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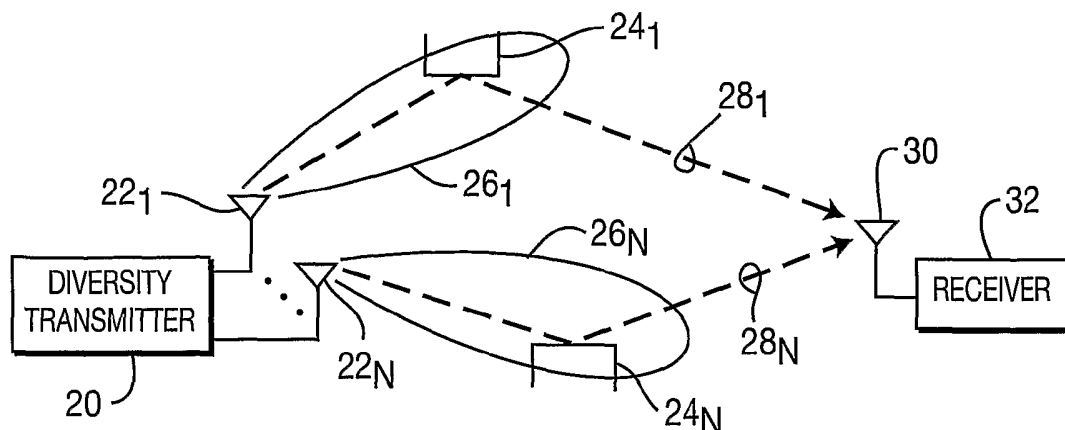
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(54) Title: METHOD AND APPARATUS FOR REDUCING ANTENNA CORRELATION



(57) Abstract: The present invention is related to a method and apparatus for reducing antenna correlation between multiple antennas. A transmitter generates at least two beams with a plurality of antennas. The generated beams are spatially separated to point away each other. Therefore, the transmitted signals travel through different channel conditions and arrive at a receiver mutually uncorrelated. The beams may be generated by antennas having different antenna pattern, or by an array antenna. The beams may be polarized differently. The schemes may be implemented on a subcarrier basis in an orthogonal frequency division multiplexing (OFDM) system. Trellis coded mapping may be utilized for adjacent symbols to be mapped to antennas with low correlation.

[0001] METHOD AND APPARATUS
 FOR REDUCING ANTENNA CORRELATION

[0002] FIELD OF INVENTION

[0003] The present invention is related to wireless communication systems. More particularly, the present invention is related to a method and apparatus for reducing antenna correlation between multiple antennas.

[0004] BACKGROUND

[0005] A scheme for utilizing multiple antennas, such as multiple-input multiple-output (MIMO) system, has been developed. By utilizing multiple transmit and receive antennas, a capacity and throughput of the wireless communication system can be enhanced. The performance enhancement is restricted as a correlation of the signals between the plurality of antennas becomes higher. If the correlation of antennas is high, the advantage of a multiple antenna system may be lost.

[0006] In a MIMO system, data is converted to a plurality of parallel data streams and the parallel data streams are transmitted simultaneously from different antennas. The data stream may be transmitted only from a subset of the antennas. Selection of antennas for transmission is often based on quality of the link seen at the antenna or other relevant quality indicators. The performance of the MIMO system degrades as signals become more correlated between antenna transmissions.

[0007] In general, the antenna correlation depends on factors such as distance between the antennas and channel state including scatterings conditions. Signals received at the receiver are subject to multipath fading and the antenna correlation becomes lower as the influence of fading differs each other. Therefore, it is desirable to lower the antenna correlation in wireless communication systems utilizing multiple antennas.

[0008] SUMMARY

[0009] The present invention is related to a method and apparatus for reducing antenna correlation between multiple antennas. A transmitter generates at least two beams with a plurality of antennas. The generated beams are spatially separated to point away each other. Therefore, the transmitted signals travel through different channel conditions and arrive at a receiver mutually uncorrelated. The beams may be generated by antennas having different antenna pattern, or by an array antenna. The beams may be polarized differently. The schemes may be implemented on a subcarrier basis in an orthogonal frequency division multiplexing (OFDM) system. Trellis coded mapping may be utilized for adjacent symbols to be mapped to antennas with low correlation.

[0010] BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figure 1 is a simplified block diagram of a diversity transmission system with directional antenna elements.

[0012] Figure 2 is a simplified diagram of a diversity transmission system utilizing beam/pattern forming.

[0013] Figure 3 is a simplified diagram of a diversity transmission system utilizing polarization.

[0014] Figure 4 is a simplified diagram of a diversity transmission system utilizing polarization in an OFDM system.

[0015] Figure 5 is an illustration of one possible assignment of subcarriers.

[0016] Figure 6 is a simplified diagram of a diversity transmission system using subcarrier grouping in an OFDM system.

[0017] Figure 7 is an illustration of one possible assignment of subcarrier groups.

[0018] Figure 8 is a simplified diagram of a diversity transmission system using trellis mapping.

[0019] Figure 9 is a simplified diagram of a diversity transmission system using time frequency multiplexing.

[0020] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] The present invention is applicable to any wireless communication systems employing multiple transmit or receive antennas for transmission and reception including, but not limited to, MIMO antenna schemes for OFDM systems.

[0022] The features of the present invention may be incorporated into an integrated circuit (IC) or be configured in a circuit comprising a multitude of interconnecting components.

[0023] Hereafter, a wireless transmit/receive unit (WTRU) includes but is not limited to a user equipment, mobile station, fixed or mobile subscriber unit, pager, or any other type of device capable of operating in a wireless environment. When referred to hereafter, a base station includes but is not limited to a Node-B, site controller, access point or any other type of interfacing device in a wireless environment. The transmitting and receiving features of the following embodiments can be utilized in a WTRU, base station or both.

[0024] Although the following embodiments emphasize transmit diversity, the same principals can be applied to reception diversity.

[0025] Figure 1 is a simplified block diagram of a diversity transmission system with directional antenna elements. A diversity transmitter 20 produces a signal or signals for transmission over an antenna array. The antenna array has antenna elements 22_1 to 22_N that are capable of producing their own antenna beam or pattern 26_1 to 26_N . These beams/patterns 26_1 to 26_N may differ in the azimuth, elevation or both.

[0026] As illustrated in Figure 1, these different beams/patterns 26_1 to 26_N result in the transmitted signals following different paths 28_1 to 28_N . Path 28_1 results from the transmission from antenna element 22_1 through beam/pattern 26_1 and being scattered off of scatterer 24_1 . Path 28_N results from the transmission from antenna element 22_N through beam/pattern 26_N and being

scattered off of scatterer 24_N. The different paths 28₁ to 28_N are received by an antenna or antenna array 30 and processed by a receiver 32. For simplicity, Figure 1 illustrates one path per beam/pattern. In practice, each beam/pattern results in various multipath scattering arrangements.

[0027] The unique beams/patterns formed by the antenna elements 22₁ to 22_N can be produced by various techniques. One technique is to alter the physical arrangement of the elements to create the differing beams/patterns. To illustrate, some beams may be planar and some may have an uptilt. Additionally, metamaterials may be used for the antenna elements. These materials can be used to create highly directional antenna elements that may be oriented to “point away” from each other. Since the antenna patterns “point away” from one another, the signals transmitted by these antennas experience different channel conditions. The channel conditions are mainly determined by the scattering environment of the channel through which the signal travels. Signals in different scattering environments have different multipath fading patterns. As a result, the transmitted signals by each transmit antenna are received mutually uncorrelated. Such an arrangement is desirable for antenna arrays with little separation between the elements. These closely packed elements can be “pointed away” from one another to reduce or eliminate cross correlation.

[0028] Figure 2 is a simplified diagram of a diversity transmission system utilizing beam/pattern forming. The diversity transmitter 20 produces a signal or signals for transmission over an antenna array. A beamformer/pattern former 34 is used to produce distinct beams/patterns over the array. As illustrated in Figure 2, an array having N elements 36₁ to 36_N may be used to form N-1 distinct beams/patterns 26₁ to 26_{N-1}. These distinct beams/patterns allow for additional transmission diversity. The signals from these distinct beams/patterns 26₁ to 26_{N-1} are received by an antenna or antenna array 30 of a receiver 32.

[0029] As illustrated in Figure 2, a first beam/pattern 26₁ directs the signal towards a scatterer 24₁ so that one path of the signal follow path 28₁. Also, an N-1

beam 26_{N-1} directs the signal towards a scatterer 24_{N-1} so that one path of the signal follows path 28_{N-1}.

[0030] One technique to generate the beams are as follows. First, a maximal set of low correlation antenna elements are identified by calculating correlation values between antennas based on received signals from the receiver on either base band or radio frequency (RF). The identification may be based on channel state information (CSI) feedback from the communication entity. The high correlation set is used to enhance the low correlation set via beamforming or other technique.

[0031] To further augment spatial diversity, reflector and isolators between antenna elements may be used to separated transmission and reception spatially. These reflectors and isolators may include the use of native geography, such as buildings.

[0032] Figure 3 is a simplified diagram of a diversity transmission system utilizing polarization. The diversity transmitter 20 produces a signals or signals for transmission. An antenna mapper 38 maps these signals to appropriate polarized antennas 40₁ to 40_N of an antenna array. Although various polarization techniques may be used, in Figure 3, the polarization is simply illustrated by a “-“ or “+” sign by each element 40₁ to 40_N. Although illustrated in the Figure as alternating polarization, the polarization may be done in a variety of manners. The polarization adds additional diversity to the transmissions, since the differing polarizations will typically result in different scatterering patterns. Such a technique is desirable for arrays with little spatial diversity between the antenna elements, such as small footprint arrays. To illustrate, the use of an alternating polarization as illustrated in Figure 3 allows for the effective spatial separation between elements of a same polarization to be doubled, decreasing the correlation between antenna elements. The polarized transmissions are sent through the air interface 42 to an antenna or antenna array 30 of a receiver 32.

[0033] Figure 4 is a simplified diagram of a diversity transmission system utilizing polarization in an OFDM system. An OFDM processor 44 produces

subcarriers for transmission. A subcarrier mapper 46 maps corresponding subcarriers to corresponding polarized element/elements 40_1 to 40_N of the antenna array. The subcarrier mapper 46 maps subcarriers that are close to each other to antennas 40_1 to 40_N having different polarization. These polarized subcarriers are sent through the air interface 42 to an antenna or antenna array 30 of a receiver 32.

[0034] Figure 5 is an illustration of one possible assignment of subcarriers. As illustrated in Figure 5, the subcarriers are divided into odd and even subcarriers with respect to their frequency. The odd subcarriers are illustrated with a narrow line and the even with a thick line. The odd subcarriers are sent over antenna TX1 and the even over antenna TX2. Antenna TX1 has a vertical polarization and TX2 has a horizontal polarization.

[0035] Figure 6 is a simplified diagram of a diversity transmission system using subcarrier grouping in an OFDM system. Correlation between antenna elements tends to be frequency dependent. As a result, the embodiment of Figure 6 groups subcarriers having a similar frequency and maps them to antennas based on the antenna correlation of the respective frequencies.

[0036] An OFDM processor 44 produces subcarriers for transmission. A subcarrier group mapper 48 maps subcarrier groups to a corresponding antenna/antennas 36_1 to 36_N . The mapping is based on antenna correlation information. Such information may be signal from the receiver or derived, such as by using channel reciprocity. The OFDM transmission is sent through the air interface 42 to an antenna or antenna array 30 and a receiver 32.

[0037] Figure 7 is an illustration of one possible assignment of subcarrier groups. The subcarriers are illustrated as horizontal line segments. The subcarriers are grouped as illustrated by the brackets "}". The odd groups of subcarriers as illustrated with the thinner lines are transmitted over antenna TX1 and the even group with the thick line are transmitted over antenna TX2.

[0038] Figure 8 is a simplified diagram of a diversity transmission system using trellis mapping. In the embodiment of Figure 8, Trellis coding is used to map signals to antennas to reduce the likelihood of adjacent symbols being

mapped to highly correlated antennas. Trellis coded modulation is traditionally used to increase the free distance in coding. The same principle is applied to increase the "correlation distance" between adjacent symbols when mapping onto antennas. The symbols are mapped to antenna elements with respect to a Trellis code and transmitted.

[0039] A diversity transmitter 20 produces symbols of a signal/signals for transmission. A trellis mapper 50 identifies the antennas having a high correlation and utilizes a trellis code to map adjacent symbols to uncorrelated antennas 36_1 to 36_N . The antenna correlation information may be signaled from the receiver or derived, such as by using channel reciprocity. The trellis mapped transmissions are sent through the air interface 42 to an antenna or antenna array 30 to a receiver 32.

[0040] Figure 9 is a simplified diagram of a diversity transmission system using time frequency multiplexing. A diversity transmitter 20 produces signals for transmission. These signals are time and/or frequency multiplexed by a time/frequency multiplexer (MUX) prior to transmission over the elements 36_1 to 36_N of the antenna array. To illustrate, in the frequency domain, if the transmission and reception paths of two signals are separated spatially, they can be transmitted within the same frequency band or time slot. Alternately, these signals can partially overlap without degrading each other's performance significantly. The multiplexed signal/signals are sent through the air interface 42 to an antenna or antenna array 30 to a receiver 32.

[0041] Although the embodiments of figures 1 through 9 are described separate from one another, they can be used in combination with one another. To illustrate, the time/frequency multiplexing of Figure 9 can be used with the directional elements of Figure 1. Additionally, the following embodiments are generally described as relating to an entire antenna arrays. However, the described embodiments may be utilized between a subset of the antennas/antenna elements.

[0042] Figure 1 is a block diagram of an apparatus 100 in accordance with an embodiment of the present invention. The apparatus 100 comprises a

plurality of antennas 102 (or antenna elements), an antenna controller 104 and a data processing unit 106. Data is processed by the data processing unit 106 for transmission. The processing includes channel coding, interleaving, modulation, power allocation, or the like. The antenna controller 104 controls the antennas for transmission of the data. The antenna controller 104 generates at least one beam or radiation pattern with the antennas. The generated beams may be spatially separated to point away each other or may be polarized differently whereby the transmitted signals arriving at a receiver are mutually uncorrelated.

[0043] The apparatus 100 may further comprise a measurement unit 108 for measuring channel condition, (i.e., correlation value between antennas or antenna elements). The apparatus makes determination on which antennas a signal is transmitted from based on the measured channel condition or a feedback received from a communicating entity.

[0044] Figure 2 is a diagram illustrating transmission utilizing a plurality of antennas having different antenna patterns for spatial separation in accordance with the present invention. In Figure 2, (and all other Figures of the present invention as well), only two transmit antennas (or beams) of the transmitter are illustrated for simplicity. However, it should be noted that any number of antennas (or beams) may be utilized and the embodiments are equally applicable to both a transmitter and a receiver. The transmitter comprises a plurality of transmit antennas, and each antenna provides a different antenna pattern. The radiation pattern of each antenna points away from each other. Therefore, the signals transmitted by the antennas experience different channel conditions.

[0045] Channel conditions are mainly determined by the scattering environment of the channel through which transmitted signals travel. Signals are introduced into different scattering environment such that the signals have different multipath fading. As a result, the transmitted signals by each transmit antenna are received by a receiver are mutually uncorrelated.

[0046] Metamaterials may be used to create highly directional elements that may be oriented to 'point away' from each other. Metamaterials are not present in nature but are synthesized by embedding inclusions with new geometric structures within some base material. Metamaterials have the interesting property that the permittivity and permeability of the material are negative over some frequency band. In other words, these materials can be designed to 'attract' RF energy in some bands. This allows for the building of antennas that are smaller than typical conventional antennas. These materials allow for the building of antennas and antenna arrays in shapes and form factors that are practical and can have directionality as desired.

[0047] In Figure 2, the dotted lines represent antenna patterns of each antenna. The two antenna patterns are pointing away from each other. Therefore, the transmitted signals travel completely different paths and are affected by different channel conditions, such as different scatterers. Therefore, the signals arriving at the receiver from the transmit antennas are mutually uncorrelated. This scheme improves performance especially in the case of closely located transmit antennas.

[0048] Figure 3 is a diagram illustrating transmission utilizing an array antenna forming a plurality of beams to reduce spatial correlation. The array antenna generates a plurality of directional beams pointing away from each other. When the two antenna patterns are pointing away from each other they are affected by different scatterers and the signals arriving at the receiver from the transmitter are mutually uncorrelated.

[0049] First, a maximal set of low correlation antenna elements are identified by calculating correlation values between antennas based on received signals from the communicating entity on either base band or RF. The identification may be based on channel state information feedback from the communication entity. The high correlation set can use beamforming or other methods to reduce correlation and therefore improve performance, whereas the low correlation antennas can operate as they are without a special consideration. The ultimate choice in which combination of solutions to choose and to which

antennas to apply will depend on the total data rate served among other requirements.

[0050] Furthermore, reflectors or isolators between antenna elements may be used to separate the transmission and reception spatially, including the use of native geography such as buildings.

[0051] Figure 4 is a diagram illustrating transmission using a plurality of antennas radiating beams in different polarization to reduce correlation between antennas in accordance with the present invention. For example, one transmit antenna transmits a beam in vertical polarization and the other transmit antenna transmits a beam in horizontal polarization. In this way, a correlation between the antennas is reduced. This scheme may be used when antennas are located closely at a transmitter or a receiver.

[0052] In an OFDM system, subcarriers that are close to each other can be transmitted from different antennas with different polarization in order to reduce the correlation between them. For example, odd and even subcarriers may be transmitted from two antennas that are polarized differently. In this way, any potential correlation that would be introduced between the neighbor subcarriers is reduced because of the separation in polarization.

[0053] Figure 5 is a diagram illustrating transmission of beams applying the foregoing embodiments of the present invention in an OFDM system. In an OFDM system, it is often the case that correlation between antennas is different in different OFDM bins. In other words, the correlation is frequency dependent. Therefore, one or more of the embodiments stated above can be applied to frequency bins in an OFDM system selectively.

[0054] Subcarriers are divided into a plurality of groups, and the subcarrier groups are transmitted by different transmit antennas. For example, if two transmit antennas are used as shown in Figure 5, even group of subcarriers are transmitted by one antenna (or beam) and odd group of subcarriers are transmitted by the other antenna (or beam). In transmitting subcarriers, any embodiments described above may be implemented. In the foregoing example, the two antennas may be the antenna having different antenna pattern; or an

array antenna may be used to generate directional beams; or the antennas may transmit beams in different polarization.

[0055] Alternatively, Trellis coding may be used to map signals to antennas for reducing likelihood of adjacent symbols being mapped to highly correlated antennas. Trellis coded modulation has long been used to increase the free distance in coding. The same principle is applied to increase the "correlation distance" between adjacent symbols when mapping onto the antennas. Trellis coded mapping of parallel data to antenna elements is to assure that the adjacent symbols are mapped to those antennas with lower correlation between them. This requires that the antenna correlation information be updated periodically. At the receive end, the trellis coded modulation is reversed.

[0056] The embodiments of the present invention may be combined for smart allocation of frequency and time. In other words, signals can be further multiplexed in frequency or time domain. For instance, in the frequency domain, if the transmission and reception paths of two signals are separated, spatially or by other means as stated above, then they can be transmitted within the same frequency band or time slot, or partially overlapped, without degrading each other's performance significantly.

[0057] Figure 6 is a flow diagram of a process 200 for reducing antenna correlation in accordance with the present invention. A transmitter generates at least two beams using a plurality of antennas (step 202). The generated beams are separated to point away each other, spatially or in polarization. Signals are transmitted using the generated beams (step 204). The transmitted signals travel through different channel condition including different scatterers, and arrive at a receiver mutually uncorrelated.

[0058] Although the features and elements of the present invention are described in the preferred embodiments in particular combinations, each feature or element can be used alone without the other features and elements of the preferred embodiments or in various combinations with or without other features and elements of the present invention.

* * *

CLAIMS

What is claimed is:

1. A method for reducing antenna correlation between a plurality of transmit antennas of a transmitter in a wireless communication system, the method comprising:

generating at least two beams, the generated beams being spatially separated to point away each other; and

transmitting signals using the generated beams, whereby the transmitted signals arriving at a receiver are mutually uncorrelated.

2. The method of claim 1 wherein the beams are generated by antennas having different antenna pattern.

3. The method of claim 1 wherein the beams are directional beams generated by an array antenna.

4. The method of claim 1 wherein the beams are generated by using at least one of a reflector and an isolator.

5. The method of claim 1 wherein the beams are generated by using Metamaterial.

6. The method of claim 1 wherein the wireless communication system is an orthogonal frequency division multiplexing (OFDM) and subcarriers are divided into a plurality of groups and adjacent group of subcarriers are transmitted by different beams.

7. The method of claim 1 further comprising the steps of:
calculating antenna correlation between the antennas; and

determining which antennas a signal is transmitted from either based on the calculated antenna correlation or a feedback received from a communicating entity.

8. A method for reducing antenna correlation between a plurality of transmit antennas of a transmitter in a wireless communication system, the method comprising:

generating at least two beams, the generated beams being polarized differently; and

transmitting signals using the generated beams, whereby the transmitted signals arriving at a receiver are mutually uncorrelated.

9. The method of claim 8 wherein the wireless communication system is an orthogonal frequency division multiplexing (OFDM) and even and odd subcarriers are transmitted through beams that are differently polarized.

10. A method for reducing antenna correlation between a plurality of transmit antennas of a transmitter in a wireless communication system, the method comprising:

receiving data;

converting the data into a parallel data; and

performing Trellis coded mapping of the parallel data to antennas, whereby adjacent symbols are mapped to antennas with low correlation.

11. An apparatus for reducing antenna correlation between a plurality of transmit antennas in a wireless communication system, the apparatus comprising:

a plurality of transmit antennas;

a data processing unit configured to process data for transmission; and

an antenna controller configured to control the antennas for transmission of the data generating at least two beams with the antennas, the generated

beams being spatially separated to point away each other, whereby the transmitted signals arriving at a receiver are mutually uncorrelated.

12. The apparatus of claim 11 wherein each antenna has different antenna pattern.

13. The apparatus of claim 11 wherein an array antenna is utilized to generate the beams.

14. The apparatus of claim 11 wherein at least one of a reflector and an isolator is utilized to generate beams.

15. The apparatus of claim 11 wherein the beams are generated by using Metamaterials.

16. The apparatus of claim 11 wherein the wireless communication system is an orthogonal frequency division multiplexing (OFDM) and subcarriers are divided into a plurality of groups and adjacent group of subcarriers are transmitted by different beams.

17. The apparatus of claim 11 further comprising a measurement unit configured to calculate antenna correlation between the antennas, whereby the antenna controller determines which antennas a signal is transmitted from either based on the calculated antenna correlation or a feedback received from a communicating entity.

18. An apparatus for reducing antenna correlation between a plurality of transmit antennas in a wireless communication system, the apparatus comprising:

a plurality of transmit antennas;

a data processing unit configured to process data for transmission; and

an antenna controller configured to control the antennas for transmission of the data generating at least two beams with the antennas, the generated beams being polarized differently, whereby the transmitted signals arriving at a receiver are mutually uncorrelated.

19. The apparatus of claim 18 wherein the wireless communication system is an orthogonal frequency division multiplexing (OFDM) and subcarriers are transmitted through beams that are differently polarized.

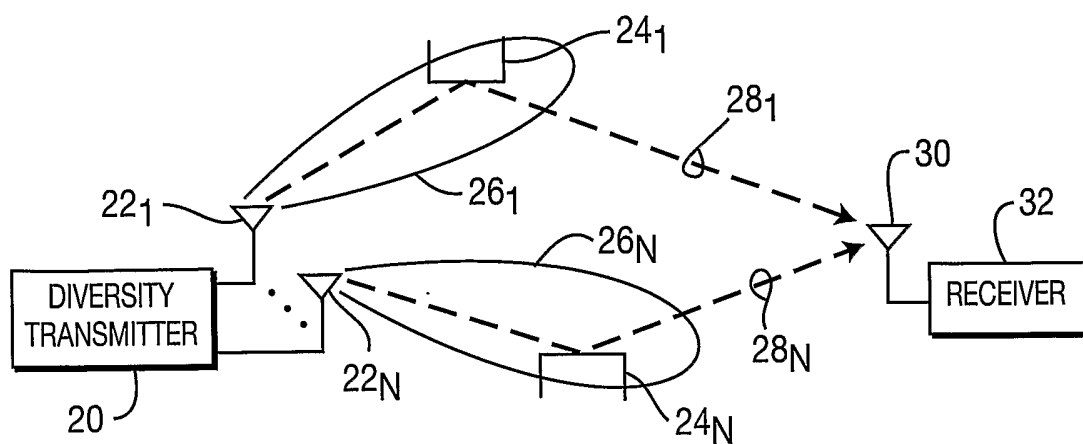
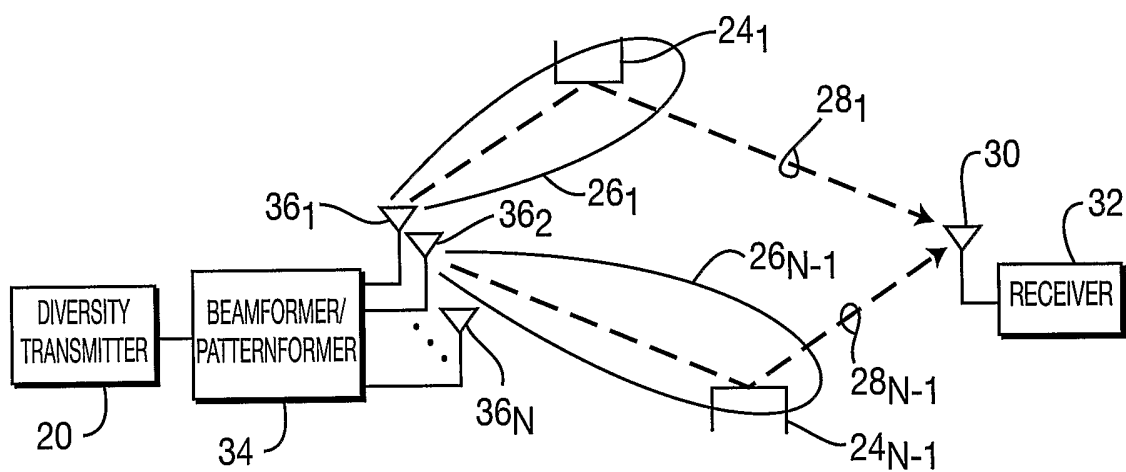
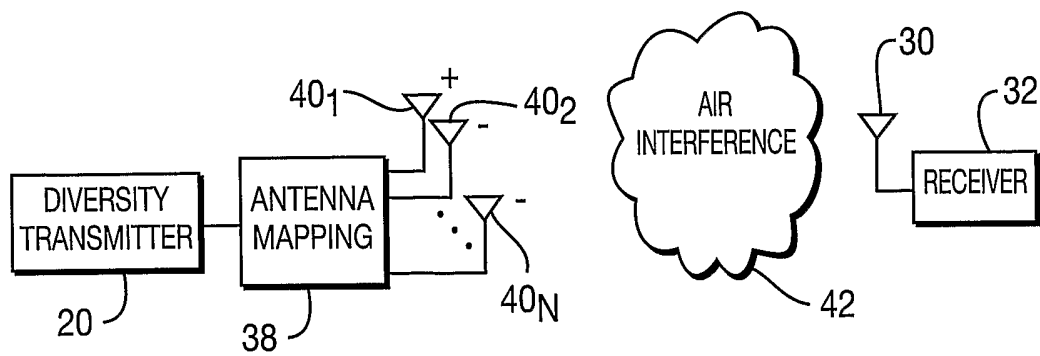
20. An apparatus for reducing antenna correlation between a plurality of transmit antennas in a wireless communication system, the apparatus comprising:

a plurality of antennas;

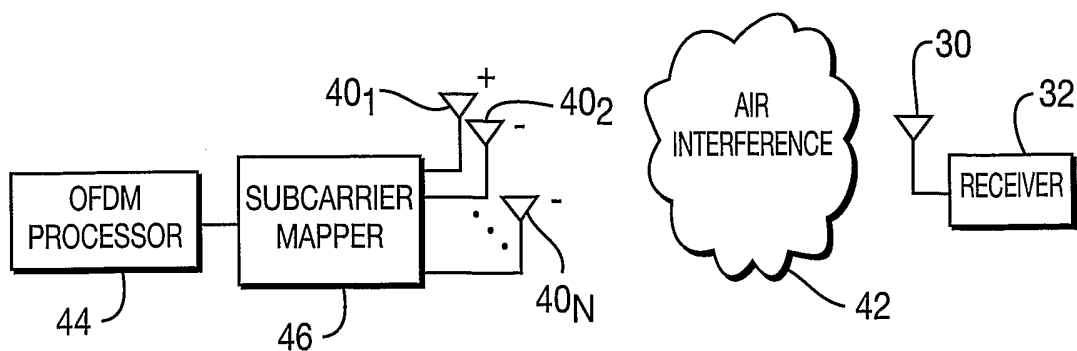
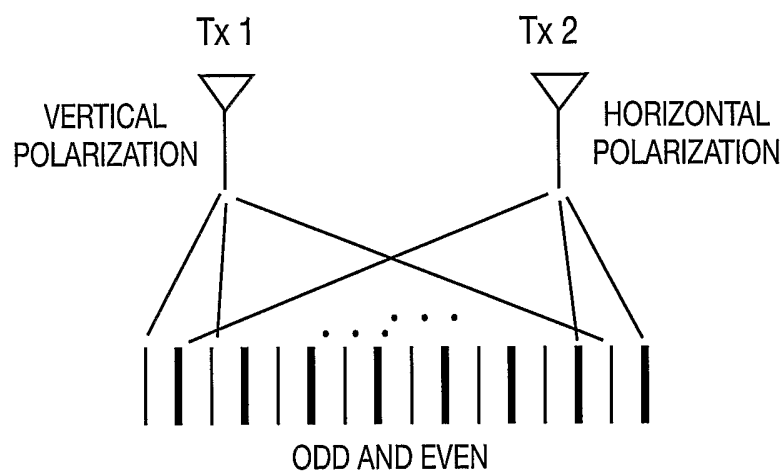
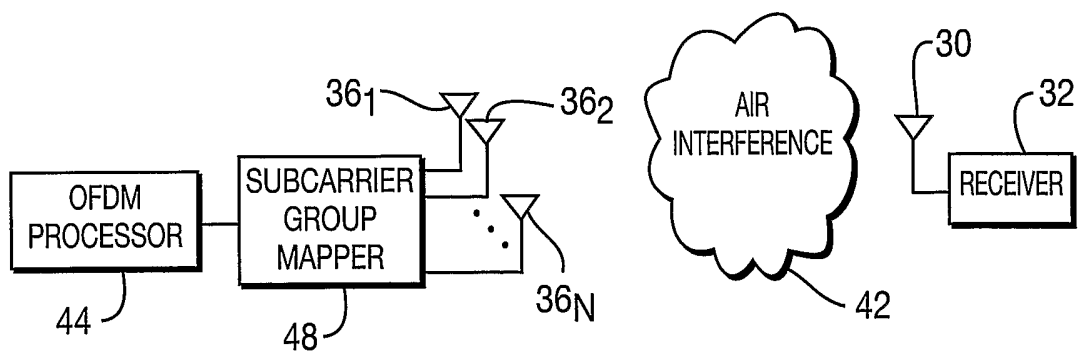
a serial-to-parallel converter configured to convert an input data stream into multiple parallel data streams; and

a Trellis coder configured to perform Trellis coded mapping of the parallel data to antennas, whereby adjacent symbols are mapped to antennas with low correlation.

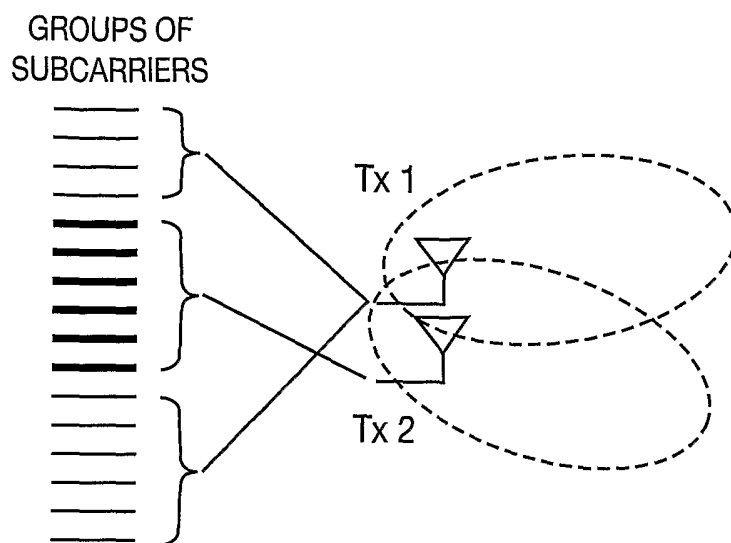
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**FIG. 1****FIG. 2****FIG. 3**

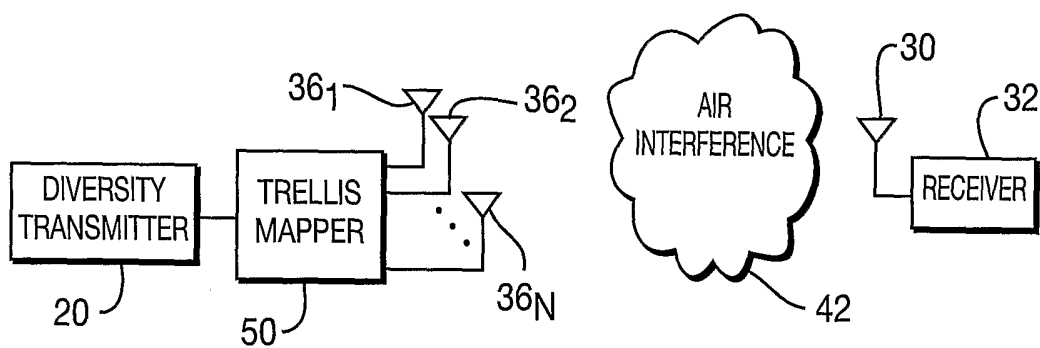
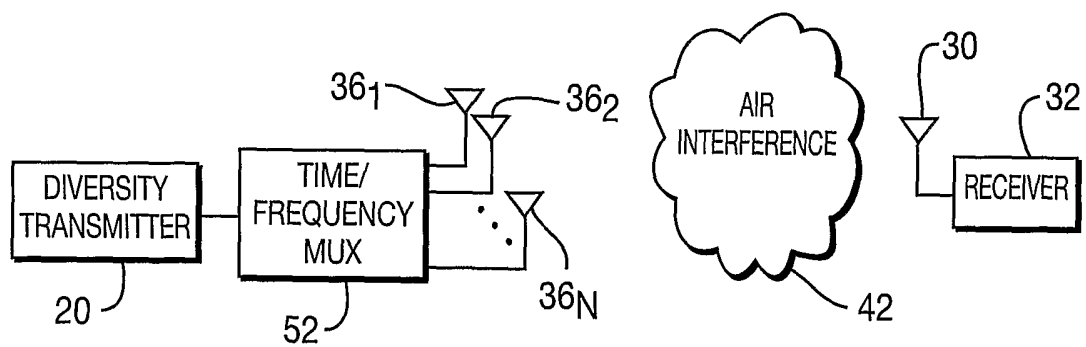
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**FIG. 4****FIG. 5****FIG. 6**

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EG. ODD AND EVEN SUBCARRIER GROUPS AT
DIFFERENT BEAMS

FIG. 7**FIG. 8****FIG. 9**