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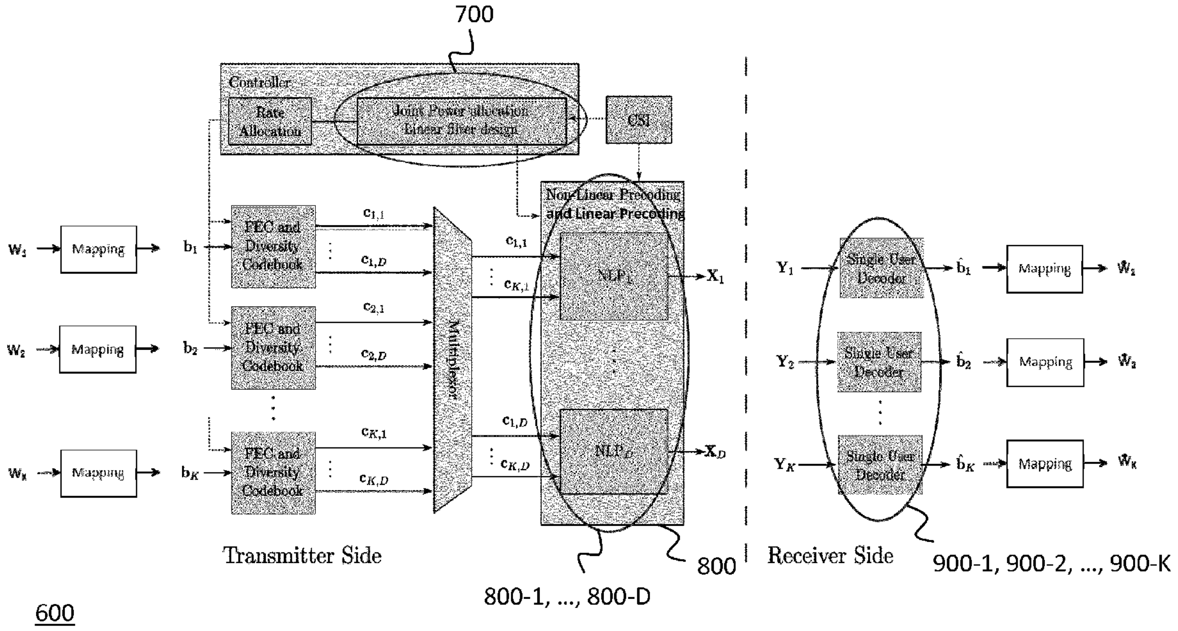

Fig. 7

(57) **Abstract:** The present invention relates to a wireless communication system for downlink transmitting, through a plurality of orthogonal carriers and according to a non-orthogonal multiple access transmission scheme in a multiple-input single-output configuration, a plurality of messages towards, respectively, a plurality of users. At the transmitter side, a power allocation strategy subjected to a total power budget constraint and a linear filter computation based on the channel state information are jointly designed to meet a prescribed fairness constraint. The computed linear filter is adapted to balance interference caused to each user by the users being served at identical resources and is then used through an intra-carrier lattice-based non-linear precoding to mitigate the interference and also through a linear precoding to output a signal to be transmitted on the respective carrier towards each user. At the receiver side, the plurality of messages is finally recovered thanks to a simple single-user decoder.

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TITLE

METHOD AND APPARATUS FOR MODULO-LATTICE NON-ORTHOGONAL MULTIPLE ACCESS FOR OVERLOADED MISO SYSTEMS

TECHNICAL FIELD

The invention relates to the field of wireless communications, and more particularly to downlink transmissions through a non-orthogonal multiple access scheme.

BACKGROUND

One of the most important challenges in the design of future wireless communication systems is the quest to improve spectral efficiency.

Fig. 1 shows a schematic wireless communication system 100, wherein a single transmitter (Tx), such as a base station (BS), communicates with a plurality of K receivers (Rx) such as user equipment devices (UE_1, …, UE_K) through a respective communication channel (H_1, …, H_K), which experiences fading.

Derived from the system 100, Fig. 2 shows a wireless communication system 200 in a multiple-input single-output (MISO) configuration, in which the single transmitter (Tx) is equipped with N_t antennas and each receiver (Rx_1, …, Rx_K) is equipped with a single antenna. If the number of transmit dimensions N_t does not allow all the UE devices to be served in an orthogonal fashion, namely if $N_t < K$, then the system is overloaded. In such overloaded systems, interference may be detrimental to any form of communication so that an efficient interference mitigation technique is required. Conversely, the transmit strategy is less challenging from an interference cancelation viewpoint and calls for comparatively less complex solutions in a non-overloaded scenario, namely in the case where $N_t \geq K$.

As depicted in Fig. 2, a plurality of messages (W_1, …, W_K) is transmitted from the single transmitter (Tx) towards, respectively, the plurality of K receivers (Rx_1, …, Rx_K). The plurality of messages (W_1, …, W_K) at the input of the transmitter (Tx) is respectively converted into a plurality of signals X_d (X_1, …, X_D) to be transmitted downlink from the output of the transmitter (Tx) towards the plurality of K receivers (Rx_1, …, Rx_K) over, respectively, a plurality of D orthogonal carriers (1, …, D) (e.g., frequency bands). Thus, $X = (X_1, …, X_D)'$ can be considered as a (N_t X D)-dimensional signal to be transmitted downlink over the entirety of the D carriers, where each X_d is a (N_t X 1)-dimensional signal to be transmitted downlink over the carrier d. Each carrier (1, …, D) is used to transmit the plurality of signals X_d (X_1, …, X_D) towards each receiver (Rx_1, …, Rx_K) through a respective communication channel ($H_{1,1}$, …, $H_{1,D}$, …, $H_{k,1}$, …, $H_{k,D}$, …, $H_{K,1}$, …, $H_{K,D}$), where $H_{k,d}$ thus denotes the channel linking the transmitter Tx to the receiver Rx_k over the carrier d. An exemplary configuration of a channel model in a NOMA scheme for D = 4 carriers and K = 6 users (UEs) is depicted in Fig. 3, in which each receiver or UE device (UE1, …, UE6) observes D non-interfering independent carriers (1, …, 4) and where each carrier (1, …, 4) is used to transmit to the K receivers or UE devices (UE1, …, UE6). At the receiver side, $Y_k = (Y_{k,1}, …, Y_{k,D})'$ is the D-dimensional received signal at each receiver k (Rx_k) over the entirety of the carriers (1, …, D), where each $Y_{k,d}$ is a scalar signal received at the receiver k over the carrier d.

Derived from the system 200, Fig. 4 shows a wireless communication system 300 in a detailed downlink transmission scheme.

At the transmitter side, the controller comprises a rate allocation module, a power allocation module and a user ordering module.

The messages (W_1, …, W_K) intended for the entirety of the receivers or UE devices are first mapped into respective binary streams (b_1, …, b_K). Under control of the rate allocation module, those binary streams (b_1, …, b_K) are then encoded into D constellation symbols or codewords ($C_{1,1}$, …, $C_{1,D}$, …, $C_{k,1}$, …, $C_{k,D}$, …, $C_{K,1}$, …, $C_{K,D}$) for each UE device, through a forward error correction (FEC) encoder alone or coupled and jointly designed with diversity codebooks, such as repetition codebooks and sparse code multiple access (SCMA) codebooks, in order to provide better diversity warranties.

All those constellation symbols ($C_{1,1}$, …, $C_{1,D}$, …, $C_{k,1}$, …, $C_{k,D}$, …, $C_{K,1}$, …, $C_{K,D}$) are then individually conveyed through a joint multiplexer towards a multi-user-to-layer mapping module comprising a plurality of mapping devices respectively dedicated to each carrier (1, …, D). In addition, the channel matrices $H_{k,d}$ are respectively communicated to the mapping devices from a channel state information (CSI) estimation module and the powers ($P_{k,d}$) allocated to each UE device over each carrier are determined by the power allocation module of the controller.

Finally, through a constellation-to-signal mapping, each mapping device maps its respective constellation symbols ($C_{1,1}$, ..., $C_{K,1}$: for carrier 1; ...; $C_{1,D}$, ..., $C_{K,D}$: for carrier D) into a respective signal (X_1, ..., X_D) dedicated to each carrier (1, ..., D) and given by the following equation:

$$X_d = f_d(c_{1,d}, \dots, c_{K,d}, P_{1,d}, \dots, P_{K,d}, H_{1,d}, \dots, H_{K,d}) \quad (1)$$

subject to: $$\sum_{k=1}^{K} \sum_{d=1}^{D} P_{k,d} = P \quad (2)$$

where X_d is the signal to be transmitted downlink from the transmitter (Tx) over the carrier d, $H_{k,d}$ is the channel matrix from the transmitter (Tx) towards the receiver Rx_k over the carrier d, $P_{k,d}$ is the power allocated to the receiver Rx_k over the carrier d in such a manner that the sum of all the powers allocated to all the receivers (Rx_1, ..., Rx_k, ..., Rx_K) over all the carriers (1, ..., D) be equal to the total power budget (P), and f_d denotes the constellation-to-signal mapping.

The constellation-to-signal mapping can be performed through linear precoding (LP) such as zero-forcing (ZF) precoding, non-linear precoding (NLP) such as Tomlinson-Harashima Precoding (THP), or a combination of linear and non-linear precoding such as QL-THP, where Q denotes an orthogonal matrix and L denotes a lower triangular matrix.

In the case of a linear precoding, the signal X_d to be transmitted downlink from the transmitter (Tx) over the carrier d is given by the following equation:

$$X_d = F_{LP} \times \begin{pmatrix} c_{1,d} \\ \vdots \\ c_{K,d} \end{pmatrix} \quad (3)$$

where F_{LP} is a linear filter that maps the constellation codewords into the N_t antennas.

In the case of a non-linear precoding, the signal X_d to be transmitted downlink from the transmitter (Tx) over the carrier d is given by the following equation:

$$\mathrm{X_d = f_{NLP}\left(c_{1,d}, \ldots, c_{K,d}\right)} \tag{4}$$

where f_{NLP} represents a non-linear filtering/mapping that maps the constellation codewords into the N_t antennas.

In the case of a combination of the linear and non-linear precoding, the signal X_d to be transmitted downlink from the transmitter (Tx) over the carrier d is given by the following equation:

$$\mathrm{X_d = F_{LP} \times f_{NLP}\left(c_{1,d}, \ldots, c_{K,d}\right)} \tag{5}$$

where F_{LP} and f_{NLP} represent a respective linear and non-linear filtering/mapping that maps the constellation codewords into the N_t antennas.

Each signal X_1, ..., X_D is then transmitted downlink from the transmitter (Tx) over its respective carrier (1, ..., D) towards each receiver (Rx_1, ..., Rx_k, ..., Rx_K) through a respective communication channel ($H_{1,1}$, ..., $H_{1,D}$, ..., $H_{k,1}$, ..., $H_{k,D}$, ..., $H_{K,1}$, ..., $H_{K,D}$),. The transmission is subjected to an input power constraint defined by: $E(||X||^2) \leq P$, where P is the total power budget.

At the receiver side, the input-output relationship over the carrier d is given by the following equation:

$$\mathrm{Y_{k,d} = H_{k,d}X_d + Z_{k,d}} \tag{6}$$

where $Y_{k,d}$ is the signal received at the receiver k (Rx_k) over the carrier d and $Z_{k,d}$ is an additive white Gaussian noise (AWGN) over the carrier d with the ambient noise power $N_{k,d}$.

Considering the entirety of the receivers (Rx_1, ..., Rx_k, ..., Rx_K), the network input-output relationship over the carrier d is then given by the following equation:

$$\begin{pmatrix} Y_{1,d} \\ \vdots \\ Y_{K,d} \end{pmatrix} = \begin{bmatrix} H_{1,d} \\ \vdots \\ H_{K,d} \end{bmatrix} X_d + \begin{pmatrix} Z_{1,d} \\ \vdots \\ Z_{K,d} \end{pmatrix} \tag{7}$$

where $(Y_{k,1}, ..., Y_{k,D})' = Y_k$ is the D-dimensional received signal at each receiver k (Rx_k) over the D carriers and $(Z_{1,d}, ..., Z_{k,d}, ..., Z_{K,d})' = Z_d$ is the K-dimensional additive white Gaussian noise vector.

Each receiver (Rx_1, ..., Rx_k, ..., Rx_K) decodes its respective signal (Y_1, ..., Y_k, ..., Y_K) received on all carriers (1, .., D) into a respective estimated binary stream ($\hat{b}_1, \dots, \hat{b}_k, \dots, \hat{b}_{K,}$) through a respective decoder and computes its estimated binary stream ($\hat{b}_1, \dots, \hat{b}_k, \dots, \hat{b}_{K,}$) so as to recover an estimation of its intended message ($\hat{W}_1, \dots,$ $\hat{W}_k, \dots,$ $\hat{W}_K$).

To cope with the issue of improving the spectral efficiency, possible waveform designs can rely on orthogonal multiple access or non-orthogonal multiple access (NOMA).

In the orthogonal multiple access schemes, the main coding aspect rests on the fact that each user (i.e., each receiver (Rx) or UE device) is served on only one carrier and each carrier serves only N_t users. This is possible through a simple linear precoding scheme, in which the encoder uses its N_t antennas to transmit orthogonally to N_t users without thereby creating an interference.

Derived from the system 300, Fig. 5 shows an orthogonal multiple access downlink transmission system 400 in a multiple-input single-output (MISO) configuration.

At the transmitter side of Fig. 5, the controller comprises a rate allocation module, a power allocation module and a user selection module.

The user selection module is adapted to define a given mapping from users to carriers (layers) so that, on each carrier d, a set of K(d) users are served, K(d) comprising the indices of the user associated to the carrier d.

Based on that user-to-carrier mapping and under control of the rate allocation module, the binary streams (b_1, ..., b_K) are encoded into D constellation symbols or codewords ($C_{1,1}$, ..., $C_{1,D}$, ..., $C_{k,1}$, ..., $C_{k,D}$, ..., $C_{K,1}$, ..., $C_{K,D}$) for each user through a forward error correction (FEC) encoder alone or coupled and jointly designed with diversity codebooks.

All those constellation symbols ($C_{1,1}$, ..., $C_{1,D}$, ..., $C_{k,1}$, ..., $C_{k,D}$, ..., $C_{K,1}$, ..., $C_{K,D}$) are then individually conveyed through the joint multiplexer towards the multi-user-to-layer mapping module comprising a plurality of mapping devices (LP_1, ..., LP_D) respectively dedicated to each carrier (1, ..., D), the constellation-to-signal mapping being performed through linear precoding (LP).

Finally, through the linear precoding (LP), each mapping device (LP_1, ..., LP_D) maps its respective constellation symbols ($C_{1,1}$, ..., $C_{K,1}$: for carrier 1; ...; $C_{1,D}$, ..., $C_{K,D}$: for carrier D) into a respective signal (X_1, ..., X_D) dedicated to each carrier (1, ..., D).

Thus, the signal X_d to be transmitted downlink from the transmitter (Tx) over the carrier d is given by the following equation:

$$X_d = F_{LP} \times \begin{pmatrix} c_{1,d} \\ \vdots \\ c_{K,d} \end{pmatrix} \tag{8}$$

where the linear filter F_{LP} is a function of the system parameters.

F_{LP} associated to the carrier d, namely F_{LPd}, is given by the following equation:

$$F_{LP_d} = f\left(P_{1,d}, \dots, P_{N_t,d}, H_{1,d}, \dots, H_{N_t,d}\right) \tag{9}$$

For simplicity, the indices of the users associated to the carrier d by the user selection module are assumed to be equal to {1, ..., N_t}, namely K(d) = {1, ..., N_t}, and the matrix F_{LP} is chosen so as to verify:

$$\begin{bmatrix} H_{1,d} \\ \vdots \\ H_{N_t,d} \end{bmatrix} F_{Lp_d} = \begin{bmatrix} l_{11,d} & 0 & 0 \\ 0 & l_{kk,d} & 0 \\ 0 & 0 & l_{N_tN_t,d} \end{bmatrix} \tag{10}$$

where $l_{kk,d}$ is the projected value of $H_{k,d}$ over the k-th column of F_{LPd} .

At the receiver side of Fig. 5, the received signal on the carrier d for the entirety of the users is given by:

$$\begin{pmatrix} Y_{1,d} \\ \vdots \\ Y_{N_t,d} \end{pmatrix} = \begin{bmatrix} H_{1,d} \\ \vdots \\ H_{N_t,d} \end{bmatrix} X_d + \begin{pmatrix} Z_{1,d} \\ \vdots \\ Z_{N_t,d} \end{pmatrix} = \begin{bmatrix} l_{11,d} & 0 & 0 \\ 0 & l_{kk,d} & 0 \\ 0 & 0 & l_{N_tN_t,d} \end{bmatrix} \times \begin{pmatrix} c_{1,d} \\ \vdots \\ c_{N_t,d} \end{pmatrix} + \begin{pmatrix} Z_{1,d} \\ \vdots \\ Z_{N_t,d} \end{pmatrix} \tag{11}$$

Thereby, the received signal on the carrier d for the k-th user (UE_k) is given by:

$$Y_{k,d} = H_{k,d}X_d + Z_{k,d} = l_{kk,d}.c_{k,d} + Z_{k,d} \tag{12}$$

which allows to recover $c_{k,d}$ through a simple single-user decoder dedicated to each user, since the signal X_d to be transmitted downlink from the transmitter (Tx) over the carrier d is designed such that the streams $c_{k,d}$ experience no interference.

Thus, the orthogonal multiple access scheme presents the benefits of suffering no interference between different information streams since they are orthogonally transmitted on the carriers, and requiring only simple single-user encoders and decoders, which have a low complexity implementation.

However, such a scheme has also some severe limitations by providing low throughput since each user is served only through one carrier, by being resource-limited since only N_t X D users can be scheduled at the same time, namely by being limited by the number of transmit antennas (resources) and frequency carriers of the system, and by being possibly unfair, in particular if the user selection module operates based on maximizing throughput and thus, serves only users experiencing good channel conditions, thereby leading to an unfair data delivery amongst all the users.

By conveying a larger number of information streams on the same resources, i.e. time and frequency, whilst efficiently mitigating interference, the NOMA scheme allows to circumvent such limitations.

In the NOMA schemes, the main coding aspect rests on the fact that all the users (i.e., all the receivers (Rx) or UE devices) can be served on all the carriers, thus creating, at each carrier, a non-orthogonal downlink transmission scheme.

Unlike the orthogonal multiple access scheme, the NOMA scheme requires an efficient interference mitigation strategy as it can serve many users using the same resources. Such a strategy can consist in the implementation at the transmitter (Tx) side of a non-linear precoder coupled with a QL decomposition of the channel in order to efficiently cope with the interference.

Derived from the system 300, Fig. 6 shows a NOMA downlink transmission system 500 with QL in a multiple-input single-output (MISO) configuration.

At the transmitter side of Fig. 6, the controller comprises a rate allocation module, a power allocation module and a user ordering module defining an ordering of the users.

Under control of the rate allocation module, the binary streams (b_1, ..., b_K) are encoded into D constellation symbols or codewords ($C_{1,1}$, ..., $C_{1,D}$, ..., $C_{k,1}$, ..., $C_{k,D}$, ..., $C_{K,1}$, ..., $C_{K,D}$) for each user through a forward error correction (FEC) encoder alone or coupled and jointly designed with diversity codebooks.

All those constellation symbols ($C_{1,1}$, ..., $C_{1,D}$, ..., $C_{k,1}$, ..., $C_{k,D}$, ..., $C_{K,1}$, ..., $C_{K,D}$) are then individually conveyed through the joint multiplexer towards the multi-user-to-layer mapping module comprising a plurality of mapping devices (NLP_1, ..., NLP_D) respectively dedicated to each carrier (1, ..., D), the constellation-to-signal mapping being performed through a combination of linear precoding (QL) consisting in the QL decomposition and subsequent non-linear precoding (NLP).

The mapping device (NLP_d) of the carrier d first computes a linear filter F_{QLd} consisting in the QL decomposition of the channel matrices of the carrier d. Thus, F_{QLd} is chosen in such a manner as to verify the following matrix, in the exemplary case where K = 6 users and N_t = 3 antennas:

$$\begin{bmatrix} H_{1,d} \\ \vdots \\ H_{K,d} \end{bmatrix} F_{QL_d} = \begin{bmatrix} l_{11,d} & 0 & 0 & 0 & 0 & 0 \\ l_{21,d} & l_{22,d} & 0 & 0 & 0 & 0 \\ l_{31,d} & l_{32,d} & l_{33,d} & l_{34,d} & l_{35,d} & l_{36,d} \\ l_{41,d} & l_{42,d} & l_{43,d} & l_{44,d} & l_{45,d} & l_{46,d} \\ l_{51,d} & l_{52,d} & l_{53,d} & l_{54,d} & l_{55,d} & l_{56,d} \\ l_{61,d} & l_{62,d} & l_{63,d} & l_{64,d} & l_{65,d} & l_{66,d} \end{bmatrix} \tag{13}$$

where $l_{kl,d}$ is the projected value of $H_{k,d}$ over the l-th column of F_{QLd}.

The interference that is created by the lower triangular terms in the above matrix is mitigated through a non-linear precoding, such as Tomlinson-Harashima Precoding (THP) and dirty paper coding (DPC), and yields the following signal:

$$\tilde{X}_d = f_{NLP}(c_{1,d}, \dots, c_{K,d}) = \begin{pmatrix} \tilde{x}_{1,d} \\ \vdots \\ \tilde{x}_{K,d} \end{pmatrix} \tag{14}$$

where the non-linear precoding f_{NLP} of the codewords ($C_{1,d}$, ..., $C_{K,d}$) for the carrier d is performed in the order specified by the user ordering module and takes into account the CSI of the channels $H_{1,d}$, ..., $H_{K,d}$ and the power allocation $P_{1,d}$, ..., $P_{K,d}$ for the carrier d.

Based on the obtained symbols $(\tilde{x}_{1,d}, \dots, \tilde{x}_{K,d})$, the mapping device ($NLP_d$) dedicated to the carrier d then generates the channel input X_d as follows:

$$X_d = F_{QL_d} \times \begin{pmatrix} \tilde{x}_{1,d} \\ \vdots \\ \tilde{x}_{K,d} \end{pmatrix} = F_{QL_d} \times f_{NLP}(c_{1,d}, \dots, c_{K,d}) \qquad (15)$$

At the receiver side of Fig. 6, the received signal $Y_{k,d}$ on the carrier d for the k-th user is given by the following equation:

$$Y_{k,d} = H_{k,d} X_d + Z_{k,d} \qquad (16)$$

If $k \leq N_t$, the received signal $Y_{k,d}$ on the carrier d for the k-th user is interference-free due to non-linear precoding and is defined as follows:

$$Y_{k,d} = l_{kk,d} . c_{k,d} + Z_{k,d} \qquad (17)$$

Thus, the k-th user can recover its intended codeword $c_{k,d}$ for the carrier d through a simple single-user decoder.

If $k > N_t$, the received signal $Y_{k,d}$ on the carrier d for the k-th user is not interference-free due to the residual interference from linear precoding and is defined as follows:

$$Y_{k,d} = l_{kk,d} . c_{k,d} + \sum_{l=k+1}^{K} l_{kl,d} . \tilde{x}_{l,d} + Z_{k,d} \qquad (18)$$

Thus, the k-th user can recover its intended codeword $c_{k,d}$ through a single-user decoder by considering the interfering codewords $(c_{k+1,d}, \dots, c_{K,d})$ as noise.

Consequently, the NOMA scheme presents the benefits of efficiently mitigating interference at the receiver side for the N_t first users, providing higher throughput compared to the orthogonal multiple access scheme since more users are served on each carrier.

However, due to the current implementation of QL, such a scheme has also some severe limitations. For example, it suffers from unbalanced interference since only the first N_t users experience an interference-free link, while the other users experience residual interference that cannot be pre-canceled through non-linear precoding. Thereby, the scheme concentrates interference on only a subset of users by rendering, if the system is overloaded, the power of the residual interference with QL scalable with the useful power of the k-th user, which prevents any communication unless a careful power allocation strategy be applied. In addition, it suffers from being very sensitive to the users' ordering and channel matrices.

SUMMARY

It is therefore an object of the present invention to provide, in a multiple-input single-output (MISO) configuration, a wireless communication system for downlink transmissions that is capable of mitigating in a fair manner any interference amongst the users served on the same resources while exhibiting a high throughput.

The object is achieved by the features of the independent claims. Further embodiments of the invention are apparent from the dependent claims, the description and the figures.

According to a first aspect, the invention relates to a base station for transmitting, through a plurality of orthogonal carriers and according to a non-orthogonal multiple access transmission scheme in a multiple-input single-output configuration, a plurality of messages towards, respectively, a plurality of user equipment devices, the base station comprising an optimization solver, which is adapted to optimize, under a fairness constraint, an inter-carrier and intra-carrier power allocation taking account of an overall power budget, and a computation of a linear filter based on a channel state information of each channel linking the whole plurality of carriers to the plurality of user equipment devices.

Thereby, a high throughput can be achieved due to the provision of the non-orthogonal multiple access scheme allowing a large number of users (i.e., receivers or user equipment devices) to be served on each carrier. In addition, any interference, which is inherent to the multiple-input single-output configuration when the amount of antennas at the transmitter side is less than the amount of users at the receiver side, can thereby be optimally mitigated due to the power allocation strategy according to the fairness constraint, which allows the overall power to be fairly split across all the carriers and the split power of each carrier to be fairly split across all the users, and due to the joint provision of the linear filter, which is specifically computed/designed according to the same fairness constraint.

According to a first implementation of the base station according to the first aspect, the optimization solver is adapted to optimize, under the fairness constraint, an ordering of the plurality of user equipment devices based on the channel state information of each channel linking the whole plurality of carriers to the plurality of user equipment devices and based on the inter-carrier and intra-carrier power allocation.

Thereby, the corresponding users' ordering can be rendered optimal and can cope with the strong sensitivity of the wireless communication system when in a non-orthogonal multiple access scheme to such an ordering.

According to a second implementation of the base station according to the first aspect or the first implementation of the first aspect, the computed linear filter is adapted to balance interference caused to each other user equipment device by the user equipment devices being served at identical resources.

Thereby, the interference is not concentrated on only a subset of users, but can be fairly distributed over the entirety of the users.

According to a third implementation of the base station according to the third first aspect or any one of the preceding implementations of the first aspect, the base station comprises a plurality of multi-user encoders individually dedicated to a respective carrier, each multi-user encoder being adapted to map, through an intra-carrier lattice-based non-linear precoding process followed by a linear precoding process, a plurality of symbols into an output signal to be transmitted on the respective carrier towards the plurality of user equipment devices, and wherein the linear precoding is performed by a linear precoder using the computed linear filter dedicated to the respective carrier and adapted to linearly precode the entirety of the signals resulting from the intra-carrier lattice-based non-linear precoding process so as to obtain the output signal to be transmitted on the respective carrier, and wherein the entirety of the signals individually output from the plurality of multi-user encoders is a function of the plurality of messages to be respectively transmitted towards the plurality of user equipment devices.

Thereby, the combination of the non-linear and linear precoding processes and the use of the computed linear filter within the linear precoding process can allow the balanced interference to be mitigated.

According to a fourth implementation of the base station according to the third implementation of the first aspect, the intra-carrier lattice-based non-linear precoding is based on the intra-carrier power allocation for the respective carrier, on the users' ordering, on the channel state information of each channel linking the respective carrier to the plurality of user equipment devices, and on the computed linear filter dedicated to the respective carrier.

Thereby, the balanced interference can be mitigated by taking a plurality of system parameters into consideration.

According to a fifth implementation of the base station according to the fourth implementation of the first aspect, the intra-carrier lattice-based non-linear precoding is carried out in a sequential manner in order to successively cancel out the interfering symbols amongst the plurality of symbols.

Thereby, the interference mitigation through the non-linear precoding can be optimally performed.

According to a sixth implementation of the base station according to the first aspect or any one of the preceding implementations of the first aspect, the fairness constraint is a throughput fairness constraint or a reliability fairness constraint.

Thereby, the fairness constraint can imply distinct designs. The throughput fairness can be related to the rates of the data to be delivered to the users, while the reliability fairness can be related to the quality of service or the quality of experience of the user.

The above object is also solved in accordance with a second aspect.

According to the second aspect, the invention relates to a user equipment device receiving a plurality of signals transmitted from a base station as claimed in the third implementation of the first aspect and individually output from the plurality of multi-user encoders through the plurality of orthogonal carriers, and comprising a single-user decoder, which is adapted to individually decode each signal of the received plurality of signals using a respective inter-carrier lattice-based decoder.

Thereby, each user can decode only its intended signal through a simple single-user decoder, the whole multi-user interference mitigation complexity being relegated to the base station (i.e., the transmitter).

The above object is also solved in accordance with a third aspect.

According to the third aspect, the invention relates to a wireless communication system comprising a base station as specified in the second aspect and a plurality of user equipment devices as individually claimed in the second aspect.

The above object is also solved in accordance with a fourth aspect.

According to the fourth aspect, the invention relates to a method for transmitting, through a plurality of orthogonal carriers and according to a non-orthogonal multiple access transmission scheme in a multiple-input single-output configuration, a plurality of messages towards, respectively, a plurality of user equipment devices, the method comprising the step of optimizing, under a fairness constraint, an inter-carrier and intra-carrier power allocation taking account of an overall power budget, and a computation of a linear filter based on a channel state information of each channel linking the whole plurality of carriers to the plurality of user equipment devices.

According a first implementation of the method according to the fourth aspect, the method comprises the step of optimizing, under the fairness constraint, an ordering of the plurality of user equipment devices based on the channel sate information of each channel linking the whole plurality of carriers to the plurality of UE devices and based on the inter-carrier and intra-carrier power allocation.

According to a second implementation of the method according to the fourth aspect or the first implementation of the fourth aspect, the method comprises for each carrier the step of mapping, through an intra-carrier lattice-based non-linear precoding process followed by a linear precoding process, a plurality of symbols into an output signal to be transmitted on a respective carrier towards the plurality of user equipment devices, wherein the linear precoding is performed by a linear precoder using the computed linear filter dedicated to the respective carrier and adapted to linearly precode the entirety of the signals resulting from the intra-carrier lattice-based non-linear precoding process so as to obtain the output signal to be transmitted on the respective carrier, and wherein the entirety of the signals individually output from the plurality of multi-user encoders is a function of the plurality of messages to be respectively transmitted towards the plurality of user equipment devices.

According to a third implementation of the method according to the second implementation of the fourth aspect, the method comprises for each user equipment device the steps of receiving from the base station a plurality of signals, which are individually output from the plurality of multi-user encoders through the plurality of orthogonal carriers, and decoding individually each signal of the received plurality of signals using a respective inter-carrier lattice-based decoder.

The above object is also solved in accordance with a fifth aspect.

According to the fifth aspect, the invention relates to a computer program comprising a program code for performing the method according to the fourth aspect or any one of the implementations of the fourth aspect when executed on a computer.

Thereby, the method can be performed in an automatic and repeatable manner.

The computer program can be performed by any one of the above apparatuses or devices. The apparatuses or devices can be programmably arranged to perform the computer program.

Embodiments of the invention can be implemented in hardware, software or in any combination thereof.

It shall further be understood that a preferred embodiment of the invention can also be any combination of the dependent claims or above embodiments with the respective independent claim.

These and other aspects of the invention will be apparent and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following detailed portion of the present disclosure, the invention will be explained in more detail with reference to the exemplary embodiments shown in the drawings, in which:

Fig. 1	shows a schematic wireless communication system 100;
Fig. 2	shows a wireless communication system 200 in a multiple-input single-output (MISO) configuration;

Fig. 3	shows an exemplary configuration of a channel model in a NOMA scheme for D = 4 carriers and K = 6 users (i.e., 6 UEs);
Fig. 4	shows a wireless communication system 300 in a detailed downlink transmission scheme;
Fig. 5	shows an orthogonal multiple access downlink transmission system 400 in a multiple-input single-output (MISO) configuration;
Fig. 6	shows a NOMA downlink transmission system 500 with QL in a multiple-input single-output (MISO) configuration;
Fig. 7	shows a NOMA downlink transmission system 600 in a multiple-input single-output (MISO) configuration according to a first embodiment of the present invention;
Fig. 8	shows a joint power allocation and linear filtering module 700 from the NOMA downlink transmission system 600 according to a second embodiment of the present invention;
Fig. 9	shows an individual multi-user encoder 800-d dedicated to a respective carrier d and using a joint non-linear and linear precoding according to a third embodiment of the present invention; and
Fig. 10	shows a single-user decoder 900-k individually dedicated to the respective k-th user according to a fourth embodiment of the present invention.

Identical reference signs are used for identical or at least functionally equivalent features.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Fig. 7 shows a NOMA downlink transmission system 600 in a multiple-input single-output (MISO) configuration according to an embodiment of the present invention.

Based on the systems 100, 200 of Figs. 1 and 2 and the channel model of Fig. 3, the system 600 comprises a single base station (i.e., a transmitter) and a plurality of K users (i.e., receivers) communicating through a plurality of respective communication channels (H_1: $H_{1,1}$, ..., $H_{1,D}$; ...; H_K: $H_{K,1}$, ..., $H_{K,D}$).

At the transmitter side of Fig. 7, the controller comprises a rate allocation module and a joint power allocation and linear filtering module.

Fig. 8 depicts a joint power allocation and linear filtering module 700 according to an embodiment of the present invention.

The module 700 comprises an optimization solver, which receives a plurality of inputs respectively related to the total power budget P, which is the total power to be split amongst all the carriers and all the users, a fairness constraint specification, which can consist in a throughput fairness or a reliability fairness, and a channel state information (CSI) of all the users on all the carriers, i.e., an information about each communication channel ($H_{1,1}$, ..., $H_{1,D}$, ..., $H_{K,1}$, ..., $H_{K,D}$).

The throughput fairness can correspond to a rate fairness defined as hereafter. Let R_1, ..., R_K be the rates of the data delivered to the K users. Maximizing the following sum-throughput:

$$\sum_{k=1}^{K} R_k \tag{19}$$

may lead to not serving at all, or otherwise only rarely, those users with a low communication channel quality. Thus, a solution for circumventing this shortcoming and inducing some throughput fairness amongst the users is to maximize a weighted sum-throughput in the following form:

$$\sum_{k=1}^{K} \mu_k . R_k, \text{ such that } \sum_{k=1}^{K} \mu_k = 1 \tag{20}$$

where the weight μ_k of the rate R_k with respect to the user k can be chosen so as to reflect the size of the data buffer with respect to that user. In a more explicit way, if the buffer with respect to a user is full or has a small size, the base station (BS) is adapted to choose to decrease the value of the associated weight coefficient.

The reliability fairness can be directly associated with the quality of service (QoS) or the quality of experience (QoE) of the user. In a scenario, it might be required, that at a given signal-to-noise ratio, all the users experience the same error rate (e.g., a bit error rate (BER), a symbol error rate (SER), a packet loss rate (PLR), and so on). In another scenario, the service delivered to the users might also require that all the error rates be no larger than a prescribed error rate or be in average below a certain threshold value.

It should be noted that those possible reliability fairness constraints can imply distinct design considerations, for example a rate and power allocation, from those imposed by the sum-throughput maximization.

Based on the above fairness constraint, the optimization solver is comprised of three units related to the power allocation, the linear precoders and the users' ordering, respectively.

The power allocation unit consists in an inter-carrier power allocation (depicted as power allocation carrier 1, ..., power allocation carrier D), in which the power is split across the carriers and which can be processed using, for instance, a water filling algorithm. Then, for each carrier, an intra-carrier power allocation splits the power of the carrier among all the users served on that carrier. The power splitting is designed in such a manner as to satisfy the total power budget P as follows:

$$\sum_{k=1}^{K} \sum_{d=1}^{D} P_{k,d} = P \tag{21}$$

The linear precoders unit consists in a design or computation of the linear filters (depicted as filter F_{LF1}, ..., filter F_{LFD}), which will be then used by the plurality of multi-user encoders (800-1, ..., 800-D). The linear filter design is based on the channel state information (CSI) and is aimed at balancing out more efficiently the interference experienced by the different users in the setting. For instance, the optimization of the overall performance of the system can require that the equivalent communication channel of the carrier d, namely the channel seen at the user k after linear filtering, be given by the following:

$$\begin{bmatrix} H_{1,d} \\ \vdots \\ H_{K,d} \end{bmatrix} F_{LF_d} = \begin{bmatrix} l_{11,d} & 0 & 0 & l_{14,d} & l_{15,d} & l_{16,d} \\ l_{21,d} & l_{22,d} & 0 & 0 & l_{25,d} & l_{26,d} \\ l_{31,d} & l_{32,d} & l_{33,d} & 0 & 0 & l_{36,d} \\ l_{41,d} & l_{42,d} & l_{43,d} & l_{44,d} & 0 & 0 \\ l_{51,d} & l_{52,d} & l_{53,d} & l_{54,d} & l_{55,d} & 0 \\ l_{61,d} & l_{62,d} & l_{63,d} & l_{64,d} & l_{65,d} & l_{66,d} \end{bmatrix} \quad (22)$$

The users' ordering unit consists in a permutation (depicted as π_1, ..., π_D) of the ordering of the K users with the aim of optimizing the performance of the whole system by maximizing the diagonal terms of the equivalent communication channel.

At the transmitter side, the messages (W_1, ..., W_K) intended for all the users (i.e., receivers or UE devices) are first mapped into respective binary streams (b_1, ..., b_K). Under control of the rate allocation module of the controller, those binary streams (b_1, ..., b_K) are then encoded into D constellation symbols or codewords ($C_{1,1}$, ..., $C_{1,D}$, ..., $C_{k,1}$, ..., $C_{k,D}$, ..., $C_{K,1}$, ..., $C_{K,D}$) for each user, through a forward error correction (FEC) encoder alone or coupled and jointly designed with diversity codebooks, such as repetition codebooks and SCMA codebooks, in order to provide better diversity warranties.

All those constellation symbols ($C_{1,1}$, ..., $C_{1,D}$, ..., $C_{k,1}$, ..., $C_{k,D}$, ..., $C_{K,1}$, ..., $C_{K,D}$) are then individually conveyed through a joint multiplexer towards a joint non-linear and linear precoding module 800 comprising a plurality of multi-user encoders (800-1, ..., 800-D) respectively dedicated to each carrier (1, ..., D).

Fig. 9 illustrates an individual multi-user encoder 800-d dedicated to a respective carrier d and using a joint non-linear and linear precoding according to an embodiment of the present invention.

In addition to its dedicated constellation symbols ($c_{1,d}$, $c_{2,d}$, ..., $c_{K,d}$), the multi-user encoder 800-d receives a plurality of inputs respectively related to the power allocation strategy for its dedicated carrier d, which corresponds to the powers allocated to the streams of its dedicated constellation symbols ($c_{1,d}$, $c_{2,d}$, ..., $c_{K,d}$), related to the users's ordering, which is based on the CSI of its dedicated carrier d and on the power allocation strategy, related to the CSI of its dedicated carrier d, which corresponds to the information about the communication channels ($H_{1,d}$, $H_{2,d}$, ..., $H_{K,d}$), and related to its dedicated linear filter F_{LFd} as designed or computed by the linear precoders unit of the optimization solver.

Based on the power allocation ($P_{1,d}$, ..., $P_{K,d}$), on the channel state information ($H_{1,d}$, $H_{2,d}$, ..., $H_{K,d}$) and on the computed linear filter (F_{LFd}), the multi-user encoder 800-d computes the precoding parameters or factors ($\alpha_{1,d}$, $\alpha_{2,d}$, ..., $\alpha_{K,d}$) using, for example, an optimal minimum mean square error (MMSE) precoding filtering for the respective user. Those precoding parameters ($\alpha_{1,d}$, $\alpha_{2,d}$, ..., $\alpha_{K,d}$) along with the powers ($P_{1,d}$, $P_{2,d}$, ..., $P_{K,d}$) allocated to each user amongst the K users are then utilized by a respective lattice encoder through an intra-carrier lattice-based non-linear precoding (f_{NLP}), which is performed in a sequential manner. Thereby, the intra-carrier lattice-based non-linear precoding cancels out successively the interfering components and yields the following signal:

$$\tilde{X}_d = \begin{pmatrix} \tilde{x}_{1,d} \\ \vdots \\ \tilde{x}_{K,d} \end{pmatrix} = f_{NLP}\left(c_{1,d}, \dots, c_{K,d}, P_{1,d}, \dots, P_{K,d}, F_{LF_d}, H_{1,d}, \dots, H_{K,d}\right) \tag{23}$$

where $\tilde{x}_{1,d}, \dots, \tilde{x}_{K,d}$ represent the intermediate signals respectively output from each lattice encoder and f_{NLP} denotes the non-linear precoding.

All the obtained intermediate signals $(\tilde{x}_{1,d}, \dots, \tilde{x}_{K,d})$ are afterwards provided to the linear precoder dedicated to the carrier d, in order to be linearly precoded into an output signal X_d through the dedicated computed linear filter F_{LFd} as previously designed or computed by the linear precoders unit of the optimization solver.

The output signal X_d, which is given by:

$$X_d = F_{LF_d} \times \begin{pmatrix} \tilde{x}_{1,d} \\ \vdots \\ \tilde{x}_{K,d} \end{pmatrix} = F_{LF_d} \times f_{NLP}\left(c_{1,d}, \dots, c_{K,d}, P_{1,d}, \dots, P_{K,d}, F_{LF_d}, H_{1,d}, \dots, H_{K,d}\right) \qquad (24)$$

is then fed to the RF components of the transmitter (Tx) for downlink transmission over the antennas of the carrier d towards the plurality of K users.

At the receiver side of Fig. 7, each one amongst the plurality of K users receives a respective D-dimensional signal (Y_1, Y_2, ..., Y_K), which is individually transmitted from the plurality of D multi-user encoders over the plurality of D carriers, and comprises a single-user decoder (900-1, 900-2, ..., 900-K) adapted to individually decode the corresponding D-dimensional signal (Y_1, Y_2, ..., Y_K).

Fig. 10 illustrates a single-user decoder 900-k individually dedicated to the respective k-th user and receiving its dedicated D-dimensional signal Y_k.

As can be seen from Fig. 10, the D-dimensional signal Y_k is de-multiplexed into a plurality of D signals ($Y_{k,1}$, $Y_{k,2}$, ..., $Y_{k,D}$), which, along with a respective receive filter parameter or decoding scalar (ß$_{k,1}$, ß$_{k,2}$, ..., ß$_{k,D}$), are individually provided to a respective inter-carrier lattice-based decoder in order to be decoded into a respective plurality of D estimated constellation codewords ($\hat{c}_{k,1}$, $\hat{c}_{k,2}$, ..., $\hat{c}_{k,D}$). Those receive filter parameters can be computed by the single-user decoder based on both the channel state information (CSI) of the k-th user on each of the D carriers and the power allocated to the k-th user. However, it should be noted that they can alternatively be computed by the transmitter (Tx) and be afterwards forwarded towards the single-user decoder 900-k of the k-th user.

All the D estimated constellation codewords ($\hat{c}_{k,1}$, $\hat{c}_{k,2}$, ..., $\hat{c}_{k,D}$) dedicated to the k-th user are then fed to a joint forward error correction (FEC) and diversity decoder, such as a sparse code multiple access (SCMA) decoder, a turbo decoder and a repetition code, in order to be decoded into a respective estimated binary stream ($\hat{b}_k$), which is then processed in order to recover an estimation of the message ($\hat{W}_k$) intended for the k-th user.

Thus, each user decodes only its intended signals through its dedicated single-user decoder of low complexity, since requiring no successive interference cancellation procedure. Thereby, all the multi-user interference mitigation complexity can be relegated to the transmitter.

In the following, an exemplary embodiment of the present invention is described in conjunction with the NOMA downlink transmission system 600 in a multiple-input single-output (MISO) configuration of Fig. 7.

In that specific embodiment, the diversity codebook is a SCMA codebook and the fairness constraint is a reliability fairness constraint.

Pertaining to the power allocation strategy and linear filter design, let us assume that all the users are required to experience a probability of error ε, such as a packet-loss rate and a bit-error rate, not less than a given level P_ε at a given SNR.

Pertaining to the optimization solver, let us assume, without loss of generality, that the users are ordered in an increasing order in k. The power allocation unit consists in an inter-carrier power allocation that is performed through the waterfilling algorithm such that:

$$P_d = \max\left(0, \max_k\left(\frac{1}{2\lambda} - \frac{N_{k,d}}{|\mathbf{H}|^2_{k,d}}\right)\right) \tag{25}$$

where λ is solution of the following equation:

$$\sum_{d=1}^{D} \max\left(0, \max_{k=1,\dots,K}\left(\frac{1}{2\lambda} - \frac{N_{k,d}}{|\mathbf{H}|^2_{k,d}}\right)\right) = P \tag{26}$$

As regards the intra-carrier power allocation, we define the signal-to-interference and noise ratio (SINR) at each k-th user over the carrier d as follows:

$$\mathrm{SINR}_{k,d} = \frac{l_{kk,d}^2 P_{k,d}}{l_{kk,d}^2 P_{k,d} + \sum_{l'=k+1}^{K} l_{kl',d}^2 P_{l',d} + N_{k,d}} \tag{27}$$

The powers ($P_{1,d}, \ldots, P_{K,d}$) allocated to all the K users over the carrier d, the linear filter F_{LF_d} and the ordering π of all the K users, are derived by solving the following optimization problem:

$$\max_{\substack{(P_{1,d},\ldots,P_{K,d}) \\ \pi \\ \mathbf{F}_{LP_d}}} \min_{k=1,\ldots K} \mathrm{SINR}_{k,d} \tag{28}$$

subject to: $$\sum_{k=1}^{K} P_{k,d} = P_d \tag{29}$$

where F_{LF_d} is a unitary matrix and π is a permutation of the set of all the possible users $\{1, \ldots, K\}$.

In conjunction with the individual multi-user encoder 800-d dedicated to the respective carrier d of Fig. 9 and with the aim of optimizing the overall performance of the wireless communication system, the equivalent communication channel of the carrier d, namely the channel seen at the user k after linear filtering through the linear precoder, is assumed to be given by the following:

$$\begin{bmatrix} H_{1,d} \\ \vdots \\ H_{K,d} \end{bmatrix} F_{LF_d} = \begin{bmatrix} l_{11,d} & 0 & 0 & l_{14,d} & l_{15,d} & l_{16,d} \\ l_{21,d} & l_{22,d} & 0 & 0 & l_{25,d} & l_{26,d} \\ l_{31,d} & l_{32,d} & l_{33,d} & 0 & 0 & l_{36,d} \\ l_{41,d} & l_{42,d} & l_{43,d} & l_{44,d} & 0 & 0 \\ l_{51,d} & l_{52,d} & l_{53,d} & l_{54,d} & l_{55,d} & 0 \\ l_{61,d} & l_{62,d} & l_{63,d} & l_{64,d} & l_{65,d} & l_{66,d} \end{bmatrix} \tag{30}$$

The respective lattice encoder can then be implemented so as to output the following intermediate signal dedicated to the k-th user:

$$\tilde{x}_{k,d} = \left[c_{k,d} + \alpha_{k,d} \sum_{l=1}^{k-1} l_{kl,d} \cdot \tilde{x}_{l,d} + d_k\right] \mathrm{mod} \Lambda_{k,d} \tag{31}$$

where $c_{k,d}$ is the constellation codeword intended for the k-th user on the carrier d, $\Lambda_{k,d}$ is a given n-dimensional lattice with a generalized second moment $\sigma_{k,d}^2 = P_{k,d}$, $l_{kl,d}$ is the projected value of $H_{k,d}$ over the l-th column of $\mathbf{F}_{LF_d}$, d_k is a random dither sequence chosen uniformly over the Voronoi region of the lattice $\Lambda_{k,d}$, and $\alpha_{k,d}$ is the optimal minimum mean square error (MMSE) precoding filter for the user k and is given by:

$$\alpha_{k,d} = \frac{l_{kk,d}^2 P_{k,d}}{l_{kk,d}^2 P_{k,d} + \sum_{l'=k+1}^{K} l_{kl',d}^2 P_{l',d} + N_{k,d}} \tag{32}$$

All the obtained intermediate signals $\left(\tilde{x}_{1,d}, \ldots, \tilde{x}_{K,d}\right)$ are afterwards provided to the linear precoder dedicated to the carrier d, in order to be linearly precoded into an output signal X_d for the carrier d:

$$X_d = F_{LF_d} \times \begin{pmatrix} \tilde{x}_{1,d} \\ \vdots \\ \tilde{x}_{K,d} \end{pmatrix} \tag{33}$$

through the dedicated computed linear filter F_{LFd} as previously designed or computed by the linear precoders unit of the optimization solver.

Referring to the single-user decoder 900-k individually dedicated to the respective k-th user of Fig. 10, the estimated constellation codeword ($\hat{c}_{k,d}$) output from the inter-carrier lattice-based decoder dedicated to the d-th carrier can be formulated as follows:

$$\hat{c}_{k,d} = \left[\beta_{k,d} \cdot y_{k,d} - d_k\right] \mathrm{mod} \Lambda_{k,d} \tag{34}$$

where $\mathrm{y}_{\mathrm{k,d}}$ is the received signal at the k-th user, d_{k} is the dither sequence associated to the k-th user, and $\beta_{\mathrm{k,d}}$ is the optimal MMSE receive filter for the k-th user and is given by:

$$\beta_{\mathrm{k,d}} = \frac{\alpha_{\mathrm{k,d}}}{\mathrm{l}_{\mathrm{kk,d}}} = \frac{\mathrm{l}_{\mathrm{kk,d}} \mathrm{P}_{\mathrm{k,d}}}{\mathrm{l}_{\mathrm{kk,d}}^2 \mathrm{P}_{\mathrm{k,d}} + \sum_{\mathrm{l}'=\mathrm{k}+1}^{\mathrm{K}} \mathrm{l}_{\mathrm{kl}',\mathrm{d}}^2 \mathrm{P}_{\mathrm{l}',\mathrm{d}} + \mathrm{N}_{\mathrm{k,d}}} \tag{35}$$

In summary, the present invention relates to a wireless communication system for downlink transmitting, through a plurality of orthogonal carriers and according to a non-orthogonal multiple access transmission scheme in a multiple-input single-output configuration, a plurality of messages towards, respectively, a plurality of users (i.e., receivers or UE devices). At the transmitter side, a power allocation strategy subjected to a total power budget constraint and a linear filter computation based on the channel state information are jointly designed to meet a prescribed fairness constraint. The computed linear filter is adapted to balance interference caused to each user by the users being served at identical resources and is then used through an intra-carrier lattice-based non-linear precoding to mitigate the interference and also through a linear precoding to output a signal to be transmitted on the respective carrier towards each user. At the receiver side, the plurality of messages is finally recovered thanks to a simple single-user decoder.

While the invention has been illustrated and described in detail in the drawings and the foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive. The invention is not limited to the disclosed embodiments. From reading the present disclosure, other modifications will be apparent to a person skilled in the art. Such modifications may involve other features that are already known in the art and that may be used instead of or in addition to features already described herein.

The invention has been described in conjunction with various embodiments herein. However, other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

Although the present invention has been described with reference to specific features and embodiments thereof, it is evident that various modifications and combinations can be made thereto without departing from the spirit and scope of the invention. The specification and drawings are, accordingly, to be regarded simply as an illustration of the invention as defined by the appended claims, and are contemplated to cover any and all modifications, variations, combinations or equivalents that fall within the scope of the present invention.

CLAIMS

1. A base station (BS) for transmitting, through a plurality of orthogonal carriers and according to a non-orthogonal multiple access (NOMA) transmission scheme in a multiple-input single-output configuration, a plurality of messages towards, respectively, a plurality of user equipment (UE) devices, the BS comprising:

- an optimization solver, the optimization solver being adapted to optimize, under a fairness constraint, an inter-carrier and intra-carrier power allocation taking account of an overall power budget, and a computation of a linear filter based on a channel state information (CSI) of each channel linking the whole plurality of carriers to the plurality of UE devices.

2. The base station of claim 1, wherein the optimization solver is adapted to optimize, under the fairness constraint, an ordering of the plurality of UE devices based on the CSI of each channel linking the whole plurality of carriers to the plurality of UE devices and based on the inter-carrier and intra-carrier power allocation.

3. The base station of claim 1 or 2, wherein the computed linear filter is adapted to balance interference caused to each other UE device by the UE devices being served at identical resources.

4. The base station of any one of the preceding claims, the BS comprising:

- a plurality of multi-user encoders individually dedicated to a respective carrier, each multi-user encoder being adapted to map, through an intra-carrier lattice-based non-linear precoding process followed by a linear precoding process, a plurality of symbols into an output signal to be transmitted on the respective carrier towards the plurality of UE devices,

wherein:

  - the linear precoding is performed by a linear precoder using the computed linear filter dedicated to the respective carrier and adapted to linearly precode the entirety of the signals resulting from the intra-carrier lattice-based non-linear precoding process so as to obtain the output signal to be transmitted on the respective carrier; and
  - the entirety of the signals individually output from the plurality of multi-user encoders is a function of the plurality of messages to be respectively transmitted towards the plurality of UE devices.

5. The base station of claim 4, wherein the intra-carrier lattice-based non-linear precoding is based on the intra-carrier power allocation for the respective carrier, on the users' ordering, on the CSI of each channel linking the respective carrier to the plurality of UE devices, and on the computed linear filter dedicated to the respective carrier.

6. The base station of claim 5, wherein the intra-carrier lattice-based non-linear precoding is carried out in a sequential manner in order to successively cancel out the interfering symbols amongst the plurality of symbols.

7. The base station of any one of the preceding claims, wherein the fairness constraint is a throughput fairness constraint or a reliability fairness constraint.

8. A user equipment (UE) device, wherein the UE device:

- receives a plurality of signals transmitted from a base station (BS) as claimed in claim 4 and individually output from the plurality of multi-user encoders through the plurality of orthogonal carriers; and
- comprises a single-user decoder, the single-user decoder being adapted to individually decode each signal of the received plurality of signals using a respective inter-carrier lattice-based decoder.

9. A wireless communication system comprising:

- a base station (BS) as specified in claim 8; and

- a plurality of user equipment (UE) devices as individually claimed in claim 8.

10. A method for transmitting, through a plurality of orthogonal carriers and according to a non-orthogonal multiple access (NOMA) transmission scheme in a multiple-input single-output configuration, a plurality of messages towards, respectively, a plurality of user equipment (UE) devices, the method comprising:

- optimizing, under a fairness constraint, an inter-carrier and intra-carrier power allocation taking account of an overall power budget, and a computation of a linear filter based on a channel state information (CSI) of each channel linking the whole plurality of carriers to the plurality of UE devices.

11. The method of claim 10, wherein the method comprises:

- optimizing, under the fairness constraint, an ordering of the plurality of UE devices based on the CSI of each channel linking the whole plurality of carriers to the plurality of UE devices and based on the inter-carrier and intra-carrier power allocation.

12. The method of claim 10 or 11, wherein the method comprises for each carrier:

- mapping, through an intra-carrier lattice-based non-linear precoding process followed by a linear precoding process, a plurality of symbols into an output signal to be transmitted on a respective carrier towards the plurality of UE devices,

wherein:

  - the linear precoding is performed by a linear precoder using the computed linear filter dedicated to the respective carrier and adapted to linearly precode the entirety of the signals resulting from the intra-carrier lattice-based non-linear precoding process so as to obtain the output signal to be transmitted on the respective carrier; and
  - the entirety of the signals individually output from the plurality of multi-user encoders is a function of the plurality of messages to be respectively transmitted towards the plurality of UE devices.

13. The method of claim 12, wherein the method comprises for each UE device:
- receiving from the BS a plurality of signals, which are individually output from the plurality of multi-user encoders through the plurality of orthogonal carriers; and
- decoding individually each signal of the received plurality of signals using a respective inter-carrier lattice-based decoder.

14. A computer program comprising program code for performing the method according to any one of claims 10 to 13 when executed on a computer.

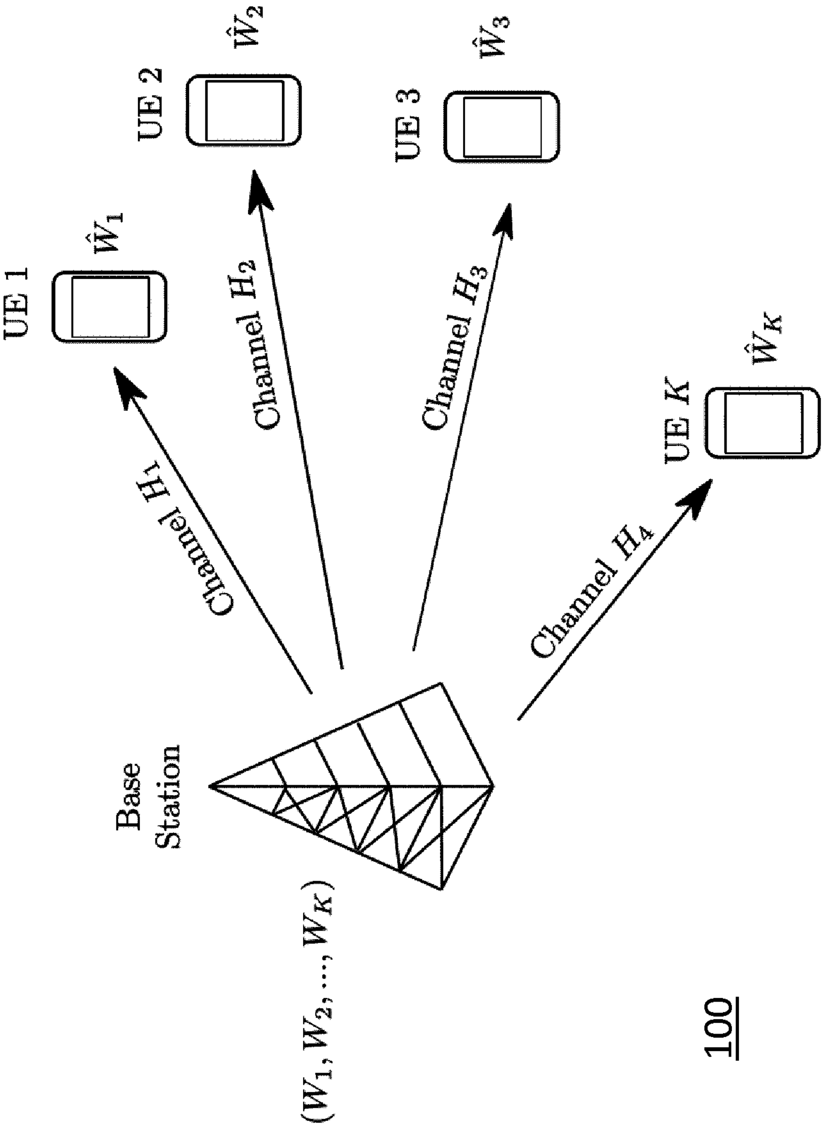
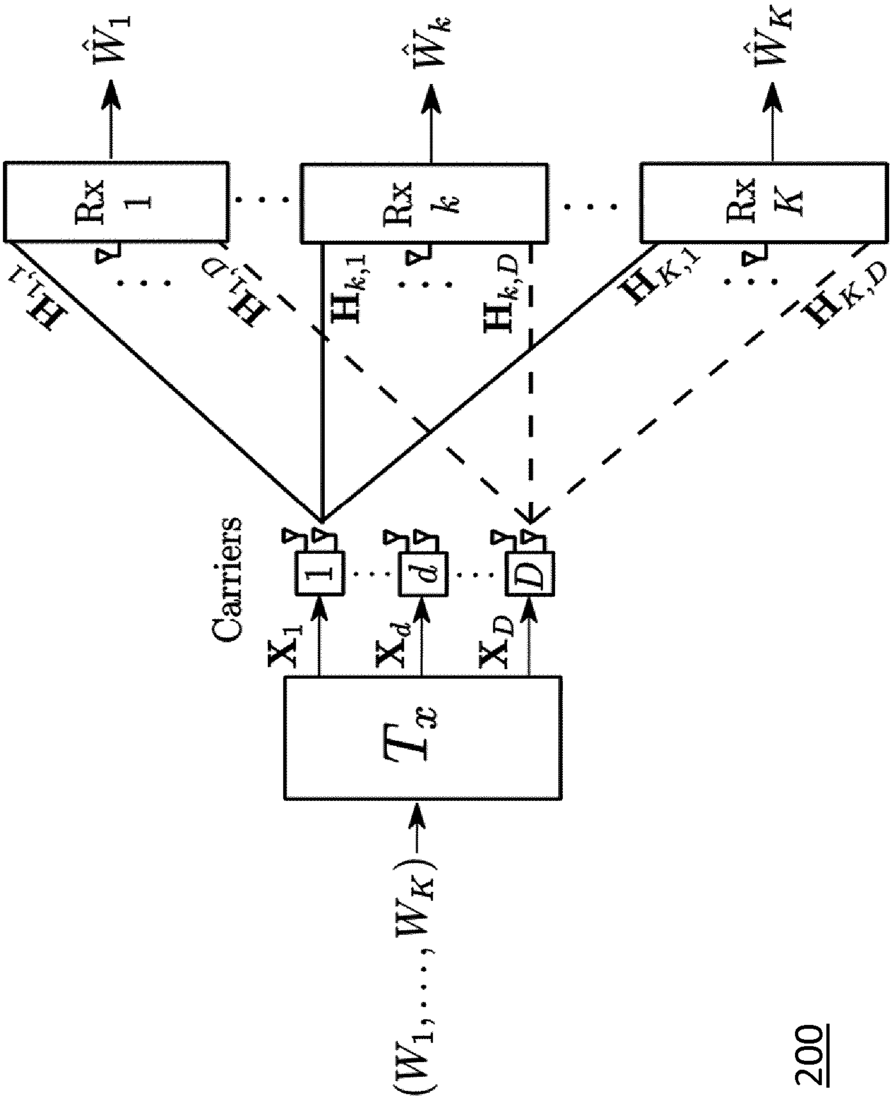

Base Station
$(W_1, W_2, \ldots, W_K)$
Channel H_1
Channel H_2
Channel H_3
Channel H_4
UE 1
$\hat{W}_1$
UE 2
$\hat{W}_2$
UE 3
$\hat{W}_3$
UE K
$\hat{W}_K$
100

Fig. 1

Fig. 2


$(W_1, \ldots, W_K)$
T_x
$\mathbf{X}_1$
$\mathbf{X}_d$
$\mathbf{X}_D$
Carriers
1
d
D
$\mathbf{H}_{1,1}$
$\mathbf{H}_{1,D}$
$\mathbf{H}_{k,1}$
$\mathbf{H}_{k,D}$
$\mathbf{H}_{K,1}$
$\mathbf{H}_{K,D}$
Rx 1
Rx k
Rx K
$\hat{W}_1$
$\hat{W}_k$
$\hat{W}_K$
200

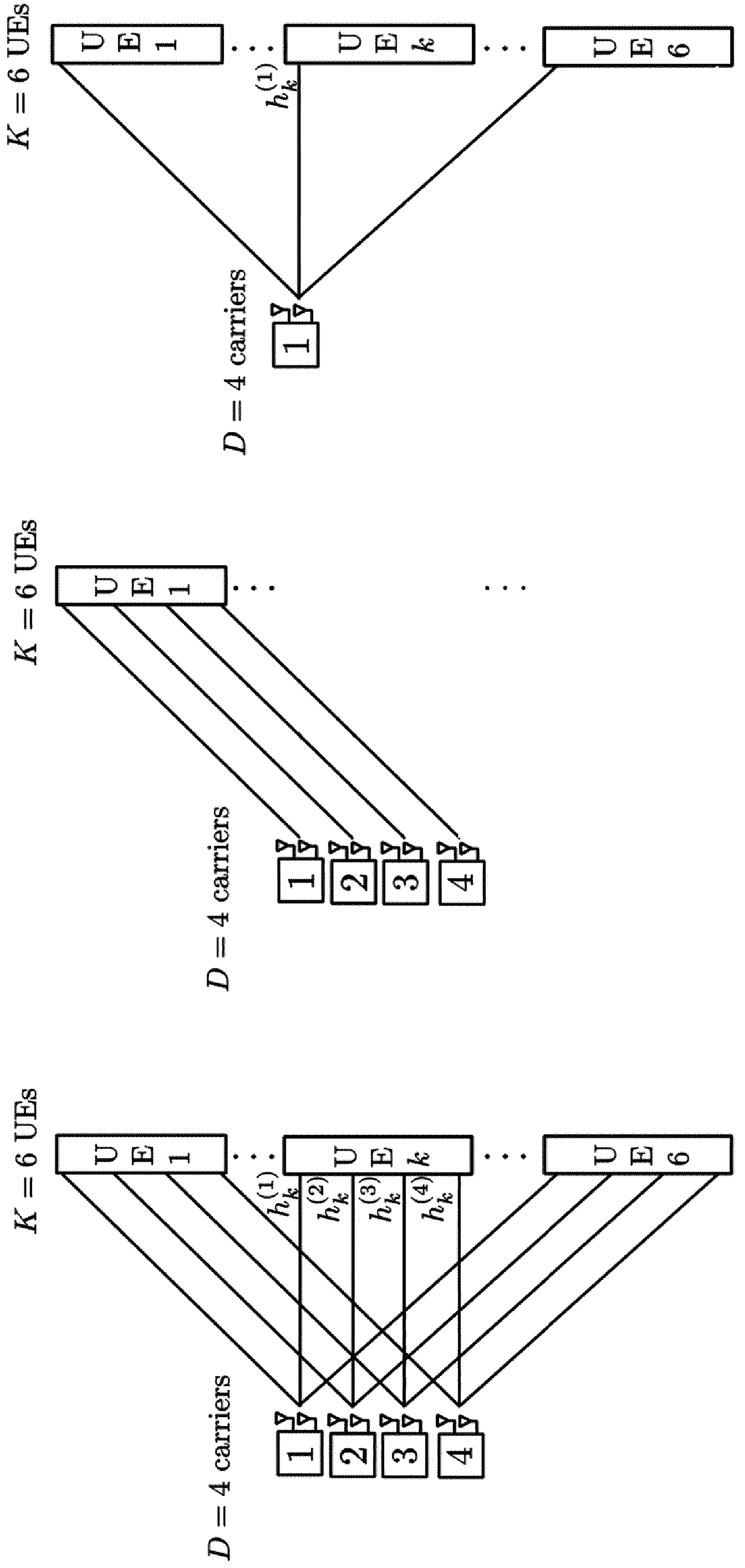
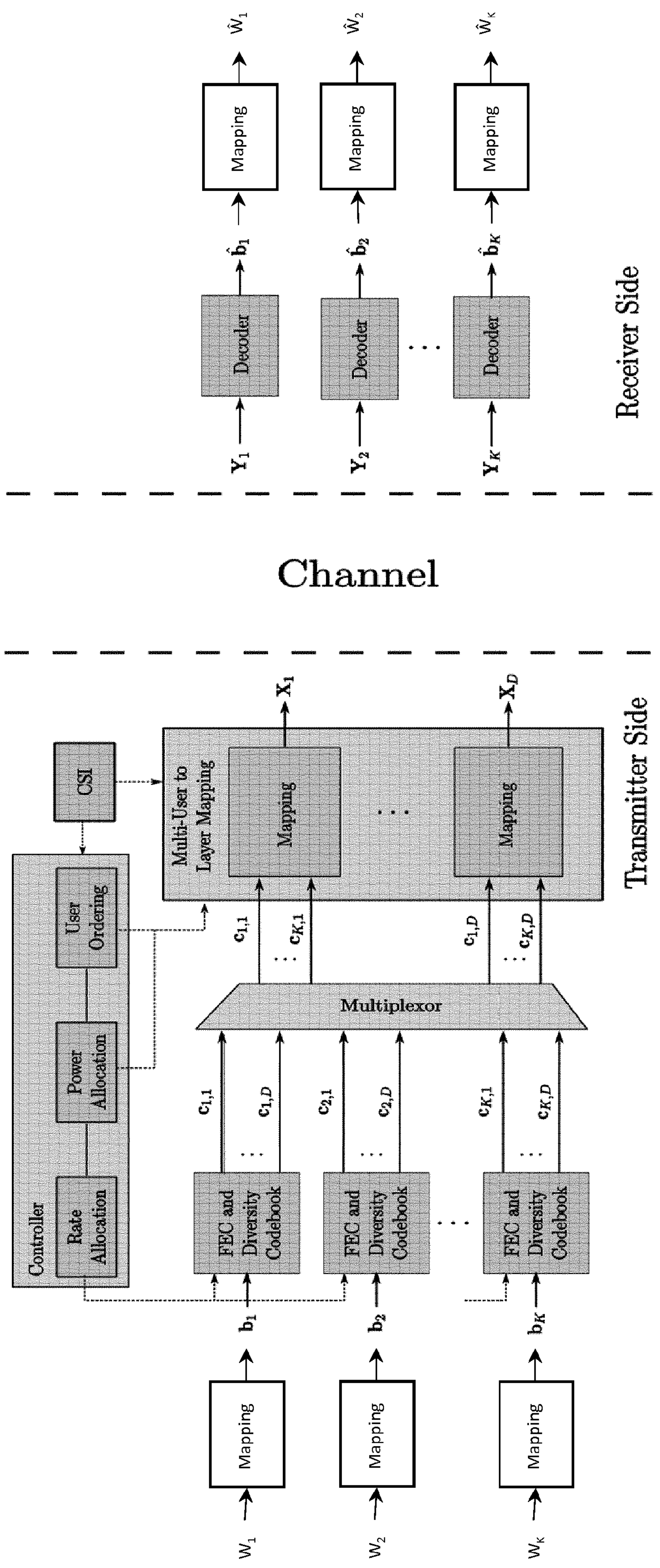

K = 6 UEs
UE 1
UE k
UE 6
$h_k^{(1)}$
D = 4 carriers
1
K = 6 UEs
UE 1
D = 4 carriers
1
2
3
4
K = 6 UEs
UE 1
UE k
UE 6
$h_k^{(1)}$
$h_k^{(2)}$
$h_k^{(3)}$
$h_k^{(4)}$
D = 4 carriers
1
2
3
4

Fig. 3


W_1
W_2
W_K
Mapping
Mapping
Mapping
$\mathbf{b}_1$
$\mathbf{b}_2$
$\mathbf{b}_K$
Controller
Rate Allocation
Power Allocation
User Ordering
CSI
FEC and Diversity Codebook
FEC and Diversity Codebook
FEC and Diversity Codebook
$\mathbf{c}_{1,1}$
$\mathbf{c}_{1,D}$
$\mathbf{c}_{2,1}$
$\mathbf{c}_{2,D}$
$\mathbf{c}_{K,1}$
$\mathbf{c}_{K,D}$
Multiplexor
$\mathbf{c}_{1,1}$
$\mathbf{c}_{K,1}$
$\mathbf{c}_{1,D}$
$\mathbf{c}_{K,D}$
Multi-User to Layer Mapping
Mapping
Mapping
$\mathbf{X}_1$
$\mathbf{X}_D$
Transmitter Side
Channel
$\mathbf{Y}_1$
$\mathbf{Y}_2$
$\mathbf{Y}_K$
Decoder
Decoder
Decoder
$\hat{\mathbf{b}}_1$
$\hat{\mathbf{b}}_2$
$\hat{\mathbf{b}}_K$
Mapping
Mapping
Mapping
$\hat{W}_1$
$\hat{W}_2$
$\hat{W}_K$
Receiver Side

300

Fig. 4

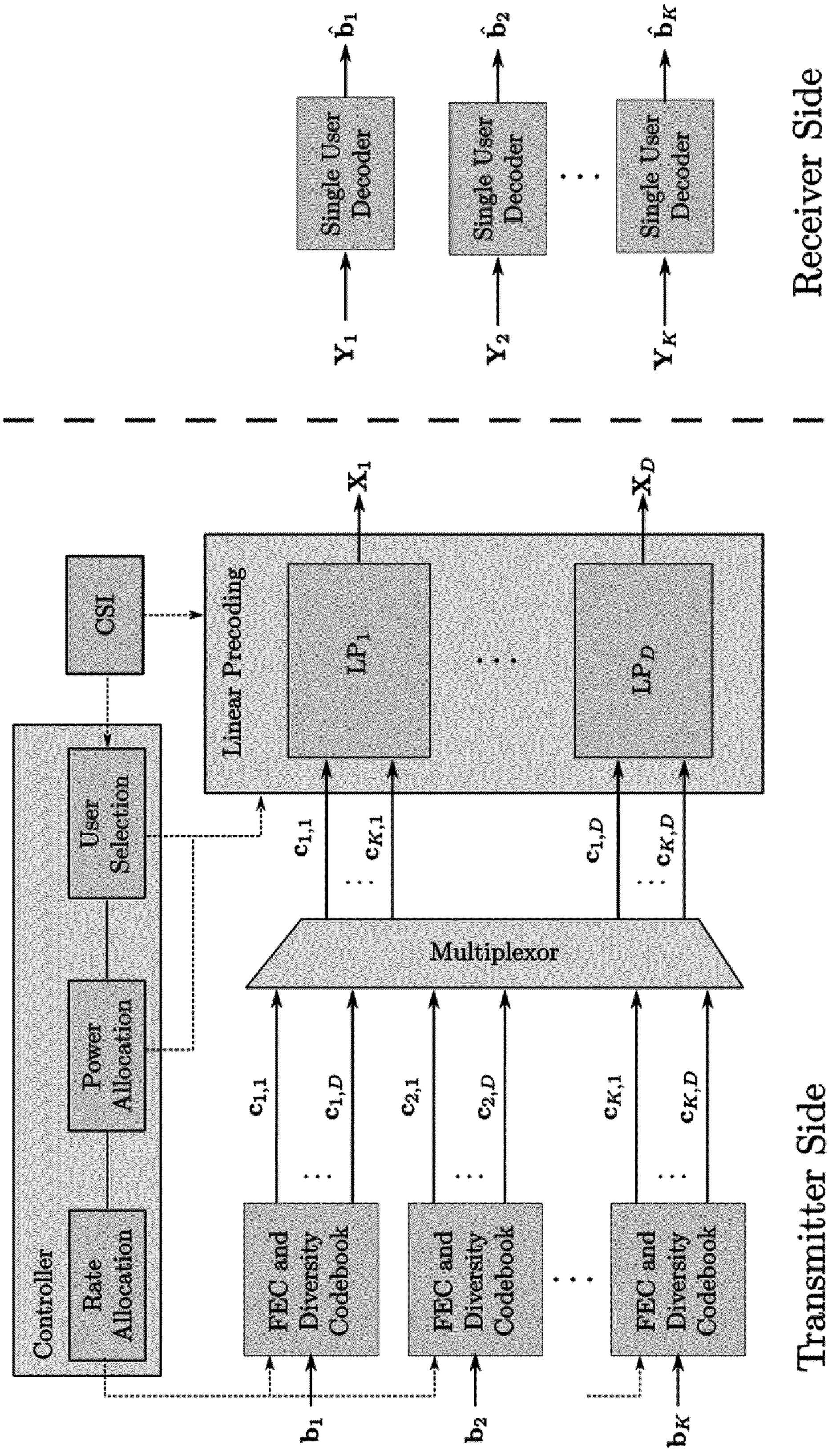

Controller
Rate Allocation
Power Allocation
User Selection
CSI
Linear Precoding
LP_1
LP_D
$\mathbf{X}_1$
$\mathbf{X}_D$
Multiplexor
FEC and Diversity Codebook
FEC and Diversity Codebook
FEC and Diversity Codebook
$\mathbf{b}_1$
$\mathbf{b}_2$
$\mathbf{b}_K$
$\mathbf{c}_{1,1}$
$\mathbf{c}_{1,D}$
$\mathbf{c}_{2,1}$
$\mathbf{c}_{2,D}$
$\mathbf{c}_{K,1}$
$\mathbf{c}_{K,D}$
Transmitter Side
Receiver Side
$\mathbf{Y}_1$
$\mathbf{Y}_2$
$\mathbf{Y}_K$
Single User Decoder
Single User Decoder
Single User Decoder
$\hat{\mathbf{b}}_1$
$\hat{\mathbf{b}}_2$
$\hat{\mathbf{b}}_K$
400

Fig. 5

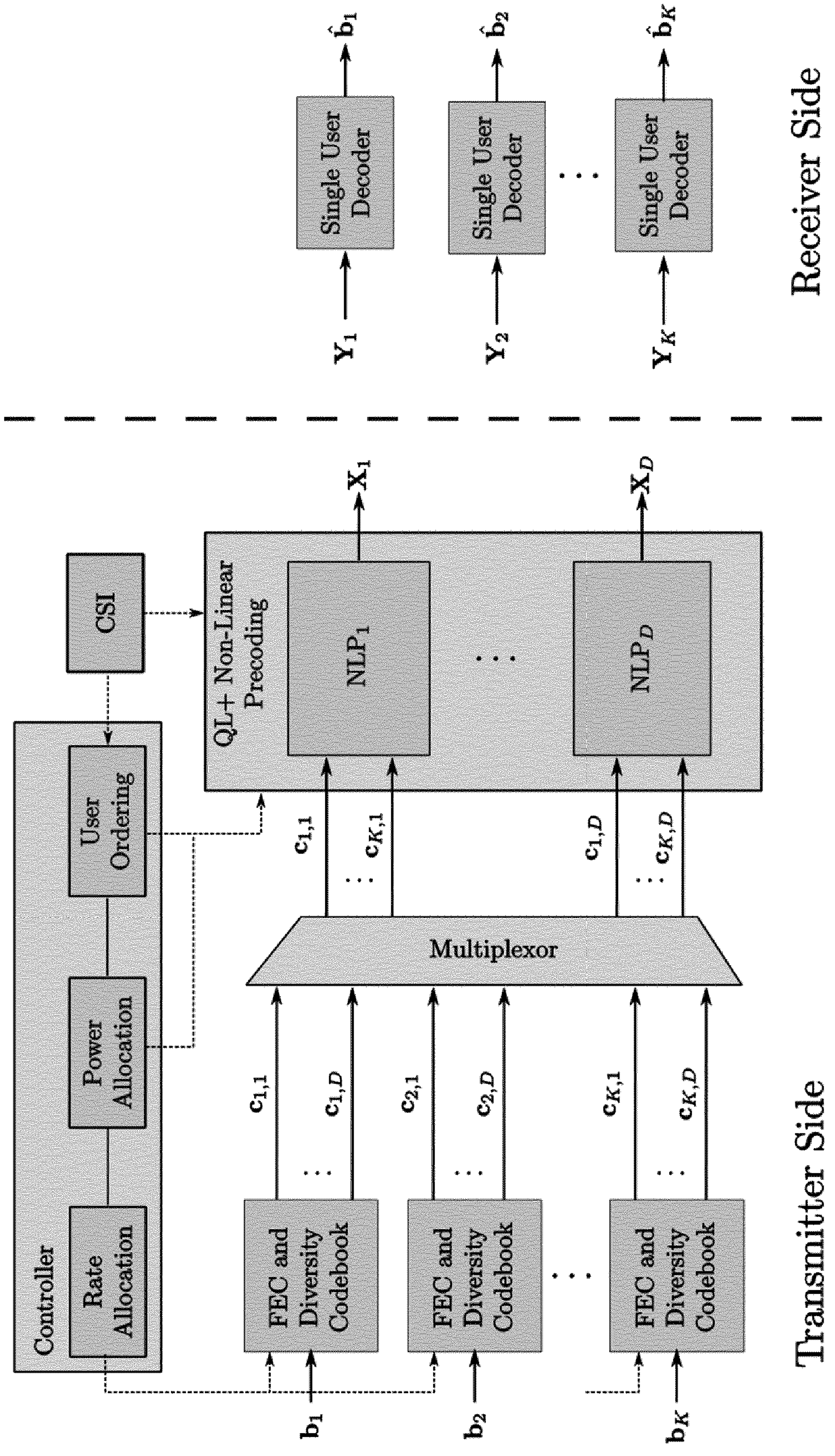

Controller
Rate Allocation
Power Allocation
User Ordering
CSI
QL+ Non-Linear Precoding
NLP$_1$
NLP$_D$
Multiplexor
FEC and Diversity Codebook
FEC and Diversity Codebook
FEC and Diversity Codebook
$\mathbf{b}_1$
$\mathbf{b}_2$
$\mathbf{b}_K$
$\mathbf{c}_{1,1}$
$\mathbf{c}_{1,D}$
$\mathbf{c}_{2,1}$
$\mathbf{c}_{2,D}$
$\mathbf{c}_{K,1}$
$\mathbf{c}_{K,D}$
$\mathbf{c}_{1,1}$
$\mathbf{c}_{K,1}$
$\mathbf{c}_{1,D}$
$\mathbf{c}_{K,D}$
$\mathbf{X}_1$
$\mathbf{X}_D$
Transmitter Side
Receiver Side
$\mathbf{Y}_1$
$\mathbf{Y}_2$
$\mathbf{Y}_K$
Single User Decoder
Single User Decoder
Single User Decoder
$\hat{\mathbf{b}}_1$
$\hat{\mathbf{b}}_2$
$\hat{\mathbf{b}}_K$
500

Fig. 6

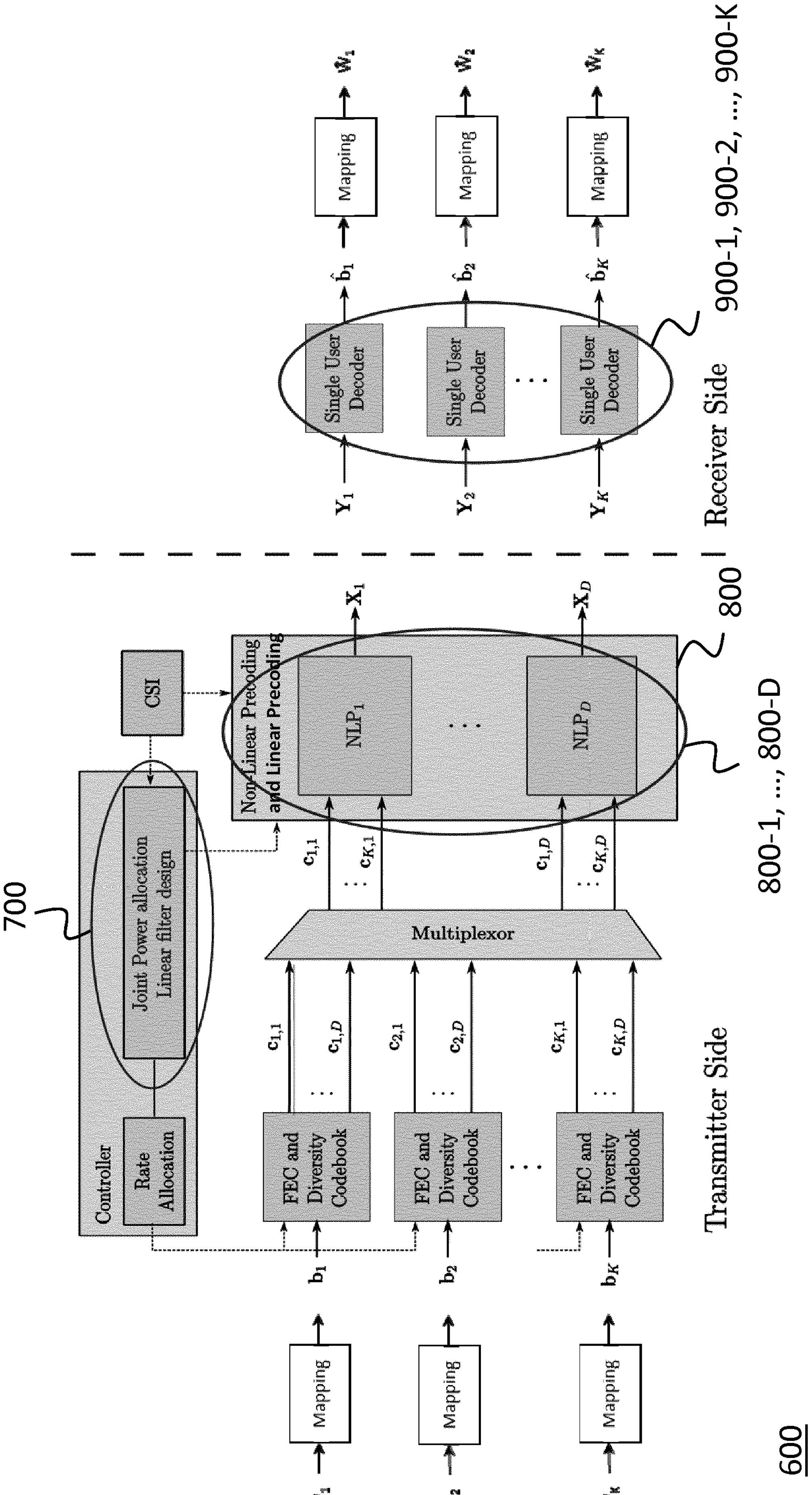

600
700
Controller
Rate Allocation
Joint Power allocation Linear filter design
CSI
$\mathbf{w}_1$
$\mathbf{w}_2$
$\mathbf{w}_K$
Mapping
Mapping
Mapping
$\mathbf{b}_1$
$\mathbf{b}_2$
$\mathbf{b}_K$
FEC and Diversity Codebook
FEC and Diversity Codebook
FEC and Diversity Codebook
$\mathbf{c}_{1,1}$
$\mathbf{c}_{1,D}$
$\mathbf{c}_{2,1}$
$\mathbf{c}_{2,D}$
$\mathbf{c}_{K,1}$
$\mathbf{c}_{K,D}$
Multiplexor
$\mathbf{c}_{1,1}$
$\mathbf{c}_{K,1}$
$\mathbf{c}_{1,D}$
$\mathbf{c}_{K,D}$
Non-Linear Precoding and Linear Precoding
NLP_1
NLP_D
$\mathbf{X}_1$
$\mathbf{X}_D$
800
800-1, ..., 800-D
Transmitter Side
$\mathbf{Y}_1$
$\mathbf{Y}_2$
$\mathbf{Y}_K$
Single User Decoder
Single User Decoder
Single User Decoder
$\hat{\mathbf{b}}_1$
$\hat{\mathbf{b}}_2$
$\hat{\mathbf{b}}_K$
Mapping
Mapping
Mapping
$\hat{\mathbf{w}}_1$
$\hat{\mathbf{w}}_2$
$\hat{\mathbf{w}}_K$
Receiver Side
900-1, 900-2, ..., 900-K

Fig. 7

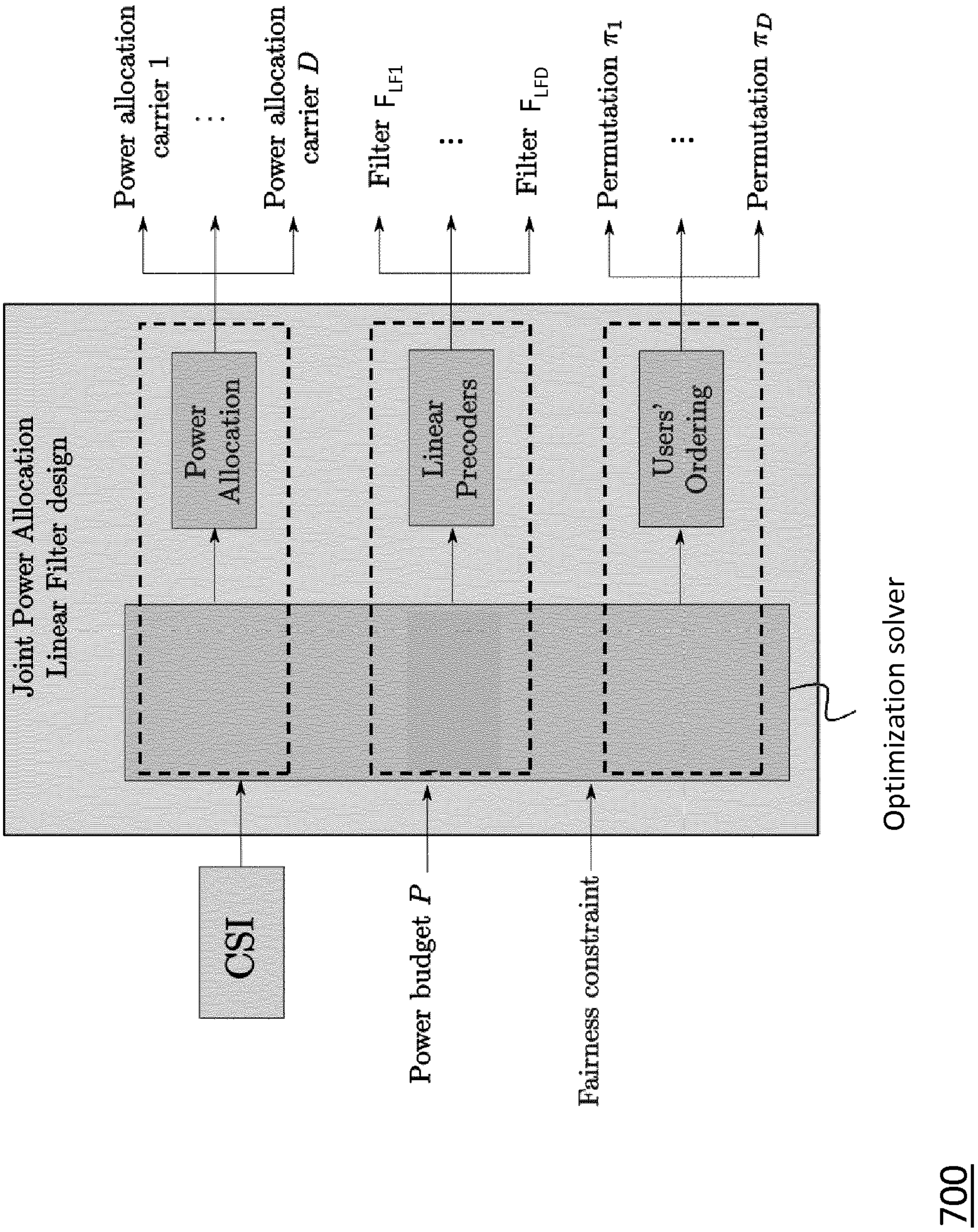

Joint Power Allocation
Linear Filter design
CSI
Power budget P
Fairness constraint
Power Allocation
Linear Precoders
Users' Ordering
Optimization solver
Power allocation carrier 1
...
Power allocation carrier D
Filter F_{LF1}
...
Filter F_{LFD}
Permutation π_1
...
Permutation π_D
700

Fig. 8

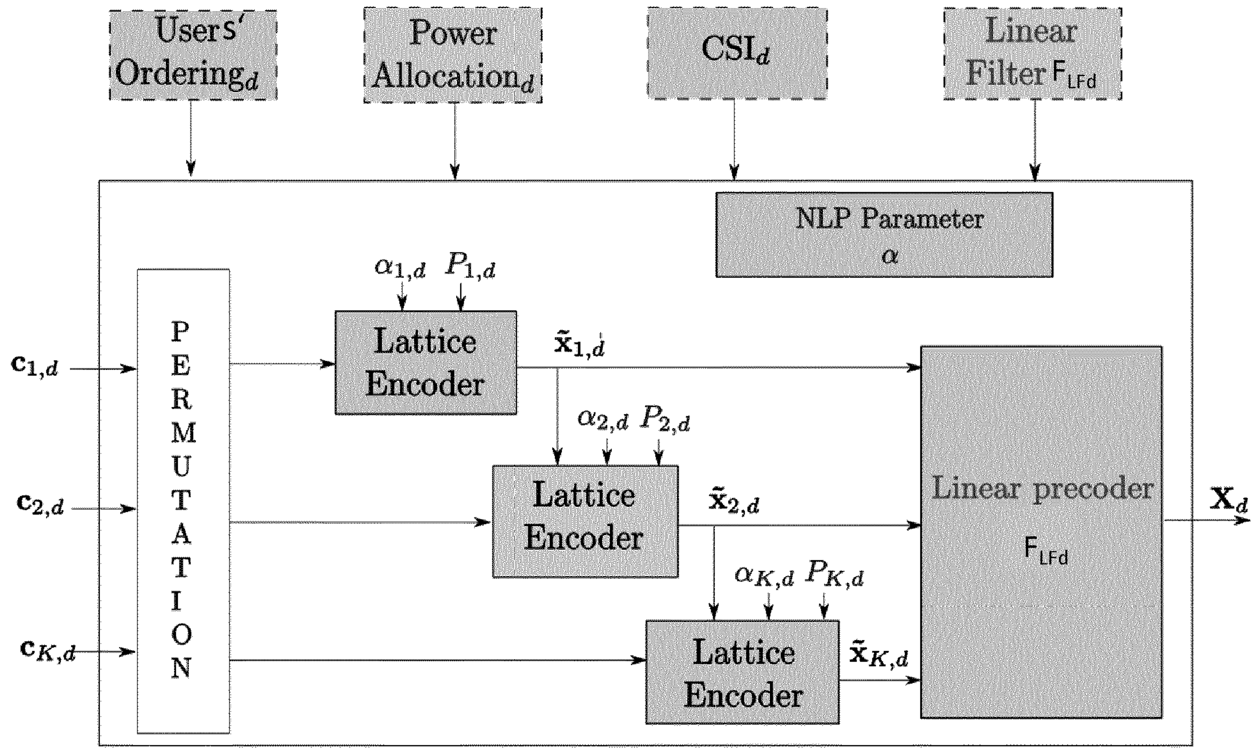

Users' Ordering$_d$
Power Allocation$_d$
CSI$_d$
Linear Filter F_{LFd}
NLP Parameter α
$\alpha_{1,d}$ $P_{1,d}$
$\mathbf{c}_{1,d}$
$\mathbf{c}_{2,d}$
$\mathbf{c}_{K,d}$
PERMUTATION
Lattice Encoder
$\tilde{\mathbf{x}}_{1,d}$
$\alpha_{2,d}$ $P_{2,d}$
Lattice Encoder
$\tilde{\mathbf{x}}_{2,d}$
$\alpha_{K,d}$ $P_{K,d}$
Lattice Encoder
$\tilde{\mathbf{x}}_{K,d}$
Linear precoder
F_{LFd}
$\mathbf{X}_d$
800-d

Fig. 9

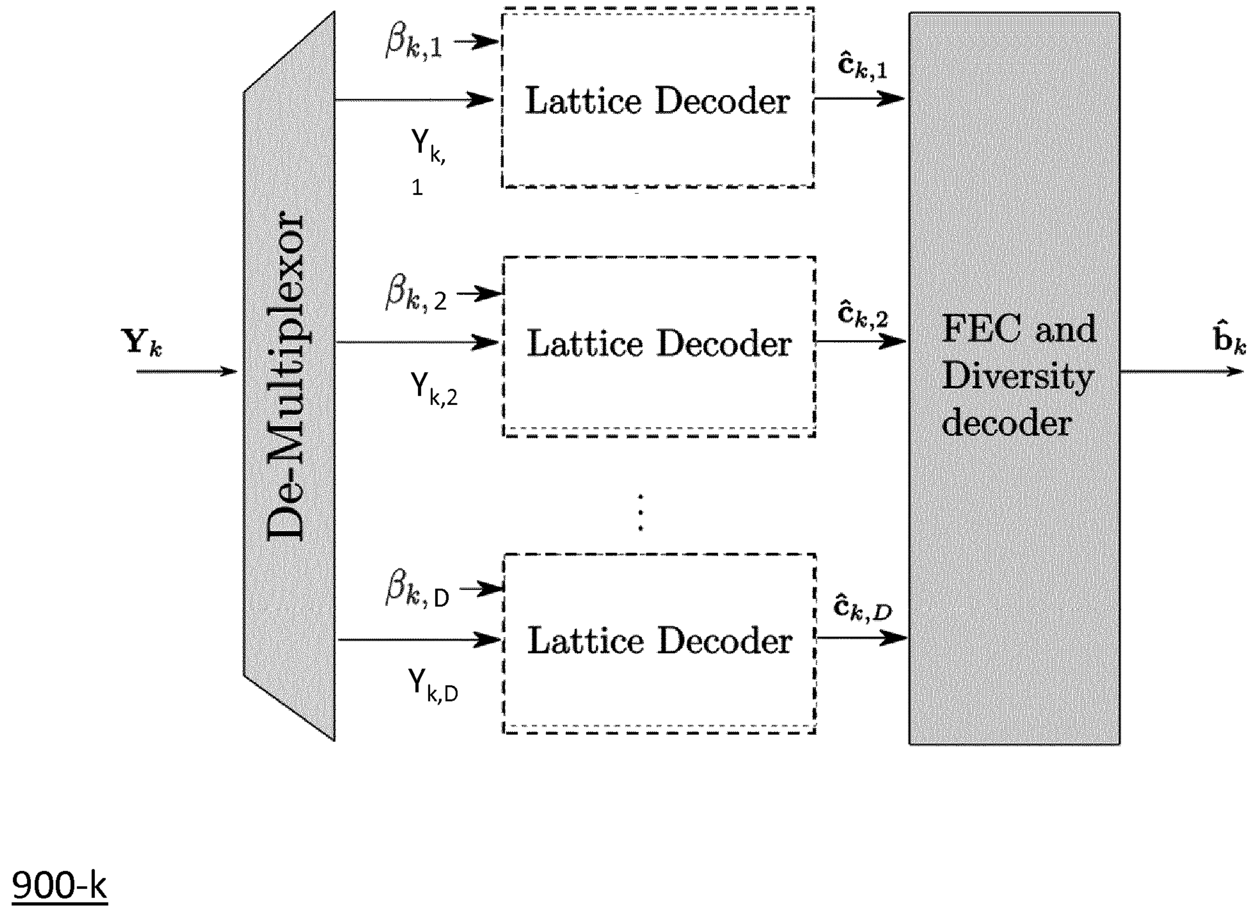

$\mathbf{Y}_k$
De-Multiplexor
$\beta_{k,1}$
Y k, 1
$\beta_{k,2}$
Y k,2
$\beta_{k,D}$
Y k,D
Lattice Decoder
Lattice Decoder
Lattice Decoder
$\hat{\mathbf{c}}_{k,1}$
$\hat{\mathbf{c}}_{k,2}$
$\hat{\mathbf{c}}_{k,D}$
FEC and Diversity decoder
$\hat{\mathbf{b}}_k$
900-k

Fig. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/066832

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W52/34 H04W52/42
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 H04B 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.
A	EP 2 983 406 A1 (NTT DOCOMO INC [JP]) 10 February 2016 (2016-02-10) abstract paragraph [0024] - paragraph [0028] paragraph [0032] - paragraph [0034] paragraph [0046] - paragraph [0047] -----	1-14
A	EP 3 038 280 A1 (NTT DOCOMO INC [JP]) 29 June 2016 (2016-06-29) paragraph [0025] - paragraph [0028] -----	1-14
A	US 2015/312074 A1 (ZHU YUAN [CN] ET AL) 29 October 2015 (2015-10-29) paragraph [0023] paragraph [0028] paragraph [0031] paragraph [0053] - paragraph [0060] paragraph [0093] - paragraph [0095] -----	1-14

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

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

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"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 10 March 2017	Date of mailing of the international search report 20/03/2017
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer López Márquez, T

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/066832

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2983406 A1	10-02-2016	EP 2983406 A1	10-02-2016
		JP 5894105 B2	23-03-2016
		JP 2014204277 A	27-10-2014
		US 2016037460 A1	04-02-2016
		WO 2014162819 A1	09-10-2014
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		US 2016183199 A1	23-06-2016
		WO 2015025664 A1	26-02-2015
US 2015312074 A1	29-10-2015	EP 3138227 A1	08-03-2017
		KR 20160124223 A	26-10-2016
		US 2015312074 A1	29-10-2015
		WO 2015167714 A1	05-11-2015