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— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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[Continued on next page]

(54) Title: POWER ALLOCATION AND PRECODING MATRIX COMPUTATION METHOD IN A WIRELESS COMMUNICATION SYSTEM

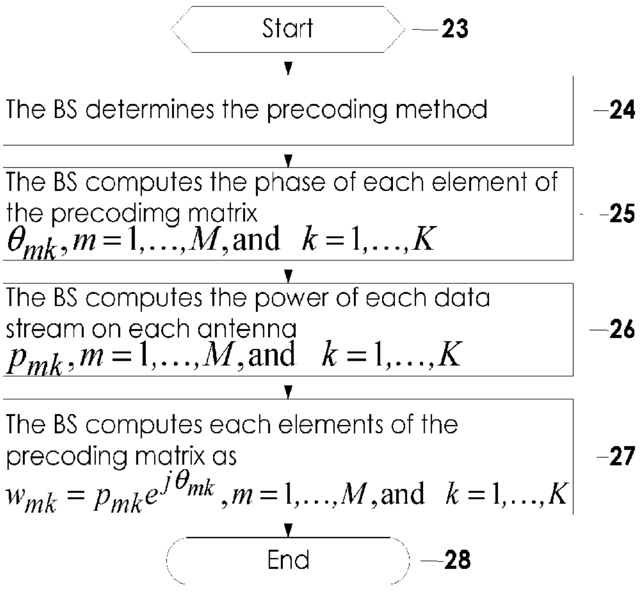

Fig. 3

(57) Abstract: This invention presents methods for power allocation for each data stream on each transmitting antennas in MU-MIMO wireless communication systems comprising the BS computing the temporary beamforming matrix, constructing special matrices and vectors with the maximum transmitting power on each antenna, the allocated power to each data stream, the channel quality of each data stream, and the amplitude of each element of the temporary beamforming matrix, calculating the power allocated to each data stream on each antenna with the calculated special matrices and vectors, and adjusting each element of the temporary beamforming matrix to obtain the final beamforming matrix.

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POWER ALLOCATION AND PRECODING MATRIX COMPUTATION METHOD IN A WIRELESS COMMUNICATION SYSTEM

This application claims the benefit of U.S. Provisional Application No. 62/185,674, filed on Jun. 28, 2015.

FIELD OF THE INVENTION

[0001] The disclosed inventions relate generally to wireless communication, and in particular, to the mechanism for a Base Station (BS) to allocate power and precode the signal before it is transmitted to the User Equipment (UE) in massive Multiple-Input Multiple-Output (MIMO) communication systems.

BACKGROUND

[0002] Large-scale MIMO systems or massive MIMO systems were firstly introduced in [1] where each BS is equipped with dozens to several hundreds of transmit antennas. One main advantage of such systems is the potential capability to offer linear capacity growth without increasing power or bandwidth [1]–[4], which is realized by employing Multi-User MIMO (MU-MIMO) to achieve the significant higher spatial multiplexing gains than conventional systems. In this system, the BS groups UEs at each scheduling slot and transmits data to them on the same time and frequency resource.

[0003] It has been proved that Zero-Forcing (ZF) precoding with a total transmitting power constraint is almost the best choice to maximize the sum rate for large-scale MU-MIMO systems [2]. However, in practice, the power of each antenna is restricted instead of the total power. It means that maximizing the power utilization requires the sum power of all users at each antenna to be the same. Unfortunately, it is generally not the case in practice, because of the randomness of the ZF precoding matrix. As a result, it causes a dilemma to the BS: on the one hand, ZF precoding could not fully use the transmit power, which leads to throughput loss; on the other hand, full power utilization means that there exists residual interference among the grouped users, since the ZF precoding matrix is violated, which also results in throughput loss. Conjugate Beamforming (CB) is another practical precoding method for MU-MIMO precoding in large-scale MIMO communication systems because of its simplicity for implementation. Similarly to ZF, CB also faces the optimal power allocation problem when the power of each antenna is restricted. Therefore, more sophisticated power allocation methods are needed to maximum the sum rate of MU-MIMO systems. Due to the aforementioned reasons, this invention provides four different methods to allocate the power to each data stream based on two different optimization objectives when ZF precoding is employed by the BS. In addition, a simple power allocation method is also offered when CB is employed by the BS. The advantages of this invention include: 1. when ZF precoding is employed, two of the four power allocation methods have better performance than the rest two in the low Signal-to-Noise Ratio (SNR) region and vice versa, so different power allocation methods could be employed in different SNR regions to achieve the maximum sum rate of MU-MIMO systems; 2. when CB is employed, a very simple power allocation method could be employed with little sum rate loss; 3. the sum rate losses of all methods provided in this invention are negligible compared to the case where the total transmitting power instead of the per-antenna power is constrained; 4. most importantly, these methods are not affected by a scaling factor of each channel vector so channel estimation with an arbitrary scaling factor would be sufficient, which alleviates the accuracy requirement of channel measurement in massive MIMO systems.

SUMMARY OF THE INVENTION

[0004] This application provides several methods to complete power allocation and precoding matrix computation in MU-MIMO systems. For ZF precoding, two methods are provided to maximize the power utilization, where one is based on orthogonal projection while the other one is based on iterative searching the optimal solution in the constraint domain. In addition, two more methods are provided to minimize the inter-user interference among UEs in the MU-MIMO user group, where one is based on linear scaling while the other one is based on iterative searching. Among the four methods, the first two methods are the better choices in the low SNR region while the latter two methods are the better choices in the high SNR region. For CB, a simple but rate-lossless method is provided where the power of each antenna could be totally consumed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The aforementioned implementation of the invention as well as additional implementations would be more clearly understood as a result of the following detailed description of the various aspects of the invention when taken in conjunction with the drawings. Like reference numerals refer to corresponding parts throughout the several views of the drawings.

[0006] Fig. 1 shows the block diagram illustrating the iteration process of searching the optimal solution to (12).

[0007] Fig. 2 shows the block diagram illustrating the iteration process of searching the optimal solution to (19).

[0008] Fig. 3 shows a block diagram illustrating the process of power allocation and precoding matrix computation.

DETAILED DESCRIPTION OF THE PREFFERD EMBODIMENTS

[0009] For a large-scale MIMO system, suppose that the number of antennas at the BS side is M, and the number of multiplexed data streams is K in the downlink on a Resource Element (RE) such as a subcarrier, or a Resource Block (RB), etc. Note that the K data streams belong to N users, where $N \leq K$. Suppose that the channel matrix corresponding to the K data streams is $\mathbf{H} = [\mathbf{h}_1\, \mathbf{h}_2\, \cdots\, \mathbf{h}_K]^{\mathrm{T}}$, which may be acquired by BS through uplink channel measurement or uplink feedback channel.

[0010] The K modulated signals on the current RE are precoded by a matrix $\mathbf{W}$ before being further processed, where $\mathbf{W}$ has the dimension of $M \times K$ and the (m,k)th element is w_{mk}, where $m = 1, 2, \cdots, M$, and $k = 1, 2, \cdots, K$.

[0011] If the ZF precoding method is employed, the BS firstly computes a temporary matrix

$$\mathbf{H}^{\mathrm{inv}} = \mathbf{H}^{\mathrm{H}}(\mathbf{H}\mathbf{H}^{\mathrm{H}})^{-1}, \qquad (1)$$

then the (m,k)th element of the matrix $\mathbf{H}^{\mathrm{inv}}$ can be written as

$$h_{mk}^{\mathrm{inv}} = \left|h_{mk}^{\mathrm{inv}}\right| e^{\mathrm{j}\theta_{mk}}. \qquad (2)$$

[0012] Let $P_1^{\mathrm{ant}}, P_2^{\mathrm{ant}}, \cdots, P_M^{\mathrm{ant}}$ denote the power allocated to the current RE belonging to the M antennas respectively, then the power allocated to the kth data stream by the BS is P_k, which satisfies $\sum_{k=1}^{K} P_k = \sum_{m=1}^{M} P_m^{\mathrm{ant}}$. One possible example is

$$P_k = \frac{\sum_{m=1}^{M} P_m^{\mathrm{ant}}}{K}. \qquad (3)$$

[0013] In order to complete the power allocation, four methods belonging to two categories are provided in this invention, where the first category is based on maximizing the power utilization, while the second one is based on minimizing the inter-user interference.

[0014] Category-1: maximizing the power utilization.

[0015] In this category, the BS constructs an $(M + K - 1) \times MK$ matrix $\mathbf{A}$ by deleting the k_{d}th row vector of the following temporary matrix

$$\mathbf{A}_{\mathrm{T}} = \begin{bmatrix} 1 & 1 & \ldots & 1 & 0 & 0 & \ldots & 0 & \ldots & 0 & 0 & \ldots & 0 \\ 0 & 0 & \ldots & 0 & 1 & 1 & \ldots & 1 & \ldots & 0 & 0 & \ldots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 & \cdots & 1 & 1 & \cdots & 1 \\ 1 & 0 & \cdots & 0 & 1 & 0 & \cdots & 0 & \cdots & 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 & 0 & 1 & \cdots & 0 & \cdots & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 & 0 & 0 & \cdots & 1 & \cdots & 0 & 0 & \cdots & 1 \end{bmatrix}, \qquad (4)$$

where the (i,j)th element of $\mathbf{A}_{\mathrm{T}}$ satisfies the conditions

$$a_{ij} = \begin{cases} 1, & \text{if } 1 \le \mathrm{i} \le K, j = (i-1)M + l, l = 1, \cdots, M, \\ 0, & \text{if } 1 \le \mathrm{i} \le K, j \ne (i-1)M + l, l = 1, \cdots, M, \\ 1, & \text{if } K + 1 \le \mathrm{i} \le K + M, j = lM + (i-K), l = 0, \cdots, K-1, \\ 0, & \text{if } K + 1 \le \mathrm{i} \le K + M, j \ne lM + (i-K), l = 0, \cdots, K-1, \end{cases} \quad (5)$$

and $k_{\mathrm{d}} \in \{1, \cdots, MK\}$ may be any one of the MK possible values.

[0016] The BS constructs an $(M + K - 1) \times 1$ vector $\mathbf{b}$ by deleting the k_{d}th element of the temporary vector

$$\mathbf{b}_{\mathrm{T}} = [P_1 \cdots P_K \, P_1^{\mathrm{ant}} \cdots P_M^{\mathrm{ant}}]^{\mathrm{T}}. \quad (6)$$

[0017] An $MK \times 1$ vector $\mathbf{r}$ is constructed as

$$\mathbf{r} = [r_{11} \cdots r_{M1} \, r_{12} \cdots r_{M2} \cdots r_{1K} \cdots r_{MK}]^{\mathrm{T}}, \quad (7)$$

where the elements of $\mathbf{r}$ satisfy

$$\frac{r_{mk}}{r_{lk}} = \frac{\left|h_{mk}^{\mathrm{inv}}\right|^2}{\left|h_{lk}^{\mathrm{inv}}\right|^2}, l, m = 1, \cdots, M, k = 1, \cdots, K, \quad (8)$$

e.g., $r_{mk} = \left|h_{mk}^{\mathrm{inv}}\right|^2$.

[0018] With the matrix $\mathbf{A}$ and vectors $\mathbf{b}$ and $\mathbf{r}$, two possible methods could be used to compute the power allocated to each data stream on each antenna.

[0019] Method-1: orthogonal projection.

[0020] In this method, the BS projects the vector $\mathbf{r}$ into the solution space of the equation $\mathbf{Ax} = \mathbf{b}$ firstly by

$$\tilde{\mathbf{p}} = \left[\mathbf{I} - \tilde{\mathbf{A}}^{\mathrm{T}}\left(\tilde{\mathbf{A}}\tilde{\mathbf{A}}^{\mathrm{T}}\right)^{-1}\tilde{\mathbf{A}}\right]\tilde{\mathbf{r}}, \quad (9)$$

where $\tilde{\mathbf{A}} = [\mathbf{A} \; \mathbf{b}]$ and $\tilde{\mathbf{r}} = [\mathbf{r}^{\mathrm{T}} \; -a]^{\mathrm{T}}$ with a being a positive real number. Then, the elements of power allocation matrix are computed as

$$p_{mk} = \frac{\tilde{\mathbf{p}}(mk)}{\tilde{\mathbf{p}}(MK+1)}, m = 1, \cdots, M, k = 1, \cdots, K. \quad (10)$$

[0021] Method-2: iterative searching.

[0022] In this method, the power allocation vector is computed by solving the following problem

$$\begin{gathered} \min \|\mathbf{p} - \mathbf{r}\|_2^2, \\ \mathrm{s.t.}\, \mathbf{Ap} - \mathbf{b} = \mathbf{0}, \\ -\mathbf{p} \le \mathbf{0}. \end{gathered} \quad (11)$$

[0023] The problem (11) can be solved by iterative searching in the constraint domain. One possible solution is to firstly transform (11) into an equivalent problem

$$\begin{gathered} \min f(t, \mathbf{p}) = -t\|\mathbf{p} - \mathbf{r}\|_2^2 - \textstyle\sum_{i=1}^{MK} p_i, \\ \mathrm{s.t.}\, \mathbf{Ap} = \mathbf{b}, \end{gathered} \quad (12)$$

then the iterative searching process in Fig. 1 is used to find the optimal $\mathbf{p}$. Specifically, after the searching process starts **1**, the input parameters are initialized as $t > 0$, $\varepsilon_{\mathrm{o}} > 0$, $\varepsilon_{\mathrm{i}} > 0$, $\mathbf{p}_0 \in \{\mathbf{Ap} = \mathbf{b},\ p_i \geq 0\}$, $\mu > 0$, and $\gamma > 0$, where ϵ_{o} and ϵ_{i} are endurable errors for the outer and inner searching cycles respectively, $\mathbf{p}_0$ is an initial power allocation matrix, while μ and γ are two adjusting parameters **2**. Then, the outer searching cycle runs while $-\frac{1}{t}\sum_{i=1}^{MK} p_i > \varepsilon_{\mathrm{o}}$ **3**, and the inner searching cycle runs while $\lambda(\mathbf{p})/2 > \varepsilon_{\mathrm{i}}$ **4**. Inside the inner cycle, the first step is to solve the equation $\begin{bmatrix} \nabla^2 f_{\mathbf{p}} & \mathbf{A}^{\mathrm{T}} \\ \mathbf{A} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \Delta\mathbf{p}_t \\ \chi \end{bmatrix} = \begin{bmatrix} -\nabla f_{\mathbf{p}} \\ \mathbf{0} \end{bmatrix}$, where χ is an adjusting parameter **5**. Then, the Newton decrement is calculated as $\lambda(\mathbf{p}) = \Delta\mathbf{p}_t^{\mathrm{T}} \nabla^2 f_{\mathbf{p}} \Delta\mathbf{p}_t$ **6**. After that, the variable $\mathbf{p}$ is updated as $\mathbf{p} \leftarrow \mathbf{p} + \gamma\Delta\mathbf{p}_t$ **7**. After the inner cycle ends **8**, the parameter t is updated as $t \leftarrow \mu t$ **9**. After the outer cycle ends **10**, the whole process ends **11**. Finally, the vector $\mathbf{p}$ is reshaped to a matrix with elements p_{mk}, $m = 1, \cdots, M$, and $k = 1, \cdots, K$.

[0024] With p_{mk}, the elements w_{mk} of the precoding matrix $\mathbf{W}$ can be computed as

$$w_{mk} = \sqrt{p_{mk}}e^{\mathrm{j}\theta_{mk}}, m = 1, \cdots, M, k = 1, \cdots, K. \qquad (13)$$

[0025] Category-2: minimizing the inter-user interference.

[0026] In this category, two possible methods are provided to minimize the inter-user interference.

[0027] Method-1: linear scaling.

[0028] In this method, the BS computes a temporary power allocation matrix with elements $\tilde{p}_{mk} = \frac{P_k \left|h_{mk}^{\mathrm{inv}}\right|^2}{\sum_{m=1}^{M} \left|h_{mk}^{\mathrm{inv}}\right|^2}$ firstly, where h_{mk}^{inv} is the same as in (2), then computes the power consumed on each antenna as $Q_m = \sum_{k=1}^{K} \tilde{p}_{mk}$, $m = 1, \cdots, M$. After that, the BS chooses the maximum value of Q_m, which is denoted as $Q_{\max}$. Finally, the power allocation matrix is computed as

$$p_{mk} = \frac{\tilde{p}_{mk} P_m^{\mathrm{ant}}}{Q_{\max}}, m = 1, \cdots, M, k = 1, \cdots, K. \qquad (14)$$

[0029] Method-2: iterative water-filling method.

[0030] In this method, the BS constructs an $(M + K) \times K$ matrix $\mathbf{A}$ with a form of

$$\mathbf{A} = \begin{bmatrix} a_{11} & \cdots & a_{1K} \\ \vdots & \ddots & \vdots \\ a_{M1} & \cdots & a_{MK} \\ -1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & -1 \end{bmatrix}, \qquad (15)$$

where the elements a_{mk}, $m = 1, \cdots, M$, and $k = 1, \cdots, K$, satisfy

$$a_{mk} = \begin{cases} \frac{\left|h_{mk}^{\mathrm{inv}}\right|^2}{\sum_{m=1}^{M}\left|h_{mk}^{\mathrm{inv}}\right|^2}, m = 1, \cdots, M, k = 1, \cdots, K, \\ 1, m = M + k, \\ 0, \text{otherwise}. \end{cases} \tag{16}$$

[0031] The BS constructs an $(M + K) \times 1$ vector $\mathbf{b}$ as

$$\mathbf{b} = [P_1^{\mathrm{ant}} \cdots\ P_M^{\mathrm{ant}}\ 0\ \cdots 0]^{\mathrm{T}}. \tag{17}$$

[0032] Let the power allocation vector $\mathbf{p}^{\mathrm{s}}$ be $\mathbf{p}^{\mathrm{s}} = [P_1^{\mathrm{s}} \cdots\ P_K^{\mathrm{s}}]^{\mathrm{T}}$, where P_k^{s}, $k = 1, \cdots, K$, are the power allocated to the kth data stream. Then, $\mathbf{p}^{\mathrm{s}}$ can be obtained by solving the following optimization problem

$$\begin{gathered} \min -\textstyle\sum_{k=1}^{K} \log(1 + g_k P_k^{\mathrm{s}}), \\ \mathrm{s.t.}\, \mathbf{A}\mathbf{p}^{\mathrm{s}} - \mathbf{b} \preceq \mathbf{0}, \end{gathered} \tag{18}$$

where $g_k = \frac{\|h_k\|^2}{\sigma_{\mathrm{NI}}^2}$ denotes the Signal-to-Interference-plus-Noise Ratio (SINR) of the kth stream with σ_{NI}^2 being the power of the noise and interference.

[0033] Problem (18) can be solved by iterative searching in the constraint domain. One possible solution is to firstly transform (18) into an equivalent problem

$$\min G_t(\mathbf{p}^{\mathrm{s}}) = \min[-\mathrm{t}\textstyle\sum_{k=1}^{K} \log(1 + g_k P_k^{\mathrm{s}}) - \textstyle\sum_{k=1}^{K+M} \log f_i(\mathbf{p}^{\mathrm{s}})], \tag{19}$$

where $f_i(\mathbf{p}^{\mathrm{s}}) = \mathbf{a}_i^{\mathrm{T}}\mathbf{p}^{\mathrm{s}} - b_i$ and $\mathbf{a}_i^{\mathrm{T}}$ is the ith column vector of $\mathbf{A}$. Then, the iterative searching process in Fig. 2 is used to find the optimal $\mathbf{p}^{\mathrm{s}}$. Specifically, after the searching process starts **12**, the input parameters are initialized as $t > 0$, $\varepsilon_{\mathrm{o}} > 0$, $\varepsilon_{\mathrm{i}} > 0$, $\mathbf{p}^{\mathrm{s}} \in \{\mathbf{A}\mathbf{p}^{\mathrm{s}} - \mathbf{b} \preceq \mathbf{0},\ p_i \geq 0\}$, $\mu > 0$, and $\gamma > 0$, where ϵ_{o} and ϵ_{i} are endurable errors for the outer and inner searching cycles respectively, while μ and γ are two adjusting parameters **13**. Then, the outer searching cycle runs while $-\frac{1}{t}\sum_{i=1}^{M+K} \log f_i(\mathbf{p}^{\mathrm{s}}) > \varepsilon_{\mathrm{o}}$ **14**, and the inner searching cycle runs while $\lambda(\mathbf{p}^{\mathrm{s}})/2 > \varepsilon_{\mathrm{i}}$ **15**. Inside the inner cycle, the first step is to calculate the decrement $\Delta\mathbf{p}^{\mathrm{s}} = -\nabla^2 G_t(\mathbf{p}^{\mathrm{s}})^{-1}\nabla G_t(\mathbf{p}^{\mathrm{s}})$ **16**. After that, the Newton decrement is calculated as $\lambda = \nabla G_t(\mathbf{p}^{\mathrm{s}})^{\mathrm{T}}\nabla^2 G_t(\mathbf{p}^{\mathrm{s}})^{-1}\nabla G_t(\mathbf{p}^{\mathrm{s}})$ **17**. Then, the variable $\mathbf{p}^{\mathrm{s}}$ is updated as $\mathbf{p}^{\mathrm{s}} \leftarrow \mathbf{p}^{\mathrm{s}} + \gamma\Delta\mathbf{p}^{\mathrm{s}}$ **18**. After the inner cycle ends **19**, the parameter t is updated as $t \leftarrow \mu t$ **20**. After the outer cycle ends **21**, the whole process ends **22**.

[0034] With the solution of problem (19), the power allocation matrix can be computed as

$$p_{mk} = \frac{P_k^{\mathrm{s}}\left|h_{mk}^{\mathrm{inv}}\right|^2}{\sum_{m=1}^{M}\left|h_{mk}^{\mathrm{inv}}\right|^2}, m = 1, \cdots, M, k = 1, \cdots, K. \tag{20}$$

[0035] With p_{mk} in (20), the elements w_{mk} of the precoding matrix $\mathbf{W}$ can be computed by $w_{mk} = \sqrt{p_{mk}}e^{\mathrm{j}\theta_{mk}}$, $m = 1, \cdots, M$, and $k = 1, \cdots, K$.

[0036] If CB is employed by the BS, it firstly computes the phases of the elements of precoding matrix $\mathbf{W}$ as

$$\emptyset_{mk} = -\theta_{mk}, m = 1, \cdots, M, k = 1, \cdots, K, \qquad (21)$$

then it computes the elements of the precoding matrix $\mathbf{W}$ as

$$w_{mk} = \sqrt{\frac{P_k}{M}} e^{j\emptyset_{mk}}, m = 1, \cdots, M, k = 1, \cdots, K. \qquad (22)$$

[0037] The process of power allocation and precoding matrix computation is illustrated in Fig. 3. Specifically, after the process starts **23**, the BS determines the precoding method first **24**. Then, the BS computes the phase of each element of the precoding matrix θ_{mk} **25**. Next, the BS computes the power of each data stream on each antenna p_{mk} **26**. After that, the BS computes each elements of the precoding matrix as $w_{mk} = p_{mk} e^{j\emptyset_{mk}}$ **27**, before the process ends **28**.

[0038] With the precoding matrix $\mathbf{W}$, the signals belonging to these K data streams are precoded, further processed, and sent by the M antennas.

[0039] Although the foregoing descriptions of the preferred embodiments of the present inventions have shown, described, or illustrated the fundamental novel features or principles of the inventions, it is understood that various omissions, substitutions, and changes in the form of the detail of the methods, elements or apparatuses as illustrated, as well as the uses thereof, may be made by those skilled in the art without departing from the spirit of the present inventions. Hence, the scope of the present inventions should not be limited to the foregoing descriptions. Rather, the principles of the inventions may be applied to a wide range of methods, systems, and apparatuses, to achieve the advantages described herein and to achieve other advantages or to satisfy other objectives as well.

CLAIMS

We claim

1. A method for power allocation in MU-MIMO wireless communication systems comprising a BS with an array of M antennas serving K data streams in a Resource Element where M≥K; and the BS allocating the power to maximize the power utilization.
2. The method in claim 1 wherein the BS maximizes the power utilization by orthogonal projection.
3. The method in claim 1 wherein the BS maximizes the power utilization by iterative searching.
4. The method in claim 1 further comprising the BS constructing special matrices and vectors based on numbers and values related to the antennas, the allocated power to each data stream, the channel quality; the BS calculating the power allocated to each data stream on each antenna using the constructed special matrices and vectors, and using the calculated results to obtain a final beamforming matrix to maximizes the power utilization.
5. The method in claim 4 wherein the BS calculates the power allocated to each data stream on each antenna by orthogonal projection using the constructed special matrices and vectors.
6. The method in claim 4 wherein the BS calculates the power allocated to each data stream on each antenna by iterative searching using the constructed special matrices and vectors.
7. A method for power allocation in MU-MIMO wireless communication systems comprising a BS with an array of M antennas serving K data streams in a Resource Element where M≥K; and the BS allocating the power to minimize the inter-user interference.
8. The method in claim 7 wherein the BS minimizes the inter-user interference by linear scaling.
9. The method in claim 8 wherein the BS minimizes the inter-user interference by linear scaling of a temporary power allocation matrix to obtain the final power allocation matrix.
10. The method in claim 7 wherein the BS minimizes the inter-user interference by iterative searching.
11. The method in claim 10 wherein the BS constructing special matrices and vectors based on numbers and values related to the antennas, the allocated power to each data stream,

and information on channel quality; and the BS using the constructed special matrices and vectors to iteratively search for a power allocation that minimizes the inter-user interference.

12. A method for power allocation in MU-MIMO wireless communication systems comprising a BS selecting a precoding method; the BS computing the phase of each element of the precoding matrix θ_{mk}; the BS computing the power of each data stream on each antenna p_{mk}; and the BS computing each elements of the precoding matrix as $w_{mk} = p_{mk}e^{j\emptyset_{mk}}$.

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FIGURES

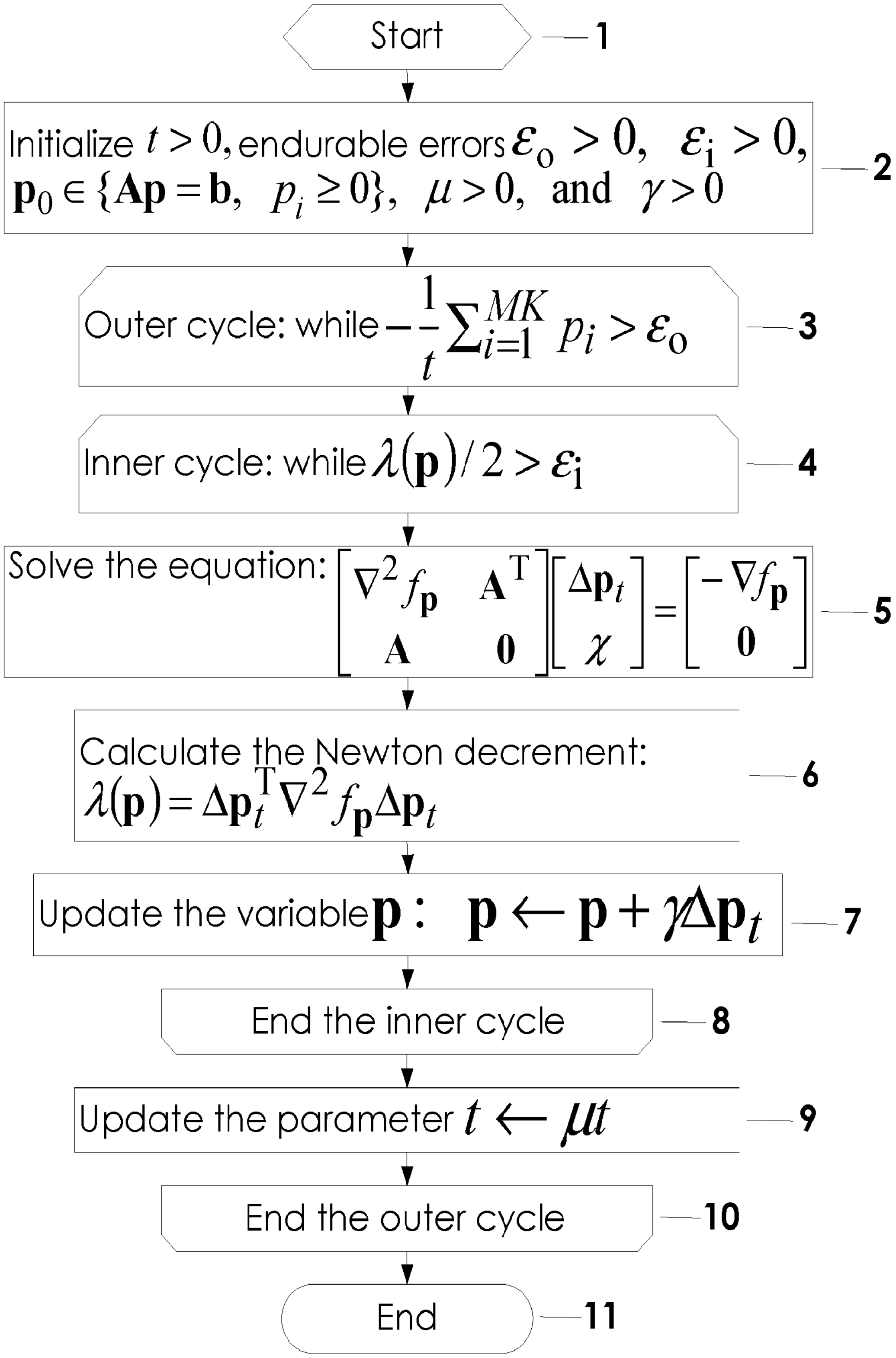

Fig. 1

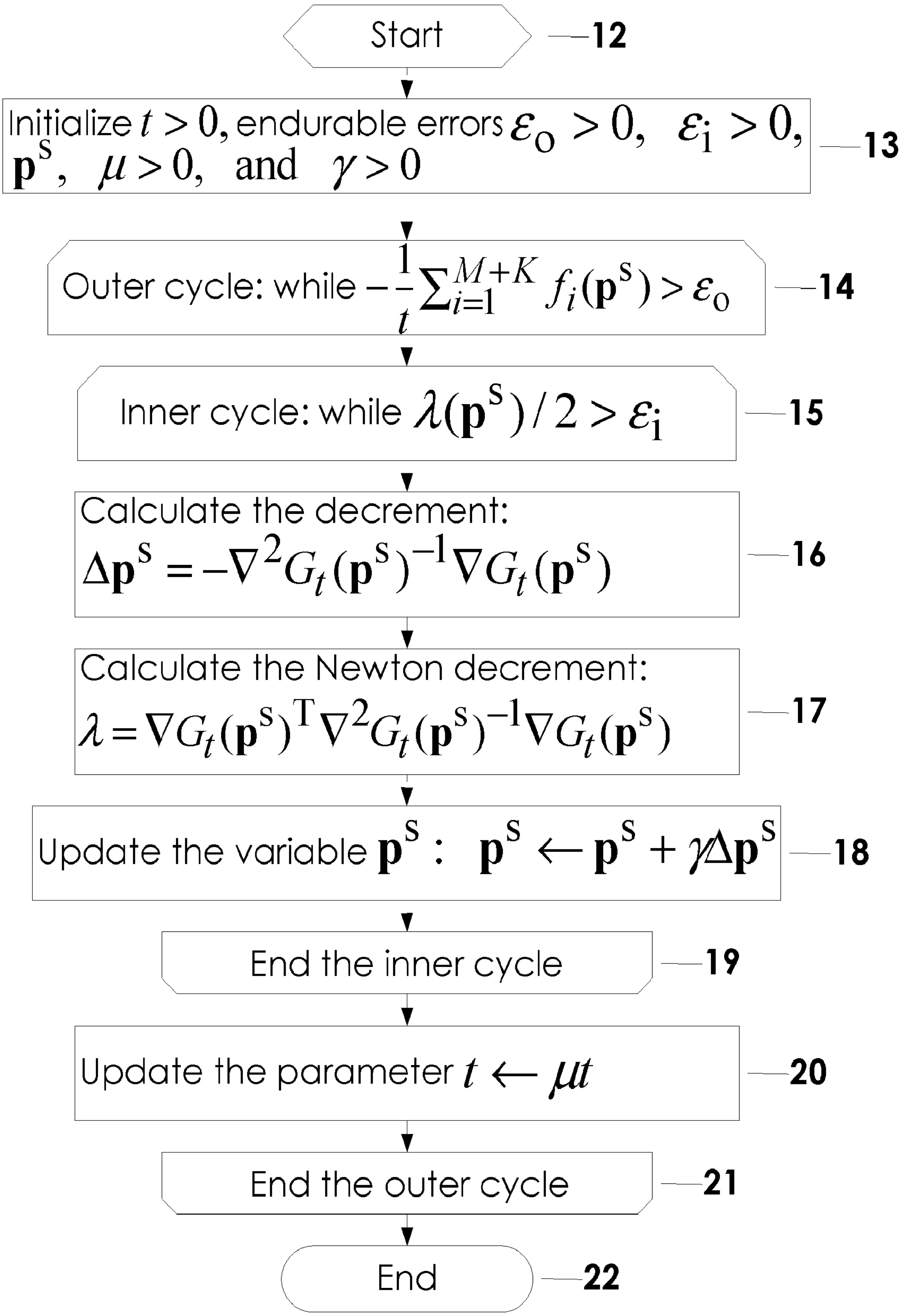
Start
12
Initialize $t > 0$, endurable errors $\varepsilon_{\mathrm{o}} > 0$, $\varepsilon_{\mathrm{i}} > 0$, $\mathbf{p}^{\mathrm{S}}$, $\mu > 0$, and $\gamma > 0$
13
Outer cycle: while $-\frac{1}{t}\sum_{i=1}^{M+K} f_i(\mathbf{p}^{\mathrm{S}}) > \varepsilon_{\mathrm{o}}$
14
Inner cycle: while $\lambda(\mathbf{p}^{\mathrm{S}})/2 > \varepsilon_{\mathrm{i}}$
15
Calculate the decrement: $\Delta\mathbf{p}^{\mathrm{S}} = -\nabla^2 G_t(\mathbf{p}^{\mathrm{S}})^{-1}\nabla G_t(\mathbf{p}^{\mathrm{S}})$
16
Calculate the Newton decrement: $\lambda = \nabla G_t(\mathbf{p}^{\mathrm{S}})^{\mathrm{T}}\nabla^2 G_t(\mathbf{p}^{\mathrm{S}})^{-1}\nabla G_t(\mathbf{p}^{\mathrm{S}})$
17
Update the variable $\mathbf{p}^{\mathrm{S}}$: $\mathbf{p}^{\mathrm{S}} \leftarrow \mathbf{p}^{\mathrm{S}} + \gamma\Delta\mathbf{p}^{\mathrm{S}}$
18
End the inner cycle
19
Update the parameter $t \leftarrow \mu t$
20
End the outer cycle
21
End
22

Fig. 2

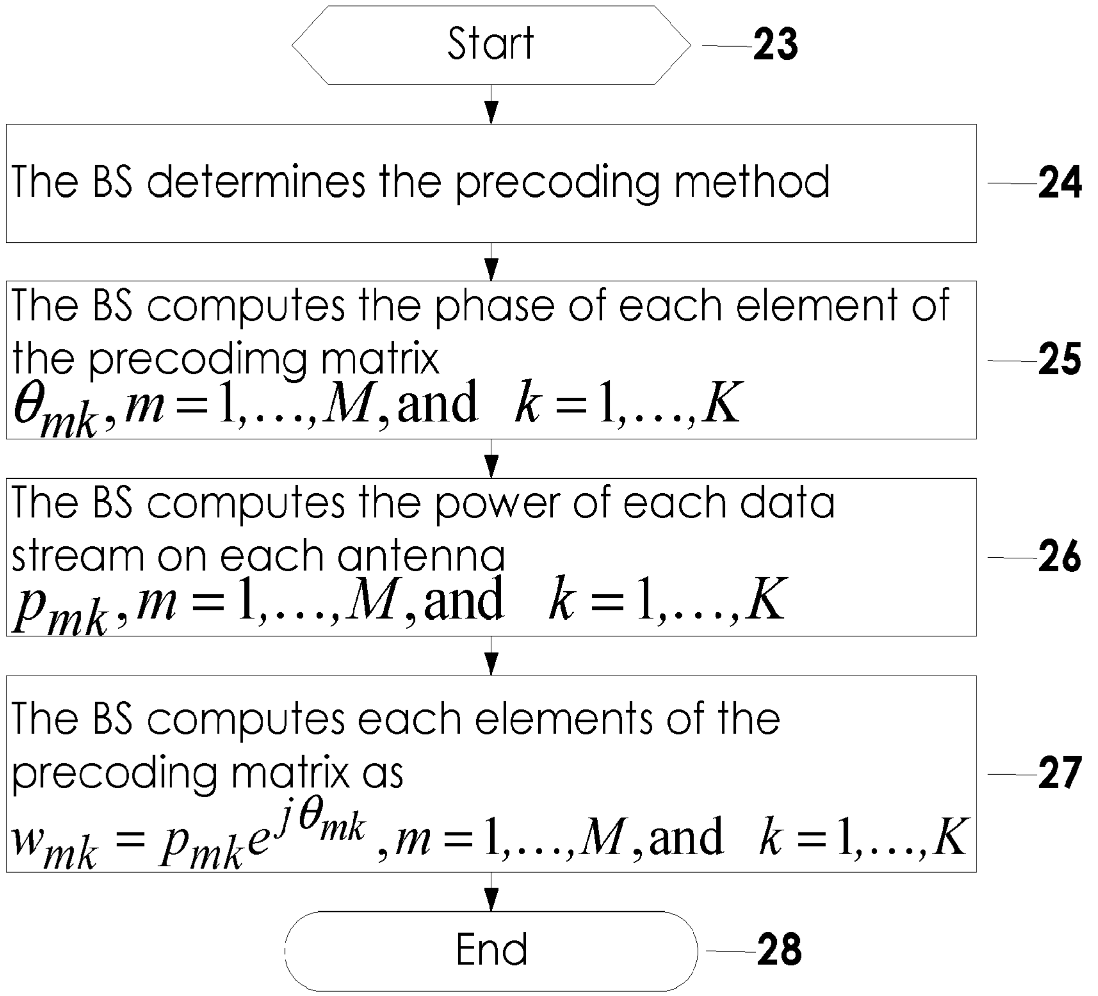
Start
23
The BS determines the precoding method
24
The BS computes the phase of each element of the precodimg matrix
$\theta_{mk}, m = 1,\ldots,M, \text{and} \quad k = 1,\ldots,K$
25
The BS computes the power of each data stream on each antenna
$p_{mk}, m = 1,\ldots,M, \text{and} \quad k = 1,\ldots,K$
26
The BS computes each elements of the precoding matrix as
$w_{mk} = p_{mk}e^{j\theta_{mk}}, m = 1,\ldots,M, \text{and} \quad k = 1,\ldots,K$
27
End
28

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US16/39685

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H04W52/24; H04W52/34; H04B7/06 (2016.01)
CPC - H04W52/241; H04W52/244; H04W52/34; H04B7/0452; H04B7/0426
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8): H04W52/24; H04W52/34; H04B7/06 (2016.01)
CPC: H04W52/241; H04W52/244; H04W52/34; H04B7/0426; H04B7/0452; H04B7/043; H04B7/0456; H04B7/0632; H04B7/0634

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)
PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); Google Scholar; Ebscohost; IEEE
Keywords: MU-MIMO, multiuser MIMO, power, utilization, allocation, antenna, vector, matrix, matrices, iterative searching, orthogonal projection, beamforming

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 2006/0098754 A1 (KIM, S et al.) 11 May 2006, figure 1, paragraphs [0013]-[0014], [0020], [0022], [0030]-[0035]	1 -- 2-6
Y	US 2004/0235529 A1 (TAROKH, V et al.) 25 November 2004, paragraphs [0254], [0257]	2, 5
Y	US 2009/0286494 A1 (LEE, J et al.) 25 September 2012, paragraph [0139], [0141]	3, 6
Y	US 8,274,431 B1 to (LEE, J et al.) 19 November 2009, column 5 lines 42-69, column 7 lines 10-15, 59-67, column 9 lines 1-15	4-6

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 07 September 2016 (07.09.2016)	Date of mailing of the international search report 28 OCT 2016
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US16/39685

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

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

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

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

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

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

This International Searching Authority found multiple inventions in this international application, as follows:
See extra sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-6

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

-***-Continued from Box No. III Observations where unity of invention is lacking -***-

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fee must be paid.

Group I: Claims 1-6 are directed towards maximizing power utilization.
Group II: Claims 7-11 are directed towards minimizing inter-user interference.
Group III: Claim 12 is directed towards a precoding method.

The inventions listed as Groups I-III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I include at least allocating the power to maximize the power utilization, which are not present in Groups II-III.

The special technical features of Group II include at least power to minimize the inter-user interference, which are not present in Groups I and III.

The special technical features of Group III include at least selecting a precoding method; the BS computing the phase of each element of the precoding matrix Θ.sub.mk; the BS computing the power of each data stream on each antenna ρ.sub.mk; and the BS computing each elements of the precoding matrix as w.sub.mk = ρ.sub.mk^(e^(jØ.sub.mk)), which are not present in Groups I-II.

The common technical features shared by Groups I-III are a method for power allocation in MU-MIMO wireless communication systems comprising: a BS with an array of M antennas serving K data streams in a Resource Element where M≥K; and the BS allocating the power.

However, these common features are previously disclosed by US 2006/0098754 A1 to KIM, S et al. (hereinafter "Kim"). Kim discloses a method for power allocation in MU-MIMO wireless communication systems comprising (a method of power allocation in a multiuser MIMO wireless communication system, paragraph [0022]): a BS with an array of M antennas serving K data streams in a Resource Element where M≥K (a Base station with an array of 6 (M) antennas serving 4 (K) data streams in a multiplexed stream group (resource element) where 6 is greater than 4), figure 1, paragraphs [0020], [0022]); and the BS allocating the power (the Base Station allocates power, paragraph [0020]).

Since the common technical features are previously disclosed by the Kim reference, these common features are not special and so Groups I-III lack unity.