

TITLE OF THE INVENTION  
REDUCED FEEDBACK FOR BEAMFORMING IN A WIRELESS  
COMMUNICATION

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CROSS REFERENCE TO RELATED PATENTS

This invention is claiming priority under 35 USC § 119(e) to a provisionally filed patent application having the same title as the present patent application, a filing date of 4/21/2005, and an application number of 60/673,451.

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BACKGROUND OF THE INVENTION  
TECHNICAL FIELD OF THE INVENTION

This invention relates generally to wireless communication systems and more particularly to wireless communications using beamforming.

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DESCRIPTION OF RELATED ART

Communication systems are known to support wireless and wire lined communications between wireless and/or wire lined communication devices. Such communication systems range from national and/or international cellular telephone systems to the Internet to point-to-point in-home wireless networks. Each type of communication system is constructed, and hence operates, in accordance with one or more communication standards. For instance, wireless communication systems may operate in accordance with one or more standards including, but not limited to, IEEE 802.11, Bluetooth, advanced mobile phone services (AMPS), digital AMPS, global system for mobile communications (GSM), code division multiple access (CDMA), local multi-point distribution systems (LMDS), multi-channel-multi-point distribution systems (MMDS), and/or variations thereof.

Depending on the type of wireless communication system, a wireless communication device, such as a cellular telephone, two-way radio, personal digital

assistant (PDA), personal computer (PC), laptop computer, home entertainment equipment, et cetera communicates directly or indirectly with other wireless communication devices. For direct communications (also known as point-to-point communications), the participating wireless communication devices tune their receivers and transmitters to the same channel or channels (e.g., one of the plurality of radio frequency (RF) carriers of the wireless communication system) and communicate over that channel(s). For indirect wireless communications, each wireless communication device communicates directly with an associated base station (e.g., for cellular services) and/or an associated access point (e.g., for an in-home or in-building wireless network) via an assigned channel. To complete a communication connection between the wireless communication devices, the associated base stations and/or associated access points communicate with each other directly, via a system controller, via the public switch telephone network, via the Internet, and/or via some other wide area network.

For each wireless communication device to participate in wireless communications, it includes a built-in radio transceiver (i.e., receiver and transmitter) or is coupled to an associated radio transceiver (e.g., a station for in-home and/or in-building wireless communication networks, RF modem, etc.). As is known, the receiver is coupled to the antenna and includes a low noise amplifier, one or more intermediate frequency stages, a filtering stage, and a data recovery stage. The low noise amplifier receives inbound RF signals via the antenna and amplifies them. The one or more intermediate frequency stages mix the amplified RF signals with one or more local oscillations to convert the amplified RF signal into baseband signals or intermediate frequency (IF) signals. The filtering stage filters the baseband signals or the IF signals to attenuate unwanted out of band signals to produce filtered signals. The data recovery stage recovers raw data from the filtered signals in accordance with the particular wireless communication standard.

As is also known, the transmitter includes a data modulation stage, one or more intermediate frequency stages, and a power amplifier. The data modulation stage converts raw data into baseband signals in accordance with a particular wireless

communication standard. The one or more intermediate frequency stages mix the baseband signals with one or more local oscillations to produce RF signals. The power amplifier amplifies the RF signals prior to transmission via an antenna.

5 In many systems, the transmitter will include one antenna for transmitting the RF signals, which are received by a single antenna, or multiple antennas, of a receiver. When the receiver includes two or more antennas, the receiver will select one of them to receive the incoming RF signals. In this instance, the wireless communication between the transmitter and receiver is a single-output-single-input (SISO) communication, even  
10 if the receiver includes multiple antennas that are used as diversity antennas (i.e., selecting one of them to receive the incoming RF signals). For SISO wireless communications, a transceiver includes one transmitter and one receiver. Currently, most wireless local area networks (WLAN) that are IEEE 802.11, 802.11a, 802.11b, or 802.11g employ SISO wireless communications.

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Other types of wireless communications include single-input-multiple-output (SIMO), multiple-input-single-output (MISO), and multiple-input-multiple-output (MIMO). In a SIMO wireless communication, a single transmitter processes data into radio frequency signals that are transmitted to a receiver. The receiver includes two or  
20 more antennas and two or more receiver paths. Each of the antennas receives the RF signals and provides them to a corresponding receiver path (e.g., LNA, down conversion module, filters, and ADCs). Each of the receiver paths processes the received RF signals to produce digital signals, which are combined and then processed to recapture the transmitted data.

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For a multiple-input-single-output (MISO) wireless communication, the transmitter includes two or more transmission paths (e.g., digital to analog converter, filters, up-conversion module, and a power amplifier) that each converts a corresponding portion of baseband signals into RF signals, which are transmitted via corresponding  
30 antennas to a receiver. The receiver includes a single receiver path that receives the

multiple RF signals from the transmitter. In this instance, the receiver uses beam forming to combine the multiple RF signals into one signal for processing.

5 For a multiple-input-multiple-output (MIMO) wireless communication, the transmitter and receiver each include multiple paths. In such a communication, the transmitter parallel processes data using a spatial and time encoding function to produce two or more streams of data. The transmitter includes multiple transmission paths to convert each stream of data into multiple RF signals. The receiver receives the multiple RF signals via multiple receiver paths that recapture the streams of data utilizing a spatial and time decoding function. The recaptured streams of data are combined and  
10 subsequently processed to recover the original data.

To further improve wireless communications, transceivers may incorporate beamforming. In general, beamforming is a processing technique to create a focused  
15 antenna beam by shifting a signal in time or in phase to provide gain of the signal in a desired direction and to attenuate the signal in other directions. Prior art papers (1) Digital beamforming basics (antennas) by Steyskal, Hans, Journal of Electronic Defense, 7/1/1996; (2) Utilizing Digital Downconverters for Efficient Digital Beamforming, by Clint Schreiner, Red River Engineering, no publication date; and (3) Interpolation Based Transmit Beamforming for MIMO-OFMD with Partial Feedback, by Jihoon Choi and  
20 Robert W. Heath, University of Texas, Department of Electrical and Computer Engineering, Wireless Networking and Communications Group, September, 13, 2003 discuss beamforming concepts.

25 In order for a transmitter to properly implement beamforming (i.e., determine the beamforming matrix  $[V]$ ), it needs to know properties of the channel over which the wireless communication is conveyed. Accordingly, the receiver must provide feedback information for the transmitter to determine the properties of the channel. One approach for sending feedback from the receiver to the transmitter is for the receiver to determine  
30 the channel response (H) and to provide it as the feedback information. An issue with

this approach is the size of the feedback packet, which may be so large that, during the time it takes to send it to the transmitter, the response of the channel has changed.

5 To reduce the size of the feedback, the receiver may decompose the channel using singular value decomposition (SVD) and send information relating only to a calculated value of the transmitter's beamforming matrix (V) as the feedback information. In this approach, the receiver calculates (V) based on  $H = UDV^*$ , where H is the channel response, D is a diagonal matrix, and U is a receiver unitary matrix. While this approach reduces the size of the feedback information, its size is still an issue for a MIMO wireless communication. For instance, in a 2x2 MIMO wireless communication, the feedback needs four elements that are all complex Cartesian coordinate values [V11 V12; V21 V22]. In general,  $V_{ik} = a_{ik} + j*b_{ik}$ , where  $a_{ik}$  and  $b_{ik}$  are values between [-1, 1]. Thus, with 1 bit express per each element for each of the real and imaginary components,  $a_{ik}$  and  $b_{ik}$  can be either  $-\frac{1}{2}$  or  $\frac{1}{2}$ , which requires  $4 \times 2 \times 1 = 8$  bits per tone. With 4 bit expressions per each element of V(f) in an orthogonal frequency division multiplexing (OFDM) 2 x 2 MIMO wireless communication, the number of bits required is 1728 per tone (e.g.,  $4 \times 2 \times 54 \times 4 = 1728$ , 4 elements per tone, 2 bits for real and imaginary components per tone, 54 data tones per frame, and 4 bits per element), which requires overhead for a packet exchange that is too large for practical applications.

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Therefore, a need exists for a method and apparatus for reducing beamforming feedback information for wireless communications.

#### BRIEF SUMMARY OF THE INVENTION

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The present invention is directed to apparatus and methods of operation that are further described in the following Brief Description of the Drawings, the Detailed Description of the Invention, and the claims. Other features and advantages of the present invention will become apparent from the following detailed description of the invention made with reference to the accompanying drawings.

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#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

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