



(19) **United States**
(12) **Patent Application Publication**
SOMICHETTY et al.

(10) **Pub. No.: US 2013/0128937 A1**
(43) **Pub. Date: May 23, 2013**

(54) **LINK ADAPTATION FOR MULTIMODE MIMO WIRELESS SYSTEM**

Publication Classification

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(51) **Int. Cl.**
H04W 24/00 (2009.01)
(52) **U.S. Cl.**
USPC **375/224**

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(57) **ABSTRACT**

(21) Appl. No.: **13/463,445**

A wireless receiver is disclosed that is capable of efficiently selecting a preferred transmission/detection scheme for use in wireless communication. The wireless receiver may be capable of communicating using any one of several transmission/detection schemes. Therefore, in order to select a preferred transmission/detection scheme, the wireless receiver calculates at least one metric for the transmission/detection schemes. In MIMO systems, the link adaptation is more complex and the metrics typically must be more accurate. Because of the potentially substantial amount of calculation that may be required to calculate the metric, the wireless receiver is capable of performing the individual calculations in optimized ways, as well as easily reducing the total number of metrics required to be calculated so as to reduce overall complexity.

(22) Filed: **May 3, 2012**

Related U.S. Application Data

(60) Provisional application No. 61/562,196, filed on Nov. 21, 2011.

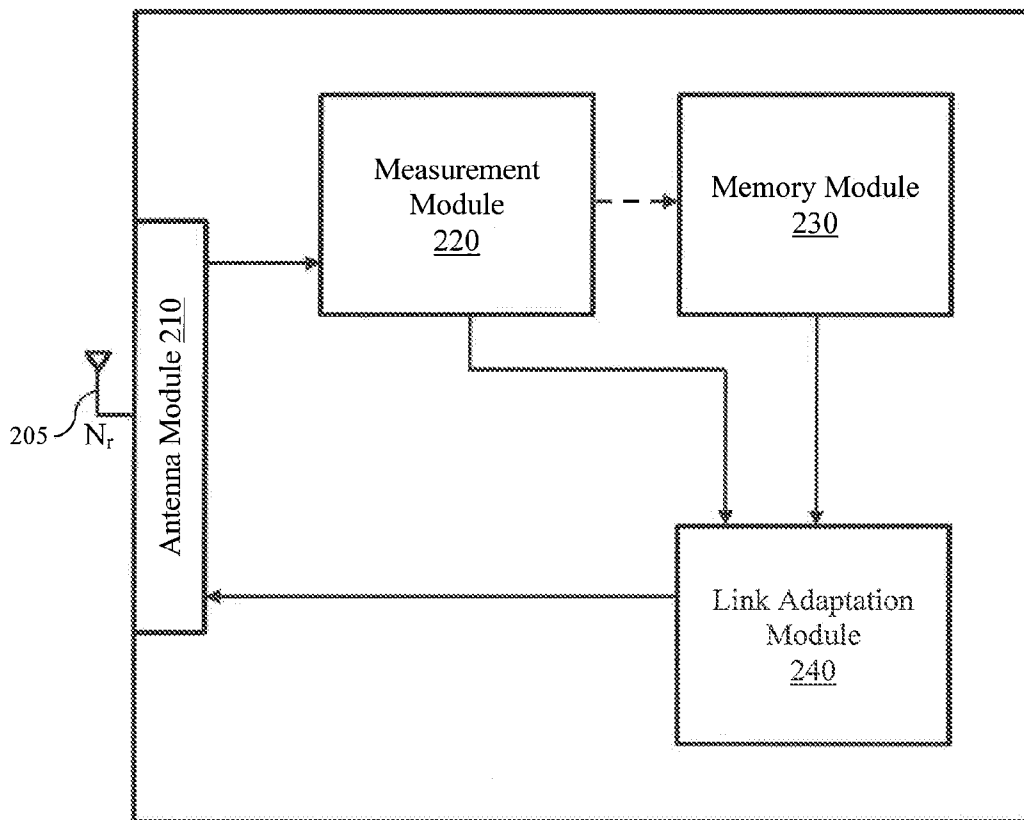


FIG. 1

100

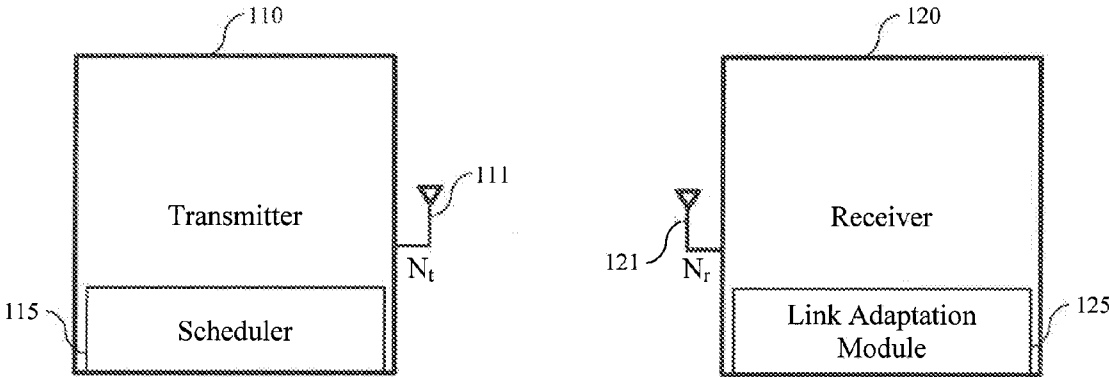


Fig. 2

200

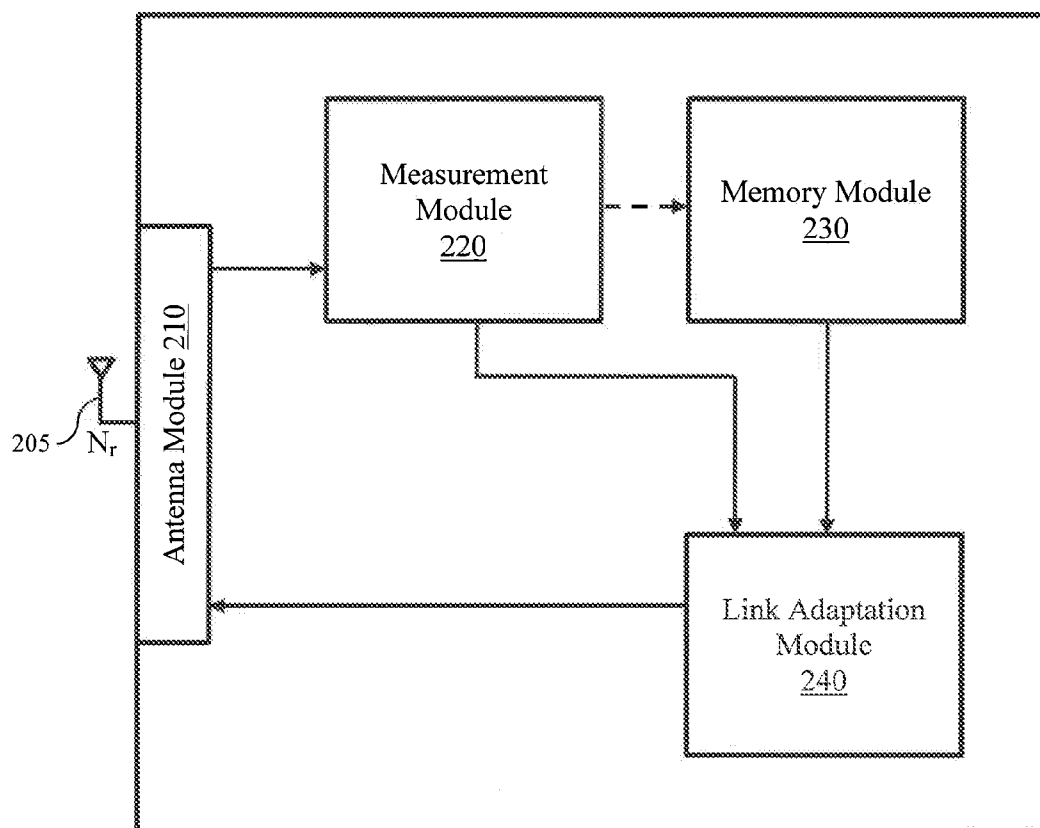


Fig. 3

300

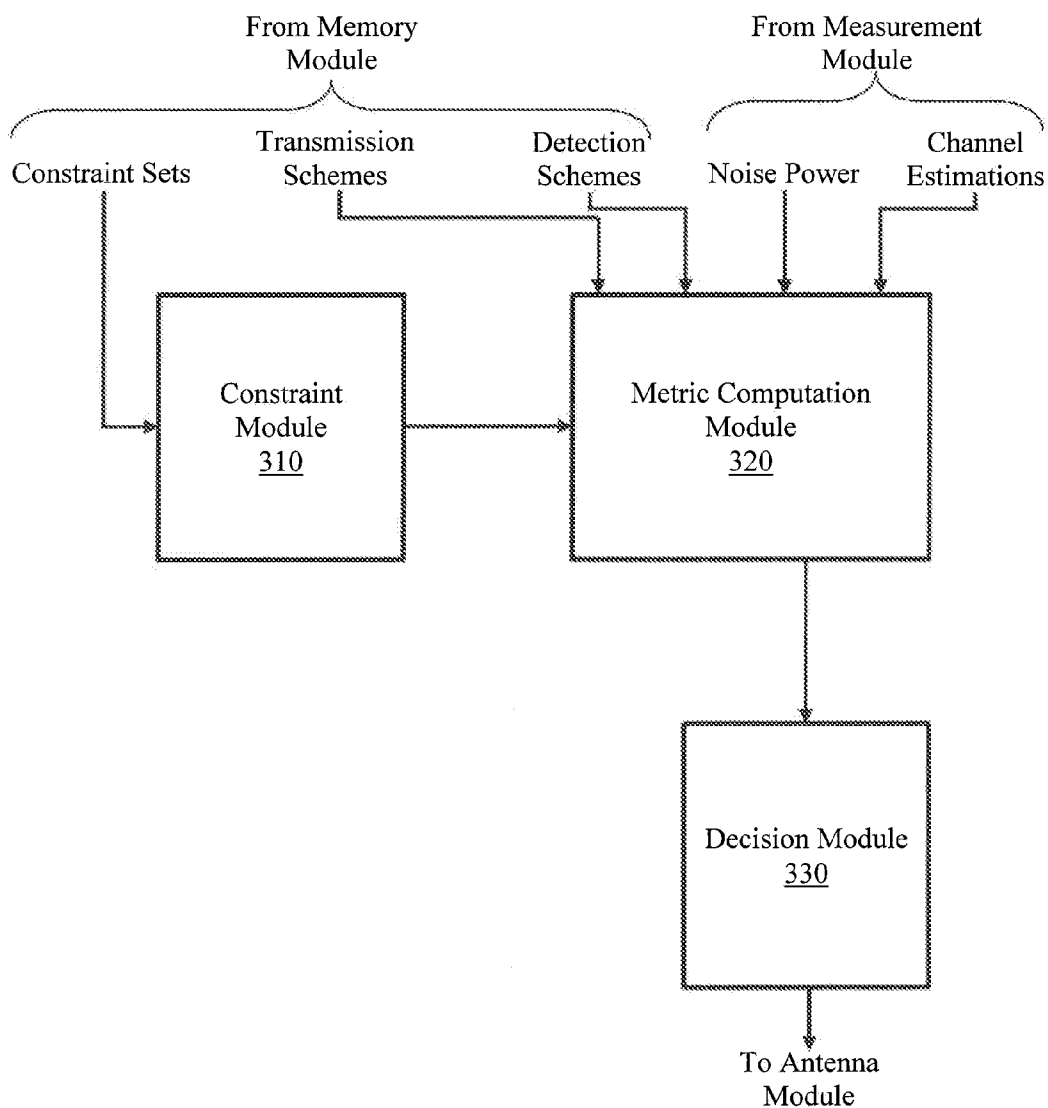


Fig. 4

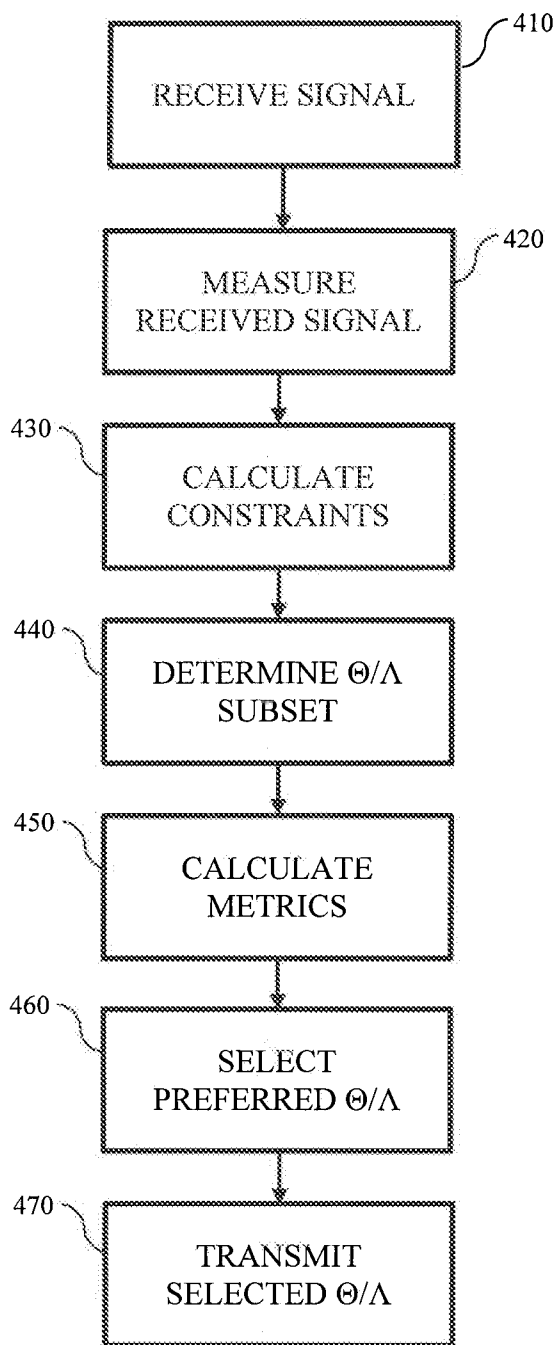
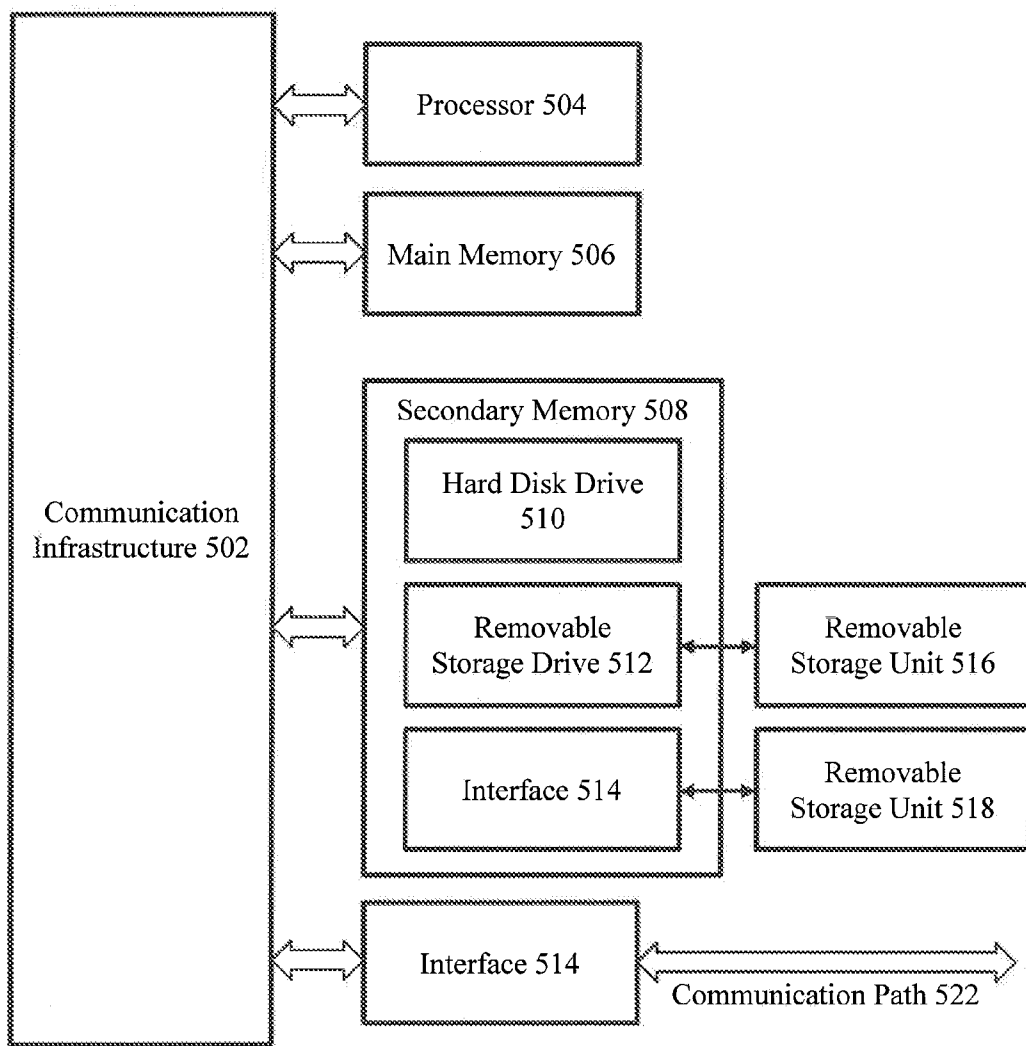


Fig. 5

500



LINK ADAPTATION FOR MULTIMODE MIMO WIRELESS SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims the benefit of U.S. Provisional Patent Application No. 61/562,196, filed Nov. 21, 2011, entitled “Fourth Generation (4G) Communication Systems,” which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] 1. Field of Invention

[0003] The disclosure relates to wireless communications, and more specifically to a wireless communication device that is capable performing link adaptation calculations with reduced complexity within a MIMO wireless system.

[0004] 2. Related Art

[0005] Wireless communication devices, such as cellular telephones to provide an example, are becoming commonplace in both personal and commercial settings. The wireless communication devices provide users with access to all kinds of information, as well as the ability to communicate with other such devices across large distances. For example, a user can access the internet through an internet browser on the device, download miniature applications (e.g., “apps”) from a digital marketplace, send and receive emails, or make telephone calls using a voice over internet protocol (VoIP). Consequently, wireless communication devices provide users with significant mobility, while allowing them to remain “connected” to communication channels and information.

[0006] Wireless communication devices communicate with one or more other wireless communication devices or wireless access points to send and receive data. Typically, a first wireless communication device generates and transmits a radio frequency signal modulated with encoded information. This radio frequency signal is transmitted into a wireless environment and is received by a second wireless communication device. The second wireless communication device demodulates and decodes the received signal to obtain the information. The second wireless communication device may then respond in a similar manner. The wireless communication devices can communicate with each other or with access points using any well-known modulation scheme, including amplitude modulation (AM), frequency modulation (FM), quadrature amplitude modulation (QAM), phase shift keying (PSK), quadrature phase shift keying (QPSK), and/or orthogonal frequency-division multiplexing (OFDM), as well as any other communication scheme that is now, or will be, known.

[0007] The receiving device may perform a link adaptation calculation in order to determine an optimal transmission scheme to be used for communication. This conventionally includes selecting a metric and, for each combination of transmission parameters (e.g., for each possible transmission scheme), calculating the metric. Although this is an acceptable method for simpler systems that do not include significant numbers of transmission parameters, performing these calculations can be extremely cumbersome for a more complex system (such as, for example, a closed loop MIMO system capable of supporting layers), and therefore may require an unacceptable amount of processing and/or operating power.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

[0008] Embodiments are described with reference to the accompanying drawings. In the drawings, like reference numbers indicate identical or functionally similar elements. Additionally, the left most digit(s) of a reference number identifies the drawing in which the reference number first appears.

[0009] FIG. 1 illustrates a block diagram of an exemplary wireless communication environment;

[0010] FIG. 2 illustrates a block diagram of an exemplary receiver that is implemented as part of the wireless communication environment;

[0011] FIG. 3 illustrates an exemplary link adaptation module that may be implemented within the receiver;

[0012] FIG. 4 illustrates an exemplary method for selecting a preferred transmission/detection scheme; and

[0013] FIG. 5 illustrates an exemplary computer system that can be used to implement aspects of the present disclosure.

DETAILED DESCRIPTION OF THE INVENTION

[0014] The following Detailed Description refers to accompanying drawings to illustrate exemplary embodiments consistent with the invention. References in the Detailed Description to “one exemplary embodiment,” “an exemplary embodiment,” “an example exemplary embodiment,” etc., indicate that the exemplary embodiment described may include a particular feature, structure, or characteristic, but every exemplary embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same exemplary embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an exemplary embodiment, it is within the knowledge of those skilled in the relevant art(s) to affect such feature, structure, or characteristic in connection with other exemplary embodiments whether or not explicitly described.

[0015] The exemplary embodiments described herein are provided for illustrative purposes, and are not limiting. Other exemplary embodiments are possible, and modifications may be made to the exemplary embodiments within the spirit and scope of the disclosure. Therefore, the Detailed Description is not meant to limit the invention. Rather, the scope of the invention is defined only in accordance with the following claims and their equivalents.

[0016] Embodiments may be implemented in hardware (e.g., circuits), firmware, software, or any combination thereof. Embodiments may also be implemented as instructions stored on a machine-readable medium, which may be read and executed by one or more processors. A machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computing device). For example, a machine-readable medium may include read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; flash memory devices; electrical, optical, acoustical or other forms of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.), and others. Further, firmware, software, routines, instructions may be described herein as performing certain actions. However, it should be appreciated that such descriptions are merely for convenience and that such actions in fact results from com-

puting devices, processors, controllers, or other devices executing the firmware, software, routines, instructions, etc. Further, any of the implementation variations may be carried out by a general purpose computer, as described below.

[0017] For purposes of this discussion, the term “module” shall be understood to include at least one of software, firmware, and hardware (such as one or more circuit, microchip, or device, or any combination thereof), and any combination thereof. In addition, it will be understood that each module may include one, or more than one, component within an actual device, and each component that forms a part of the described module may function either cooperatively or independently of any other component forming a part of the module. Conversely, multiple modules described herein may represent a single component within an actual device. Further, components within a module may be in a single device or distributed among multiple devices in a wired or wireless manner.

[0018] The following Detailed Description of the exemplary embodiments will so fully reveal the general nature of the invention that others can, by applying knowledge of those skilled in relevant art(s), readily modify and/or adapt for various applications such exemplary embodiments, without undue experimentation, without departing from the spirit and scope of the disclosure. Therefore, such adaptations and modifications are intended to be within the meaning and plurality of equivalents of the exemplary embodiments based upon the teaching and guidance presented herein. It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by those skilled in relevant art(s) in light of the teachings herein.

[0019] Although the following description is to be described in terms of wireless communication (specifically cellular communication), those skilled in the relevant art(s) will recognize that this description may also be applicable to other communications that use wired, optical, or other wireless communication methods without departing from the spirit and scope of the present disclosure.

[0020] An Exemplary Wireless Communications Environment

[0021] FIG. 1 illustrates a block diagram of a wireless communication environment 100 according to an exemplary embodiment of the disclosure. The wireless communication environment 100 provides wireless communication of information, such as one or more commands and/or data, between wireless communication devices. The wireless communication devices may each be implemented as a standalone or a discrete device, such as a mobile telephone, or may be incorporated within or coupled to another electrical device or host device, such as a portable computing device, a camera, or a Global Positioning System (GPS) unit or another computing device such as a personal digital assistant, a video gaming device, a laptop, a desktop computer, or a tablet, a computer peripheral such as a printer or a portable audio and/or video player to provide some examples and/or any other suitable electronic device that will be apparent to those skilled in the relevant art(s) without departing from the spirit and scope of the invention.

[0022] The exemplary wireless communication environment 100 includes a wireless transmitter 110 and a wireless receiver 120. Each of the wireless transmitter 110 and the wireless receiver 120 may be included within corresponding

wireless communication devices that are each capable of both wireless transmission and wireless reception. The wireless transmitter 110 may represent an exemplary embodiment of a base station, and the wireless receiver 120 may represent an exemplary embodiment of a user equipment/subscriber station within a cellular communications network.

[0023] The wireless transmitter 110 includes a scheduler 115 for preparing outgoing signals for transmission in accordance with a selected transmission scheme, and includes an antenna 111 for transmitting the signals into the wireless communication environment 100. Those skilled in the relevant art(s) will recognize that the antenna 111 may include an array of N_r antennas, where N_r is a positive integer, and that the antenna 111 may be capable of both transmitting and receiving signals.

[0024] The wireless receiver 120 includes a link adaptation module 125 configured to perform the link adaptation calculations in accordance with one or more of the embodiments discussed in the present disclosure, and includes an antenna 121 for receiving the signals from the wireless communication environment 100. Those skilled in the relevant art(s) will recognize that the antenna 121 may include an array of N_r antennas, where N_r is a positive integer, and that the antenna 121 may be capable of both transmitting and receiving signals.

[0025] Detailed functionality of the wireless receiver 120 and the link adaptation module 125 are discussed below, with respect to the relevant figures.

[0026] Exemplary Wireless Communication Device

[0027] FIG. 2 illustrates a block diagram of an exemplary wireless receiver 200 that may be implemented as part of the wireless communication environment 100. The wireless receiver 200 includes a measurement module 220, a memory module 230, and a link adaptation module 240, and may represent an exemplary embodiment of the wireless receiver 120.

[0028] The wireless receiver 200 receives signals from the wireless communication environment 100 via its antenna 205 connected to an antenna module 210. Again, the antenna 205 may include N_r antennas, where N_r is a positive integer. Each of the N_r antennas may be capable of individually receiving signals from the wireless communication environment 100. The antenna module 210 forwards the received signals to the measurement module 220.

[0029] The measurement module 220 takes various measurements of the received signals, which may be needed for performing the link adaptation calculations. Such measurements may include, for example, channel estimates (e.g. amplitude and phase response) and/or noise powers. For example, the measurement module 220 may measure a channel estimate H_1, H_2, \dots, H_M , for each of M channels, where each channel H will have the size $N_r \times N_r$. The M channels can be distributed over the frequency domain (e.g., as carriers in an OFDM system) or in the time domain (e.g., space time codes). Similarly, the measurement module 220 may calculate per channel noise plus interference powers (hereinafter “noise power”) σ_i^2 , where $i=1, 2, \dots, M$. The measurement module 220 forwards the measurements to the link adaptation module 240 for use in the link adaptation calculation.

[0030] The measurement module 220 may also forward one or more measurements and/or information to the memory module 230 for storage. The memory module 230 stores various aspects and/or parameters of the system that may be needed by the link adaptation module 240 to perform the link

adaptation calculations. Such parameters may include a set of transmission schemes Θ available with the current wireless transmitter 110, a set of detection schemes Λ available for use by the wireless receiver 200, and a constraints set C that dictates various limitations on the wireless receiver 200 and/or on calculations performed by the wireless receiver 200, discussed in further detail below. In an embodiment, these various parameters may be stored in one or more look-up tables that are accessible by the link adaptation module.

[0031] The link adaptation module 240 receives the measurements from the measurement module 220 and the various parameters from the memory module 230. Using this information, the link adaptation module 240 performs the link adaptation calculations for the wireless receiver 200 in order to determine a preferred transmission scheme to be employed between the wireless transmitter 110 and the wireless receiver 200.

[0032] Once the link adaptation module 240 has determined a preferred transmission scheme, the link adaptation module 240 informs the antenna module 210 of the preferred transmission scheme, which forwards a signal to the wireless transmitter 110 via the antenna 205. Upon receiving the preferred transmission scheme from the wireless receiver 200, the wireless transmitter 110 instructs its scheduler 115 accordingly, which then employs the preferred transmission scheme for communicating with the wireless receiver 200.

[0033] Exemplary Link Adaptation Module

[0034] FIG. 3 illustrates an exemplary link adaptation module 300 that may be implemented within the wireless receiver 200. The link adaptation module 300 includes a constraint module 310, a metric computation module 320, and a decision module 330, and may represent an exemplary embodiment of the link adaptation module 240.

[0035] In the link adaptation module 300, the constraint module 310 receives the constraint sets C from the memory module 230. From these constraint sets, the constraint module 310 determines the current constraints on the link adaptation.

[0036] 1. Exemplary Constraints

[0037] As discussed above, there may be several different constraints on which the constraint module 310 may restrict the transmission/detection schemes analyzed by the metric computation module 320.

[0038] In one example, the constraint module 310 calculates a constraint $C_1(H_1, H_1, \dots, H_M, \Theta, \Lambda)$, where C_1 denotes the exponent of the complexity of a detector used in the receiver, under the possible channel model represented by the channels H and the transmit/receiver pair Θ/Λ . The constraint module 310 may require C_1 to be below a predetermined threshold. For example, if the constraint module 310 requires C_1 to be less than 1, then only linear receivers will be permitted.

[0039] In another example, the constraint module 310 may restrict channel uses and/or throughput. For example, the constraint module 310 may calculate the number of channel uses that can be allocated to a user as constraint C_2 , and calculate the inverse of the throughput that the user is expected to achieve as a part of the Quality of Service (QoS) as constraint C_3 . The constraint module 310 can then require each of these constraints C_2 and C_3 to be below corresponding thresholds. In this manner, if the constraint C_2 is too tight, then the module can bias its selection towards the higher rate transmission schemes (in terms of spatial-time-frequency rate).

[0040] In another example, the constraint module 310 may restrict power consumption. For example, the constraint module 310 may calculate power consumption and any boundaries on power consumption (e.g., battery life) as constraint C_4 , and may calculate the inverse of the minimum QoS as constraint C_5 . The constraint module 310 can then require each of these constraints C_4 and C_5 to be below corresponding thresholds. In this manner, the constraint module 310 will bias possible transmission/detection schemes towards those which involve less receiver power consumption.

[0041] In another example, the constraint module 310 may take into account the spatial correlation factor. For example, the constraint module 310 may calculate spatial correlation of the channel and compare the result with predetermined thresholds to determine possible transmission/detection schemes. If the spatial correlation is high, the constraint module 310 will bias possible transmission/detection schemes towards those that include fewer layers.

[0042] Once the constraint module 310 has calculated the constraints, the constraint module forwards the constraints to the metric computation module 320.

[0043] 2. Exemplary Metric Computation Module

[0044] The metric computation module 320 measures at least one metric for each applicable transmission and detection scheme. In order to determine the applicable transmission and detection schemes, the metric computation module 320 receives the set of transmission schemes Θ and the set of detection schemes Λ from the memory module 230. The metric computation module 320 also receives the constraints from the constraint module 310. By applying the constraints to the received set of transmission schemes Θ and set of detection schemes Λ , the metric module is able to determine the applicable transmission and detection schemes $\{\Theta_i, \Lambda_i\}$.

[0045] Once the applicable transmission and detection schemes have been determined, the metric computation module 320 then calculates at least one metric for a plurality of these applicable transmission and detection scheme combinations. The metrics can be selected based on desired performance characteristics (e.g., signal quality, power consumption, etc.) and should provide some value or other means by which to compare the abilities of the transmission and detection scheme combinations to satisfy the desired performance characteristics. Examples of such metrics include Effective signal-to-noise ratio (SNR), effective exponential SNR mapping (EESM), capacity based SNR metric, and normalized modulation constrained capacity (NMCC) (also known as “receive bit information rate (RBIR)”). It will be noted that the metric computation module 320 need not calculate the same metric for each of the transmission/detection scheme combinations. Further, the metric may be represented as a function of the channel estimates, the noise power, the applicable transmission schemes, and the applicable detection schemes as $\xi(H_1, H_2, \dots, H_M, \sigma^2, \Theta, \Lambda)$.

[0046] Once the metrics have been calculated for the plurality of acceptable transmission and detection schemes, the metric computation module 320 forwards the calculated metrics to the decision module 330. The decision module 330 compares the calculated metrics to each other and selects a preferred transmission scheme and/or a preferred detection scheme based on which of the metrics is preferred. In an embodiment, the preferred metric may be the metric that best satisfies the desired performance characteristic, and/or which may have the highest or lowest value from among the similarly-calculated metrics.

[0047] Metric: Per Layer SNR

[0048] In an embodiment, the link adaptation module 300 may calculate the SNR for each applicable transmission/detection scheme. Although this calculation is relatively established for a single-layer system (rank 1 system—a system that communicates only a single data symbol per channel use), this calculation has conventionally been unsuited to multi-layer systems due to its complexity. Therefore, below is provided an exemplary configuration for calculating a rank 2 (2-layer system) per layer SNR.

[0049] In this configuration, the measurement module 220 measures the effective channel H between the receive antennas 205 and the two layers in the rank 2 system. The effective channel H can thus be represented as a $[N_r, 2]$ matrix. In addition, the measurement module 220 also measures the average noise power σ^2 at the receive antennas. The measurement module 220 then forwards this information to the metric computation module 320 of the link adaptation module 300.

[0050] The metric computation module 320 first generates a matrix $A=H^H \times H$, where $()^H$ represents the Hermitian (transpose—conjugate)

$$\begin{bmatrix} A(1, 1) & A(1, 2) \\ A(1, 2)^* & A(2, 2) \end{bmatrix} \quad (1)$$

In this matrix, A(1,1) may represent the power from a first symbol to all receive antennas, and A(2,2) represents the power from a second symbol to all the receive antennas. A(1,2) and A(1,2)* represent the leakage from one layer into the other.

[0051] From this information, the metric computation module 320 calculates the average SNR as:

$$\text{Avg_Rank_2_SNR}_{dB} = 10 \log 10 (\sqrt{|A|}) - 10 \log 10(\sigma^2), \quad (2)$$

where |A| represents the determinant of A. Equation (2) provides the total SNR averaged over the different channels. However, in order to obtain more accurate metric measurements, it may be desired to determine the average SNR on each channel individually. It has been found that the individual channel averages can be calculated as functional differences of the $\text{Avg}_{13} \text{Rank_2_SNR}_{dB}$. Therefore, the metric computation module 320 calculates the individual layer SNRs as:

$$\text{Rank_2_Layer_1_SNR}_{dB} = \text{Avg_Rank_2_SNR}_{dB} + \Delta(A)_{dB}, \text{ and} \quad (3)$$

$$\text{Rank_2_Layer_2_SNR}_{dB} = \text{Avg_Rank_2_SNR}_{dB} - \Delta(A)_{dB}, \quad (4)$$

where $\Delta(A)$ is a channel differential and is a function of A.

[0052] Assuming that the layer 1 SNR is proportional to A(1,1) and that the layer 2 SNR is proportional to A(2,2), the metric computation module 320 can then, in one embodiment, calculate $\Delta(A)_{dB}$ as:

$$\Delta(A)_{dB} = k * 10 \log 10 \left(\frac{A(1, 1)}{A(2, 2)} \right), \quad (5)$$

where k is a tuning parameter. During implementation, it was discovered that k value of 0.5 functioned as a good general approximation for most multilayer receivers.

[0053] Once the metric computation module has calculated the $\Delta(A)_{dB}$, the metric computation module 320 enters the result into equations (3) and (4) in order to obtain the per layer SNR metrics. The decision module 330 can then compare these calculated metrics with those of other transmission schemes in order to select a preferred transmission scheme.

[0054] It should be noted that, if the receiver detection is linear (e.g., zero forcing (ZF), minimum mean squared error (MMSE), etc.), the SNR metric for each layer, regardless of the number of layers, is a direct function of H and σ^2 . In this case, computing the SNR metrics is much simpler than in the above equations. For example, in a zero forcing configuration, the first layer SNR (SNR_1) and the second layer SNR (SNR_2) can be calculated as:

$$\text{SNR}_1 = \frac{1}{\sigma^2} \times \frac{|A|}{A(2, 2)}, \text{ and} \quad (6)$$

$$\text{SNR}_2 = \frac{1}{\sigma^2} \times \frac{|A|}{A(1, 1)}. \quad (7)$$

[0055] It should be understood that, although the above equations are specifically described with respect to a 2-layer system, similar mathematical principles can be applied to systems having more than two layers. Therefore, the present disclosure should not be limited to a system having only two layers.

[0056] Metric: Per Layer NMCC

[0057] In an embodiment, an additional or alternative metric that the link adaptation module 300 may calculate is the per layer NMCC. In multilayer systems, multiple different factors may affect the NMCC. For example, such factors may include the modulation of the layer under consideration Q, the modulation of the other layer not under consideration Q', the effective SNR of the layer under consideration $\gamma_{dB, layer}$, a channel orthogonality factor $\Omega(A)$, and the SNR offset of the other layer with respect to the layer under consideration γ_{offset} .

[0058] Therefore, in this embodiment, the link adaptation module 300 acquires the modulations Q and Q' from the memory module 230 (the modulations Q and Q' are part of the transmission scheme and thus can be derived from the information relating to the transmission scheme). The metric computation module 320 calculates the effective SNR of the layer under consideration $\gamma_{dB, layer}$ using equations (1)-(5), above, and calculates the SNR offset of the layer not under consideration γ_{offset} by comparing the calculated SNR of the layer not under consideration to the SNR of the layer under consideration.

[0059] The metric computation module 320 also calculates the channel orthogonality factors as:

$$\Omega(A)_{layer1} = \frac{|A(1, 2)|}{A(1, 1)}, \text{ and} \quad (8)$$

$$\Omega(A)_{layer2} = \frac{|A(1, 2)|}{A(2, 2)}. \quad (9)$$

After this information has been calculated, the metric computation module 320 can then calculate the NMCC as a function of Q, Q', $\Omega(A)$, $\gamma_{dB, layer}$, and γ_{offset} .

[0060] The NMCC, based on these values, can be precomputed empirically and stored for future use. For example, the

precomputed values can be stored in a look-up table which can then be accessed based on one or more variables, such as, for example, Q , Q' , $\Omega(A)$, $\gamma_{dB, layer}$, and γ_{offset} , discussed above.

[0061] Metric: Receiver-Specific NMCC

[0062] Although the theoretically calculated per-layer NMCC is applicable to most receivers, the characteristics of some receivers may make the “theoretical” NMCC unsuitable. Therefore, rather than employing the theoretical NMCC calculations, the NMCC can be calculated and normalized based on the actual implemented receiver. In other words, the NMCC can be calculated in an offline manner by employing the implemented receiver and a simulated transmitter. The pre-calculated NMCC values can be stored as part of look-up tables in the memory module **230**.

[0063] In this embodiment, wireless receiver **200** receives a signal from the simulated wireless communication environment that includes a plurality of symbols $Y=[y_0, y_1, \dots, y_{|L|-1}]$ contained within a constellation L , where $|L|$ is the size of the constellation. The measurement module **220** measures the size of a QAM constellation $|L|$, and forwards the constellation size $|L|$, as well as received symbols Y of the received signal to the link adaptation module **300**.

[0064] Based on the information received from the measurement module **220**, the metric computation module **320** calculates the mutual information $\mu(X, Y)$ between the received symbols Y and the transmitted symbols $X=[x_0, x_1, \dots, x_{|L|-1}]$ as:

$$\mu(X, y) = \frac{1}{|L|} \sum_{x_i=0}^{|L|-1} E(\log_2(M \times f_{x_i|y}(x_i|y))), \quad (10)$$

$$\text{where } M = \log_2(|L|), \text{ and} \quad (11)$$

where $E(f_{a|b}(a|b))$ is the expectation of “a” given “b”. In other words, because the receiver knows the values of Y , equations (10) and (11) calculate, in part, the expectation of a particular transmitted value based on the received value.

[0065] Once the mutual information $\mu(X, Y)$ has been calculated, the metric computation module **320** then calculates the NMCC with respect to the constellation L as:

$$NMCC_L = \frac{\mu(X, Y)}{\log_2(|L|)}. \quad (12)$$

[0066] After performing the NMCC calculation, the link adaptation module **300** may store the pre-calculated NMCC as part of look-up tables within the memory module **230**. These pre-calculated NMCC’s can then later be retrieved by the decision module **330** and compared to one another so as to select a preferred configuration.

[0067] It should be noted that, although the conditioned probability $f_{x_i|y}$ can be easily computed for a rank 1 system, it becomes very difficult to compute for multilayer systems (e.g., a rank 2 system). Therefore, when using a multilayer communication configuration, the metric computation module **320** employs a simplified calculation for $f_{x_i|y}$. For example, if the transmitted symbol x_i has M bits, then the bits of the transmitted symbol x_i are $b_i=[b_{i,0}, b_{i,1}, \dots, b_{i,M-1}]$. The metric computation module **320** can then calculate the symbol probability as:

$$f_{x_i|y} = f_{b_{i,0}|y} \times f_{b_{i,1}|y} \times \dots \times f_{b_{i,M-1}|y} \quad (13)$$

[0068] By splitting the computation into individual bit probabilities, the Log Likelihood Ratios calculated by the

wireless receiver **200** for error correction can be directly applied to easily compute the conditioned bit probabilities $f_{b_i|y}$. Consequently, the calculation can be significantly simplified over conventional methods. Further, by operating on information actually received by the wireless receiver **200**, the multilayer performance characteristics of the wireless receiver **200** can be taken into account. As a result, if the receiver is close to optimal, the calculated NMCC will be close to the theoretical value, whereas if the receiver is sub-optimal, the calculated NMCC will be compensated for that condition and be less aggressive as a result.

[0069] Exemplary Configurations for Reducing Metric Calculation Complexity

[0070] As can be seen from the above equations, for systems having several possible transmission/detection configurations, the complexity for calculating and comparing the metrics for all possibilities can be extremely cumbersome. As a result, below are described several configurations for reducing the complexity of the computations.

[0071] As described above, some metrics are more complicated than others to evaluate. In addition, some metrics are more accurate than others. Therefore, in an embodiment, the metric computation module **320** can calculate different metrics for selecting different parameters in the transmission scheme. For example, each transmission parameter may have a corresponding cardinality (e.g., number of options). For a parameter having a larger cardinality, the metric computation module **320** can calculate metrics having lower complexity, but also lower accuracy, in order to simplify the selection process. Conversely, for parameters having smaller cardinality, the metric computation module **320** can calculate metrics having a higher accuracy, but also higher complexity.

[0072] In another embodiment, less accurate/low complexity metrics can be initially calculated in order to reduce the set of values that may be implemented for a particular transmission parameters. For example, for a transmission parameter having a high cardinality, the metric computation module may first calculate a low-complexity, low accuracy metric for each of its possible values. From this initial metric calculation, the decision module **330** may filter out only those parameter values whose metric exceeds some threshold value. This subset of parameter values can then be forwarded back to the metric computation module **320**, which then calculates a more complex, and more accurate metric for each of the filtered parameter values. In this manner, simple calculations can be performed on the large number of values in order to reduce the number of possibilities, and then the complex calculations need only be performed on those remaining.

[0073] In another embodiment, a metric computation for a single transmission scheme can be broken up into more simplistic calculations based on each individual channel. In particular, in a MIMO system, due to metric dependencies, one layer may impact other layers. Therefore, calculating a particular metric over all channel uses would be extremely complex. Therefore, the metric computation module **320** can calculate the metric for an M -channel configuration as:

$$\xi(H_1, H_2, \dots, H_M, \sigma^2, \Theta) \approx \sum_{x=1}^M \xi'(H_x, \sigma^2, \Theta). \quad (14)$$

The metric should be chosen such that the relationship of equation (14) holds substantially true. One metric that has

been found to substantially satisfy this relationship is NMCC, however, there may be several other metrics that achieve similar or improved results.

[0074] In another embodiment, when the metric can be broken up by channel, as shown in equation (14), it may also be possible to subsample across the channels. In other words, rather than measure each individual channel, the metric computation module 320 may be able to measure only every s^{th} channel in order to approximate the metric. For example, the above summation may be further simplified as:

$$\sum_{x=1}^M \xi'(H_x, \sigma^2, \Theta) \approx \sum_{k=1}^{\lfloor M/s \rfloor} \xi'(H_{sk}, \sigma^2, \Theta), \quad (15)$$

where s is a subsampling factor, and H_{sk} is the subsampled channel. Using this approximation, the metric calculation for a MIMO system can be even further simplified.

[0075] Exemplary Method for Selecting a Preferred Transmission/Detection Scheme

[0076] FIG. 4 illustrates an exemplary method for selecting a preferred transmission/detection scheme.

[0077] In the method, the wireless receiver receives a signal from the wireless transmitter (410). The wireless receiver performs various measurements of this signal, which may include channel estimations, noise power, etc. (420). In addition, the wireless receiver also calculates constraints that are to be implemented by the wireless receiver (430). Such constraints may include power consumption, complexity, quality of service, etc.

[0078] Once the constraints have been calculated, the wireless receiver determines, as a subset of all possible transmission/detection schemes, the acceptable transmission/detection schemes that fall within the constraints (440). The wireless receiver then calculates at least one metric for each of the acceptable transmission/detection schemes (450), based on the various signal measurements. Such metrics may include power, SNR, NMCC, EESM, etc.

[0079] After metrics have been calculated, the wireless receiver compares the calculated metrics to each other and selects, based on the comparison, a preferred transmission/detection scheme (460). For example, the preferred transmission/detection scheme may be the transmission/detection scheme whose calculated metric exceeds the metrics of all the other transmission/detection schemes. Once the preferred transmission/detection scheme has been determined, the wireless receiver transmits at least the preferred transmission scheme to the wireless transmitter so that it may implement that preferred transmission scheme for future communication (470).

[0080] Those skilled in the relevant art(s) will recognize that the method can additionally or alternatively include any of the functionality of the wireless receiver 200 and/or the link adaptation module 300 discussed above, and the above description of the exemplary method should neither be construed to limit the method nor the description of the wireless receiver 200 or the link adaptation module 300.

[0081] Exemplary Computer System Implementation

[0082] It will be apparent to persons skilled in the relevant art(s) that various elements and features of the present disclosure, as described herein, can be implemented in hardware using analog and/or digital circuits, in software, through the

execution of instructions by one or more general purpose or special-purpose processors, or as a combination of hardware and software.

[0083] The following description of a general purpose computer system is provided for the sake of completeness. Embodiments of the present disclosure can be implemented in hardware, or as a combination of software and hardware. Consequently, embodiments of the disclosure may be implemented in the environment of a computer system or other processing system. An example of such a computer system 500 is shown in FIG. 5. One or more of the modules depicted in the previous figures can be at least partially implemented on one or more distinct computer systems 500, including, for example, the measurement module 220, the link adaptation module 340, and any of the constraint module 310, the metric computation module 320 and/or the decision module 330 contained therein.

[0084] Computer system 500 includes one or more processors, such as processor 504. Processor 504 can be a special purpose or a general purpose digital signal processor. Processor 504 is connected to a communication infrastructure 502 (for example, a bus or network). Various software implementations are described in terms of this exemplary computer system. After reading this description, it will become apparent to a person skilled in the relevant art(s) how to implement the disclosure using other computer systems and/or computer architectures.

[0085] Computer system 500 also includes a main memory 506, preferably random access memory (RAM), and may also include a secondary memory 508. Secondary memory 508 may include, for example, a hard disk drive 510 and/or a removable storage drive 512, representing a floppy disk drive, a magnetic tape drive, an optical disk drive, or the like. Removable storage drive 512 reads from and/or writes to a removable storage unit 516 in a well-known manner. Removable storage unit 516 represents a floppy disk, magnetic tape, optical disk, or the like, which is read by and written to by removable storage drive 512. As will be appreciated by persons skilled in the relevant art(s), removable storage unit 516 includes a computer usable storage medium having stored therein computer software and/or data.

[0086] In alternative implementations, secondary memory 508 may include other similar means for allowing computer programs or other instructions to be loaded into computer system 500. Such means may include, for example, a removable storage unit 518 and an interface 514. Examples of such means may include a program cartridge and cartridge interface (such as that found in video game devices), a removable memory chip (such as an EPROM, or PROM) and associated socket, a thumb drive and USB port, and other removable storage units 518 and interfaces 514 which allow software and data to be transferred from removable storage unit 518 to computer system 500.

[0087] Computer system 500 may also include a communications interface 520. Communications interface 520 allows software and data to be transferred between computer system 500 and external devices. Examples of communications interface 520 may include a modem, a network interface (such as an Ethernet card), a communications port, a PCMCIA slot and card, etc. Software and data transferred via communications interface 520 are in the form of signals which may be electronic, electromagnetic, optical, or other signals capable of being received by communications interface 520. These signals are provided to communications

interface **520** via a communications path **522**. Communications path **522** carries signals and may be implemented using wire or cable, fiber optics, a phone line, a cellular phone link, an RF link and other communications channels.

[0088] As used herein, the terms “computer program medium” and “computer readable medium” are used to generally refer to tangible storage media such as removable storage units **516** and **518** or a hard disk installed in hard disk drive **510**. These computer program products are means for providing software to computer system **500**.

[0089] Computer programs (also called computer control logic) are stored in main memory **506** and/or secondary memory **508**. Computer programs may also be received via communications interface **520**. Such computer programs, when executed, enable the computer system **500** to implement the present disclosure as discussed herein. In particular, the computer programs, when executed, enable processor **504** to implement the processes of the present disclosure, such as any of the methods described herein. Accordingly, such computer programs represent controllers of the computer system **500**. Where the disclosure is implemented using software, the software may be stored in a computer program product and loaded into computer system **500** using removable storage drive **512**, interface **514**, or communications interface **520**.

[0090] In another embodiment, features of the disclosure are implemented primarily in hardware using, for example, hardware components such as application-specific integrated circuits (ASICs) and gate arrays. Implementation of a hardware state machine so as to perform the functions described herein will also be apparent to persons skilled in the relevant art(s).

Conclusion

[0091] It is to be appreciated that the Detailed Description section, and not the

[0092] Abstract section, is intended to be used to interpret the claims. The Abstract section may set forth one or more, but not all exemplary embodiments, and thus, is not intended to limit the invention and the appended claims in any way.

[0093] The invention has been described above with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries may be defined so long as the specified functions and relationships thereof are appropriately performed.

[0094] It will be apparent to those skilled in the relevant art(s) that various changes in form and detail can be made therein without departing from the spirit and scope of the disclosure. Thus, the invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. A wireless receiver capable of communicating with a wireless transmitter within a wireless communication environment, the wireless receiver comprising:

a measurement module configured to measure, based on a signal received from the wireless transmitter, a communication parameter;

a memory module configured to store transmission schemes that may be implemented by the wireless transmitter; and

a link adaptation module configured to select, from the stored transmission schemes, a preferred transmission scheme based on the communication parameter, the link adaptation module including:

a constraint module configured to determine a performance constraint; and

a metric computation module configured to calculate a metric based on the communications parameter by which to compare each of the transmission schemes that satisfy the performance constraint.

2. The wireless receiver of claim **1**, wherein each of the transmission schemes is defined by a corresponding combination of transmission parameters.

3. The wireless receiver of claim **1**, wherein the communication parameter is indicative of a characteristic of a channel over which the received signal was communicated.

4. The wireless receiver of claim **1**, wherein the memory module is configured to store constraint sets corresponding to at least one of wireless receiver performance, wireless transmitter capabilities, and channel conditions, and

wherein the constraint module is configured to determine the performance constraint based on the stored constraint sets.

5. The wireless receiver of claim **1**, wherein the metric computation module is configured to generate a subset of viable transmission schemes that satisfy the performance constraint, and

wherein the metric computation module calculates a metric only for each of the viable transmission schemes.

6. The wireless receiver of claim **5**, wherein the metric computation module is configured to calculate a first metric for a first viable transmission scheme and to calculate a second metric for a second viable transmission scheme,

wherein the first metric is different from the second metric.

7. The wireless receiver of claim **1**, further comprising a decision module configured to compare the metrics calculated by the metric computation module, and to select the preferred transmission scheme based on the comparison.

8. The wireless receiver of claim **7**, wherein the decision module is configured to select, as the preferred transmission scheme, the transmission scheme having a preferred metric from among the transmission schemes.

9. A multilayer wireless receiver capable of communicating with a wireless transmitter within a wireless communication environment over multiple layers, the wireless receiver comprising:

a metric computation module configured to determine a plurality of viable transmission/detection scheme pairs, and to calculate a metric for each of the viable transmission/detection scheme pairs,

wherein the metric is calculated individually for each of the multiple layers.

10. The multilayer wireless receiver of claim **9**, wherein the metric includes per layer signal-to-noise ratio.

11. The multilayer wireless receiver of claim **10**, wherein the metric computation module is configured to calculate an average signal-to-noise ratio across the multiple layers and a channel differential, and

wherein the metric computation module is configured to calculate the per layer signal-to-noise ratio for a first channel by adding the calculated channel differential to the average signal-to-noise ratio, and for a second channel by subtracting the calculated channel differential from the average signal-to-noise ratio.

12. The multilayer wireless receiver of claim 9, wherein the at least one metric includes per layer normalized modulation constrained capacity.

13. The multilayer wireless receiver of claim 12, wherein the metric computation module is configured to calculate the normalized modulation constrained capacity for a first layer based on a modulation of the first layer, a modulation of a second layer, effective signal-to-noise ratio of the first layer, signal-to-noise offset of the second layer with respect to the first layer, and orthogonality of the first and second layers.

14. The multilayer wireless receiver of claim 12, wherein the metric computation module is configured to calculate the per layer normalized modulation constrained capacity based on a conditional probability of values of a transmitted data symbol based on the values of a received data symbol corresponding to the transmitted symbol.

15. The multilayer wireless receiver of claim 14, wherein the metric computation module calculates the conditional probability as a combination of sub-probabilities of a plurality of bits of the transmitted data symbol, and

wherein metric computation module is configured to calculate the sub-probabilities from the log likelihood ratios of the corresponding bits.

16. A method of selecting a preferred transmission/detection scheme by a wireless receiver that is capable of communicating with a wireless transmitter via a wireless communication environment, the method comprising:

measuring a signal received from the wireless transmitter to obtain a communication parameter;

determining a plurality of viable transmission/detection schemes that fall within a performance constraint;

calculating a metric for each of the viable transmission/detection schemes based on the communication parameter;

comparing the calculated metrics of the viable transmission/detection schemes;

selecting, based on the comparison, a preferred transmission/detection scheme; and

informing the wireless transmitter of the preferred transmission/detection scheme.

17. The method of claim 16, wherein the wireless transmitter and the wireless receiver communicate over multiple layers, and

wherein the calculating of the metric includes, for each of the viable transmission/detection schemes, calculating the metric individually for each of the multiple layers.

18. The method of claim 17, wherein the calculating of the metric includes calculating a first metric for a first subset of the viable transmission/detection schemes and calculating a second metric for a second subset of the viable transmission/detection schemes.

19. The method of claim 17, wherein each of the multiple layers includes a plurality of channels, and

wherein the calculating of the metric individually for each of the multiple layers includes calculating, for each of the multiple layers, the metric individually for each of the channels.

20. The method of claim 16, wherein the calculating of the metric includes:

calculating a first metric for the viable transmission/detection schemes;

selecting, based on the calculating of the first metric, a subset of the viable transmission/detection schemes; and

calculating a second metric for the subset of the viable transmission/detection schemes,

wherein the first metric requires less computation to calculate than the second metric, and

wherein the comparing of the calculated metrics includes comparing the calculated second metrics.

21. The method of claim 16, wherein the wireless transmitter and the wireless receiver communicate over multiple layers, and

wherein the calculating of the metric includes:

sub-sampling channels for which the metric can be calculated; and

calculating the metric individually for each of the sub-sampled layers.

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