embodiments above. The smaller the ISDs in the network, the better the performance of the power allocation strategies. When links are deactivated and, consequently, the SINR targets are increased to prevent loss of system spectral efficiency, the

larger transmit powers needed to satisfy the γ_{up}^* are bound by P_{max} . Reducing the ISDs is equivalent to increasing P_{max} due to the greater desired link gains. Hence, POS and the SR algorithm will achieve the spectral efficiency target for much higher SINRs as the MS-groups with only two or one link(s) active are not bound by P_{max} . The differences that can
5 be seen between POS and the SR algorithm represent the direct gains received through the grouping procedure in the Pareto scheduler. It is evident that gains over 1 bits/s/Hz are possible for varying ISDs. In general, it is evident that POS outperforms all other techniques for the scenarios (ISDs) investigated.

Fig. 10 shows a graph of the system power usage results for the various power control techniques. Fig. 10 shows the total system power usage. While POPC uses almost no power due to its low availability, the Foschini-Miljanic algorithm converges to maximum power transmission. The system powers of POS and the SR algorithm are much lower than the other techniques (except for conventional power control, which however does not
15 achieve the spectral efficiency target of the system). The reduction in transmit power for smaller ISDs is explained by the reduction in the desired link gains. For each ISD the lower SINRs POS requires slightly more power than the SR algorithm, mainly because more users are being scheduled. This is, however, inverted after $\gamma^* = 12\text{dB}$, as here the (most likely) single remaining link per group requires more power in the SR algorithm than the
20 two or three links scheduled in POS. In the end, however, both converge to (for all ISDs) $P_{max}/3$. From Figs. 9 and 10 it is clear that POS delivers close to optimal performance in terms of spectral efficiency, and performs very well in terms of power usage over a wide range of SINR targets.

25 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.

30 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
35 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 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.

Claims

1. A method for scheduling users (MS_1 - MS_5) in a cellular environment such that a Pareto optimal power control can be applied, wherein in each cell (C_1 - C_3) of the cellular environment there are a plurality of users (MS_1 - MS_5), the method comprising:

scheduling users (MS_1 - MS_5) such that a number of groups of interfering users from different cells (C_1 - C_3) which fulfill a feasibility condition for the Pareto optimal power control is maximized.

2. The method of claim 1, wherein scheduling comprises:

iterating through combinations of users (MS_1 - MS_5) in the cells (C_1 - C_3), and allocating resource blocks to the users (MS_1 - MS_5) such that the combinations fulfilling the feasibility condition are scheduled as interferers.

3. The method of claim 1 or 2, wherein scheduling comprises:

searching all combinations of users (MS_1 - MS_5), each combination including one user (MS_1 - MS_5) in a neighboring cell (C_1 - C_3);

adding to a set of candidates each combination which fulfills the feasibility condition; and

allocating the users (MS_1 - MS_5) until all users in the set of candidates have been allocated, wherein allocating starts with users being part in the fewest combinations.

4. The method of claim 3, wherein scheduling the users (MS_1 - MS_5) is repeated until all users in the set of candidates have been scheduled.

5. The method of claim 3 or 4, wherein, in case there are users (MS_1 - MS_5) which are not part of any combination fulfilling the feasibility condition, scheduling further comprises:

deactivating for each user one link;

adapting a SINR target for each user to maintain system spectral efficiency;

adding each combination of users which fulfills a modified feasibility condition to a further set of candidates; and

5 allocating the users until all users in the further set of candidates have been allocated, wherein the allocation starts with a user being part in the fewest combinations.

6. The method of claim 5, wherein the steps of deactivating, adapting, adding and allocating are repeated for users not part of any combination fulfilling the modified feasibility condition until all links to users in neighboring cells have been deactivated.

7. The method of one of claims 1 to 6, wherein for a three cell scenario the feasibility condition is as follows:

$$F_{12}F_{21} + F_{13}F_{31} + F_{23}F_{32} + F_{12}F_{23}F_{31} + F_{13}F_{21}F_{32} < 1$$

where

20 $F_{ij} = \frac{\gamma_i^* G_{j,v_i}}{G_{i,v_i}}$ are the elements of the interference matrix $\mathbf{F}$,
 γ_i^* is the target SINR of user i , and
 G_{j,v_i} is the path gain between user j and the BS v_i of MS i .

8. The method of one of claims 1 to 7, further comprising:

25 in case of one or more users (MS₁-MS₅) in a cell (C₁-C₃) that cannot form a combination fulfilling the feasibility condition, switching off the links to users in neighboring cells (C₁-C₃).

9. The method of claim 8, wherein the links are switched off over a plurality of consecutive time slots, wherein the SINR target of the remaining links is changed for maintaining the system spectral efficiency.

10. The method of claim 9, wherein the SINR target of the remaining links is changed as follows:

35

$$\gamma_{(1),up}^* = \frac{\prod_j^K (1 + \gamma_j^*)}{1 + \gamma_{(2),up}^*} - 1,$$

where $\gamma_{(i),up}^*$ represents the updated SINR target of the i^{th} remaining link.

- 5 11. The method of claim 10, further comprising:

grouping three cells with coinciding beam patterns to form a cluster substantially shielded from neighboring sectors' interference;

- 10 applying the scheduling the these three cells; and

tessellating the clusters over the cell environment, thereby applying the scheduling separately to each cluster.

- 15 12. The method of one of claims 1 to 11, comprising for each combination fulfilling the feasibility condition:

calculating the Pareto optimal power allocation and assigning it to the users.

- 20 13. A computer program product comprising instructions to perform a method of one of claims 1 to 12 when executing the instructions on a computer.

14. A scheduler for a wireless network having a plurality of cells (C_1 - C_3), each including a plurality of users (MS_1 - MS_5), the scheduler being configured to schedule the
25 users (MS_1 - MS_5) in accordance with one of claims 1 to 12.

15. A wireless network comprising a plurality of cells (C_1 - C_3), each including a plurality of users, and a scheduler of claim 14.

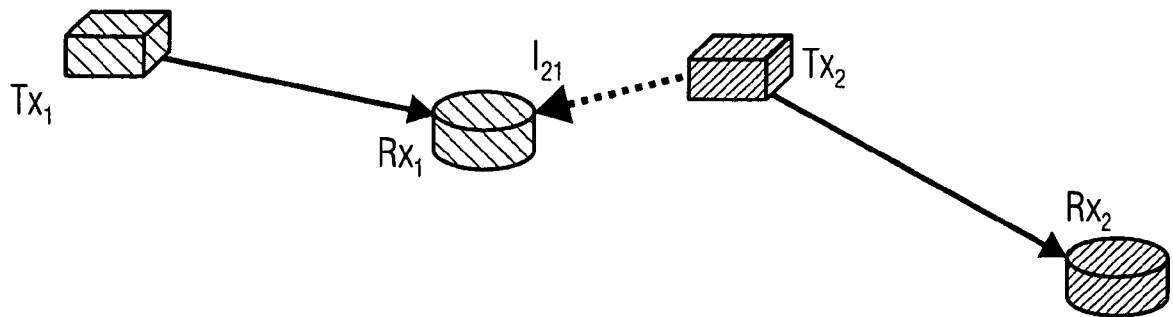


FIG 1

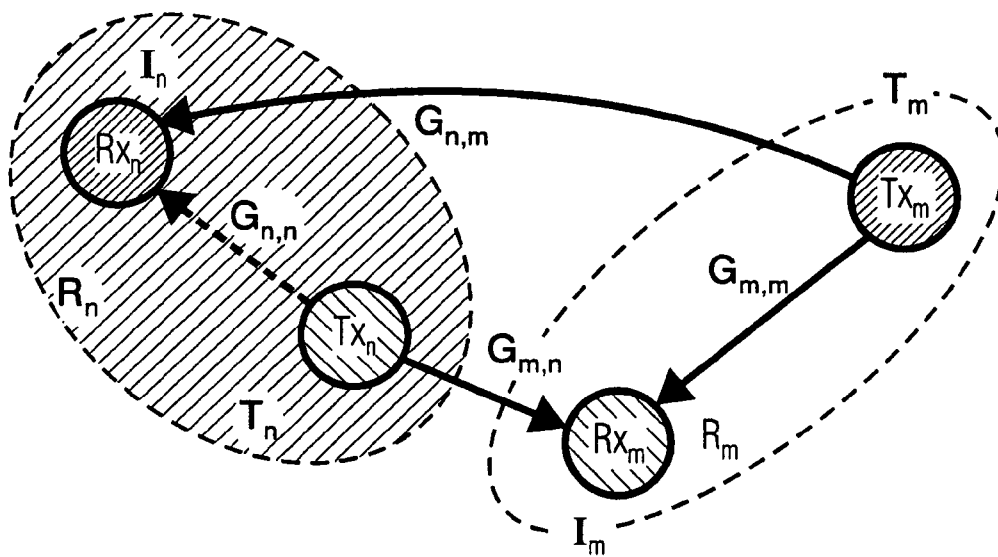


FIG 2A

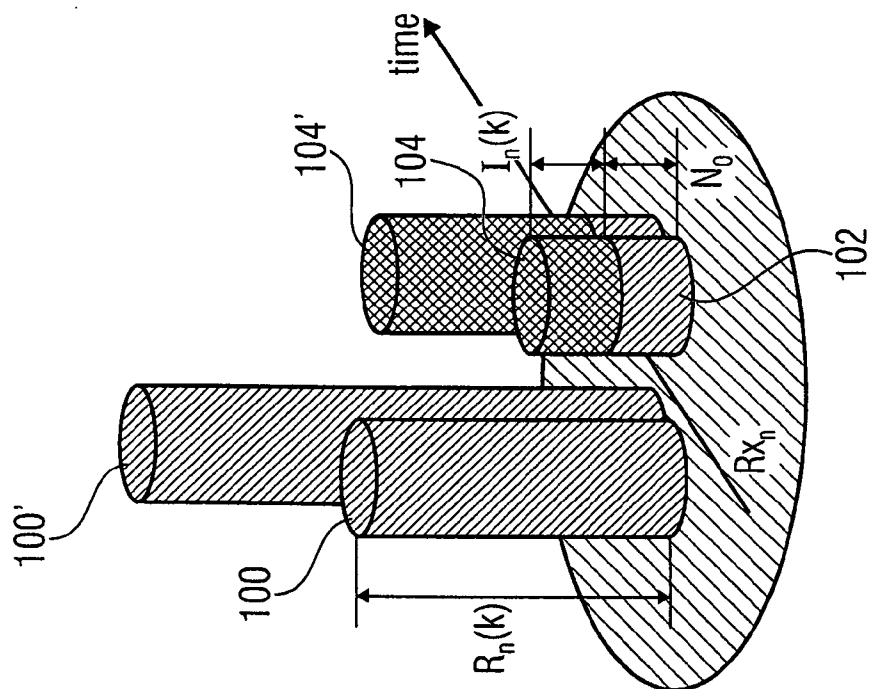


FIG 2B

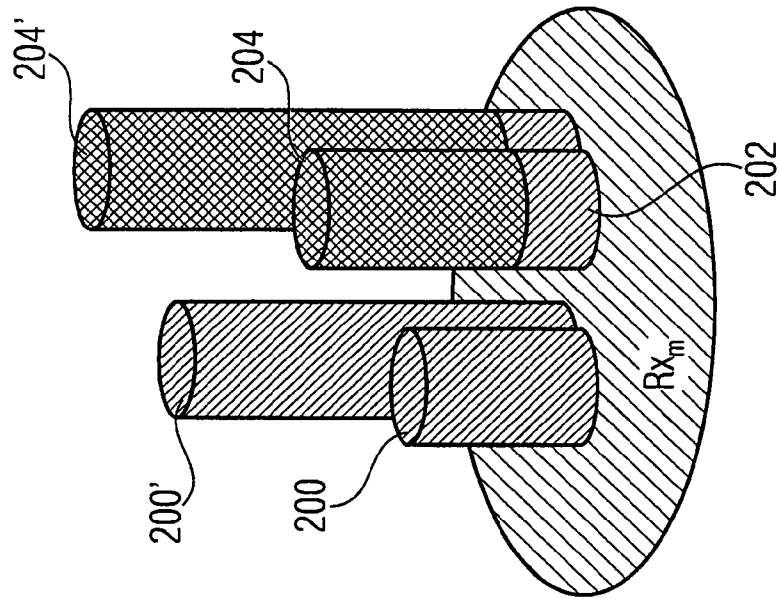


FIG 2C

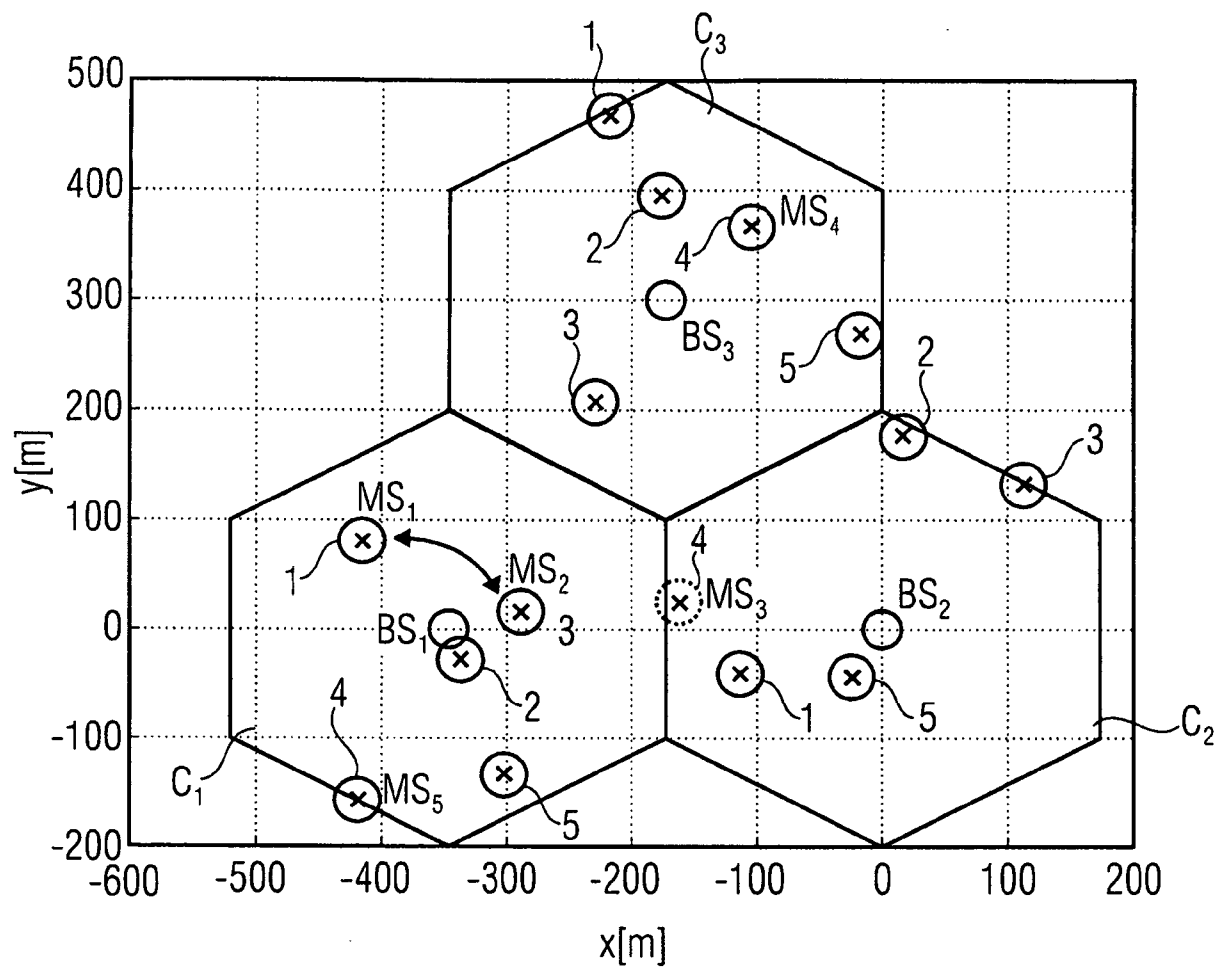


FIG 3A

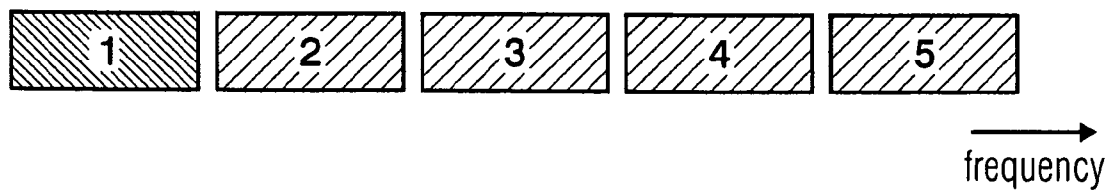


FIG 3B

FIG 4

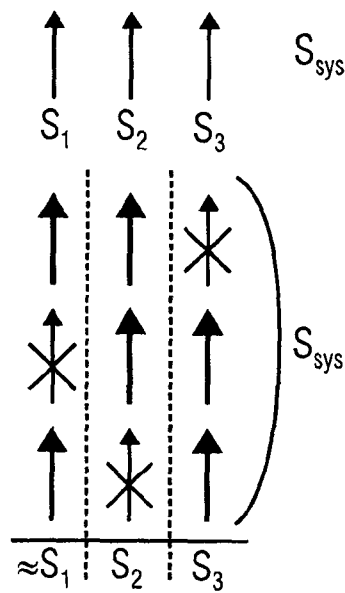
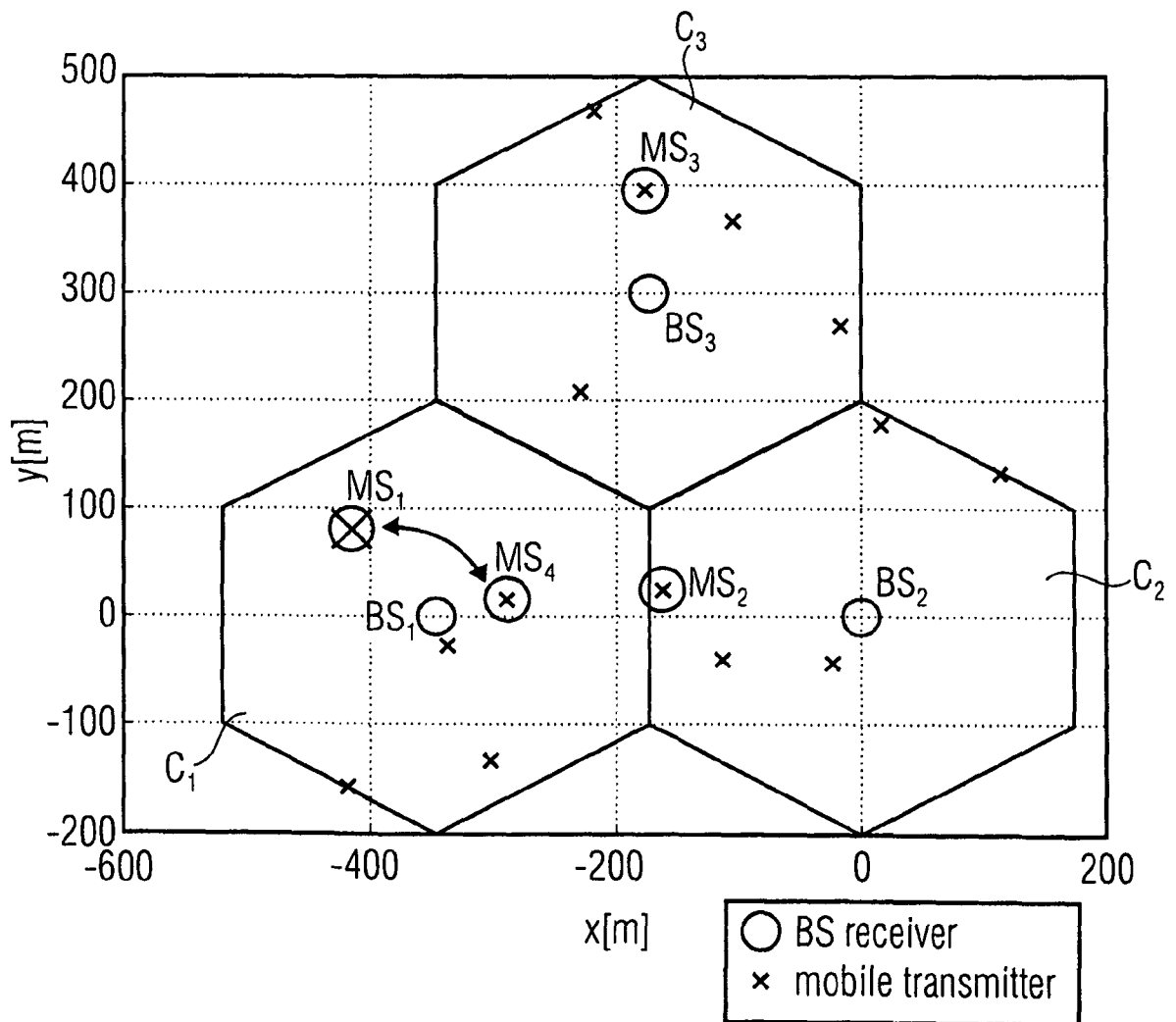


FIG 5



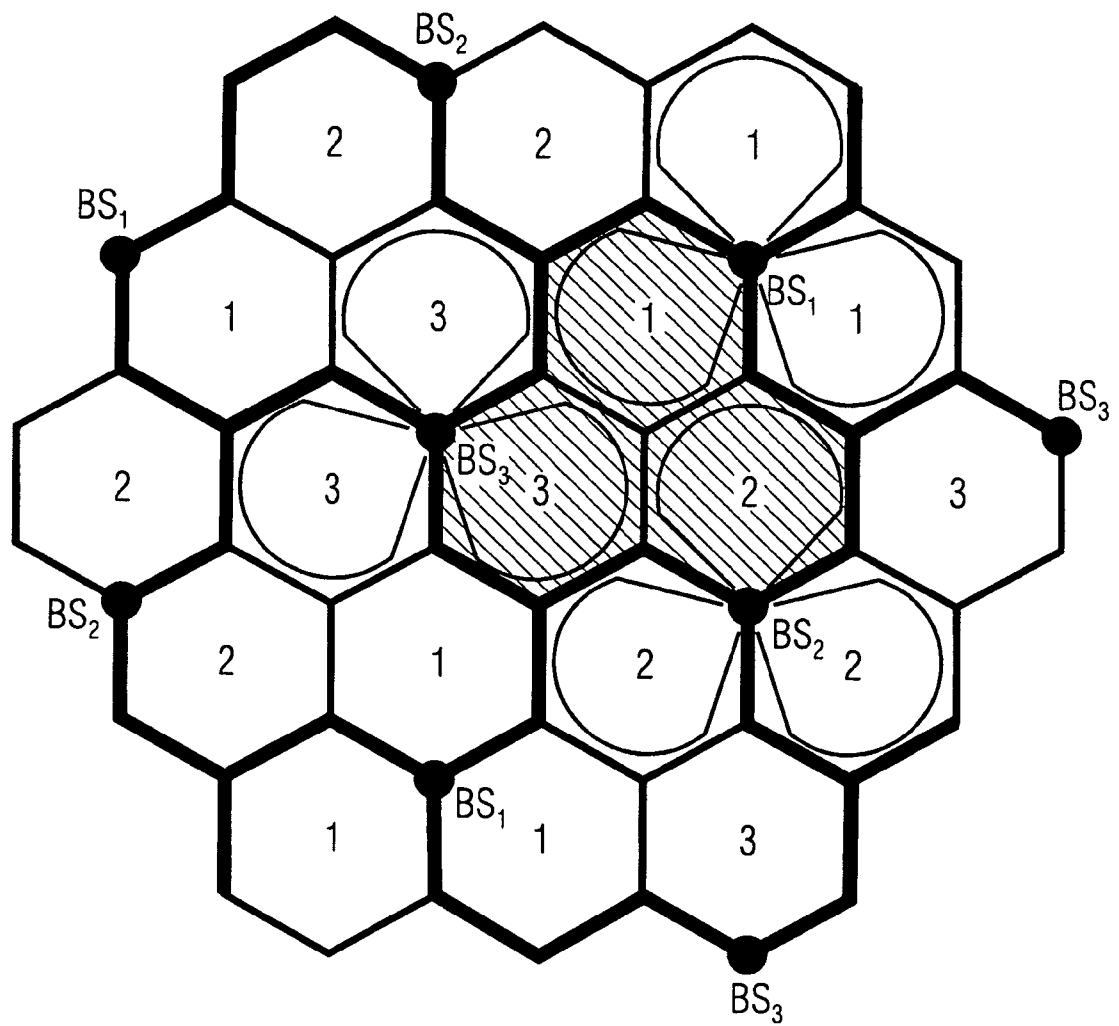


FIG 6

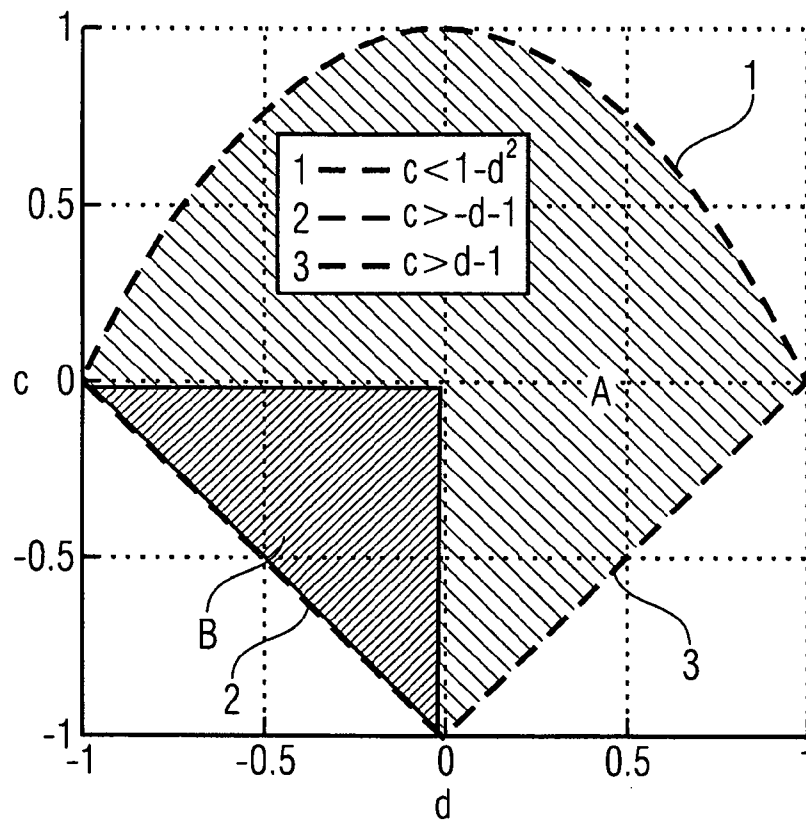


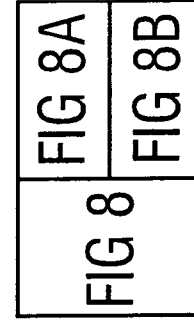
FIG 7

Algorithm 1 Pareto Optimal Scheduler

- 1: Let $\mathcal{U}$ be the set of all unscheduled users
- 2: Let $\mathcal{C}$ be the set of all cells
- 1st round of Grouping*
 - 3: Let $\mathcal{S}$ be the set containing all MS-groups in $\mathcal{U}$ for which (7) is satisfied
 - 4: Let $\mathbf{N}$ be the vector containing the number of occurrences of each MS in $\mathcal{S}$
Set zero entries of $\mathbf{N}$ to arbitrarily large constant $\alpha > \max \{\mathbf{N}\}$
 - 5: **while** $\mathcal{S} \neq \emptyset$ **do**
 - 6: Find $i \leftarrow \arg\min \{\mathbf{N}\}$
 - 7: Find set $\mathcal{D}$ containing all MS-groups in $\mathcal{S}$ of which MS i is a member
 - 8: Find MS-group A in $\mathcal{D}$ s.t. $A \leftarrow \arg\min_A \{\mathbf{N}(A)\}$
 - 9: Remove all MS-groups from $\mathcal{S}$ that contain any element (*i.e.*, MS) of A
 - 10: Remove all MSs in A from $\mathcal{U}$
 - 11: Set $\mathbf{N}(A)$ to arbitrarily large constant $\beta > \alpha$
 - 12: Add A to allocation vector $\mathcal{A}$
 - 13: **end while**

2nd round of Grouping

- 14: Update remaining user SINR targets according to (8)
- 15: Let $\mathcal{S}$ be the set containing all MS-pairs in $\mathcal{U}$ for which (16) is satisfied
- 16: Let $\mathbf{N}$ be the vector containing the number of occurrences of each MS in $\mathcal{S}$
Set zero entries of $\mathbf{N}$ to α
- 17: **while** $\mathcal{S} \neq \emptyset$ **do**
 - 18: Find $i \leftarrow \arg\min \{\mathbf{N}\}$
 - 19: Find set $\mathcal{D}$ containing all MS-pairs in $\mathcal{S}$ of which MS i is a member
 - 20: Find MS-pair A in $\mathcal{D}$ s.t. $A \leftarrow \arg\min_A \{\mathbf{N}(A)\}$

FIG 8A

21: Add MS j from cell $\mathcal{O}_j = \mathcal{C} \setminus \mathcal{C}(A)$ to A for which $N(j) = \alpha$ **or** $j \leftarrow \operatorname{argmin} \{N(\mathcal{O}_j)\}$

22: Remove all MS-groups from $\mathcal{S}$ that contain any element (*i.e.*, MS) of A

23: Remove all MSs in A from $\mathcal{U}$

24: Set $N(A)$ to arbitrarily large constant $\beta > \alpha$

25: Add A to allocation vector $\mathcal{A}$

26: **end while**

3rd round of Grouping

27: Update remaining user SINR targets according to (11)

28: Let $\mathcal{S}$ be the set containing all MSs in $\mathcal{U}$

29: Let G be the vector of desired link path gains of all MSs in $\mathcal{S}$

30: **while** $\mathcal{S} \neq \emptyset$ **do**

31: Find $A \leftarrow \operatorname{argmax} \{G\}$

32: Add MSs j, k from cells $\mathcal{O}_j, \mathcal{O}_k = \mathcal{C} \setminus \mathcal{C}(A)$ to A for which $j, k \leftarrow \operatorname{argmin} \{G(\mathcal{O}_j), G(\mathcal{O}_k)\}$

33: Remove all MSs in A from $\mathcal{S}$ and $\mathcal{U}$

34: Add A to allocation vector $\mathcal{A}$

35: **end while**

Power Allocation

36: **for** $k = 1$ to $|A|$ **do**

37: Construct $\mathbf{F}_T$ and $\mathbf{u}_T$ for MS-group $T \leftarrow \mathcal{A}(k)$
 For T allocated in 2nd round, $\mathbf{F}_T \leftarrow \mathbf{F}_{T,2 \times 2}$, $\mathbf{u}_T \leftarrow \mathbf{u}_{T,2 \times 1}$
 For T allocated in 3rd round, $\mathbf{F}_T \leftarrow 0$, $\mathbf{u}_T \leftarrow \mathbf{u}_T$

38: Calculate $\mathbf{P}_T = (\mathbf{I} - \mathbf{F}_T)^{-1} \mathbf{u}_T$

39: Limit component-wise $\mathbf{P}_T \leq P_{\max}$

40: **end for**

FIG 8B

FIG 8	FIG 8A
	FIG 8B

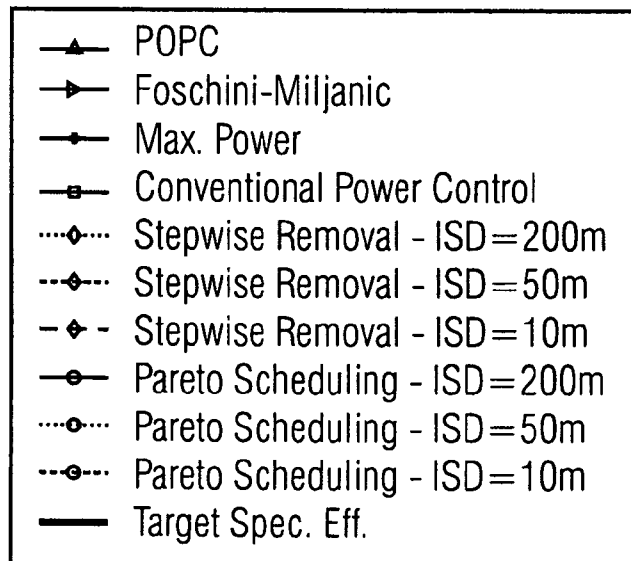
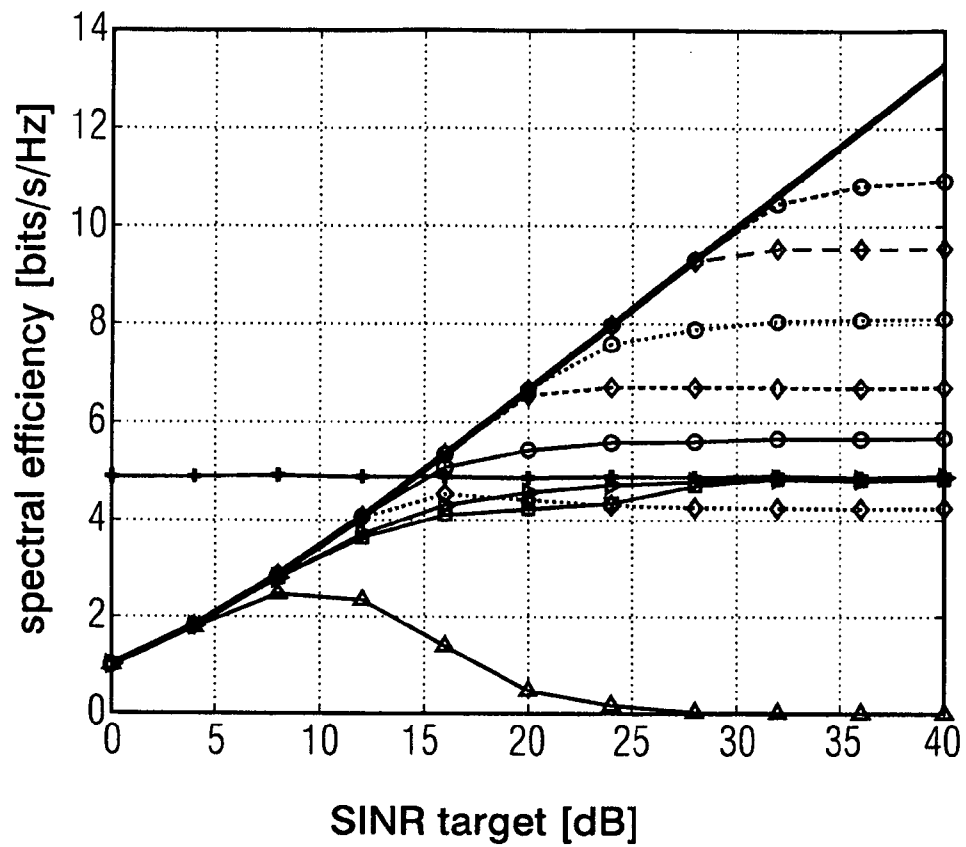


FIG 9

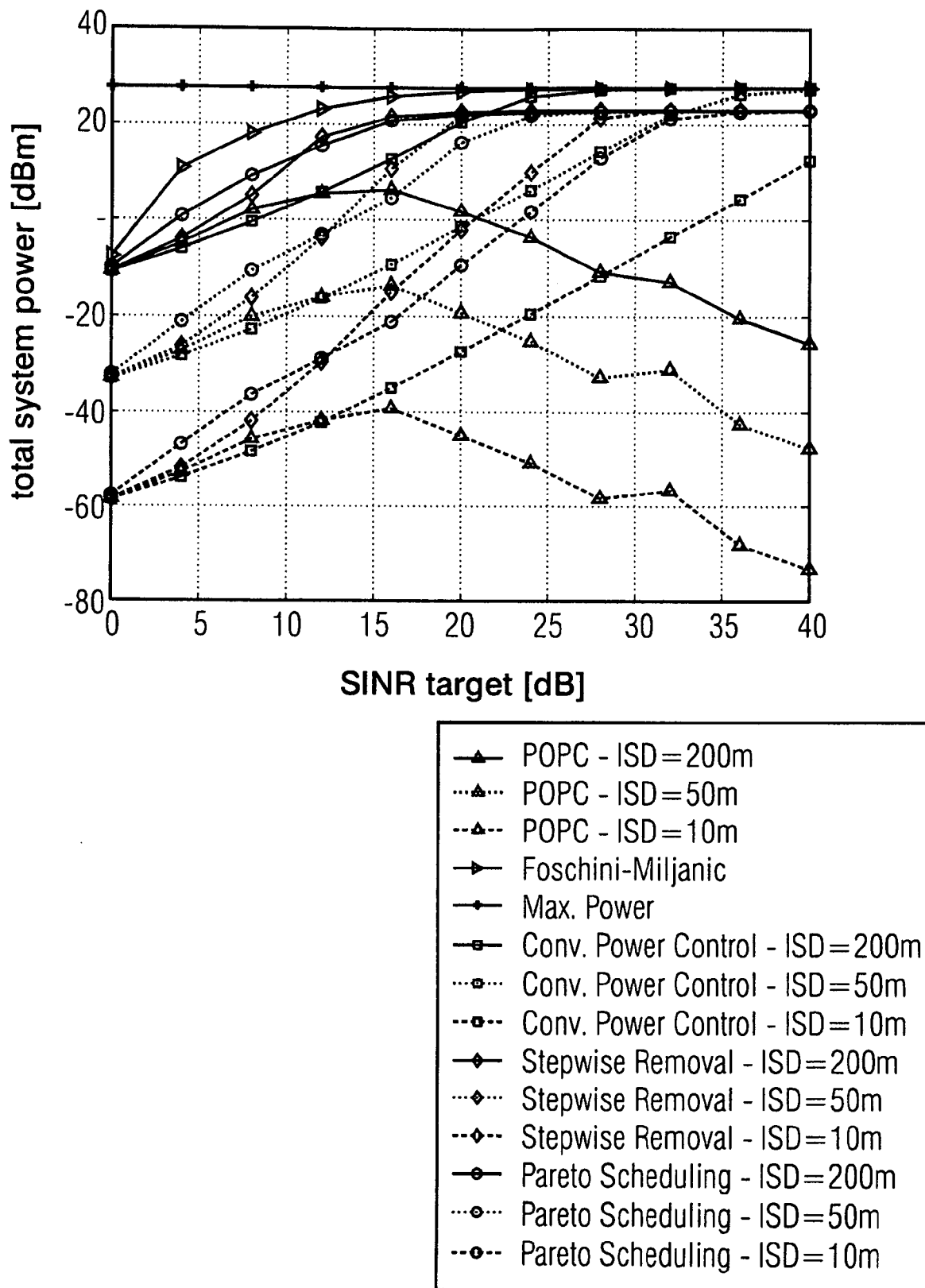


FIG 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/061341

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W52/24 H04W52/34 H04W72/00 H04L5/00
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 H04L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KOLYUZHNOV D ET AL: "Power Controlled Random Access in Multi-Cell OFDMA Uplink", VEHICULAR TECHNOLOGY CONFERENCE, 2008. VTC 2008-FALL. IEEE 68TH, IEEE, PISCATAWAY, NJ, USA, 21 September 2008 (2008-09-21), pages 1-5, XP031352557, ISBN: 978-1-4244-1721-6	1-4,8,9, 12-15
A	abstract page 1, left-hand column, paragraph 1 - page 4, right-hand column, last paragraph figures 1-3 ----- -/-	5-7,10, 11



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

4 September 2012

Date of mailing of the international search report

11/09/2012

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2012/061341

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	A. Goldsmith: "Wireless Communications", 8 August 2005 (2005-08-08), Cambridge University Press, XP002661650, ISBN: 9780521837163 cited in the application	1-4,8,9, 12-15
A	page 435 - page 437 page 484 - page 486 figure 15.9 -----	5-7,10, 11