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(54) **Title:** METHODS AND APPARATUS TO ENABLE SPATIAL REUSE IN A WIRELESS NETWORK

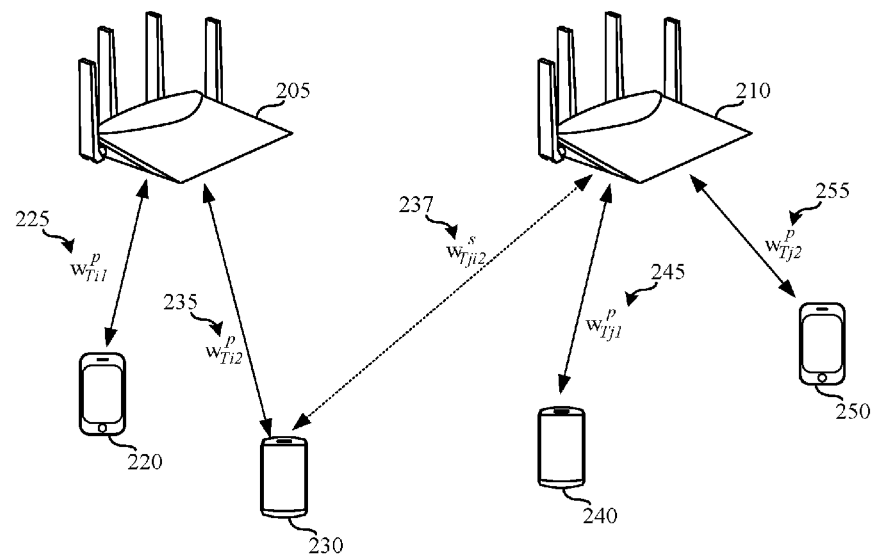

FIG. 2

(57) **Abstract:** Methods, apparatus, systems and articles of manufacture to enable spatial reuse in a wireless network are disclosed. An example apparatus includes a beamforming report collector to collect a plurality of beamforming reports. An access point and mobile station pair identifier is to include a first access point and mobile station pair in a collaborative beamforming set. The access point and mobile station pair identifier is to identify a second access point and mobile station pair based on one of the plurality of beamforming reports. An interference estimator is to estimate an amount of interference caused by inclusion of the second access point and mobile station pair in the collaborative beamforming set. The access point and mobile station pair identifier is to add the second access point and mobile station pair to the collaborative beamforming set when the estimated amount of interference is less than an interference threshold.

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METHODS AND APPARATUS TO ENABLE SPATIAL REUSE IN A WIRELESS NETWORK

FIELD OF THE DISCLOSURE

[0001] This disclosure relates generally to wireless networking, and, more particularly, to methods and apparatus to enable spatial reuse in a wireless network.

BACKGROUND

[0002] Wireless networks enable devices to communicate with other systems such as, for example, the Internet. Access to such wireless networks is provided by one or more access points (APs). In areas where there is a high density of users of mobile devices such as stadiums, conference halls, etc., multiple access points may be installed to facilitate the larger area of coverage and/or the larger number of expected devices.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. 1 is diagram of an example environment of use implemented in accordance with the teachings of this disclosure to enable spatial reuse in a wireless network.

[0004] FIG. 2 is a diagram of example primary and secondary associations between access points and mobile stations.

[0005] FIG. 3 is a block diagram of an example implementation of the example access point controller of FIG. 1.

[0006] FIG. 4 is a block diagram of an example implementation of the example access point of FIG. 1.

[0007] FIG. 5 is a block diagram of an example implementation of the example mobile station of FIG. 1.

[0008] FIG. 6 is an example communication diagram representing communications among the example access point controller, the example access point(s), and the example mobile station(s) of FIGS. 1, 2, 3, 4, and/or 5.

[0009] FIG. 7 is an example communication diagram representing communications between the example access point of FIGS. 1 and/or 4 and mobile stations to collect beamforming report(s).

[0010] FIG. 8 is a flowchart representative of example machine readable instructions which, when executed, cause the example access point controller of FIGS. 1 and/or 3 to enable spatial reuse in a wireless network.

[0011] FIG. 9 is a flowchart representative of example machine readable instructions which, when executed, cause the example access point of FIGS. 1 and/or 4 to transmit data to a mobile station.

[0012] FIG. 10 is a flowchart representative of example machine readable instructions which, when executed, cause the example mobile station to estimate interference and apply equalization adjustments.

[0013] FIG. 11 is a block diagram of an example processor platform 1100 capable of executing the instructions of FIG. 6, and/or 8 to implement the example access point controller of FIGS. 1 and/or 3.

[0014] FIG. 12 is a block diagram of an example processor platform 1200 capable of executing the instructions of FIGS. 6, 7, and/or 9 to implement the example access point of FIGS. 1 and/or 4.

[0015] FIG. 13 is a block diagram of an example processor platform 1300 capable of executing the instructions of FIGS. 6, 7, and/or 10 to implement the example mobile station of FIGS. 1 and/or 5.

[0016] The figures are not to scale. Wherever possible, the same reference numbers will be used throughout the drawing(s) and accompanying written description to refer to the same or like parts.

DETAILED DESCRIPTION

[0017] In areas where high density of mobile stations (e.g., mobile devices) exists such as stadiums, conference halls, etc., wireless access points are utilized to facilitate wireless service to mobile stations. To benefit from such a dense deployment of access points, the network should allow multiple access points to transmit at the same time and same channel. For example, the first access point may transmit to and/or receive data from a first device using a first wireless channel while a second access point that is in close physical proximity to the first access point may transmit to and/or receive data from a second device using the first wireless channel.

[0018] Such transmissions are enabled by the use of beamforming. When using beamforming techniques, wireless access points may utilize one or more antennas in an antenna array to achieve spatial selectivity when transmitting a wireless signal. That is, for an access point utilizing an antenna array, one or more antennas in the array may be used to transmit the wireless signal directly towards a mobile station, as opposed to transmitting the wireless signal omnidirectionally.

[0019] Existing Wi-Fi standards such as, for example, IEEE 802.11ax introduce the concept of spatial reuse, where stations are able to identify signals from overlapping basic service sets provided by access points, and make decisions on wireless resource contention based on such information. Such approaches do not, however, account for aligning interference between multiple access points.

[0020] Example approaches disclosed herein enable collaborative beamforming (CBF) and interference alignment between multi-APs in Wi-Fi networks to facilitate spatial reuse. In examples disclosed herein, access points operating on the same channel are allowed to deliver their packets simultaneously to multiple users without interfering each other. To enable such spatial reuse, beamforming techniques are utilized in connection with selection of the access point and mobile station pairs for spatial reuse. In examples disclosed herein, a collaborative access point set is utilized, where multiple access points operate as a collaborative set. Each mobile station (STA) is associated with one primary access point in the collaborative access point set and, in some examples, may be associated with one or more secondary access points in the collaborative access point set. In some examples, multiple mobile stations can be primarily associated to the same access point.

[0021] To facilitate such simultaneous transmissions, a central controller is utilized that enables exchanges of information among multiple access points for coordinated beamforming. Beamforming reports are collected from the stations by their corresponding access points, and are reported to the central controller for analysis. In examples disclosed herein, beamforming reports are collected in response to a null data packet (NDP) transmission. In examples disclosed herein, a collaborative beamforming (CBF) NDP data structure is utilized that enables the access points in the collaborative access point set to transmit their NDP transmissions and/or channel sounding requests sequentially (e.g., in a time division multiple access (TDMA) fashion). In example approaches disclosed herein, the CBF NDP data structure defines the order in which the access points are to transmit their NDP messages.

[0022] The channel from each mobile station to its primary access point, as well as any secondary access points is measured and one or more beamforming feedback reports are transmitted to the access point(s) and/or central controller. Based on the exchange outlined above, the beamforming feedback reports from primarily associated access point and mobile station pairs are used to calculate pre-coding beamforming matrices. In examples disclosed herein, beamforming reports from secondarily associated access point and mobile station pairs are used to calculate the interference between candidate pairs for spatial reuse. In examples disclosed herein, rank-1 beamforming report(s) (e.g., low rate rank-1 beamforming report(s)) are utilized for the secondarily associated access point and mobile station pairs. In examples disclosed herein, by using these beamforming feedback reports, access point and mobile station pairs where simultaneous transmission can be allowed because the expected interference is low can be identified.

[0023] FIG. 1 is diagram of an example environment of use 100 implemented in accordance with the teachings of this disclosure to enable spatial reuse in a wireless network. The example environment of use 100 of the illustrated example of FIG. 1 includes an access point controller 102 in communication with a network 105. Via the network 105, the example access point controller 102 communicates with a set of wireless access points 109. In the illustrated example of FIG. 1, the example set of wireless access points 109 includes a first wireless access point 110, a second wireless access point 112, and a third wireless access point 114. In the illustrated example of FIG. 1, the set of wireless access points 109 provides a wireless service (e.g., Wi-Fi) for one or more mobile stations 120.

[0024] In the illustrated example of FIG. 1, a first mobile station 121 communicates with the first wireless access point 110, a second mobile station 122 communicates with the first wireless access point 110, a third mobile station 123 communicates with the second wireless access point 112, a fourth mobile station 124 communicates with the third wireless access point 114, and a fifth mobile station 125 communicates with the third wireless access point 114. In the illustrated example of FIG. 1 each of the mobile stations 121, 122, 123, 124, 125 primarily communicates with a single one of the wireless access points 109. In examples disclosed herein, the example wireless access points 110, 112, 114 utilize beamforming to communicate directly with their corresponding mobile station(s). In examples disclosed herein, because beamforming is used, when a first wireless channel is used to communicate from a first access point to a first mobile station (e.g., the first wireless access point 110 communicates with the first mobile station 121), such communications might not cause wireless interference when another wireless access point communicates on the same channel with another mobile station (e.g., the second wireless access point 112 communicates with the third mobile station 123).

[0025] In examples disclosed herein, the wireless resources (e.g., a wireless channel) may be simultaneously used by one or more access points when communicating with their corresponding mobile stations. For example the first wireless access point 110 may communicate on a first channel with the first mobile station 121 while the second wireless access point 112 may simultaneously communicate with the third example mobile station 123 using the first channel (e.g., the same channel as used by the communications between the first wireless access point 110 and the first mobile station 121), without the risk of causing interference and/or disrupting communications between the first wireless access point and the first mobile station 121.

[0026] The example access point controller 102 of the illustrated example of FIG. 1 controls collaborative beamforming operations of the example set of wireless access points 109. To control such operations, the example the access point controller 102 identifies the wireless access points 110, 112, 114 as being wireless access points included in the set of wireless access points 109. The example access point controller 102 directs each of the wireless access points 110, 112, 114 to transmit one or more sounding message(s) (e.g., a null data packet) to their corresponding mobile stations 120. Beamforming reports indicating signal strengths associated with receipt of the sounding message(s) are collected and reported to the access point controller 102. The access point controller 102 processes the beamforming reports to identify wireless access point and mobile station pairs where simultaneous communications are to be allowed. In examples disclosed herein, pairs are selected when interference that would be caused by such communication is below an interference threshold. The example access point controller 102 communicates such identifications to the wireless access points 110, 112, 114 such that the wireless access points 110, 112, 114 may identify whether simultaneous communication is allowed when transmitting data to their corresponding mobile stations 120. An example implementation of the access point controller 102 is further described in connection with FIG. 3.

[0027] In the illustrated example of FIG. 1, the example access point controller 102 is represented as a separate element from the wireless access points 110, 112, 114. In some examples, the example access point controller 102 may be implemented by one of the wireless access points 110, 112, 114. That is, one of the wireless access points 110, 112, 114 may act as the controller for itself and the other wireless access points.

[0028] In some examples, the access point controller 102 is remote from the set of wireless access points 109. That is, while the example set of wireless access points may provide wireless services for a facility (e.g., a single geographic location), the example access point controller 102 may be implemented as a server operated at a facility separate from the set of wireless access points 109 (e.g., in the cloud).

[0029] The example network 105 of the illustrated example of FIG. 1 facilitates communication between the access point controller 102 and the wireless access points 110, 112, 114 in the set of wireless access points 109. In examples disclosed herein, the network 105 is implemented as an Ethernet network. However, the access point controller 102 may communicate with the wireless access points 110, 112, 114 and any other fashion. In some examples, the network 105 may be implemented by the Internet.

[0030] The example set of wireless access points 109 of the illustrated example of FIG. 1 includes multiple wireless access points. In examples disclosed herein, the example set of wireless access points 109 are access points that are utilized together (e.g., that provide a same wireless network and/or wireless service to the mobile stations 120). In some examples, the wireless access points 110, 112, 114 communicate using a same service set identifier (SSID).

[0031] In the illustrated example of FIG. 1, three wireless access points 110, 112, 114 are included in the set of wireless access points 109. However, any number of wireless access points may additionally or alternatively be used. Moreover, in the illustrated example of FIG. 1, the wireless access points are depicted in a linear fashion (e.g., in a line). However, the wireless access points may be arranged in any fashion. In the illustrated example of FIG. 1, the wireless access points 110, 112, 114 are a same type of wireless access point (e.g., being of a same make and model, and/or having similar specifications). However, in some examples, the wireless access points may be different from each other. That is, multiple different makes and/or models of wireless access points may be utilized in combination with each other.

[0032] In examples disclosed herein, the example wireless access points 110, 112, 114 are owned and/or operated by an entity providing a wireless service. For example, an entity operating a venue (e.g., a sports arena) may own and/or operate the wireless access points 110, 112, 114 to provide wireless services to attendees of the venue. In some examples, the access point controller 102 is owned and/or operated by an entity other than the entity operating the venue.

[0033] The example mobile stations 120 of the illustrated example of FIG. 1 are implemented as mobile devices such as, for example smart phones. However, any other device that may communicate with an access point may additionally or alternatively be used such as, for example, a tablet, a laptop, a desktop, an Internet of Things (IOT) device, etc. In examples disclosed herein, the mobile stations 120 are provided by users of the corresponding mobile stations. That is, the mobile stations 120 are not necessarily provided, operated, and/or owned by the same entity as the wireless access points 109. In examples disclosed herein, the example mobile stations 120 are implemented by different types of devices. For example, while the first mobile station 121 may be implemented by an Apple iPhone, the second example mobile station 122 may be implemented by a Samsung Galaxy S8.

[0034] In examples disclosed herein, the example mobile stations 120 communicate with the example wireless access points 109 using Wi-Fi (e.g., 802.11 based technology). However, any other past, present, and/or future wireless communication technologies may additionally or alternatively be used such as, for example Bluetooth, cellular communications, etc.

[0035] FIG. 2 is a diagram of example primary and secondary associations between access points and mobile stations. In the illustrated example of FIG. 2, two access points 205, 210 are shown. In the illustrated example of FIG. 2, both of the access points 205, 210 are part of the same collaborative set of wireless access points. In the illustrated example of FIG. 2, four mobile stations 220, 230, 240, 250 are shown. However, any number of mobile stations and/or access points may additionally or alternatively be used. In the illustrated example of FIG. 2, the first mobile station 220 has a first primary association 225 with the first access point 205. The second mobile station 230 has a second primary association 235 with the first access point 205. The second mobile station 230 also has a secondary association 237 with the second access point 210. That is, the second mobile station 230 is in wireless communication range of both the first access points 205 and the second access point 210. The third mobile station 240 has a third primary association 245 with the wireless access point 210. The fourth mobile station 250 has a fourth primary association 255 with the second access point 210.

[0036] A signal strength of the first primary association 225 is represented by w_{Ti1}^{p}. A signal strength of the second primary association 235 is represented by w_{Ti2}^{p}. A signal strength of the secondary association 237 is represented by w_{Tij2}^{s}.

A signal strength of the third primary association 245 is represented by w^{p}_{Tj1}. A signal strength of the fourth primary association 255 is represented by w^{p}_{Tj2}.

[0037] FIG. 3 is a block diagram of an example implementation of the example access point controller 102 of FIG. 1. The example access point controller 102 of the illustrated example of FIG. 3 includes an access point communicator 310, a beamforming report collector 320, a beamforming report data store 330, an access point and mobile station pair identifier 340, an interference estimator 350, a collaborative beamforming set data store 360, and an access point instructor 370.

[0038] The example access point communicator 310 of the illustrated example of FIG. 3 enables the access point controller 102 to communicate with the access points 109 via the network 105. In examples disclosed herein, the example access point communicator 310 is implemented using an Ethernet port. However, any other past, present, and/or future approaches to facilitating communication between the access point controller 102 and the access points 109 may additionally or alternatively be used. In examples disclosed herein, the example access point communicator 310 transmits a collaborative beamforming null data packet (CBF NDP) message to the set of access points 109 and, in response, receives one or more beamforming reports. The example access point communicator 310 also transmits, to the access points, an identification of access point and mobile station pairs that are to participate in collaborative beamforming (e.g., that are identified as part of a collaborative beamforming set).

[0039] The example beamforming report collector 320 of the illustrated example of FIG. 3 instructs the example access point communicator 310 to request beamforming reports from the set of wireless access points 109. The beamforming reports are then collected by the example beamforming report collector 320 and are stored in the example beamforming report data store 330, and are later utilized for calculation of precoding matrices and for identifying access point and mobile station pairs for inclusion in collaborative beamforming set.

[0040] The example beamforming report data store 330 of the illustrated example of FIG. 3 is implemented by any memory, storage device and/or storage disc for storing data such as, for example, flash memory, magnetic media, optical media, etc. Furthermore, the data stored in the example beamforming report data store 330 may be in any data format such as, for example, binary data, comma delimited data, tab delimited data, structured query language (SQL) structures, etc. While in the illustrated example the beamforming report data store 330 is illustrated as a single element, the example beamforming report data store 330 and/or any other data storage elements described herein may be implemented by any number and/or type(s) of memories. In the illustrated example of FIG. 3, the example beamforming report data store 330 stores beamforming reports collected by the beamforming report collector 320.

[0041] The example access point and mobile station pair identifier 340 of the illustrated example of FIG. 3 analyzes the beamforming reports stored in the example beamforming report data store 330 to identify access point and mobile station pairs. In examples disclosed herein, the access point and mobile station pair identifier 340 identifies access point and mobile station pairs for inclusion in the collaborative beamforming set. When included in the collaborative beamforming set, access points may transmit to their corresponding mobile stations without delay (e.g., without having to schedule transmissions with other access points due to expected interference). In examples disclosed herein, the example access point and mobile station pair identifier 340 causes the example interference estimator to estimate interference that would be cause by the potential addition of one or more access point and mobile station pairs to the collaborative beamforming set. Such potential additions are added to the collaborative beamforming set when, for example, the estimated interferences below an interference threshold.

[0042] The example interference estimator 350 of the illustrated example of FIG. 3 estimates interference that would be caused by the potential addition of one or more access point and mobile station pairs to the collaborative beamforming set. In examples disclosed herein, such estimation is performed based on the beamforming reports stored in the example beamforming report data store 330. In examples disclosed herein, rank-1 beamforming reports are utilized for secondary associations between access points and corresponding mobile stations. In examples disclosed herein, a rank-1 beamforming report is defined to be a type of beamforming report that contains less information than a standard beamforming report, but enough information to estimate interference on other access point and mobile station pairs. As used herein, interference is defined to be a lack of available signal strength. Interference may be caused by, for example, physical obstructions between the access point and the mobile station, a distance between the access point and the mobile station, other mobile stations and/or access points communicating in the proximity of the access point and/or mobile station, etc.

[0043] In examples disclosed herein, the reduced amount of information of the rank-1 beamforming report is beneficial, as it reduces bandwidth requirements for collection of such reports, as well as reduces an amount of memory space needed to store such reports. However, in some examples, traditional beamforming reports may be collected instead of rank-1 beamforming reports. In examples disclosed herein, the rank-1 beamforming reports are collected from all secondary access point and mobile station associations (e.g., if a mobile station were primarily associated with a first access point and secondarily associated with three other access points, three rank-1 beamforming reports would be created corresponding to the associations of the mobile station with each of the three other access points).

[0044] The example collaborative beamforming set data store 360 of the illustrated example of FIG. 3 is implemented by any memory, storage device and/or storage disc for storing data such as, for example, flash memory, magnetic media, optical media, etc. Furthermore, the data stored in the example collaborative beamforming set data store 360 may be in any data format such as, for example, binary data, comma delimited data, tab delimited data, structured query language (SQL) structures, etc. While in the illustrated example the collaborative beamforming set data store 360 is illustrated as a single element, the example collaborative beamforming set data store 360 and/or any other data storage elements described herein may be implemented by any number and/or type(s) of memories. In the illustrated example of FIG. 3, the example collaborative beamforming set data store 360 stores the collaborative beamforming set identified by the access point and mobile station pair identifier 340.

[0045] The example access point instructor 370 of the illustrated example of FIG. 3 instructs the access point communicator 310 to inform the set of access points 109 of collaborative beamforming set stored in the example collaborative beamforming set data store 360. In examples disclosed herein, the example access point instructor 370 causes the example access point communicator 310 to transmit a message to each of the access points in the set of access points 109 identifying all of the access point and mobile station pairs in the collaborative beamforming set. That is, each access point may be informed of access point and mobile station pairs with which it is not associated.

[0046] However, in some examples, the example access point instructor 370 may cause the access point communicator 310 to transmit identifications of access point and mobile station pairs only to such access points that are involved in those access point and mobile station pairs. For example, if a first access point were involved in three access point and mobile station pairs and the second access point were involved in two access point and mobile station pairs, the example access point instructor 370 may inform the first access point of the three access point and mobile station pairs with which it is involved, and not inform the first access point of the two access point and mobile station pairs with which it is not involved.

[0047] FIG. 4 is a block diagram of an example implementation of the example access point 110 of FIG. 1. The example access point 110 of the illustrated example of a FIG. 4 includes a network communicator 410, a communications processor 420, and array controller 430, and antenna array 440, and a beamforming report requester 450. In operation, the example network communicator 410 receives information from the network 105 such as, for example, data packets. Such data packets may be destined for a mobile station, and the example communications processor 420 may cause the antenna array 440 to transmit the data packets to the mobile station. The antenna array 440 operates in accordance with instructions and/or configurations applied by the array controller 430. The example beamforming report requester 450 causes the antenna array 440 to transmit information to the mobile station such as, for example, a null data packet, a beamforming report request, etc.

[0048] The example network communicator 410 of the illustrated example of FIG. 4 is implemented by an Ethernet port. The example networking indicator 410 enables communication from the access point 110 to the network 105. While an Ethernet port is used in the illustrated example of FIG. 4, any other approach to facilitating communication between the example the access point 110 in the example network 105 may additionally or alternatively be used. For example, the network communicator 410 may be implemented using one or more wired and wireless protocols, communication systems, etc.

[0049] The example communications processor 420 of the illustrated example of FIG. 4 analyzes communications received from the network communicator 410 to determine whether the communications are directed to the access point 110. In some examples, the information received from the example network includes information from the example access point controller 102. In some examples, the communications transmitted to the access point 110 include collaborative beamforming null data packet messages (CBF NDP) and/or identifications of the collaborative beamforming set.

[0050] The example array controller 430 of the illustrated example of FIG. 4 identifies a pre-coding matrix that enables the antenna array 440 to directionally transmit data towards a particular mobile station (e.g., uni-directionally as opposed to omni-directionally). The example array controller 430 applies gain values to the antenna array 440 when transmitting to a particular mobile station based on the pre-coding matrix.

[0051] The example antenna array 440 of the illustrated example of FIG. 4 includes one or more antennas for wireless transmission of data to and/or from the mobile stations. To facilitate communication via the one or more antennas, the example antenna array 440 includes wireless communication circuitry such as, for example, orthogonal frequency division modulation circuitry, an upconverter, a downconverter, an amplifier, a filter, a mixer, an encoder, a decoder, etc. In examples disclosed herein the antennas included in the antenna array 440 are directional antennas and, transmit data directionally. When, for example multiple antennas are used to transmit data, the direction in which data is transmitted can be adjusted. The example antenna array 440 transmits data to wireless stations according to a beamforming pre-coding matrix identified by the array controller 430. Thus, when transmitting data to a particular mobile station, the antenna array 440 can transmit directly to that mobile station, as opposed to transmitting omni-directionally.

[0052] The example beamforming report requester 450 the illustrated example of FIG. 4 transmits a null data packet (NDP) message via the example antenna array 440. The null data packet message provides information to mobile stations in proximity of the access point for preparation of beamforming reports. The example beamforming report requester 450 requests, via the antenna array 440, beamforming reports to be transmitted back to the access point 110. In addition to requesting beamforming reports from stations that are primarily associated with the access point 110, the example beamforming report requester 450 requests rank-1 beamforming reports from those stations that are secondarily associated with the access point 110. The example beamforming report requester 450 relays, via the network communicator 410, the received beamforming reports to the example access point controller 102.

[0053] FIG. 5 is a block diagram of an example implementation of the example mobile station 121 of FIG. 1. The example mobile station 121 includes a wireless communicator 510, a beamforming report generator 520, a channel estimator 530, and native mobile station functionality 550.

[0054] The example wireless communicator 510 of the illustrated example of FIG. 5 enables the mobile station to communicate with one or more access point(s) 110. In some examples, the example wireless communicator 510 includes one or more antennas to enable wireless communications. To facilitate communication via the one or more antennas, the example wireless communicator 510 includes wireless communication circuitry such as, for example, orthogonal frequency division modulation circuitry, an upconverter, a downconverter, an amplifier, a filter, a mixer, an encoder, a decoder, etc. In examples disclosed herein, the wireless communicator 510 communicates using a WiFi protocol. However, any other past, present, and/or future protocol(s) and/or communication system(s) may additionally or alternatively be used.

[0055] The example beamforming report generator 520 of the illustrated example of FIG. 5 monitors for null data packet (NDP) messages from the access point(s), and prepares beamforming report(s) indicating properties and/or characteristics of the NDP messages (e.g., a signal strength of the received NDP message). The example beamforming report generator 520 transmits the beamforming report(s) to the access point that requested the beamforming report.

[0056] The example channel estimator 530 of the illustrated example of FIG. 5 receives long training field message(s) from one or more access points and estimates channel interference encountered at the mobile station when receiving the LTF message(s). The example channel estimator 530 applies gain modifications to tune the wireless communicator 510.

[0057] The example native mobile station functionality 550 of the illustrated example of FIG. 5 implements intended operations of the example mobile station 121. For example, the native mobile station functionality 550 may implement an operating system, an app, a program, etc. In examples disclosed herein, while the native mobile station functionality 550 is not directly involved in the wireless communication between the mobile station 121 and the access points, the example native mobile station functionality 550 benefits from the increased throughput and/or reduced latency encountered as a result of the use of the example approaches disclosed herein.

[0058] While an example manner of implementing the example access point controller 102 of FIG. 1 is illustrated in FIG. 3, one or more of the elements, processes and/or devices illustrated in FIGS. 1 and/or 3 may be combined, divided, re-arranged, omitted, eliminated and/or implemented in any other way. While an example manner of implementing the example access point 110 of FIG. 1 is illustrated in FIG. 4, one or more of the elements, processes and/or devices illustrated in FIG. 1 and/or 4 may be combined, divided, re-arranged, omitted, eliminated and/or implemented in any other way. While an example manner of implementing the example mobile station 121 of FIG. 1 is illustrated in FIG. 5, one or more of the elements, processes and/or devices illustrated in FIGS. 1 and/or 5 may be combined, divided, re-arranged, omitted, eliminated and/or implemented in any other way. Further, the example access point communicator 310, the example beamforming report collector 320, the example access point and mobile station pair identifier 340, the example interference estimator 350, the example access point instructor 370, and/or, more generally, the example access point controller 102 of FIGS. 1 and/or 3, the example network communicator 410, the example communications processor 420, the example array controller 430, the example antenna array 440, the example beamforming report requester 450, and/or, more generally, the example access point 110 of FIGS. 1 and/or 4, the example wireless communicator 510, the example beamforming report generator 520, the example channel estimator 530, the example native mobile station functionality 550, and/or, more generally, the example mobile station 121 of FIGS. 1 and/or 5 may be implemented by hardware, software, firmware and/or any combination of hardware, software and/or firmware. Thus, for example, any of the example access point communicator 310, the example beamforming report collector 320, the example access point and mobile station pair identifier 340, the example interference estimator 350, the example access point instructor 370, and/or, more generally, the example access point controller 102 of FIGS. 1 and/or 3, the example network communicator 410, the example communications processor 420, the example array controller 430, the example antenna array 440, the example beamforming report requester 450, and/or, more generally, the example access point 110 of FIGS. 1 and/or 4, the example wireless communicator 510, the example beamforming report generator 520, the example channel estimator 530, the example native mobile station functionality 550, and/or, more generally, the example mobile station 121 of FIGS. 1 and/or 5 could be implemented by one or more analog or digital circuit(s), logic circuits, programmable processor(s), application specific integrated circuit(s) (ASIC(s)), programmable logic device(s) (PLD(s)) and/or field programmable logic device(s) (FPLD(s)). When reading any of the apparatus or system claims of this patent to cover a purely software and/or firmware implementation, at least one of the example access point communicator 310, the example beamforming report collector 320, the example access point and mobile station pair identifier 340, the example interference estimator 350, the example access point instructor 370, and/or, more generally, the example access point controller 102 of FIGS. 1 and/or 3, the example network communicator 410, the example communications processor 420, the example array controller 430, the example antenna array 440, the example beamforming report requester 450, and/or, more generally, the example access point 110 of FIGS. 1 and/or 4, the example wireless communicator 510, the example beamforming report generator 520, the example channel estimator 530, the example native mobile station functionality 550, and/or, more generally, the example mobile station 121 of FIGS. 1 and/or 5 is/are hereby expressly defined to include a non-transitory computer readable storage device or storage disk such as a memory, a digital versatile disk (DVD), a compact disk (CD), a Blu-ray disk, etc. including the software and/or firmware. Further still, the example access point controller 102, the example access point 110, and/or the example mobile station 121 of FIGS. 1, 3, 4, and/or 5 may include one or more elements, processes and/or devices in addition to, or instead of, those illustrated in FIGS. 1, 3, 4, and/or 5, and/or may include more than one of any or all of the illustrated elements, processes and devices.

[0059] A flowchart representative of example machine readable instructions for implementing the example access point controller 102 of FIGS 1 and/or 3 is shown in FIG. 8. In this example, the machine readable instructions comprise a program for execution by a processor such as the processor 1112 shown in the example processor platform 1100 discussed below in connection with FIG. 11. The program may be embodied in software stored on a non-transitory computer readable storage medium such as a CD-ROM, a floppy disk, a hard drive, a digital versatile disk (DVD), a Blu-ray disk, or a memory associated with the processor 1112, but the entire program and/or parts thereof could alternatively be executed by a device other than the processor 1112 and/or embodied in firmware or dedicated hardware. Further, although the example program is described with reference to the flowchart illustrated in FIG. 8, many other methods of implementing the example access point controller 102 may alternatively be used. For example, the order of execution of the blocks may be changed, and/or some of the blocks described may be changed, eliminated, or combined. Additionally or alternatively, any or all of the blocks may be implemented by one or more hardware circuits (e.g., discrete and/or integrated analog and/or digital circuitry, a Field Programmable Gate Array (FPGA), an Application Specific Integrated circuit (ASIC), a comparator, an operational-amplifier (op-amp), a logic circuit, etc.) structured to perform the corresponding operation without executing software or firmware.

[0060] A flowchart representative of example machine readable instructions for implementing the example access point 110 of FIGS. 1 and/or 4 is shown in FIG. 9. In this example, the machine readable instructions comprise a program for execution by a processor such as the processor 1212 shown in the example processor platform 1200 discussed below in connection with FIG. 12. The program may be embodied in software stored on a non-transitory computer readable storage medium such as a CD-ROM, a floppy disk, a hard drive, a digital versatile disk (DVD), a Blu-ray disk, or a memory associated with the processor 1212, but the entire program and/or parts thereof could alternatively be executed by a device other than the processor 1212 and/or embodied in firmware or dedicated hardware. Further, although the example program is described with reference to the flowchart illustrated in FIG. 9, many other methods of implementing the example access point 110 may alternatively be used. For example, the order of execution of the blocks may be changed, and/or some of the blocks described may be changed, eliminated, or combined. Additionally or alternatively, any or all of the blocks may be implemented by one or more hardware circuits (e.g., discrete and/or integrated analog and/or digital circuitry, a Field Programmable Gate Array (FPGA), an Application Specific Integrated circuit (ASIC), a comparator, an operational-amplifier (op-amp), a logic circuit, etc.) structured to perform the corresponding operation without executing software or firmware.

[0061] A flowchart representative of example machine readable instructions for implementing the example mobile station 121 of FIGS. 1 and/or 5 is shown in FIG. 10. In this example, the machine readable instructions comprise a program for execution by a processor such as the processor 1312 shown in the example processor platform 1300 discussed below in connection with FIG. 13. The program may be embodied in software stored on a non-transitory computer readable storage medium such as a CD-ROM, a floppy disk, a hard drive, a digital versatile disk (DVD), a Blu-ray disk, or a memory associated with the processor 1312, but the entire program and/or parts thereof could alternatively be executed by a device other than the processor 1312 and/or embodied in firmware or dedicated hardware. Further, although the example program is described with reference to the flowchart illustrated in FIG. 13, many other methods of implementing the example mobile station 121 of FIGS. 1 and/or 5 may alternatively be used. For example, the order of execution of the blocks may be changed, and/or some of the blocks described may be changed, eliminated, or combined. Additionally or alternatively, any or all of the blocks may be implemented by one or more hardware circuits (e.g., discrete and/or integrated analog and/or digital circuitry, a Field Programmable Gate Array (FPGA), an Application Specific Integrated circuit (ASIC), a comparator, an operational-amplifier (op-amp), a logic circuit, etc.) structured to perform the corresponding operation without executing software or firmware.

[0062] As mentioned above, the example processes of FIGS. 8, 9, and/or 10 may be implemented using coded instructions (e.g., computer and/or machine readable instructions) stored on a non-transitory computer and/or machine readable medium such as a hard disk drive, a flash memory, a read-only memory, a compact disk, a digital versatile disk, a cache, a random-access memory and/or any other storage device or storage disk in which information is stored for any duration (e.g., for extended time periods, permanently, for brief instances, for temporarily buffering, and/or for caching of the information). As used herein, the term non-transitory computer readable medium is expressly defined to include any type of computer readable storage device and/or storage disk and to exclude propagating signals and to exclude transmission media. "Including" and "comprising" (and all forms and tenses thereof) are used herein to be open ended terms. Thus, whenever a claim lists anything following any form of "include" or "comprise" (e.g., comprises, includes, comprising, including, etc.), it is to be understood that additional elements, terms, etc. may be present without falling outside the scope of the corresponding claim. As used herein, when the phrase "at least" is used as the transition term in a preamble of a claim, it is open-ended in the same manner as the term "comprising" and "including" are open ended.

[0063] FIG. 6 is an example communication diagram representing communications among the example access point controller 102, the example access point(s) 109, and the example mobile station(s) 120 of FIGS. 1, 2, 3, 4, and/or 5. The example communication diagram 600 of the illustrated example of FIG. 6 begins when the example access point controller 102 establishes a collaborative access point set. (Block 605). In examples disclosed herein, access points that are part of the example set of wireless access points 109 are included in the collaborative set based on their geographic association and/or being in communication with the network 105.

[0064] In examples disclosed herein, a single collaborative access point set is identified. However, in some examples, multiple collaborative point sets may be identified. For example, a first collaborative access point set may be identified in connection with access points located in a first wing of a building and a second collaborative access point set may be identified in connection with access points located in a second wing of a building separate from the first wing. In some examples, the multiple collaborative access point sets may provide a same wireless resource (e.g., may host a same wireless network). Moreover, the example access point controller 102 may provide controller services for multiple different facilities and/or networks of sets of access points.

[0065] The example access point controller 102 communicates with the example access points 109 to identify associations between mobile stations (e.g., the mobile stations 120) and access points in the set of wireless access points 109. (Block 610). In examples disclosed herein, the access point controller 102 identifies associations where there is a primary association between a mobile station and an access point. In examples disclosed herein, each mobile station is only primarily associated with a single access point.

[0066] The example access point controller 102 transmits an instruction that causes each of the access points 110, 112, 114 in the set of wireless access points 109 to collect beamforming report(s). (Block 615). In examples disclosed herein, the instruction to collect beamforming report(s) is a collaborative beamforming null data packet (CBF NDP) announcement. The CBF NDP announcement instructs each of the wireless access points in the set 109 to broadcast a sounding message (e.g., a null data packet) to facilitate collection of beamforming reports. The example access points 110, 112, 114 in the example set of wireless access points 109 direct the creation of beamforming reports. (Block 620). In examples disclosed herein, the beamforming reports include traditional beamforming reports, but additionally include rank-1 beamforming reports for mobile stations that are secondarily associated with one or more access point(s). Each of the mobile stations 120 generate their corresponding beamforming report(s), and transmit the same to the access point with which the beamforming report was generated. (Block 625). The access point receiving the beamforming report transmits the collected beamforming report(s) to the access point controller 102. (Block 630).

[0067] The example access point controller 102 reviews the collected beamforming reports to generate a collaborative beamforming set. (Block 635). In examples disclosed herein, the collaborative beamforming set is a list of access point and mobile station pairs that are allowed to participate in collaborative beamforming. When participating in collaborative beamforming, data may be transmitted between the access point and mobile station pairs without the need to arrange for a transmission time (e.g., a time slot in which the access point can transmit data to the mobile station), as access point and mobile station pairs in the collaborative beamforming set do not cause interference with each other that would interrupt those transmissions (e.g., the expected interference is below an interference threshold). An example approach to generating the collaborative beamforming set is described in connection with FIG. 8, below.

[0068] The example access point controller 102 informs the access point(s) 109 of the collaborative beamforming set. (Block 640). In examples disclosed herein, the example access point controller 102 informs each access point in the collaborative beamforming set of all of the access point and mobile station pairs in the collaborative beamforming set. However, in some examples, the access point controller 102 may only inform the access points of the access point and mobile station pairs of which they are a part of. In examples disclosed herein, a single collaborative beamforming set is identified. However, in some examples, multiple collaborative beamforming sets may be identified.

[0069] The example access points 109 then transmits training field messages to their mobile stations. (Block 645). In examples disclosed herein, the training field messages are long training field (LTF) messages. However, any other type of message may additionally or alternatively be used. The example training field messages are transmitted from each access point in the set of wireless access points, and are made to be user specific, and are beamformed in the direction(s) of the primary mobile stations of each access point. During channel estimation, each mobile station experiences the same interference that it will receive during data transmission, as all access points in the collaborative beamforming set simultaneously (and/or substantially simultaneously) transmit the training field messages. Using the training field messages, the example mobile stations estimate interference and apply adjustments to their wireless interface(s). (Block 650). Because the training field messages are transmitted simultaneously, the mobile stations are able to estimate interference caused by other access point and mobile station pairs participating in collaborative beamforming. The example process 600 of FIG. 6 may be repeated periodically and/or a-periodically. For example, the process 600 may be repeated every five minutes, ten minutes, hour, etc. In some examples, the process 600 of FIG. 6 may be performed in response to an indication that interference is being experienced between the access point(s) and mobile station(s) 120. For example, as mobile stations move with respect to the access point(s), the collaborative beamforming set may need to be modified, updated, etc. to account for the changing wireless environment.

[0070] FIG. 7 is an example communication diagram 700 representing communications between the example access point of FIGS. 1 and/or 4 and mobile stations to collect beamforming report(s). The example communication diagram 700 corresponds to an example implementation of blocks 620 and 625 of FIG. 6. The example process 700 of FIG. 7 identifies operations (e.g., machine readable instructions) that may be performed by an access point 705 (e.g., an access point in the set of wireless access points 109), one or more primary mobile stations 710 for the access point 705, and one or more secondary stations 712 for the access point 705. In the illustrated example of FIG. 7, the example access point 705 accesses the CBF NDP announcement transmitted by the example access point controller 102 (See block 615 of FIG. 6). (Block 720). In examples disclosed herein, the CBF NDP announcement indicates an order in which the access points in the set of wireless access points 109 are to transmit their sounding messages. The example access point waits until its scheduled time (as indicated in the CBF NDP message), and transmits a very high throughput null data packet (VHT NDP), which is received by the primary stations 710 and the secondary stations 712. (Block 725). The example access point 705 then transmits a first polling message to collect beamforming reports from the primary stations 710 of the access point. (Block 730). In examples disclosed herein, the primary stations 710 for the access point generate beamforming reports and provide the beamforming reports to the access point. (Block 735). The example access point 705 transmits a second polling message to the secondary stations 712 for the access point to collect rank-1 beamforming reports from those secondary stations 712. (Block 740). The secondary stations 712 generate a rank-1 beamforming report and transmit the same to the access point 705. (Block 745). The example process then returns to FIG. 6, where the access point 705 transmits the collected beamforming reports to the access point controller 102 (see block 630 of FIG. 6).

[0071] FIG. 8 is a flowchart representative of example machine readable instructions which, when executed, cause the example access point controller 102 of FIGS. 1 and/or 3 to enable spatial reuse in a wireless network. The example process 800 of the illustrated example of FIG. 8 corresponds to block 635 and 640 of the illustrated example of FIG. 6. The example process 800 of the illustrated example of FIG. 8 begins when the example beamforming report collector 320 collects beamforming reports from the access points in the set of wireless access points 109. (Block 810). In examples disclosed herein, the collected beamforming reports include rank-1 beamforming reports. The example beamforming report collector 320 stores the collected beamforming reports in the example beamforming report data store 330.

[0072] The example access point and mobile station pair identifier 340 selects a first access point and mobile station pair appearing in the collected beamforming reports. (Block 820). In examples disclosed herein, access point and mobile station pairs are identified only when they are reported as being primary associations between the mobile station and its corresponding access point. However, any other approach to selecting access point and mobile station pairs may additionally or alternatively be used. In examples disclosed herein, the first access point and mobile station pair that is selected is the access point and mobile station pair that has the highest signal strength. However, any other approach to selecting one of the access point and mobile station pairs may additionally or alternatively be used such as, for example, a priority of a particular mobile station, an indication of which mobile station was first in communication with an access point, etc. The selected first access point and mobile station pair are added to the collaborative beamforming set stored in the example collaborative beamforming set data store 360. (Block 830).

[0073] The example access point and mobile station pair identifier 340 then identifies a second access point and mobile station pair. (Block 840). The example interference estimator 350 estimates and amount of interference caused by potential addition of the second access point and mobile station pair to the collaborative beamforming set. (Block 850).

[0074] In examples disclosed herein, to estimate the interference generated by each added access point and mobile station pair to the collaborative beamforming set, beamforming reports from mobile stations on their secondary access points are utilized (e.g., the rank-1 beamforming reports are used). The example approaches described in connection with FIG. 8 are described in view of the labels applied to the example first and second access points, the example mobile stations, and the example communication paths of FIG. 2. Using the beamforming reports, the example interference estimator 350 creates a signature for the interference channel between a second access point 210 and each mobile station primarily associated with a first access point 205. Such calculation is performed using the pre-coding vector calculated at the second access point 210. A same approach is used for interference estimation from the first access point

205 transmitting to the stations primarily associated with the second access point 210.

[0075] In examples disclosed herein, interference received at every mobile station is a result of transmission from other access points to their primary mobile stations. In examples disclosed herein, because beamforming is used, such transmissions are directional, thereby (in general) reducing such interference. Example approaches disclosed herein utilize Equation 1, below, for estimating the amount of interference received the primary station.

$$I_{il}^{j} \leq \sum_{m=1}^{2} \frac{p_m}{p_l} |\alpha_{lm}|^2 \qquad l = 1,2 \quad i \neq j$$

Equation 1

[0076] In equation 1, p_m and p_l are transmit powers for mobile stations m and l, respectively. I_{il}^{j} represents an amount of interference caused by the potential addition of the access point and mobile station pair to the collaborative beamforming set. The following assumptions, shown in Equation 2, below, are also used:

$$\alpha_{lm} = h_{il}^{j} * W_{TJm}^{p} = w_{Tjil}^{S}{}' * W_{TJm}^{p} \qquad l = 1,2 \quad m = 1,2 \quad i \neq j$$

Equation 2

[0077] The example approaches disclosed herein represent an upper bound of estimated interference as, for example, receiver beamforming is not considered. If, for example, each mobile station also was to apply receiver beamforming, the resultant interference would be less. Using the estimated amount of interference, the example access point and mobile station pair identifier 340 determines whether the estimated interference is below an interference threshold. (Block 860). If the estimated interference is below the interference threshold (e.g., block 860 returns a result of YES), the example access point and mobile station pair identifier 340 adds the second access point and mobile station pair to the collaborative beamforming set stored in the example collaborative beamforming set data store 360. (Block 870). If the example access point and mobile station pair identifier 340 determines that the estimated interference is not below the interference threshold, (e.g., block 860 returns a result of NO) the second access points and mobile station pair are not added to the collaborative beamforming set. In examples disclosed herein, the example interference threshold is a value stored in a memory of the access point controller 102. However, any other approach to storing and/or utilizing an interference threshold may additionally or alternatively be used. For example, the interference threshold may be dynamically determined such that a threshold maximum number of access point and mobile station pairs may be permitted to be part of the collaborative beamforming set.

[0078] The example access point and mobile station pair identifier determines whether any additional access point and mobile station pairs exist for consideration for addition to the collaborative beamforming set. (Block 880). If additional access point and mobile station pairs exist for consideration, (e.g., block 880 returns a result of YES), the example access point and mobile station pair identifier 340 identifies a further access point and mobile station mobile station pair (block 840), and the example interference estimator 350 estimates interference caused by potential addition of the further access point and mobile station pair to the collaborative beamforming set. The example process of blocks 840 through 880 is repeated until no additional access point and mobile station pairs exist for consideration for addition to the collaborative beamforming set (e.g., until block 880 returns a result of NO). Having considered all access point and mobile station pairs for addition to the collaborative beamforming set, the access point instructor 370 informs the access points and stations of the collaborative beamforming set via the access point communicator 310. (Block 890). The example process 800 the illustrated example of FIG. 8 then terminates. The example process 800 of the illustrated example of FIG. 8 may then be repeated at a later time to update and/or modify the collaborative beamforming set.

[0079] In examples disclosed herein, the example equations described above in connection with FIG. 8 can be directly extended to more than two access points and to more than two mobile stations per access point. In such examples, the other pair connections are added as long as the total interference power receive that each mobile station is less than the interference threshold.

[0080] FIG. 9 is a flowchart representative of example machine readable instructions which, when executed, cause the example access point of FIGS. 1 and/or 4 to transmit data to a mobile station. The example process 900 of the illustrated example of FIG. 9 begins when the example network communicator 410 receives a packet for transmission to a mobile station. The example communications processor 420 inspects the packet to determine the identity of the mobile station to which the packet is to be transmitted. (Block 910). The example communications processor 420 determines whether the access point and mobile station pair are identified in the collaborative beamforming set. (Block 920). If the identified mobile station is not identified as a mobile station that is associated with the access point (e.g. the access point and mobile station are not identified as an access point and mobile station pair in the collaborative beamforming set) (e.g., block 920 returns a result of NO), the example communications processor 420 coordinates with communications processors of other access points to schedule a time for transmission of the data to the mobile station. (Block 930). According to the scheduling, the example communications processor 420 then transmits the packet to the mobile station. (Block 940).

[0081] If the identified mobile station is identified as a mobile station associated with the access point in the collaborative beamforming set (e.g., block 920 returns a result of YES), the example communications processor transmits the packet to the mobile station (block 940) without delay. That is, the access point at which the communications were received need not communicate with other access points to schedule transmission of data to a mobile station because such transmissions are already known to not cause interference between other access point and mobile station pairs. The example process 900 of the illustrated example of FIG. 9 is repeated upon subsequent receipt of additional data packets for transmission to a mobile station.

[0082] FIG. 10 is a flowchart representative of example machine readable instructions which, when executed, cause the example mobile station to estimate interference and apply equalization adjustments. The example process 1000 of the illustrated example of FIG. 10 begins when the example wireless communicator 510 of the example mobile station accesses a long training field message transmitted by an access point. (Block 1010). In examples disclosed herein, the long training field message is transmitted from every access point, is made to be mobile station specific, and is formed/multiplexed in the directions of its primary users (e.g., the mobile station). In examples disclosed herein, the data transmission follows a legacy protocol (e.g., IEEE 802.11ac, IEEE 802.11ax, etc.), with the exception that training fields are transmitted in a mobile station specific (e.g., user-specific) fashion, are beamformed in the directions of all mobile stations (e.g., users). Such an approach does not have any impact on user channel estimation and/or the channel detection process. When receiving such messages, the example channel estimator 530 estimates interference received at the mobile station. (Block 1020). During such channel estimation, each mobile station is experiencing the same interference that it will receive during data transmission as all access points in the collaborative beamforming set are transmitting a user specific long training field team formed message towards their primary users. Such an approach results in adequate information for implementing accurate equalization at the mobile station. Using the estimated interference identified in block 1020, the example channel estimator applies equalization adjustments to the example wireless communicator 510 based on the estimated interference. (Block 1030). The example process 1000 of the illustrated example of FIG. 10 may be repeated in response to subsequent long training field messages.

[0083] FIG. 11 is a block diagram of an example processor platform 1100 capable of executing the instructions of FIG. 6, and/or 8 to implement the example access point controller of FIGS. 1 and/or 3. The processor platform 1100 can be, for example, a server, a personal computer, a mobile device (e.g., a cell phone, a smart phone, a tablet such as an iPad™), a personal digital assistant (PDA), an Internet appliance, a DVD player, a CD player, a digital video recorder, a Blu-ray player, a gaming console, a personal video recorder, a set top box, or any other type of computing device.

[0084] The processor platform 1100 of the illustrated example includes a processor 1112. The processor 1112 of the illustrated example is hardware. For example, the processor 1112 can be implemented by one or more integrated circuits, logic circuits, microprocessors or controllers from any desired family or manufacturer. The hardware processor may be a semiconductor based (e.g., silicon based) device. In this example, the processor 1112 implements the example beamforming report collector 320, the example access point and mobile station pair identifier 340, the example interference estimator 350, and the example access point instructor 370.

[0085] The processor 1112 of the illustrated example includes a local memory 1113 (e.g., a cache). The processor 1112 of the illustrated example is in communication with a main memory including a volatile memory 1114 and a non-volatile memory 1116 via a bus 1118. The volatile memory 1114 may be implemented by Synchronous Dynamic Random Access Memory (SDRAM), Dynamic Random Access Memory (DRAM), RAMBUS Dynamic Random Access Memory (RDRAM) and/or any other type of random access memory device. The non-volatile memory 1116 may be implemented by flash memory and/or any other desired type of memory device. Access to the main memory 1114, 1116 is controlled by a memory controller.

[0086] The processor platform 1100 of the illustrated example also includes an interface circuit 1120. The interface circuit 1120 may be implemented by any type of interface standard, such as an Ethernet interface, a universal serial bus (USB), and/or a PCI express interface. In this example, the example interface 1120 implements the example access point communicator 310.

[0087] In the illustrated example, one or more input devices 1122 are connected to the interface circuit 1120. The input device(s) 1122 permit(s) a user to enter data and/or commands into the processor 1112. The input device(s) can be implemented by, for example, an audio sensor, a microphone, a camera (still or video), a keyboard, a button, a mouse, a touchscreen, a track-pad, a trackball, isopoint and/or a voice recognition system.

[0088] One or more output devices 1124 are also connected to the interface circuit 1120 of the illustrated example. The output devices 1124 can be implemented, for example, by display devices (e.g., a light emitting diode (LED), an organic light emitting diode (OLED), a liquid crystal display, a cathode ray tube display (CRT), a touchscreen, a tactile output device, a printer and/or speakers). The interface circuit 1120 of the illustrated example, thus, typically includes a graphics driver card, a graphics driver chip and/or a graphics driver processor.

[0089] The interface circuit 1120 of the illustrated example also includes a communication device such as a transmitter, a receiver, a transceiver, a modem and/or network interface card to facilitate exchange of data with external machines (e.g., computing devices of any kind) via a network 1126 (e.g., an Ethernet connection, a digital subscriber line (DSL), a telephone line, coaxial cable, a cellular telephone system, etc.).

[0090] The processor platform 1100 of the illustrated example also includes one or more mass storage devices 1128 for storing software and/or data. Examples of such mass storage devices 1128 include floppy disk drives, hard drive disks, compact disk drives, Blu-ray disk drives, RAID systems, and digital versatile disk (DVD) drives.

[0091] The coded instructions 1132 of FIG. 8 may be stored in the mass storage device 1128, in the volatile memory 1114, in the non-volatile memory 1116, and/or on a removable tangible computer readable storage medium such as a CD or DVD. The example mass storage device 1128 of the illustrated example of FIG. 11 implements the example beamforming report data store 330 and the example collaborative beamforming set data store 360.

[0092] FIG. 12 is a block diagram of an example processor platform 1200 capable of executing the instructions of FIGS. 6, 7, and/or 9 to implement the example access point of FIGS. 1 and/or 4. The processor platform 1200 can be, for example, a server, a personal computer, a mobile device (e.g., a cell phone, a smart phone, a tablet such as an iPad™), a personal digital assistant (PDA), an Internet appliance, a DVD player, a CD player, a digital video recorder, a Blu-ray player, a gaming console, a personal video recorder, a set top box, or any other type of computing device.

[0093] The processor platform 1200 of the illustrated example includes a processor 1212. The processor 1212 of the illustrated example is hardware. For example, the processor 1212 can be implemented by one or more integrated circuits, logic circuits, microprocessors or controllers from any desired family or manufacturer. The hardware processor may be a semiconductor based (e.g., silicon based) device. In this example, the processor 1212 implements the example communications processor 420, the example array controller 430, and the example beamforming report requester 450.

[0094] The processor 1212 of the illustrated example includes a local memory 1213 (e.g., a cache). The processor 1212 of the illustrated example is in communication with a main memory including a volatile memory 1214 and a non-volatile memory 1216 via a bus 1218. The volatile memory 1214 may be implemented by Synchronous Dynamic Random Access Memory (SDRAM), Dynamic Random Access Memory (DRAM), RAMBUS Dynamic Random Access Memory (RDRAM) and/or any other type of random access memory device. The non-volatile memory 1216 may be implemented by flash memory and/or any other desired type of memory device. Access to the main memory 1214, 1216 is controlled by a memory controller.

[0095] The processor platform 1200 of the illustrated example also includes an interface circuit 1220. The interface circuit 1220 may be implemented by any type of interface standard, such as an Ethernet interface, a universal serial bus (USB), and/or a PCI express interface. In the illustrated example of FIG. 12, the example interface 1220 implements the example network communicator 410 and the example antenna array 440.

[0096] In the illustrated example, one or more input devices 1222 are connected to the interface circuit 1220. The input device(s) 1222 permit(s) a user to enter data and/or commands into the processor 1212. The input device(s) can be implemented by, for example, an audio sensor, a microphone, a camera (still or video), a keyboard, a button, a mouse, a touchscreen, a track-pad, a trackball, isopoint and/or a voice recognition system.

[0097] One or more output devices 1224 are also connected to the interface circuit 1220 of the illustrated example. The output devices 1224 can be implemented, for example, by display devices (e.g., a light emitting diode (LED), an organic light emitting diode (OLED), a liquid crystal display, a cathode ray tube display (CRT), a touchscreen, a tactile output device, a printer and/or speakers). The interface circuit 1220 of the illustrated example, thus, typically includes a graphics driver card, a graphics driver chip and/or a graphics driver processor.

[0098] The interface circuit 1220 of the illustrated example also includes a communication device such as a transmitter, a receiver, a transceiver, a modem and/or network interface card to facilitate exchange of data with external machines (e.g., computing devices of any kind) via a network 1226 (e.g., an Ethernet connection, a digital subscriber line (DSL), a telephone line, coaxial cable, a cellular telephone system, etc.).

[0099] The processor platform 1200 of the illustrated example also includes one or more mass storage devices 1228 for storing software and/or data. Examples of such mass storage devices 1228 include floppy disk drives, hard drive disks, compact disk drives, Blu-ray disk drives, RAID systems, and digital versatile disk (DVD) drives.

[00100] The coded instructions 1232 of FIG. 9may be stored in the mass storage device 1228, in the volatile memory 1214, in the non-volatile memory 1216, and/or on a removable tangible computer readable storage medium such as a CD or DVD.

[00101] FIG. 13 is a block diagram of an example processor platform 1300 capable of executing the instructions of FIGS. 6, 7, and/or 10 to implement the example mobile station of FIGS. 1 and/or 5. The processor platform 1300 can be, for example, a server, a personal computer, a mobile device (e.g., a cell phone, a smart phone, a tablet such as an iPad™), a personal digital assistant (PDA), an Internet appliance, a DVD player, a CD player, a digital video recorder, a Blu-ray player, a gaming console, a personal video recorder, a set top box, or any other type of computing device.

[00102] The processor platform 1300 of the illustrated example includes a processor 1312. The processor 1312 of the illustrated example is hardware. For example, the processor 1312 can be implemented by one or more integrated circuits, logic circuits, microprocessors or controllers from any desired family or manufacturer. The hardware processor may be a semiconductor based (e.g., silicon based) device. In this example, the processor 1312 implements the example beamforming report generator 520, the example channel estimator 530, and the example native mobile station functionality 550.

[00103] The processor 1312 of the illustrated example includes a local memory 1313 (e.g., a cache). The processor 1312 of the illustrated example is in communication with a main memory including a volatile memory 1314 and a non-volatile memory 1316 via a bus 1318. The volatile memory 1314 may be implemented by Synchronous Dynamic Random Access Memory (SDRAM), Dynamic Random Access Memory (DRAM), RAMBUS Dynamic Random Access Memory (RDRAM) and/or any other type of random access memory device. The non-volatile memory 1316 may be implemented by flash memory and/or any other desired type of memory device. Access to the main memory 1314, 1316 is controlled by a memory controller.

[00104] The processor platform 1300 of the illustrated example also includes an interface circuit 1320. The interface circuit 1320 may be implemented by any type of interface standard, such as an Ethernet interface, a universal serial bus (USB), and/or a PCI express interface. The example interface circuit 1320 of the illustrated example of FIG. 13 implements the example wireless communicator 510.

[00105] In the illustrated example, one or more input devices 1322 are connected to the interface circuit 1320. The input device(s) 1322 permit(s) a user to enter data and/or commands into the processor 1312. The input device(s) can be implemented by, for example, an audio sensor, a microphone, a camera (still or video), a keyboard, a button, a mouse, a touchscreen, a track-pad, a trackball, isopoint and/or a voice recognition system.

[00106] One or more output devices 1324 are also connected to the interface circuit 1320 of the illustrated example. The output devices 1324 can be implemented, for example, by display devices (e.g., a light emitting diode (LED), an organic light emitting diode (OLED), a liquid crystal display, a cathode ray tube display (CRT), a touchscreen, a tactile output device, a printer and/or speakers). The interface circuit 1320 of the illustrated example, thus, typically includes a graphics driver card, a graphics driver chip and/or a graphics driver processor.

[00107] The interface circuit 1320 of the illustrated example also includes a communication device such as a transmitter, a receiver, a transceiver, a modem and/or network interface card to facilitate exchange of data with external machines (e.g., computing devices of any kind) via a network 1326 (e.g., an Ethernet connection, a digital subscriber line (DSL), a telephone line, coaxial cable, a cellular telephone system, etc.).

[00108] The processor platform 1300 of the illustrated example also includes one or more mass storage devices 1328 for storing software and/or data. Examples of such mass storage devices 1328 include floppy disk drives, hard drive disks, compact disk drives, Blu-ray disk drives, RAID systems, and digital versatile disk (DVD) drives.

[00109] The coded instructions 1332 of FIG. 10 may be stored in the mass storage device 1328, in the volatile memory 1314, in the non-volatile memory 1316, and/or on a removable tangible computer readable storage medium such as a CD or DVD.

[00110] From the foregoing, it will be appreciated that example methods, apparatus and articles of manufacture have been disclosed that enable spatial reuse in a wireless network. For example, by collecting beamforming reports from multiple access points and the mobile stations that utilize those access points, a set of access point and mobile station pairs can be identified to form a collaborative beamforming set. The access point and mobile station pairs, when utilized by the example access points, enable the access point(s) to transmit data to their corresponding mobile devices without needing to schedule transmissions among multiple access points. To that end, increased bandwidth and/or data rates can be achieved as a result of the spatial reuse.

[00111] Example 1 includes an apparatus to enable spatial reuse in a wireless network, the apparatus comprising a beamforming report collector to collect a plurality of beamforming reports from mobile stations communicatively coupled to at least one access point of a plurality of access points, an access point and mobile station pair identifier to identify a first access point and mobile station pair based on a first one of the plurality of beamforming reports, the access point and mobile station pair identifier to include the first access point and mobile station pair in a collaborative beamforming set, the access point and mobile station pair identifier to identify a second access point and mobile station pair based on a second one of the plurality of beamforming reports, an interference estimator to estimate an amount of interference caused by inclusion of the second access point and mobile station pair in the collaborative beamforming set, the access point and mobile station pair identifier to add the second access point and mobile station pair to the collaborative beamforming set when the estimated amount of interference is less than an interference threshold, and an access point instructor to inform the plurality of access points of the collaborative beamforming set.

[00112] Example 2 includes the apparatus of example 1, wherein the interference estimator is to estimate the amount of interference based on a third one of the plurality of beamforming reports.

[00113] Example 3 includes the apparatus of example 2, wherein the third one of the plurality of beamforming reports is a rank-1 beamforming report.

[00114] Example 4 includes the apparatus of example 2, wherein the first one of the plurality of beamforming reports and the second one of the plurality of beamforming reports are a first type of beamforming report, and the third one of the plurality of beamforming reports is a second type of beamforming report different from the first type of beamforming report.

[00115] Example 5 includes the apparatus of example 1, wherein the beamforming report collector is to establish a a collaborative access point set representing the plurality of access points that are to participate in collaborative beamforming.

[00116] Example 6 includes the apparatus of example 1, wherein the first access point and mobile station pair are to communicate using a beamformed communication path.

[00117] Example 7 includes the apparatus any of examples 1 through 6, wherein the beamforming report collector is to transmit a collaborative beamforming null data packet message to the plurality of access points.

[00118] Example 8 includes the apparatus of example 7, wherein the collaborative beamforming null data packet message instructs respective ones of the plurality of access points to sequentially transmit channel sounding messages, and request the plurality of beamforming reports in response to the channel sounding messages.

[00119] Example 9 includes the apparatus of example 8, wherein the channel sounding messages are null data packet messages.

[00120] Example 10 includes a non-transitory computer readable medium comprising instructions which, when executed, cause an access point controller to at least collect a plurality of beamforming reports from mobile stations communicatively coupled to at least one access point of a plurality of access points, identify a first access point and mobile station pair based on a first one of the plurality of beamforming reports, include the first access point and mobile station pair in a collaborative beamforming set, identify a second access point and mobile station pair based on a second one of the plurality of beamforming reports, estimate an amount of interference caused by inclusion of the second access point and mobile station pair in the collaborative beamforming set, add the second access point and mobile station pair to the collaborative beamforming set when the estimated amount of interference is less than an interference threshold, and inform the plurality of access points of the collaborative beamforming set.

[00121] Example 11 includes the non-transitory computer readable medium of example 10, wherein the estimating of the amount of interference is based on a third one of the plurality of beamforming reports.

[00122] Example 12 includes the non-transitory computer readable medium of example 11, wherein the third one of the plurality of beamforming reports is a rank-1 beamforming report.

[00123] Example 13 includes the non-transitory computer readable medium of example 11, wherein the first one of the plurality of beamforming reports and the second one of the plurality of beamforming reports are a first type of beamforming report, and the third one of the plurality of beamforming reports

is a second type of beamforming report different from the first type of beamforming report.

[00124] Example 14 includes the non-transitory computer readable medium of example 11, wherein the instructions, when executed, cause the access point controller to establish a collaborative access point set representing the plurality of access points that are to participate in collaborative beamforming.

[00125] Example 15 includes the non-transitory computer readable medium of example 11, wherein the first access point and mobile station pair are to communicate using a beamformed communication path.

[00126] Example 16 includes the non-transitory computer readable medium of example 11, wherein the collecting of the plurality of beamforming reports is in response to transmitting a collaborative beamforming null data packet message to the plurality of access points.

[00127] Example 17 includes the non-transitory computer readable medium of example 16, wherein the collaborative beamforming null data packet message instructs respective ones of the plurality of access points to sequentially transmit channel sounding messages, and request the plurality of beamforming reports in response to the channel sounding messages.

[00128] Example 18 includes the non-transitory computer readable medium of example 17, wherein the channel sounding messages are null data packet messages.

[00129] Example 19 includes a method to enable spatial reuse in a wireless network, the method comprising collecting a plurality of beamforming reports from mobile stations communicatively coupled to at least one access point of a plurality of access points, identifying a first access point and mobile station pair based on a first one of the plurality of beamforming reports, including the first access point and mobile station pair in a collaborative beamforming set, identifying a second access point and mobile station pair based on a second one of the plurality of beamforming reports, estimating an amount of interference caused by inclusion of the second access point and mobile station pair in the collaborative beamforming set, adding the second access point and mobile station pair to the collaborative beamforming set when the estimated amount of interference is less than an interference threshold, and informing the plurality of access points of the collaborative beamforming set.

[00130] Example 20 includes the method of example 19, wherein the estimating of the amount of interference is based on a third one of the plurality of beamforming reports.

[00131] Example 21 includes the method of example 20, wherein the third one of the plurality of beamforming reports is a rank-1 beamforming report.

[00132] Example 22 includes the method of example 20, wherein the first one of the plurality of beamforming reports and the second one of the plurality of beamforming reports are a first type of beamforming report, and the third one of the plurality of beamforming reports is a second type of beamforming report different from the first type of beamforming report.

[00133] Example 23 includes the method of example 19, further including establishing a collaborative access point set representing the plurality of access points that are to participate in collaborative beamforming.

[00134] Example 24 includes the method of example 19, wherein the first access point and mobile station pair are to communicate using a beamformed communication path.

[00135] Example 25 includes the method of any one of examples 19 through 24, wherein the collecting of the plurality of beamforming reports is in response to transmitting a collaborative beamforming null data packet message to the plurality of access points.

[00136] Example 26 includes the method of example 25, wherein the collaborative beamforming null data packet message instructs respective ones of the plurality of access points to sequentially transmit channel sounding messages, and request the plurality of beamforming reports in response to the channel sounding messages.

[00137] Example 27 includes the method of example 26, wherein the channel sounding messages are null data packet messages.

[00138] Example 28 includes an apparatus to enable spatial reuse in a wireless network, the apparatus comprising means for collecting a plurality of beamforming reports from mobile stations communicatively coupled to at least one access point of a plurality of access points, means for identifying a first access point and mobile station pair based on a first one of the plurality of beamforming reports, means for including the first access point and mobile station pair in a collaborative beamforming set, means for identifying a second access point and mobile station pair based on a second one of the plurality of beamforming reports, means for estimating an amount of interference caused by inclusion of the second access point and mobile station pair in the collaborative beamforming set, means for adding the second access point and mobile station pair to the collaborative beamforming set when the estimated amount of interference is less than an interference threshold, and means for informing the plurality of access points of the collaborative beamforming set.

[00139] Example 29 includes the apparatus of example 28, wherein means for estimating estimates the amount of interference based on a third one of the plurality of beamforming reports.

[00140] Example 30 includes the apparatus of example 29, wherein the third one of the plurality of beamforming reports is a rank-1 beamforming report.

[00141] Example 31 includes the apparatus of example 29, wherein the first one of the plurality of beamforming reports and the second one of the plurality of beamforming reports are a first type of beamforming report, and the third one of the plurality of beamforming reports is a second type of beamforming report different from the first type of beamforming report.

[00142] Example 32 includes the apparatus of example 28, further including means for establishing a collaborative access point set representing the plurality of access points that are to participate in collaborative beamforming.

[00143] Example 33 includes the apparatus of example 28, wherein the first access point and mobile station pair are to communicate using a beamformed communication path.

[00144] Example 34 includes the apparatus of any one of examples 28 through 33, further including means for transmitting a collaborative beamforming null data packet message to the plurality of access points.

[00145] Example 35 includes the apparatus of example 34, wherein the collaborative beamforming null data packet message instructs respective ones of the plurality of access points to sequentially transmit channel sounding messages, and request the plurality of beamforming reports in response to the channel sounding messages.

[00146] Example 36 includes the apparatus of example 35, wherein the channel sounding messages are null data packet messages.

[00147] Although certain example methods, apparatus and articles of manufacture have been disclosed herein, the scope of coverage of this patent is not limited thereto. On the contrary, this patent covers all methods, apparatus and articles of manufacture fairly falling within the scope of the claims of this patent.

What Is Claimed Is:

1. An apparatus to enable spatial reuse in a wireless network, the apparatus comprising:

a beamforming report collector to collect a plurality of beamforming reports from mobile stations communicatively coupled to at least one access point of a plurality of access points;

an access point and mobile station pair identifier to identify a first access point and mobile station pair based on a first one of the plurality of beamforming reports, the access point and mobile station pair identifier to include the first access point and mobile station pair in a collaborative beamforming set, the access point and mobile station pair identifier to identify a second access point and mobile station pair based on a second one of the plurality of beamforming reports;

an interference estimator to estimate an amount of interference caused by inclusion of the second access point and mobile station pair in the collaborative beamforming set, the access point and mobile station pair identifier to add the second access point and mobile station pair to the collaborative beamforming set when the estimated amount of interference is less than an interference threshold; and

an access point instructor to inform the plurality of access points of the collaborative beamforming set.

2. The apparatus of claim 1, wherein the interference estimator is to estimate the amount of interference based on a third one of the plurality of beamforming reports.

3. The apparatus of claim 2, wherein the third one of the plurality of beamforming reports is a rank-1 beamforming report.

4. The apparatus of claim 2, wherein the first one of the plurality of beamforming reports and the second one of the plurality of beamforming reports are a first type of beamforming report, and the third one of the plurality of

beamforming reports is a second type of beamforming report different from the first type of beamforming report.

5. The apparatus of claim 1, wherein the beamforming report collector is to establish a collaborative access point set representing the plurality of access points that are to participate in collaborative beamforming.

6. The apparatus of claim 1, wherein the first access point and mobile station pair are to communicate using a beamformed communication path.

7. The apparatus any of claims 1 through 6, wherein the beamforming report collector is to transmit a collaborative beamforming null data packet message to the plurality of access points.

8. The apparatus of claim 7, wherein the collaborative beamforming null data packet message instructs respective ones of the plurality of access points to sequentially transmit channel sounding messages, and request the plurality of beamforming reports in response to the channel sounding messages.

9. The apparatus of claim 8, wherein the channel sounding messages are null data packet messages.

10. A non-transitory computer readable medium comprising instructions which, when executed, cause an access point controller to at least:

collect a plurality of beamforming reports from mobile stations communicatively coupled to at least one access point of a plurality of access points;

identify a first access point and mobile station pair based on a first one of the plurality of beamforming reports;

include the first access point and mobile station pair in a collaborative beamforming set;

identify a second access point and mobile station pair based on a second one of the plurality of beamforming reports;

estimate an amount of interference caused by inclusion of the second access point and mobile station pair in the collaborative beamforming set;

add the second access point and mobile station pair to the collaborative beamforming set when the estimated amount of interference is less than an interference threshold; and

inform the plurality of access points of the collaborative beamforming set.

11. The non-transitory computer readable medium of claim 10, wherein the estimating of the amount of interference is based on a third one of the plurality of beamforming reports.

12. The non-transitory computer readable medium of claim 11, wherein the third one of the plurality of beamforming reports is a rank-1 beamforming report.

13. The non-transitory computer readable medium of claim 11, wherein the first one of the plurality of beamforming reports and the second one of the plurality of beamforming reports are a first type of beamforming report, and the third one of the plurality of beamforming reports is a second type of beamforming report different from the first type of beamforming report.

14. The non-transitory computer readable medium of claim 10, wherein the instructions, when executed, cause the access point controller to establish a collaborative access point set representing the plurality of access points that are to participate in collaborative beamforming.

15. The non-transitory computer readable medium of claim 10, wherein the first access point and mobile station pair are to communicate using a beamformed communication path.

16. The non-transitory computer readable medium of claim 10, wherein the collecting of the plurality of beamforming reports is in response to transmitting a collaborative beamforming null data packet message to the plurality of access points.

17. A method to enable spatial reuse in a wireless network, the method comprising:

collecting a plurality of beamforming reports from mobile stations communicatively coupled to at least one access point of a plurality of access points;

identifying a first access point and mobile station pair based on a first one of the plurality of beamforming reports;

including the first access point and mobile station pair in a collaborative beamforming set;

identifying a second access point and mobile station pair based on a second one of the plurality of beamforming reports;

estimating an amount of interference caused by inclusion of the second access point and mobile station pair in the collaborative beamforming set;

adding the second access point and mobile station pair to the collaborative beamforming set when the estimated amount of interference is less than an interference threshold; and

informing the plurality of access points of the collaborative beamforming set.

18. The method of claim 17, wherein the estimating of the amount of interference is based on a third one of the plurality of beamforming reports.

19. The method of claim 18, wherein the third one of the plurality of beamforming reports is a rank-1 beamforming report.

20. The method of claim 18, wherein the first one of the plurality of beamforming reports and the second one of the plurality of beamforming reports

are a first type of beamforming report, and the third one of the plurality of beamforming reports is a second type of beamforming report different from the first type of beamforming report.

21. The method of claim 17, further including establishing a collaborative access point set representing the plurality of access points that are to participate in collaborative beamforming.

22. The method of any one of claims 17 through 23, wherein the collecting of the plurality of beamforming reports is in response to transmitting a collaborative beamforming null data packet message to the plurality of access points.

23. The method of claim 22, wherein the collaborative beamforming null data packet message instructs respective ones of the plurality of access points to sequentially transmit channel sounding messages, and request the plurality of beamforming reports in response to the channel sounding messages.

24. The method of claim 23, wherein the channel sounding messages are null data packet messages.

25. An apparatus to enable spatial reuse in a wireless network, the apparatus comprising: means for collecting a plurality of beamforming reports from mobile stations communicatively coupled to at least one access point of a plurality of access points;

means for identifying a first access point and mobile station pair based on a first one of the plurality of beamforming reports;

means for including the first access point and mobile station pair in a collaborative beamforming set;

means for identifying a second access point and mobile station pair based on a second one of the plurality of beamforming reports;

means for estimating an amount of interference caused by inclusion of the second access point and mobile station pair in the collaborative beamforming set;

means for adding the second access point and mobile station pair to the collaborative beamforming set when the estimated amount of interference is less than an interference threshold; and

means for informing the plurality of access points of the collaborative beamforming set.

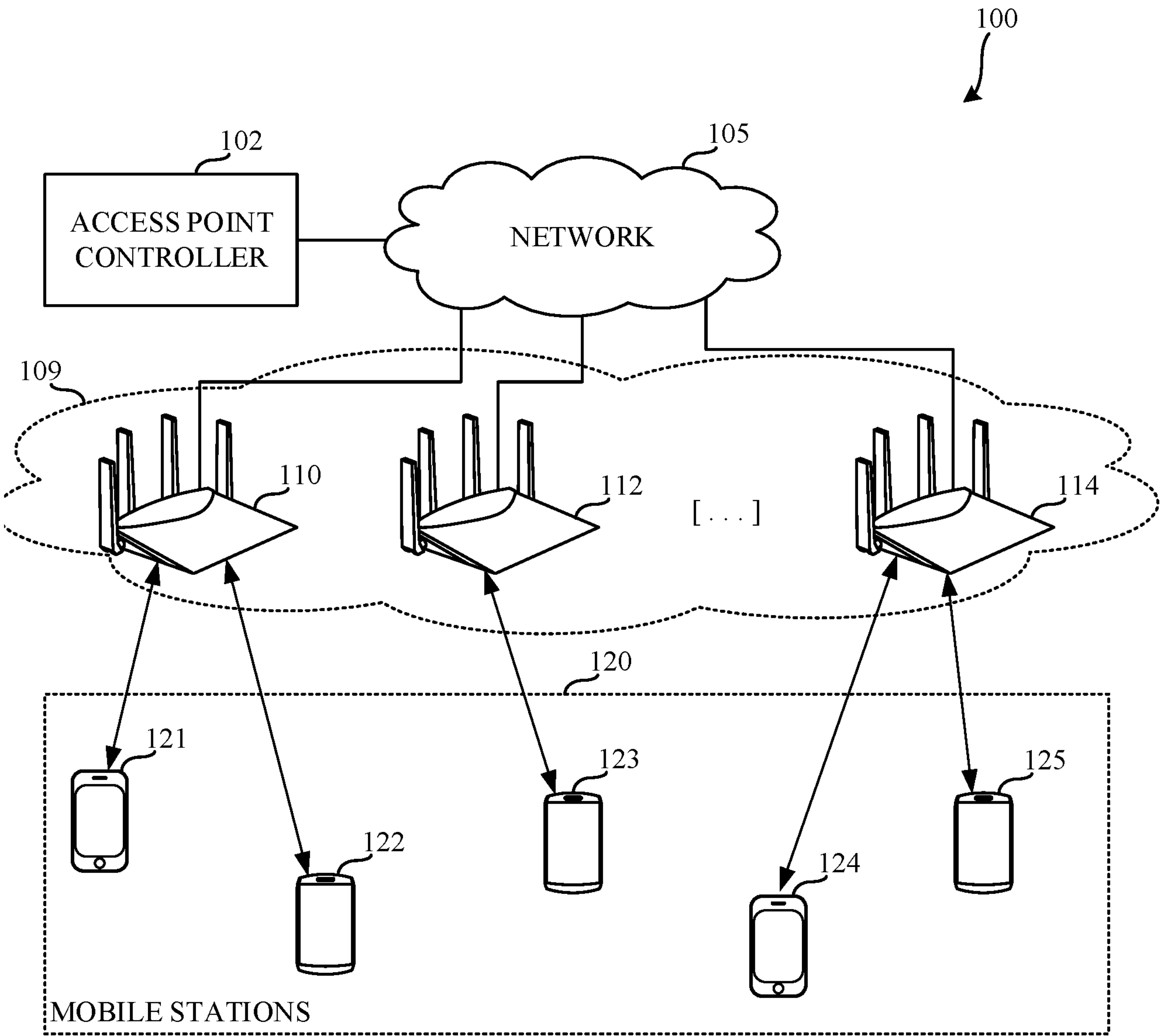
100
102
ACCESS POINT CONTROLLER
105
NETWORK
109
110
112
[. . .]
114
120
121
122
123
124
125
MOBILE STATIONS

FIG. 1

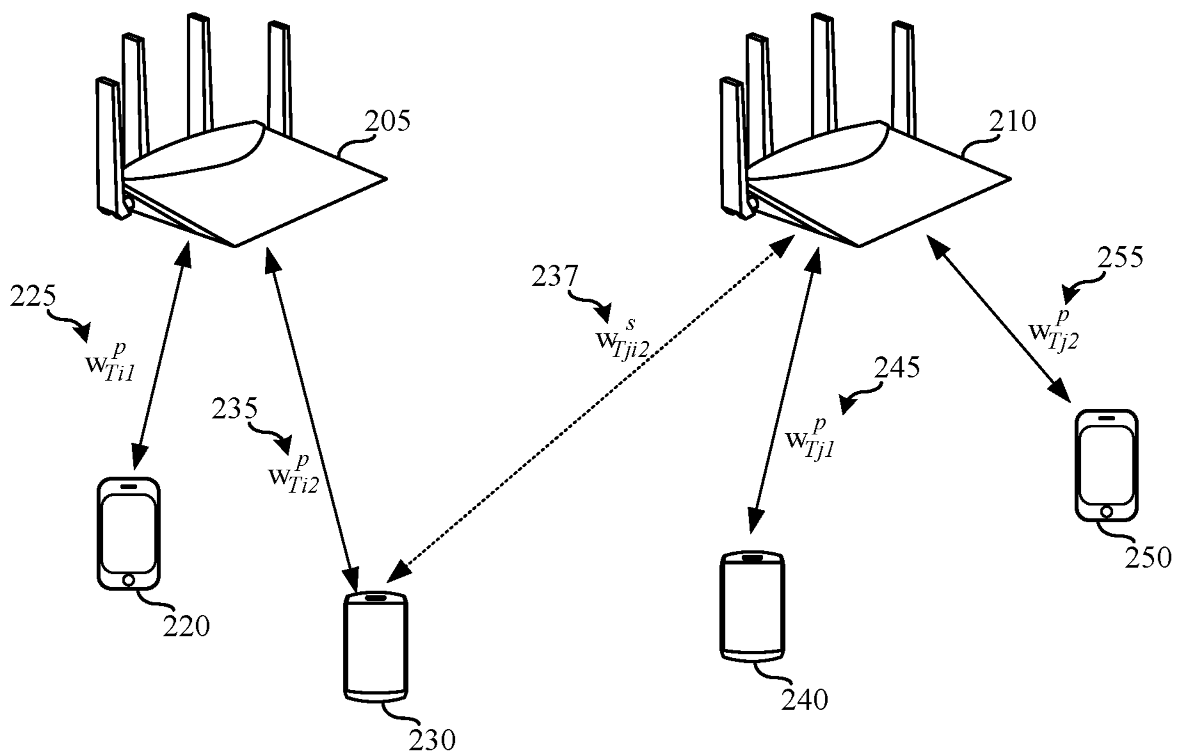
205
210
225
w^p_{Ti1}
235
w^p_{Ti2}
237
w^s_{Tji2}
245
w^p_{Tj1}
255
w^p_{Tj2}
220
230
240
250

FIG. 2

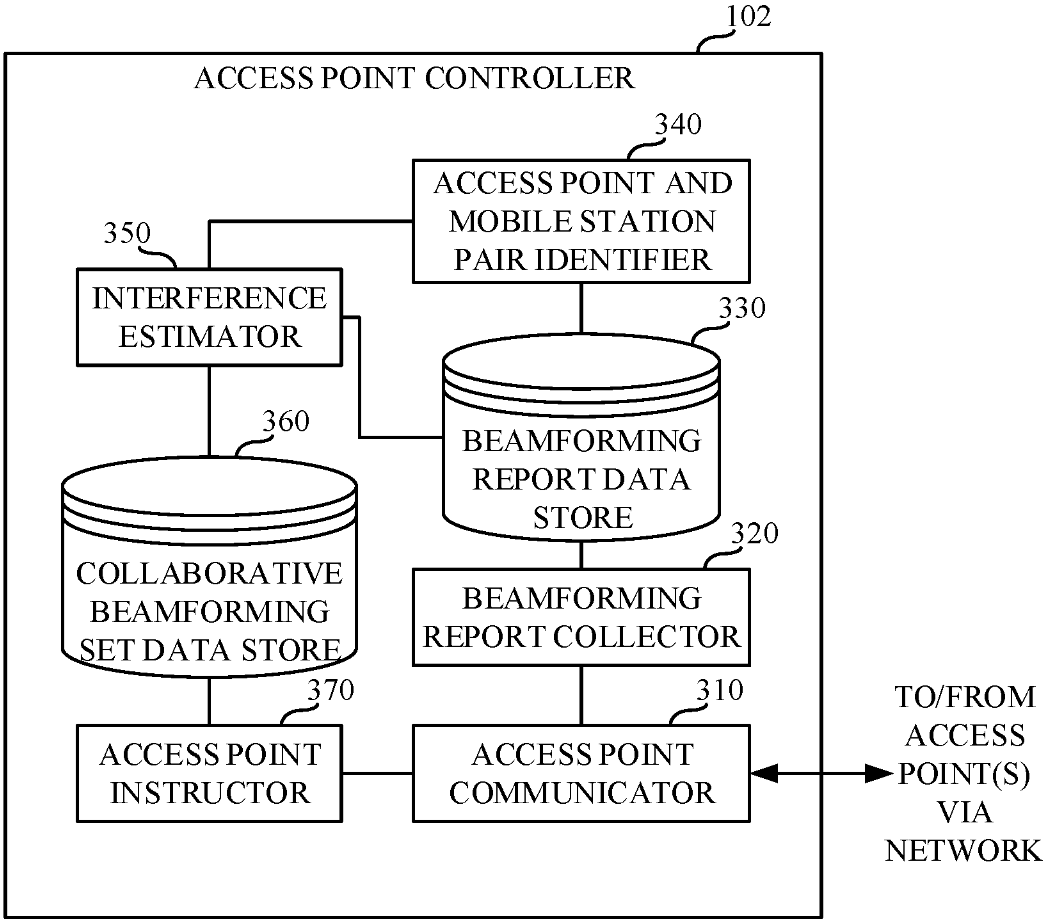
102
ACCESS POINT CONTROLLER
340
ACCESS POINT AND MOBILE STATION PAIR IDENTIFIER
350
INTERFERENCE ESTIMATOR
330
BEAMFORMING REPORT DATA STORE
360
COLLABORATIVE BEAMFORMING SET DATA STORE
320
BEAMFORMING REPORT COLLECTOR
370
310
ACCESS POINT INSTRUCTOR
ACCESS POINT COMMUNICATOR
TO/FROM ACCESS POINT(S) VIA NETWORK

FIG. 3

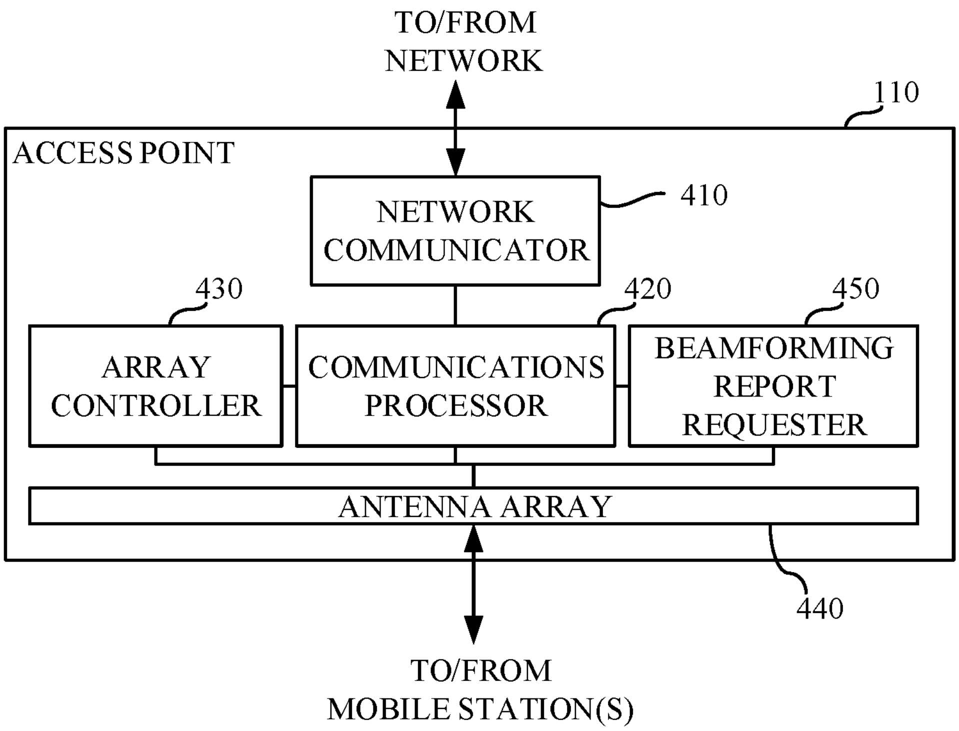
TO/FROM
NETWORK
110
ACCESS POINT
NETWORK
COMMUNICATOR
410
430
420
450
ARRAY
CONTROLLER
COMMUNICATIONS
PROCESSOR
BEAMFORMING
REPORT
REQUESTER
ANTENNA ARRAY
440
TO/FROM
MOBILE STATION(S)

FIG. 4

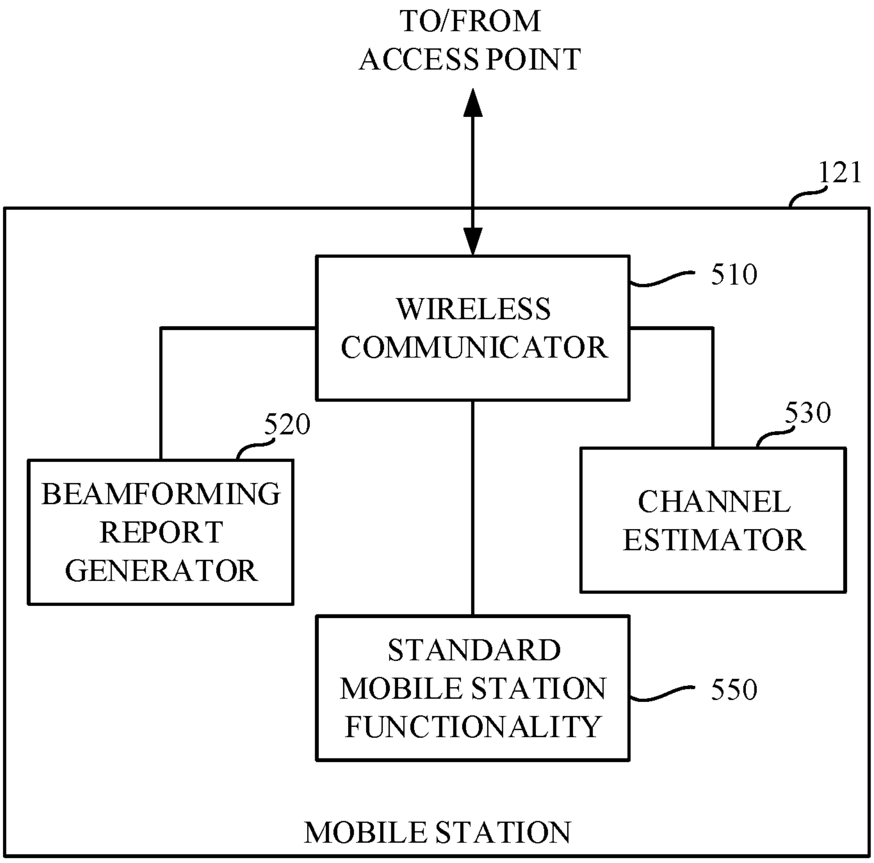
TO/FROM
ACCESS POINT
121
WIRELESS
COMMUNICATOR
510
520
BEAMFORMING
REPORT
GENERATOR
530
CHANNEL
ESTIMATOR
STANDARD
MOBILE STATION
FUNCTIONALITY
550
MOBILE STATION

FIG. 5

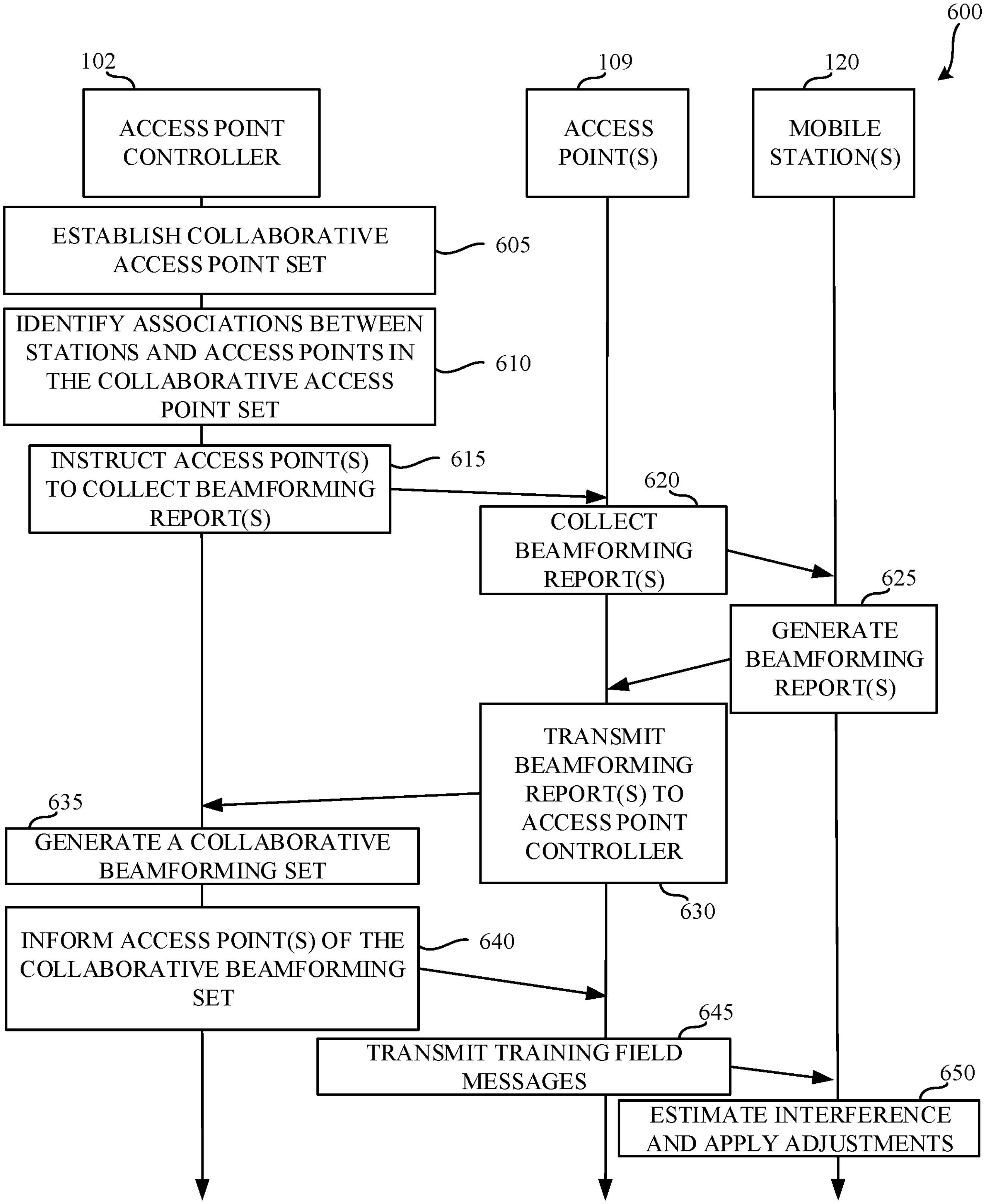
600
102
ACCESS POINT CONTROLLER
109
ACCESS POINT(S)
120
MOBILE STATION(S)
ESTABLISH COLLABORATIVE ACCESS POINT SET
605
IDENTIFY ASSOCIATIONS BETWEEN STATIONS AND ACCESS POINTS IN THE COLLABORATIVE ACCESS POINT SET
610
INSTRUCT ACCESS POINT(S) TO COLLECT BEAMFORMING REPORT(S)
615
620
COLLECT BEAMFORMING REPORT(S)
625
GENERATE BEAMFORMING REPORT(S)
TRANSMIT BEAMFORMING REPORT(S) TO ACCESS POINT CONTROLLER
630
635
GENERATE A COLLABORATIVE BEAMFORMING SET
INFORM ACCESS POINT(S) OF THE COLLABORATIVE BEAMFORMING SET
640
645
TRANSMIT TRAINING FIELD MESSAGES
650
ESTIMATE INTERFERENCE AND APPLY ADJUSTMENTS

FIG. 6

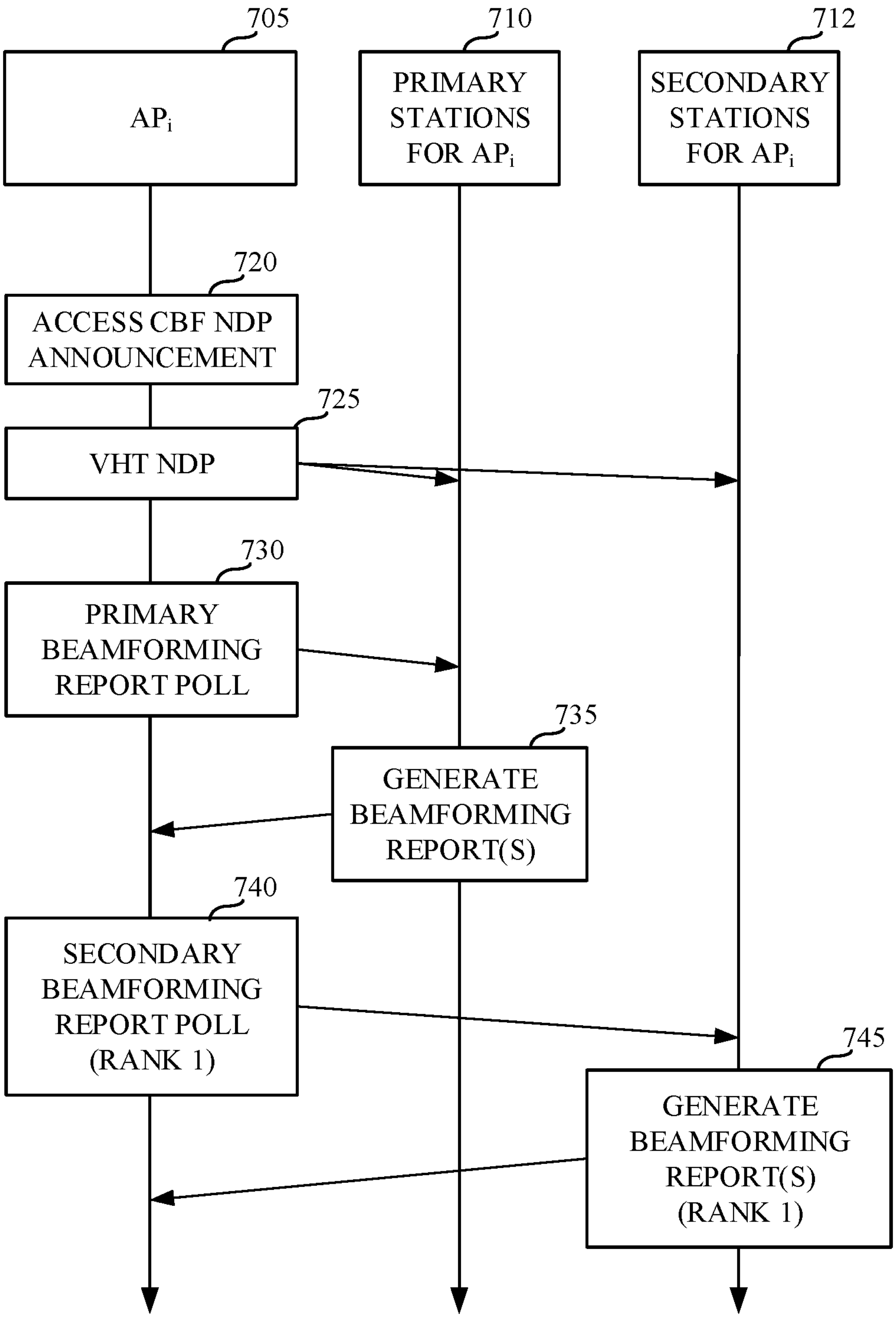
705
AP_i
710
PRIMARY STATIONS FOR AP_i
712
SECONDARY STATIONS FOR AP_i
720
ACCESS CBF NDP ANNOUNCEMENT
725
VHT NDP
730
PRIMARY BEAMFORMING REPORT POLL
735
GENERATE BEAMFORMING REPORT(S)
740
SECONDARY BEAMFORMING REPORT POLL (RANK 1)
745
GENERATE BEAMFORMING REPORT(S) (RANK 1)

FIG. 7

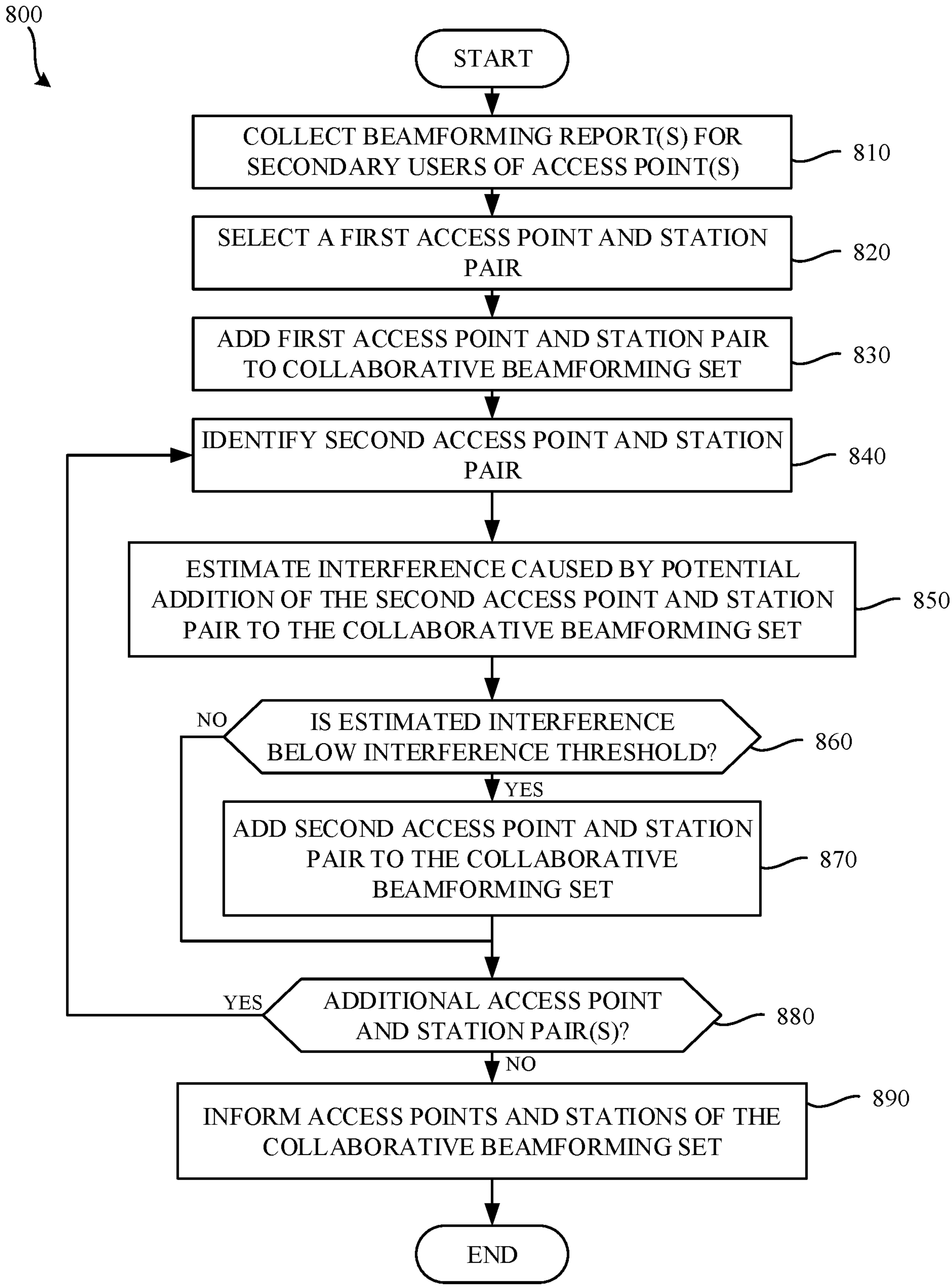
800
START
COLLECT BEAMFORMING REPORT(S) FOR SECONDARY USERS OF ACCESS POINT(S)
810
SELECT A FIRST ACCESS POINT AND STATION PAIR
820
ADD FIRST ACCESS POINT AND STATION PAIR TO COLLABORATIVE BEAMFORMING SET
830
IDENTIFY SECOND ACCESS POINT AND STATION PAIR
840
ESTIMATE INTERFERENCE CAUSED BY POTENTIAL ADDITION OF THE SECOND ACCESS POINT AND STATION PAIR TO THE COLLABORATIVE BEAMFORMING SET
850
IS ESTIMATED INTERFERENCE BELOW INTERFERENCE THRESHOLD?
860
NO
YES
ADD SECOND ACCESS POINT AND STATION PAIR TO THE COLLABORATIVE BEAMFORMING SET
870
ADDITIONAL ACCESS POINT AND STATION PAIR(S)?
880
YES
NO
INFORM ACCESS POINTS AND STATIONS OF THE COLLABORATIVE BEAMFORMING SET
890
END

FIG. 8

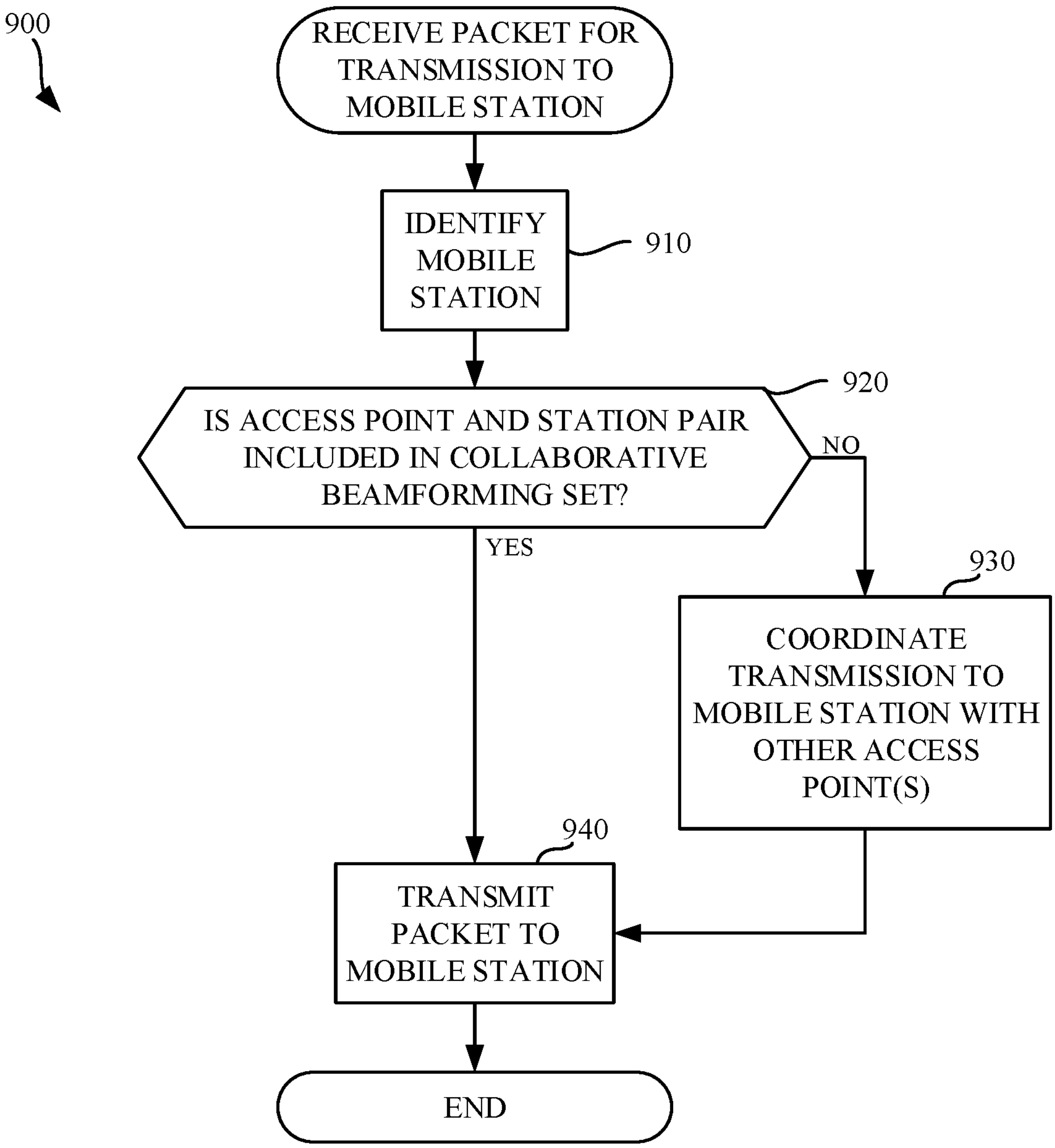
900
RECEIVE PACKET FOR TRANSMISSION TO MOBILE STATION
IDENTIFY MOBILE STATION
910
920
IS ACCESS POINT AND STATION PAIR INCLUDED IN COLLABORATIVE BEAMFORMING SET?
NO
YES
930
COORDINATE TRANSMISSION TO MOBILE STATION WITH OTHER ACCESS POINT(S)
940
TRANSMIT PACKET TO MOBILE STATION
END

FIG. 9

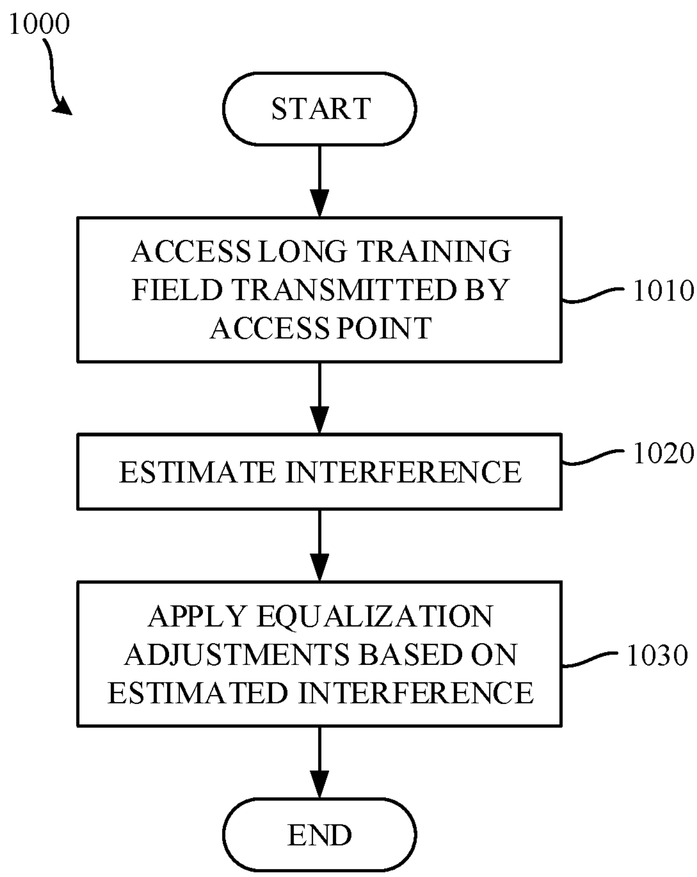
1000
START
ACCESS LONG TRAINING FIELD TRANSMITTED BY ACCESS POINT
1010
ESTIMATE INTERFERENCE
1020
APPLY EQUALIZATION ADJUSTMENTS BASED ON ESTIMATED INTERFERENCE
1030
END

FIG. 10

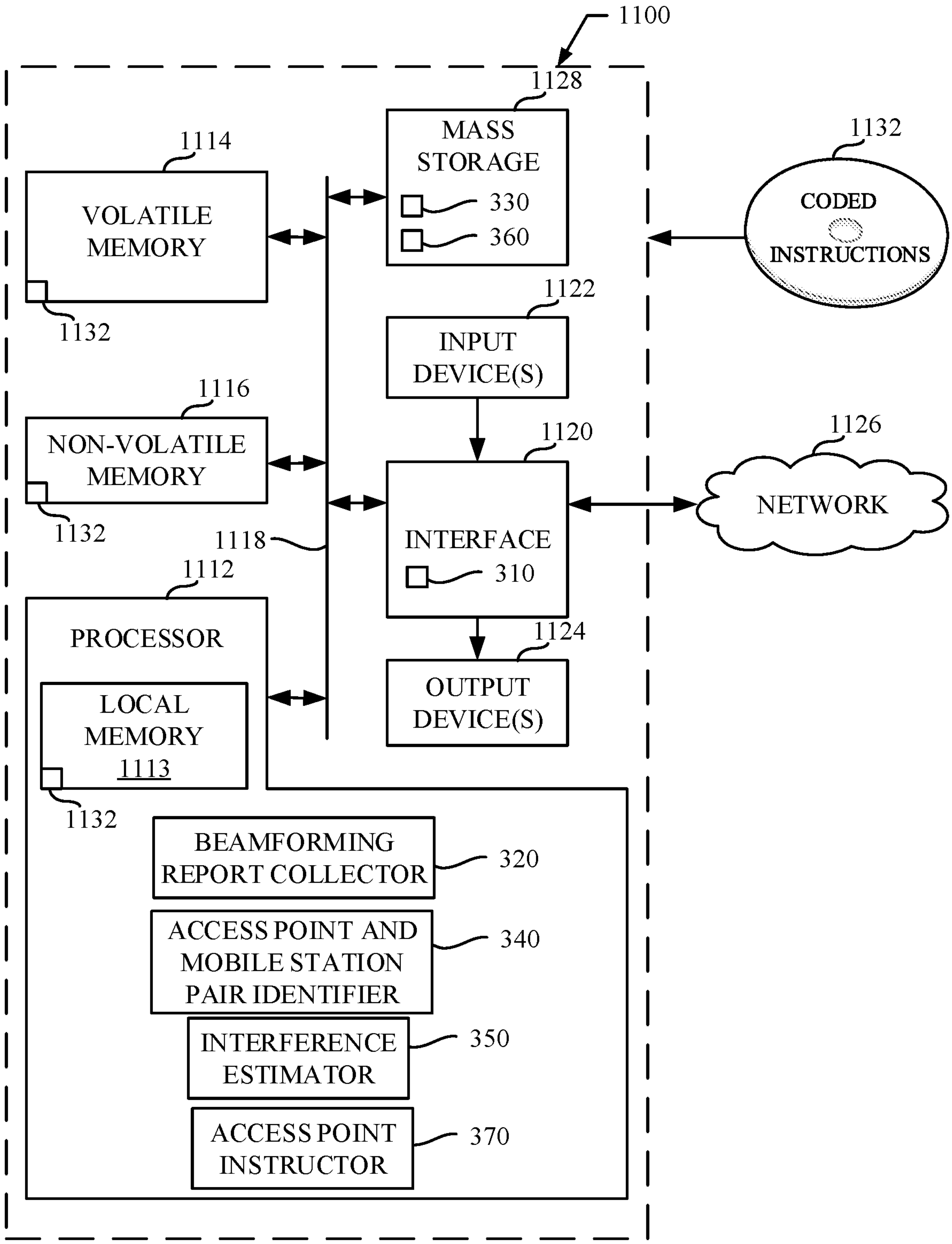
1100
1128
MASS STORAGE
330
360
1114
VOLATILE MEMORY
1132
1132
CODED INSTRUCTIONS
1122
INPUT DEVICE(S)
1116
NON-VOLATILE MEMORY
1132
1120
1126
NETWORK
1118
INTERFACE
310
1112
PROCESSOR
1124
LOCAL MEMORY 1113
OUTPUT DEVICE(S)
1132
BEAMFORMING REPORT COLLECTOR
320
ACCESS POINT AND MOBILE STATION PAIR IDENTIFIER
340
INTERFERENCE ESTIMATOR
350
ACCESS POINT INSTRUCTOR
370

FIG. 11

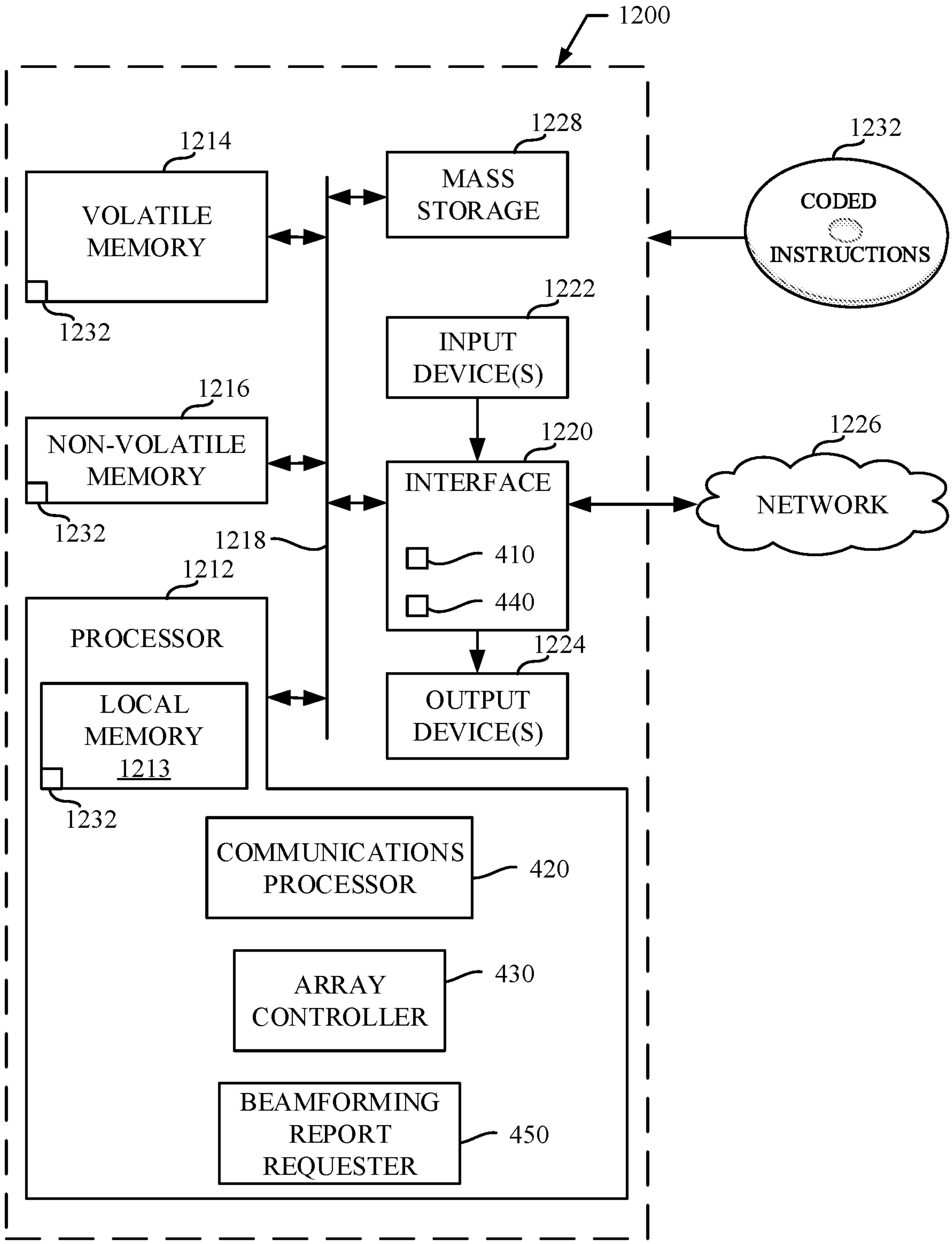
1200
1214
VOLATILE MEMORY
1232
1228
MASS STORAGE
1232
CODED INSTRUCTIONS
1222
INPUT DEVICE(S)
1216
NON-VOLATILE MEMORY
1232
1220
INTERFACE
410
440
1226
NETWORK
1218
1212
PROCESSOR
LOCAL MEMORY 1213
1232
1224
OUTPUT DEVICE(S)
COMMUNICATIONS PROCESSOR
420
ARRAY CONTROLLER
430
BEAMFORMING REPORT REQUESTER
450

FIG. 12

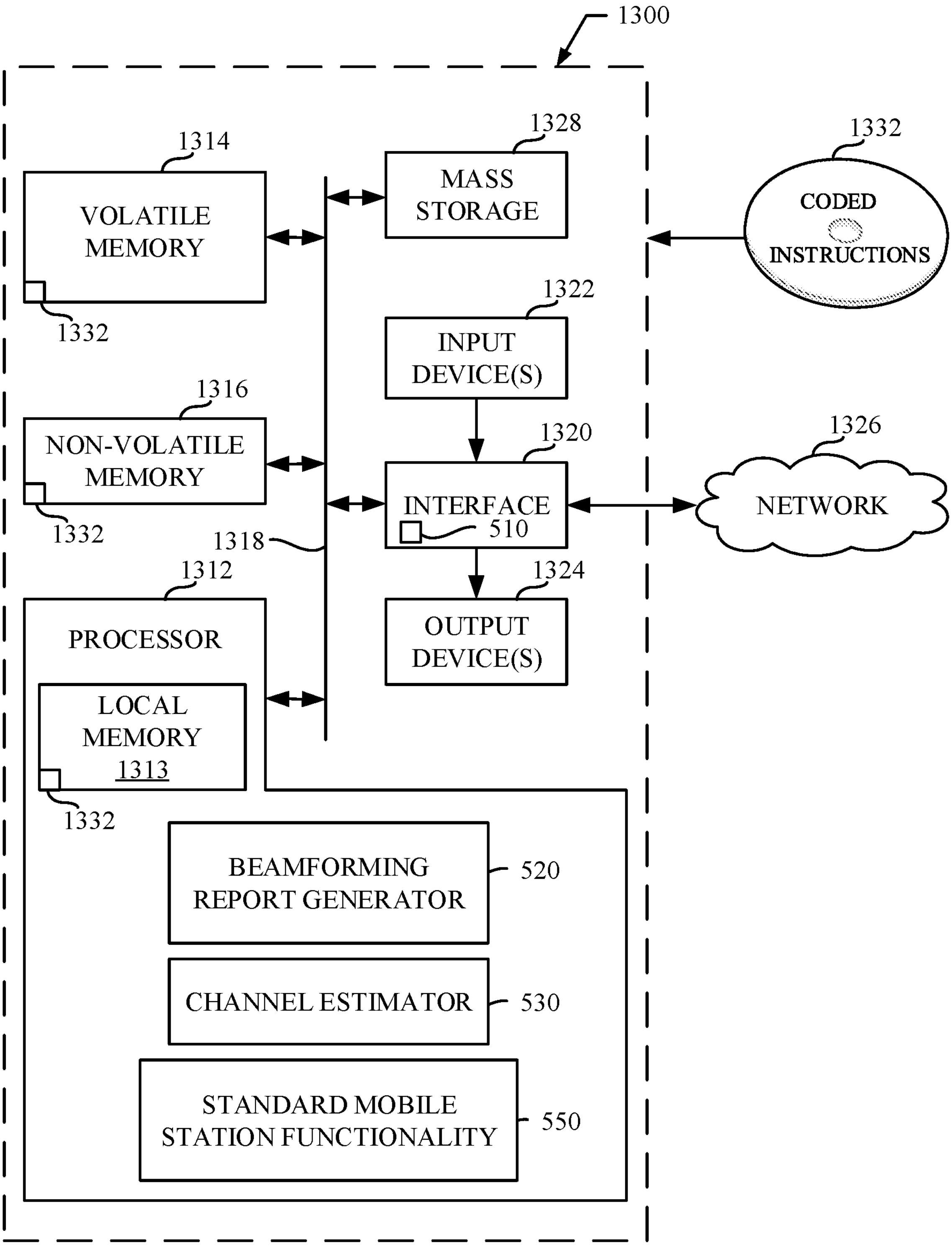
1300
1314
VOLATILE MEMORY
1332
1328
MASS STORAGE
1332
CODED INSTRUCTIONS
1322
INPUT DEVICE(S)
1316
NON-VOLATILE MEMORY
1332
1320
INTERFACE
510
1326
NETWORK
1318
1312
PROCESSOR
1324
OUTPUT DEVICE(S)
LOCAL MEMORY
1313
1332
BEAMFORMING REPORT GENERATOR
520
CHANNEL ESTIMATOR
530
STANDARD MOBILE STATION FUNCTIONALITY
550

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/048192

A. CLASSIFICATION OF SUBJECT MATTER

H04W 24/06(2009.01)i, H04W 24/10(2009.01)i, H04W 16/28(2009.01)i, H04W 88/12(2009.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W 24/06; H04W 24/02; H04W 72/12; H04B 7/06; H04W 24/10; H04W 72/04; H04W 72/08; H04B 7/155; H04W 16/28; H04W 88/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: spatial, reuse, access point, STA, pair, report, beamforming, collaborative set, interference, estimate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016-0150424 A1 (ELECTRONICS AND TELECOMMUNICATIONS RESEARCH INSTITUTE) 26 May 2016 See paragraphs [0033]-[0034], [0064], [0071], [0081], [0092], [0136]; and figure 1.	1-25
Y	US 2013-0208604 A1 (MOON-IL LEE et al.) 15 August 2013 See paragraphs [0004], [0098]-[0099], [0104], [0117], [0202]-[0204], [0225], [0227]; and figure 3.	1-25
Y	US 2014-0056205 A1 (FUTUREWEI TECHNOLOGIES, INC.) 27 February 2014 See paragraphs [0005]-[0006]; and figure 7.	7-9,16,22-24
A	US 2015-0382360 A1 (PO-KAI HUANG et al.) 31 December 2015 See paragraphs [0019]-[0028]; and figures 2-3.	1-25
A	KR 10-1269823 B1 (ALCATEL LUCENT) 30 May 2013 See paragraphs [0014]-[0017]; and figure 1.	1-25

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:
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"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 March 2018 (28.03.2018)	**29 March 2018 (29.03.2018)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/048192

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