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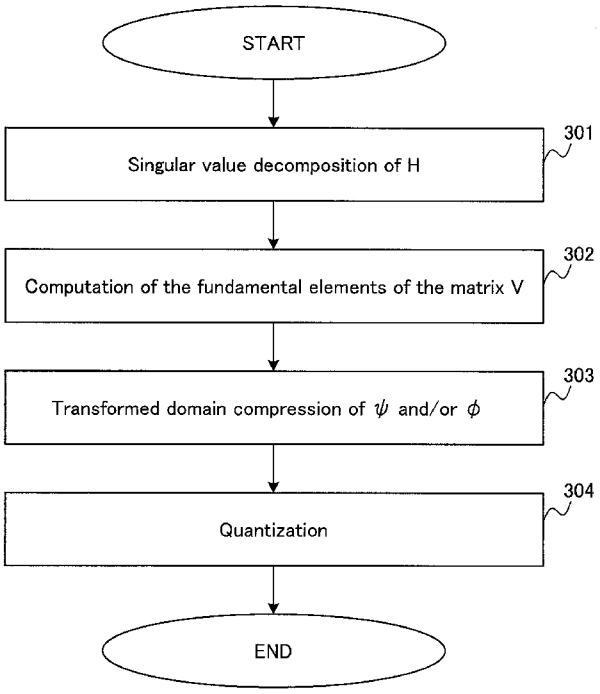
[Continued on next page]

(54) Title: FEEDBACK COMPRESSION FOR REDUCING OVERHEAD IN MIMO COMMUNICATION SYSTEM

(57) Abstract: A MIMO receiving device employed in a MIMO communication system comprises a decomposition computation module in which the fundamental elements that represent the channel characteristics are obtained, and a transformed domain compression module in which the fundamental elements are transformed to a transformed domain and compressed to reduce feedback overhead.

FIG. 3



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DESCRIPTION

FEEDBACK COMPRESSION FOR REDUCING OVERHEAD IN MIMO COMMUNICATION SYSTEM

TECHNICAL FIELD

[0001]

This invention relates to a MIMO receiving device and MIMO communication system.

Priority is claimed on Japanese Patent Application No. 2012-270631, filed December 11, 2012, the content of which is incorporated herein by reference.

BACKGROUND ART

[0002]

There are many instances in which a transmitting wireless communication access point (from now on AP) benefits from knowing the characteristics of the channel between the antennas at the AP and the antennas at the receiving wireless communication station (from now on STA).

This information can give the AP the capacity to perform precoding, modifying a signal in a way that it will be perceived by the STA as interference free after going through the channel. Precoding can be used for single antenna operation or multi-input multi-output operation (MIMO), either for the single user case (SU-MIMO) or the multi-user case (MU-MIMO), in which the AP transmits information to multiple antennas belonging to different STAs.

The information about the condition of the channel can serve other purposes, e.g. the AP chooses the STAs to which to transmit according to their current channel

conditions, etc.

[0003]

In a time-division duplexing (TDD), the measure of the channel can be estimated by the AP. The STA transmits a signal known by the AP, which can extract the channel characteristic observing its alteration. In TDD, this process results in very small overhead. However, it requires a precise calibration of the elements at the AP and the STA, as slight divergences can induce high error.

In a frequency-division duplexing (FDD), the AP and the STA transmit at different frequencies. Therefore, it is not possible for the AP to measure the characteristic of the channel. In FDD, it is the STA that must measure the channel characteristic and transmit that measurement to the AP as feedback.

The feedback can be transmitted in numerous ways. The elements of the computed channel matrix can be quantized and transmitted without further transformation. Or, the STA can compute the precoding matrix to be used by the AP, quantize it and transmit it. Or, the STA can transmit as feedback only the average SNR of subsets of one or more subcarriers.

[0004]

One especially relevant example is the case of SVD precoding. In this case, the precoding matrix to be used by the AP is unitary and orthonormal. Considering these characteristics, the reduction of the matrix to its fundamental components is advantageous. The STA can compute these components and send them to the AP, which can reconstruct the precoding matrix from them.

The embodiments included in this document are explained taking as a baseline example the 802.11 standard in its current form (non-patent reference 1) and relevant amendments such as 11ac (non-patent reference 2). This is chosen as reference, and it

is noteworthy that the embodiments of the invention are not limited to this standard.

It's important to note that in this document the concept of antenna is taken as the device or a set of devices that allows the transmission or reception of one stream. That is, in this document, a station that can transmit or receive up to one stream is considered as being furnished with one antenna; a station that can transmit or receive up to two streams is considered to be furnished with two antennas; etc.

CITATION LIST

[0005]

NPL 1: "IEEE 802.11-2012 (Revision of IEEE Std 802.11-1999)", March 2012

NPL 2: "IEEE P802.11ac/D3.0", June 2012

DISCLOSURE OF INVENTION

Problems to be Solved by the Invention

[0006]

In an FDD system, the overhead caused by the transmission of feedback from the STA to the AP is an element of concern. This overhead can be especially taxing in the case of MIMO communications, in which the number of possible paths between antennas at AP and STA increases geometrically. Besides, the requirements of accuracy are higher for MU-MIMO transmissions, especially the ones based on non-linear techniques, which can achieve a higher data rate than the relatively simple linear techniques, but are more sensitive to channel estimation errors.

In order to be able to leverage the increasing number of antennas at APs and STAs, the feedback overhead must be reduced without compromising its accuracy.

Means for Solving the Problems

[0007]

The present invention has been made to solve the above-described problem. According to an embodiment of the present invention, there is provided a decomposition computation module in which the fundamental elements that represent the channel characteristics of the communication system are obtained, and a transformed domain compression module in which the fundamental elements are transformed to a transformed domain and compressed in a MIMO receiving device employed in a MIMO communication system.

Effects of the Invention

[0008]

The feedback overhead is reduced without compromising its accuracy.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

[Fig. 1] Figure 1 shows an example MIMO communication system.

[Fig. 2] Figure 2A and 2B show the maximum absolute values obtained in the transformed domain for angles ϕ and ψ, respectively.

[Fig. 3] Figure 3 shows a flow diagram in which the angles ψ and/or ϕ are compressed in the transformed domain.

[Fig. 4] Figure 4 shows the flow diagram of an example transformed domain compression.

[Fig. 5] Figure 5 shows the reverse process at AP.

[Fig. 6] Figure 6 shows the flow diagram of the process that recovers the angles

ψ.

[Fig. 7] Figure 7 shows an alternative flow diagram for transformed domain compression.

[Fig. 8] Figure 8 shows an example flow diagram for obtaining the angles from the feedback.

[Fig. 9] Figure 9 shows an example of block diagram for STA according to the first embodiment.

[Fig. 10] Figure 10 shows an example of block diagram for AP according to the first embodiment.

[Fig. 11] Figure 11 shows an example of block diagram for STA according to the second embodiment.

[Fig. 12] Figure 12 shows an example of block diagram for AP according to the second embodiment.

[Fig. 13] Figure 13 shows the curves of an example set of enveloping functions.

[Fig. 14] Figure 14 shows an example method by which an enveloping function can be found.

[Fig. 15] Figure 15 shows an example flow diagram of a quantization block that includes the range delimitation by an enveloping function.

[Fig. 16] Figure 16 shows an example flow diagram of the reverse quantization process at the AP.

[Fig. 17] Figure 17 shows an example of block diagram for STA according to the third embodiment.

[Fig. 18] Figure 18 shows an example of block diagram for AP according to the third embodiment.

BEST MODE FOR CARRYING OUT THE INVENTION

[0010]

Now, preferred embodiments of the present invention will be explained in detail with reference to the annexed drawings. The embodiments relates to WLAN (wireless Local Area Network), but they are not restricted to the WLAN, but are also applicable to a mobile phone network.

THE FIRST EMBODIMENT

[0011]

Figure 1 shows an example wireless system. AP (MIMO transmitting device) 101 acts as the AP of the basic service set BSS 1. AP 101 can communicate with STAs (MIMO receiving devices) 111 to 118.

AP 101 may be endowed with many antennas that are capable of inputting different signals into the medium at the same time and in the same frequency bandwidth through spatial multiplexing. If the STA also has multiple antennas, AP 101 can transmit different data streams from each antenna at AP 101, each stream targeting a different STA antenna (single user MIMO, SU-MIMO). Alternatively, AP 101 can transmit different data streams to different antennas that may belong to different STAs (multiuser MIMO, MU-MIMO).

In this example, AP 101 and STAs 111 to 118 belong to BSS1 (Basic Service Set). BSS2 is also shown, comprising AP 102 and STA 121. The emissions of AP 102 are received as interference by STAs 111 and 112. Similarly, BSS3 comprises AP 103 and STA 131. The emissions of AP 103 are received as interference by STAs 116 and 117.

[0012]

However, the antennas (belonging to the same STA or not) to which the MU-MIMO multiplexed signals are addressed perceive the signal intended to other antennas as interference, which leads to a performance degradation in bandwidth. In order to restrain the interference, STAs 111 to 118 send information about the channel to AP 101. AP 101 performs precoding, altering the signal in a way that after passing through the channel the signal will be seen as interference free by the receiving antennas.

A well-known way of performing precoding is by singular value decomposition (SVD). Equation 1 shows the singular value decomposition of the channel matrix **H**.

[0013]

[Equation 1]

$$\mathbf{H}_{N_R x N_T} = \mathbf{U}_{N_R x N_R} \cdot \mathbf{S}_{N_R x N_T} \cdot \mathbf{V}^{H}_{N_T x N_T} \quad (1)$$

[0014]

In the above equation, **U** and **V** are unitary matrices, **S** is a diagonal matrix of singular values, N_R is the number of antennas at the STA, N_T is the number of antennas at AP 101, and $\mathbf{V}^H$ is the Hermitian (complex conjugate transpose) of **V**. **V** is the matrix sent as feedback from the STA to AP 101.

The signal received by the STA is shown in equation 2.

[0015]

[Equation 2]

$$\mathbf{Y} = \mathbf{H} \cdot \mathbf{x} + \boldsymbol{\eta} \quad (2)$$

[0016]

In the above equation, **H** is the channel matrix between the transmitting antennas and the receiving antennas, **x** is the signal transmitted by AP 101, $\boldsymbol{\eta}$ is the noise as seen by the STAs and **Y** is the signal received by the STAs.

AP 101 pre-multiplies the transmitted signal by the matrix **V** as in equation 3.

[0017]

[Equation 3]

$$\mathbf{Y} = \mathbf{H} \cdot \mathbf{x}' + \boldsymbol{\eta} = \mathbf{H} \cdot \mathbf{V} \cdot \mathbf{x} + \boldsymbol{\eta} = (\mathbf{U} \cdot \mathbf{S} \cdot \mathbf{V}^H) \cdot \mathbf{V} \cdot \mathbf{x} + \boldsymbol{\eta} = \mathbf{U} \cdot \mathbf{S} \cdot \mathbf{x} + \boldsymbol{\eta} \quad (3)$$

[0018]

In the above equation, **x'** is the signal to be transmitted by AP 101 after precoding. At reception, the STA pre-multiplies **Y** by the hermitian of the matrix **U** as in equation 3a.

[0019]

[Equation 3a]

$$\mathbf{Y}' = \mathbf{U}^H \cdot \mathbf{Y} = \mathbf{U}^H \cdot (\mathbf{H} \cdot \mathbf{x}' + \boldsymbol{\eta}) = \mathbf{U}^H \cdot \mathbf{H} \cdot \mathbf{V} \cdot \mathbf{x} + \mathbf{U}^H \cdot \boldsymbol{\eta} = \mathbf{U}^H \cdot (\mathbf{U} \cdot \mathbf{S} \cdot \mathbf{V}^H) \cdot \mathbf{V} \cdot \mathbf{x} + \boldsymbol{\eta}' = \mathbf{S} \cdot \mathbf{x} + \boldsymbol{\eta}' \quad (3a)$$

[0020]

In the above equation, **Y'** is the received signal **Y** after pre-multiplying by $\mathbf{U}^H$, and the resulting noise $\boldsymbol{\eta}$ is equivalent to the original noise factor $\boldsymbol{\eta}$, being the matrix $\mathbf{U}^H$ unitary and therefore not affecting the magnitude of the noise.

The matrix **V** is orthonormal. This implies that there is some redundancy into it. An efficient way of transmitting this matrix to the AP 101 is by finding the fundamental elements of **V** and transmitting only those that are essential to reconstruct the matrix at the AP 101. The fundamental elements of V may be defined as the elements of the matrix V, or as an arbitrary number of extracted elements from V, or as an average of an arbitrary number of elements of V, or the coefficients of a curve fitting the elements of V, or a set of angles obtained as a result of the decomposition of the matrix V (for instance, the angles obtained through Givens rotation, or the angles obtained through Householder reflection).

[0021]

The 802.11 standard gives an example in which this can be accomplished by the use of Givens rotation. The Givens rotation operation can be used to reduce the columns of a matrix so all elements other than the diagonal elements are zero. However, this operation can only be performed over real numbers. The process described in the standard [non-patent reference 2] obtains two fundamental angles that represent the matrix, i.e. the rotation angles needed to rotate the elements of a given column to the real domain, and the Givens rotation angles themselves, that show the common planar rotation of two dimensions to reduce the elements other than the diagonal element of the column under consideration. In the rest of the document, we will refer to the rotation angles as ϕ, and to the Givens rotation angles as ψ.

The number of angles N_{angles} of each kind required to represent the matrix **V** varies depending on the size of the parts to be given as feedback, as shown in equation 4.

[0022]

[Equation 4]

$$N_{angles} = F(\mathbf{V}) - N_R = 2 \cdot N_T \cdot N_R - N_R^{\,2} - N_R \qquad (4)$$

[0023]

The rotation suffered by the streams arriving at the receiving antennas of the STA can be estimated by the STA, therefore they can be omitted. F(**V**) represents the degrees of freedom of the matrix **V**.

The level of compression attained through this process is high, and it's indeed optimal from the point of view of lossless compression. The matrix V cannot be compressed further without incurring into losses. However, other steps of the feedback transmission process introduce losses into the system, such as the quantization step,

denying part of the benefits of lossless compression techniques.

It is worth noting that similar results could be obtained through other methods instead of Givens rotation, for example Householder reflections. The document gives an exemplary procedure for the elements obtained through Givens rotation, but other methods that follow the spirit of reducing the precoding matrix **V** to its fundamental angular elements is also included.

Some embodiments of the invention can further reduce the feedback overhead by applying transformed domain compression techniques to the obtained angles (introducing losses).

In the case of the ϕ angles, their variation depends exclusively on the channel variation experienced by the corresponding stream. This leads to some instances of rapid variation, which in turn causes a relatively high energy spread characteristic in the transformed domain.

[0024]

Figure 2A shows the maximum absolute values obtained in the transformed domain for the angles ϕ for an exemplary case of a 4x4 transmission with a 40 MHz bandwidth under channel model D (defined for the 802.11 standard to simulate the conditions of a typical office). In figure 2A, the abscissa means transformed domain samples n and the ordinate represents the value of the samples ($DCT(\phi(SC_i))$). A detailed explanation of the transformed domain will be provided later. It can be seen in this figure that there is significant energy remaining in the high samples.

Due to this spread, the compression of the ϕ angles presents many difficulties through time domain techniques.

On the other hand, the angles ψ represent the common variation or correlated

variation experienced by 4 different streams after passing through the channel.

Figure 2B shows the maximum absolute values obtained in the transformed domain for the angles ψ for the exemplary case mentioned above. In figure 2B, the abscissa means transformed domain samples n and the ordinate represents the value of the samples ($DCT(\psi(SC_i))$). In the case of the angles ψ, the energy quickly drops to nearly zero for the medium to high samples.

This stability makes the angles ψ appropriate for transformed domain compression.

[0025]

Figure 3 shows a flow diagram in which the channel matrix **H** is compressed to be fed back for preparing the precoding matrix at AP 101. The STA performs singular value decomposition to the channel matrix **H** (301), and extracts the fundamental elements of the orthonormal matrix **V** (302). In our example explanation, this is done following the procedure described in [non-patent reference 1]. After computing the angles ψ and the angles ϕ, transformed domain compression is performed to either of them or both of them (303). However, for the reasons explained above, little benefit is obtained from compressing the angles ϕ, and therefore the recommended way of action is compressing the angles ψ and leaving the angles ϕ untouched. The resulting elements of that transformed domain compression (and the angles to which compression has not been performed) are given to block 304, which quantizes their values for the beamforming report (the feedback or the feedback information).

For the rest of the document, the assumed exemplary operation is the transformed domain compression of the angles ψ and no compression of the angles ϕ, although the opposite could be true, or both of the angles could be compressed through

the same process in which the parameters may or may not change.

[0026]

Figure 4 shows the flow diagram of an example transformed domain compression technique that can be performed in block 303 in figure 3.

The angles ψ are divided into two regions (401). One region, the lower region, comprises the angles corresponding to the subcarriers that are positioned before the DC subcarriers. The other region, the upper region, comprises the subcarriers that are positioned after the DC subcarriers.

First, the working set W is taken as the lower region (402). The ψ corresponding to the set W can be considered as a function of the frequency:

[0027]

[Equation 5]

$$\psi_i(SC_j)$$
$$i = 1,2,...N_{angles}$$
$$SC_j = 1,2,...\frac{N_{SC}}{2} \quad (5)$$

[0028]

In the above equation, N_{SC} is the total number of subcarriers and $N_{SC}/2$ represents the number of subcarriers present in the lower region.

This frequency domain functions are converted to the transformed domain by means of the DCT transformation (Discrete Cosine Transformation) as shown in equation 6 (403).

[0029]

[Equation 6]

$$X_i[n] = DCT(\psi_i[k]) = \sum_{k=0}^{N_{DCT}-1} \psi_i[k] \cdot \cos\left(\frac{\pi}{2 \cdot N_{DCT}} \cdot i \cdot (2 \cdot k + 1) \cdot n\right) \quad (6)$$

[0030]

In the above equation, 'n' represents a sample of the transformed domain, 'k' represents a sample of the frequency domain, and N_{DCT} is the number of points of the DCT operation.

The compression is attained by truncating the function X[n] and transmitting only the first L samples, where most of the energy is concentrated (404). L can be any value from 1 to $N_{SC}/2$, which is the number of subcarriers in each one of the regions. Equation 7 shows this process.

[0031]

[Equation 7]

$$X_i^{feedback}[l] = X_i[l] \qquad l = 1,2,...L \tag{7}$$

[0032]

If all the regions have been computed, the operation ends (405). If the upper region has not been computed yet, the working set W is updated to the upper region (406) as shown in equation 8 and the process is iterated from block 403.

[0033]

[Equation 8]

$$\psi_i(SC_j)$$
$$i = 1,2,...N_{angles}$$
$$SC_j = \frac{N_{SC}}{2} + 1,....N_{SC} \tag{8}$$

[0034]

Figure 5 shows the reverse process at AP 101. AP 101 first extracts the values of the angles ψ and ϕ from the feedback sent by the STA (501). Reverse quantization is applied to these values for further operations (502). With the values of ψ and ϕ, AP 101

computes the precoding matrix V (503).

Figure 6 shows the flow diagram of recovering the angles ψ that can be performed in block 501 in figure 5.

First, the values corresponding to the lower region are assigned to the variable X (601). The samples that were truncated by the STA are considered as of value '0' by AP 101 (602). The inverse DCT operation is performed to X as shown in equation 9 (603):

[0035]

[Equation 9]

$$\psi_i[k] = iDCT(\mathbf{X}[n]) = \frac{1}{N}\cdot \mathbf{X}[0] + \frac{2}{N}\cdot \sum_{n=1}^{N_{DCT}-1} \mathbf{X}[n]\cdot \cos\left(\frac{\pi}{2\cdot N}\cdot(2\cdot n+1)\cdot k\right) \quad (9)$$

[0036]

The recovered values of ψ are stored (604). If not all the regions have been computed yet (605), X is updated with the values of the upper region (606), and the process is iterated from block 602.

Once all the regions have been iterated, the stored angles corresponding to each stage are arranged back together in the appropriate order (607).

Figure 7 shows an alternative flow diagram for "transformed domain compression of ψ". In this case, the values of the angles for the DC subcarriers are interpolated and inserted in their corresponding position to conform W according to equation 10 (701).

[0037]

[Equation 10]

$$\mathbf{W} = \left[\psi\left(1, \frac{N_{SC}}{2}\right) \quad \mathbf{DC}_{interpolated} \quad \psi\left(\frac{N_{SC}}{2}+1, N_{SC}\right)\right] \quad (10)$$

[0038]

The DCT operation is applied to the resulting W (702). In this case, as opposed to the previous example, the subcarriers are not divided by regions. Therefore, only one DCT operation is required. The resulting transformed domain characteristic is truncated to the first L samples (703). The remaining samples are omitted.

[0039]

Figure 8 shows another example flow diagram for "Obtain the angles ψ from the feedback" which is paired to the flow described in figure 7.

First, the L transformed domain samples are extracted from the feedback and assigned to X (801). X is updated by setting the omitted samples to '0' (802). Inverse DCT is performed to the X (803). The result includes the value for the DC subcarriers, which were interpolated by the STA. The values for the relevant subcarriers are extracted from the result (804).

Some exemplary options have been described in detail in the precedent paragraphs, but they don't preclude the utilization of other techniques following the same spirit, which is the compression of the rotation angles ψ through transformed domain transformation and selection of the most representative points therein.

Apart from DCT, other transformation techniques such as DHT (Discrete Hartley Transform) or DFT (Discrete Fourier Transform) can be employed.

[0040]

Figure 9 shows one example of the configuration of STA 110. STA 110 is a general term for STAs 111 to 118.

Signal reception 901 handles the data streams from AP 101 received at antenna 911, extracts the guard interval from the received signal after down-conversion to the baseband and AD conversion, and applies Fast Fourier Transformation (FFT) to change the signal to the frequency domain.

Pilot demultiplexing 902 extracts the pilot symbols from the frequency domain signal. It conveys these pilot signal values to Channel estimation 906 and the signal without the pilot symbols to Un-rotation 903. The subcarriers that appear in a prefixed configuration in training fields are considered as pilot symbols in this document.

Channel estimation 906, based on the values of the extracted pilot symbols, estimates the channel characteristics and the SINR (Signal to Interference Noise Ratio) perceived by each receiving antenna 911 from each transmitting antenna at AP 101.

Decomposition computation 909 performs the singular value decomposition (SVD) of the channel estimated by Channel estimation 906 and obtains two fundamental angles ϕ and ψ. It outputs the two fundamental angles ϕ and ψ to the Feedback creation 907.

Rotation estimation 905 estimates the rotation experienced by the signal by observing the long training field pilot signals, and gives the result to Un-rotation 903.

Un-rotation 903 pre-multiplies the received data symbols by the inverse of the rotation matrix estimated by rotation estimation 905.

Data extraction 904 demodulates the data symbols output by Un-rotation 903 and performs error correction to the demodulated data streams, retrieving the reception data streams.

[0041]

Feedback creation 907, according to the indications of Control 911, creates the feedback to be transmitted to AP 101, using the results from Channel estimation 906, the precoding matrix **V** (the angles ϕ and ψ) from Decomposition computation 909, and the elements corresponding to the compression in the transformed domain of the angles ψ as computed by transformed domain compression 910. In Feedback creation 907, the angles ϕ transferred from Decomposition computation 909 and the truncated samples in

the transformed domain for angles ψ transferred from Transformed domain compression 910 are quantized and sent to Wireless transmission 908. Feedback creation 907 gives feedback information to Wireless transmission 908.

Transformed domain compression 910 receives the angles ψ from feedback creation 907 and performs compression of the rotation angles ψ through transformed domain transformation as explained above.

Wireless transmission 908 transmits the prepared feedback through antenna 911 to AP 101.

Control 911 processes the necessary actions for the above mentioned modules.

[0042]

Figure 10 shows one example of block diagram for AP 101.

Wireless reception 1006 receives the data transmitted from each STA arriving at antennas 1005-1 to 1005-n.

Feedback analyzer 1007 extracts the feedback information from each of the data streams received from STAs. Feedback analyzer 1007 gives the transformed domain compressed angles ψ to ψ recovery 1008, the angles ϕ to V-retriever 1009, and the SINR information to Selection 1010 after performing reverse quantization.

ψ recovery 1008 receives the transformed domain compressed samples corresponding to the angles ψ and recovers the value of the angles ψ by any of the procedures described above.

V-retriever 1009 obtains the precoding matrix (equations 1 to 4) from the angles ϕ given by Feedback Analyzer 1007 and the angles ψ given by ψ recovery 1008.

Selection 1010, based on the SINR feedback information given by Feedback analyzer 1007 and the V matrices obtained by V-retriever 1009, selects a group with

potentially many affiliated STAs to perform MU-MIMO.

[0043]

Transmission buffer 1001 stores the transmission data streams coming from upper layers that is intended to be transmitted to STAs, and conveys it to Signal creation 1002-i as indicated by Selection 1010, which takes care of addressing each data stream 1 to n to its corresponding STA. The number 'i' is either of 1 to n.

Signal creation 1002-i performs forward error correction to the data coming from transmission buffer 1001. Furthermore, it performs rate matching (through puncturing) to adapt the coding rate to the rate selected by Selection 1010 for each of the data streams. Afterwards, modulated streams are created by modulating the resulting streams and the pilot symbols are multiplexed with them.

Precoding 1003, having as an input the modulated streams and the matrix **V** from V-retriever 1009, performs precoding to those streams.

Transmission 1004-i performs IFFT (Inverse Fast Fourier Transform) to each of the precoded streams (OFDM (Orthogonal Frequency Division Multiplexing) streams), inserts the guard interval (GI), carry out DA (digital to analog conversion) and frequency conversions and transmits from Antenna 1005-i each of the streams.

Control 1011 processes the necessary actions for the above mentioned modules.

[0044]

According to the first embodiment, less overhead for feedback prepared by the MIMO receiving device may be used in the MIMO communication system.

THE SECOND EMBODIMENT

[0045]

Another embodiment of this invention is a communication system as the one

proposed in the first embodiment in which the statistical properties of the transformed domain transformation of the angles ψ are leveraged by the use of a non-linear quantization scheme for those values. In the rest of the text, some details for some specific cases of logarithmic quantization are given, but this doesn't preclude other forms to be employed by the system.

Most of the energy of the transformed domain characteristic of ψ is concentrated in the first samples. Subsequent samples are typically near zero. However, some samples present a much higher energy than the average. These instances can cause a noticeable loss of precision if the quantization range is defined too low. On the other hand, defining a quantization range capable of coping with these spikes results in a loss of precision due to lack of detail in the representation of the small values. In order to capture both cases, a non-linear quantization scheme such as logarithmic quantization can be employed. It presents a large enough dynamic range to include the occasional spikes while preserving the fineness to represent the statistically dominant small values.

A compression operation is performed to the function to be quantized, and the result is quantized by any linear means.

Equation 11 presents the typical form of μ-law logarithmic companion.

[0046]

[Equation 11]

$$F(x)=\mathrm{sgn}(x)\cdot\frac{Ln(1+\mu\cdot|x|)}{Ln(1+\mu)} \qquad -1\le x\le 1 \tag{11}$$

[0047]

In the above equation, 'x' is the normalized input (in the range [–1,1]), F(x) is the logarithmic compression function and the law μ is typically 255.

The resulting F(x) is quantized and transmitted through the channel. AP 101a

receives it, performs the appropriate reverse quantization and recovers the original values through the operation described in equation 12. In equation 12, $F^{-1}(y)$ is the logarithmic expansion function.

[0048]

[Equation 12]

$$F^{-1}(y) = \mathrm{sgn}(y) \cdot \left(\frac{1}{y}\right) \cdot \left((1+\mu)^{|y|} - 1\right) \qquad -1 \le y \le 1 \tag{12}$$

[0049]

Equation 13 shows the similar case of A-law.

[0050]

[Equation 13]

$$F(x) = \mathrm{sgn}(x) \cdot \begin{cases} \dfrac{A \cdot |x|}{1 + Ln(A)}, & |x| < \dfrac{1}{A} \\ \dfrac{1 + Ln(A \cdot |x|)}{1 + Ln(A)}, & \dfrac{1}{A} < |x| \le 1 \end{cases}$$

$$F^{-1}(y) = \mathrm{sgn}(y) \cdot \begin{cases} \dfrac{|y| \cdot (1 + Ln(A))}{A}, & |y| < \dfrac{1}{1 + Ln(A)} \\ \dfrac{\exp(|y| \cdot (1 + Ln(A)) - 1)}{A}, & \dfrac{1}{1 + Ln(A)} \le |y| \le 1 \end{cases} \tag{13}$$

[0051]

Any other form of non-linear quantization can also be employed, being part of the scope of the embodiments of the invention.

Figure 11 shows an exemplary configuration of STA 110a adapted for the functionality of this embodiment. In figure 11, Non-linear quantization 1101 is added to the configuration of STA 110 depicted in figure 9. Non-linear quantization 1101 receives the elements corresponding to the compression of the rotation angles ψ through

transformed domain transformation from Transformation domain compression 910 and performs non-linear quantization to them. These values are then given to Feedback creation 907 and sent to Wireless transmission 908. In Feedback creation 907, the angles ϕ transferred from Decomposition computation 909 are quantized and also sent to Wireless transmission 908. Control 911 processes the necessary actions for the above mentioned modules.

Figure 12 shows an exemplary configuration of AP 101a including the functionality described in this embodiment. In figure 12, Reverse non-linear quantization 1201 is added to the configuration of AP 101 depicted in figure 10.

Reverse non-linear quantization 1201 receives the quantized values of the transformed domain compressed angles ψ from Feedback analyzer 1007 and performs reverse non-linear quantization to them. The resulting values are given to ψ recovery 1008. Control 1011 processes the necessary actions for the above mentioned modules.

[0052]

According to the second embodiment, less overhead for feedback prepared by a MIMO receiving device may be used in a MIMO communication system, in which the effect of spikes for medium to high samples are reflected.

THE THIRD EMBODIMENT

[0053]

Another embodiment of this invention is a system in which the STA, leveraging the statistical properties of the transformed domain transformation of the angles ψ, approximates the resulting transformed domain characteristic to a function among a set of possible options. The value of that function at each transformed domain sample is used as the full range quantization value. The STA 110b transmits the index of the

employed function to AP 101b along with the feedback. AP 101b uses this information to perform reverse quantization of the received values.

The values of the transformed domain representation of the angles ψ follow approximately a decreasing negative exponential function. Therefore, as stated above, the first values quickly decrease to an average value of near zero, and barring occasional spikes, they stay in the vicinity of zero.

The quantization of the values of the function under these conditions has already been tackled in the second embodiment by the use of non-linear quantization, which gives more precision to small values, and performs a rougher quantization for the larger ones.

However, the sole use of non-linear quantization is greatly inefficient. Defining the quantization range according to the first sample sets a too high range. The highest value to be experienced by farther samples is a small fraction of that range. Even under non-linear quantization, the loss of precision is too high.

Adapting the quantization range to each sample ensures an efficient quantization able to provide a nearly optimum degree of accuracy.

Equation 14 shows a simple example of functions that can be used to assimilate the characteristic of the transformed domain transformation of the angles ψ.

[0054]

[Equation 14]

$$Q_{envelope}(n,i) = n^{Q_{\exp}(i)}$$
$$i = 1,2,...N_Q \qquad (14)$$

[0055]

In the above equation, 'n' represents the transformed domain samples, and 'i' is the index for the possible enveloping functions (N_Q in total).

The shown functions are just some simple examples that don't require much computational power from neither the STA 110b nor AP 101b. Any other function that tries to model the behavior of the transform domain transformation of the angles ψ is included in this embodiment of the invention.

Figure 13 shows the characteristic of the exemplary curves defined in equation 14. The steepness of the decline depends on the parameter Q_{exp}.

[0056]

In the third embodiment, the flow diagram in which the channel matrix **H** is compressed to be fed back is the same as in figure 3 for the first embodiment except the quantization box 304.

Figure 14 shows a flow diagram which corresponds to the quantization block 304 in figure 3.

The STA 110b analyzes the characteristic of the transformed domain signal and chooses the signal whose envelope most resembles it among a predefined set of functions (1401).

The value of the chosen assimilated function at each sample is computed and assigned as the quantization range for the corresponding sample (1402).

Non-linear quantization is performed with a different quantization range for each sample as defined above (1403). In the block 1403, "l" represents each sample from 1 to L.

Figure 15 shows a flow diagram for block 1401 in figure 14. This is a possible way in which the STA 110b can select the most appropriate enveloping function out of a given set.

First, the STA 110b normalizes the characteristic of the transformed domain angle ψ transformation (1501). This means that the first sample has a value '1', and the

rest are escalated proportionally as shown in equation 15.

[0057]

[Equation 15]

$$\psi_{normalized}(n) = \frac{\psi(n)}{\psi(0)} \tag{15}$$

[0058]

The STA 110b then computes for each possible enveloping function the difference between it and the estimated channel at each transformed domain sample. The STA 110b finds the maximum divergence value for each case as shown in equation 16 (1502).

[0059]

[Equation 16]

$$div(i) = \max(\psi_{normalized}(i) - Q_{envelope}(n,i))$$
$$i = 1,2,...N_Q \tag{16}$$

[0060]

The selected enveloping function is the one that presents the minimum maximum divergence value from the transformed domain angle ψ transformation, as can be seen in equation 17 (1503). The selected curve is used for defining the quantization range of each sample, and its index K is sent as part of the feedback to enable the reverse quantization at AP 101b.

[0061]

[Equation 17]

$$selected = Q_{envelope}(n,K) \quad / \quad div(K) = \min(div(i)) \tag{17}$$

[0062]

Figure 16 shows a flow diagram of the reverse quantization.

AP 101b identifies the enveloping function used for quantization attending to the code received from the STA 110b (1601).

The quantization range at each sample is taken as the value of the enveloping function at that point (1602).

Reverse non-linear quantization is performed with a different quantization range for each sample as defined above (1603).

[0063]

Figure 17 shows an exemplary structure of STA 110b including the functionality described in this embodiment. In figure 17, Enveloping function search 1701 is added to the configuration of STA 110a depicted in figure 11. Enveloping function search 1701 receives the transformed domain compressed characteristic of ψ from Transformed domain compression 910 and evaluates which among a finite set of possible function provides a more accurate approximation of the envelope.

Non-linear quantization 1101 receives the identity of the chosen function from Enveloping function search 1701 and the transformed domain compressed characteristic of ψ from Transformed domain compression 910, and performs non-linear quantization taking the values of the chosen function at each sample as the quantization range for that sample.

Control 911 processes the necessary actions for the above mentioned modules.

[0064]

Figure 18 shows an exemplary structure of AP 101b including the functionality described in this embodiment. In figure 18, Envelope function identification 1801 is added to the configuration of AP 101a depicted in figure 10.

Enveloping function identification 1801 receives the field of the feedback corresponding to the employed enveloping function at the STA 110b and gives this

function to reverse non-linear quantization 1201.

Reverse non-linear quantization 1201 performs reverse quantization to the values received in the feedback taking the value of the enveloping function at each sample as the quantization range for that sample.

Control 1011 processes the necessary actions for the above mentioned modules.

According to the third embodiment, less overhead for feedback prepared by a MIMO receiving device may be used in a MIMO communication system, in which the effect of spikes for medium to high samples are reflected.

THE FOURTH EMBODIMENT

[0065]

Another embodiment of this invention is a system in which the STA 110c changes the parameters of the feedback process according to the channel conditions. The STA 110c is assimilating the channel to an enveloping function, which is chosen from N_Q possible scenarios. The chosen function differs according to the channel condition. Mild channels, which do not present many sudden variations in frequency, result in a transform domain characteristic in which the energy is highly concentrated in the first few samples. On the contrary, a harsher channel, with high variation in the frequency domain, presents more energy in higher transform domain samples. The STA 110c can vary the parameters described in previous embodiments to provide an adequate level of quality of the channel feedback for each of the possible N_Q scenarios. The value of the parameters for each scenario is fixed and well known by the STA 110c and AP 101c. AP 101c knows the scenario following the enveloping function indication which is part of the feedback.

The statistical properties of the transformed domain characteristic are not

constant for all samples. While the last samples typically present small values with some occasional spikes, the first few samples are more varied, with a more even distribution of values alongside their range. Therefore, applying the same μ-law or A-law for the logarithmic quantization for all the samples is not optimum.

In this embodiment, the law of the logarithmic quantization is not fixed and varies depending on the transformed domain sample, as shown in equation 18 for the case of μ-law.

[0066]

[Equation 18]

$$F(x)=\mathrm{sgn}(x)\cdot\frac{Ln(1+\mu(z)\cdot|x|)}{Ln(1+\mu(z))} \qquad -1\le x\le 1$$

$$F^{-1}(y)=\mathrm{sgn}(y)\cdot\left(\frac{1}{y}\right)\cdot\left((1+\mu(z))^{|y|}-1\right) \qquad -1\le y\le 1 \tag{18}$$

[0067]

In the above equation, μ(z) is a function whose value depends on the sample it is computed for.

The evolution of the "law" of the logarithmic quantization method (μ, A) with the transformed domain samples depends on the channel characteristics. Slowly varying channels present a more homogeneous distribution of the transformed domain values centered around zero, while quickly varying ones present more spikes and are more heterogeneous. This determines how quickly the value of the law increases or decreases.

For example, the A-law logarithmic quantization is equivalent to linear quantization for A = 1. Increasing the value of A results in a higher concentration of

values near zero, resulting in higher precision for those values and lower precision elsewhere. Considering that most of the energy is present in the first few samples of the transformed domain transformation of the angles ψ, a system using A-law could find it advantageous to use A = 1 for the first sample, consecutively increasing the value of the law A for subsequent samples.

[0068]

[Equation 19]

$$F(x)=\mathrm{sgn}(x)\cdot\begin{cases}\dfrac{A(z)\cdot|x|}{1+Ln(A(z))}, & |x|<\dfrac{1}{A(z)}\\ \dfrac{1+Ln(A(z)\cdot|x|)}{1+Ln(A(z))}, & \dfrac{1}{A(z)}<|x|\le 1\end{cases}$$

$$F^{-1}(y)=\mathrm{sgn}(y)\cdot\begin{cases}\dfrac{|y|\cdot(1+Ln(A(y)))}{A(y)}, & |y|<\dfrac{1}{1+Ln(A(y))}\\ \dfrac{\exp(|y|\cdot(1+Ln(A(y))))-1)}{A(y)}, & \dfrac{1}{1+Ln(A(y))}\le|y|\le 1\end{cases}$$

$$A(x)=\frac{C}{x^n}$$

(19)

[0069]

In the above equation, 'C' is a constant, 'x' is the sample to be quantized, A(z) is the value of the A-law factor for the working sample 'z', and 'n' is a real number that determines the speed of the variation of the law factor.

The exemplary increment of the law factor shown in equation 19 is linear, but it can be exponential, polynomial, fixed according to some tables, or variable in any other way related to the transformed domain sample.

The distribution of the values of the transformed domain samples is linked to the channel coherence bandwidth. A wider coherence bandwidth channel results in a lower

variation of the angles ψ, which is reflected in the transformed domain transformation as a higher concentration of energy in the first samples and a steeper decline to zero. In this case, a high increase of the law A with the transformed domain samples is desired.

On the other hand, a channel with a narrow coherence bandwidth results in a higher variation of the values of the angles ψ, reflected in the transformed domain by a larger spread of the energy. In this case, a slower increase of the law A with the transformed domain is desired.

Following the linear example shown above, equation 20 relates the constant C multiplying the law factor dependant on the selected enveloping function.

[0070]

[Equation 20]

$$A(x) = \frac{C(K)}{x^n}$$

$$selected = Q_{envelope}(n, K) \quad / \quad div(K) = \min(div(i))$$

(20)

[0071]

The dissertation about the A-law can be applied to any other law of a logarithmic quantization, such as the μ-law, and equivalent definitions to those given in equations 19 and 20 for the A-law are included in the embodiments of the invention.

In a similar way, the number of transformed domain samples required to correctly recover the angles ψ at AP 101c depends on the channel.

Wide coherence bandwidth channels present a steeper decline to zero in the transformed domain representation of the angles ψ. The number of samples with significant energy is reduced, and no more samples are required to recover the angles ψ.

On the other hand, narrow coherence bandwidth channels present a more spread

energy, with more samples holding significant energy. In these cases, AP 101c needs more samples for a satisfactory recovery of the angles ψ.

Equation 21 shows a case in which the number of samples to truncate L depends on the selected envelope for the transformed domain representation of the angles ψ, which in turn depends on the channel coherence bandwidth.

[0072]

[Equation 21]

$$X_i^{feedback}[l] = X_i[l] \qquad l = 1,2,...L(K)$$

$$selected = Q_{envelope}(n,K) \quad / \quad div(K) = \min(div(i)) \tag{21}$$

[0073]

In the same line as the above expositions, it is clear that the first few samples of the transformed domain characteristic are more relevant than the following ones. The energy contained in each sample in the transform domain is a decreasing function. The average energy contained in the first sample is higher than that of the second sample, which is higher than that of the third sample, etc. The steepness of this decrease is directly related to the coherence bandwidth of the channel. Milder channels, with more permissive coherence bandwidth, result in a higher accumulation of energy in the first samples, and therefore a steeper decrease. Harsher channels, with a tighter coherence bandwidth, present a higher energy spread, which results in a slower decrease of the energy per sample.

An embodiment of this invention employs a decreasing number of quantization bits for each transformed domain sample to achieve a higher precision in the recovered angles ψ at AP 101c. For example, in a very simple case, the samples 1 to 10 are

quantized using N_B bits, the samples 11 to 17 are quantized using $N_B - 1$ bits, the samples 18 to 25 using $N_B - 2$ bits, etc.

Equation 22 shows a case in which the number of quantization bits is dependent of the sample it is used for. It is a more general case of the simple example given above (which is a particular case of it).

[0074]

[Equation 22]

$$N_b = f(K)$$

$$selected = Q_{envelope}(n, K) \quad / \quad div(K) = \min(div(i)) \tag{22}$$

According to the fourth embodiment, less overhead for feedback prepared by a MIMO receiving device may be used in a MIMO communication system in which the non-linear quantization is optimized

THE FIFTH EMBODIMENT

[0075]

Another embodiment of the invention is any of the systems of the first to fourth embodiments in which AP 101d can request the STA 110d to alter the conditions of the feedback the STA 110d is sending.

The first time the AP 101d sounds the STA 110d, the STA 110d sends normal feedback to the AP 101d. For subsequent sounding processes, the AP 101d can request the STA 110d to reduce or increase the size of the feedback message, or to increase or reduce the quality, etc. The STA 110d can attend to this request by varying the parameters explained in the previous embodiment, for instance choosing a smaller truncation parameter L for the case in which the AP 101d requests smaller feedback size.

Another example, following the decreasing number of quantization bits for each transformed domain sample system introduced in the previous embodiment, could be to make longer intervals in which each quantization value is used. This would result in an increase of the accuracy at the request of AP 101d at the expense of an increased overhead.

According to the fifth embodiment, the size or quality of the feedback message sent by the STA 110d can be changed based on the request from the access point.

[0076]

The embodiments include any kind of program that, exerting control over AP or STAs, realizes the functions related to the invention described in the embodiments by, for example, controlling the operation of a CPU (Central Processing Unit). The information used by this terminal, as well as the results of its processing, can be stored in RAM (Random Access Memory) to be later stored in a more permanent solution such as Flash ROM (Read Only Memory) or other kinds of ROMs or HDDs (Hard Disk Drives). Said information can be read from that memory as needed by the CPU, which has the ability to correct or overwrite that data.

In order to realize all the functions described in the embodiments of the invention, the information is registered in a storage medium that can be read by a computer. The computer is able to access this information and load it into the computer system, carrying out the processing identified with each module. Furthermore, in this text, "computer system" includes the operating system and all the required hardware.

[0077]

"A storage medium that can be read by a computer" can be a flexible disk, a magnetic or optic disk, a ROM, a CD-ROM, a portable device with storage capabilities, etc. It is any kind of storage device that can be connected to the computer system.

Furthermore, "storage medium that can be read by a computer" also includes any way of sending the program in a sufficiently short time through the internet, a network, a telephone circuit, etc. in a way such that the program is dynamically maintained in the pair server – client. The above stated program includes any device conceived in order to perform part of the previously mentioned functions, as well as any computer system in which the previously mentioned functions are already embedded, providing the capability of performing any combination of them. The embodiment also includes any integrated circuit that can carry out part or all of the functionalities described in the communications systems above (related to either transmission or reception). A microchip being able to perform part or all of the above described individual diagram blocks of communications system is also considered. This description is not limited to specific purpose integrated circuits (for instance LSI or VLSI), but also includes more general purpose devices that perform these operations. It is also possible to substitute the semi-conductors present in the integrated circuits with any other material that allows the above described operations. That is also included in the present invention.

[0078]

Although the above text references the figures to give a detailed explanation of an example configuration of this invention, it is not limited to it. Any possible configuration that changes the blocks but does not deviate from the main point and idea of this document is included.

INDUSTRIAL APPLICABILITY

[0079]

This invention can be used in a field of MIMO communication.

DESCRIPTION OF REFERENCE NUMERALS

[0080]

101, 102, 103: MIMO transmitting devices

111 to 118, 121, 131: MIMO receiving devices

110, 110a, 110b: MIMO transmitting devices

100, 100a, 100b: MIMO receiving devices

CLAIMS

1. A MIMO receiving device employed in a MIMO communication system, characterized in that the device comprises a decomposition computation module in which the fundamental elements that represent the channel characteristics of the communication system are obtained, and a transformed domain compression module in which the fundamental elements are transformed to a transformed domain and compressed.

2. A MIMO receiving device according to Claim 1, characterized in that the fundamental elements that represent the channel characteristics of the communication system are the angles obtained through Givens rotation decomposition.

3. A MIMO receiving device according to Claim 2, characterized in that the device further comprises a non-linear quantization module in which the non-linear quantization is performed on the compressed Givens rotation angles on the transformed domain.

4. A MIMO receiving device according to Claim 3, characterized in that the device further comprises an enveloping module in which an enveloping function is selected to define the quantization range.

5. A MIMO receiving device according to Claim 3 or 4, characterized in that the law of the non-linear quantization varies depending on the transformed domain sample.

6. A MIMO communication system comprising a MIMO transmitting device and one or more MIMO receiving devices, characterized in that the MIMO receiving devices

comprise a decomposition computation module in which the fundamental elements that represent the channel characteristics of the communication system are obtained, a transformed domain compression module in which the fundamental elements are transformed to a transformed domain and compressed and a feedback creation module, and the MIMO transmitting device comprises a precoding module in which the precoding is performed, using the feedback information.

7. A MIMO communication system according to Claim 6, characterized in that the MIMO transmitting device requests the MIMO receiving device to alter the conditions of the feedback the MIMO receiving device is sending.

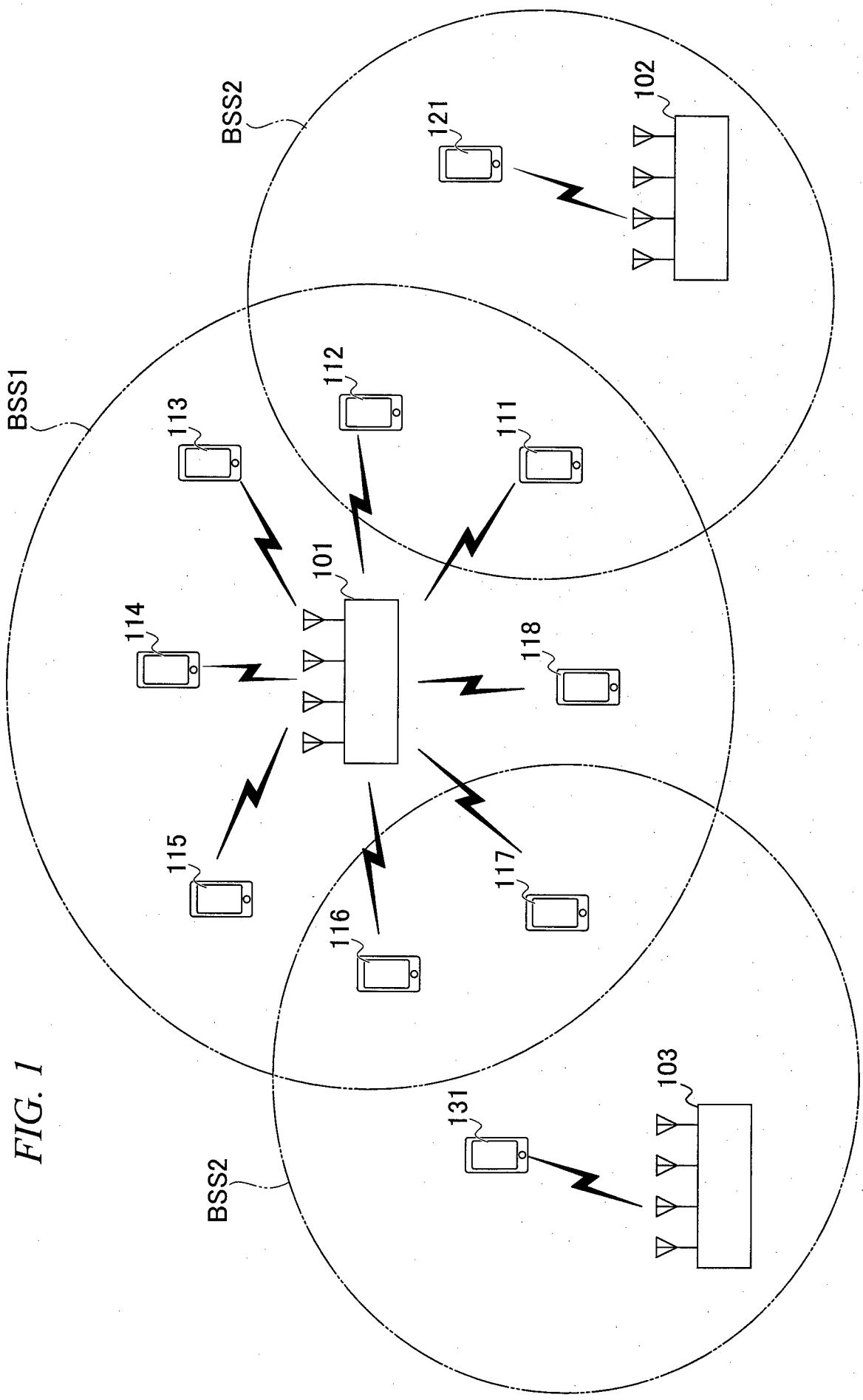

BSS2
102
121
BSS1
112
113
111
101
114
118
115
117
116
BSS2
103
131

FIG. 1

FIG. 2A

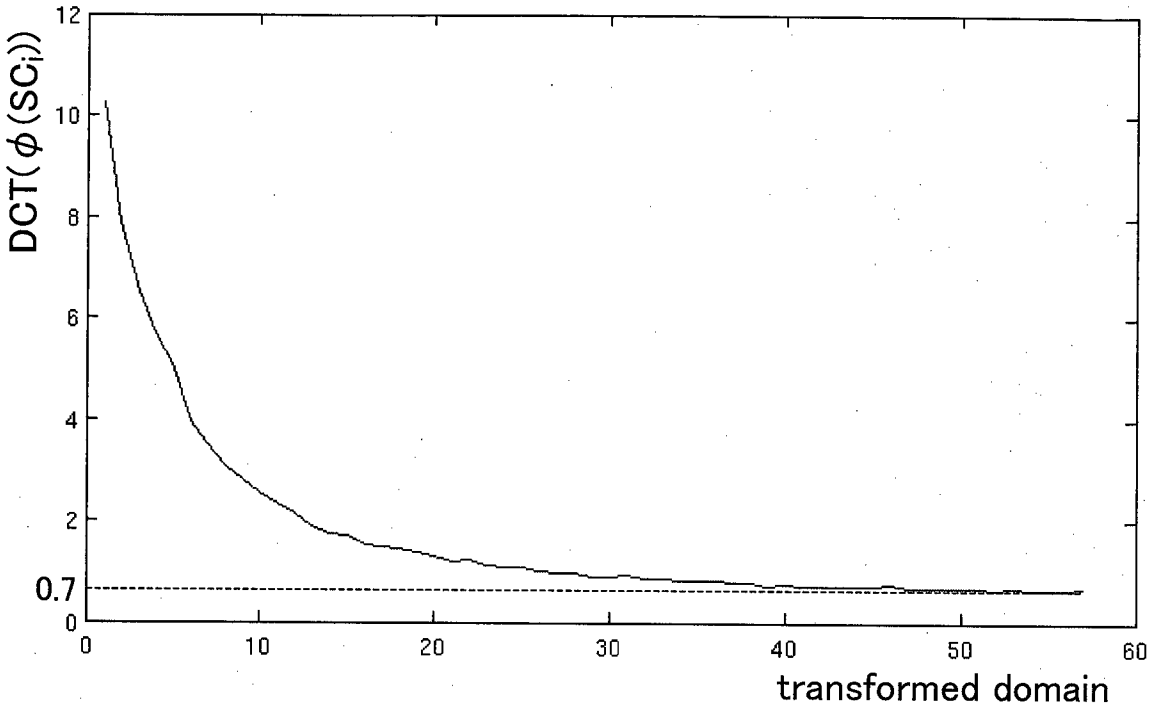

DCT(φ(SCi))
12
10
8
6
4
2
0.7
0
0
10
20
30
40
50
60
transformed domain

FIG. 2B

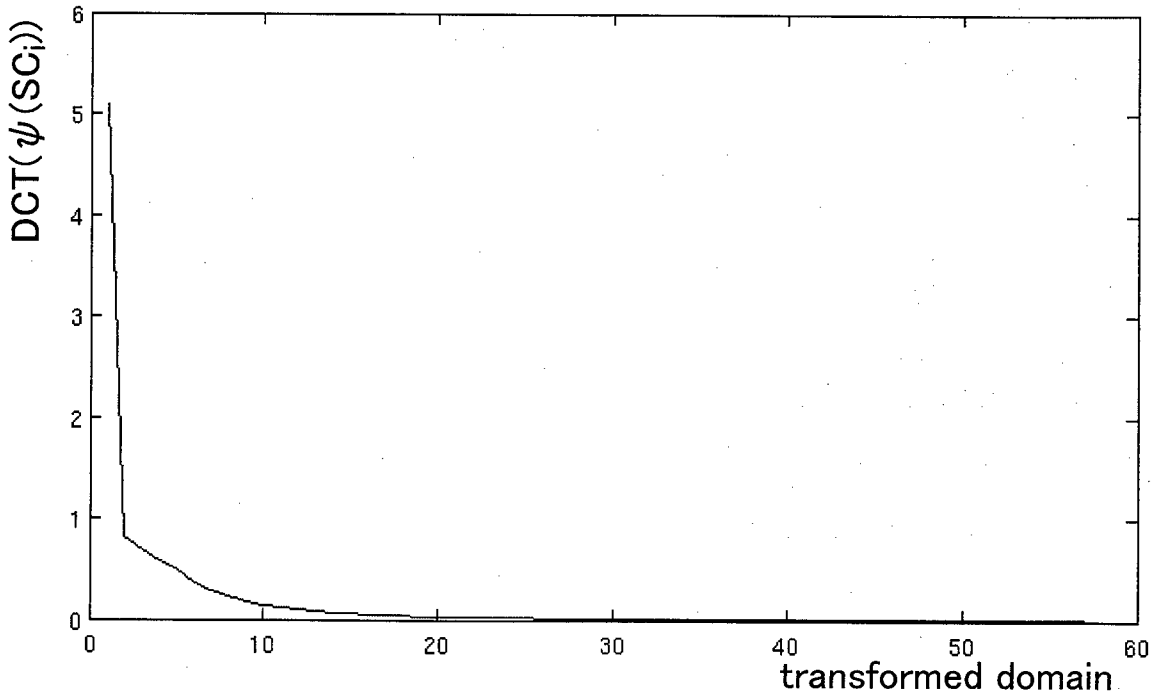
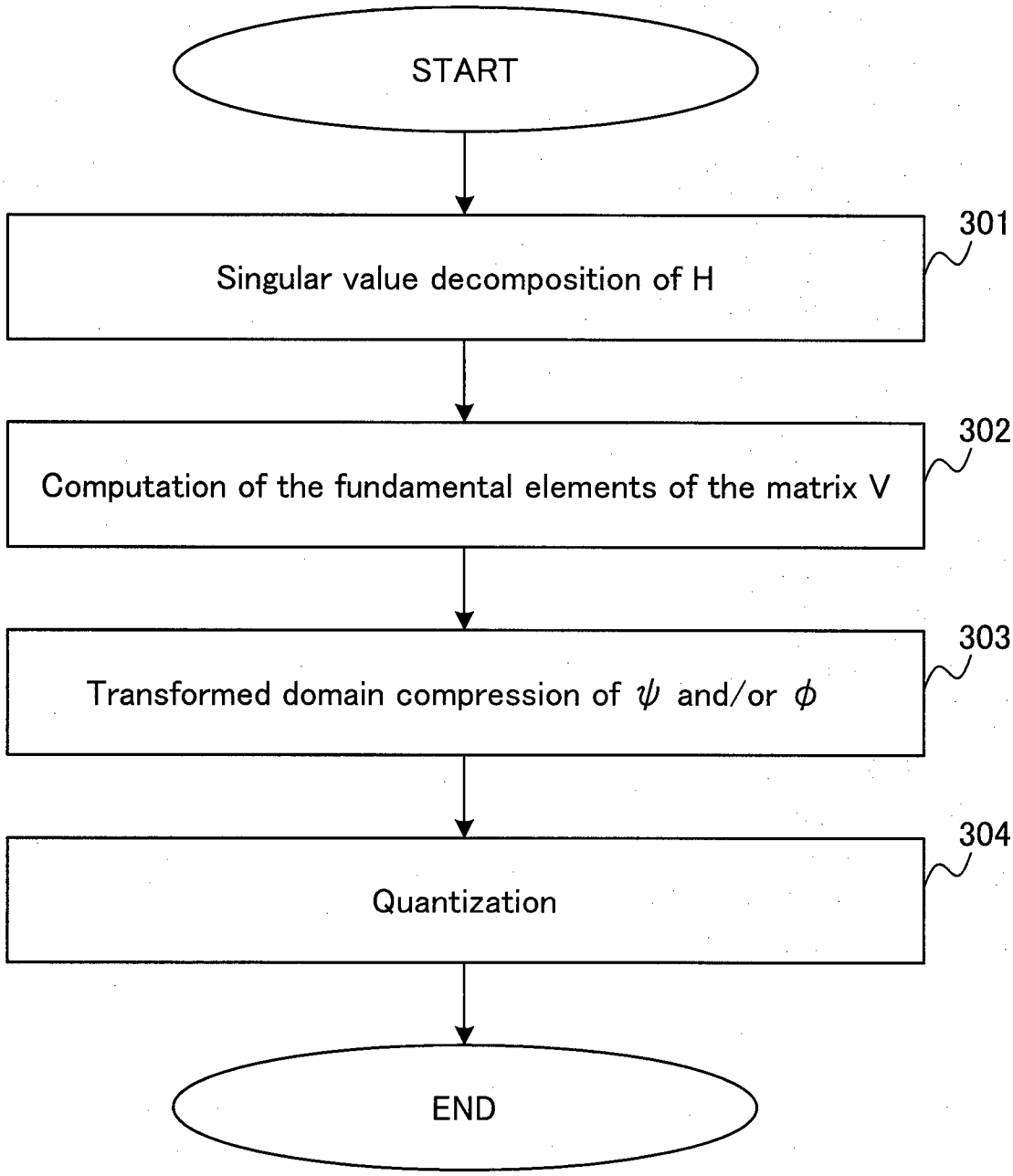

DCT(ψ(SCi))
6
5
4
3
2
1
0
0
10
20
30
40
50
60
transformed domain

FIG. 3


START
Singular value decomposition of H
301
Computation of the fundamental elements of the matrix V
302
Transformed domain compression of ψ and/or ϕ
303
Quantization
304
END

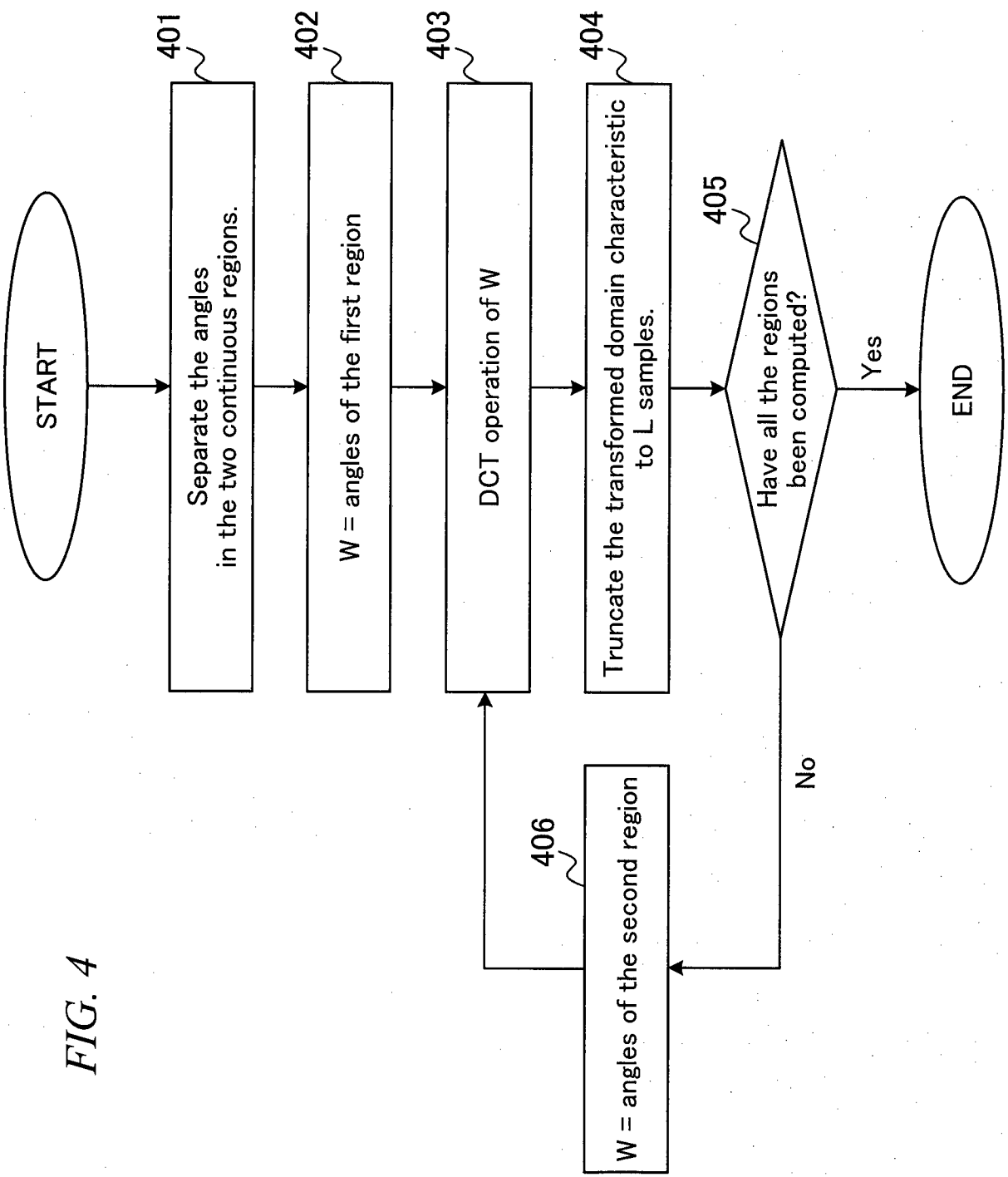
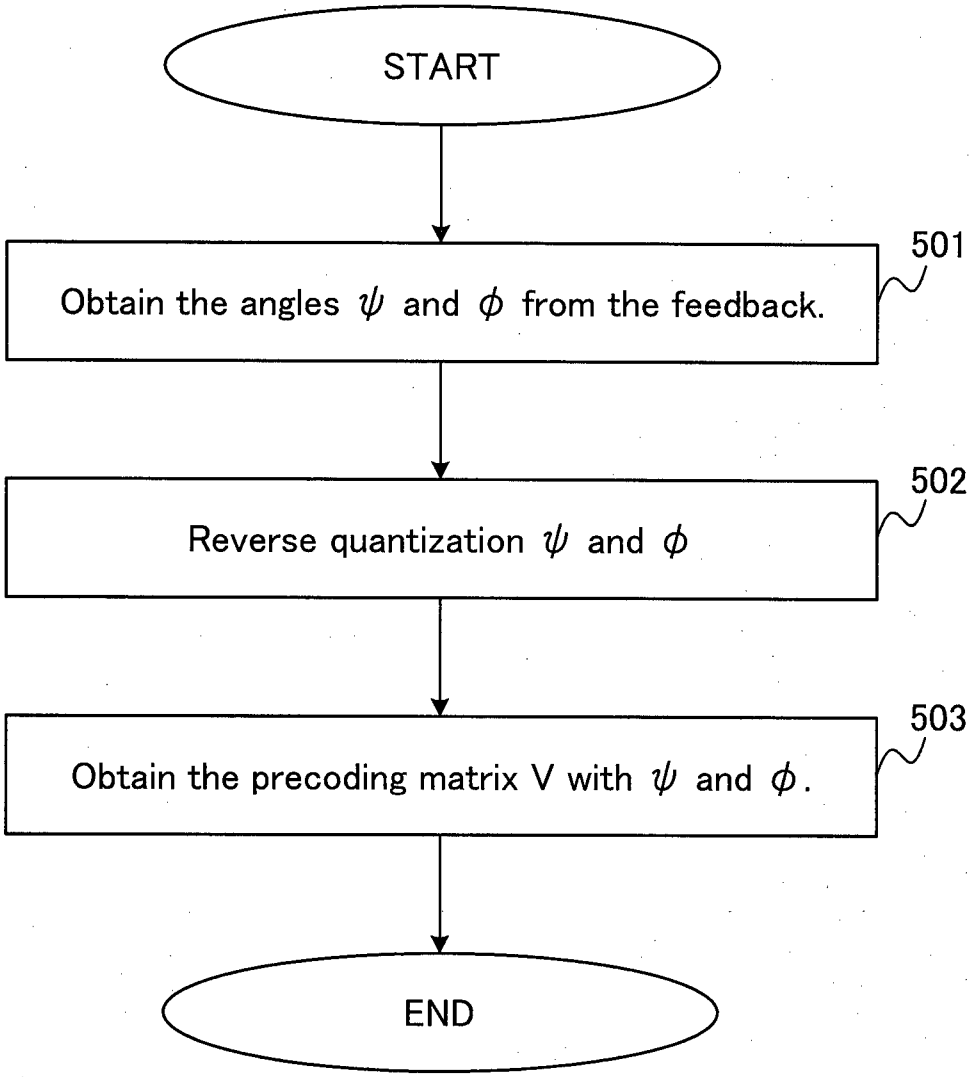

START
401
Separate the angles in the two continuous regions.
402
W = angles of the first region
403
DCT operation of W
404
Truncate the transformed domain characteristic to L samples.
405
Have all the regions been computed?
Yes
END
No
406
W = angles of the second region

FIG. 4

FIG. 5


START
Obtain the angles ψ and ϕ from the feedback.
501
Reverse quantization ψ and ϕ
502
Obtain the precoding matrix V with ψ and ϕ.
503
END

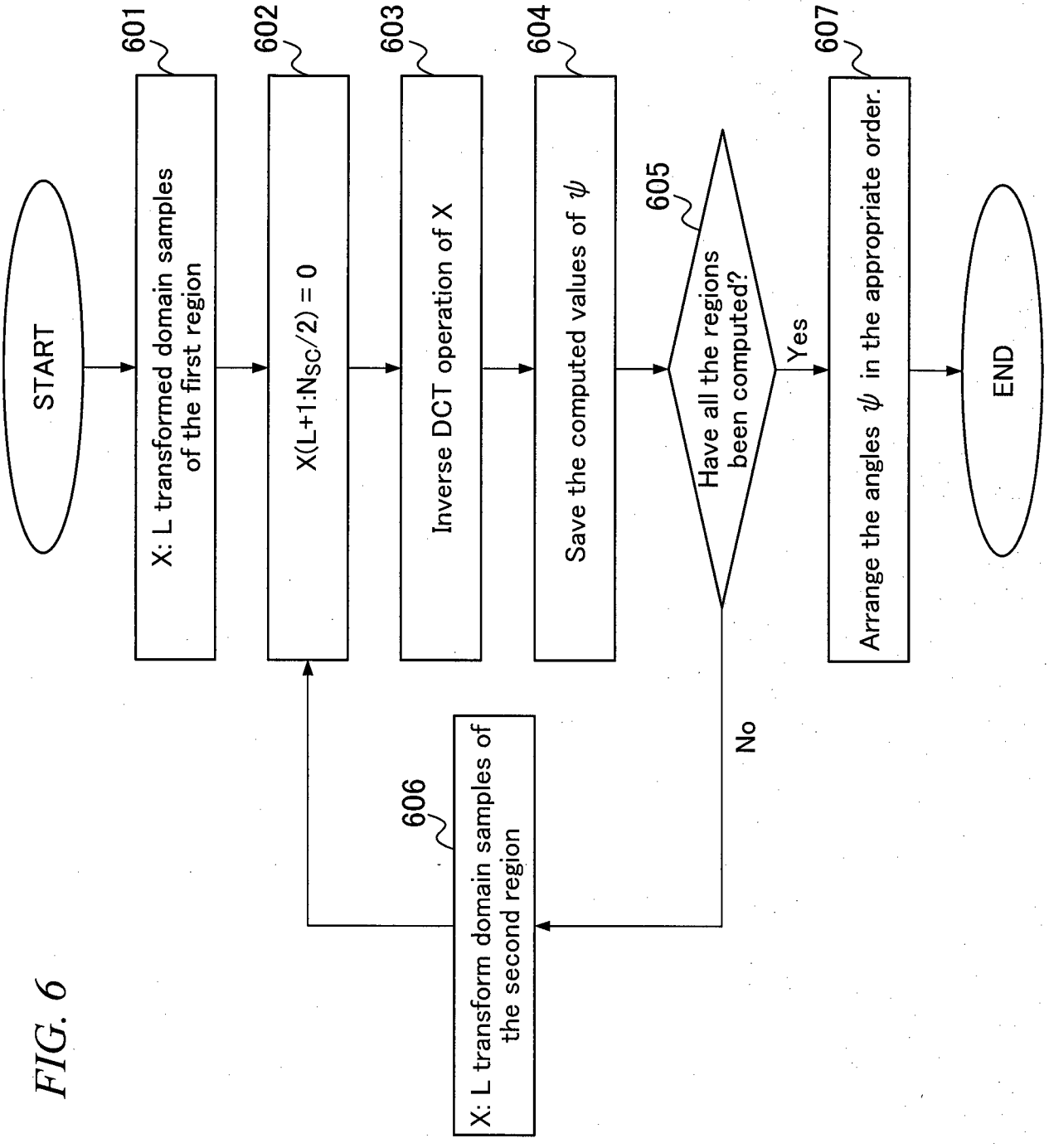

START
601
X: L transformed domain samples of the first region
602
X(L+1:Nsc/2) = 0
603
Inverse DCT operation of X
604
Save the computed values of ψ
605
Have all the regions been computed?
Yes
607
Arrange the angles ψ in the appropriate order.
END
No
606
X: L transform domain samples of the second region

FIG. 6

FIG. 7

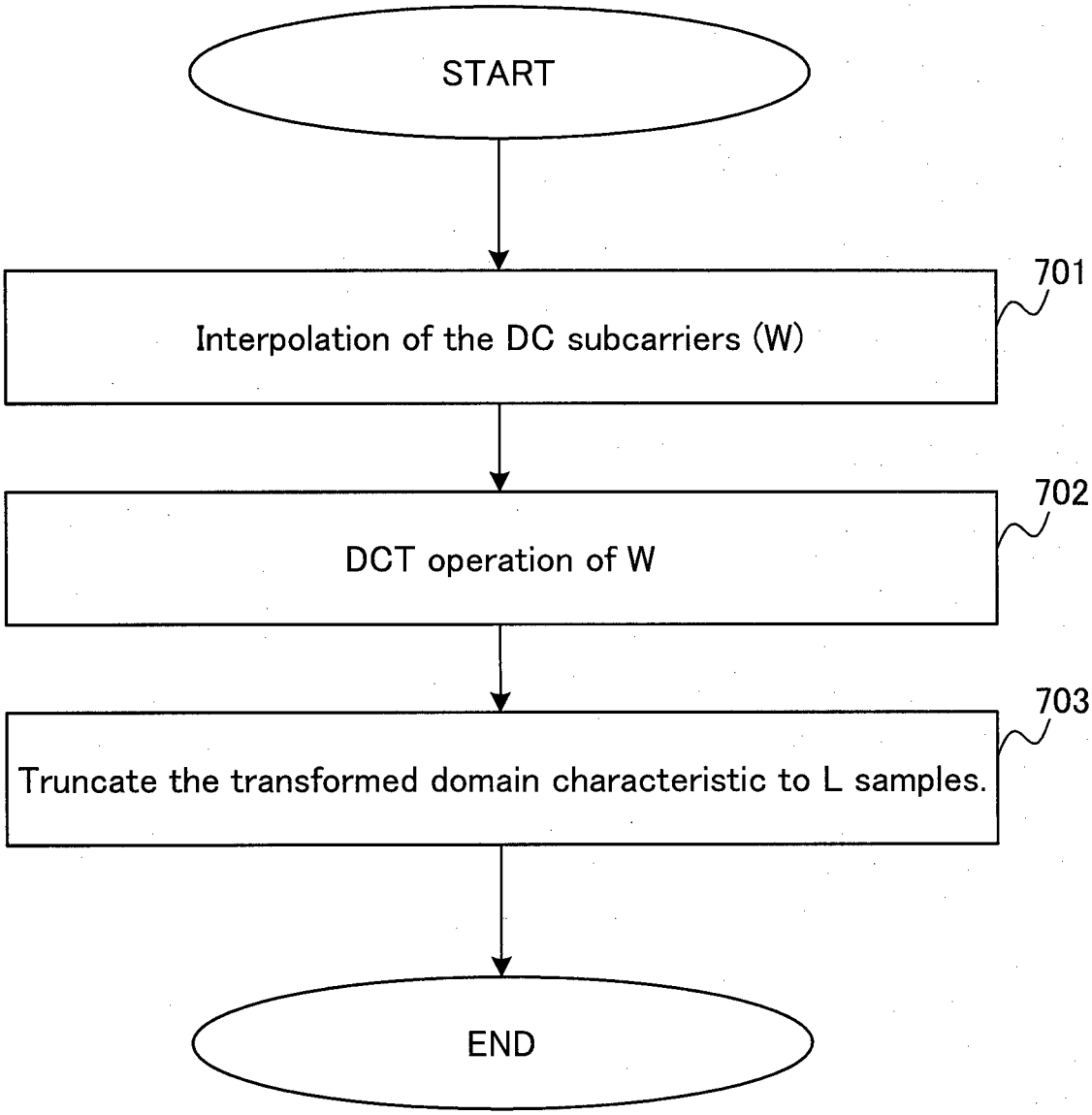

START
Interpolation of the DC subcarriers (W)
701
DCT operation of W
702
Truncate the transformed domain characteristic to L samples.
703
END

FIG. 8

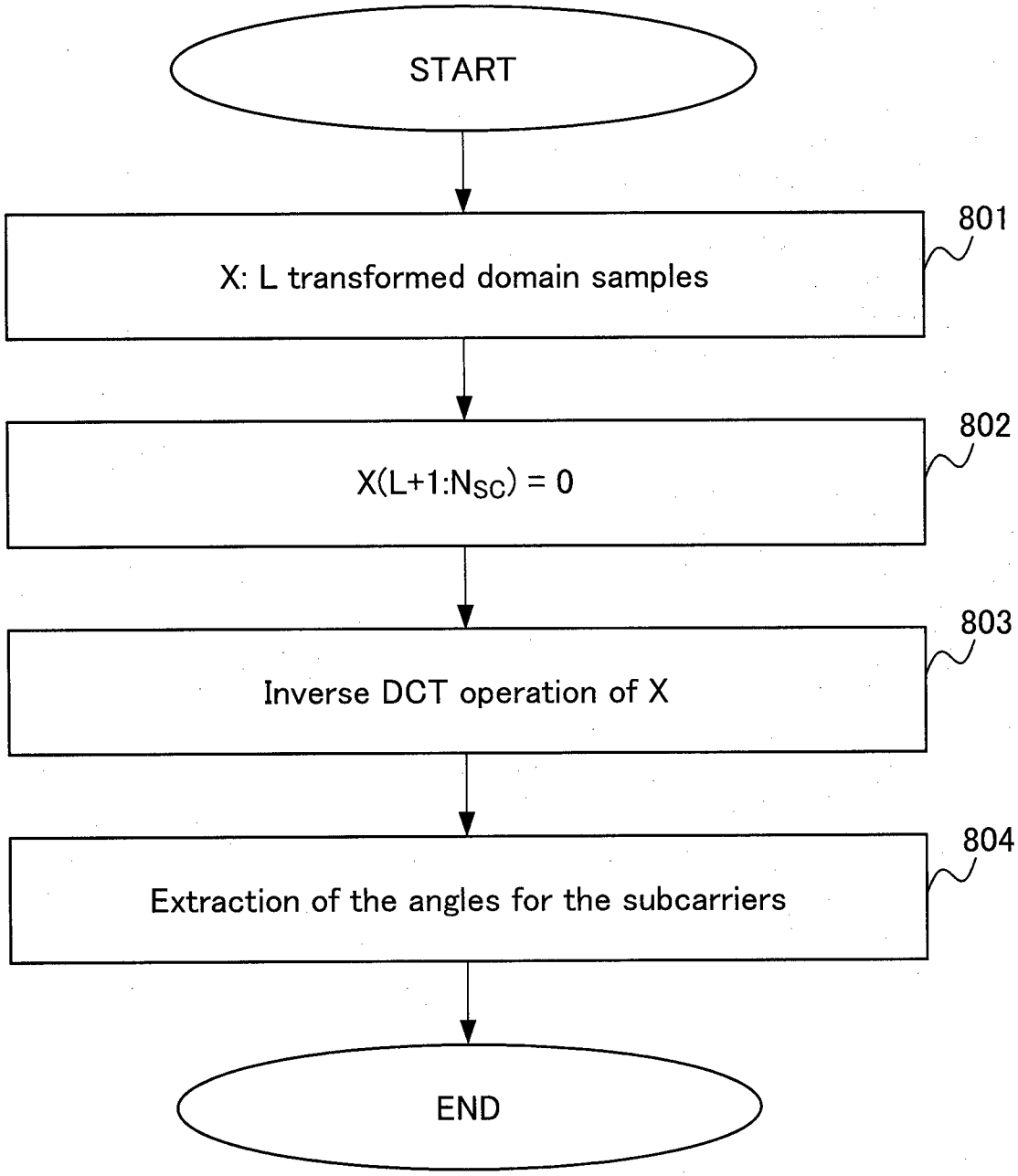

START
X: L transformed domain samples
801
X(L+1:N_{SC}) = 0
802
Inverse DCT operation of X
803
Extraction of the angles for the subcarriers
804
END

FIG. 9

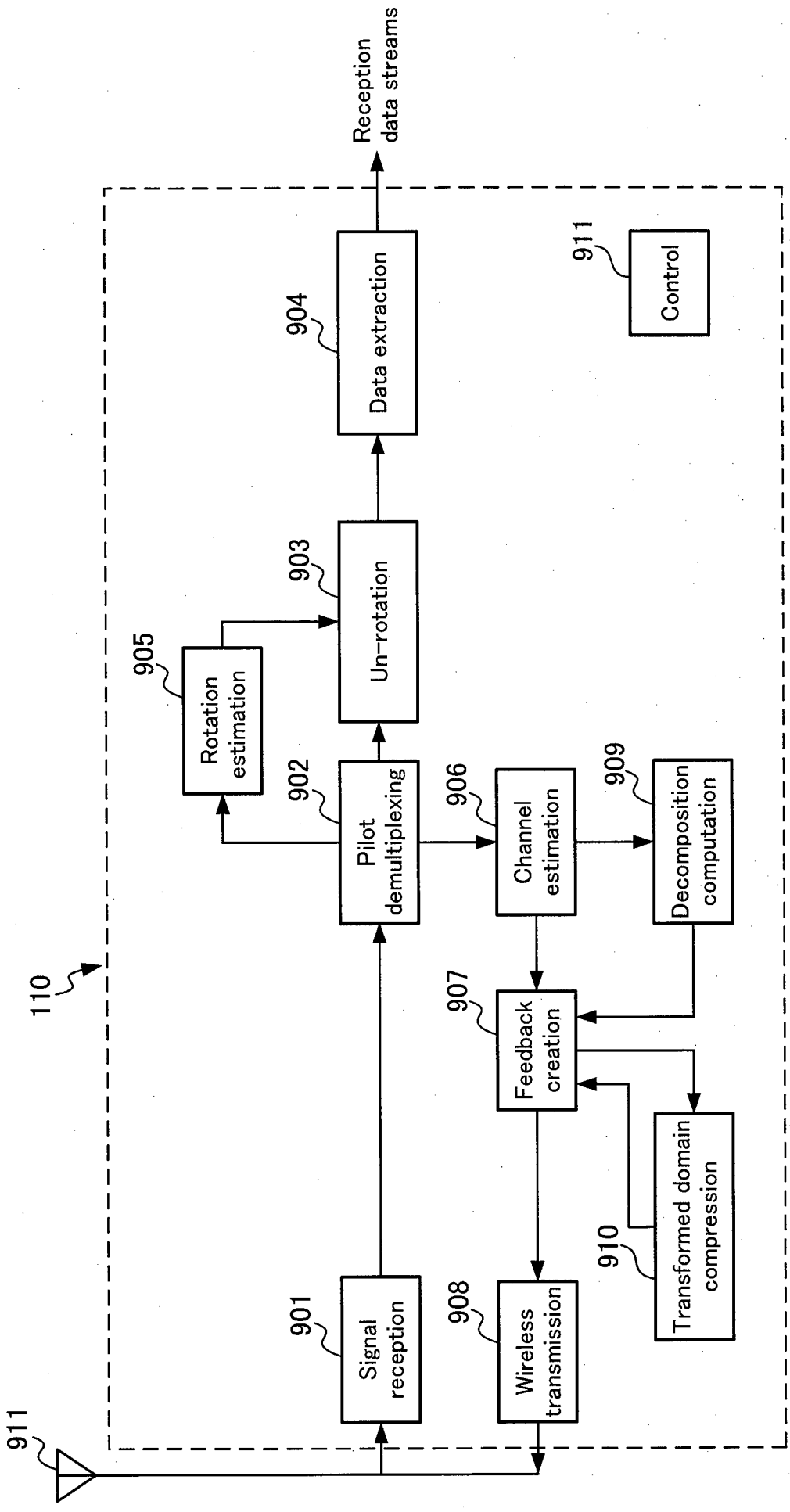

Reception data streams
911
Control
904
Data extraction
903
Un-rotation
905
Rotation estimation
902
Pilot demultiplexing
906
Channel estimation
909
Decomposition computation
110
907
Feedback creation
910
Transformed domain compression
901
Signal reception
908
Wireless transmission
911

FIG. 10

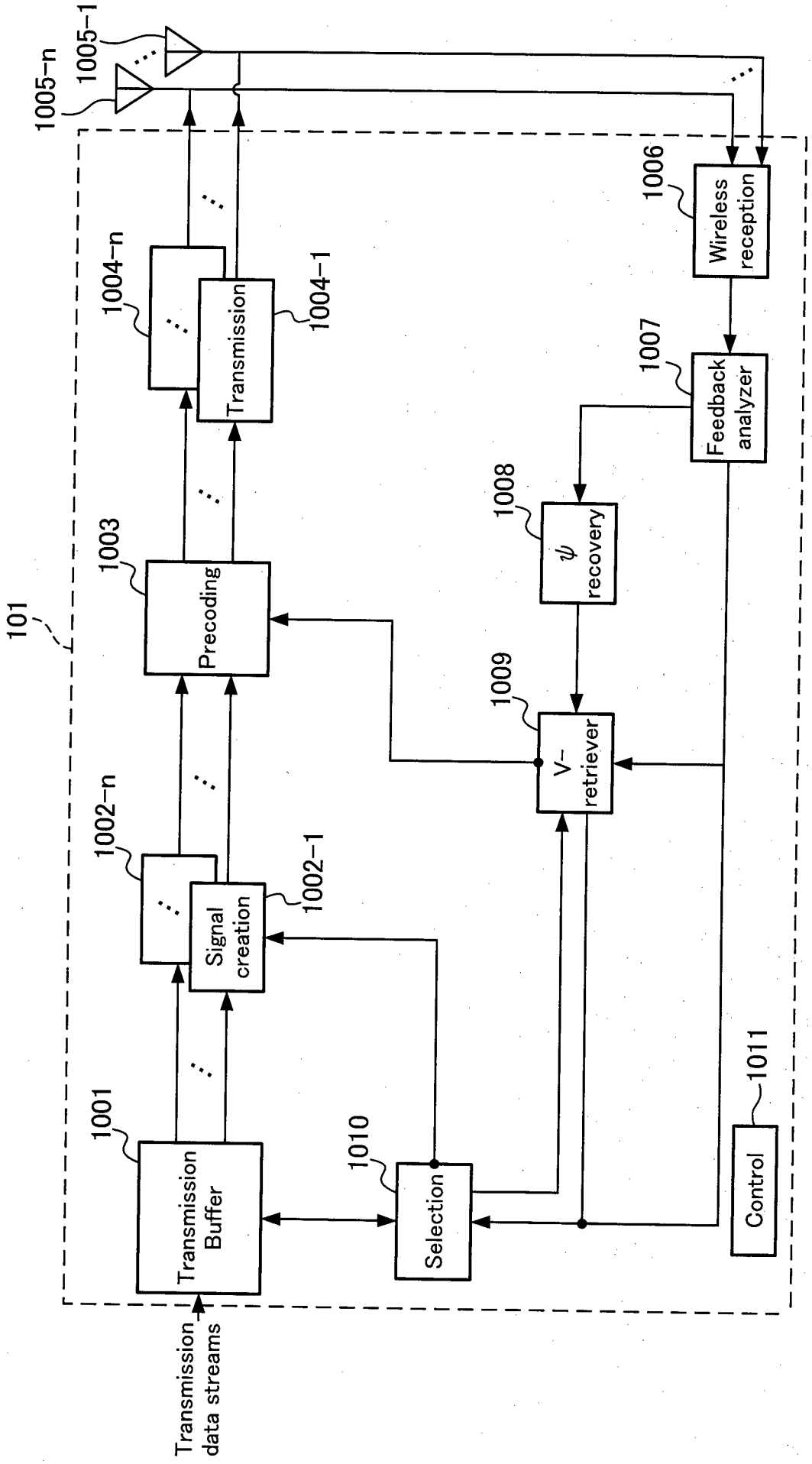

1005-n
1005-1
1006
Wireless reception
1004-n
1004-1
Transmission
1007
Feedback analyzer
1008
ψ recovery
1003
Precoding
101
1009
V-retriever
1002-n
1002-1
Signal creation
1001
Transmission Buffer
1010
Selection
1011
Control
Transmission data streams

FIG. 11

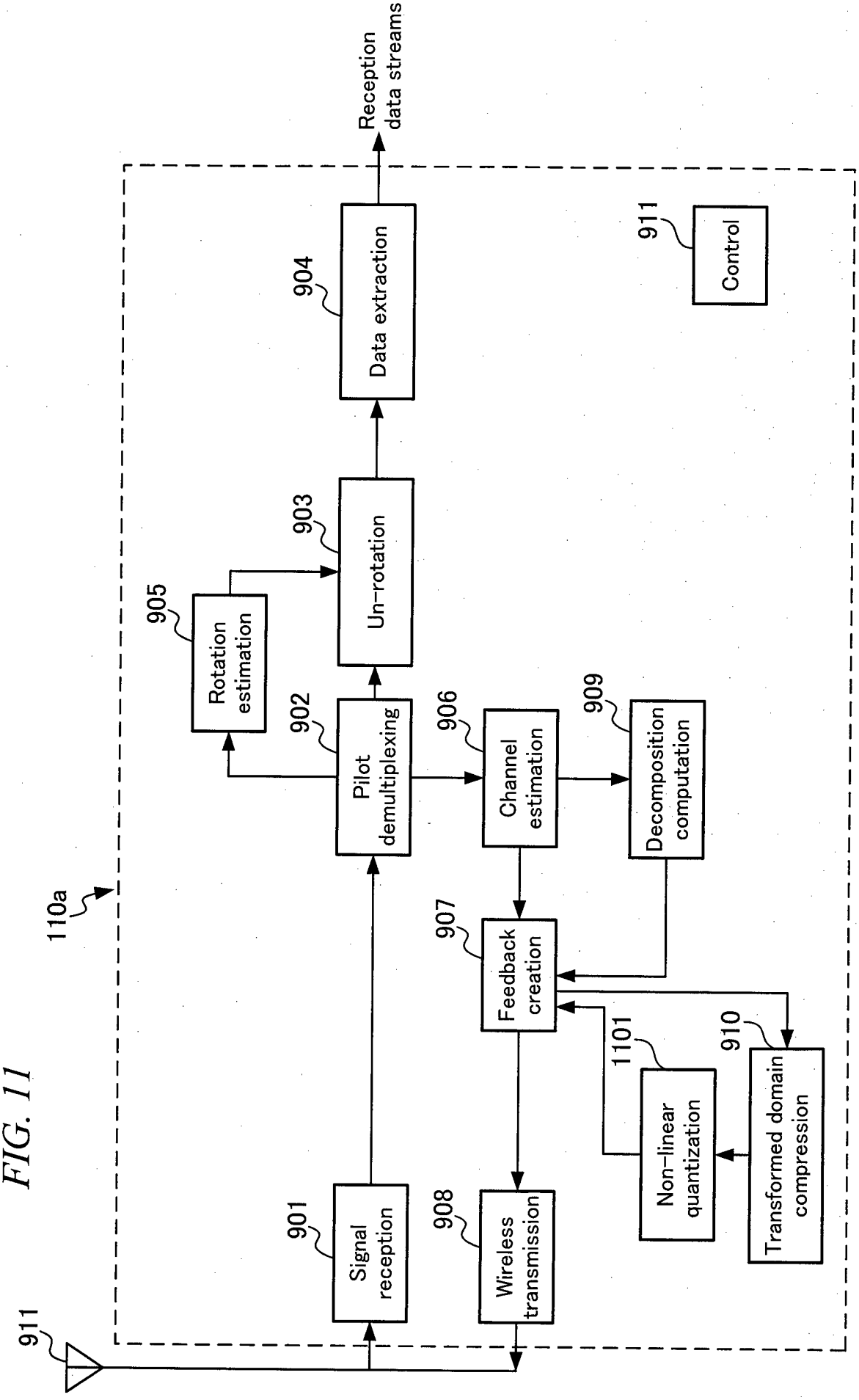

Reception data streams
911
Control
904
Data extraction
903
Un-rotation
905
Rotation estimation
902
Pilot demultiplexing
906
Channel estimation
909
Decomposition computation
110a
907
Feedback creation
1101
910
Non-linear quantization
Transformed domain compression
901
Signal reception
908
Wireless transmission
911

FIG. 12

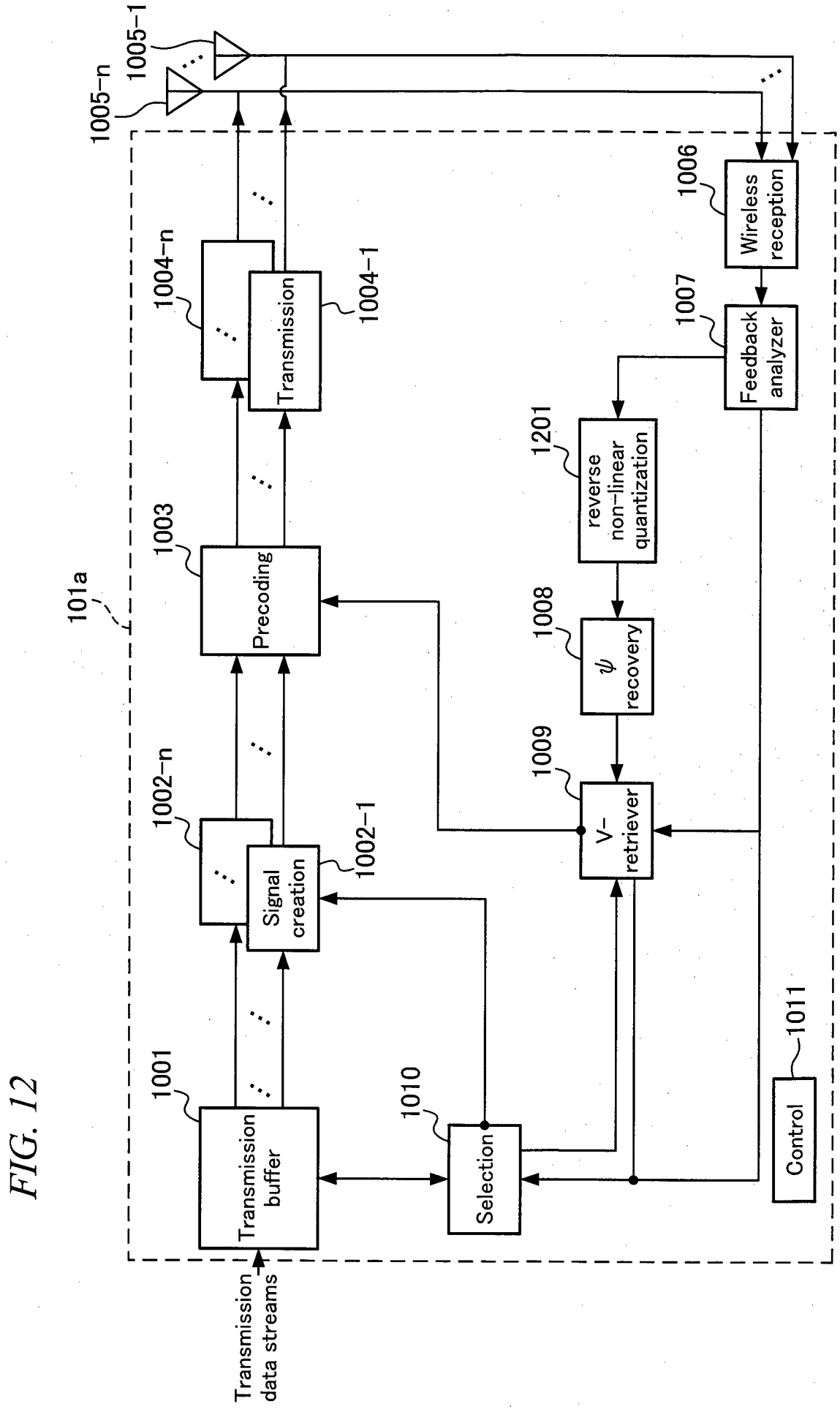

1005-n
1005-1
1006
Wireless reception
1007
Feedback analyzer
1004-n
1004-1
Transmission
1201
reverse non-linear quantization
1003
Precoding
101a
1008
ψ recovery
1009
V-retriever
1002-n
1002-1
Signal creation
1001
Transmission buffer
1010
Selection
1011
Control
Transmission data streams

FIG. 13

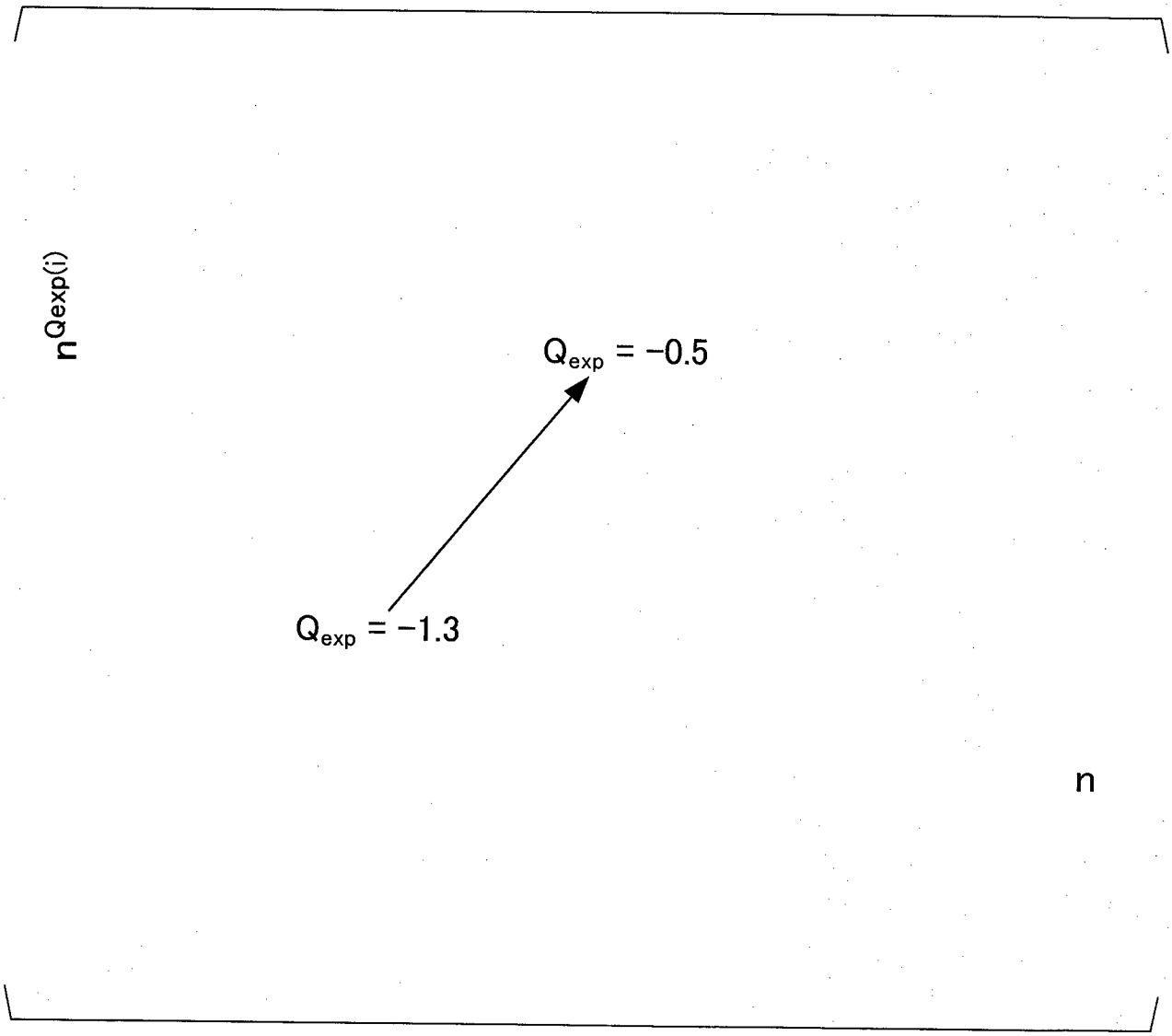


FIG. 14

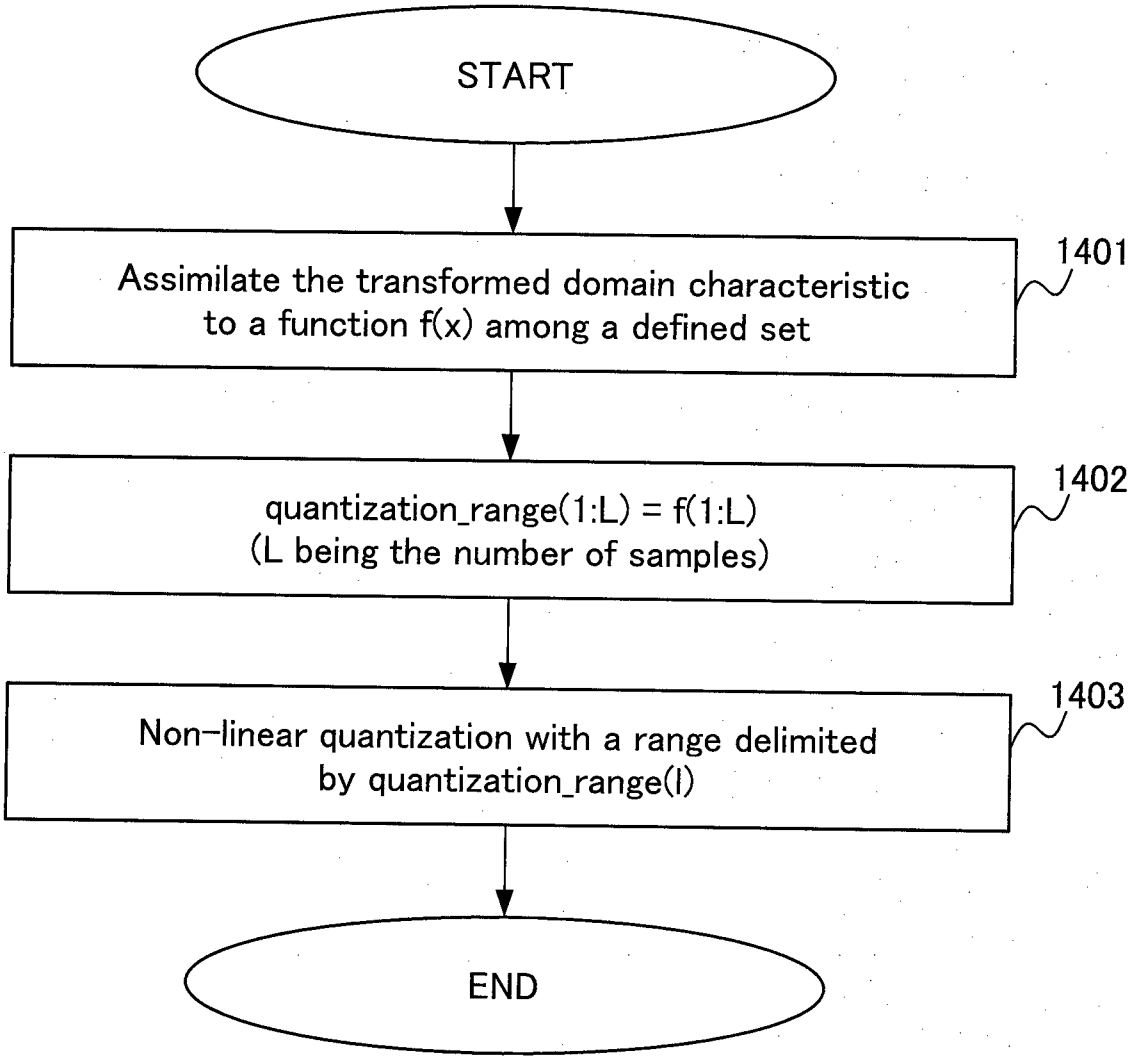

START
Assimilate the transformed domain characteristic to a function f(x) among a defined set
1401
quantization_range(1:L) = f(1:L) (L being the number of samples)
1402
Non-linear quantization with a range delimited by quantization_range(l)
1403
END

FIG. 15

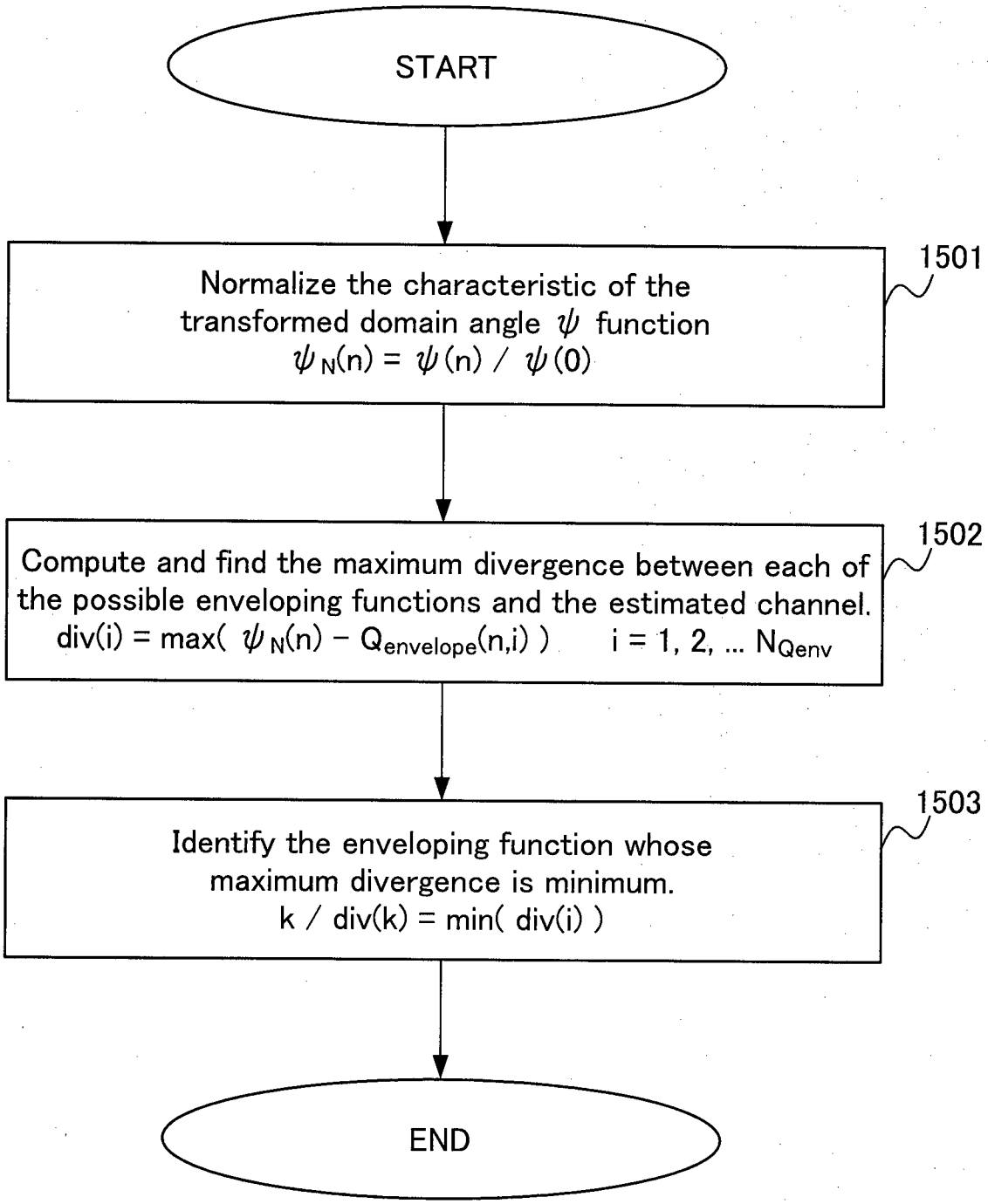

START
Normalize the characteristic of the transformed domain angle ψ function
ψN(n) = ψ(n) / ψ(0)
1501
Compute and find the maximum divergence between each of the possible enveloping functions and the estimated channel.
div(i) = max(ψN(n) − Qenvelope(n,i)) i = 1, 2, ... NQenv
1502
Identify the enveloping function whose maximum divergence is minimum.
k / div(k) = min(div(i))
1503
END

FIG. 16

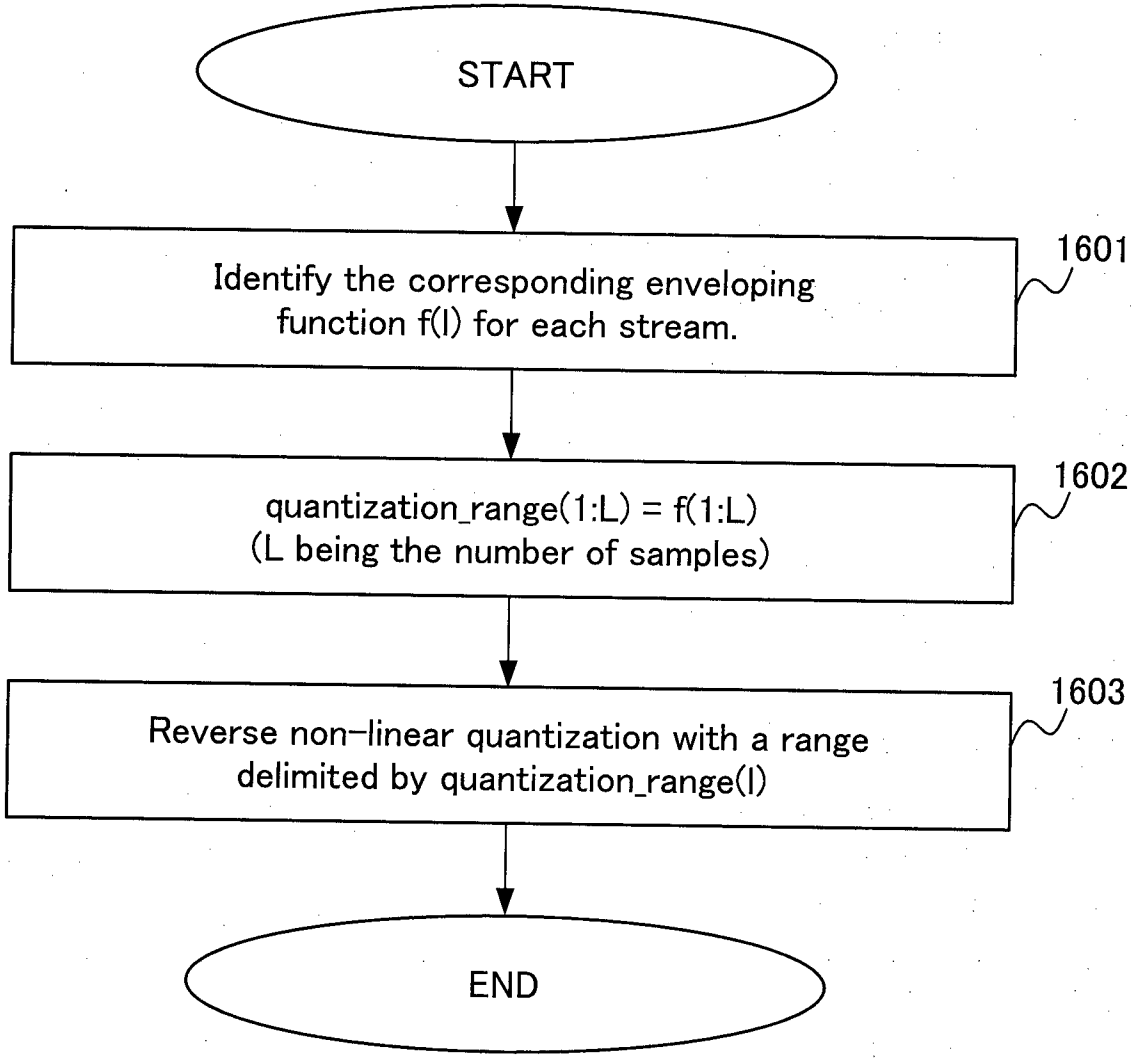

START
Identify the corresponding enveloping function f(I) for each stream.
1601
quantization_range(1:L) = f(1:L) (L being the number of samples)
1602
Reverse non-linear quantization with a range delimited by quantization_range(I)
1603
END

FIG. 17

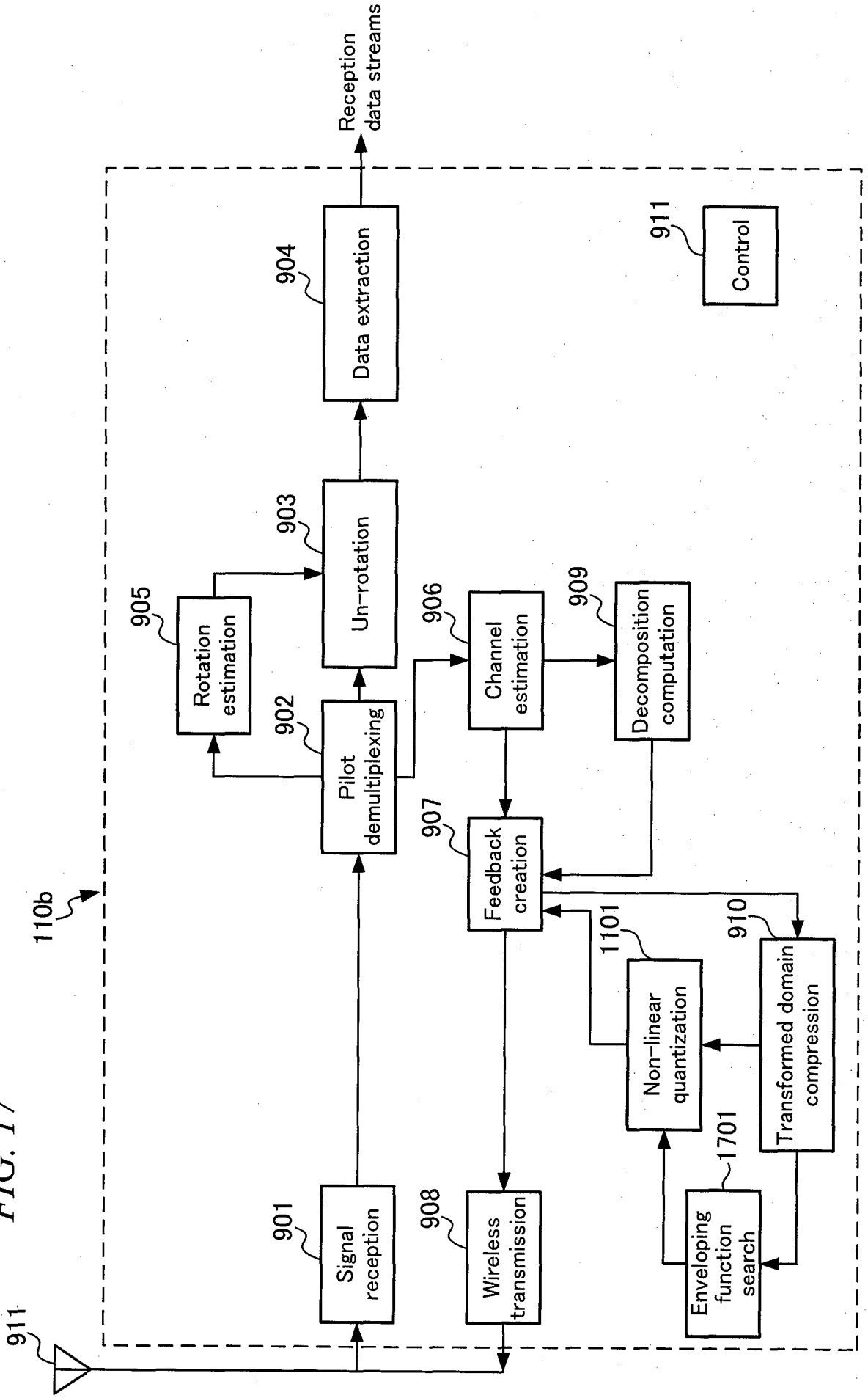
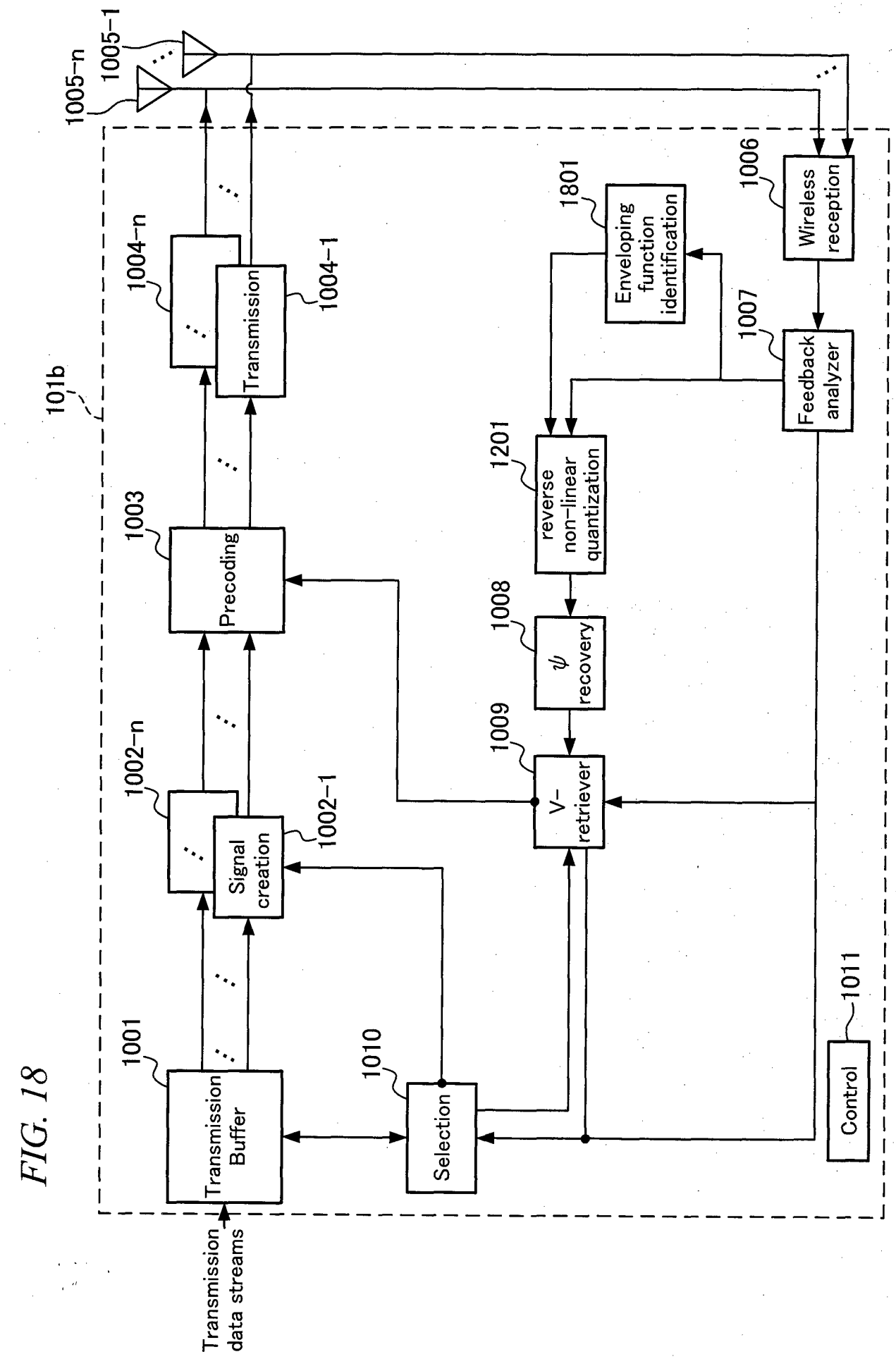

Reception data streams
911
Control
904
Data extraction
903
Un-rotation
905
Rotation estimation
902
Pilot demultiplexing
906
Channel estimation
909
Decomposition computation
907
Feedback creation
1101
Non-linear quantization
910
Transformed domain compression
1701
Enveloping function search
901
Signal reception
908
Wireless transmission
911
110b

FIG. 18


1005-n
1005-1
101b
1004-n
1004-1
Transmission
1003
Precoding
1002-n
1002-1
Signal creation
1001
Transmission Buffer
Transmission data streams
1010
Selection
1801
Enveloping function identification
1201
reverse non-linear quantization
1008
ψ recovery
1009
V- retriever
1006
Wireless reception
1007
Feedback analyzer
1011
Control

INTERNATIONAL SEARCH REPORT

International application No
PCT/JP2013/082903

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/06
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)
H04B

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FILIPPO TOSATO: "Frequency-Selective Channel State Feedback in Multiuser MIMO Downlink", IEEE TRANSACTIONS ON COMMUNICATIONS, IEEE SERVICE CENTER, PISCATAWAY, NJ. USA, vol. 60, no. 8, 1 August 2012 (2012-08-01) , pages 2230-2239, XP011456645, ISSN: 0090-6778, DOI: 10.1109/TCOMM.2012.070912.110184 the whole document ----- -/--	1-7

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 March 2014	09/04/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Neeb, Christoph

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CHAU YUEN ET AL: "Beamforming matrix quantization with variable feedback rate", PERSONAL, INDOOR AND MOBILE RADIO COMMUNICATIONS, 2008. PIMRC 2008. IEEE 19TH INTERNATIONAL SYMPOSIUM ON, IEEE, PISCATAWAY, NJ, USA, 15 September 2008 (2008-09-15), pages 1-5, XP031371407, DOI: 10.1109/PIMRC.2008.4699541 ISBN: 978-1-4244-2643-0 the whole document ----- ALCATEL-LUCENT: "Comparison of CSI Feedback Schemes", 3GPP DRAFT; R1-093343, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, no. Shenzhen, China; 20090824, 24 August 2009 (2009-08-24), XP050388123, [retrieved on 2009-08-29] setcion 3, 8 ----- KOICHI ISHIHARA (NTT): "Time-Domain CSI Compression Schemes for Explicit Beamforming in MU-MIMO ; 11-10-1131-00-00ac-time-domain-csi-compression-schemes-for-explicit-beamforming-in-mu-mimo", IEEE DRAFT; 11-10-1131-00-00AC-TIME-DOMAIN-CSI-COMPRESSION-SCHEMES-FOR-EXPLICIT-BEAMFORMING-IN-MU-MIMO, IEEE-SA MENTOR, PISCATAWAY, NJ USA, vol. 802.11ac, 14 September 2010 (2010-09-14), pages 1-12, XP017676127, [retrieved on 2010-09-14] the whole document -----	1-7 1-7 1-7