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Rate and antenna selection using single TXOP

Abstract

In an example, a method includes obtaining, in a probing Wi-Fi device a transmit opportunity (TXOP) on a Wi-Fi channel. The method also includes transmitting a probe packet from the probing Wi-Fi device to a receiving Wi-Fi device during the TXOP with a first antenna. The method includes receiving first feedback responsive to transmitting the probe packet with the first antenna. The method also includes transmitting the probe packet from the probing Wi-Fi device to the receiving Wi-Fi device during the TXOP with a second antenna. The method includes receiving second feedback responsive to transmitting the probe packet with the second antenna. The method also includes setting, by the probing Wi-Fi device, a transmission parameters set and a selected antenna based at least in part on the first feedback or the second feedback.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. patent application Ser. No. 17/850,715 filed Jun. 27, 2022, which application is hereby incorporated herein by reference.

BACKGROUND
(1) Wi-Fi is a term used to represent communications using various ones of the Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of wireless network protocols. Wi-Fi stations communicate by sending each other blocks of data (packets) over radio links. Link adaption refers to the matching of the modulation, coding, and other signal and protocol parameters to the conditions on the radio link. Link adaptation algorithms react to channel conditions by changing the operating point of the radio link with the goal of achieving performance criteria that may include a highest possible throughput and the lowest power consumption.
SUMMARY
(2) In accordance with at least one example of the description, a method includes obtaining, in a probing Wi-Fi device a transmit opportunity (TXOP) on a Wi-Fi channel. The method also includes

transmitting a probe packet from the probing Wi-Fi device to a receiving Wi-Fi device during the TXOP with a first antenna. The method includes receiving first feedback responsive to transmitting the probe packet with the first antenna. The method also includes transmitting the probe packet from the probing Wi-Fi device to the receiving Wi-Fi device during the TXOP with a second antenna. The method includes receiving second feedback responsive to transmitting the probe packet with the second antenna. The method also includes setting, by the probing Wi-Fi device, a transmission parameters set and a selected antenna based at least in part on the first feedback or the second feedback.
(3) In accordance with at least one example of the description, a method includes obtaining, in a probing Wi-Fi device a TXOP on a Wi-Fi channel. The method also includes transmitting a first probe packet from the probing Wi-Fi device to a receiving Wi-Fi device during the TXOP with a first antenna, where the first probe packet is transmitted with a first transmission parameters set. The method includes receiving first feedback responsive to transmitting the first probe packet with the first antenna. The method also includes transmitting a second probe packet from the probing Wi-Fi device to the receiving Wi-Fi device during the TXOP with the first antenna, where the second probe packet is transmitted with a second transmission parameters set. The method includes receiving second feedback responsive to transmitting the second probe packet with the first antenna. The method also includes transmitting the second probe packet from the probing Wi-Fi device to the receiving Wi-Fi device during the TXOP with a second antenna, where the second probe packet is transmitted with the second transmission parameters set. The method includes receiving third feedback responsive to transmitting the second probe packet with the second antenna. The method also includes setting, by the probing Wi-Fi device, one or more transmission parameters within a transmission parameters set based at least in part on the first feedback, the second feedback, or the third feedback.
(4) In accordance with at least one example of the description, a system includes a memory storing instructions in a probing Wi-Fi device. The system includes a processor coupled to a Wi-Fi transmitter and a Wi-Fi receiver in the probing Wi-Fi device, the Wi-Fi transmitter and the Wi-Fi receiver configured to communicate via a Wi-Fi channel. The processor is configured to execute the instructions stored in the memory. The instructions are executed to obtain a TXOP on a Wi-Fi channel. The instructions are also executed to transmit, by the Wi-Fi transmitter, a probe packet to a receiving Wi-Fi device during the TXOP with a first antenna, where the probe packet is transmitted with a transmission parameter within a transmission parameters set. The instructions are executed to receive first feedback at the Wi-Fi receiver responsive to transmitting the probe packet with the first antenna. The instructions are executed to transmit, by the Wi-Fi transmitter, the probe packet to the receiving Wi-Fi device during the TXOP with a second antenna, where the probe packet is transmitted with the transmission parameter within the transmission parameters set. The instructions are also executed to receive second feedback at the Wi-Fi receiver responsive to transmitting the probe packet with the second antenna. The instructions are executed to set, by the probing Wi-Fi device, the transmission parameter within the transmission parameters set and a selected antenna based at least in part on the first feedback or the second feedback.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a block diagram of a Wi-Fi device in accordance with various examples.
(2) FIG. **2** is a timing diagram of antenna selection in accordance with various examples.
(3) FIG. **3** is a timing diagram of antenna and rate selection in accordance with various examples.
(4) FIG. **4** is a timing diagram of antenna and rate selection in accordance with various examples.
(5) FIG. **5** is a flow diagram of a method for antenna selection in accordance with various

examples.
(6) FIG. **6** is a flow diagram of a method for antenna and rate selection in accordance with various examples.
(7) FIG. **7** is a flow diagram of a method for antenna and rate selection in accordance with various examples.
(8) The same reference numbers or other reference designators are used in the drawings to designate the same or similar (functionally and/or structurally) features.

DETAILED DESCRIPTION

(9) Link adaptation in 802.11 protocol technologies includes the use of algorithm that change the device operating point of the link responsive to channel conditions. Some common degrees of freedom exercised by link adaptation algorithms are the choices of the modulation and coding scheme and the transmission power. For a multiple input multiple output (MIMO) system, more degrees of freedom are present. For example, the number of spatial streams and the specific antenna elements that may be used for those streams are also choices that may be evaluated by the link adaptation algorithm.
(10) A Transmit Opportunity (TXOP) is a Quality of Service (QoS) feature of the IEEE 802.11 protocol that provides a Wi-Fi device with contention-free channel access for a limited period of time. The Wi-Fi device has to win an air access (using 802.11 enhanced distributed channel access (EDCA) procedure) to a specific channel for the duration of the TXOP. After the TXOP is complete, the Wi-Fi device may have to re-win the air access and issue a next available TXOP before transmitting again. In some systems, a Wi-Fi device determines its transmission characteristics or operation profile by assessing channel conditions before transmitting a data packet over the channel. The Wi-Fi device can assess channel conditions such as throughput (e.g., bit rate), power consumption (e.g., transmitter power), modulation coding scheme (MCS), or other transmitter and channel characteristics. The Wi-Fi device may seek to achieve performance criteria based on these channel characteristic estimations that may include the highest bit rate and/or lowest transmitter power that can be used.
(11) In some assessment processes, the Wi-Fi device sets its transmitter channel characteristics assessments based on trial settings for bit rate and/or transmitter power and sends a probe packet to a receiving Wi-Fi device during a first TXOP. If the sending device receives a reply packet (e.g., an Acknowledgement (ACK) or other feedback indication) from the receiving device, the sending device may interpret it as an indication that the trial settings were effective for reliable transmission of the probe packet. The Wi-Fi device may then send one or more such additional probe packets sent at different trial settings to assess channel conditions during a second or subsequent TXOP. After the Wi-Fi device has assessed channel conditions, it transmits its data packet using selected transmitter settings that are based on the assessed channel conditions. However, transmitting each probe packet at a different TXOP may take a significant amount of time, as the Wi-Fi device must re-win the air access for the next available TXOP in the system. Also, in a system with multiple antennas, using a separate TXOP for each antenna can cause the duration of the link assessment process to grow with the number of antennas. In systems with large numbers of antennas that send multiple probes for each antenna, the time to complete the link assessment process may increase significantly.
(12) In examples herein, a single TXOP is used for the link assessment process. During the single TXOP, an efficient and optimal transmission parameters setting is determined along with antenna selection. The collection of transmission parameters may be referred to herein as a transmission parameters set. A single receive chain transmitter generates a sequence of probes within a single TXOP. The probes may be Physical Layer Convergence Protocol (PLCP) Protocol Data Units (PPDUs) in some examples. In some examples, the probe packets are packets that are null, but the probing Wi-Fi device selects these packets to cause the receiving Wi-Fi device to send a reply. Each PPDU corresponds to a different set of transmission parameters via a different antenna. The

probes are sent to a receiving device, which may send feedback to the transmitter if the PPDU was received. The transmitter, based on the feedback or lack of feedback responsive to a PPDU, chooses the next set of transmission probing parameters and antenna. The next PPDU could have lower or higher power, a lower or higher complexity power, modulation, and coding scheme, a different antenna, etc. The transmitter may again receive feedback and then send another probing PPDU. The Wi-Fi device may be configured to repeat the process until a suitable or optimal antenna is selected with a suitable or optimal set of transmission parameters within a transmission parameters set corresponding to the communication medium. In some examples, a data exchange may occur between the Wi-Fi devices during the single TXOP after the probing Wi-Fi device selects the antenna and transmission parameters.

(13) FIG. **1** is a block diagram of Wi-Fi device **100** in accordance with various examples herein. Wi-Fi device **100** includes a processor **102** and a memory **104**. The memory **104** stores instructions or logic **106** that, when executed by the processor **102**, cause the processor **102** to perform the various functionalities described herein. The memory **104** is one example of a non-transitory, computer-readable medium. The components in Wi-Fi device **100** may be coupled through a bus **108**, or in any other suitable manner. In FIG. **1**, an example in which the components are coupled through a bus **108** is shown.

(14) Wi-Fi device **100** also includes a transmitter **110** and receiver **112**. Wi-Fi device **100** may be a single receive chain device in one example. Wi-Fi device **100** may include any number of antennas, such as antenna **114.1**, **114.2**, and so on, to antenna **114**.N (collectively, antennas **114**). Wi-Fi device **100** may communicate with another Wi-Fi device **116** over a link **118**. In some examples, Wi-Fi device **100** is referred to as a probing Wi-Fi device and Wi-Fi device **116** is referred to as a receiving Wi-Fi device.

(15) The processor **102** is configured to read and execute computer-readable instructions. For example, the processor **102** is configured to invoke and execute instructions in a program stored in the memory **104**, including logic **106**. In some examples, logic **106** includes one or more link adaptation algorithms. Responsive to the processor **102** transmitting data, the processor **102** drives or controls the transmitter **110** to perform the transmitting. The processor **102** also drives or controls the receiver **112** to perform receiving, responsive to the processor **102** receiving data. Therefore, the processor **102** may be considered as a control center for performing the transmitting or receiving of data and the transmitter **110** and receiver **112** are executors for performing the transmitting and receiving operations.

(16) This disclosure attributes functionality to the Wi-Fi device **100**, the processor **102**, and the logic **106**. Wi-Fi device **100**, processor **102**, and logic **106** may include processing circuitry such as one or more processors (e.g., one or more processing cores). Wi-Fi device **100**, the processor **102**, and the logic **106** may include any combination of integrated circuitry, discrete logic circuitry, analog circuitry, such as one or more microprocessors, microcontrollers, digital signal processors, application specific integrated circuits, central processing units, field-programmable gate arrays, and/or any other processing resources. The techniques described in this disclosure may also be embodied or encoded in an article of manufacture including a non-transitory computer-readable storage medium, such as memory **104**. Although processor **102** is described as a single processor, the processor **102** may include multiple components, such as any combination of the processing resources listed above, as well as other discrete or integrated logic circuitry, and/or analog circuitry.

(17) In some examples, the memory **104** is coupled to the processor **102** through the bus **108**. In other examples, the memory **104** is integrated with the processor **102**. The memory **104** is configured to store various software programs and/or multiple groups of instructions, including the logic **106**. The memory **104** may include one or more storage devices. For example, the memory **104** may include a high-speed random-access memory and/or may include a nonvolatile memory such as one or more disk storage devices, a flash memory, another nonvolatile solid-state storage device, or a pseudo-static random-access memory (PSRAM). The memory **104** may store an OS

such as ANDROID, IOS, WINDOWS or LINUX. The memory **104** may further store a network communications program. The network communications program is useful for performing communications with one or more attached devices, one or more user devices, or one or more network devices. The memory **104** may further store a user interface program. The user interface program displays content of an application through a graphical interface and receives data or an operation performed by a user on the application via an input control such as a menu, a dialog box or a physical input device (not shown). The memory **104** is configured to store the instructions or logic **106** for implementing the various methods and processes provided in accordance with the various examples of this description.

(18) The Wi-Fi device **100** may also include another communication component such as a Global Positioning System (GPS) module, cellular module, a BLUETOOTH or BLUETOOTH Low Energy (BLE) module, Zigbee module, Long Term Evolution (LTE), LTE-Machine Type Communication (LTE-M), Narrow Band LTE (NB-LTE), Sub-Gigahertz Communication (sub1G), or a Wireless Fidelity (WI-FI) module. The Wi-Fi device **100** may also support another wireless communication signal such as a satellite signal or a short-wave signal. The Wi-Fi device **100** may also be provided with a wired network interface or a local area network (LAN) interface to support wired communication.

(19) In various examples, the Wi-Fi device **100** may further include an input/output interface (not shown) for enabling communications between Wi-Fi device **100** and one or more input/output devices (not shown). Examples of the input/output devices include an audio input/output device, a key input device, a display and the like. The input/output devices are configured to implement interaction between the Wi-Fi device **100** and a user or an external environment. The input/output device may further include a camera, a touchscreen, a sensor, and the like. The input/output device communicates with the processor **102** through a user interface.

(20) The Wi-Fi device **100** shown in FIG. **1** is an example of a Wi-Fi system or device. During actual application, the Wi-Fi device **100** may include more or fewer components. The Wi-Fi device **100** may connect to other Wi-Fi devices, such as Wi-Fi device **116**, during operation.

(21) In an example operation, Wi-Fi device **100** performs a transmission rate and antenna selection process that includes the following phases at a single TXOP. First, Wi-Fi device **100** performs an initial transmission rate selection phase at an initial antenna. Second, Wi-Fi device **100** performs a probing phase at an alternate antenna, and then performs antenna selection. Third, Wi-Fi device **100** may perform an optional final rate selection phase. Fourth, Wi-Fi device **100** may perform a data exchange phase with another Wi-Fi device.

(22) In examples herein, Wi-Fi device **100** may can alternate between antenna elements and the transmission parameters optimization during a single TXOP channel assessment probing phase. During a TXOP, the channel used is unavailable to other devices or users. Therefore, other users will not interfere with the link assessment procedure performed by Wi-Fi device **100**, allowing Wi-Fi device **100** to complete the link assessment procedure in a timely fashion. This becomes more important as the number of antenna increases, which may require a longer link assessment procedure to find an optimal antenna. If the Wi-Fi device **100** were to use multiple TXOPs, the Wi-Fi device **100** would have to compete for each TXOP with other devices, and would have to wait until the channel is clear again if Wi-Fi device **100** lost the competition for a TXOP. By using a single TXOP, Wi-Fi device **100** can select a suitable or optimal antenna with a suitable or optimal set of transmission parameters within a transmission parameters set corresponding to the communication medium without waiting for additional TXOPs to become available.

(23) In one example operation, Wi-Fi device **100** generates a sequence of multi-antenna probing PPDUs that will be transmitted during a single TXOP. This sequence may be referred to as a PPDU burst. The PPDUs may be a short, probing transmission that does not include any data payload, such as a QoS (quality of service) Null frame. Each PPDU in the burst may correspond to a different transmission antenna **114** in one example. Transmitter **110** begins transmitting the PPDU

burst at an initial antenna, such as antenna **114**.**1**.
(24) The Wi-Fi device **100** then receives feedback regarding the transmitted PPDUs. The feedback can be an acknowledgement, or ACK, in one example. If Wi-Fi device **100** receives an ACK, then the transmission parameters used for that PPDU were good enough to successfully complete a transmission for that channel and that receiving device. If Wi-Fi device **100** does not receive an acknowledgement, a NACK results (not acknowledgement or negative acknowledgement). If a NACK occurs, this means the transmission parameters and/or the antenna did not complete the transmission. Another type of feedback received by Wi-Fi device **100** may be the packet error rate. Another type of feedback may be channel state information (CSI). The Wi-Fi device **100** may transmit a probe that results in Wi-Fi device **100** receiving some type of CSI back in return.
(25) After the Wi-Fi device **100** receives feedback responsive to the PPDUs, Wi-Fi device **100** analyzes the feedback. Based on the feedback, Wi-Fi device **100** can assess and evaluate the channel condition. If the PPDU resulted in an ACK, the Wi-Fi device **100** may proceed to transmitting data using the same antenna and transmission parameters set as the successful PPDU. The Wi-Fi device **100** may send another PPDU using the same antenna with a different transmission parameters set. The Wi-Fi device **100** may send another PPDU using a different antenna with the same transmission parameters set as the first PPDU, or with a different transmission parameters set. The Wi-Fi device **100** may be configured to perform all of these actions during the same TXOP. The TXOP may last as long as requested, so Wi-Fi device **100** may request enough time to perform the potential PPDU bursts for the antennas **114**.
(26) In another example operation, Wi-Fi device **100** may prepare a PPDU burst that corresponds to a different set of transmission parameters, such as antenna, bit rate, transmitter power, modulation and coding scheme, etc. With this option, the Wi-Fi device **100** may select an optimal antenna along with transmission parameters that match the communication medium in which the system operates. Therefore, the Wi-Fi device **100** may be configured to perform antenna selection and transmission parameters set optimization at the same TXOP.
(27) In another example operation, the Wi-Fi device **100** may combine probing with data exchange. A PPDU burst may include a data exchange after the probing sequence. The multi-antenna selection methodology described herein allows the setting of a subsequent transmission's configurations to an optimal or suitable state based on the results of the link assessment process. Therefore, the Wi-Fi device **100** may perform antenna selection, transmission parameters set optimization, and data exchange at the same TXOP.
(28) FIG. **2** is a timing diagram **200** of antenna selection using a PPDU burst in accordance with various examples herein. Timing diagram **200** shows a TXOP **202** where a Wi-Fi device performs antenna selection using a consecutive multi-antenna probing PPDU burst. In timing diagram **200**, the Wi-Fi device selects the antenna to be used for a next transmission.
(29) The example of timing diagram **200** includes two antennas, a first antenna **114**.**1** and a second antenna **114**.**2**. The TXOP **202** in this examples includes an antenna selection phase **204** and a data exchange phase **206**. At the start of the antenna selection phase **204**, first antenna **114**.**1** transmits a first probe packet **208**A to a receiving Wi-Fi device, such as Wi-Fi device **116**. The Wi-Fi device **100** transmits first probe packet **208**A with a set of transmission parameters. For example, first probe packet **208**A may have a certain transmission power, a certain bit rate, a certain MCS, etc. The MCS may be binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), quadrature amplitude modulation (QAM), or any other suitable modulation coding scheme. The first probe packet **208**A may include other transmission parameters as well. The Wi-Fi device **100** may be configured to store the transmission parameters in a memory such as memory **104**, so the Wi-Fi device **100** may track the performance of the probe packets with different transmission parameters in order to assess the channel conditions to find a suitable or optimal antenna and a suitable or optimal set of transmission parameters corresponding to the communication medium.
(30) After the Wi-Fi device **100** transmits first probe packet **208**A, first antenna **114**.**1** may receive

feedback **210**. Feedback **210** may be in the form of an ACK from the receiving Wi-Fi device. Feedback **210** may be a packet that includes CSI regarding the channel. Feedback **210** may include any other type of data that provides information regarding the channel. Also, in some examples, the Wi-Fi device **100** may not receive a response from the receiving Wi-Fi device. This non-acknowledgement, or NACK, is also a form of feedback that the Wi-Fi device **100** may receive. The Wi-Fi device **100** may store the feedback **210**, for example in memory **104**. The Wi-Fi device **100** may be configured to set a transmission parameter based at least in part on the feedback **210** and other feedback.

(31) In the example of FIG. **2**, after the Wi-Fi device **100** receives feedback **210**, the Wi-Fi device **100** transmits a second probe packet **208**B to a receiving Wi-Fi device using a second antenna **114**.**2**. In this example, first probe packet **208**A and second probe packet **208**B have the same transmission parameters, with the exception of being transmitted by different antennas. For example, if first probe packet **208**A has a first transmission power and a first bit rate, second probe packet **208**B also has the first transmission power and the first bit rate.

(32) After the Wi-Fi device **100** transmits second probe packet **208**B, second antenna **114**.**2** may receive feedback **212**. Feedback **212** may be any of the type of feedback described above with respect to feedback **210**. In this example, Wi-Fi device **100** analyzes the feedback **210** and **212** and determines that second antenna **114**.**2**, with the transmission parameters of second probe packet **208**B, provides a suitable or optimal communication medium using those specific transmission parameters. For example, first antenna **114**.**1** may have received a NACK for feedback **210**, while second antenna **114**.**2** received an ACK for feedback **212**. Wi-Fi device may then transmit data during the data exchange phase **206** of TXOP **202** using second antenna **114**.**2** and the transmission parameters of probe packet **208**B. This data transmission is shown as PPDU Transmission **214** in FIG. **2**. After the Wi-Fi device **100** transmits PPDU Transmission **214** to a receiving Wi-Fi device, the second antenna **114**.**2** may receive feedback **216** from the receiving Wi-Fi device. The Wi-Fi device **100** may be configured to store and/or use this feedback **216** for later transmissions.

(33) As shown in FIG. **2**, a Wi-Fi device can use a single TXOP **202** for antenna selection with a multi-antenna probing PPDU burst. While two antennas are shown in FIG. **2**, a Wi-Fi device may use any number of antennas in other examples. For example, the Wi-Fi device **100** may transmit a probe packet such as first probe packet **208**A from more than two antennas, with the feedback from each probe packet used to select an optimal antenna and transmission parameters. After the Wi-Fi device **100** selects the antenna and transmission parameters, the Wi-Fi device **100** may transmit data to a receiving Wi-Fi device. The Wi-Fi device **100** may be configured to perform the entire process, including the data transmission, during a single TXOP **202**. By using a single TXOP, the Wi-Fi device **100** does not have to compete with other devices for a TXOP for each antenna, which could take a large amount of time if the Wi-Fi device **100** had, for example, eight antennas.

(34) FIG. **3** is a timing diagram **300** of antenna and rate selection using a PPDU burst in accordance with various examples herein. Timing diagram **300** shows a TXOP **302** where a Wi-Fi device performs antenna and rate selection and optimization using a consecutive multi-antenna probing PPDU burst. In timing diagram **300**, the Wi-Fi device selects the antenna to be used for a next transmission and optimizes the transmission parameters according to the communication channel.

(35) The example of timing diagram **300** includes two antennas, a first antenna **114**.**1** and a second antenna **114**.**2**. The TXOP **302** in this examples includes an antenna selection and transmission parameters tuning phase **304** and a data exchange phase **306**. At the start of tuning phase **304**, first antenna **114**.**1** transmits a first probe packet **308**A to a receiving Wi-Fi device, such as Wi-Fi device **116**. The Wi-Fi device **100** transmits first probe packet **308**A with a set of transmission parameters. For example, first probe packet **308**A may have a certain transmission power, a certain bit rate, a certain MCS, a certain format, etc. The Wi-Fi device **100** may store transmission parameters in a memory such as memory **104**, so the Wi-Fi device **100** may track the performance of the probe packets with different transmission parameters in order to assess the channel conditions to find a

suitable or optimal antenna and a suitable or optimal set of transmission parameters corresponding to the communication medium.

(36) After the Wi-Fi device **100** transmits first probe packet **308**A, first antenna **114.1** may receive feedback **310**. Feedback **310** may be in the form of an ACK from the receiving Wi-Fi device, a NACK, CSI, etc., as described above. The Wi-Fi device **100** may be configured to store the feedback **310**, for example in memory **104**. The Wi-Fi device **100** may be configured to set antenna selection and transmission parameters based at least in part on the feedback **310** and other feedback.

(37) In the example of FIG. **3**, after the Wi-Fi device **100** receives feedback **310**, the Wi-Fi device **100** transmits a second probe packet **308**B to a receiving Wi-Fi device using a second antenna **114.2**. In this example, first probe packet **308**A and second probe packet **308**B have the same transmission parameters, with the exception of being transmitted by different antennas. For example, if first probe packet **308**A has a first transmission power and a first bit rate, second probe packet **308**B also has the first transmission power and the first bit rate.

(38) After the Wi-Fi device **100** transmits second probe packet **308**B, second antenna **114.2** may receive feedback **312**. Feedback **312** may be any of the type of feedback described above with respect to feedback **310**. Next, the Wi-Fi device **100** transmits a third probe packet **314**A by first antenna **114.1**. The third probe packet **314**A in this example includes a different set of transmission parameters than the first probe packet **308**A or the second probe packet **308**B. In this example, the Wi-Fi device **100** transmits probe packets with different transmission parameters on the various antennas to optimize both the antenna selection and the transmissions parameters. For example, the Wi-Fi device **100** may be configured to transmit the first probe packet **308**A and the second probe packet **308**B with a first transmission power, while the Wi-Fi device **100** may be configured to transmit the third probe packet **314**A with a second transmission power different from the first transmission power. Or, the third probe packet **314**A may have a different MCS, or other transmission parameters compared to the first probe packet **308**A and the second probe packet **308**B. The Wi-Fi device **100** may be configured to select the transmission parameters of the third probe packet **314**A based at least in part on the feedback **310** and/or the feedback **312** in some examples. In other examples, memory **104** may store preset transmission parameters for the various probe packets.

(39) After the Wi-Fi device **100** transmits third probe packet **314**A by first antenna **114.1**, the Wi-Fi device **100** may receive feedback **316**. Feedback **316** may be any of the type of feedback described above with respect to feedback **310**. After the Wi-Fi device **100** receives feedback **316**, second antenna **114.2** may transmit fourth probe packet **314**B. In this example, fourth probe packet **314**B has the same transmission parameters as third probe packet **314**A, with the exception of being transmitted by different antennas. For example, if third probe packet **314**A has a second transmission power and a second bit rate, fourth probe packet **314**B also has the second transmission power and the second bit rate.

(40) After the Wi-Fi device **100** transmits fourth probe packet **314**B, second antenna **114.2** may receive feedback **318**. Feedback **318** may be any of the type of feedback described above with respect to feedback **310**. Next, the Wi-Fi device **100** transmits a fifth probe packet **320** by first antenna **114.1**. The Wi-Fi device **100** may be configured to transmit fifth probe packet **320** in this example with a different set of transmission parameters than the first probe packet **308**A, the second probe packet **308**B, the third probe packet **314**A, or the fourth probe packet **314**B. After the Wi-Fi device **100** transmits fifth probe packet **320** by first antenna **114.1**, the Wi-Fi device **100** may receive feedback **322**. Feedback **322** may be any of the type of feedback described above with respect to feedback **310**.

(41) In this example, after the Wi-Fi device **100** receives feedback **322**, Wi-Fi device **100** selects first antenna **114.1** and the transmission parameters associated with fifth probe packet **320**. The process then moves to the data exchange phase **306** of TXOP **302**. In the data exchange phase **306**,

a PPDU transmission **324** transmits data from Wi-Fi device **100** to a receiving Wi-Fi device using first antenna **114.1** and the transmission parameters of fifth probe packet **320**. First antenna **114.1** may then receive feedback **326** from the receiving Wi-Fi device. As shown in FIG. **3**, the Wi-Fi device **100** may be configured to conduct all of the antenna selection and transmission parameters tuning phase **304** and the data exchange phase **306** in a single TXOP **302**.

(42) In other examples, the Wi-Fi device **100** may use more than two antennas, and the Wi-Fi device **100** may transmit any number of probe packets to tune the transmission parameters. The Wi-Fi device **100** may receive feedback from the probe packets and used to select the best antenna and transmission parameters for the communication medium.

(43) FIG. **4** is a timing diagram **400** of antenna and rate selection using a PPDU burst in accordance with various examples herein. Timing diagrams **200**, **300**, and **400** are shown as separate processes, but a probing Wi-Fi device may be configured to implement any combination of the techniques described with respect to timing diagrams **200**, **300**, and **400**. Timing diagram **400** shows a TXOP **402** where the probing Wi-Fi device performs antenna and rate selection and optimization using a consecutive multi-antenna probing PPDU burst. In timing diagram **400**, the Wi-Fi device **100** selects the antenna to be used for a next transmission and optimizes the transmission parameters according to the communication channel. In this example, the Wi-Fi device **100** optimizes a first antenna using multiple probe packets. After that process is complete, the Wi-Fi device **100** can use the optimized parameters as a starting point for a second antenna. A similar process may continue for any number of antennas. This iterative process may reduce the amount of probe packets used during the selection and optimization process compared to other examples.

(44) The example of timing diagram **400** includes two antennas, a first antenna **114.1** and a second antenna **114.2**. The TXOP **402** in this examples includes an antenna selection and transmission parameters tuning phase **404** and a data exchange phase **406**. At the start of phase **404**, first antenna **114.1** transmits a first probe packet **408** to a receiving Wi-Fi device, such as Wi-Fi device **116**. The Wi-Fi device **100** transmits first probe packet **408** with a set of transmission parameters. For example, first probe packet **408** may have a certain transmission power, a certain bit rate, a certain MCS, a certain format, etc. The Wi-Fi device **100** may store the transmission parameters in a memory such as memory **104**, so the Wi-Fi device **100** may track the performance of the probe packets with different transmission parameters in order to assess the channel conditions to find a suitable or optimal antenna and a suitable or optimal set of transmission parameters corresponding to the communication medium.

(45) After the Wi-Fi device **100** transmits first probe packet **408**, first antenna **114.1** may receive feedback **410**. Feedback **410** may be in the form of an ACK from the receiving Wi-Fi device, a NACK, CSI, etc., as described above. The Wi-Fi device **100** may store the feedback **410**, for example in memory **104**. The Wi-Fi device **100** may be configured to set antenna selection and transmission parameters based at least in part on the feedback **410** and other feedback.

(46) In the example of FIG. **4**, after the Wi-Fi device **100** receives feedback **410**, the Wi-Fi device **100** transmits a second probe packet **412**A to a receiving Wi-Fi device using first antenna **114.1**. After the Wi-Fi device **100** transmits the second probe packet **412**A, first antenna **114.1** may receive feedback **414**. Feedback **414** may be any of the type of feedback described above with respect to feedback **410**. As described above, the Wi-Fi device **100** may be configured to transmit a number of probe packets from the first antenna **114.1** to optimize the transmission parameters for the first antenna **114.1**. After the first antenna **114.1** transmits the probe packets and the Wi-Fi device **100** optimizes the transmission parameters, the process moves to a second antenna, using the optimized transmission parameters as a starting point for the second antenna. The Wi-Fi device **100** may be configured to repeat the process for any number of antennas, using any number of probe packets, until the Wi-Fi device **100** finds an optimal antenna and optimal transmission parameters. The Wi-Fi device **100** may be configured to perform these processes in a single TXOP as described herein.

(47) In timing diagram **400**, after the Wi-Fi device **100** receives feedback **414**, the optimization of the transmission parameters for first antenna **114.1** is complete. The process then moves to second antenna **114.2**, which transmits third probe packet **412**B in this example. Third probe packet **412**B has the same transmission parameters as second probe packet **412**A. Second probe packet **412**A included the optimized transmission parameters for first antenna **114.1**, and Wi-Fi device **100** can use these transmission parameters as the starting point for second antenna **114.2**.
(48) After the Wi-Fi device **100** transmits third probe packet **412**B, second antenna **114.2** receives feedback **416** from the Wi-Fi receiving device. Then, second antenna **114.2** transmits fourth probe packet **418**. Fourth probe packet **418** has different transmission parameters than first probe packet **408**, second probe packet **412**A, or third probe packet **412**B. After the Wi-Fi device **100** transmits fourth probe packet **418**, the Wi-Fi device **100** receives feedback **420**. Feedback **420** may be any of the type of feedback described above with respect to feedback **410**.
(49) In this example, Wi-Fi device **100** determines that second antenna **114.2** using the transmission parameters of fourth probe packet **418** is optimal for the communication medium. Therefore, the antenna selection and transmission parameters tuning phase **404** ends and the data exchange phase **406** begins. In the data exchange phase **406**, a PPDU transmission **422** transmits data from Wi-Fi device **100** to a receiving Wi-Fi device using second antenna **114.2** and the transmission parameters of fourth probe packet **418**. Second antenna **114.2** may then receive feedback **424** from the receiving Wi-Fi device. As shown in FIG. **4**, the Wi-Fi device **100** may be configured to conduct all of the antenna selection and transmission parameters tuning phase **404** and the data exchange phase **406** in a single TXOP **402**.
(50) In examples herein, a probing Wi-Fi device may be configured to use any number of probing packets to find the optimal transmission parameters. Tradeoffs may be performed between choosing suitable transmission parameters quickly or choosing the best or optimal parameters using a longer process. The probing Wi-Fi device may use complex algorithms that utilize transmission power, bit rate, MCS, packet size, format, and other transmission parameters to optimize the communication. The Wi-Fi device **100**, based on the feedback from previous probe packets, may choose the next best probe packet to transmit from among any number of potential probe packets. Additionally or alternatively, the Wi-Fi device **100** may be configured to determine whether or not to issue a another probing PPDU based on the evaluation result. The Wi-Fi device **100** may store the results in memory **104** in some examples.
(51) FIG. **5** is a flow diagram of a method **500** for antenna selection in accordance with various examples herein. The steps of method **500** may be performed in any suitable order. The hardware components described above with respect to FIG. **1** may perform method **500** in some examples. Any suitable hardware or digital logic may perform method **500** in some examples.
(52) Method **500** begins at **510**, where a probing Wi-Fi device such as Wi-Fi device **100** wins the air access and obtains a TXOP on a Wi-Fi channel. The steps described in method **500** are performed at a single TXOP.
(53) Method **500** continues at **520**, where the probing Wi-Fi device transmits a probe packet with transmission parameters settings to a receiving Wi-Fi device during the TXOP with a first antenna. The probe packet may be a packet such as probe packet **208**A described above. The probe packet may include any number of transmission parameters settings in various examples.
(54) Method **500** continues at **530**, where the probing Wi-Fi device receives first feedback responsive to transmitting the probe packet with the first antenna. The first feedback may be feedback such as feedback **210** described above.
(55) Method **500** continues at **540**, where the probing Wi-Fi device transmits the probe packet with the transmission parameters settings from the probing Wi-Fi device to the receiving Wi-Fi device during the TXOP with a second antenna. In this example, the probe packet may be a probe packet such as probe packet **208**B, which has transmission parameters similar to probe packet **208**A.
(56) Method **500** continues at **550**, where the probing Wi-Fi device receives second feedback

responsive to transmitting the probe packet with the second antenna. The second feedback may be feedback such as feedback **212** described above.
(57) Method **500** continues at **560**, where the probing Wi-Fi device sets a transmission parameters set and the selected antenna based at least in part on the first feedback or the second feedback. The transmission parameters set may include any number or type of transmission parameters. As an example, in FIG. **2**, the probing Wi-Fi device **100** transmits a PPDU Transmission **214** to a receiving Wi-Fi device using the transmission parameters set of probe packet **208**B. In that example, the probing Wi-Fi device **100** uses the second antenna **114**.**2** for the PPDU Transmission **214**, but the probing Wi-Fi device **100** may use another antenna in another example. In other examples, the probing Wi-Fi device **100** may use any number of antennas and send any number of probe packets before selecting transmission parameters.
(58) FIG. **6** is a flow diagram of a method **600** for antenna and rate selection in accordance with various examples herein. The steps of method **600** may be performed in any suitable order. The hardware components described above with respect to FIG. **1** may perform method **600** in some examples. Any suitable hardware or digital logic may perform method **600** in some examples.
(59) Method **600** begins at **610**, where a probing Wi-Fi device wins the air access and obtains a TXOP on a Wi-Fi channel. The steps described in method **600** are performed at a single TXOP.
(60) Method **600** continues at **620**, where the probing Wi-Fi device transmits a first probe packet with a first transmission parameters set to a receiving Wi-Fi device during the TXOP with a first antenna. As an example, the Wi-Fi device transmits the first probe packet **408** in FIG. **4** during TXOP **402**.
(61) Method **600** continues at **630**, where the probing Wi-Fi device receives first feedback responsive to transmitting the first probe packet with the first antenna. The first feedback may be feedback **410** in one example.
(62) Method **600** continues at **640**, where the probing Wi-Fi device transmits a second probe packet with a second transmission parameters set to the receiving Wi-Fi device during the TXOP with the first antenna. The second probe packet may be second probe packet **412**A in one example.
(63) Method **600** continues at **650**, where the probing Wi-Fi device receives second feedback responsive to transmitting the second probe packet with the first antenna. The second feedback may be feedback **414** in one example.
(64) Method **600** continues at **660**, where the probing Wi-Fi device transmits the second probe packet with the second transmission parameters set to the receiving Wi-Fi device during the TXOP with a second antenna. As an example, the probing Wi-Fi device transmits the second probe packet **412**B with the second antenna **114**.**2**.
(65) Method **600** continues at **670**, where the probing Wi-Fi device receives third feedback responsive to transmitting the second probe packet with the second antenna. The third feedback may be feedback **416** in one example.
(66) Method **600** continues at **680**, where the probing Wi-Fi device sets one or more transmission parameters within a transmission parameters set based at least in part on the first feedback, the second feedback, or the third feedback. As an example, in FIG. **4**, the probing Wi-Fi device transmits a PPDU transmission **422** to a receiving Wi-Fi device using the transmission parameters of probe packet **418**. In that example, the Wi-Fi device **100** uses the second antenna **114**.**2** for the PPDU transmission **422**, but Wi-Fi device **100** may use another antenna in another example. In other examples, Wi-Fi device **100** may use any number of antennas and send any number of probe packets before selecting transmission parameters.
(67) FIG. **7** is a flow diagram of a method **700** for antenna and rate selection in accordance with various examples herein. The steps of method **700** may be performed in any suitable order. The hardware components described above with respect to FIG. **1** may perform method **700** in some examples. Any suitable hardware or digital logic may perform method **700** in some examples.
(68) Method **700** describes a memory, such as memory **104**, storing instructions in a probing Wi-Fi

device, such as Wi-Fi device **100**. The Wi-Fi device **100** includes a processor **102** coupled to a Wi-Fi transmitter **110** and Wi-Fi receiver **112** in the probing Wi-Fi device **100**. The Wi-Fi transmitter **110** and Wi-Fi receiver **112** are configured to communicate via a Wi-Fi channel, such as link **118**. The processor **102** is configured to execute instructions or logic **106** stored in memory **104** to perform the steps of method **700**.
(69) Method **700** begins at **710**, where the instructions cause the Wi-Fi device **100** to obtain a TXOP on a Wi-Fi channel. The steps described in method **700** are performed at a single TXOP.
(70) Method **700** continues at **720**, where the instructions cause the Wi-Fi transmitter **110** to transmit a probe packet to a receiving Wi-Fi device during the TXOP with a first antenna, where the Wi-Fi transmitter **110** transmits the probe packet with a transmission parameter within a transmission parameters set. As an example, the first antenna **114.1** may be configured to transmit probe packet **208**A in FIG. **2**.
(71) Method **700** continues at **730**, where instructions cause the Wi-Fi device **100** to receive first feedback at the Wi-Fi receiver **112** responsive to transmitting the probe packet with the first antenna. The first feedback may be feedback **210** in one example.
(72) Method **700** continues at **740**, where the instructions cause the Wi-Fi transmitter **110** to transmit the probe packet to the receiving Wi-Fi device during the TXOP with a second antenna, where the Wi-Fi transmitter **110** transmits the probe packet with the transmission parameter within the transmission parameters set. In this example, second antenna **114.2** transmits probe packet **208**B to the receiving Wi-Fi device.
(73) Method **700** continues at **750**, where the instructions cause the Wi-Fi device **100** to receive second feedback at the Wi-Fi receiver **112** responsive to transmitting the probe packet with the second antenna. The second feedback may be feedback **212** in one example.
(74) Method **700** continues at **760**, where the instructions cause the probing Wi-Fi device, such as Wi-Fi device **100**, to set the transmission parameter within the transmission parameters set and a selected antenna based at least in part on the first feedback or the second feedback.
(75) In examples herein, a single probing TXOP is performed, where the probing Wi-Fi device generates feedback for multiple antennas from consecutive probing PPDUs during the single TXOP. The antenna selection time is faster than in other examples due to performing the antenna selection during a single TXOP, because the Wi-Fi device does not have to repeatedly compete for TXOPs with other devices. Also, the Wi-Fi device **100** may be configured to combine antenna selection and data transmission in a single TXOP, rather than applying the discovered transmission parameters to a data transmission during the next TXOP. This process provides more efficient data transmissions.
(76) Moreover, the Wi-Fi device performs antenna selection and probing for transmission parameters in a single TXOP in some examples. The Wi-Fi device **100** may be configured to change the antenna used for a transmission during a TXOP, rather than waiting for the next TXOP. Also, the Wi-Fi device **100** can optimize multiple antennas during a single TXOP.
(77) The term "couple" is used throughout the specification. The term may cover connections, communications, or signal paths that enable a functional relationship consistent with this description. For example, if device A generates a signal to control device B to perform an action, in a first example device A is coupled to device B, or in a second example device A is coupled to device B through intervening component C if intervening component C does not substantially alter the functional relationship between device A and device B such that device B is controlled by device A via the control signal generated by device A.
(78) A device that is "configured to" perform a task or function may be configured (e.g., programmed and/or hardwired) at a time of manufacturing by a manufacturer to perform the function and/or may be configurable (or re-configurable) by a user after manufacturing to perform the function and/or other additional or alternative functions. The configuring may be through firmware and/or software programming of the device, through a construction and/or layout of

hardware components and interconnections of the device, or a combination thereof.
(79) Unless otherwise stated, “about,” “approximately,” or “substantially” preceding a value means+/−10 percent of the stated value. Modifications are possible in the described examples, and other examples are possible within the scope of the claims.

Claims

1. An electronic device comprising: a transceiver configured to be coupled to first and second antennas; and a processor configured to: transmit, via the transceiver and the first antenna, a first probe packet including a first transmission parameter during a first transmit opportunity (TXOP); receive, via the transceiver, a first response packet responsive to the first probe packet; transmit, via the transceiver and the second antenna, a second probe packet during the first TXOP, the second probe packet being equal to the first probe packet; receive, via the transceiver, a second response packet responsive to the second probe packet; transmit, via the transceiver, a third probe packet including a second transmission parameter during the first TXOP, wherein the second transmission parameter is different than the first transmission parameter; receive, via the transceiver, a third response packet responsive to the third probe packet; and set at least one of the first and second transmission parameters or select one of the first and second antennas based on the first, second, and third response packets.
2. The electronic device of claim 1, wherein the processor is configured to set at least one of the first and second transmission parameters based on the first, second, and third response packets.
3. The electronic device of claim 1, wherein the processor is configured to select one of the first and second antennas based on the first, second, and third response packets.
4. The electronic device of claim 1, wherein the processor is configured to set at least one of the first and second transmission parameters and select one of the first and second antennas based on the first, second, and third response packets.
5. The electronic device of claim 1, wherein the processor is configured to transmit the third probe packet via one of the first and second antennas.
6. The electronic device of claim 1, wherein the processor is configured to transmit, via the transceiver, a data packet during the first TXOP after setting the at least one of the first and second transmission parameters.
7. The electronic device of claim 1, wherein the first probe packet is a Physical Layer Convergence Protocol (PLCP) protocol data unit (PPDU).
8. The electronic device of claim 1, wherein the processor is configured transmit the third probe packet after transmitting the first probe packet.
9. The electronic device of claim 1, further comprising first and second antennas coupled to the transceiver.
10. The electronic device of claim 1, wherein the processor is configured to obtain the first TXOP on a wireless communication channel prior to transmitting the first probe packet.
11. The electronic device of claim 1, wherein the first response packet comprises channel state information (CSI).
12. The electronic device of claim 1, wherein the first response packet is an acknowledgement (ACK).
13. The electronic device of claim 1, wherein the first response packet is a negative acknowledgement (NACK).
14. The electronic device of claim 1, wherein the first transmission parameter is transmission power.
15. The electronic device of claim 1, wherein the first transmission parameter is a modulation coding scheme.
16. The electronic device of claim 15, wherein the modulation coding scheme is binary phase shift

keying (BPSK), quadrature phase shift keying (QPSK), or quadrature amplitude modulation (QAM).

17. The electronic device of claim 1, wherein the processor is configured to: transmit the third probe packet via the first antenna; transmit, via the transceiver and the second antenna, a fourth probe packet including the second transmission parameter during the first TXOP; and receive, via the transceiver, a fourth response packet responsive to the fourth probe packet, wherein setting at least one of the first and second transmission parameters or selecting one of the first and second antennas is further based on the fourth response packet.

18. The electronic device of claim 1, wherein the processor is configured to: transmit, via the transceiver, a fourth probe packet including a third transmission parameter during the first TXOP, the third transmission parameter being different than the first and second transmission parameters; and receive, via the transceiver, a fourth response packet responsive to the fourth probe packet, wherein setting at least one of the first and second transmission parameters or selecting one of the first and second antennas is further based on the fourth response packet.

19. The electronic device of claim 1, wherein the first TXOP is a TXOP according to an IEEE 802.11 protocol.

20. The electronic device of claim 1, wherein: transmitting the first probe packet comprises transmitting the first probe packet to a wireless device; transmitting the second probe packet comprises transmitting the second probe packet to the wireless device; transmitting the third probe packet comprises transmitting the third probe packet to the wireless device; receiving the first response packet comprises receiving the first response packet from the wireless device; receiving the second response packet comprises receiving the second response packet from the wireless device; and receiving the third response packet comprises receiving the third response packet from the wireless device.

21. The electronic device of claim 1, wherein the first response packet comprises a packet error rate.