DESCRIPTION

Title of Invention: TRANSMISSION APPARATUS, RECEPTION APPARATUS, TRANSMISSION METHOD, RECEPTION METHOD, AND METHOD FOR GENERATING ROTATED MULTI-DIMENSIONAL CONSTELLATIONS

[Technical Field]

[0001] The present invention relates to digital data communication, in particular to methods for generating multi-dimensional constellations for digital data modulation, methods for modulating and transmitting data on the basis of multi-dimensional constellations, and a corresponding apparatus.

[Background Art]

[0002] Fading is one of the major problems in communication systems. It represents random fluctuations in the amplitude of the received signal due to multi-path propagation. If the delay spread of the channel is larger than the symbol period of the signal, the fading is also frequency selective. The amplitude of fading is usually approximated by a Rayleigh distribution. Such fading is referred to as Rayleigh fading.

[0003] In digital communication systems, information is encoded as a sequence of symbols belonging to a discrete alphabet, referred to as a constellation. Such a constellation has N dimensions and encodes B information bits per dimension. The number of possible values, also referred to as constellation points, is therefore 2^{N*B}. The number of bits per dimension B directly determines the spectral efficiency of the transmission, given in bits/Hz. The number of dimensions N has no effect on the spectral efficiency. An example constellation with $N = 2$ and $B = 1$ is illustrated in FIG. 1A.

[0004] Traditionally, for example in a quadrature amplitude modulation (QAM) constellation shown in FIG. 1A, each transmitted bit affects only one dimension. Referring to FIG. 1A, "b_1" of each constellation point "b_1b_2" (= "00", "01", "10" and "11") affects only the dimension represented by the horizontal axis, whereas "b_2" of each constellation point "b_1b_2" affects only the dimension represented by the vertical axis. If the dimension affected by the transmitted bits undergoes a deep fading, all bits that modulate this dimension will be extremely unreliable, which increases the error probability. This effect is illustrated by the errors in FIG. 1A. For example, if the channel represented by the vertical axis fades away, the constellation points "00", "01", "10" and "11" will approach the horizontal axis (along the solid arrows of FIG. 1A). As a result, the constellation points "00" and "01", as well as the constellation points "10" and "11", will be indiscernible.

CLAIMS

[Claim 1] A transmission apparatus for transmitting a block of data over a plurality of transmission channels, the transmission apparatus comprising:

a modulator operable to generate one of a plurality of rotated constellation points in accordance with the block of data to be transmitted, each of the plurality of rotated constellation points having N components; and

a transmitter operable to transmit each component of the generated rotated constellation point over a different one of the plurality of transmission channels, wherein

the plurality of rotated constellation points are obtained by applying an orthogonal transformation to each of a plurality of initial constellation points that has N components,

N is a multiple of four, and

the orthogonal transformation has one of (i) an N-by-N matrix representation with absolute values of all elements on a main diagonal equal to a first value, and with absolute values of all elements not on the main diagonal equal to a non-zero second value, and (ii) a matrix representation obtained by permuting either or both of rows and columns in the N-by-N matrix representation.

[Claim 2] A reception apparatus for receiving a block of data over a plurality of transmission channels, the reception apparatus comprising:

a receiver operable to receive N component signals over the plurality of transmission channels; and

a demodulator operable to select one of a plurality of rotated constellation points in accordance with the plurality of received N component signals, wherein

the plurality of rotated constellation points are obtained by applying an orthogonal transformation to each of a plurality of initial constellation points that has N components,

N is a multiple of four, and

the orthogonal transformation has one of (i) an N-by-N matrix representation with absolute values of all elements on a main diagonal equal to a first value, and with absolute values of all elements not on the main diagonal equal to a non-zero second value, and (ii) a matrix representation obtained by permuting either or both of rows and columns in the N-by-N matrix representation.

[Claim 3] A transmission method for transmitting a block of data over a plurality of transmission channels, the transmission method comprising the steps of:

generating one of a plurality of rotated constellation points in accordance with the block of data to be transmitted, each of the plurality of rotated constellation points having N components; and

transmitting each component of the generated rotated constellation point over a different one of the plurality of transmission channels, wherein

the plurality of rotated constellation points are obtained by applying an orthogonal transformation to each of a plurality of initial constellation points that has N components,

N is a multiple of four, and

the orthogonal transformation has one of (i) an N-by-N matrix representation with absolute values of all elements on a main diagonal equal to a first value, and with absolute values of all elements not on the main diagonal equal to a non-zero second value, and (ii) a matrix representation obtained by permuting either or both of rows and columns in the N-by-N matrix representation.

[Claim 4] A reception method for receiving a block of data over a plurality of transmission channels, the reception method comprising the steps of:

receiving N component signals over the plurality of transmission channels; and

selecting one of a plurality of rotated constellation points in accordance with the plurality of received N component signals, wherein

the plurality of rotated constellation points are obtained by applying an orthogonal transformation to each of a plurality of initial constellation points that has N components,

N is a multiple of four, and

the orthogonal transformation has one of (i) an N-by-N matrix representation with absolute values of all elements on a main diagonal equal to a first value, and with absolute values of all elements not on the main diagonal equal to a non-zero second value, and (ii) a matrix representation obtained by permuting either or both of rows and columns in the N-by-N matrix representation.

[Claim 5] A generation method for generating an N-dimensional rotated constellation for a digital modulation scheme in a data communication system, the generation method comprising the steps of:

receiving a plurality of vectors of an N-dimensional vector space; and

obtaining constellation points of the N-dimensional rotated constellation by applying an orthogonal transformation to the plurality of vectors received, wherein

the orthogonal transformation is adapted for increasing a minimum number of different values in components of any two distinct N-dimensional rotated constellation points relative to a minimum number of different values in components of any two distinct vectors received, and

the orthogonal transformation has one of (i) an N-by-N matrix representation with absolute values of all elements on a main diagonal equal to a first value, and with absolute values of all elements not on the main diagonal equal to a non-zero second value, and (ii) a matrix representation obtained by permuting either or both of rows and columns in the N-by-N matrix representation.

Description

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[0003] In digital communication systems, information is encoded as a sequence of symbols belonging to a discrete alphabet, referred to as a constellation. Such a constellation has N dimensions and encodes B information bits per dimension. The number of possible values, also referred to as constellation points, is therefore 2^{N*B}. The number of bits per dimension B directly determines the spectral efficiency of the transmission, given in bits/Hz. The number of dimensions N has no effect on the spectral efficiency. An example constellation with N = 2 and B = 1 is illustrated in FIG. 1A.

[0004] Traditionally, for example in a quadrature amplitude modulation (QAM) constellation shown in FIG. 1A, each transmitted bit affects only one dimension. Referring to FIG. 1A, "b_1" of each constellation point "b_1b_2" (= "00", "01", "10" and "11") affects only the dimension represented by the horizontal axis, whereas "b_2" of each constellation point "b_1b_2" affects only the dimension represented by the vertical axis. If the dimension affected by the transmitted bits undergoes a deep fading, all bits that modulate this dimension will be extremely unreliable, which increases the error probability. This effect is illustrated by the errors in FIG. 1A. For example, if the channel represented by the vertical axis fades away, the constellation points "00", "01", "10" and "11" will approach the horizontal axis (along the solid arrows of FIG. 1A). As a result, the constellation points "00" and "01", as well as the constellation points "10" and "11", will be indiscernible.

CLAIMS

[Claim 1] A transmission apparatus for transmitting a block of data over a plurality of transmission channels, the transmission apparatus comprising:

a modulator operable to select one of a plurality of constellation points in accordance with the block of data to be transmitted, each of the plurality of constellation points having a plurality of components; and

a transmitter operable to transmit each component of the selected constellation point over a different one of the plurality of transmission channels, wherein

the plurality of constellation points are defined by positions thereof within an N-dimensional space, the positions being obtained by applying an orthogonal transformation to a subset of

$$\mathbb{Z}^N$$

,

which is an N-dimensional integer lattice,

N is a multiple of four, and

the orthogonal transformation has one of (i) an N-by-N matrix representation with absolute values of all elements on a main diagonal equal to a first value, and with absolute values of all elements not on the main diagonal equal to a non-zero second value, and (ii) a matrix representation obtained by permuting rows and/or columns in the N-by-N matrix representation.

[Claim 2] The transmission apparatus according to claim 1, further comprising a mapper operable to map each component of the selected constellation

point to the corresponding one of the plurality of transmission channels over which the component is to be transmitted, such that fading of each of the plurality of transmission channels is uncorrelated with fading of any other one of the plurality of transmission channels.

[Claim 3] The transmission apparatus according to claim 1, wherein the transmitter is adapted for transmitting each component of the selected constellation point over a different one of a plurality of time slots, frequencies, transmitter antennas, or combinations thereof.

[Claim 4] The transmission apparatus according to claim 1, wherein the plurality of transmission channels comprise a plurality of different carriers in an orthogonal frequency-division multiplexing scheme.

[Claim 5] The transmission apparatus according to claim 1, wherein the plurality of transmission channels comprise a plurality of different symbols in an orthogonal frequency-division multiplexing scheme.

[Claim 6] A reception apparatus for receiving a block of data over a plurality of transmission channels, the reception apparatus comprising:

a receiver operable to receive a plurality of component signals over the plurality of transmission channels; and

a demodulator operable to select one of a plurality of constellation points in accordance with the plurality of received component signals, wherein the plurality of constellation points are defined by positions thereof within an N-dimensional space, the positions being obtained by applying an orthogonal transformation to a subset of

$\mathbb{Z}^N$,

which is an N-dimensional integer lattice,

N is a multiple of four, and

the orthogonal transformation has one of (i) an N-by-N matrix representation with absolute values of all elements on a main diagonal equal to a first value, and with absolute values of all elements not on the main diagonal equal to a non-zero second value, and (ii) a matrix representation obtained by permuting rows and/or columns in the N-by-N matrix representation.

[Claim 7] The reception apparatus according to claim 6, wherein the plurality of transmission channels comprise a plurality of different carriers in an orthogonal frequency-division multiplexing scheme.

[Claim 8] The reception apparatus according to claim 6, wherein the plurality of transmission channels comprise a plurality of different symbols in an orthogonal frequency-division multiplexing scheme.

[Claim 9] A transmission method for transmitting a block of data over a plurality of transmission channels, the transmission method comprising the steps of:

selecting one of a plurality of constellation points in accordance with the block of data to be transmitted, each of the plurality of constellation points having a plurality of components; and

transmitting each component of the selected constellation point over a different one of the plurality of transmission channels, wherein the

plurality of constellation points are defined by positions thereof within an N-dimensional space, the positions being obtained by applying an orthogonal transformation to a subset of

$$\mathbb{Z}^N$$

,

which is an N-dimensional integer lattice,

N is a multiple of four, and

the orthogonal transformation has one of (i) an N-by-N matrix representation with absolute values of all elements on a main diagonal equal to a first value, and with absolute values of all elements not on the main diagonal equal to a non-zero second value, and (ii) a matrix representation obtained by permuting rows and/or columns in the N-by-N matrix representation.

[Claim 10] The transmission method according to claim 9, further comprising the step of mapping each component of the selected constellation point to the corresponding one of the plurality of transmission channels over which the component is to be transmitted, such that fading of each of the plurality of transmission channels is uncorrelated with fading of any other one of the plurality of transmission channels.

[Claim 11] The transmission method according to claim 9, wherein the plurality of transmission channels comprise a plurality of different carriers in an orthogonal frequency-division multiplexing scheme.

[Claim 12] The transmission method according to claim 9, wherein the plurality of transmission channels comprise a plurality of different symbols in an

orthogonal frequency-division multiplexing scheme.

[Claim 13] A reception method for receiving a block of data over a plurality of transmission channels, the reception method comprising the steps of:

receiving a plurality of component signals over the plurality of transmission channels; and

selecting one of a plurality of constellation points in accordance with the plurality of received component signals, wherein the plurality of constellation points are defined by positions thereof within an N-dimensional space, the positions being obtained by applying an orthogonal transformation to a subset of

$$\mathbb{Z}^N$$

,

which is an N-dimensional integer lattice,

N is a multiple of four, and

the orthogonal transformation has one of (i) an N-by-N matrix representation with absolute values of all elements on a main diagonal equal to a first value, and with absolute values of all elements not on the main diagonal equal to a non-zero second value, and (ii) a matrix representation obtained by permuting rows and/or columns in the N-by-N matrix representation.

[Claim 14] The reception method according to claim 13, wherein the plurality of transmission channels comprise a plurality of different carriers in an orthogonal frequency-division multiplexing scheme.

[Claim 15] The reception method according to claim 13, wherein the plurality of

transmission channels comprise a plurality of different symbols in an orthogonal frequency-division multiplexing scheme.

[Claim 16] A generation method for generating a multi-dimensional constellation for a digital modulation scheme in a data communication system, the generation method comprising the steps of:

receiving a plurality of vectors of a multi-dimensional vector space; and

obtaining constellation points of the multi-dimensional constellation by applying an orthogonal transformation to the plurality of vectors received, wherein

the orthogonal transformation is adapted for increasing a minimum number of different values in components of any two distinct multi-dimensional constellation points relative to a minimum number of different values in components of any two distinct vectors received, and

the orthogonal transformation has one of (i) an N-by-N matrix representation, N being a multiple of four, with absolute values of all elements on a main diagonal equal to a first value, and with absolute values of all elements not on the main diagonal equal to a non-zero second value, and (ii) a matrix representation obtained by permuting rows and/or columns in the N-by-N matrix representation.

[Claim 17] The generation method according to claim 16, further comprising the steps of:

selecting a rotation factor r as a real number between 0 and 1;

calculating the first value, a, by evaluating an expression

$$a = \sqrt{1 - \frac{r(N-1)}{N}}$$;

calculating the second value, b, by evaluating an expression

$$b = \sqrt{\frac{r}{N}}$$;

and determining the orthogonal transformation by selecting a sign value si,j for each element (i, j) of a matrix representation

$$\mathrm{R} = \begin{pmatrix} s_{1,1}a & s_{1,2}b & \cdots & s_{1,N}b \\ s_{2,1}b & s_{2,2}a & & \vdots \\ \vdots & & \ddots & s_{N-1,N}b \\ s_{N,1}b & \cdots & s_{N,N-1}b & s_{N,N}a \end{pmatrix}$$,

such that the matrix representation is orthogonal.

[Claim 18] The generation method according to claim 17, wherein the selected rotation factor r maximizes the minimum number of different values in the components of any two distinct multi-dimensional constellation points.

[Claim 19] The generation method according to claim 16, wherein the plurality of vectors received represent a subset of

$$\mathbb{Z}^N$$,

which is an N-dimensional integer lattice.