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(54) METHOD AND ARRANGEMENT IN WIRELESS COMMUNICATION NETWORKS USING RELAYING

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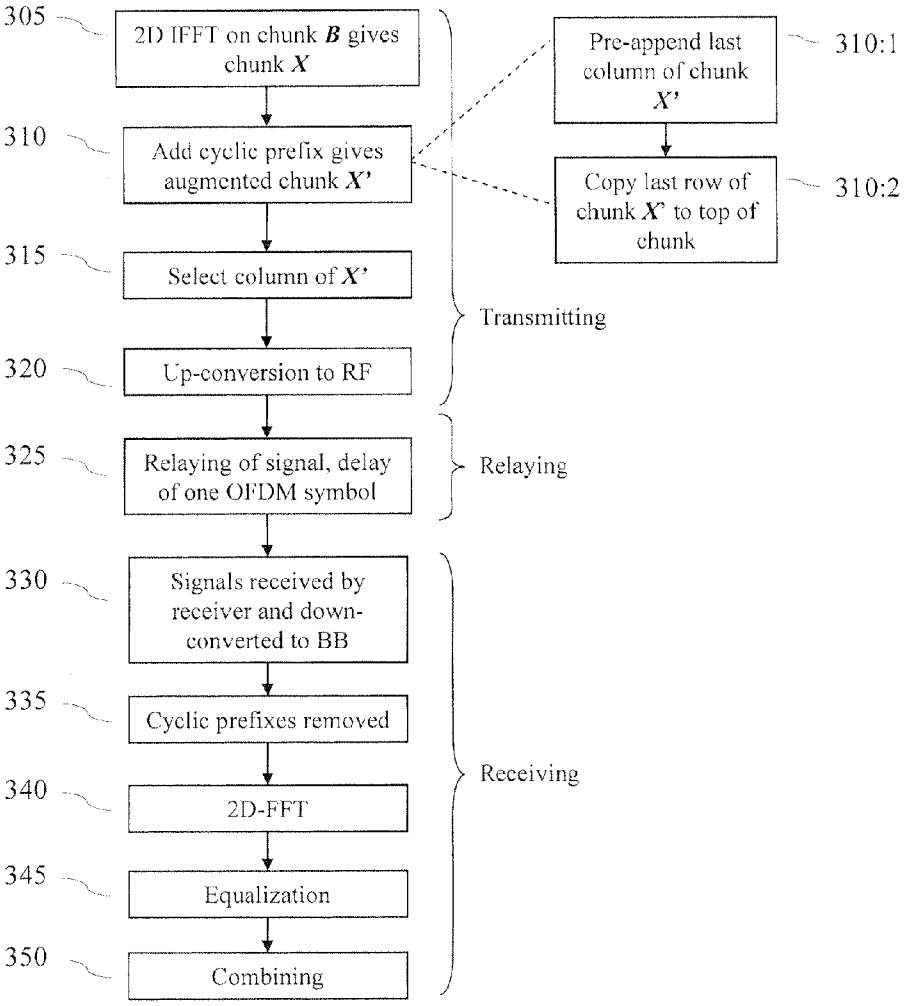
(57) **ABSTRACT**

A wireless communication system with relaying to enhance performance provides artificial frequency selectivity and spatial diversity by introducing delay diversity. A OFDM chunk is subjected to a 2D cyclic prefix by pre-appending to a representation of the chunk the last column of the representation. The last row of the pre-appended chunk is copied to the top of the augmented chunk forming an augmented chunk.



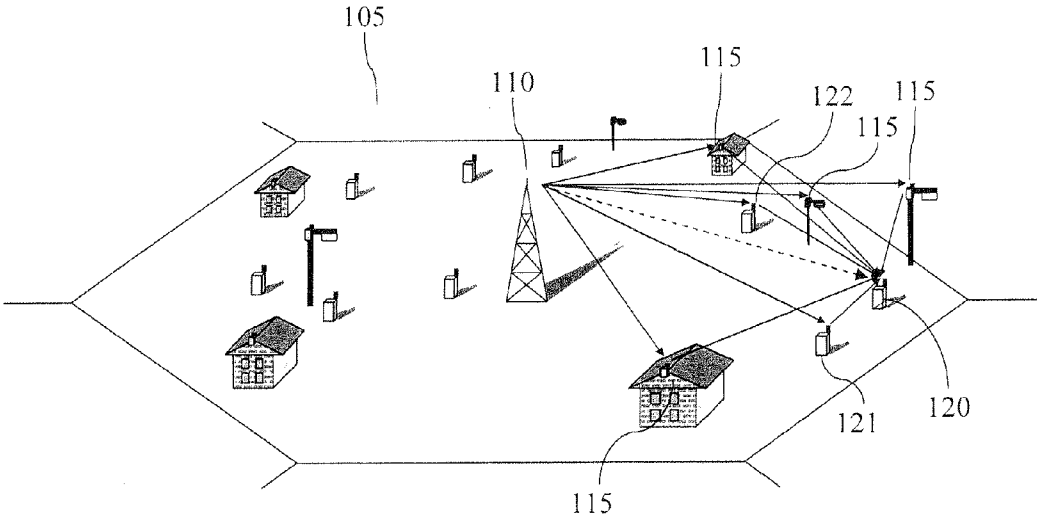

105
110
115
122
115
115
121
120
115

Fig. 1a

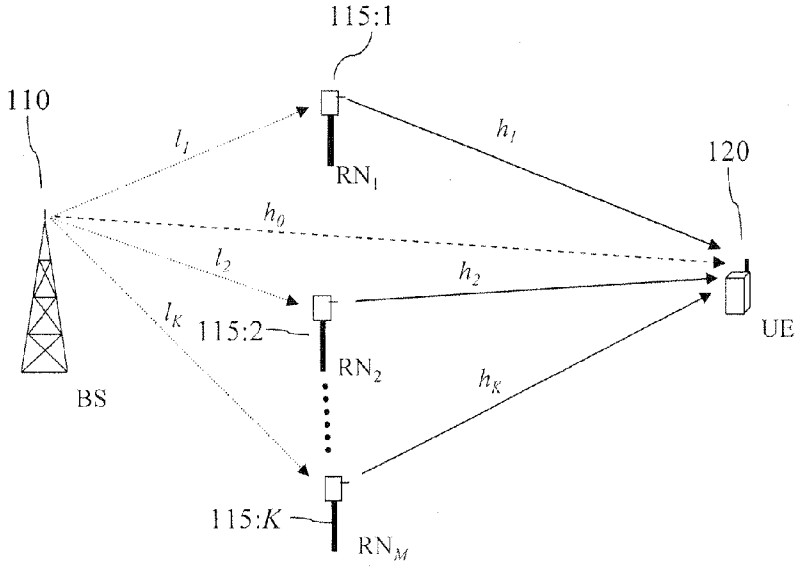

115:1
110
l_1
h_1
RN_1
120
h_0
l_2
h_2
l_K
115:2
RN_2
UE
h_K
BS
115:K
RN_M

Fig. 1b

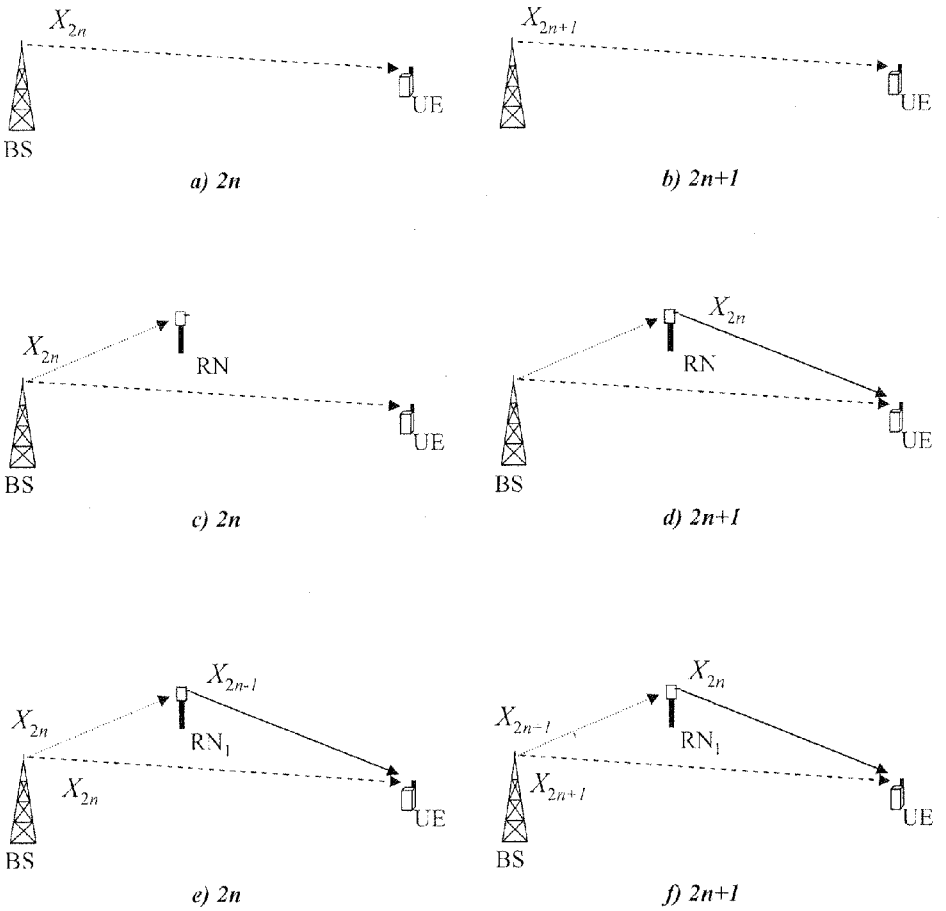

X_{2n}
UE
BS
a) 2n
X_{2n+1}
UE
b) 2n+1
X_{2n}
RN
UE
BS
c) 2n
X_{2n}
RN
UE
BS
d) 2n+1
X_{2n-1}
X_{2n}
RN_1
X_{2n}
UE
BS
e) 2n
X_{2n}
X_{2n-1}
RN_1
X_{2n+1}
UE
BS
f) 2n+1

Fig. 2a-f

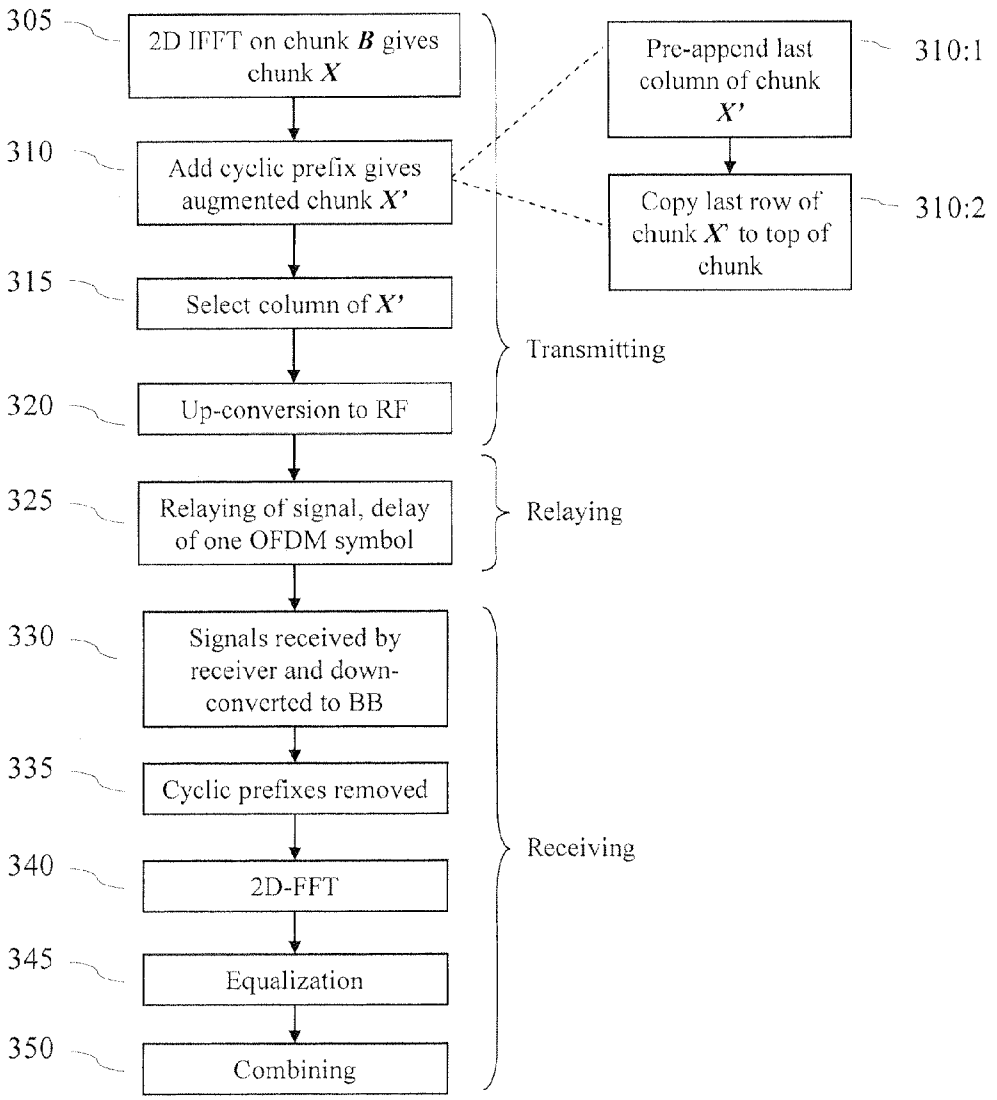

305
2D IFFT on chunk B gives chunk X
310
Add cyclic prefix gives augmented chunk X'
315
Select column of X'
320
Up-conversion to RF
325
Relaying of signal, delay of one OFDM symbol
330
Signals received by receiver and down-converted to BB
335
Cyclic prefixes removed
340
2D-FFT
345
Equalization
350
Combining
Pre-append last column of chunk X'
310:1
Copy last row of chunk X' to top of chunk
310:2
Transmitting
Relaying
Receiving

Fig. 3

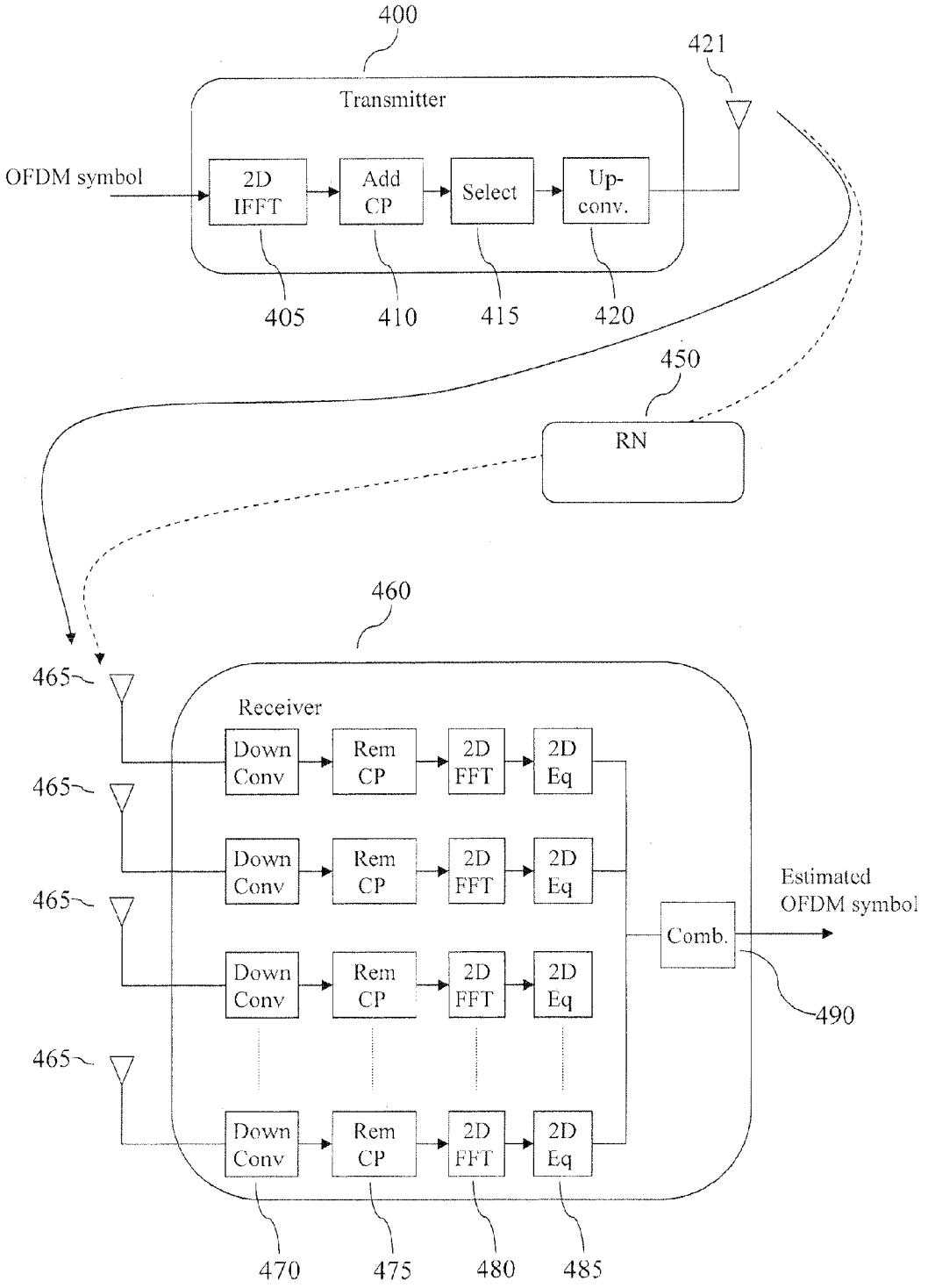

400
421
Transmitter
OFDM symbol
2D IFFT
Add CP
Select
Up-conv.
405
410
415
420
450
RN
460
465
Receiver
Down Conv
Rem CP
2D FFT
2D Eq
Comb.
Estimated OFDM symbol
490
470
475
480
485

Fig. 4

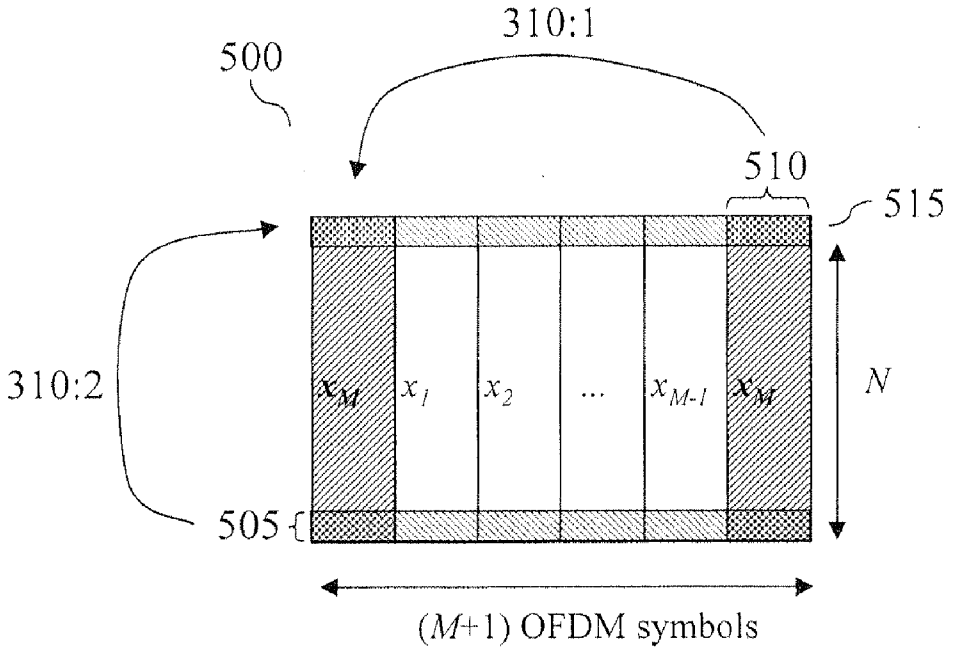

310:1
500
510
515
310:2
x_M x_1 x_2 ... x_{M-1} x_M
N
505
(M+1) OFDM symbols

Fig. 5

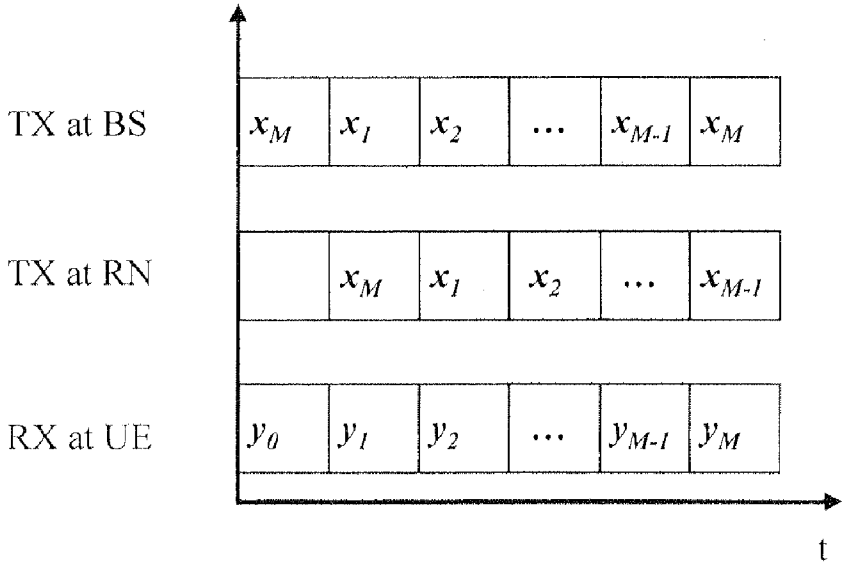

TX at BS
x_M x_1 x_2 ... x_{M-1} x_M
TX at RN
x_M x_1 x_2 ... x_{M-1}
RX at UE
y_0 y_1 y_2 ... y_{M-1} y_M
t

Fig. 6

METHOD AND ARRANGEMENT IN WIRELESS COMMUNICATION NETWORKS USING RELAYING

[0001] This application is a divisional of U.S. application Ser. No. 11/730,003, filed on Mar. 29, 2007, which claims priority to U.S. Provisional Application. No. 60/786,710, filed Mar. 29, 2006, the entire contents of which are hereby incorporated by reference.

TECHNICAL FIELD

[0002] The technical field relates to wireless communication systems wherein relaying is used to enhance performance. The technology described in this application relates to a method and arrangement for providing diversity in a wireless communication system utilizing Orthogonal Frequency Domain Multiplexing (OFDM) technology.

BACKGROUND

[0003] A main striving force in the development of wireless/cellular communication networks and systems is to provide, apart from many other aspects, increased coverage or support of higher data rate, or a combination of both. At the same time, the cost aspect of building and maintaining the system is of great importance and is expected to become even more so in the future. As data rates and/or communication distances are increased, the problem of increased battery consumption is another area of concern.

[0004] Until recently the main topology of wireless communication systems has been fairly unchanged, including the three existing generations of cellular networks. The topology of existing wireless communication systems is characterized by the cellular architecture with the fixed radio base stations and the mobile stations as the only transmitting and receiving entities in the networks typically involved in a communication session.

[0005] Several new transmission, or radio access, technologies have been proposed to increase capacity, flexibility and/or coverage in the communication systems. A promising technology is Orthogonal Frequency Domain Multiplexing (OFDM) that transmits multiple signals simultaneously over a wired or wireless communication medium. In wireless communications, the OFDM receiver is relative simple, since the multiple data streams are transmitted over a number of parallel flat fading channels. In fact, equalization is not done in the time domain; instead, one-tap filters in the frequency domain are sufficient. Despite this simplicity, uncoded OFDM transmission lacks inherent diversity that greatly helps to combat loss in the radio propagation environment, i.e. path loss, fast fading, etc.

[0006] One way to introduce diversity in the received signal is to utilize multiple antennas at the transmitter and possibly also at the receiver. The use of multiple antennas offers significant diversity and multiplexing gains relative to single antenna systems. A system utilizing multiple antennas both at the transmitter and at the receiver is often referred to as Multiple-Input Multiple-Output (MIMO) wireless systems. The spatial diversity offered by such systems can thus improve the link reliability and the spectral efficiency relative to Single-Input Single-Output (SISO) system.

[0007] An alternative approach to introduce macro-diversity is cooperative relaying. Cooperative relaying systems have many features and advantages in common with the more well-known multihop networks, wherein typically, in a wireless scenario, a communication involves a plurality of transmitting and receiving entities in a relaying configuration. Such systems offer possibilities of significantly reduced path loss between communicating (relay) entities, which may benefit the end-to-end (ETE) users. The cooperative relaying systems are typically limited to only two (or a few) hop relaying. A typical cooperative relaying system comprises of an access point, for example a radio base station which communicates with one or more user equipments, for example a mobile station, via a plurality of relay nodes.

[0008] In contrast to multihop networks, cooperative relaying systems exploits aspects of parallelism and also adopts themes from advanced antenna systems. These systems have cooperation among multiple stations or relay nodes, as a common denominator. In recent research literature, several names are in use, such as cooperative diversity, cooperative coding, and virtual antenna arrays. In the present application the terms "cooperative relaying system" and "cooperative schemes/methods" is meant to encompass all systems and networks utilizing cooperation among multiple stations and the schemes/methods used in these systems, respectively. The term "relaying system" is meant to encompass all systems and networks utilizing relying in any form, for example multihop system and cooperative relaying systems, A comprehensive overview of cooperative communication schemes are given in Cooperative Diversity in Wireless Networks: Algorithms and Architectures, J. N. Laneman, Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, Mass., August 2002.

[0009] Various formats of a relayed signal may be deployed. A signal may be decoded, re-modulated and forwarded, or alternatively simply amplified and forwarded. The former is known as decode-and-forward or regenerative relaying, whereas the latter is known as amplify-and-forward, or non-regenerative relaying. Both regenerative and non-regenerative relaying is well known, e.g. by traditional multihopping and repeater solutions respectively. Various aspects of the two approaches are addressed in "An Efficient Protocol for Realizing Distributed Spatial Diversity in Wireless Ad-Hoc Networks", J. N. Laneman and G. W. Women, Proc. of ARL FedLab Symposium on Advanced Telecommunications and Information Distribution (ATIRP-2001), (College Park, Md.), March 2001.

[0010] Diversity gain is particularly attractive since it offers increased robustness of communication performance as well as allowing reduction of experienced average SNR for the same BER. In addition the cooperative relaying may provide other positive effects such as beamforming (or directivity) gain, and spatial multiplexing gain. The general benefits of the mentioned gains include higher data rates, reduced outage primarily due to different forms of diversity, increased battery life, and extended coverage.

[0011] There are several schemes that offer diversity gain: Alamouti diversity based cooperative relaying for example described in "Distributed Space-Time Coding in Cooperative Networks", P. A. Anghel et al, Proc. of the Nordic Signal Processing Symp., Norway, October 2002. coherent combining based relaying, which in addition offer a beamforming gain as described in "Large-Scale Cooperative Relay Network with Optimal Coherent Combining under Aggregate Relay Power Constraints", P. Larsson, Proc. Future Telecommunications Conference (FTC2003), Beijing, China, 9-10/12

2003. pp 166-170. and relay cyclic delay diversity as described in WO06121381. According to the scheme the relay nodes, in their forwarding between the base station and the user equipement, applies cyclic shifts to their respective forwarded OFDM symbols.

[0012] These schemes require two transmission phases for each down link (DL) and up link (UL) direction: for example in the DL, in the first transmission phase the basestation transmits to the relay node, and in the second transmission phase the relay node transmits to the user equipment. The two phase transmission methods may effectively reduce the data throughput by half.

SUMMARY

[0013] Significant shortcomings of the prior art are evident from the above. Hence, it would be desirable to provide a method that introduces artificial frequency, time and spatial diversity and requires only a single transmission phase for each direction in a cooperative relaying wireless communication system.

[0014] An object is to provide a method, a relay node and a system that overcomes the drawbacks of the prior art techniques.

[0015] A communication system uses relaying and Orthogonal Frequency Domain Multiplexing (OFDM). A transmitting radio node, for example a radio base station, is engaged in communication with at least one receiving radio nodes, for example a user equipment. Part of the communication between the transmitting and receiving node is direct, and part is via at least one relay node. Data is transmitted in the form of OFDM chunks comprising a plurality of OFDM symbols. A cyclic prefix is added to a representation of an OFDM during the transmission phase by:

[0016] pre-appending to the representation of the OFDM chunk the last OFDM symbol from the end of the representation of the OFDM chunk;

[0017] after the pre-appending, copying a pre-determined number of last rows of the pre-appended OFDM chunk to the top of the representation of the OFDM chunk forming an augmented OFDM chunk.

[0018] The first step can be seen as providing a column-wise cyclic prefix, and the second step as providing a row-wise cyclic prefix, resulting in a 2-dimensional cyclic prefix procedure.

[0019] The number of rows selected to be copied to the top of the augmented chunk should correspond to the length of the cyclic prefix or guard interval which depends on the delay spread of the radio channels.

[0020] One non-limiting, example embodiment comprises the steps of:

[0021] defining a OFDM chunk B comprising N sub-carriers and spanning a time window corresponding to M OFDM symbols;

[0022] applying a 2-dimensional IFFT to the OFDM chunk B, resulting in a transformed chunk X;

[0023] pre-appending to the transformed chunk X the last OFDM symbol of the transformed chunk X;

[0024] after the pre-appending of the transformed chunk X copying the last rows of the pre-appended transformed chunk X to the top of the transformed chunk X forming an augmented OFDM chunk X'.

[0025] In the relaying performed by one or more relay nodes the re-transmission is delayed with one OFDM symbol.

[0026] A transmitter for use in a radio node in a communication system utilizing relaying and Orthogonal Frequency Domain Multiplexing comprises a cyclic prefix module adapted for adding a 2 dimensional cyclic prefix to a representation of the OFDMA chunks, by pre-appending to a representation of the OFDM chunk the last OFDM symbol of the representation of the OFDM chunk, and copying the last rows of the pre-appended OFDM chunk to the top of the pre-appended OFDM chunk, forming an augmented OFDM chunk.

[0027] Full advantage of the combined advantages of the OFDM technique and cooperative relaying, without increasing the complexity of the transmitter and receivers in any significant way and without requiring any extensive control signaling that could reduce the traffic capacity. In contrast to prior art techniques, only one transmission phase is needed.

[0028] The 2D-CP method and arrangements can provide substantial Data Rate increase in the order of (2M−2)/M, wherein M is the number of OFDM symbols in the chunk. For example, if M=15 then the gain is approximately 93%.

[0029] A further advantage is that antenna specific pilots are not required. Instead, the same pilot pattern on the frequency/time grid are to be transmitted from all transmit antennas. The receiver, user equipment, for example, has knowledge of the pilot pattern so that channel estimates can be obtained.

[0030] A still further advantage is increased frequency and time selectivity of the overall effective channel.

[0031] Other objects, advantages and novel features will become apparent from the following detailed description considered in conjunction with the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE FIGURES

[0032] The features and advantages outlined above are described more fully below in the detailed description in conjunction with the drawings where like reference numerals refer to like elements throughout, in which:

[0033] FIGS. **1***a* and **1***b* illustrates schematically a cellular system using cooperative relaying wherein the method and arrangement may be advantageously implemented;

[0034] FIG. **2***a-f* illustrates the transmission phase for 1-hop systems (a-b), 2-hop systems (c-d) and 2-hop systems utilizing the 2D-CP (e-f);

[0035] FIG. **3** is a flowchart over an example method;

[0036] FIG. **4** is a schematic illustration of an example transmitter and a receiver;

[0037] FIG. **5** is a schematic illustration an example the augmented OFDM chunk; and

[0038] FIG. **6** is a schematic illustration of how a block of OFDM symbols may be transmitted by the BS, the RN and received by the UE.

DETAILED DESCRIPTION

[0039] Non-limiting example embodiments will now be described with reference to the figures.

[0040] The network outlined in FIG. **1** is an example of a cooperative relaying network. The figure shows one cell **105** of the wireless network comprising a transmitting communication node, an access point (AP) **110**, a plurality of relay nodes (RN) **115** and a plurality of receiving communication nodes or user equipment (UE) **120**. The access point is typically a radio base station (BS) providing the point of access to

and from the core network to the radio access network. User equipments, also referred to as user terminals include, but are not limited to for example, mobile stations, laptop computers and PDAs equipped with wireless communication means and vehicles and machinery equipped with wireless communication means. As shown in the figure, the relaying nodes **115** are mounted on masts, buildings, lamp posts etc. Fixed relay nodes may be used as line of sight conditions can be arranged, directional antennas towards the basestation may be used in order to improve SNR (Signal-to-Noise Ratio) or interference suppression and the fixed relay nodes may not be severely limited in transmit power as the electricity supply network typically may be utilized. However, mobile relays, **121** and **122**, such as mobile user terminals, may also be used, either as a complement to fixed relay nodes or independently. The user terminal **120** is in active communication with the base station **110**. The radio communication, as indicated with arrows, is essentially simultaneously using a plurality of paths, characterized by two hops, i.e. via at least one relay node **115**. The first part, from the access point **110** to at least one relay node **115**, will be referred to as the first link, and the second part, from the relay node or nodes to the user terminal **120** will be referred to as the second link. In addition direct communication between the access point **110** and the user terminal **120** is utilized, in the figure indicated with a dashed arrow. The communication system may simultaneously set up and maintain a large plurality of communication sessions between the BS **110** and user equipments **120**, and in the different communication sessions using different sets of relay nodes **115**. The relay nodes engaged in a specific communication may change during the session as the user terminal moves or the radio environment changes for other reasons.

[0041] The real world cellular system outlined in FIG. **1***a* is for simplicity modeled by system model shown in FIG. **1***b*, here with focus on a single pair of transmitter and receiver, utilizing an arbitrary number K of relay nodes. The notation is adapted to a BS **110** as a transmitter and an UE **120** as a receiver, but not limited thereto. The communication between the BS **110** and the UE **120** can be described as comprising two main parts: the transmissions from the BS **110** to the relay nodes 115:k, kϵ{1, 2, . . . K}, referred to as the first link, and the transmissions from the relay nodes 115:k to the UE 120 referred to as the second link. The radio paths on the first link are characterized by the respective channel impulse response l_k, and the radio paths on the second link by the respective channel impulse response h_k.

[0042] Each of radio nodes, i.e. BS **110**, RN **115** and UE **120** utilizes of one or more antennas. The BS **110** transmits to K RNs and to the UE during a predefined period. The RN forwards the information received from a first node (e.g. BS **110**) to a second node (e.g. UE) with one symbol delayed. This can be done either with amplify and forward, decode and forward, or a hybrid of the two.

[0043] FIG. **2***a-f* illustrates the difference between the 1-hop, classical 2-hop and the 2D-CP system. As shown in FIGS. **2***a* and **2***b*, in a 1-hop system the data signal is transmitted to the UE in two consecutive time slots (i.e. 2n and 2n+1). For instance, the symbol x_{2n} is transmitted at the time slot 2n and is followed by x_{2n+1} at the next slot. By contrast in a 2-hop system, in order to avoid the BS **110** and RN interfering with each other the transmission is done in two phases (i.e. hops). During the first hop, 2n slot in FIG. **2***c*, the BS **110** transmits the data signal x_{2n} to the RN. The UE may also receive x_{2n}. During the second hop (2n+1) the RN retransmits the same data signal x_{2n} to the UE as shown in FIG. **2***d*.

[0044] A transmission scheme is illustrated in FIGS. **2***e-f* where signals are transmitted in the form of OFDM chunks comprising a plurality of OFDM symbols. A cyclic prefix is added to a representation of the OFDM chunks by pre-appending to the representation of the OFDM chunk the last OFDM symbol of the representation of the OFDM chunk, forming an augmented OFDM chunk. The procedure will be described in detail below. In contrast to the classical 2-hop system, the transmission can now be in full duplex. In fact, the BS **110** will transmit during the two consecutive phases, eg. 2n and 2n+1, two different data signals x_{2n}, and x_{2n+1}, respectively. As shown in FIG. **2***e*, during time slot 2n, the RN will forward data x_{2n+1}, which was received from the BS **210** at the previous time slot, 2n−1. During time slot 2n+1, the RN will forward the signal data x_{2n} (see FIG. **21**).

[0045] FIG. **3** is flowchart of the transmission, and FIG. **4** illustrates a transmitter **400** and a receiver **460** adapted to carry out the procedure. The transmission is both direct, indicated with the solid arrow, and via a relay node **450**, indicated with a dashed arrow. The basic time-frequency resource unit in a OFDM system is defined as a chunk. Each chunk entity comprises of N sub-carriers and spans a time window of M OFDM symbols, and B denotes the N×M matrix of the chunk.

[0046] The method comprises the steps of:

[0047] **305**: A 2D-IFFT module **405** of the transmitter **400** performs an inverse 2-dimensional fast Fourier Transform (2D-IFFT) of the chunk B of the coded input data stream. The output from the 2D-IFFT module **405** is denoted X and is an representation of the chunk B.

[0048] **310**: A cyclic prefix module **410**, in connection with the 2D-IFFT module **405**, subjects the transformed chunk X to 2D cyclic prefix. The procedure, which is further illustrated in FIG. **5**, comprises the substeps of:

[0049] **310**:**1** pre-appending to the chunk X **500** the last OFDM symbol of the chunk X , corresponding to the last column of X, **510**, giving a column-wise cyclic prefix.

[0050] **310**:**2** copying a pre-determined number of the last rows **505** of the pre-appended chunk to the top **515** of the chunk X, giving a row-wise cyclic prefix.

[0051] The row-wise cyclic prefixing eliminates the inter-OFDM symbol-interference. Similarly, the column-wise cyclic prefix, as will be described, eliminates the interference from the simultaneous transmission of the data from the BS and RN. The resulting augmented chunk, which is outputted from the cyclic prefix module **405** is denoted X'.

[0052] The second substep, **310**:**2**, corresponds to the use of cyclic prefix in prior art OFDM transmission techniques. An appropriate size of the cyclic prefix, as well as a suitable size of the OFDM chunk depend on characteristics of the radio channels and are determined in conventional manners. The appropriate sizes are to be considered as known input parameters to the method and arrangement.

[0053] **315**: In a selection module **415**, in connection with the cyclic prefix module **410**, the augmented block X' is subjected to linear operations consisting of selecting one column of X' during each OFDM symbol transmission. At the first instant the first column of X' is

selected, the second time instant the second column of X' is selected. The procedure is repeated until all columns of X' are transmitted.

[0054] **320**: An up conversion and transmitting module **420**, converts the baseband signals outputted from the selection module **415** into the RF-band, and transmitted from the antenna or antennas **421**.

[0055] **325**: The transmitted signal is relayed by at least one relay node, The re-transmission is delayed with one OFDM symbol, i.e. one column of X' is re-transmitted at the same time as a consecutive column of X' is transmitted from transmitter **400**.

[0056] **330**: The transmitted signals, both direct from the transmitter **400** and from the relay node **450** or relay nodes, are received by the receiver **460**, depicted in FIG. **4**. Each receive antenna **465** is connected to a respective down conversion module **470**, wherein the signal is down-converted from the RF-band into the baseband.

[0057] **335**: In cyclic prefix removal modules **475** the cyclic prefix is removed from the signals provided from the down conversion modules **470**.

[0058] **340**: A 2-dimensional fast Fourier transform is applied to respective signal by 2D FFT modules **480**.

[0059] **345**: Each signal is equalised by a 2-dimensional equalisation process by equalizer modules **485**, in connection with respective 2D FFT modules.

[0060] **350**: The signals originating from each antenna **465** is finally combined in a combining process, for example with a Maximum Ratio Combining (MRC) procedure in a combining module **490**. Outputted from the combining module **490** is the chunk estimate $\hat{B}$ of B.

[0061] The relaying performed by the relay node or nodes in step **325** does not require a 2-dimensional processing as in the receiver and transmitter, one-dimensional FFTs and an IFFT, for the receiving and transmitting respectively, are sufficient. Hence, a relay node employed HERE can be identical to a relay node in prior art relayed OFDM systems.

[0062] The transmission process according to the method is further illustrated in FIG. **6**, wherein the augmented chunk X' at the BS (transmitter) and the RN and the received chunk $\hat{B}$ at UE (receiver) are illustrated. As shown in the figure, during the first time instant (t=0), the last symbol x_M is transmitted by the BS, and a noisy version of the signal is received by the UE; the received signal is denoted by y_0. The RN also receives the signal X_M, but forwards it during the subsequent time slot. At time instant (t=1), the BS transmits the first symbol x_1 in the data block and the UE will receive a linear combination of x_M from the RN and x_1 from the BS. The process is repeated until the BS transmits the entire data sequence in X'.

[0063] The arrangements have been described in terms of modules and blocks which are to be regarded as functional parts of a transmitting and/or receiving node in a communication system, and not necessarily as physical objects by themselves. The modules and blocks may be implemented, for example, as software code means like a computer. The term "comprising" does primarily refer to a logical structure and the term "connected" should here be interpreted as links between functional parts and not necessarily physical connections. However, depending on the chosen implementation, certain modules may be realized as physically distinctive objects in a receiver or transmitter.

[0064] The mathematical definitions of the terms used in the application will be given and exemplified in the following section:

[0065] Notation:

[0066] Let • and $\otimes$ denote the Hadamard and the Kronecker product, respectively. $(\bullet)^T$ denotes the transpose and $(\bullet)^H$ the Hermitian transpose operator. Capital letters represent matrices, and lower case letters represent vectors or scalars.

[0067] Definitions:

[0068] Definition 1: F_M denotes the FFT matrix of size M×M. The (n,m)th element of F_M, for n,m$\in\{1, 2, \ldots, M\}$ is given by

$$F_M(n,m)=\frac{1}{\sqrt{N}}\exp\left(-\frac{j2\pi(n-1)(m-1)}{N}\right) \quad (1)$$

[0069] Definition 2: For an M×1 vector $a=[a(1), a(2), \ldots, a(M)]^T$, the right circulant matrix $A \triangleq \mathrm{Circ}(a)$, is generated as follows

$$A=\begin{bmatrix} a(1) & a(M) & a(M-1) & \ldots & a(2) \\ a(2) & a(1) & a(M) & \ldots & a(3) \\ a(3) & a(2) & a(1) & \ldots & a(4) \\ \vdots & \vdots & \vdots & \ldots & \vdots \\ a(M) & a(M-1) & a(M-2) & \ldots & a(1) \end{bmatrix} \quad (2)$$

[0070] The right circulant matrix A is diagonalized using the FFT matrix FM as follows

$$A=\sqrt{M}F^H_M D(F_M a)F_M \quad (3)$$

where D(x) denotes a diagonal matrix with x on its main diagonal.

[0071] Definition 3: The two dimensional (2D) FFT of a matrix X of size N×M, denoted by $\tilde{X}$, is given by

$$\tilde{X}=F_N X F_M, \quad (4)$$

[0072] An illustrative example will be given with reference to FIG. **2***b*, wherein one BS, K RNs and one UE are in communication. The BS and the RNs are each assumed to be equipped with a single transmit antenna. Furthermore, the OFDM symbols are correctly detected by the RNs before being forwarded to the UE.

[0073] Under this assumption, the received symbol y_m at the UE is a linear combination of the transmitted symbol x_m from the BS and the delayed symbol x_{m-1} transmitted from the RNs. y_m can be expressed as:

$$y_m=H_0 x_{1+(m-1)_M}+H_e x_{1+(m-2)_M} \quad (5)$$

where $H_0=\mathrm{Circ}(h_0)$ is the channel matrix between the BS transmit antenna and the UE, H_e is the combined channel matrix, or effective channel matrix, from all K RNs to the UE. H_e can be expressed as: $H_e=\Sigma_{k=1}^{K}\mathrm{Circ}(h_k)=\mathrm{Circ}(h_e)$ where h_k for $k\in\{1, 2, \ldots, K\}$ denotes the channel impulse response from the kth RN to the UE. h_e is the effective channel impulse response and its FFT can be expressed as:

$$\tilde{h}_e=\sqrt{N}\sum_{k=1}^{K}\left(\tilde{h}_k\cdot\tilde{e}_{\delta_k}\right) \quad (6)$$

[0074] Ignoring the first received symbol of the chunk at the UE, the M following received symbols from the same chunk can be written in a matrix form as follows:

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \vdots \\ y_{M-1} \\ y_M \end{bmatrix} = \begin{bmatrix} H_0 & 0 & 0 & \dots & 0 & H_e \\ H_e & H_0 & 0 & \dots & 0 & 0 \\ 0 & H_e & H_0 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & H_0 & 0 \\ 0 & 0 & 0 & \dots & H_e & H_0 \end{bmatrix} \times \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_{M-1} \\ x_M \end{bmatrix} \quad (7)$$

[0075] Define the following

$$Y=[y_1, y_2, \dots, y_M], \quad (8)$$

$$X=[x_1, x_2, \dots, x_M], \quad (9)$$

$$H=[h_0, h_e, 0, \dots, 0]. \quad (10)$$

[0076] Then it can be shown that the received signal after applying a 2D-FFT is given by:

$$\tilde{Y}=\sqrt{NM}\tilde{H}\bullet B, \quad (11)$$

where H̃ and Ỹ denote the 2D-FFT of the channel matrix H and the received data block Y.

[0077] The technology described in this application has in the above embodiments been envisaged in a two hop cooperative relaying scenario but may advantageously be utilized also in other systems wherein a plurality of nodes are engaged in a communication session, for example a multihop system. In a typical multihop system a majority of the nodes are user equipment of various kinds, but the system may also comprise fixed nodes, such as access points. Preferably all nodes have the capability of receiving and forwarding data.

[0078] While the technology described in this application has been described in connection with what is presently considered to be the most practical and preferred embodiments, it is to be understood that the claims are not to be limited to the disclosed embodiments, but on the contrary, are intended to cover various modifications and equivalent arrangements.

1. A receiving radio node configured for communication in a communication system that uses relaying and Orthogonal Frequency Domain Multiplexing (OFDM), comprising means for removing a two-dimensional cyclic prefix from a received representation of an OFDM chunk.

2. The receiving radio node according to claim **1**, wherein a processing module for removing a two-dimensional cyclic prefix is provided for each antenna stream.

3. The receiving radio node according to claim **1**, further comprising a module for combining a plurality of signals to a common signal provided after the cyclic prefix removing modules.

4. A receiving radio node configured for communication in a communication system that uses relaying and Orthogonal Frequency Domain Multiplexing (OFDM), comprising electronic circuitry configured to remove a two-dimensional cyclic prefix from a received representation of an OFDM chunk.

5. The receiving radio node according to claim **4** having multiple antenna systems, wherein a processing module for removing a two-dimensional cyclic prefix is provided for each antenna stream.

6. The receiving radio node according to claim **4**, further comprising a module for combining a plurality of signals to a common signal provided after the cyclic prefix is removed.

7. A method in a radio receiver, comprising:

receiving an orthogonal frequency domain multiplex (OFDM) radio signal;

extracting a received representation of an OFDM chunk from the received OFDM radio signal;

removing a two-dimensional cyclic prefix from the received representation of the OFDM chunk.

8. The method in claim **7**, wherein the received OFDM radio signal includes multiple receive antenna streams, the method further comprising removing a two-dimensional cyclic prefix for each antenna stream.

9. The method in claim **7**, wherein the received OFDM radio signal includes multiple receive antenna streams, the method further comprising combining plural signal corresponding to different antenna streams that have had a two dimensional prefix removed.

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