US012395214B2

(12) **United States Patent**
Raghavan et al.

(10) **Patent No.: US 12,395,214 B2**
(45) **Date of Patent: Aug. 19, 2025**

(54) **SWITCHING TO AN ADAPTIVE BEAM WEIGHT-BASED HYBRID BEAMFORMING PROCEDURE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 429 days.

(21) Appl. No.: **17/880,482**

(22) Filed: **Aug. 3, 2022**

(65) **Prior Publication Data**

US 2024/0048198 A1 Feb. 8, 2024

(51) **Int. Cl.**
H04B 7/06 (2006.01)
H04B 7/08 (2006.01)
H04L 5/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H04B 7/0617*** (2013.01); ***H04B 7/088*** (2013.01); ***H04L 5/0051*** (2013.01)

(58) **Field of Classification Search**
CPC H04B 7/0617; H04B 7/088; H04B 7/0456; H04L 5/0051
See application file for complete search history.

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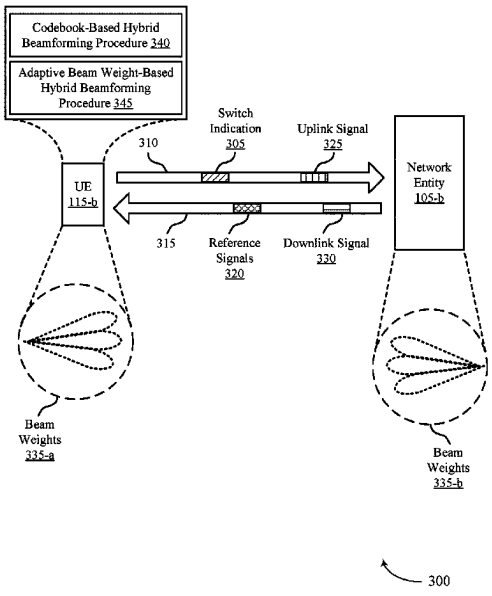
(57) **ABSTRACT**

Methods, systems, and devices for wireless communications are described. In some systems, a user equipment (UE) may detect a material proximate to the UE and may determine one or more properties of the material which may affect beamformed communications. The UE may transmit (e.g., based on the detected material) an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure. The UE may receive, from a network entity, one or more reference signals to use for adaptive beam weight selection in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure. The UE may communicate, with the network entity, in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

25 Claims, 18 Drawing Sheets



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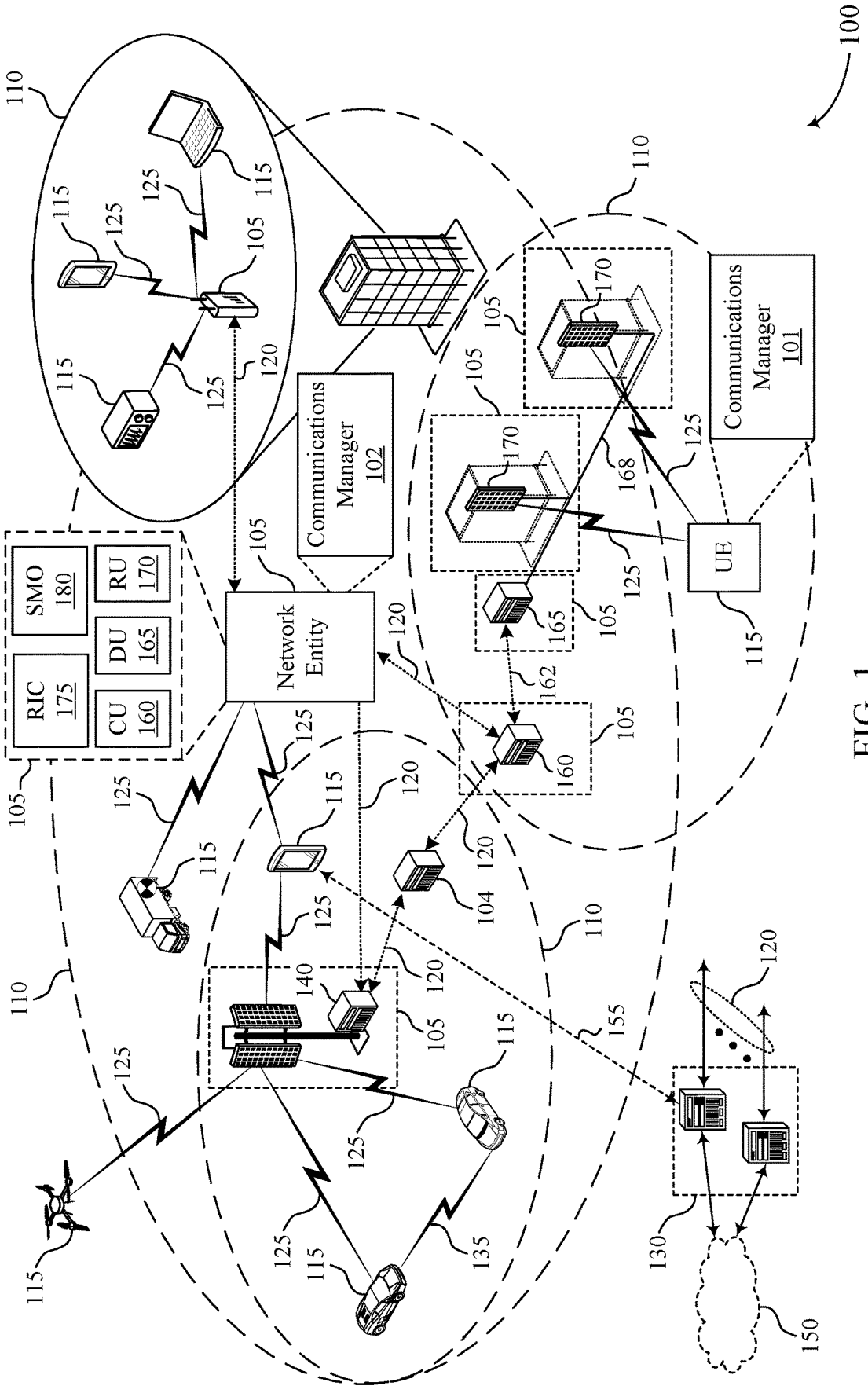
100
110
105
115
125
120
Communications Manager 102
Communications Manager 101
Network Entity
SMO 180
RU 170
RIC 175
DU 165
CU 160
UE
170
165
160
162
168
104
140
155
130
150
135

FIG. 1

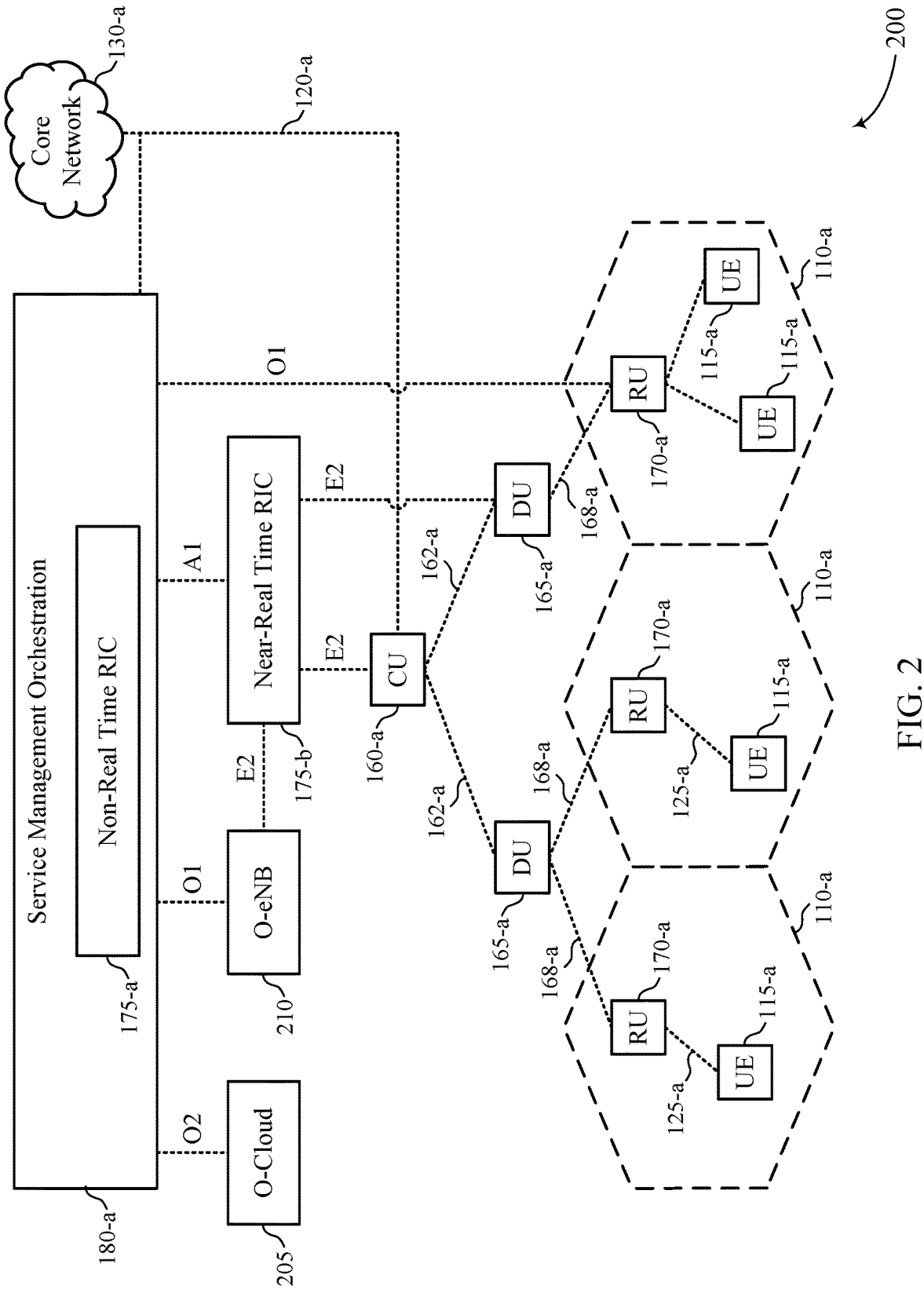
200
Core Network
130-a
120-a
Service Management Orchestration
180-a
Non-Real Time RIC
175-a
Near-Real Time RIC
175-b
O-eNB
210
O-Cloud
205
A1
O1
O1
O2
E2
E2
E2
CU
160-a
DU
165-a
RU
170-a
UE
115-a
162-a
168-a
125-a
110-a

FIG. 2

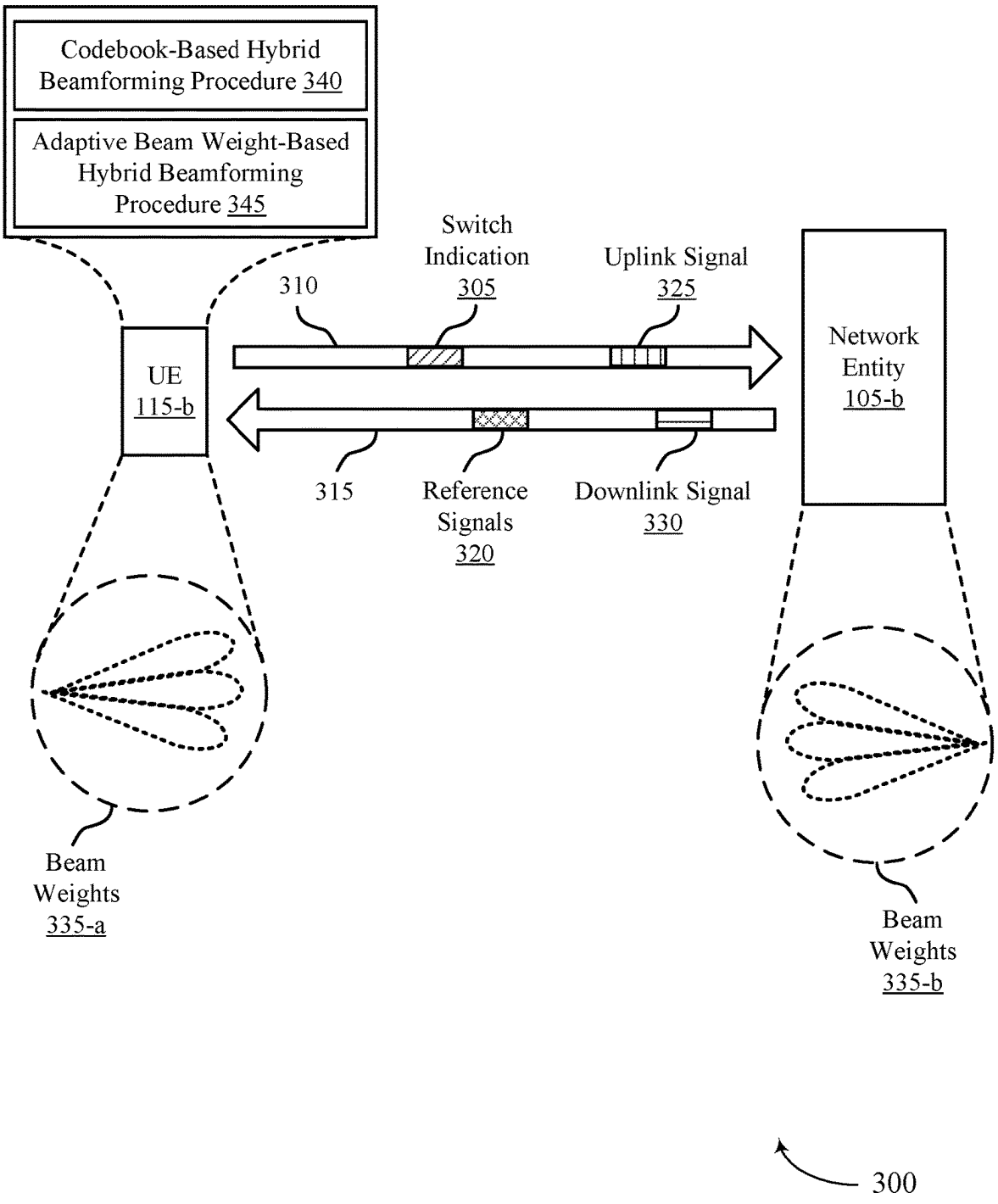
Codebook-Based Hybrid Beamforming Procedure 340
Adaptive Beam Weight-Based Hybrid Beamforming Procedure 345
UE 115-b
Network Entity 105-b
310
Switch Indication 305
Uplink Signal 325
315
Reference Signals 320
Downlink Signal 330
Beam Weights 335-a
Beam Weights 335-b
300

FIG. 3

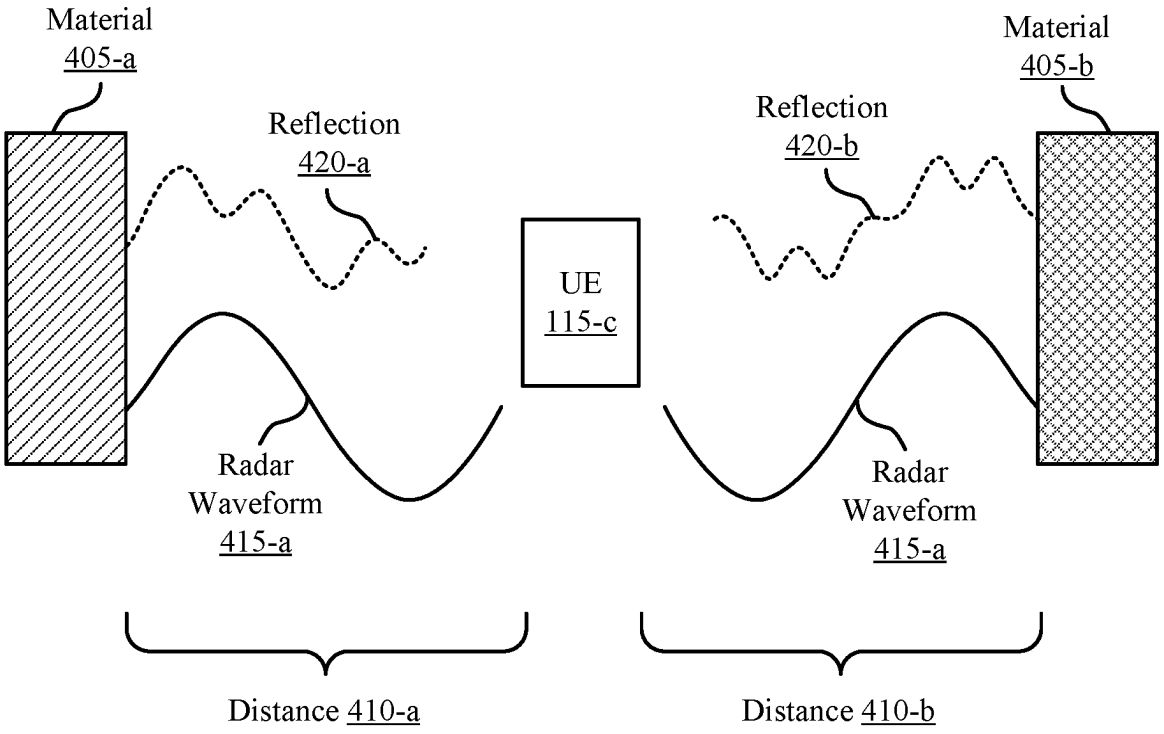
Material
405-a
Reflection
420-a
UE
115-c
Material
405-b
Reflection
420-b
Radar
Waveform
415-a
Radar
Waveform
415-a
Distance 410-a
Distance 410-b
400

FIG. 4

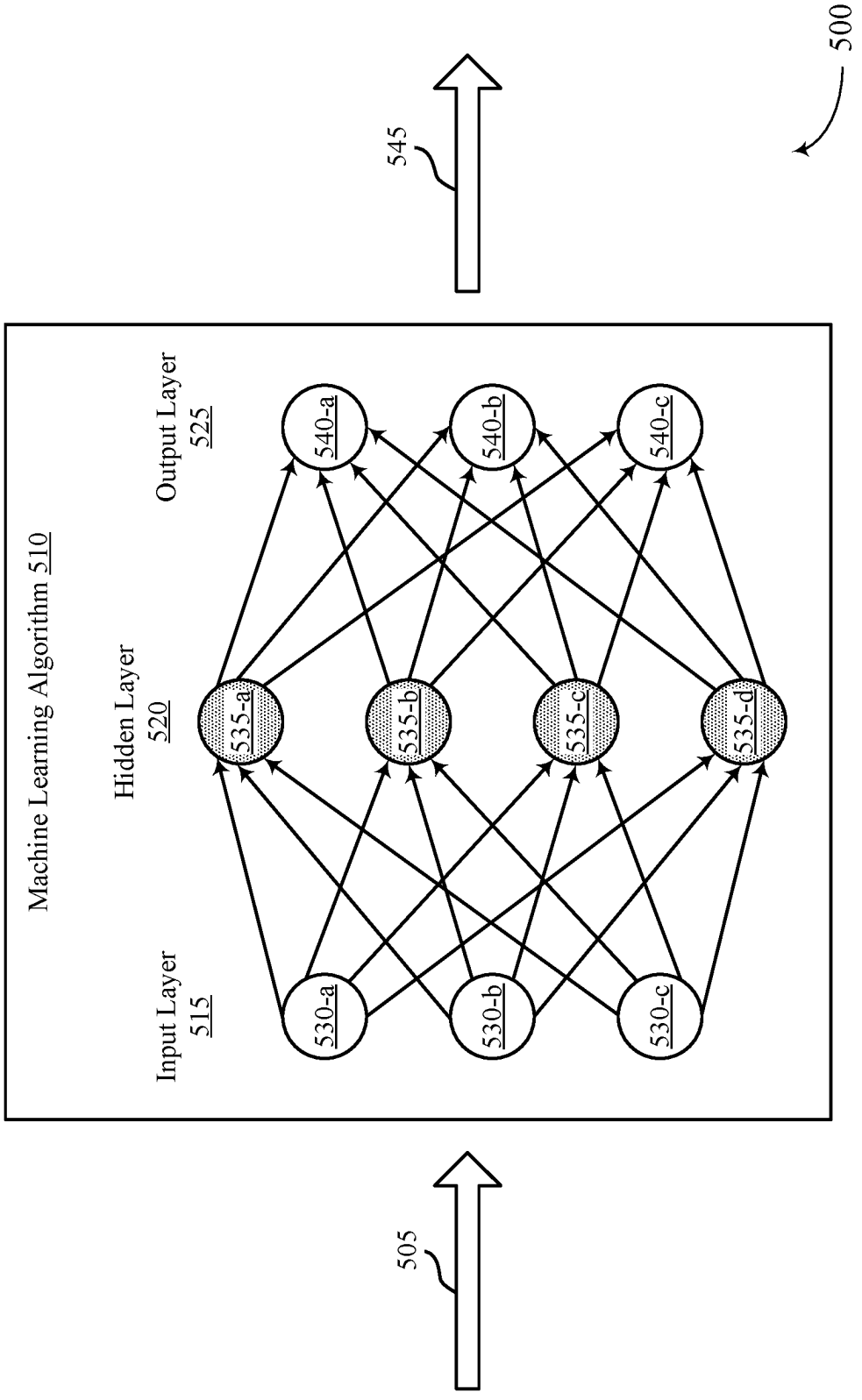
500
545
505
Machine Learning Algorithm 510
Input Layer 515
Hidden Layer 520
Output Layer 525
530-a
530-b
530-c
535-a
535-b
535-c
535-d
540-a
540-b
540-c

FIG. 5

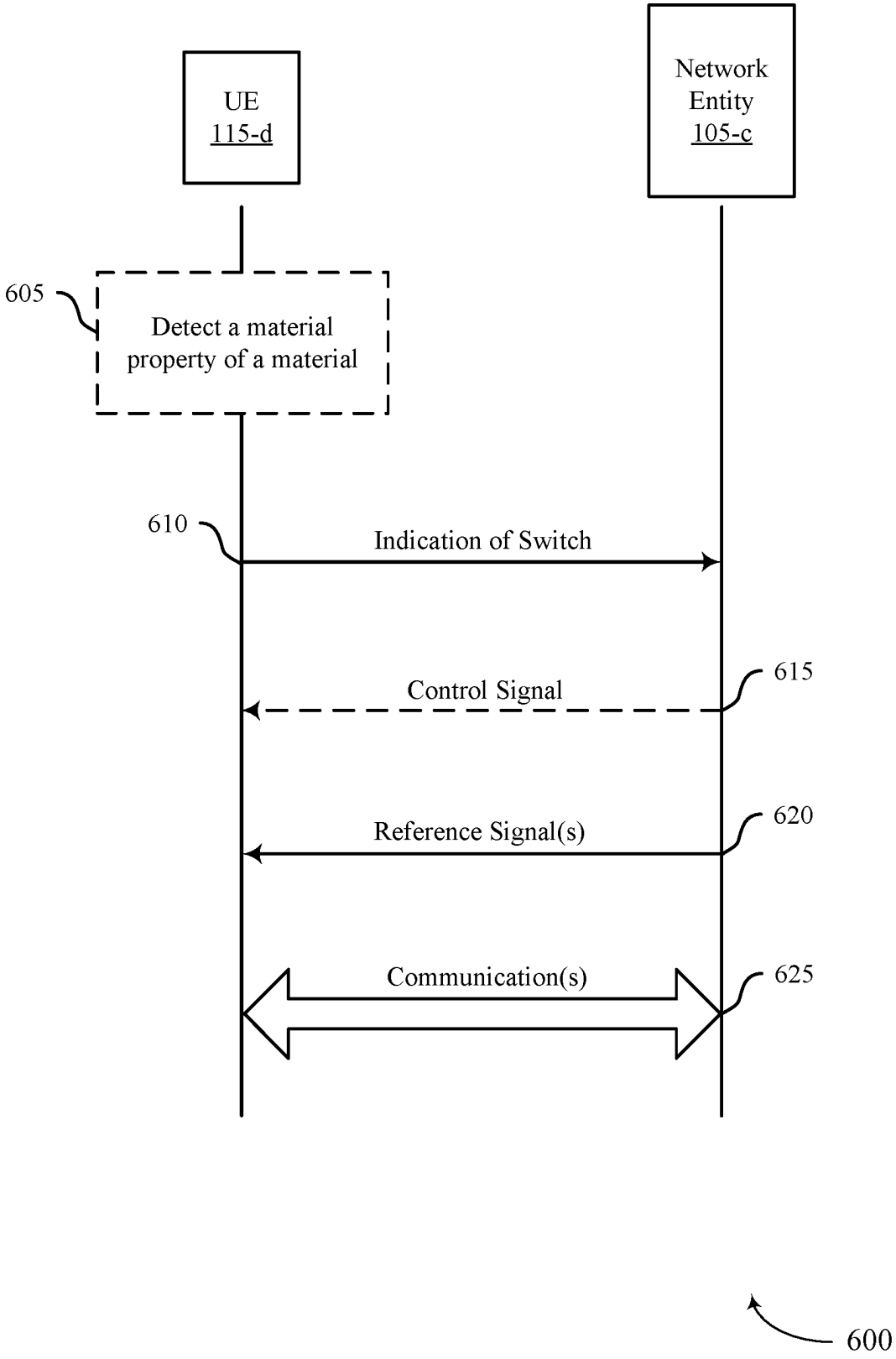
UE
115-d
Network
Entity
105-c
605
Detect a material
property of a material
610
Indication of Switch
Control Signal
615
Reference Signal(s)
620
Communication(s)
625
600

FIG. 6

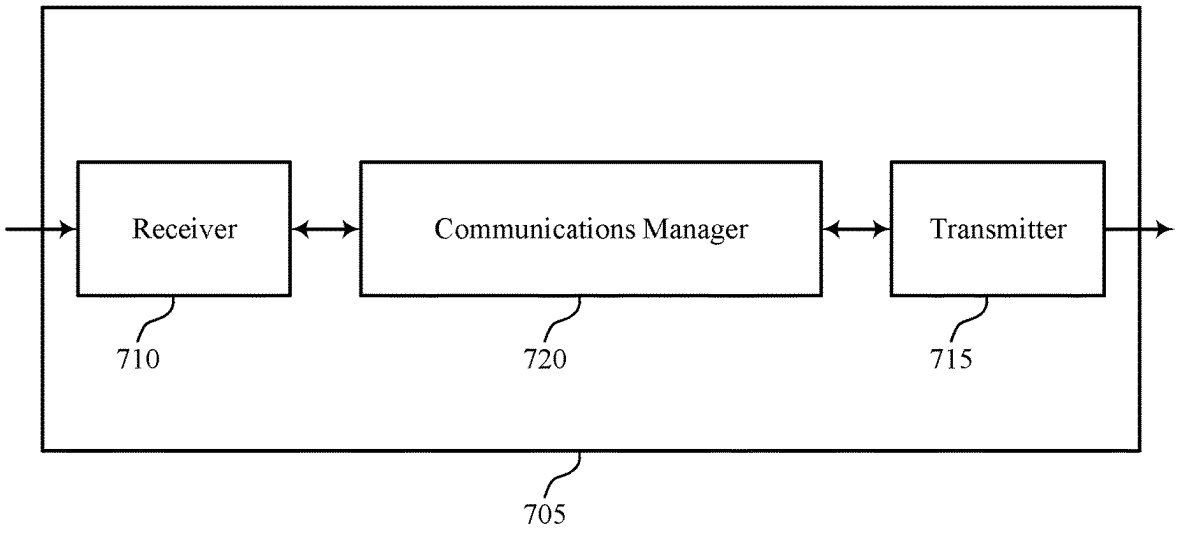
Receiver
Communications Manager
Transmitter
710
720
715
705
700

FIG. 7

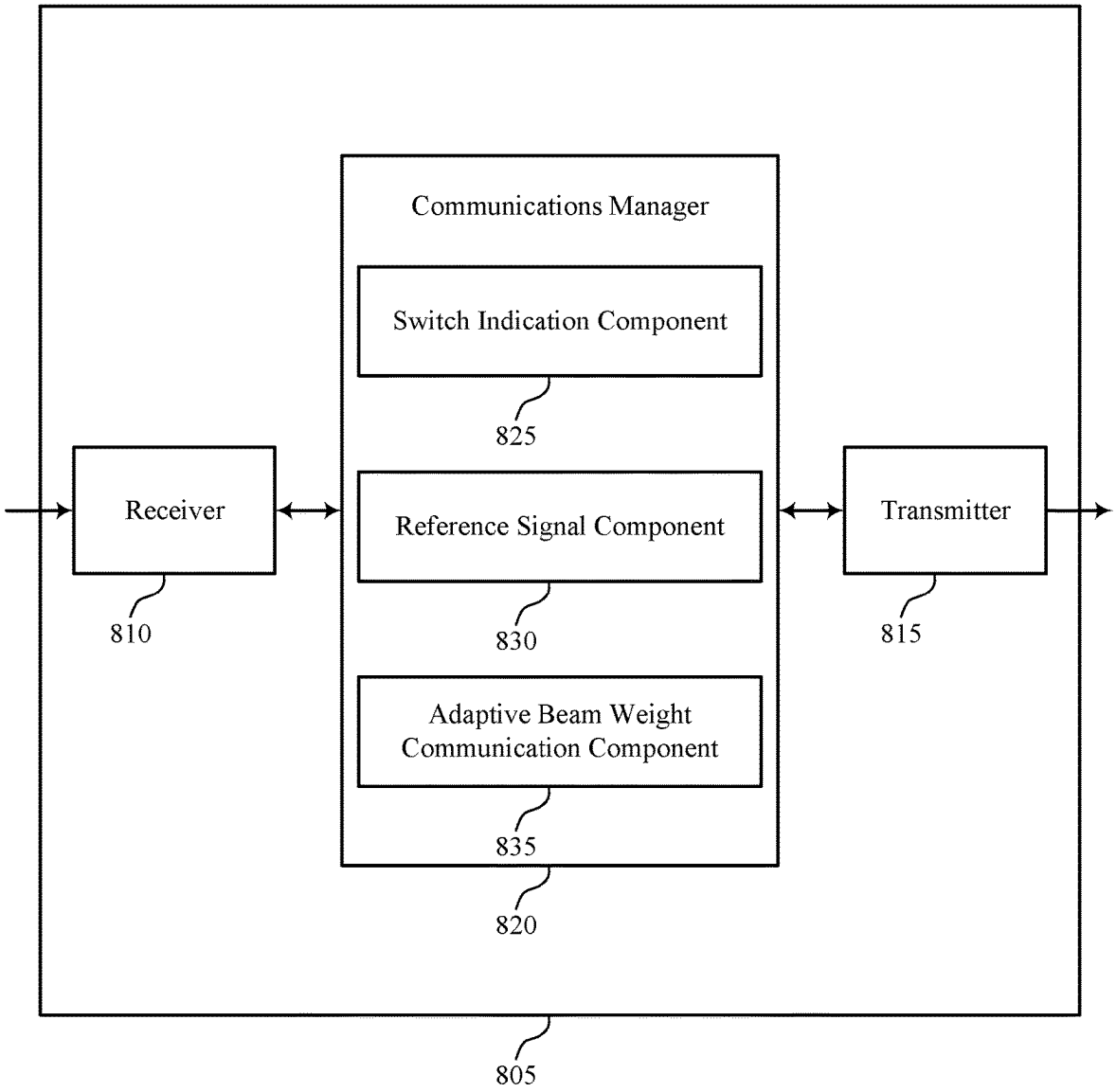
Communications Manager
Switch Indication Component
825
Receiver
Reference Signal Component
Transmitter
810
830
815
Adaptive Beam Weight Communication Component
835
820
805
800

FIG. 8

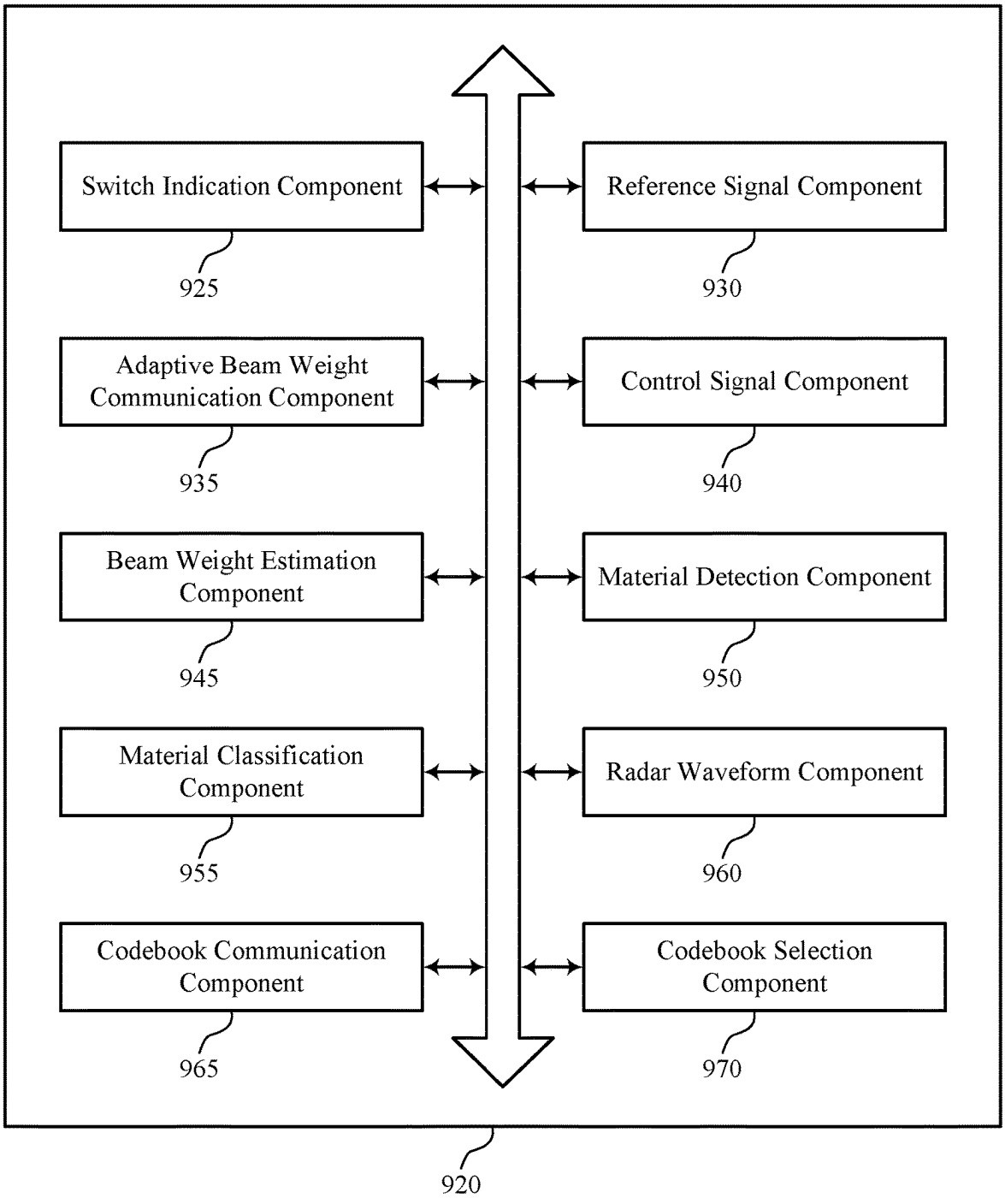
Switch Indication Component
925
Reference Signal Component
930
Adaptive Beam Weight Communication Component
935
Control Signal Component
940
Beam Weight Estimation Component
945
Material Detection Component
950
Material Classification Component
955
Radar Waveform Component
960
Codebook Communication Component
965
Codebook Selection Component
970
920
900

FIG. 9

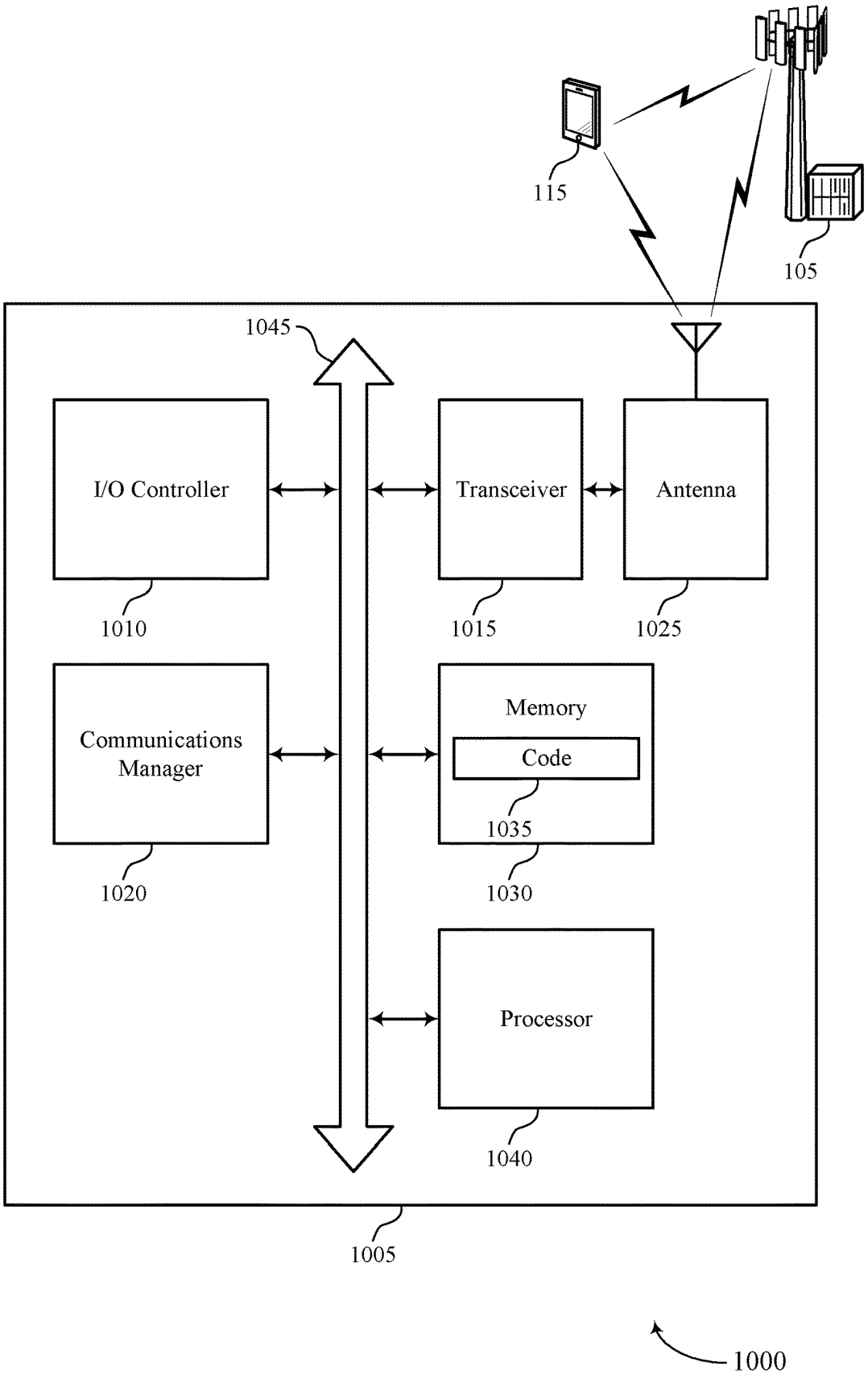
115
105
1045
I/O Controller
Transceiver
Antenna
1010
1015
1025
Communications Manager
Memory
Code
1035
1020
1030
Processor
1040
1005
1000

FIG. 10

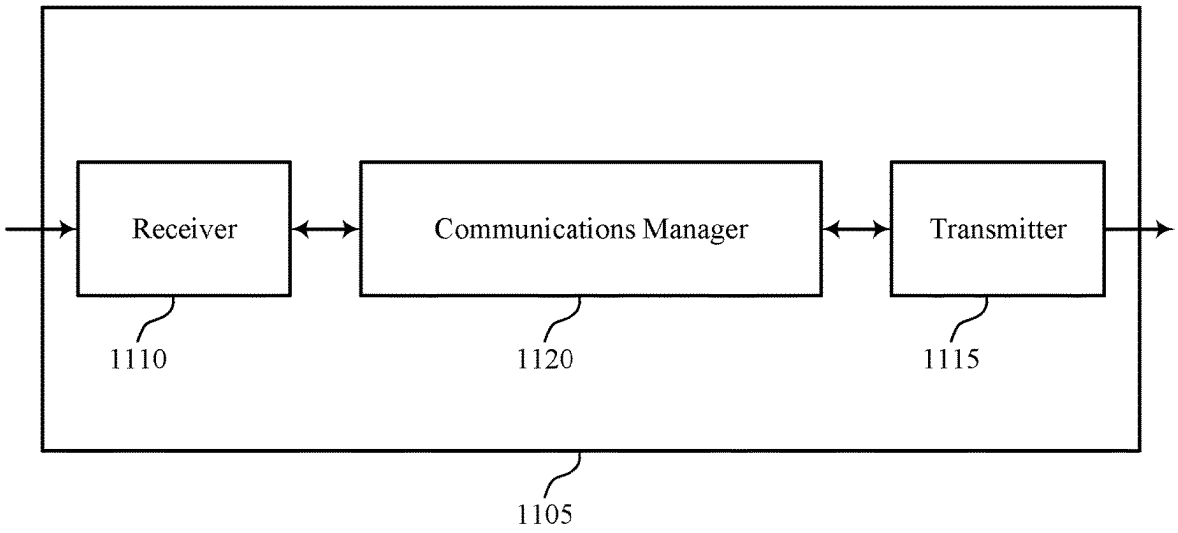
Receiver
Communications Manager
Transmitter
1110
1120
1115
1105
1100

FIG. 11

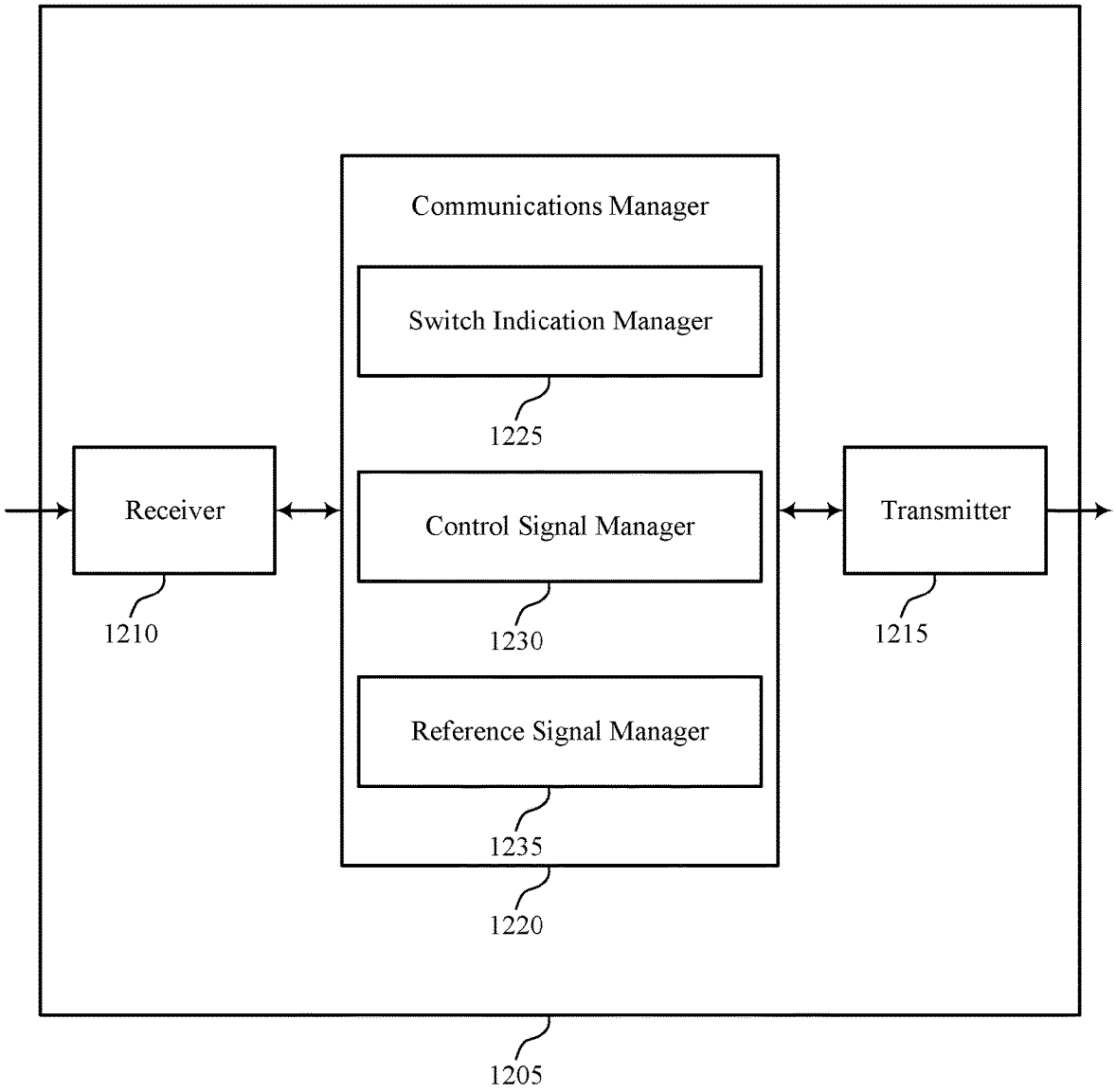
Communications Manager
Switch Indication Manager
1225
Receiver
Control Signal Manager
Transmitter
1210
1230
1215
Reference Signal Manager
1235
1220
1205
1200

FIG. 12

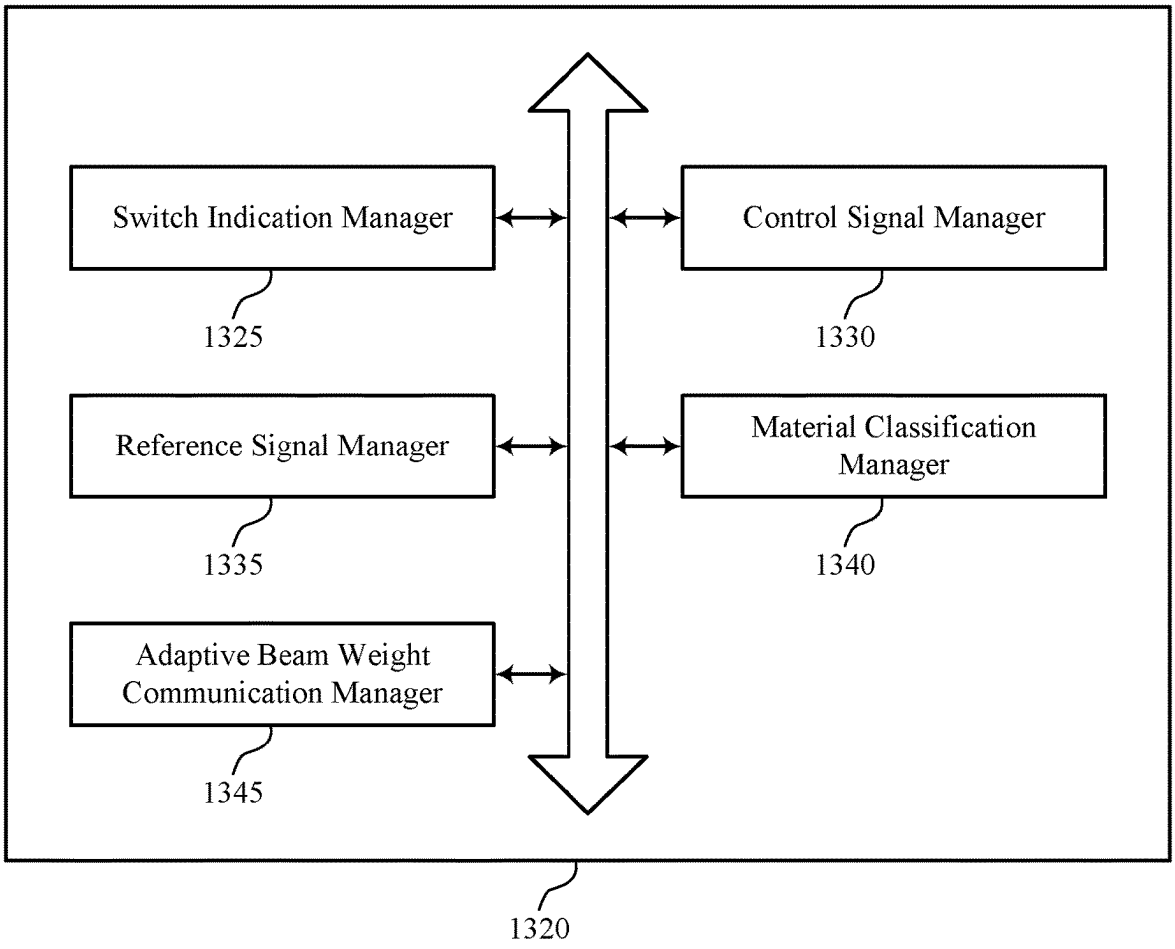
Switch Indication Manager
1325
Control Signal Manager
1330
Reference Signal Manager
1335
Material Classification Manager
1340
Adaptive Beam Weight Communication Manager
1345
1320
1300

FIG. 13

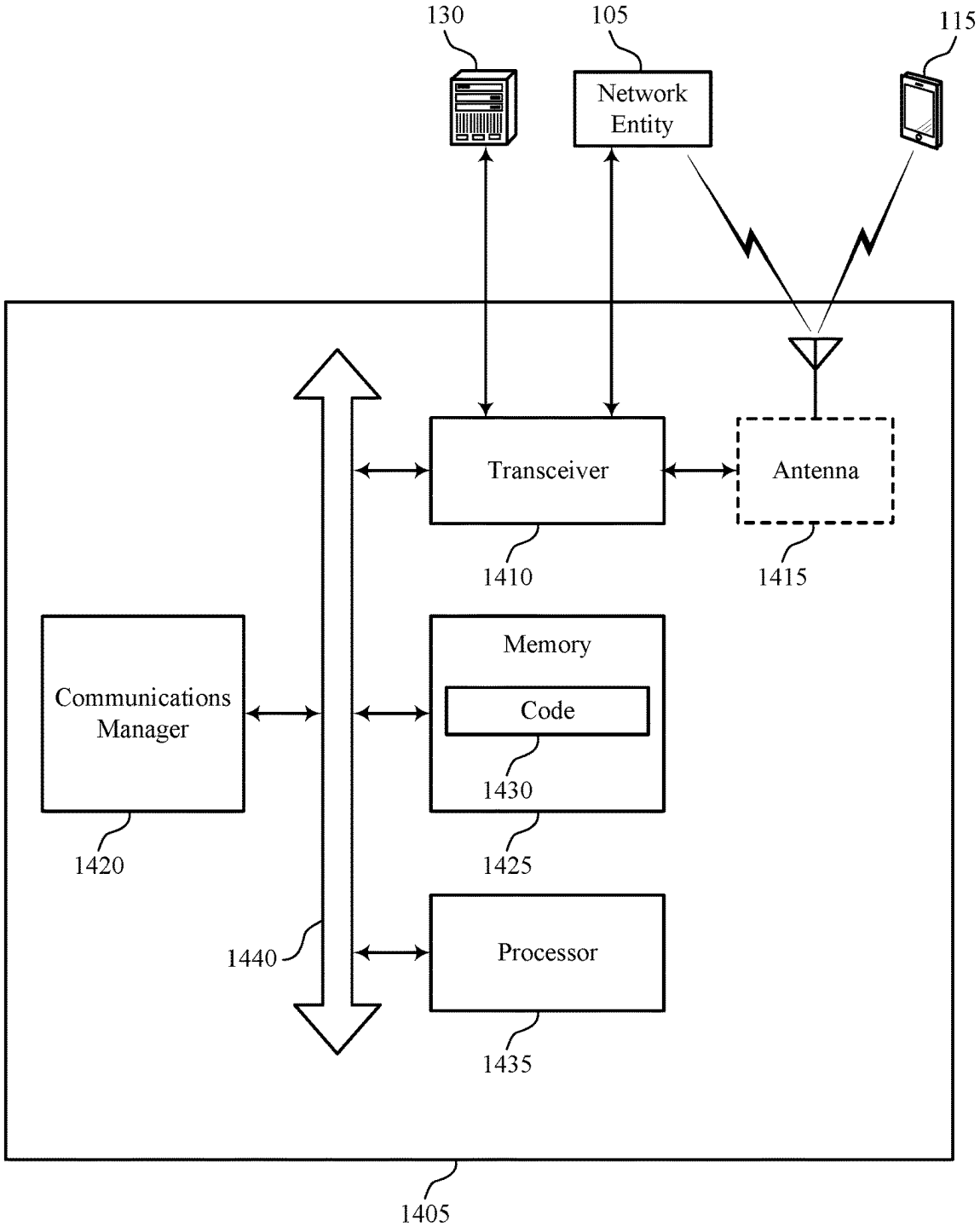
130
105
115
Network Entity
Transceiver
Antenna
1410
1415
Memory
Code
1430
Communications Manager
1420
1425
1440
Processor
1435
1405
1400

FIG. 14

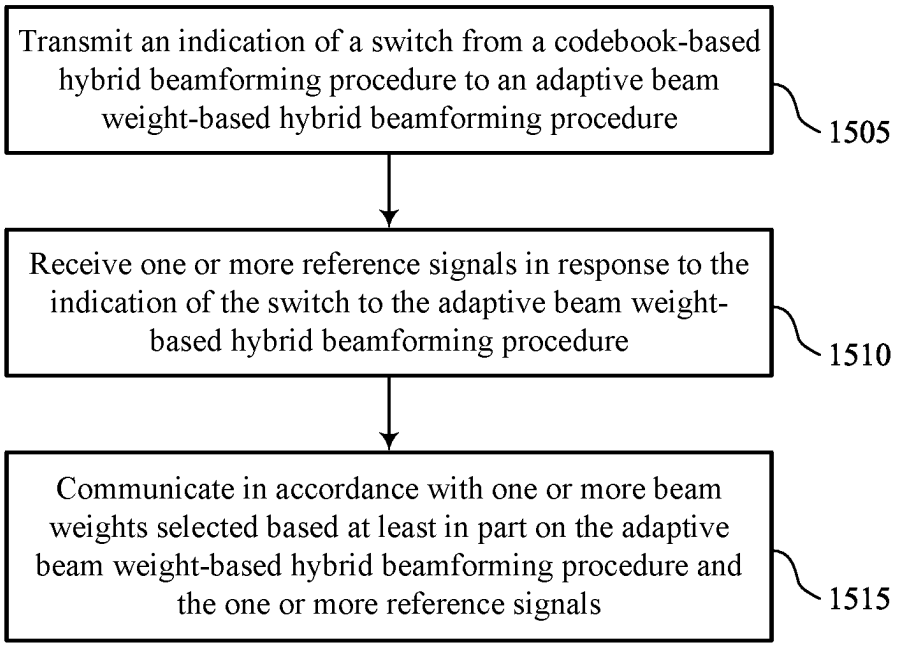
Transmit an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure
1505
Receive one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure
1510
Communicate in accordance with one or more beam weights selected based at least in part on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals
1515
1500

FIG. 15

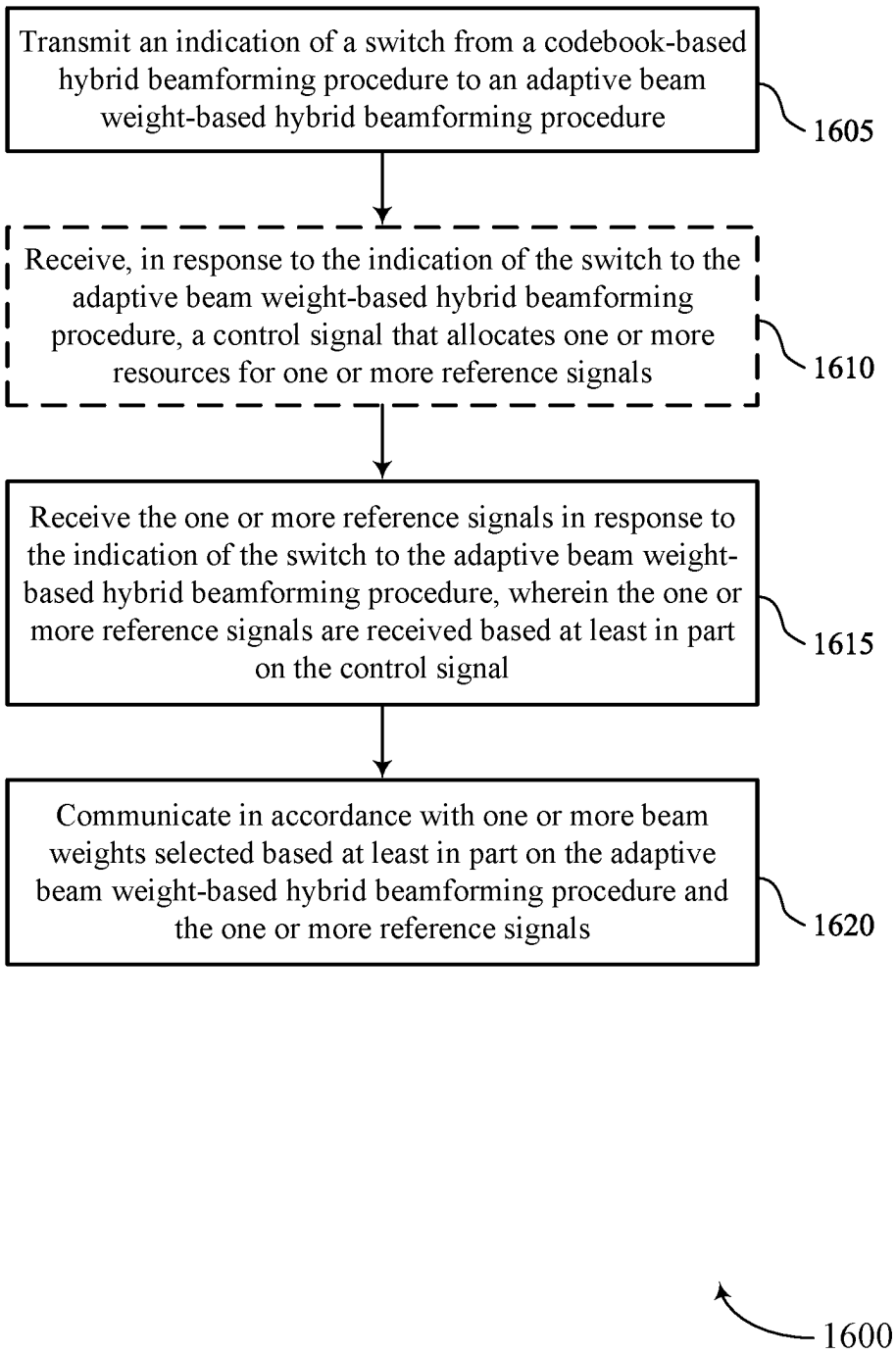
Transmit an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure
1605
Receive, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, a control signal that allocates one or more resources for one or more reference signals
1610
Receive the one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, wherein the one or more reference signals are received based at least in part on the control signal
1615
Communicate in accordance with one or more beam weights selected based at least in part on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals
1620
1600

FIG. 16

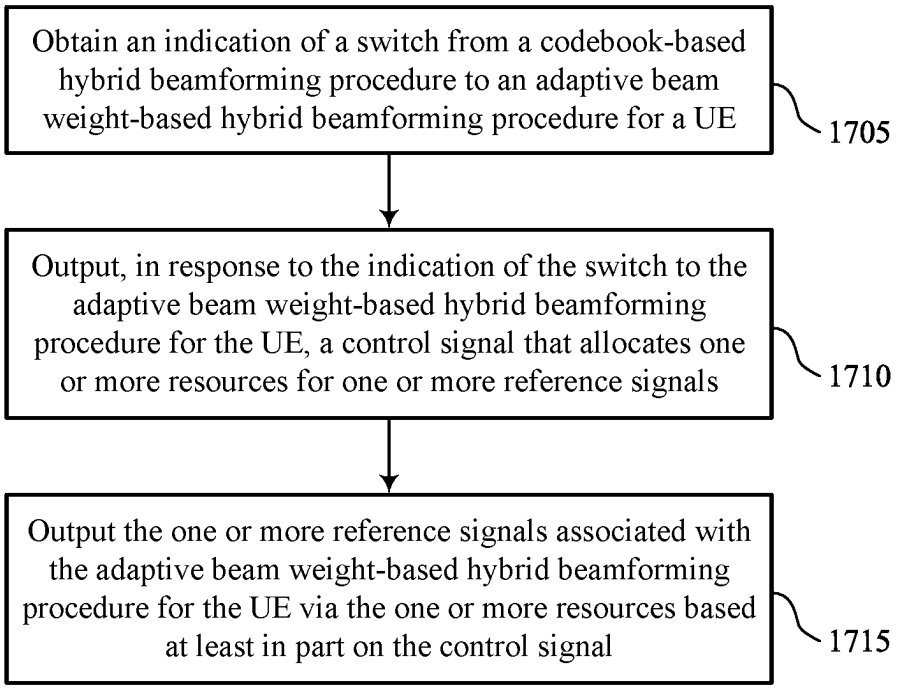
Obtain an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE
1705
Output, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals
1710
Output the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based at least in part on the control signal
1715
1700

FIG. 17

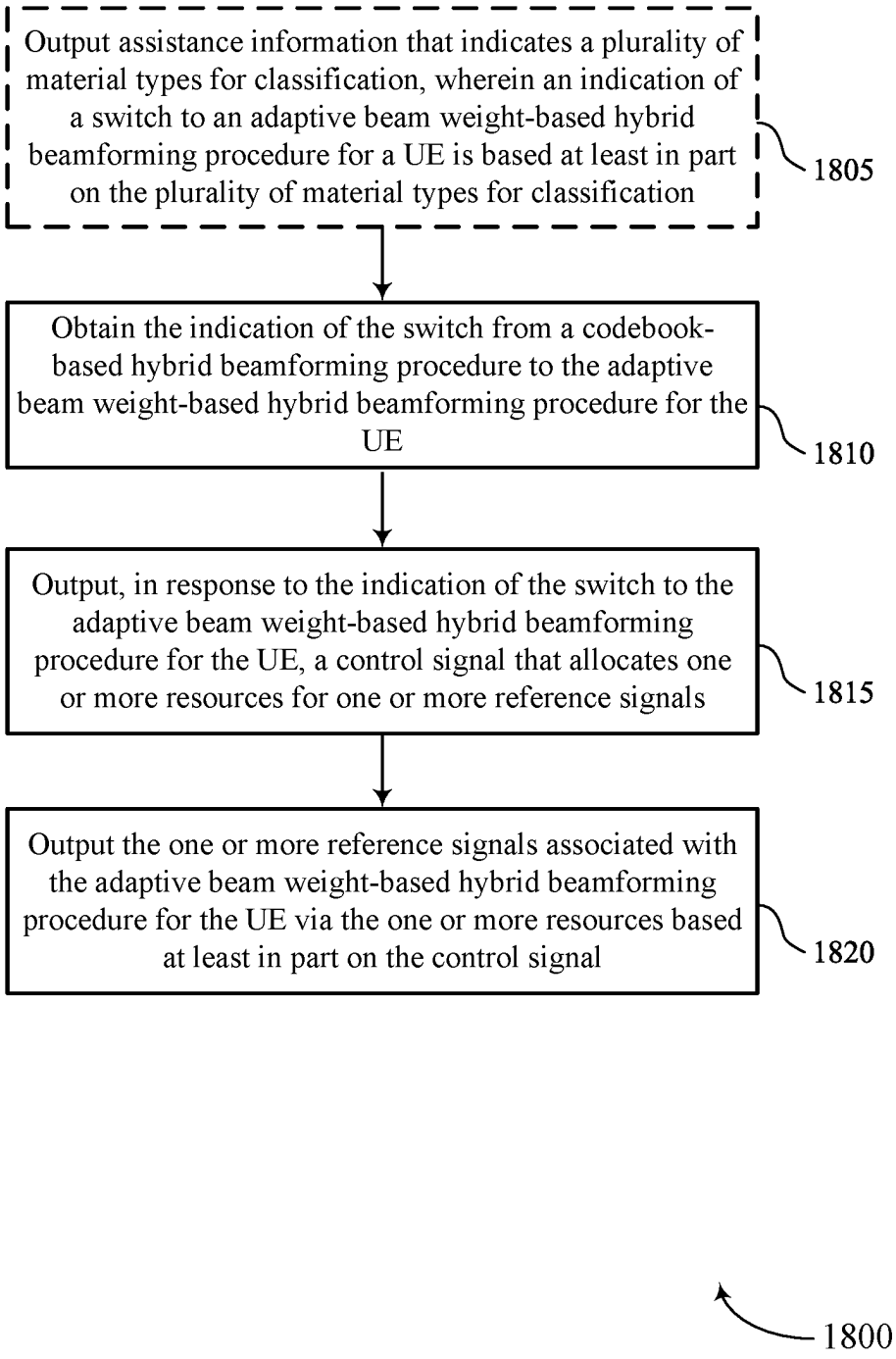
Output assistance information that indicates a plurality of material types for classification, wherein an indication of a switch to an adaptive beam weight-based hybrid beamforming procedure for a UE is based at least in part on the plurality of material types for classification
1805
Obtain the indication of the switch from a codebook-based hybrid beamforming procedure to the adaptive beam weight-based hybrid beamforming procedure for the UE
1810
Output, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals
1815
Output the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based at least in part on the control signal
1820
1800

FIG. 18

SWITCHING TO AN ADAPTIVE BEAM WEIGHT-BASED HYBRID BEAMFORMING PROCEDURE

FIELD OF TECHNOLOGY

The following relates to wireless communications, and more specifically to techniques for managing beamforming procedures.

INTRODUCTION

Wireless communications systems are widely deployed to provide various types of communication content such as voice, video, packet data, messaging, broadcast, and so on. These systems may be capable of supporting communication with multiple users by sharing the available system resources (e.g., time, frequency, and power). Examples of such multiple-access systems include fourth generation (4G) systems such as Long Term Evolution (LTE) systems, LTE-Advanced (LTE-A) systems, or LTE-A Pro systems, and fifth generation (5G) systems which may be referred to as New Radio (NR) systems. These systems may employ technologies such as code division multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), or discrete Fourier transform spread orthogonal frequency division multiplexing (DFT-S-OFDM). A wireless multiple-access communications system may include one or more base stations, each supporting wireless communication for communication devices, which may be known as user equipment (UE).

SUMMARY

A method for wireless communications at a UE is described. The method may include transmitting an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure, receiving one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, and communicating in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

An apparatus for wireless communications at a UE is described. The apparatus may include a processor and memory coupled with the processor. The processor may be configured to transmit an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure, receive one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, and communicate in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

Another apparatus for wireless communications at a UE is described. The apparatus may include means for transmitting an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure, means for receiving one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, and means for communicating in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

A non-transitory computer-readable medium storing code for wireless communications at a UE is described. The code may include instructions executable by a processor to transmit an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure, receive one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, and communicate in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for receiving, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, a control signal that allocates one or more resources for the one or more reference signals, where the one or more reference signals may be received based on the control signal.

In some examples of the method, apparatuses, and non-transitory computer-readable medium described herein, receiving the one or more reference signals may include operations, features, means, or instructions for receiving one or more channel state information reference signals (CSI-RSs), one or more sounding reference signals (SRSs), or a combination thereof for beam weight estimation and selection.

Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for dynamically performing beam weight estimation based on the one or more reference signals, where the one or more beam weights may be based on the beam weight estimation.

Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for detecting a dielectric property, a conductivity property, or both for a material within a threshold distance from the UE and communicating using the adaptive beam weight-based hybrid beamforming procedure based on the detected dielectric property, the detected conductivity property, or both.

Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for classifying the material with a material type from a set of multiple material types based on the detected dielectric property, the detected conductivity property, or both, where communicating using the adaptive beam weight-based hybrid beamforming procedure may be based on the material type.

Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for receiving assistance information that indicates the set of multiple material types for classification, where the material may be classified with the material type based on the assistance information.

Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for transmitting a radar waveform and receiving, in response to the radar waveform, a reflection of the radar waveform

from the material within the threshold distance from the UE, where communicating using the adaptive beam weight-based hybrid beamforming procedure may be based on a distortion metric of the reflection of the radar waveform that satisfies a distortion threshold.

Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for inputting one or more waveform parameters of the reflection of the radar waveform into a machine learning model, where the one or more waveform parameters include at least the distortion metric. Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for classifying the material with a material type in accordance with an output of the machine learning model based on the one or more waveform parameters input into the machine learning model.

Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for detecting a second material property for a second material within the threshold distance from the UE, communicating using the codebook-based hybrid beamforming procedure based on the second material property for the second material, and selecting a codebook from a set of multiple codebooks based on the codebook-based hybrid beamforming procedure and the second material property for the second material.

In some examples of the method, apparatuses, and non-transitory computer-readable medium described herein, the set of multiple codebooks indicates different quantities of beam weights, different beam properties, different phase quantization for the beam weights, different amplitude quantization for the beam weights, or any combination thereof.

A method for wireless communications is described. The method may include obtaining an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE, outputting, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals, and outputting the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based on the control signal.

An apparatus for wireless communications is described. The apparatus may include a processor and memory coupled with the processor. The processor may be configured to obtain an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE, output, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals, and output the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based on the control signal.

Another apparatus for wireless communications is described. The apparatus may include means for obtaining an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE, means for outputting, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals, and means for outputting the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based on the control signal.

A non-transitory computer-readable medium storing code for wireless communications is described. The code may include instructions executable by a processor to obtain an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE, output, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals, and output the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based on the control signal.

Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for outputting assistance information that indicates a set of multiple material types for classification, where the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE may be based on the set of multiple material types for classification.

Some examples of the method, apparatuses, and non-transitory computer-readable medium described herein may further include operations, features, means, or instructions for obtaining or outputting one or more communications based on the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE.

In some examples of the method, apparatuses, and non-transitory computer-readable medium described herein, outputting the one or more reference signals may include operations, features, means, or instructions for outputting one or more CSI-RSs, one or more SRSs, or a combination thereof for beam weight estimation and selection.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an example of a wireless communications system that supports switching to an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIG. **2** illustrates an example of a network architecture that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIG. **3** illustrates an example of a wireless communications system that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIG. **4** illustrates an example of a material classification scheme that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIG. **5** illustrates an example of a machine learning process that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIG. **6** illustrates an example of a process flow that supports techniques for managing an adaptive beam weight-

based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIGS. **7** and **8** show block diagrams of devices that support techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIG. **9** shows a block diagram of a communications manager that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIG. **10** shows a diagram of a system including a device that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIGS. **11** and **12** show block diagrams of devices that support techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIG. **13** shows a block diagram of a communications manager that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIG. **14** shows a diagram of a system including a device that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

FIGS. **15** through **18** show flowcharts illustrating methods that support techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure.

DETAILED DESCRIPTION

A wireless communications system may include a device, such as a UE or a network entity (e.g., an eNodeB (eNB), a next-generation NodeB or a giga-NodeB, either of which may be referred to as a gNB, or some other base station or network entity), that supports wireless communications using one or multiple radio access technologies. Examples of radio access technologies include 4G systems, such as LTE systems, 5G systems, which may be referred to as NR systems, or other systems and radio technologies, including future systems and radio technologies not explicitly mentioned herein (e.g., sixth generation (6G) systems). In the wireless communications system, a UE may be surrounded by—or located near—a material. For example, the UE (e.g., a mobile phone) may be positioned in a user's hand or may be lying on a table. Different materials may have different material properties, such as reflectivity, conductivity, permissivity, or other associated dielectric properties. Due to the different dielectric properties of different materials, a UE may experience different effective array gain responses for beamformed communications based on the UE being located near different types of materials. Accordingly, the performance of beamformed communications at the UE may change based on the materials near or around the UE.

The UE may detect one or more materials proximate to the UE and may perform beamforming operations in order to select at least some beam parameters (e.g., beam weights, beam properties, phase quantization for the beam weights, amplitude quantization for the beam weights) for communications with other UEs or a network entity. In some cases, the UE may perform such beamforming operations in accordance with a codebook-based hybrid beamforming procedure or an adaptive beam weight-based hybrid beamforming procedure. As described herein, the codebook-based hybrid beamforming procedure may refer to a beamforming process involving a static codebook, and the adaptive beam weight-based hybrid beamforming procedure may refer to a dynamic beam weight selection. If the UE performs beamforming according to the codebook-based hybrid beamforming procedure, the UE may select beam weights to be used for beamforming from a configured (e.g., a priori) set of possible values defined for the codebook. If the UE performs beamforming communications according to the adaptive beam weight-based hybrid beamforming procedure, the UE may receive one or more reference signals to learn beam weights via a machine learning process, such that the UE may train a machine learning algorithm to select more optimal beam weights (e.g., supporting additional beam weight values beyond a configured set for a codebook). The UE may support additional flexibility in beamforming operations and relatively more beam weight options for communications by using the adaptive beam weight-based hybrid beamforming procedure in comparison to the codebook-based hybrid beamforming procedure. However, the UE may support improved beamforming complexity and processing overhead by using the codebook-based hybrid beamforming procedure as compared to the adaptive beam weight-based hybrid beamforming procedure.

As described herein, a device may support techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with a switch indication. In some examples, a UE may tailor beamforming operations in accordance with the sensing of a material surrounding—or otherwise near—the UE. For example, the UE may detect a material property (e.g., a dielectric property) of a material that is within a threshold distance from the UE. In some cases, the UE may classify the material with a material type based on the detected material property. Based on the detected material (e.g., the classification of the material), the UE may determine whether the cost associated with processing reference signals for beam weight learning is worth the performance gains that may result from the adaptive beam weight-based hybrid beamforming procedure in the presence of the material.

Based on the classified material type of the detected material, the UE may transmit, to a network entity, an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure. For instance, if the UE classifies the material type to be one of relatively high conductivity (e.g., a metal or other material relatively close in dielectric property to a metal such as a human hand or body part made mostly of water which is a metallic conductor), the UE may transmit an indication of a switch to an adaptive beam weight-based hybrid beamforming procedure because the UE may determine that the processing cost for using the adaptive beam weight-based hybrid beamforming procedure may be worth the higher gain resulting from the relatively high conductivity material type. Alternatively, if the UE classifies the material type to be one of relatively low conductivity (e.g., wood), the UE may refrain from transmitting an indication of a switch to an adaptive beam weight-based hybrid beamforming procedure because the UE may determine that the processing cost for using the adaptive beam weight-based hybrid beamforming procedure may not be worth the lower gain resulting from the relatively low conductivity material type. In response to transmitting the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, the UE may receive one or more reference signals for beam weight learning and may perform beam weight estimation of an adaptive type to select one or more beam weights based on the one or more

reference signals. In accordance with the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals, the UE may communicate (e.g., with a network entity, with another UE) using the one or more selected beam weights.

Aspects of the subject matter described herein may be implemented by a device to support reduced processing complexity at the UE. For example, the UE may refrain from transmitting an indication of a switch from a codebook-based beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure based on one or more materials detected near the UE and may instead communicate using beam weights selected using the codebook-based beamforming procedure to support a reduced processing overhead associated with beamforming at the UE. Additionally, or alternatively, the UE may transmit the indication of the switch and communicate using beam weights estimated using the adaptive beam weight-based hybrid beamforming procedure to improve antenna array gain and—correspondingly—signal quality and communication reliability based on the one or more materials detected near the UE. Accordingly, the UE may manage saving processing resources (and thereby power consumption and the resultant thermal overhead) and supporting beam weight flexibility for performing beamforming operations with the switch indication, for example, based on material detection at the UE.

Aspects of the disclosure are initially described in the context of wireless communications systems. Examples of a material classification scheme, a machine learning process, and a process flow supporting techniques for managing an adaptive beam weight-based hybrid beamforming procedure are then described. Aspects of the disclosure are further illustrated by and described with reference to apparatus diagrams, system diagrams, and flowcharts that relate to switching to an adaptive beam weight-based hybrid beamforming procedure.

FIG. **1** illustrates an example of a wireless communications system **100** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The wireless communications system **100** may include one or more network entities **105**, one or more UEs **115**, and a core network **130**. In some examples, the wireless communications system **100** may be an LTE network, an LTE-Advanced (LTE-A) network, an LTE-A Pro network, an NR network, or a network operating in accordance with other systems and radio technologies, including future systems and radio technologies not explicitly mentioned herein.

The network entities **105** may be dispersed throughout a geographic area to form the wireless communications system **100** and may include devices in different forms or having different capabilities. In various examples, a network entity **105** may be referred to as a network element, a mobility element, a radio access network (RAN) node, or network equipment, among other nomenclature. In some examples, network entities **105** and UEs **115** may wirelessly communicate via one or more communication links **125** (e.g., a radio frequency (RF) access link). For example, a network entity **105** may support a coverage area **110** (e.g., a geographic coverage area) over which the UEs **115** and the network entity **105** may establish one or more communication links **125**. The coverage area **110** may be an example of a geographic area over which a network entity **105** and a UE **115** may support the communication of signals according to one or more radio access technologies (RATs).

The UEs **115** may be dispersed throughout a coverage area **110** of the wireless communications system **100**, and each UE **115** may be stationary, or mobile, or both at different times. The UEs **115** may be devices in different forms or having different capabilities. Some example UEs **115** are illustrated in FIG. **1**. The UEs **115** described herein may be capable of supporting communications with various types of devices, such as other UEs **115** or network entities **105**, as shown in FIG. **1**.

As described herein, a node of the wireless communications system **100**, which may be referred to as a network node, or a wireless node, may be a network entity **105** (e.g., any network entity described herein), a UE **115** (e.g., any UE described herein), a network controller, an apparatus, a device, a computing system, one or more components, or another suitable processing entity configured to perform any of the techniques described herein. For example, a node may be a UE **115**. As another example, a node may be a network entity **105**. As another example, a first node may be configured to communicate with a second node or a third node. In one aspect of this example, the first node may be a UE **115**, the second node may be a network entity **105**, and the third node may be a UE **115**. In another aspect of this example, the first node may be a UE **115**, the second node may be a network entity **105**, and the third node may be a network entity **105**. In yet other aspects of this example, the first, second, and third nodes may be different relative to these examples. Similarly, reference to a UE **115**, network entity **105**, apparatus, device, computing system, or the like may include disclosure of the UE **115**, network entity **105**, apparatus, device, computing system, or the like being a node. For example, disclosure that a UE **115** is configured to receive information from a network entity **105** also discloses that a first node is configured to receive information from a second node.

Consistent with this disclosure, once a specific example is broadened in accordance with this disclosure (e.g., a UE is configured to receive information from a base station also discloses that a first network node is configured to receive information from a second network node), the broader example of the narrower example may be interpreted in the reverse, but in a broad open-ended way. In the example above where a UE being configured to receive information from a network entity also discloses that a first network node being configured to receive information from a second network node, the first network node may refer to a first UE, a first base station, a first apparatus, a first device, a first computing system, a first one or more components, a first processing entity, or the like configured to receive the information; and the second network node may refer to a second UE, a second base station, a second apparatus, a second device, a second computing system, a second one or more components, a second processing entity, or the like.

As described herein, communication of information (e.g., any information, signal, or the like) may be described in various aspects using different terminology. Disclosure of one communication term includes disclosure of other communication terms. For example, a first network node may be described as being configured to transmit information to a second network node. In this example and consistent with this disclosure, disclosure that the first network node is configured to transmit information to the second network node includes disclosure that the first network node is configured to provide, send, output, communicate, or transmit information to the second network node. Similarly, in this example and consistent with this disclosure, disclosure that the first network node is configured to transmit information to the second network node includes disclosure that the second network node is configured to receive, obtain, or

decode the information that is provided, sent, output, communicated, or transmitted by the first network node.

In some examples, network entities **105** may communicate with the core network **130**, or with one another, or both. For example, network entities **105** may communicate with the core network **130** via one or more backhaul communication links **120** (e.g., in accordance with an S1, N2, N3, or other interface protocol). In some examples, network entities **105** may communicate with one another via a backhaul communication link **120** (e.g., in accordance with an X2, Xn, or other interface protocol) either directly (e.g., directly between network entities **105**) or indirectly (e.g., via a core network **130**). In some examples, network entities **105** may communicate with one another via a midhaul communication link **162** (e.g., in accordance with a midhaul interface protocol) or a fronthaul communication link **168** (e.g., in accordance with a fronthaul interface protocol), or any combination thereof. The backhaul communication links **120**, midhaul communication links **162**, or fronthaul communication links **168** may be or include one or more wired links (e.g., an electrical link, an optical fiber link), one or more wireless links (e.g., a radio link, a wireless optical link), among other examples or various combinations thereof. A UE **115** may communicate with the core network **130** via a communication link **155**.

One or more of the network entities **105** described herein may include or may be referred to as a base station **140** (e.g., a base transceiver station, a radio base station, an NR base station, an access point, a radio transceiver, a NodeB, an eNB, a next-generation NodeB or a giga-NodeB (either of which may be referred to as a gNB), a 5G NB, a next-generation eNB (ng-eNB), a Home NodeB, a Home eNodeB, or other suitable terminology). In some examples, a network entity **105** (e.g., a base station **140**) may be implemented in an aggregated (e.g., monolithic, standalone) base station architecture, which may be configured to utilize a protocol stack that is physically or logically integrated within a single network entity **105** (e.g., a single RAN node, such as a base station **140**).

In some examples, a network entity **105** may be implemented in a disaggregated architecture (e.g., a disaggregated base station architecture, a disaggregated RAN architecture), which may be configured to utilize a protocol stack that is physically or logically distributed among two or more network entities **105**, such as an integrated access backhaul (IAB) network, an open RAN (O-RAN) (e.g., a network configuration sponsored by the O-RAN Alliance), or a virtualized RAN (vRAN) (e.g., a cloud RAN (C-RAN)). For example, a network entity **105** may include one or more of a central unit (CU) **160**, a distributed unit (DU) **165**, a radio unit (RU) **170**, a RAN Intelligent Controller (RIC) **175** (e.g., a Near-Real Time RIC (Near-RT RIC), a Non-Real Time RIC (Non-RT RIC)), a Service Management and Orchestration (SMO) **180** system, or any combination thereof. An RU **170** may also be referred to as a radio head, a smart radio head, a remote radio head (RRH), a remote radio unit (RRU), or a transmission reception point (TRP). One or more components of the network entities **105** in a disaggregated RAN architecture may be co-located, or one or more components of the network entities **105** may be located in distributed locations (e.g., separate physical locations). In some examples, one or more network entities **105** of a disaggregated RAN architecture may be implemented as virtual units (e.g., a virtual CU (VCU), a virtual DU (VDU), a virtual RU (VRU)).

The split of functionality between a CU **160**, a DU **165**, and an RU **170** is flexible and may support different functionalities depending on which functions (e.g., network layer functions, protocol layer functions, baseband functions, RF functions, and any combinations thereof) are performed at a CU **160**, a DU **165**, or an RU **170**. For example, a functional split of a protocol stack may be employed between a CU **160** and a DU **165** such that the CU **160** may support one or more layers of the protocol stack and the DU **165** may support one or more different layers of the protocol stack. In some examples, the CU **160** may host upper protocol layer (e.g., layer 3 (L3), layer 2 (L2)) functionality and signaling (e.g., Radio Resource Control (RRC), service data adaption protocol (SDAP), Packet Data Convergence Protocol (PDCP)). The CU **160** may be connected to one or more DUs **165** or RUs **170**, and the one or more DUs **165** or RUs **170** may host lower protocol layers, such as layer 1 (L1) (e.g., physical (PHY) layer) or L2 (e.g., radio link control (RLC) layer, medium access control (MAC) layer) functionality and signaling and may each be at least partially controlled by the CU **160**. Additionally, or alternatively, a functional split of the protocol stack may be employed between a DU **165** and an RU **170** such that the DU **165** may support one or more layers of the protocol stack and the RU **170** may support one or more different layers of the protocol stack. The DU **165** may support one or multiple different cells (e.g., via one or more RUs **170**). In some cases, a functional split between a CU **160** and a DU **165**, or between a DU **165** and an RU **170** may be within a protocol layer (e.g., some functions for a protocol layer may be performed by one of a CU **160**, a DU **165**, or an RU **170**, while other functions of the protocol layer are performed by a different one of the CU **160**, the DU **165**, or the RU **170**). A CU **160** may be functionally split further into CU control plane (CU-CP) and CU user plane (CU-UP) functions. A CU **160** may be connected to one or more DUs **165** via a midhaul communication link **162** (e.g., F1, F1-c, F1-u), and a DU **165** may be connected to one or more RUs **170** via a fronthaul communication link **168** (e.g., open fronthaul (FH) interface). In some examples, a midhaul communication link **162** or a fronthaul communication link **168** may be implemented in accordance with an interface (e.g., a channel) between layers of a protocol stack supported by respective network entities **105** that are in communication via such communication links.

In wireless communications systems (e.g., wireless communications system **100**), infrastructure and spectral resources for radio access may support wireless backhaul link capabilities to supplement wired backhaul connections, providing an IAB network architecture (e.g., to a core network **130**). In some cases, in an IAB network, one or more network entities **105** (e.g., IAB nodes **104**) may be partially controlled by each other. One or more IAB nodes **104** may be referred to as a donor entity or an IAB donor. One or more DUs **165** or one or more RUs **170** may be partially controlled by one or more CUs **160** associated with a donor network entity **105** (e.g., a donor base station **140**). The one or more donor network entities **105** (e.g., IAB donors) may be in communication with one or more additional network entities **105** (e.g., IAB nodes **104**) via supported access and backhaul links (e.g., backhaul communication links **120**). IAB nodes **104** may include an IAB mobile termination (IAB-MT) controlled (e.g., scheduled) by DUs **165** of a coupled IAB donor. An IAB-MT may include an independent set of antennas for relay of communications with UEs **115**, or may share the same antennas (e.g., of an RU **170**) of an IAB node **104** used for access via the DU **165** of the IAB node **104** (e.g., referred to as virtual IAB-MT (vIAB-MT)). In some examples, the IAB nodes **104** may include DUs **165** that support communication links

with additional entities (e.g., IAB nodes **104**, UEs **115**) within the relay chain or configuration of the access network (e.g., downstream). In such cases, one or more components of the disaggregated RAN architecture (e.g., one or more IAB nodes **104** or components of IAB nodes **104**) may be configured to operate according to the techniques described herein.

For instance, an access network (AN) or RAN may include communications between access nodes (e.g., an IAB donor), IAB nodes **104**, and one or more UEs **115**. The IAB donor may facilitate connection between the core network **130** and the AN (e.g., via a wired or wireless connection to the core network **130**). That is, an IAB donor may refer to a RAN node with a wired or wireless connection to core network **130**. The IAB donor may include a CU **160** and at least one DU **165** (e.g., and RU **170**), in which case the CU **160** may communicate with the core network **130** via an interface (e.g., a backhaul link). IAB donor and IAB nodes **104** may communicate via an F1 interface according to a protocol that defines signaling messages (e.g., an F1 AP protocol). Additionally, or alternatively, the CU **160** may communicate with the core network via an interface, which may be an example of a portion of backhaul link, and may communicate with other CUs **160** (e.g., a CU **160** associated with an alternative IAB donor) via an Xn-C interface, which may be an example of a portion of a backhaul link.

An IAB node **104** may refer to a RAN node that provides IAB functionality (e.g., access for UEs **115**, wireless self-backhauling capabilities). A DU **165** may act as a distributed scheduling node towards child nodes associated with the IAB node **104**, and the IAB-MT may act as a scheduled node towards parent nodes associated with the IAB node **104**. That is, an IAB donor may be referred to as a parent node in communication with one or more child nodes (e.g., an IAB donor may relay transmissions for UEs through one or more other IAB nodes **104**). Additionally, or alternatively, an IAB node **104** may also be referred to as a parent node or a child node to other IAB nodes **104**, depending on the relay chain or configuration of the AN. Therefore, the IAB-MT entity of IAB nodes **104** may provide a Uu interface for a child IAB node **104** to receive signaling from a parent IAB node **104**, and the DU interface (e.g., DUs **165**) may provide a Uu interface for a parent IAB node **104** to signal to a child IAB node **104** or UE **115**.

For example, IAB node **104** may be referred to as a parent node that supports communications for a child IAB node, or referred to as a child IAB node associated with an IAB donor, or both. The IAB donor may include a CU **160** with a wired or wireless connection (e.g., a backhaul communication link **120**) to the core network **130** and may act as parent node to IAB nodes **104**. For example, the DU **165** of IAB donor may relay transmissions to UEs **115** through IAB nodes **104**, or may directly signal transmissions to a UE **115**, or both. The CU **160** of IAB donor may signal communication link establishment via an F1 interface to IAB nodes **104**, and the IAB nodes **104** may schedule transmissions (e.g., transmissions to the UEs **115** relayed from the IAB donor) through the DUs **165**. That is, data may be relayed to and from IAB nodes **104** via signaling via an NR Uu interface to MT of the IAB node **104**. Communications with IAB node **104** may be scheduled by a DU **165** of IAB donor and communications with IAB node **104** may be scheduled by DU **165** of IAB node **104**.

In the case of the techniques described herein applied in the context of a disaggregated RAN architecture, one or more components of the disaggregated RAN architecture may be configured to support switching to an adaptive beam weight-based hybrid beamforming procedure as described herein. For example, some operations described as being performed by a UE **115** or a network entity **105** (e.g., a base station **140**) may additionally, or alternatively, be performed by one or more components of the disaggregated RAN architecture (e.g., IAB nodes **104**, DUs **165**, CUs **160**, RUs **170**, RIC **175**, SMO **180**).

A UE **115** may include or may be referred to as a mobile device, a wireless device, a remote device, a handheld device, or a subscriber device, or some other suitable terminology, where the "device" may also be referred to as a unit, a station, a terminal, or a client, among other examples. A UE **115** may also include or may be referred to as a personal electronic device such as a cellular phone, a personal digital assistant (PDA), a tablet computer, a laptop computer, or a personal computer. In some examples, a UE **115** may include or be referred to as a wireless local loop (WLL) station, an Internet of Things (IoT) device, an Internet of Everything (IoE) device, or a machine type communications (MTC) device, among other examples, which may be implemented in various objects such as appliances, or vehicles, meters, among other examples.

The UEs **115** described herein may be able to communicate with various types of devices, such as other UEs **115** that may sometimes act as relays as well as the network entities **105** and the network equipment including macro eNBs or gNBs, small cell eNBs or gNBs, or relay base stations, among other examples, as shown in FIG. **1**.

The UEs **115** and the network entities **105** may wirelessly communicate with one another via one or more communication links **125** (e.g., an access link) using resources associated with one or more carriers. The term "carrier" may refer to a set of RF spectrum resources having a defined physical layer structure for supporting the communication links **125**. For example, a carrier used for a communication link **125** may include a portion of a RF spectrum band (e.g., a bandwidth part (BWP)) that is operated according to one or more physical layer channels for a given radio access technology (e.g., LTE, LTE-A, LTE-A Pro, NR). Each physical layer channel may carry acquisition signaling (e.g., synchronization signals, system information), control signaling that coordinates operation for the carrier, user data, or other signaling. The wireless communications system **100** may support communication with a UE **115** using carrier aggregation or multi-carrier operation. A UE **115** may be configured with multiple downlink component carriers and one or more uplink component carriers according to a carrier aggregation configuration. Carrier aggregation may be used with both frequency division duplexing (FDD) and time division duplexing (TDD) component carriers. Communication between a network entity **105** and other devices may refer to communication between the devices and any portion (e.g., entity, sub-entity) of a network entity **105**. For example, the terms "transmitting," "receiving," or "communicating," when referring to a network entity **105**, may refer to any portion of a network entity **105** (e.g., a base station **140**, a CU **160**, a DU **165**, a RU **170**) of a RAN communicating with another device (e.g., directly or via one or more other network entities **105**).

The communication links **125** shown in the wireless communications system **100** may include downlink transmissions (e.g., forward link transmissions) from a network entity **105** to a UE **115**, uplink transmissions (e.g., return link transmissions) from a UE **115** to a network entity **105**, or both, among other configurations of transmissions. Carriers may carry downlink or uplink communications (e.g., in an

FDD mode) or may be configured to carry downlink and uplink communications (e.g., in a TDD mode).

Signal waveforms transmitted via a carrier may be made up of multiple subcarriers (e.g., using multi-carrier modulation (MCM) techniques such as orthogonal frequency division multiplexing (OFDM) or discrete Fourier transform spread OFDM (DFT-S-OFDM)). In a system employing MCM techniques, a resource element may refer to resources of one symbol period (e.g., a duration of one modulation symbol) and one subcarrier, in which case the symbol period and subcarrier spacing may be inversely related. The quantity of bits carried by each resource element may depend on the modulation scheme (e.g., the order of the modulation scheme, the coding rate of the modulation scheme, or both), such that a relatively higher quantity of resource elements (e.g., in a transmission duration) and a relatively higher order of a modulation scheme may correspond to a relatively higher rate of communication. A wireless communications resource may refer to a combination of an RF spectrum resource, a time resource, and a spatial resource (e.g., a spatial layer, a beam), and the use of multiple spatial resources may increase the data rate or data integrity for communications with a UE **115**.

The time intervals for the network entities **105** or the UEs **115** may be expressed in multiples of a basic time unit which may, for example, refer to a sampling period of $T_s=1/(\Delta f_{max} \cdot N_f)$ seconds, for which Δf_{max} may represent a supported subcarrier spacing, and N_f may represent a supported discrete Fourier transform (DFT) size. Time intervals of a communications resource may be organized according to radio frames each having a specified duration (e.g., 10 milliseconds (ms)). Each radio frame may be identified by a system frame number (SFN) (e.g., ranging from 0 to 1023).

Each frame may include multiple consecutively-numbered subframes or slots, and each subframe or slot may have the same duration. In some examples, a frame may be divided (e.g., in the time domain) into subframes, and each subframe may be further divided into a quantity of slots. Alternatively, each frame may include a variable quantity of slots, and the quantity of slots may depend on subcarrier spacing. Each slot may include a quantity of symbol periods (e.g., depending on the length of the cyclic prefix prepended to each symbol period). In some wireless communications systems **100**, a slot may further be divided into multiple mini-slots associated with one or more symbols. Excluding the cyclic prefix, each symbol period may be associated with one or more (e.g., N_f) sampling periods. The duration of a symbol period may depend on the subcarrier spacing or frequency band of operation.

A subframe, a slot, a mini-slot, or a symbol may be the smallest scheduling unit (e.g., in the time domain) of the wireless communications system **100** and may be referred to as a transmission time interval (TTI). In some examples, the TTI duration (e.g., a quantity of symbol periods in a TTI) may be variable. Additionally, or alternatively, the smallest scheduling unit of the wireless communications system **100** may be dynamically selected (e.g., in bursts of shortened TTIs (sTTIs)).

Physical channels may be multiplexed for communication using a carrier according to various techniques. A physical control channel and a physical data channel may be multiplexed for signaling via a downlink carrier, for example, using one or more of time division multiplexing (TDM) techniques, frequency division multiplexing (FDM) techniques, or hybrid TDM-FDM techniques. A control region (e.g., a control resource set (CORESET)) for a physical control channel may be defined by a set of symbol periods and may extend across the system bandwidth or a subset of the system bandwidth of the carrier. One or more control regions (e.g., CORESETs) may be configured for a set of the UEs **115**. For example, one or more of the UEs **115** may monitor or search control regions for control information according to one or more search space sets, and each search space set may include one or multiple control channel candidates in one or more aggregation levels arranged in a cascaded manner. An aggregation level for a control channel candidate may refer to an amount of control channel resources (e.g., control channel elements (CCEs)) associated with encoded information for a control information format having a given payload size. Search space sets may include common search space sets configured for sending control information to multiple UEs **115** and UE-specific search space sets for sending control information to a specific UE **115**.

A network entity **105** may provide communication coverage via one or more cells, for example a macro cell, a small cell, a hot spot, or other types of cells, or any combination thereof. The term "cell" may refer to a logical communication entity used for communication with a network entity **105** (e.g., using a carrier) and may be associated with an identifier for distinguishing neighboring cells (e.g., a physical cell identifier (PCID), a virtual cell identifier (VCID), or others). In some examples, a cell also may refer to a coverage area **110** or a portion of a coverage area **110** (e.g., a sector) over which the logical communication entity operates. Such cells may range from smaller areas (e.g., a structure, a subset of structure) to larger areas depending on various factors such as the capabilities of the network entity **105**. For example, a cell may be or include a building, a subset of a building, or exterior spaces between or overlapping with coverage areas **110**, among other examples.

In some examples, a carrier may support multiple cells, and different cells may be configured according to different protocol types (e.g., MTC, narrowband IoT (NB-IoT), enhanced mobile broadband (eMBB)) that may provide access for different types of devices.

In some examples, a network entity **105** (e.g., a base station **140**, an RU **170**) may be movable and therefore provide communication coverage for a moving coverage area **110**. In some examples, different coverage areas **110** associated with different technologies may overlap, but the different coverage areas **110** may be supported by the same network entity **105**. In some other examples, the overlapping coverage areas **110** associated with different technologies may be supported by different network entities **105**. The wireless communications system **100** may include, for example, a heterogeneous network in which different types of the network entities **105** provide coverage for various coverage areas **110** using the same or different radio access technologies.

Some UEs **115**, such as MTC or IoT devices, may be low cost or low complexity devices and may provide for automated communication between machines (e.g., via Machine-to-Machine (M2M) communication). M2M communication or MTC may refer to data communication technologies that allow devices to communicate with one another or a network entity **105** (e.g., a base station **140**) without human intervention. In some examples, M2M communication or MTC may include communications from devices that integrate sensors or meters to measure or capture information and relay such information to a central server or application program that uses the information or presents the information to humans interacting with the application program. Some UEs **115** may be designed to

collect information or enable automated behavior of machines or other devices. Examples of applications for MTC devices include smart metering, inventory monitoring, water level monitoring, equipment monitoring, healthcare monitoring, wildlife monitoring, weather and geological event monitoring, fleet management and tracking, remote security sensing, physical access control, and transaction-based business charging.

Some UEs **115** may be configured to employ operating modes that reduce power consumption, such as half-duplex communications (e.g., a mode that supports one-way communication via transmission or reception, but not transmission and reception concurrently). In some examples, half-duplex communications may be performed at a reduced peak rate. Other power conservation techniques for the UEs **115** include entering a power saving deep sleep mode when not engaging in active communications, operating using a limited bandwidth (e.g., according to narrowband communications), or a combination of these techniques. For example, some UEs **115** may be configured for operation using a narrowband protocol type that is associated with a defined portion or range (e.g., set of subcarriers or resource blocks (RBs)) within a carrier, within a guard-band of a carrier, or outside of a carrier.

The wireless communications system **100** may be configured to support ultra-reliable communications or low-latency communications, or various combinations thereof. For example, the wireless communications system **100** may be configured to support ultra-reliable low-latency communications (URLLC). The UEs **115** may be designed to support ultra-reliable, low-latency, or critical functions. Ultra-reliable communications may include private communication or group communication and may be supported by one or more services such as push-to-talk, video, or data. Support for ultra-reliable, low-latency functions may include prioritization of services, and such services may be used for public safety or general commercial applications. The terms ultra-reliable, low-latency, and ultra-reliable low-latency may be used interchangeably herein.

In some examples, a UE **115** may be configured to support communicating directly with other UEs **115** via a device-to-device (D2D) communication link **135** (e.g., in accordance with a peer-to-peer (P2P), D2D, or sidelink protocol). In some examples, one or more UEs **115** of a group that are performing D2D communications may be within the coverage area **110** of a network entity **105** (e.g., a base station **140**, an RU **170**), which may support aspects of such D2D communications being configured by (e.g., scheduled by) the network entity **105**. In some examples, one or more UEs **115** of such a group may be outside the coverage area **110** of a network entity **105** or may be otherwise unable to or not configured to receive transmissions from a network entity **105**. In some examples, groups of the UEs **115** communicating via D2D communications may support a one-to-many (1:M) system in which each UE **115** transmits to each of the other UEs **115** in the group. In some examples, a network entity **105** may facilitate the scheduling of resources for D2D communications. In some other examples, D2D communications may be carried out between the UEs **115** without an involvement of a network entity **105**.

The core network **130** may provide user authentication, access authorization, tracking, Internet Protocol (IP) connectivity, and other access, routing, or mobility functions. The core network **130** may be an evolved packet core (EPC) or 5G core (5GC), which may include at least one control plane entity that manages access and mobility (e.g., a mobility management entity (MME), an access and mobility management function (AMF)) and at least one user plane entity that routes packets or interconnects to external networks (e.g., a serving gateway (S-GW), a Packet Data Network (PDN) gateway (P-GW), or a user plane function (UPF)). The control plane entity may manage non-access stratum (NAS) functions such as mobility, authentication, and bearer management for the UEs **115** served by the network entities **105** (e.g., base stations **140**) associated with the core network **130**. User IP packets may be transferred through the user plane entity, which may provide IP address allocation as well as other functions. The user plane entity may be connected to IP services **150** for one or more network operators. The IP services **150** may include access to the Internet, Intranet(s), an IP Multimedia Subsystem (IMS), or a Packet-Switched Streaming Service.

The wireless communications system **100** may operate using one or more frequency bands, which may be in the range of 300 megahertz (MHz) to 300 gigahertz (GHz). The region from 300 MHz to 3 GHz may be known as the ultra-high frequency (UHF) region or decimeter band because the wavelengths range from approximately one decimeter to one meter in length. UHF waves may be blocked or redirected by buildings and environmental features, which may be referred to as clusters, but the waves may penetrate structures sufficiently for a macro cell to provide service to the UEs **115** located indoors. Communications using UHF waves may be associated with smaller antennas and shorter ranges (e.g., less than 100 kilometers) compared to communications using the smaller frequencies and longer waves of the high frequency (HF) or very high frequency (VHF) portion of the spectrum below 300 MHz.

The wireless communications system **100** may also operate using a super high frequency (SHF) region, which may be in the range of 3 GHz to 30 GHz, also known as the centimeter band, or using an extremely high frequency (EHF) region of the spectrum (e.g., from 30 GHz to 300 GHz), also known as the millimeter band. In some examples, the wireless communications system **100** may support millimeter wave (mmW) communications between the UEs **115** and the network entities **105** (e.g., base stations **140**, RUs **170**), and EHF antennas of the respective devices may be smaller and more closely spaced than UHF antennas. In some examples, such techniques may facilitate using antenna arrays within a device. The propagation of EHF transmissions, however, may be subject to even greater attenuation and shorter range than SHF or UHF transmissions. The techniques disclosed herein may be employed across transmissions that use one or more different frequency regions, and designated use of bands across these frequency regions may differ by country or regulating body.

The wireless communications system **100** may utilize both licensed and unlicensed RF spectrum bands. For example, the wireless communications system **100** may employ License Assisted Access (LAA), LTE-Unlicensed (LTE-U) radio access technology, or NR technology using an unlicensed band such as the 5 GHz industrial, scientific, and medical (ISM) band. While operating using unlicensed RF spectrum bands, devices such as the network entities **105** and the UEs **115** may employ carrier sensing for collision detection and avoidance. In some examples, operations using unlicensed bands may be based on a carrier aggregation configuration in conjunction with component carriers operating using a licensed band (e.g., LAA). Operations using unlicensed spectrum may include downlink transmissions, uplink transmissions, P2P transmissions, or D2D transmissions, among other examples.

The electromagnetic spectrum is often subdivided, based on frequency/wavelength, into various classes, bands, channels, etc. In 5G NR two initial operating bands have been identified as frequency range designations FR1 (410 MHz-7.125 GHz) and FR2 (24.25 GHz-52.6 GHz). It should be understood that although a portion of FR1 is greater than 6 GHz, FR1 is often referred to (interchangeably) as a "Sub-6 GHz" band in various documents and articles. A similar nomenclature issue sometimes occurs with regard to FR2, which is often referred to (interchangeably) as a "millimeter wave" band in documents and articles, despite being different from the extremely high frequency (EHF) band (30 GHz-300 GHz) which is identified by the International Telecommunications Union (ITU) as a "millimeter wave" band.

The frequencies between FR1 and FR2 are often referred to as mid-band frequencies. Recent 5G NR studies have identified an operating band for these mid-band frequencies as frequency range designation FR3 (7.125 GHz-24.25 GHz). Frequency bands falling within FR3 may inherit FR1 characteristics or FR2 characteristics, and thus may effectively extend features of FR1 or FR2 into mid-band frequencies. In addition, higher frequency bands are currently being explored to extend 5G NR operation beyond 52.6 GHz. For example, three higher operating bands have been identified as frequency range designations FR4a or FR4-1 (52.6 GHz-71 GHz), FR4 (52.6 GHz-114.25 GHz), and FR5 (114.25 GHz-300 GHz). Each of these higher frequency bands falls within the EHF band.

With the above aspects in mind, unless specifically stated otherwise, it should be understood that the term "sub-6 GHz" or the like if used herein may broadly represent frequencies that may be less than 6 GHz, may be within FR1, or may include mid-band frequencies. Further, unless specifically stated otherwise, it should be understood that the term "millimeter wave" or the like if used herein may broadly represent frequencies that may include mid-band frequencies, may be within FR2, FR4, FR4-a or FR4-1, or FR5, or may be within the EHF band.

A network entity **105** (e.g., a base station **140**, an RU **170**) or a UE **115** may be equipped with multiple antennas, which may be used to employ techniques such as transmit diversity, receive diversity, multiple-input multiple-output (MIMO) communications, or beamforming. The antennas of a network entity **105** or a UE **115** may be located within one or more antenna arrays or antenna panels, which may support MIMO operations or transmit or receive beamforming. For example, one or more base station antennas or antenna arrays may be co-located at an antenna assembly, such as an antenna tower. In some examples, antennas or antenna arrays associated with a network entity **105** may be located at diverse geographic locations. A network entity **105** may include an antenna array with a set of rows and columns of antenna ports that the network entity **105** may use to support beamforming of communications with a UE **115**. Likewise, a UE **115** may include one or more antenna arrays that may support various MIMO or beamforming operations. Additionally, or alternatively, an antenna panel may support RF beamforming for a signal transmitted via an antenna port.

Beamforming, which may also be referred to as spatial filtering, directional transmission, or directional reception, is a signal processing technique that may be used at a transmitting device or a receiving device (e.g., a network entity **105**, a UE **115**) to shape or steer an antenna beam (e.g., a transmit beam, a receive beam) along a spatial path between the transmitting device and the receiving device. Beamforming may be achieved by combining the signals communicated via antenna elements of an antenna array such that some signals propagating along particular orientations with respect to an antenna array experience constructive interference while others experience destructive interference. The adjustment of signals communicated via the antenna elements may include a transmitting device or a receiving device applying amplitude offsets, phase offsets, or both to signals carried via the antenna elements associated with the device. The adjustments associated with each of the antenna elements may be defined by a beamforming weight set associated with a particular orientation (e.g., with respect to the antenna array of the transmitting device or receiving device, or with respect to some other orientation).

A network entity **105** or a UE **115** may use beam sweeping techniques as part of beamforming operations. For example, a network entity **105** (e.g., a base station **140**, an RU **170**) may use multiple antennas or antenna arrays (e.g., antenna panels) to conduct beamforming operations for directional communications with a UE **115**. Some signals (e.g., synchronization signals, reference signals, beam selection signals, or other control signals) may be transmitted by a network entity **105** multiple times along different directions. For example, the network entity **105** may transmit a signal according to different beamforming weight sets associated with different directions of transmission. Transmissions along different beam directions may be used to identify (e.g., by a transmitting device, such as a network entity **105**, or by a receiving device, such as a UE **115**) a beam direction for later transmission or reception by the network entity **105**.

Some signals, such as data signals associated with a particular receiving device, may be transmitted by a transmitting device (e.g., a transmitting network entity **105**, a transmitting UE **115**) along a single beam direction (e.g., a direction associated with the receiving device, such as a receiving network entity **105** or a receiving UE **115**). In some examples, the beam direction associated with transmissions along a single beam direction may be determined based on a signal that was transmitted along one or more beam directions. For example, a UE **115** may receive one or more of the signals transmitted by the network entity **105** along different directions and may report to the network entity **105** an indication of the signal that the UE **115** received with a highest signal quality or an otherwise acceptable signal quality.

In some examples, transmissions by a device (e.g., by a network entity **105** or a UE **115**) may be performed using multiple beam directions, and the device may use digital precoding, beamforming, or a combination thereof to generate a combined beam for transmission (e.g., from a network entity **105** to a UE **115**). The UE **115** may report feedback that indicates precoding weights for one or more beam directions, and the feedback may correspond to a configured set of beams across a system bandwidth or one or more sub-bands. The network entity **105** may transmit a reference signal (e.g., a cell-specific reference signal (CRS), a CSI-RS, which may be precoded or unprecoded. The UE **115** may provide feedback for beam selection, which may be a precoding matrix indicator (PMI) or codebook-based feedback (e.g., feedback associated with a multi-panel type codebook, a linear combination type codebook, a port selection type codebook). Although some techniques are described herein with reference to signals transmitted along one or more directions by a network entity **105** (e.g., a base station **140**, an RU **170**), a UE **115** may employ similar techniques for transmitting signals multiple times along different directions (e.g., for identifying a beam direction for subsequent transmission or reception by the UE **115**) or for

transmitting a signal along a single direction (e.g., for transmitting data to a receiving device).

A receiving device (e.g., a UE **115**) may perform reception operations in accordance with multiple receive configurations (e.g., directional listening) when receiving various signals from a receiving device (e.g., a network entity **105**), such as synchronization signals, reference signals, beam selection signals, or other control signals. For example, a receiving device may perform reception in accordance with multiple receive directions by receiving via different antenna subarrays, by processing received signals according to different antenna subarrays, by receiving according to different receive beamforming weight sets (e.g., different directional listening weight sets) applied to signals received at multiple antenna elements of an antenna array, or by processing received signals according to different receive beamforming weight sets applied to signals received at multiple antenna elements of an antenna array, any of which may be referred to as "listening" according to different receive configurations or receive directions. In some examples, a receiving device may use a single receive configuration to receive along a single beam direction (e.g., when receiving a data signal). The single receive configuration may be aligned along a beam direction determined based on listening according to different receive configuration directions (e.g., a beam direction determined to have a highest signal strength, highest signal-to-noise ratio (SNR), or otherwise acceptable signal quality based on listening according to multiple beam directions).

In some examples, the wireless communications system **100** may be a millimeter wave (mmW) system. In some cases, a device (e.g., a UE **115**, a network entity **105**) may use a carrier frequency in the "28" and "39" GHz mmW bands to communicate with other devices in the wireless communications system **100**. Additionally, or alternatively, the device may use a carrier frequency in upper mmW bands (e.g., greater than 52.6 GHz such as the WiFi bands in 57 to 71 GHz) for communications. Additionally, or alternatively, the device may use a carrier frequency in sub-Terahertz bands (e.g., greater than 114.25 GHz) for communications. In some examples, a device in the wireless communications system **100** may use analog or hybrid beamforming applications to steer energy in specific directions of beamspace using one or more directional beams. Such analog or hybrid beamforming applications may be viewed as a static (e.g., directional beam) codebook approach, which may also be referred to as a codebook-based beamforming procedure.

In some cases, a device in the wireless communications system **100** may use a more flexible set of adaptive (e.g., dynamic) beam weights instead of the static codebook approach by performing an adaptive beam weight-based hybrid beamforming procedure. The device may use the adaptive beam weight-based hybrid beamforming procedure to mitigate signaling loss resulting from relatively wide angular spreads for a dominant cluster that captures the channel environment, multi-beam effects (e.g., multiple lobes across multiple clusters), side lobe control and hand blockage or UE-material related impairments, or polarization-specific impairments at the UE **115** (e.g., due to the housing of the UE **115**, materials or sensors at the UE **115**, or a combination thereof).

If the UE **115** performs a codebook-based beamforming procedure, the UE **115** may use static beam weights that are configured (e.g., set or otherwise defined) for a codebook. Alternatively, if the UE **115** performs an adaptive beam weight-based hybrid beamforming procedure, the UE **115** may use adaptive beam weights that the UE **115** may learn on-the-fly (e.g., according to a machine learning model, a heuristic, or some other beam weight selection process). For instance, a static beam weight steering energy along a 60° angle for a 4×1 array configuration may be in the form of Matrix 1.

$$[1 \; e^{j\pi \sin(60°)} \; e^{j2\pi \sin(60°)} \; e^{j3\pi \sin(60°)}] \tag{1}$$

Alternatively, an adaptive beam weight steering energy for the same array configuration may be in the form of Matrix 2 or any other form according to a machine learning model.

$$[1 \; i \; -1 \; -i] \tag{2}$$

In some examples, the UE **115** may have no or negligible beam weight constraints for adaptive beam weights based on a quantity of layers (e.g., spatial layers) used at the UE **115**. In some cases, the UE **115** may learn the beam weights using an online beam training process (e.g., similar to the process used for channel state feedback (CSF) but in the RF domain), or the UE **115** may determine the beam weights using a machine learning model that is trained offline.

In some cases, the performance of beamformed communications at the UE **115** may change based on the materials around the UE **115**. For instance, in the wireless communications system **100**, a UE **115** may be surrounded by—or located near—a material (e.g., wood, metal, a human hand, air or free space). Different materials may have different dielectric properties, such as reflectivity properties, conductivity properties, permissivity properties, or some combination thereof. Due to the various properties of different materials (e.g., dielectric properties) located around or proximate to the UE **115** (e.g., within a threshold distance from the UE **115** or from one or more sensors at the UE **115**), the UE **115** may experience different effective array gain responses for beamformed communications, impacting the performance of beamformed communications at the UE **115**. For example, materials that are relatively more conductive may spread energy coming from a single direction to many directions more easily than materials that are relatively less conductive. In contrast, materials that are relatively less conductive may concentrate energy coming from a single direction around that single direction. Accordingly, the effective array gain response of a signal transmitted by a UE **115** and reflected from a material may increase as the material around or near the antenna module of the UE **115** becomes more conductive.

The performance of beamformed communications at the UE **115** when surrounded by—or located near—a material may be improved when an adaptive beam weight-based hybrid beamforming procedure is used for the beamformed communications. In contrast, using a codebook-based hybrid beamforming procedure may reduce the processing complexity at the UE **115** associated with beamformed communications. For instance, to perform an adaptive beam weight-based hybrid beamforming procedure, the UE **115** may receive and process a relatively greater quantity of reference signals than for a codebook-based hybrid beamforming procedure. The relatively greater quantity of reference signals may support improved beamforming performance for the adaptive beam weight-based hybrid beamforming procedure. However, depending on one or more materials proximate to the UE **115**, the UE **115** may prioritize reducing the processing overhead or improving the performance of the beamformed communications. Accordingly, the UE **115** may switch between the codebook-based hybrid beamforming procedure and the adaptive beam weight-based hybrid beamforming procedure based on

material properties of materials detected proximate to the UE **115** to improve beamforming procedures.

Various aspects of the present disclosure relate to enabling a network entity **105** and a UE **115** to support signaling related to techniques for managing beamforming procedures in communications systems such as the wireless communications system **100**. For example, a UE **115** may support switching between a codebook-based hybrid beamforming procedure and an adaptive beam weight-based hybrid beamforming procedure based on a material detection process. The UE **115** may tailor a beamforming approach to be used for beamforming communications in accordance with material sensing techniques performed at the UE **115** and a switch indication for switching to the adaptive beam weight-based hybrid beamforming procedure. The UE **115** may include a communications manager **101** and the network entity **105** may include a communications manager **102** in accordance with examples as disclosed herein. The communications manager **101** may be an example of aspects of a communications manager as described with reference to FIGS. **7** through **10**. The communications manager **102** may be an example of aspects of a communications manager as described with reference to FIGS. **11** through **14**.

The communications manager **101** may output or transmit, and the communications manager **102** may receive or obtain, an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure. The communications manager **102** may output or transmit one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure. The communications manager **101** may receive or obtain the one or more reference signals for beam training and beam weight selection. In accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals, the communications manager **101** and the communications manager **102** may exchange further signaling such that the UE **115** may effectively communicate with the network entity **105** or other communication devices in the wireless communications system **100** as described herein.

FIG. **2** illustrates an example of a network architecture **200** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The network architecture **200** may be an example of a disaggregated base station architecture, a disaggregated RAN architecture, or both. The network architecture **200** may illustrate an example for implementing one or more aspects of the wireless communications system **100**. The network architecture **200** may include one or more CUs **160**-*a* that may communicate directly with a core network **130**-*a* via a backhaul communication link **120**-*a*, or indirectly with the core network **130**-*a* through one or more disaggregated network entities **105** (e.g., a Near-RT RIC **175**-*b* via an E2 link, or a Non-RT RIC **175**-*a* associated with an SMO **180**-*a* (e.g., an SMO Framework), or both). A CU **160**-*a* may communicate with one or more DUs **165**-*a* via respective midhaul communication links **162**-*a* (e.g., an F1 interface). The DUs **165**-*a* may communicate with one or more RUs **170**-*a* via respective fronthaul communication links **168**-*a*. The RUs **170**-*a* may be associated with respective coverage areas **110**-*a* and may communicate with UEs **115**-*a* via one or more communication links **125**-*a*. In some examples, a UE **115**-*a* may be concurrently served by multiple RUs **170**-*a*.

Each of the network entities **105** of the network architecture **200** (e.g., CUs **160**-*a*, DUs **165**-*a*, RUs **170**-*a*, Non-RT RICs **175**-*a*, Near-RT RICs **175**-*b*, SMOs **180**-*a*, Open Clouds (O-Clouds) **205**, Open eNBs (O-eNBs) **210**) may include one or more interfaces or may be coupled with one or more interfaces configured to receive or transmit signals (e.g., data, information) via a wired or wireless transmission medium. Each network entity **105**, or an associated processor (e.g., controller) providing instructions to an interface of the network entity **105**, may be configured to communicate with one or more of the other network entities **105** via the transmission medium. For example, the network entities **105** may include a wired interface configured to receive or transmit signals over a wired transmission medium to one or more of the other network entities **105**. Additionally, or alternatively, the network entities **105** may include a wireless interface, which may include a receiver, a transmitter, or transceiver (e.g., an RF transceiver) configured to receive or transmit signals, or both, over a wireless transmission medium to one or more of the other network entities **105**.

In some examples, a CU **160**-*a* may host one or more higher layer control functions. Such control functions may include RRC, PDCP, SDAP, or the like. Each control function may be implemented with an interface configured to communicate signals with other control functions hosted by the CU **160**-*a*. A CU **160**-*a* may be configured to handle user plane functionality (e.g., CU-UP), control plane functionality (e.g., CU-CP), or a combination thereof. In some examples, a CU **160**-*a* may be logically split into one or more CU-UP units and one or more CU-CP units. A CU-UP unit may communicate bidirectionally with the CU-CP unit via an interface, such as an E1 interface when implemented in an O-RAN configuration. A CU **160**-*a* may be implemented to communicate with a DU **165**-*a*, as necessary, for network control and signaling.

A DU **165**-*a* may correspond to a logical unit that includes one or more functions (e.g., base station functions, RAN functions) to control the operation of one or more RUs **170**-*a*. In some examples, a DU **165**-*a* may host, at least partially, one or more of an RLC layer, a MAC layer, and one or more aspects of a PHY layer (e.g., a high PHY layer, such as modules for FEC encoding and decoding, scrambling, modulation and demodulation, or the like) depending, at least in part, on a functional split, such as those defined by the 3rd Generation Partnership Project (3GPP). In some examples, a DU **165**-*a* may further host one or more low PHY layers. Each layer may be implemented with an interface configured to communicate signals with other layers hosted by the DU **165**-*a*, or with control functions hosted by a CU **160**-*a*.

In some examples, lower-layer functionality may be implemented by one or more RUs **170**-*a*. For example, an RU **170**-*a*, controlled by a DU **165**-*a*, may correspond to a logical node that hosts RF processing functions, or low-PHY layer functions (e.g., performing fast Fourier transform (FFT), inverse FFT (iFFT), digital beamforming, physical random access channel (PRACH) extraction and filtering, or the like), or both, based on the functional split, such as a lower-layer functional split. In such an architecture, an RU **170**-*a* may be implemented to handle over the air (OTA) communication with one or more UEs **115**-*a*. In some examples, real-time and non-real-time aspects of control and user plane communication with the RU(s) **170**-*a* may be controlled by the corresponding DU **165**-*a*. In some examples, such a configuration may enable a DU **165**-*a* and a CU **160**-*a* to be implemented in a cloud-based RAN architecture, such as a vRAN architecture.

The SMO **180**-*a* may be configured to support RAN deployment and provisioning of non-virtualized and virtualized network entities **105**. For non-virtualized network entities **105**, the SMO **180**-*a* may be configured to support the deployment of dedicated physical resources for RAN coverage thresholds which may be managed via an operations and maintenance interface (e.g., an O1 interface). For virtualized network entities **105**, the SMO **180**-*a* may be configured to interact with a cloud computing platform (e.g., an O-Cloud **205**) to perform network entity life cycle management (e.g., to instantiate virtualized network entities **105**) via a cloud computing platform interface (e.g., an O2 interface). Such virtualized network entities **105** can include, but are not limited to, CUs **160**-*a*, DUs **165**-*a*, RUs **170**-*a*, and Near-RT RICs **175**-*b*. In some cases, the SMO **180**-*a* may communicate with components configured in accordance with a 4G RAN (e.g., via an O1 interface). Additionally, or alternatively, in some examples, the SMO **180**-*a* may communicate directly with one or more RUs **170**-*a* via an O1 interface. The SMO **180**-*a* also may include a Non-RT RIC **175**-*a* configured to support functionality of the SMO **180**-*a*.

The Non-RT RIC **175**-*a* may be configured to include a logical function that enables non-real-time control and optimization of RAN elements and resources, Artificial Intelligence (AI) or machine learning workflows including model training and updates, or policy-based guidance of applications/features in the Near-RT RIC **175**-*b*. The Non-RT RIC **175**-*a* may be coupled to or communicate with (e.g., via an A1 interface) the Near-RT RIC **175**-*b*. The Near-RT RIC **175**-*b* may be configured to include a logical function that enables near-real-time control and optimization of RAN elements and resources via data collection and actions over an interface (e.g., via an E2 interface) connecting one or more CUs **160**-*a*, one or more DUs **165**-*a*, or both, as well as an O-eNB **210**, with the Near-RT RIC **175**-*b*.

In some examples, to generate AI/machine learning models to be deployed in the Near-RT RIC **175**-*b*, the Non-RT RIC **175**-*a* may receive parameters or external enrichment information from external servers. Such information may be utilized by the Near-RT RIC **175**-*b* and may be received at the SMO **180**-*a* or the Non-RT RIC **175**-*a* from non-network data sources or from network functions. In some examples, the Non-RT RIC **175**-*a* or the Near-RT RIC **175**-*b* may be configured to tune RAN behavior or performance. For example, the Non-RT RIC **175**-*a* may monitor long-term trends and patterns for performance and employ AI or machine learning models to perform corrective actions through the SMO **180**-*a* (e.g., reconfiguration via O1) or via generation of RAN management policies (e.g., A1 policies).

In some examples, the AI/machine learning models may support material classification, beam weight selection, or both. For example, a network entity **105** (e.g., an RU **170**-*a*, a DU **165**-*a*, a CU **160**-*a*, or some combination thereof) may train a machine learning model to support material classification or beam weight selection and may signal the machine learning model (e.g., aspects of the machine learning model) to a UE **115**-*a*. Additionally, or alternatively, the UE **115**-*a* may train the machine learning model to support material classification or beam weight selection. The UE **115**-*a* may use a machine learning model for material classification to determine whether a detected material proximate to the UE **115**-*a* (e.g., within a threshold distance from the UE **115**) triggers a switch to an adaptive beam weight-based hybrid beamforming procedure (or, in some cases, a switch to a codebook-based hybrid beamforming procedure). The UE **115**-*a* may use a machine learning model for beam weight selection to select one or more beams (e.g., beamforming parameters) for communication if the UE **115**-*a* is operating according to the adaptive beam weight-based hybrid beamforming procedure.

FIG. **3** illustrates an example of a wireless communications system **300** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure **345** in accordance with one or more aspects of the present disclosure. The wireless communications system **300** may implement or be implemented by aspects of the wireless communications system **100**. For example, the wireless communications system **300** may include a network entity **105**-*b* and a UE **115**-*b*, which may be examples of a network entity **105** (e.g., an RU **170**, a DU **165**, a CU **160**, a base station **140**, or some combination thereof) and a UE **115** as described with reference to FIGS. **1** and **2**. The network entity **105**-*b* and the UE **115**-*b* may communicate with one another via an uplink channel **310** and a downlink channel **315**, which may be examples or components of a communication link **125** as described with reference to FIG. **1**. The UE **115**-*b* may support techniques for managing an adaptive beam weight-based hybrid beamforming procedure **345**. By managing the adaptive beam weight-based hybrid beamforming procedure **345**, the UE **115**-*b* may manage processing complexity at the UE **115**-*b* by determining whether the cost of processing one or more reference signals is worth the performance gain resulting from an adaptive beam weight-based hybrid beamforming procedure **345**, promoting resource efficiency and improved beamforming procedures for the wireless communications system **300**.

Different materials around the UE **115**-*b* may cause different reflection responses for a signal transmitted by the UE **115**-*b*, resulting in different effective array gain behaviors observed at the UE **115**-*b* (e.g., over a multi-antenna array). For instance, a human hand or body may be located around or near the UE **115**-*b* (e.g., if the UE **115**-*b* is a mobile phone being held by a human). Additionally, or alternatively, the UE **115**-*b* may be placed on a wooden desk or near a metallic object. Additionally, or alternatively, different protective cases or covers of plastic, silicone, leather, or some other material may surround the UE **115**-*b*. In some examples, the shape of an object around the UE **115**-*b* (e.g., a plastic, silicon, or leather case enveloping the UE **115**-*b* in multiple dimensions versus a table being located in one direction from the UE **115**-*b*) may impact the array gain performance at the UE **115**-*b*.

In some examples, the UE **115**-*b* may detect one or more materials within a threshold distance of the UE **115**-*b*. In some cases, the UE **115**-*b* may classify a material (e.g., with a material type or classification from a configured list of supported material types or classifications) using a machine learning model. For instance, the UE **115**-*b* may detect different materials as well as the shapes of the materials based on measuring spectral responses with a frequency modulated continuous wave (FMCW) radar or other reflectivity test (e.g., using capacitive sensors, radar sensors or components, or any other detection mechanism). The machine learning model may be trained online (e.g., by the UE **115**-*b*) or offline (e.g., by the UE **115**-*b*, the network entity **105**-*b*, or another device or system) to classify a material based on one or more spectral responses or other parameters of the material. For example, to train the machine learning model, a set of materials may be labeled with types or classifications, and a system or device may input spectral responses or other parameters associated with the materials into the machine learning model to train the model to output the proper types or classifications. Accord-

ingly, the system or device may train a machine learning model (e.g., a neural network) to classify materials (e.g., with coarse or fine classifications) based on detected material properties (e.g., from spectral responses). Coarse or fine classifications may refer to a quantity of different material types or classifications supported by the model. For example, a coarse classification may indicate a material type from less than a threshold quantity of different types, while a fine classification may indicate a material type from more than the threshold quantity of different types. In some cases, the model training may involve user feedback or other feedback to tune the model parameters and improve the classification process. The machine learning model may continue to learn during operation by the UE **115**-*b* or may be trained prior to operation at the UE **115**-*b*.

The UE **115**-*b* may use the trained machine learning model to classify a detected material, for example, based on a spectral response from the material (e.g., in response to a radar signal or other signal). Additionally, or alternatively, the UE **115**-*b* may sense dielectric constants of different materials via polarization tests, similar to a weather radar where horizontal transmit, vertical receive (H-V) polarization rotations may be used to classify the presence of cloudy, rainy, or sunny days. Accordingly, a material around the UE **115**-*b* may be detected, classified, or both based on the spectral responses of the material. That is, the UE **115**-*b* may classify the material with a material type from multiple supported material types based on a detected dielectric property, a detected conductivity property, or both.

For example, the UE **115**-*b* may transmit a radar waveform, receive a reflection of the radar waveform from a material that is within a threshold distance from the UE **115**-*b*, and estimate or obtain a distortion metric of the reflection of the radar waveform. The UE **115**-*b* may detect a material property of the material based on whether the distortion metric satisfies (e.g., exceeds) or fails to satisfy a distortion threshold. The distortion threshold may be predetermined and pre-configured for the UE **115**-*b*. Additionally, or alternatively, the distortion threshold may be configured for the UE **115**-*b* via RRC signaling, MAC-CE signaling, DCI signaling, or other configuration signaling types by the network entity **105**-*b*. In some cases, the UE **115**-*b* may dynamically select the distortion threshold based on one or more other parameters (e.g., a reliability threshold, a latency threshold, a channel metric). Accordingly, the UE **115**-*b* may classify a material or surface with dielectric or conductivity properties that may impact the distortion metric of a signal transmitted by the UE **115**-*b*.

In some aspects, the classification network (e.g., machine learning model) used by the UE **115**-*b* may perform coarse or fine resolution detection. For instance, in some examples, the UE **115**-*b* may perform a binary classification of a detected material and determine whether the material is human or non-human in an application for maximum permissible exposure (MPE) detection. As such, the UE **115**-*b* may determine whether MPE thresholds are met if a human is detected to be within the threshold distance of the UE **115**-*b*. In some other examples, the UE **115**-*b* may perform a fine resolution detection of materials (e.g., within a non-human class). In some such examples, the UE **115**-*b* may receive, from the network entity **105**-*b* or some other transmitter, assistance information on a candidate list of materials that may potentially be detected. For instance, the UE **115**-*b* may receive assistance information that indicates multiple material types for classification, and the UE **115**-*b* may classify the material with a material type based on the assistance information. In some cases, the network entity **105**-*b* may acquire such assistance information through visual-aided or perception-based communications, machine learning approaches, or other approaches of the like, and the network entity **105**-*b* may transmit the assistance information to the UE **115**-*b*. Additionally, or alternatively, the network entity **105**-*b* may provide the assistance information to the UE **115**-*b* based on location information across different UEs **115** (e.g., if phones are placed on the same table).

In some aspects, the UE **115**-*b* may switch from one analog/hybrid beamforming codebook (e.g., codebook_1) to another codebook (e.g., codebook_2) based on a material type sensed by the UE **115**-*b*. The UE **115**-*b* may switch across codebooks within a class of codebooks or between different classes of codebooks. The codebooks may have different sizes (e.g., quantities of beam weights), different beam properties (e.g., main lobe level, side lobe level, beamwidth properties), different phase or amplitude quantization levels, different other properties, or any combination thereof. For instance, the UE **115**-*b* may detect a material property for a material within a threshold distance from the UE **115**-*b*. Based on the detected material property (e.g., a dielectric property) for the material, the UE **115**-*b* may communicate using a codebook-based hybrid beamforming procedure **340**. Additionally, based on the codebook-based hybrid beamforming procedure **340** and the detected material property for the material, the UE **115**-*b* may select a codebook from a set of codebooks. For example, the UE **115**-*b* may select a second codebook associated with a relatively finer grid of beams than a first codebook associated with a relatively coarser grid of beams, and the UE **115**-*b* may perform beamformed communications using the second codebook.

In some other aspects, the UE **115**-*b* may switch from the codebook-based hybrid beamforming procedure **340** to an adaptive beam weight-based hybrid beamforming procedure **345** based on a material type sensed by the UE **115**-*b*. For instance, the UE **115**-*b* may transmit a radar waveform, receive a reflection of the radar waveform from a material within a threshold distance from the UE **115**-*b*, and determine a distortion metric of the reflection of the radar waveform. The UE **115**-*b* may determine that the distortion metric of the reflection of the radar waveform satisfies a distortion threshold. Because the distortion metric of the reflection of the radar waveform satisfies the distortion threshold, the UE **115**-*b* may determine that the processing overhead associated with using the adaptive beam weight-based hybrid beamforming procedure **345** is worth the expected performance gain. Accordingly, the UE **115**-*b* may transmit an indication of the switch (e.g., a switch indication **305**) from a codebook-based hybrid beamforming procedure **340** to an adaptive beam weight-based hybrid beamforming procedure **345**. For instance, the UE **115**-*b* in the presence of a hand may be expected to have relatively greater gains using adaptive beam weights **335**-*a* (as opposed to a static codebook) than the UE **115**-*b* in the presence of wood. Accordingly, the UE **115**-*b* in the presence of a hand may use the adaptive beam weight-based hybrid beamforming procedure **345** (e.g., to improve beamformed communication performance), and the UE **115**-*b* in the presence of wood may use the codebook-based hybrid beamforming procedure **340** (e.g., to save processing overhead).

In some examples, the UE **115**-*b* may input one or more waveform parameters of the reflection of the radar waveform into the machine learning model, where the one or more waveform parameters may include at least the distortion metric. By using the machine learning model, the UE

115-*b* may learn adaptive or dynamic beam weights for beamformed communications on-the-fly. The UE **115**-*b* may classify the material with a material type in accordance with an output of the machine learning model based on the one or more waveform parameters input into the machine learning model.

For the adaptive beam weight-based hybrid beamforming procedure **345**, the UE **115**-*b* may estimate and select one or more beam weights **335**-*a* dynamically using a set of system resources. For instance, the UE **115**-*b* may receive, in response to the switch indication **305**, one or more reference signals **320**. The one or more reference signals **320** may include one or more CSI-RSs, one or more SRSs, or a combination thereof for beam weight estimation and selection. Additionally, or alternatively, the UE **115**-*b* may receive, in response to the switch indication **305**, a control signal that allocates one or more resources for the one or more reference signals **320**, and the UE **115**-*b* may receive the one or more reference signals **320** in the configured resources. Based on the one or more reference signals **320**, the UE **115**-*b* may dynamically perform beam weight estimation, where the one or more beam weights **335**-*a* may be selected based on the beam weight estimation. Additionally, or alternatively, the network entity **105**-*b* may dynamically perform beam weight estimation, where one or more beam weights **335**-*b* may be selected based on the beam weight estimation. The one or more beam weights **335**-*b* may be associated with or correspond to the one or more beam weights **335**-*a*.

The UE **115**-*b* may communicate in accordance with the one or more beam weights **335**-*a* selected based on the adaptive beam weight-based hybrid beamforming procedure **345** and the one or more reference signals **320**. Additionally, or alternatively, the network entity **105**-*b* may communicate in accordance with the one or more beam weights **335**-*b* selected based on the adaptive beam weight-based hybrid beamforming procedure **345**. For example, the UE **115**-*b* may transmit an uplink signal **325** to the network entity **105**-*b* using the beam weights **335**-*a* selected from the adaptive beam weight-based hybrid beamforming procedure **345**. The network entity **105**-*b* may receive the uplink signal **325** using the beam weights **335**-*b* selected from the adaptive beam weight-based hybrid beamforming procedure **345**. Additionally, or alternatively, the network entity **105**-*b* may transmit a downlink signal **330** to the UE **115**-*b* using the beam weights **335**-*b* selected from the adaptive beam weight-based hybrid beamforming procedure **345**, and the UE **115**-*b* may receive the downlink signal **330** using the beam weights **335**-*a* selected from the adaptive beam weight-based hybrid beamforming procedure **345**. For example, the beam weights **335**-*a* may correspond to one or more uplink transmit beams, downlink receive beams, or a combination thereof. The beam weights **335**-*b* may correspond to one or more uplink receive beams, downlink transmit beams, or a combination thereof.

FIG. **4** illustrates an example of a material classification scheme **400** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The material classification scheme **400** may be implemented by aspects of the wireless communications system **100**, the network architecture **200**, the wireless communications system **300**, or some combination thereof. For example, a UE **115**-*c*, which may be an example of a UE **115** as described with reference to FIGS. **1** through **3**, may implement the material classification scheme **400**. The UE **115**-*c* may support techniques for managing an adaptive beam weight-based hybrid beamforming procedure based on the material classification scheme **400**. By managing the adaptive beam weight-based hybrid beamforming procedure, the UE **115**-*c* may manage processing complexity at the UE **115**-*c* by determining whether to process one or more reference signals to support a performance gain for beamformed communications according to the adaptive beam weight-based hybrid beamforming procedure.

In some examples, one or more materials may be within a threshold distance from the UE **115**-*c*. For example, a material **405**-*a* may be within a threshold distance from the UE **115**-*c*. Additionally, or alternatively, a material **405**-*b* may be within the threshold distance from the UE **115**-*c*. In some examples, the material **405**-*b* may be a second material that is different from the material **405**-*a*.

The material **405**-*a* and the material **405**-*b* may be associated with material properties, including one or more dielectric properties, one or more conductivity properties, or some combination thereof. If the material **405**-*a* is different from the material **405**-*b*, the material **405**-*a* and the material **405**-*b* may each have a different dielectric property, conductivity property, or both. In some cases, the UE **115**-*c* may support classifying the materials (e.g., with a material type, a material classification). For instance, the UE **115**-*c* may support classifying a material as wood, skin, or metal. On a scale of conductivity, a set of materials proximate to the UE **115**-*c* may be ranked, at least, as the following (from least conductive to most conductive): free space (e.g., no detected material), wood, skin (e.g., a human hand), and metal. In a non-limiting example, the material **405**-*a* may have a relatively high conductivity (e.g., metal), and the material **405**-*b* may have a relatively low conductivity (e.g., wood). As such, the material **405**-*a* may be relatively more conductive than the material **405**-*b*. Accordingly, the same signaling transmitted by the UE **115**-*c* may perform differently in the presence of the material **405**-*a* as compared to the material **405**-*b*.

In some examples, the UE **115**-*c* may include an FMCW radar for MPE detection. In some cases, the FMCW radar may be associated with an antenna module (e.g., on a back mount) of the UE **115**-*c*. The UE **115**-*c* may use the FMCW radar to determine the presence or absence of a material (e.g., fingers or skin, a table, a phone case) in a nearby vicinity, or within a threshold distance, of the UE **115**-*c*. For instance, the UE **115**-*c* may transmit a radar waveform **415**-*a* from a set of antennas (e.g., from the antenna module including the FMCW radar component), the radar waveform **415**-*a* may bounce off a material **405**-*a*, and the UE **115**-*c* may use the same set of antennas to receive a reflection **420**-*a* of the radar waveform **415**-*a*. Additionally, or alternatively, the radar waveform **415**-*a* or a different radar waveform may bounce off a material **405**-*b*, and the UE **115**-*c* may receive the reflection **420**-*b* of the radar waveform **415**-*a* reflected by the material **405**-*b*. Based on receiving the reflection **420**-*a* of the radar waveform **415**-*a*, the FMCW radar of the UE **115**-*c* may determine a distance **410**-*a* between the material **405**-*a* and the UE **115**-*c*. Additionally, or alternatively, the FMCW radar of the UE **115**-*c* may determine whether or not the material **405**-*a* is moving based on receiving the reflection **420**-*a*. Similarly, based on receiving the reflection **420**-*b* of the radar waveform **415**-*a*, the FMCW radar of the UE **115**-*c* may determine a distance **410**-*b* between the material **405**-*b* and the UE **115**-*c*. Additionally, or alternatively, the FMCW radar of the UE **115**-*c* may determine whether or not the material **405**-*b* is moving based on receiving the reflection **420**-*b*. As such, the UE **115**-*c* may detect the material **405**-*a* if the distance **410**-*a* is

equal to or less than a threshold distance from the UE **115**-*c*. Additionally, or alternatively, the UE **115**-*c* may detect the material **405**-*b* if the distance **410**-*b* is equal to or less than the threshold distance. The threshold distance for detection by the UE **115**-*c* may be pre-configured or may correspond to a parameter received at the UE **115**-*c* via higher layer signaling (e.g., RRC signaling from a network entity **105**).

In some examples, the conductivity of the material **405**-*a* and the material **405**-*b* may directly correlate to a gain response of a signal transmitted by the UE **115**-*c*. Additionally, the reflection of the signal rebounding from a material may indicate the conductivity of the material (e.g., a gain response of the radar waveform **415**-*a* with the reflection **420**-*a* or the reflection **420**-*b* may indicate the conductivity). For example, for the set of materials including wood, skin, and metal, the effective array gain response of a transmitted signal reflected from each of the set of materials may be ranked similarly to that for conductivity, as the following (from least gain to most gain): freespace (e.g., no blocking material), wood, skin, and metal. Freespace (e.g., no blocking material), wood, and other materials associated with relatively less gain may be classified as low-loss (e.g., non-dispersive) dielectric materials, and skin, metal, and other materials associated with relatively more gain may be classified as high-loss (e.g., dispersive) dielectric materials. In some examples, the material **405**-*a* may be a high-loss dielectric material, and the material **405**-*b* may be a low-loss dielectric material. In some cases, classifying the materials may include a binary classification, for example, as either a high-loss or a low-loss dielectric material.

Because the material **405**-*a* and the material **405**-*b* may have different reflectivity, conductivity, permissivity, or dielectric properties, the material **405**-*a* and the material **405**-*b* may have different capabilities of distorting the array gain response of a signal transmitted from the UE **115**-*c*. For example, if the material **405**-*a* is a high-loss dielectric material with a relatively high conductive property, the reflection **420**-*a* may be a relatively heavy distortion of the radar waveform **415**-*a* (e.g., above a distortion threshold). Additionally, or alternatively, if the material **405**-*b* is a low-loss dielectric material with a relatively low conductive property, the reflection **420**-*b* may be a relatively light distortion of the radar waveform **415**-*a* (e.g., below a distortion threshold). As such, a material with a low-loss dielectric property may lead to relatively fewer or less substantial distortions of the radar waveform **415**-*a* than a material with a high-loss dielectric property.

The performance of beamformed communications at the UE **115**-*c* when surrounded or near either or both of the material **405**-*a* and the material **405**-*b* may change based on whether the UE **115**-*c* uses the adaptive beam weight-based hybrid beamforming procedure or the codebook-based beamforming procedure to select beam weights for beamformed communications. In some cases, comparison between the performance gain of beamformed communications at the UE **115**-*c* using the adaptive beam weight-based hybrid beamforming procedure and the performance gain of beamformed communications at the UE **115**-*c* using the codebook-based beamforming procedure may be determined for the material **405**-*a* and the material **405**-*b* by estimating a sum SNR gain over 2-layer polarization transmissions with adaptive beam weights over a static codebook.

For instance, if the material **405**-*b* is wood and the material **405**-*a* is a human hand, the material **405**-*a* may reflect more transmitted signals onto the antennas of the UE **115**-*c* than the material **405**-*b* because the human hand (a high-loss dielectric material) is relatively more conductive than wood (a low-loss dielectric material). Because the human hand may reflect more signals onto the antennas of the UE **115**-*c*, the human hand may distort the effective array response observed by the multiple antenna array of the UE **115**-*c* more dramatically. The distortions of the array gain response of a signal transmitted from or to the UE **115**-*c* (e.g., the radar waveform **415**-*a*) and reflected by the material **405**-*a* or the material **405**-*b* (e.g., the reflection **420**-*a* or the reflection **420**-*b*) may be undone or otherwise mitigated by the selection of adaptive beam weights in the adaptive beam weight-based hybrid beamforming procedure. For instance, adaptive beam weights may focus on multiple clusters in a channel and combine energy across these clusters, whereas static beam weights may focus on a single, or dominant, cluster in the channel. As such, adaptive beam weights may mitigate the high-loss dielectric properties of some materials, such as a human hand.

Because high-loss dielectric materials tend to spread energy in more directions than low-loss dielectric materials, performance gains for beamformed communications when using the adaptive beam weight-based hybrid beamforming procedure may be more dramatic with high-loss dielectric materials, such as the human hand, than with low-loss dielectric materials, such as wood. For instance, performance gains for beamformed communications when using the adaptive beam weight-based hybrid beamforming procedure with a hand may be 95% with a human hand and 80% with wood, with median gains being greater than 3 decibels (dB) for a human hand and greater than 1 dB for wood.

Although the adaptive beam weight-based procedure may lead to performance gains for beamformed communications near low-loss dielectric materials, such as the material **405**-*b*, and high-loss dielectric materials, such as the material **405**-*a*, the UE **115**-*c* may process additional reference signals (e.g., CSI-RSs) to support beam weight learning for the adaptive beam weight-based procedure. In some applications, the cost of processing the greater quantity of reference signals may offset the performance gains of using the adaptive beam weights. Accordingly, the UE **115**-*c* may classify the material near or around the UE **115**-*c* and may determine as to whether the processing overhead cost of using the adaptive beam weight-based hybrid beamforming procedure associated with more reference signals is worth the performance gains of the resulting beamformed communications.

In the material classification scheme **400**, the UE **115**-*c* may classify a material type by determining whether or not the energy from a signal direction is spread across many directions. In some examples, a distortion threshold may be configured for the UE **115**-*c* (e.g., by a network entity **105** or by an original equipment manufacturer (OEM)), and the UE **115**-*c* may communicate using the adaptive beam weight-based hybrid beamforming procedure based on a distortion metric of the reflection **420**-*a* or of the reflection **420**-*b* that satisfies the distortion threshold. For instance, the distortion metric of the reflection **420**-*a* may exceed the distortion threshold. In some examples, the distortion metric may measure an average difference (e.g., in amplitude, in frequency) between the radar waveform **415**-*a* and the reflection **420**-*a* or may measure a peak difference (e.g., in amplitude, in frequency) between the radar waveform **415**-*a* and the reflection **420**-*a*. Accordingly, the UE **115**-*c* may classify the material to be a high-loss dielectric material type and dynamically select beam weights for beamformed communications using the adaptive beam weight-based hybrid beamforming procedure in the presence of the material

405-*a*. Additionally, or alternatively, the distortion metric of the reflection **420**-*b* may be below the distortion threshold. Accordingly, the UE **115**-*c* may classify the material **405**-*b* to be a low-loss dielectric material type and select beam weights for beamformed communications using the codebook-based hybrid beamforming procedure in the presence of the material **405**-*b*.

FIG. **5** illustrates an example of a machine learning process **500** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The machine learning process **500** may be implemented at a network entity **105**, or a UE **115**, or both as described with reference to FIGS. **1** through **4**.

The machine learning process **500** may include a machine learning algorithm **510**. As illustrated, the machine learning algorithm **510** may be an example of a neural network, such as a feed forward (FF) or deep feed forward (DFF) neural network, a recurrent neural network (RNN), a long/short term memory (LSTM) neural network, or any other type of neural network. However, any other machine learning algorithms may be supported. For example, the machine learning algorithm **510** may implement a nearest neighbor algorithm, a linear regression algorithm, a Naïve Bayes algorithm, a random forest algorithm, or any other machine learning algorithm. Furthermore, the machine learning process **500** may involve supervised learning, unsupervised learning, semi-supervised learning, reinforcement learning, or any combination thereof.

The machine learning algorithm **510** may include an input layer **515**, one or more hidden layers **520**, and an output layer **525**. In a fully connected neural network with one hidden layer **520**, each hidden layer node **535** may receive a value from each input layer node **530** as input, where each input may be weighted. These neural network weights may be based on a cost function that is revised during training of the machine learning algorithm **510**. Similarly, each output layer node **540** may receive a value from each hidden layer node **535** as input, where the inputs are weighted. If post-deployment training (e.g., online training) is supported, memory may be allocated to store errors or gradients for reverse matrix multiplication. These errors or gradients may support updating the machine learning algorithm **510** based on output feedback. Training the machine learning algorithm **510** may support computation of the weights (e.g., connecting the input layer nodes **530** to the hidden layer nodes **535** and the hidden layer nodes **535** to the output layer nodes **540**) to map an input pattern to a desired output outcome. This training may result in a device-specific machine learning algorithm **510** based on the historic application data and data transfer for a specific network entity **105** or UE **115**.

In some examples, input values **505** may be sent to the machine learning algorithm **510** for processing. In some examples, preprocessing may be performed according to a sequence of operations on the input values **505** such that the input values **505** may be in a format that is compatible with the machine learning algorithm **510**. The input values **505** may be converted into a set of k input layer nodes **530** at the input layer **515**. In some cases, different measurements may be input at different input layer nodes **530** of the input layer **515**. Some input layer nodes **530** may be assigned default values (e.g., values of 0) if the quantity of input layer nodes **530** exceeds the quantity of inputs corresponding to the input values **505**. As illustrated, the input layer **515** may include three input layer nodes **530**-*a*, **530**-*b*, and **530**-*c*. However, it is to be understood that the input layer **515** may include any quantity of input layer nodes **530** (e.g., 20 input nodes).

The machine learning algorithm **510** may convert the input layer **515** to a hidden layer **520** based on a quantity of input-to-hidden weights between the k input layer nodes **530** and then hidden layer nodes **535**. The machine learning algorithm **510** may include any quantity of hidden layers **520** as intermediate steps between the input layer **515** and the output layer **525**. Additionally, each hidden layer **520** may include any quantity of nodes. For example, as illustrated, the hidden layer **520** may include four hidden layer nodes **535**-*a*, **535**-*b*, **535**-*c*, and **535**-*d*. However, it is to be understood that the hidden layer **520** may include any quantity of hidden layer nodes **535** (e.g., 10 input nodes). In a fully connected neural network, each node in a layer may be based on each node in the previous layer. For example, the value of hidden layer node **535**-*a* may be based on the values of input layer nodes **530**-*a*, **530**-*b*, and **530**-*c* (e.g., with different weights applied to each node value).

The machine learning algorithm **510** may determine values for the output layer nodes **540** of the output layer **525** following one or more hidden layers **520**. For example, the machine learning algorithm **510** may convert the hidden layer **520** to the output layer **525** based on a quantity of hidden-to-output weights between the n hidden layer nodes **535** and the m output layer nodes **540**. In some cases, n=m. Each output layer node **540** may correspond to a different output value **545** of the machine learning algorithm **510**. As illustrated, the machine learning algorithm **510** may include three output layer nodes **540**-*a*, **540**-*b*, and **540**-*c*, supporting three different threshold values. However, it is to be understood that the output layer **525** may include any quantity of output layer nodes **540**. In some examples, post-processing may be performed on the output values **545** according to a sequence of operations such that the output values **545** may be in a format that is compatible with reporting the output values **545**.

The machine learning algorithm **510** may support material classification, adaptive beam weight selection, or both. For example, for material classification, the input values **505** may include distortion metrics for a reflected radar signal (e.g., an FMCW waveform), material properties, or other information relating to a detected material. The output values **545** may classify the material, for example, between to binary output values (e.g., low-less dielectric or high-loss dielectric) or between multiple material types (e.g., wood, skin, metal, plastic, leather). For adaptive beam weight selection, the input values **505** may include reference signal measurements (e.g., a reference signal received power (RSRP), a reference signal received quality (RSRQ), an SNR value) for multiple reference signals received from another device (e.g., a network entity **105**), and the output values **545** may include beam weights for communication beams (e.g., a receive beam, a transmit beam, or both).

FIG. **6** illustrates an example of a process flow **600** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The process flow **600** may include a network entity **105**-*c* and a UE **115**-*d*, which may be examples of a network entity **105** and a UE **115** as described with reference to FIGS. **1** through **5**. The process flow **600** may be implemented by the network entity **105**-*c* and the UE **115**-*d* to allow the UE **115**-*d* to switch to an adaptive beam weight-based hybrid beamforming procedure in accordance with a material surrounding or nearby the UE **115**-*d*. In the following description of the

process flow **600**, the operations between the network entity **105**-*c* and the UE **115**-*d* may be performed in a different order than the example order shown. Some operations may be omitted from the process flow **600**, and other operations may be added to the process flow **600**.

In some examples, at **605**, the UE **115**-*d* may detect a material property of a material that is within a threshold distance from the UE **115**-*d*. Additionally, or alternatively, the UE **115**-*d* may detect a second material property for a second material within the threshold distance from the UE **115**-*d*. For instance, the UE **115**-*d* may detect a dielectric property, a conductive property, or both for a material within a threshold distance from the UE **115**-*d*. The UE **115**-*d* may classify the material with a material type from a set of multiple material types based on the detected dielectric property, the detected conductivity property, or both. In some examples, the UE **115**-*d* may receive (e.g., from the network entity **105**-*c*) assistance information that indicates the set of multiple material types for classification. In some such examples, the material may be classified with the material type based on the assistance information.

In some examples, the UE **115**-*d* may detect the material property of the material that is within a threshold distance from the UE **115**-*d* based on a distortion metric of a reflection of a radar waveform transmitted by the UE **115**-*d* and reflected from the material. For instance, the UE **115**-*d* may transmit a radar waveform and receive, in response to the radar waveform, a reflection of the radar waveform from the material within the threshold distance from the UE **115**-*d*. The UE **115**-*d* may determine the material property of the material based on the distortion metric of the reflection of the radar waveform satisfying a distortion threshold. For example, a material with relatively high conductivity may correspond to a relatively high distortion metric (e.g., satisfying or otherwise exceeding the distortion threshold). Additionally, or alternatively, a material with relatively low conductivity may correspond to a relatively low distortion metric (e.g., failing to satisfy or otherwise falling below the distortion threshold). If the UE **115**-*d* transmits a radar waveform and receives, in response to the radar waveform, a reflection of the radar waveform, the UE **115**-*d* may determine the distortion metric of the reflection of the radar waveform. If the distortion metric is equal to or below a low distortion threshold, the UE **115**-*d* may determine that the material has low conductivity. Additionally, or alternatively, if the distortion metric is equal to or above a high distortion threshold, the UE **115**-*d* may determine that the material has high conductivity. In some examples, the low distortion threshold and the high distortion threshold may be a same distortion threshold (e.g., for binary classification).

For example, the UE **115**-*d* may transmit the radar waveform and receive, in response to the radar waveform, a reflection of the waveform from the material within the threshold distance from the UE **115**-*d*. The UE **115**-*d* may input one or more waveform parameters of the reflection of the radar waveform into a machine learning model, where the one or more waveform parameters include at least the distortion metric. Based on the one or more waveform parameters input into the machine learning model, the UE **115**-*d* may classify the material with a material type in accordance with an output of the machine learning model.

At **610**, the UE **115**-*d* may transmit, and the network entity **105**-*c* may receive (e.g., obtain), an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure. For example, the UE **115**-*d* may switch to the adaptive beam weight-based hybrid beamforming procedure based on the detected material corresponding to a high-loss dielectric. Additionally, or alternatively, the UE **115**-*d* may operate according to the codebook-based hybrid beamforming procedure (e.g., if the detected material corresponds to a low-loss dielectric) and may select a codebook from a set of multiple codebooks based on the codebook-based hybrid beamforming procedure and the detected material. In some examples, the UE **115**-*d* may transmit an indication of the selected codebook to the network entity **105**-*c*.

In some examples, at **615**, the network entity **105**-*c* may transmit (e.g., output), and the UE **115**-*d* may receive, a control signal that allocates one or more resources for one or more reference signals. The UE **115**-*d* may receive the control signal in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure. For example, the network entity **105**-*c* may configure additional reference signal resources to support adaptive beam weight selection. The control signal may be an example of an RRC signal, a MAC-CE, or a DCI signal configuring the additional reference signal resources for the UE **115**-*d*.

At **620**, the network entity **105**-*c* may transmit (e.g., output), and the UE **115**-*d* may receive, one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure. The UE **115**-*d* may receive the one or more reference signals to estimate and select one or more beam weights for beamformed communications. For example, the UE **115**-*d* may receive one or more CSI-RSs, one or more SRSs, or a combination thereof for beam weight estimation and selection. The UE **115**-*d* may receive the one or more reference signals based on the control signal that allocates the one or more resources for the one or more reference signals. In some examples, the UE **115**-*d* may dynamically perform beam weight estimation based on the one or more reference signals, where the one or more beam weights may be based on the beam weight estimation.

At **625**, the UE **115**-*d* may exchange, with the network entity **105**-*c*, signaling for one or more communications. For instance, the network entity **105**-*c* may output, and the UE **115**-*d* may receive, one or more communications (e.g., a downlink signal). Additionally, or alternatively, the UE **115**-*d* may transmit, and the network entity **105**-*c* may obtain, one or more communications (e.g., an uplink signal). In some aspects, the UE **115**-*d* may communicate with the network entity **105**-*c* in accordance with one or more beam weights selected based on the adaptive beam weigh-based hybrid beamforming procedure and the one or more reference signals. In some such aspects, the UE **115**-*d* may communicate using the adaptive beam weight-based hybrid beamforming procedure based on the detected dielectric property, the detected conductivity property, or both. Additionally, or alternatively, communicating with the adaptive beam weight-based hybrid beamforming procedure may be based on the material type. Additionally, or alternatively, communicating using the adaptive beam weight-based hybrid beamforming procedure may be based on a distortion metric of the reflection of the radar waveform that satisfies a distortion threshold.

In some other aspects, the UE **115**-*d* may communicate with the network entity **105**-*c* using a codebook-based hybrid beamforming procedure based on the material type. In some such other aspects, the UE **115**-*d* may select a codebook from a set of multiple codebooks based on the codebook-based hybrid beamforming procedure and the material property for the material. The set of multiple codebooks may indicate different quantities of beam

weights, different beam properties, different phase quantization for the beam weights, different amplitude quantization for the beam weights, or any combination thereof. The UE **115**-*d* may communicate signaling with the network entity **105**-*c* using the selected codebook (e.g., using beam weights from the selected codebook).

FIG. **7** shows a block diagram **700** of a device **705** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The device **705** may be an example of aspects of a UE **115** as described herein. The device **705** may include a receiver **710**, a transmitter **715**, and a communications manager **720**. The device **705** may also include a processor. Each of these components may be in communication with one another (e.g., via one or more buses).

The receiver **710** may provide a means for receiving information such as packets, user data, control information, or any combination thereof associated with various information channels (e.g., control channels, data channels, information channels related to switching to an adaptive beam weight-based hybrid beamforming procedure). Information may be passed on to other components of the device **705**. The receiver **710** may utilize a single antenna or a set of multiple antennas.

The transmitter **715** may provide a means for transmitting signals generated by other components of the device **705**. For example, the transmitter **715** may transmit information such as packets, user data, control information, or any combination thereof associated with various information channels (e.g., control channels, data channels, information channels related to switching to an adaptive beam weight-based hybrid beamforming procedure). In some examples, the transmitter **715** may be co-located with a receiver **710** in a transceiver module. The transmitter **715** may utilize a single antenna or a set of multiple antennas.

The communications manager **720**, the receiver **710**, the transmitter **715**, or various combinations thereof or various components thereof may be examples of means for performing various aspects of switching to an adaptive beam weight-based hybrid beamforming procedure as described herein. For example, the communications manager **720**, the receiver **710**, the transmitter **715**, or various combinations or components thereof may support a method for performing one or more of the functions described herein.

In some examples, the communications manager **720**, the receiver **710**, the transmitter **715**, or various combinations or components thereof may be implemented in hardware (e.g., in communications management circuitry). The hardware may include a processor, a digital signal processor (DSP), a central processing unit (CPU), an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA) or other programmable logic device, a microcontroller, discrete gate or transistor logic, discrete hardware components, or any combination thereof configured as or otherwise supporting a means for performing the functions described in the present disclosure. In some examples, a processor and memory coupled with the processor may be configured to perform one or more of the functions described herein (e.g., by executing, by the processor, instructions stored in the memory).

Additionally, or alternatively, in some examples, the communications manager **720**, the receiver **710**, the transmitter **715**, or various combinations or components thereof may be implemented in code (e.g., as communications management software or firmware) executed by a processor. If implemented in code executed by a processor, the functions of the communications manager **720**, the receiver **710**, the transmitter **715**, or various combinations or components thereof may be performed by a general-purpose processor, a DSP, a CPU, an ASIC, an FPGA, a microcontroller, or any combination of these or other programmable logic devices (e.g., configured as or otherwise supporting a means for performing the functions described in the present disclosure).

In some examples, the communications manager **720** may be configured to perform various operations (e.g., receiving, obtaining, monitoring, outputting, transmitting) using or otherwise in cooperation with the receiver **710**, the transmitter **715**, or both. For example, the communications manager **720** may receive information from the receiver **710**, send information to the transmitter **715**, or be integrated in combination with the receiver **710**, the transmitter **715**, or both to obtain information, output information, or perform various other operations as described herein.

Additionally, or alternatively, the communications manager **720** may support wireless communications at a UE in accordance with examples as disclosed herein. For example, the communications manager **720** may be configured as or otherwise support a means for transmitting an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure. The communications manager **720** may be configured as or otherwise support a means for receiving one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure. The communications manager **720** may be configured as or otherwise support a means for communicating in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

By including or configuring the communications manager **720** in accordance with examples as described herein, the device **705** (e.g., a processor controlling or otherwise coupled with the receiver **710**, the transmitter **715**, the communications manager **720**, or a combination thereof) may support techniques for reduced processing overhead, reduced power consumption, and more efficient utilization of communication resources. For example, the device **705** may switch to a codebook-based hybrid beamforming procedure to reduce the processing overhead associated with reference signal reception and processing (e.g., for reference signals used for beam weight selection). Additionally, or alternatively, the device **705** may switch to an adaptive beam weight-based hybrid beamforming procedure to reduce the processing overhead associated with retransmissions by improving signal reliability (e.g., by improving the performance of beamformed communications).

FIG. **8** shows a block diagram **800** of a device **805** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The device **805** may be an example of aspects of a device **705** or a UE **115** as described herein. The device **805** may include a receiver **810**, a transmitter **815**, and a communications manager **820**. The device **805** may also include a processor. Each of these components may be in communication with one another (e.g., via one or more buses).

The receiver **810** may provide a means for receiving information such as packets, user data, control information, or any combination thereof associated with various information channels (e.g., control channels, data channels, information channels related to switching to an adaptive beam weight-based hybrid beamforming procedure). Information

may be passed on to other components of the device **805**. The receiver **810** may utilize a single antenna or a set of multiple antennas.

The transmitter **815** may provide a means for transmitting signals generated by other components of the device **805**. For example, the transmitter **815** may transmit information such as packets, user data, control information, or any combination thereof associated with various information channels (e.g., control channels, data channels, information channels related to switching to an adaptive beam weight-based hybrid beamforming procedure). In some examples, the transmitter **815** may be co-located with a receiver **810** in a transceiver module. The transmitter **815** may utilize a single antenna or a set of multiple antennas.

The device **805**, or various components thereof, may be an example of means for performing various aspects of switching to an adaptive beam weight-based hybrid beamforming procedure as described herein. For example, the communications manager **820** may include a switch indication component **825**, a reference signal component **830**, an adaptive beam weight communication component **835**, or any combination thereof. The communications manager **820** may be an example of aspects of a communications manager **720** as described herein. In some examples, the communications manager **820**, or various components thereof, may be configured to perform various operations (e.g., receiving, obtaining, monitoring, outputting, transmitting) using or otherwise in cooperation with the receiver **810**, the transmitter **815**, or both. For example, the communications manager **820** may receive information from the receiver **810**, send information to the transmitter **815**, or be integrated in combination with the receiver **810**, the transmitter **815**, or both to obtain information, output information, or perform various other operations as described herein.

The communications manager **820** may support wireless communications at a UE in accordance with examples as disclosed herein. The switch indication component **825** may be configured as or otherwise support a means for transmitting an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure. The reference signal component **830** may be configured as or otherwise support a means for receiving one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure. The adaptive beam weight communication component **835** may be configured as or otherwise support a means for communicating in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

FIG. **9** shows a block diagram **900** of a communications manager **920** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The communications manager **920** may be an example of aspects of a communications manager **720**, a communications manager **820**, or both, as described herein. The communications manager **920**, or various components thereof, may be an example of means for performing various aspects of switching to an adaptive beam weight-based hybrid beamforming procedure as described herein. For example, the communications manager **920** may include a switch indication component **925**, a reference signal component **930**, an adaptive beam weight communication component **935**, a control signal component **940**, a beam weight estimation component **945**, a material detection component **950**, a material classification component **955**, a radar waveform component **960**, a codebook communication component **965**, a codebook selection component **970**, or any combination thereof. Each of these components may communicate, directly or indirectly, with one another (e.g., via one or more buses).

The communications manager **920** may support wireless communications at a UE in accordance with examples as disclosed herein. The switch indication component **925** may be configured as or otherwise support a means for transmitting an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure. The reference signal component **930** may be configured as or otherwise support a means for receiving one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure. The adaptive beam weight communication component **935** may be configured as or otherwise support a means for communicating in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

In some examples, the control signal component **940** may be configured as or otherwise support a means for receiving, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, a control signal that allocates one or more resources for the one or more reference signals, where the one or more reference signals are received based on the control signal.

In some examples, to support receiving the one or more reference signals, the reference signal component **930** may be configured as or otherwise support a means for receiving one or more CSI-RSs, one or more SRSs, or a combination thereof for beam weight estimation and selection.

In some examples, the beam weight estimation component **945** may be configured as or otherwise support a means for dynamically performing beam weight estimation based on the one or more reference signals, where the one or more beam weights are based on the beam weight estimation.

In some examples, the material detection component **950** may be configured as or otherwise support a means for detecting a dielectric property, a conductivity property, or both for a material within a threshold distance from the UE. In some examples, the adaptive beam weight communication component **935** may be configured as or otherwise support a means for communicating using the adaptive beam weight-based hybrid beamforming procedure based on the detected dielectric property, the detected conductivity property, or both.

In some examples, the material classification component **955** may be configured as or otherwise support a means for classifying the material with a material type from a set of multiple material types based on the detected dielectric property, the detected conductivity property, or both, where communicating using the adaptive beam weight-based hybrid beamforming procedure is based on the material type.

In some examples, the material classification component **955** may be configured as or otherwise support a means for receiving assistance information that indicates the set of multiple material types for classification, where the material is classified with the material type based on the assistance information.

In some examples, the radar waveform component **960** may be configured as or otherwise support a means for transmitting a radar waveform. In some examples, the radar waveform component **960** may be configured as or otherwise support a means for receiving, in response to the radar

waveform, a reflection of the radar waveform from the material within the threshold distance from the UE, where communicating using the adaptive beam weight-based hybrid beamforming procedure is based on a distortion metric of the reflection of the radar waveform that satisfies a distortion threshold.

In some examples, the material classification component **955** may be configured as or otherwise support a means for inputting one or more waveform parameters of the reflection of the radar waveform into a machine learning model, where the one or more waveform parameters include at least the distortion metric. In some examples, the material classification component **955** may be configured as or otherwise support a means for classifying the material with a material type in accordance with an output of the machine learning model based on the one or more waveform parameters input into the machine learning model.

In some examples, the material detection component **950** may be configured as or otherwise support a means for detecting a second material property for a second material within the threshold distance from the UE. In some examples, the codebook communication component **965** may be configured as or otherwise support a means for communicating using the codebook-based hybrid beamforming procedure based on the second material property for the second material. In some examples, the codebook selection component **970** may be configured as or otherwise support a means for selecting a codebook from a set of multiple codebooks based on the codebook-based hybrid beamforming procedure and the second material property for the second material.

In some examples, the set of multiple codebooks indicates different quantities of beam weights, different beam properties, different phase quantization for the beam weights, different amplitude quantization for the beam weights, or any combination thereof.

FIG. **10** shows a diagram of a system **1000** including a device **1005** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The device **1005** may be an example of or include the components of a device **705**, a device **805**, or a UE **115** as described herein. The device **1005** may communicate (e.g., wirelessly) with one or more network entities **105**, one or more UEs **115**, or any combination thereof. The device **1005** may include components for bi-directional voice and data communications including components for transmitting and receiving communications, such as a communications manager **1020**, an input/output (I/O) controller **1010**, a transceiver **1015**, an antenna **1025**, a memory **1030**, code **1035**, and a processor **1040**. These components may be in electronic communication or otherwise coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more buses (e.g., a bus **1045**).

The I/O controller **1010** may manage input and output signals for the device **1005**. The I/O controller **1010** may also manage peripherals not integrated into the device **1005**. In some cases, the I/O controller **1010** may represent a physical connection or port to an external peripheral. In some cases, the I/O controller **1010** may utilize an operating system such as iOS®, ANDROID®, MS-DOS®, MS-WINDOWS®, OS/2®, UNIX®, LINUX®, or another known operating system. Additionally, or alternatively, the I/O controller **1010** may represent or interact with a modem, a keyboard, a mouse, a touchscreen, or a similar device. In some cases, the I/O controller **1010** may be implemented as part of a processor, such as the processor **1040**. In some cases, a user may interact with the device **1005** via the I/O controller **1010** or via hardware components controlled by the I/O controller **1010**.

In some cases, the device **1005** may include a single antenna **1025**. However, in some other cases, the device **1005** may have more than one antenna **1025**, which may be capable of concurrently transmitting or receiving multiple wireless transmissions. The transceiver **1015** may communicate bi-directionally, via the one or more antennas **1025**, wired, or wireless links as described herein. For example, the transceiver **1015** may represent a wireless transceiver and may communicate bi-directionally with another wireless transceiver. The transceiver **1015** may also include a modem to modulate the packets, to provide the modulated packets to one or more antennas **1025** for transmission, and to demodulate packets received from the one or more antennas **1025**. The transceiver **1015**, or the transceiver **1015** and one or more antennas **1025**, may be an example of a transmitter **715**, a transmitter **815**, a receiver **710**, a receiver **810**, or any combination thereof or component thereof, as described herein.

The memory **1030** may include random access memory (RAM) and read-only memory (ROM). The memory **1030** may store computer-readable, computer-executable code **1035** including instructions that, when executed by the processor **1040**, cause the device **1005** to perform various functions described herein. The code **1035** may be stored in a non-transitory computer-readable medium such as system memory or another type of memory. In some cases, the code **1035** may not be directly executable by the processor **1040** but may cause a computer (e.g., when compiled and executed) to perform functions described herein. In some cases, the memory **1030** may contain, among other things, a basic I/O system (BIOS) which may control basic hardware or software operation such as the interaction with peripheral components or devices.

The processor **1040** may include an intelligent hardware device (e.g., a general-purpose processor, a DSP, a CPU, a microcontroller, an ASIC, an FPGA, a programmable logic device, a discrete gate or transistor logic component, a discrete hardware component, or any combination thereof). In some cases, the processor **1040** may be configured to operate a memory array using a memory controller. In some other cases, a memory controller may be integrated into the processor **1040**. The processor **1040** may be configured to execute computer-readable instructions stored in a memory (e.g., the memory **1030**) to cause the device **1005** to perform various functions (e.g., functions or tasks supporting switching to an adaptive beam weight-based hybrid beamforming procedure). For example, the device **1005** or a component of the device **1005** may include a processor **1040** and memory **1030** coupled with or to the processor **1040**, the processor **1040** and memory **1030** configured to perform various functions described herein.

Additionally, or alternatively, the communications manager **1020** may support wireless communications at a UE in accordance with examples as disclosed herein. For example, the communications manager **1020** may be configured as or otherwise support a means for transmitting an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure. The communications manager **1020** may be configured as or otherwise support a means for receiving one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure. The communications manager **1020** may be configured as or otherwise support a means for communi-

cating in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

By including or configuring the communications manager **1020** in accordance with examples as described herein, the device **1005** may support techniques for reduced latency, improved user experience related to reduced processing, reduced power consumption, more efficient utilization of communication resources, longer battery life, and improved utilization of processing capability.

In some examples, the communications manager **1020** may be configured to perform various operations (e.g., receiving, monitoring, transmitting) using or otherwise in cooperation with the transceiver **1015**, the one or more antennas **1025**, or any combination thereof. Although the communications manager **1020** is illustrated as a separate component, in some examples, one or more functions described with reference to the communications manager **1020** may be supported by or performed by the processor **1040**, the memory **1030**, the code **1035**, or any combination thereof. For example, the code **1035** may include instructions executable by the processor **1040** to cause the device **1005** to perform various aspects of switching to an adaptive beam weight-based hybrid beamforming procedure as described herein, or the processor **1040** and the memory **1030** may be otherwise configured to perform or support such operations.

FIG. **11** shows a block diagram **1100** of a device **1105** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The device **1105** may be an example of aspects of a network entity **105** as described herein. The device **1105** may include a receiver **1110**, a transmitter **1115**, and a communications manager **1120**. The device **1105** may also include a processor. Each of these components may be in communication with one another (e.g., via one or more buses).

The receiver **1110** may provide a means for obtaining (e.g., receiving, determining, identifying) information such as user data, control information, or any combination thereof (e.g., I/Q samples, symbols, packets, protocol data units, service data units) associated with various channels (e.g., control channels, data channels, information channels, channels associated with a protocol stack). Information may be passed on to other components of the device **1105**. In some examples, the receiver **1110** may support obtaining information by receiving signals via one or more antennas. Additionally, or alternatively, the receiver **1110** may support obtaining information by receiving signals via one or more wired (e.g., electrical, fiber optic) interfaces, wireless interfaces, or any combination thereof.

The transmitter **1115** may provide a means for outputting (e.g., transmitting, providing, conveying, sending) information generated by other components of the device **1105**. For example, the transmitter **1115** may output information such as user data, control information, or any combination thereof (e.g., I/Q samples, symbols, packets, protocol data units, service data units) associated with various channels (e.g., control channels, data channels, information channels, channels associated with a protocol stack). In some examples, the transmitter **1115** may support outputting information by transmitting signals via one or more antennas. Additionally, or alternatively, the transmitter **1115** may support outputting information by transmitting signals via one or more wired (e.g., electrical, fiber optic) interfaces, wireless interfaces, or any combination thereof. In some examples, the transmitter **1115** and the receiver **1110** may be co-located in a transceiver, which may include or be coupled with a modem.

The communications manager **1120**, the receiver **1110**, the transmitter **1115**, or various combinations thereof or various components thereof may be examples of means for performing various aspects of switching to an adaptive beam weight-based hybrid beamforming procedure as described herein. For example, the communications manager **1120**, the receiver **1110**, the transmitter **1115**, or various combinations or components thereof may support a method for performing one or more of the functions described herein.

In some examples, the communications manager **1120**, the receiver **1110**, the transmitter **1115**, or various combinations or components thereof may be implemented in hardware (e.g., in communications management circuitry). The hardware may include a processor, a DSP, a CPU, an ASIC, an FPGA or other programmable logic device, a microcontroller, discrete gate or transistor logic, discrete hardware components, or any combination thereof configured as or otherwise supporting a means for performing the functions described in the present disclosure. In some examples, a processor and memory coupled with the processor may be configured to perform one or more of the functions described herein (e.g., by executing, by the processor, instructions stored in the memory).

Additionally, or alternatively, in some examples, the communications manager **1120**, the receiver **1110**, the transmitter **1115**, or various combinations or components thereof may be implemented in code (e.g., as communications management software or firmware) executed by a processor. If implemented in code executed by a processor, the functions of the communications manager **1120**, the receiver **1110**, the transmitter **1115**, or various combinations or components thereof may be performed by a general-purpose processor, a DSP, a CPU, an ASIC, an FPGA, a microcontroller, or any combination of these or other programmable logic devices (e.g., configured as or otherwise supporting a means for performing the functions described in the present disclosure).

In some examples, the communications manager **1120** may be configured to perform various operations (e.g., receiving, obtaining, monitoring, outputting, transmitting) using or otherwise in cooperation with the receiver **1110**, the transmitter **1115**, or both. For example, the communications manager **1120** may receive information from the receiver **1110**, send information to the transmitter **1115**, or be integrated in combination with the receiver **1110**, the transmitter **1115**, or both to obtain information, output information, or perform various other operations as described herein.

Additionally, or alternatively, the communications manager **1120** may support wireless communications in accordance with examples as disclosed herein. For example, the communications manager **1120** may be configured as or otherwise support a means for obtaining an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE. The communications manager **1120** may be configured as or otherwise support a means for outputting, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals. The communications manager **1120** may be configured as or otherwise support a means for outputting the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based on the control signal.

By including or configuring the communications manager **1120** in accordance with examples as described herein, the device **1105** (e.g., a processor controlling or otherwise coupled with the receiver **1110**, the transmitter **1115**, the communications manager **1120**, or a combination thereof) may support techniques for reduced processing overhead, reduced power consumption, and more efficient utilization of communication resources.

FIG. **12** shows a block diagram **1200** of a device **1205** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The device **1205** may be an example of aspects of a device **1105** or a network entity **105** as described herein. The device **1205** may include a receiver **1210**, a transmitter **1215**, and a communications manager **1220**. The device **1205** may also include a processor. Each of these components may be in communication with one another (e.g., via one or more buses).

The receiver **1210** may provide a means for obtaining (e.g., receiving, determining, identifying) information such as user data, control information, or any combination thereof (e.g., I/Q samples, symbols, packets, protocol data units, service data units) associated with various channels (e.g., control channels, data channels, information channels, channels associated with a protocol stack). Information may be passed on to other components of the device **1205**. In some examples, the receiver **1210** may support obtaining information by receiving signals via one or more antennas. Additionally, or alternatively, the receiver **1210** may support obtaining information by receiving signals via one or more wired (e.g., electrical, fiber optic) interfaces, wireless interfaces, or any combination thereof.

The transmitter **1215** may provide a means for outputting (e.g., transmitting, providing, conveying, sending) information generated by other components of the device **1205**. For example, the transmitter **1215** may output information such as user data, control information, or any combination thereof (e.g., I/Q samples, symbols, packets, protocol data units, service data units) associated with various channels (e.g., control channels, data channels, information channels, channels associated with a protocol stack). In some examples, the transmitter **1215** may support outputting information by transmitting signals via one or more antennas. Additionally, or alternatively, the transmitter **1215** may support outputting information by transmitting signals via one or more wired (e.g., electrical, fiber optic) interfaces, wireless interfaces, or any combination thereof. In some examples, the transmitter **1215** and the receiver **1210** may be co-located in a transceiver, which may include or be coupled with a modem.

The device **1205**, or various components thereof, may be an example of means for performing various aspects of switching to an adaptive beam weight-based hybrid beamforming procedure as described herein. For example, the communications manager **1220** may include a switch indication manager **1225**, a control signal manager **1230**, a reference signal manager **1235**, or any combination thereof. The communications manager **1220** may be an example of aspects of a communications manager **1120** as described herein. In some examples, the communications manager **1220**, or various components thereof, may be configured to perform various operations (e.g., receiving, obtaining, monitoring, outputting, transmitting) using or otherwise in cooperation with the receiver **1210**, the transmitter **1215**, or both. For example, the communications manager **1220** may receive information from the receiver **1210**, send information to the transmitter **1215**, or be integrated in combination with the receiver **1210**, the transmitter **1215**, or both to obtain information, output information, or perform various other operations as described herein.

The communications manager **1220** may support wireless communications in accordance with examples as disclosed herein. The switch indication manager **1225** may be configured as or otherwise support a means for obtaining an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE. The control signal manager **1230** may be configured as or otherwise support a means for outputting, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals. The reference signal manager **1235** may be configured as or otherwise support a means for outputting the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based on the control signal.

FIG. **13** shows a block diagram **1300** of a communications manager **1320** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The communications manager **1320** may be an example of aspects of a communications manager **1120**, a communications manager **1220**, or both, as described herein. The communications manager **1320**, or various components thereof, may be an example of means for performing various aspects of switching to an adaptive beam weight-based hybrid beamforming procedure as described herein. For example, the communications manager **1320** may include a switch indication manager **1325**, a control signal manager **1330**, a reference signal manager **1335**, a material classification manager **1340**, an adaptive beam weight communication manager **1345**, or any combination thereof. Each of these components may communicate, directly or indirectly, with one another (e.g., via one or more buses) which may include communications within a protocol layer of a protocol stack, communications associated with a logical channel of a protocol stack (e.g., between protocol layers of a protocol stack, within a device, component, or virtualized component associated with a network entity **105**, between devices, components, or virtualized components associated with a network entity **105**), or any combination thereof.

Additionally, or alternatively, the communications manager **1320** may support wireless communications in accordance with examples as disclosed herein. The switch indication manager **1325** may be configured as or otherwise support a means for obtaining an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE. The control signal manager **1330** may be configured as or otherwise support a means for outputting, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals. The reference signal manager **1335** may be configured as or otherwise support a means for outputting the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based on the control signal.

In some examples, the material classification manager **1340** may be configured as or otherwise support a means for outputting assistance information that indicates a set of multiple material types for classification, where the indica-

tion of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE is based on the set of multiple material types for classification.

In some examples, the adaptive beam weight communication manager **1345** may be configured as or otherwise support a means for obtaining or outputting one or more communications based on the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE.

In some examples, to support outputting the one or more reference signals, the reference signal manager **1335** may be configured as or otherwise support a means for outputting one or more CSI-RSs, one or more SRSs, or a combination thereof for beam weight estimation and selection.

FIG. **14** shows a diagram of a system **1400** including a device **1405** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The device **1405** may be an example of or include the components of a device **1105**, a device **1205**, or a network entity **105** as described herein. The device **1405** may communicate with one or more network entities **105**, one or more UEs **115**, or any combination thereof, which may include communications over one or more wired interfaces, over one or more wireless interfaces, or any combination thereof. The device **1405** may include components that support outputting and obtaining communications, such as a communications manager **1420**, a transceiver **1410**, an antenna **1415**, a memory **1425**, code **1430**, and a processor **1435**. These components may be in electronic communication or otherwise coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more buses (e.g., a bus **1440**).

The transceiver **1410** may support bi-directional communications via wired links, wireless links, or both as described herein. In some examples, the transceiver **1410** may include a wired transceiver and may communicate bi-directionally with another wired transceiver. Additionally, or alternatively, in some examples, the transceiver **1410** may include a wireless transceiver and may communicate bi-directionally with another wireless transceiver. In some examples, the device **1405** may include one or more antennas **1415**, which may be capable of transmitting or receiving wireless transmissions (e.g., concurrently). The transceiver **1410** may also include a modem to modulate signals, to provide the modulated signals for transmission (e.g., by one or more antennas **1415**, by a wired transmitter), to receive modulated signals (e.g., from one or more antennas **1415**, from a wired receiver), and to demodulate signals. In some implementations, the transceiver **1410** may include one or more interfaces, such as one or more interfaces coupled with the one or more antennas **1415** that are configured to support various receiving or obtaining operations, or one or more interfaces coupled with the one or more antennas **1415** that are configured to support various transmitting or outputting operations, or a combination thereof. In some implementations, the transceiver **1410** may include or be configured for coupling with one or more processors or memory components that are operable to perform or support operations based on received or obtained information or signals, or to generate information or other signals for transmission or other outputting, or any combination thereof. In some implementations, the transceiver **1410**, or the transceiver **1410** and the one or more antennas **1415**, or the transceiver **1410** and the one or more antennas **1415** and one or more processors or memory components (for example, the processor **1435**, or the memory **1425**, or both), may be included in a chip or chip assembly that is installed in the device **1405**. The transceiver **1410**, or the transceiver **1410** and one or more antennas **1415** or wired interfaces, where applicable, may be an example of a transmitter **1115**, a transmitter **1215**, a receiver **1110**, a receiver **1210**, or any combination thereof or component thereof, as described herein. In some examples, the transceiver may be operable to support communications via one or more communications links (e.g., a communication link **125**, a backhaul communication link **120**, a midhaul communication link **162**, a fronthaul communication link **168**).

The memory **1425** may include RAM and ROM. The memory **1425** may store computer-readable, computer-executable code **1430** including instructions that, when executed by the processor **1435**, cause the device **1405** to perform various functions described herein. The code **1430** may be stored in a non-transitory computer-readable medium such as system memory or another type of memory. In some cases, the code **1430** may not be directly executable by the processor **1435** but may cause a computer (e.g., when compiled and executed) to perform functions described herein. In some cases, the memory **1425** may contain, among other things, a BIOS which may control basic hardware or software operation such as the interaction with peripheral components or devices.

The processor **1435** may include an intelligent hardware device (e.g., a general-purpose processor, a DSP, an ASIC, a CPU, an FPGA, a microcontroller, a programmable logic device, discrete gate or transistor logic, a discrete hardware component, or any combination thereof). In some cases, the processor **1435** may be configured to operate a memory array using a memory controller. In some other cases, a memory controller may be integrated into the processor **1435**. The processor **1435** may be configured to execute computer-readable instructions stored in a memory (e.g., the memory **1425**) to cause the device **1405** to perform various functions (e.g., functions or tasks supporting switching to an adaptive beam weight-based hybrid beamforming procedure). For example, the device **1405** or a component of the device **1405** may include a processor **1435** and memory **1425** coupled with the processor **1435**, the processor **1435** and memory **1425** configured to perform various functions described herein. The processor **1435** may be an example of a cloud-computing platform (e.g., one or more physical nodes and supporting software such as operating systems, virtual machines, or container instances) that may host the functions (e.g., by executing code **1430**) to perform the functions of the device **1405**. The processor **1435** may be any one or more suitable processors capable of executing scripts or instructions of one or more software programs stored in the device **1405** (such as within the memory **1425**). In some implementations, the processor **1435** may be a component of a processing system. A processing system may refer to a system or series of machines or components that receives inputs and processes the inputs to produce a set of outputs (which may be passed to other systems or components of, for example, the device **1405**). For example, a processing system of the device **1405** may refer to a system including the various other components or subcomponents of the device **1405**, such as the processor **1435**, or the transceiver **1410**, or the communications manager **1420**, or other components or combinations of components of the device **1405**. The processing system of the device **1405** may interface with other components of the device **1405**, and may process information received from other components (such as inputs or signals) or output information to other components. For example, a chip or modem of the device **1405** may include a processing system and an interface to

output information, or to obtain information, or both. The interface may be implemented as or otherwise include a first interface configured to output information and a second interface configured to obtain information. In some implementations, the first interface may refer to an interface between the processing system of the chip or modem and a transmitter, such that the device **1405** may transmit information output from the chip or modem. In some implementations, the second interface may refer to an interface between the processing system of the chip or modem and a receiver, such that the device **1405** may obtain information or signal inputs, and the information may be passed to the processing system. A person having ordinary skill in the art will readily recognize that the first interface also may obtain information or signal inputs, and the second interface also may output information or signal outputs.

In some examples, a bus **1440** may support communications of (e.g., within) a protocol layer of a protocol stack. In some examples, a bus **1440** may support communications associated with a logical channel of a protocol stack (e.g., between protocol layers of a protocol stack), which may include communications performed within a component of the device **1405**, or between different components of the device **1405** that may be co-located or located in different locations (e.g., where the device **1405** may refer to a system in which one or more of the communications manager **1420**, the transceiver **1410**, the memory **1425**, the code **1430**, and the processor **1435** may be located in one of the different components or divided between different components).

In some examples, the communications manager **1420** may manage aspects of communications with a core network **130** (e.g., via one or more wired or wireless backhaul links). For example, the communications manager **1420** may manage the transfer of data communications for client devices, such as one or more UEs **115**. In some examples, the communications manager **1420** may manage communications with other network entities **105**, and may include a controller or scheduler for controlling communications with UEs **115** in cooperation with other network entities **105**. In some examples, the communications manager **1420** may support an X2 interface within an LTE/LTE-A wireless communications network technology to provide communication between network entities **105**.

Additionally, or alternatively, the communications manager **1420** may support wireless communications in accordance with examples as disclosed herein. For example, the communications manager **1420** may be configured as or otherwise support a means for obtaining an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE. The communications manager **1420** may be configured as or otherwise support a means for outputting, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals. The communications manager **1420** may be configured as or otherwise support a means for outputting the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based on the control signal.

By including or configuring the communications manager **1420** in accordance with examples as described herein, the device **1405** may support techniques for reduced latency, improved user experience related to reduced processing, reduced power consumption, more efficient utilization of communication resources, longer battery life, and improved utilization of processing capability.

In some examples, the communications manager **1420** may be configured to perform various operations (e.g., receiving, obtaining, monitoring, outputting, transmitting) using or otherwise in cooperation with the transceiver **1410**, the one or more antennas **1415** (e.g., where applicable), or any combination thereof. Although the communications manager **1420** is illustrated as a separate component, in some examples, one or more functions described with reference to the communications manager **1420** may be supported by or performed by the processor **1435**, the memory **1425**, the code **1430**, the transceiver **1410**, or any combination thereof. For example, the code **1430** may include instructions executable by the processor **1435** to cause the device **1405** to perform various aspects of switching to an adaptive beam weight-based hybrid beamforming procedure as described herein, or the processor **1435** and the memory **1425** may be otherwise configured to perform or support such operations.

FIG. **15** shows a flowchart illustrating a method **1500** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The operations of the method **1500** may be implemented by a UE or its components as described herein. For example, the operations of the method **1500** may be performed by a UE **115** as described with reference to FIGS. **1** through **10**. In some examples, a UE may execute a set of instructions to control the functional elements of the UE to perform the described functions. Additionally, or alternatively, the UE may perform aspects of the described functions using special-purpose hardware.

At **1505**, the method may include transmitting an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure. The operations of **1505** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1505** may be performed by a switch indication component **925** as described with reference to FIG. **9**.

At **1510**, the method may include receiving one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure. The operations of **1510** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1510** may be performed by a reference signal component **930** as described with reference to FIG. **9**.

At **1515**, the method may include communicating in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals. The operations of **1515** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1515** may be performed by an adaptive beam weight communication component **935** as described with reference to FIG. **9**.

FIG. **16** shows a flowchart illustrating a method **1600** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The operations of the method **1600** may be implemented by a UE or its components as described herein. For example, the operations of the method **1600** may be performed by a UE **115** as described with reference to FIGS. **1** through **10**. In some examples, a UE may execute a set of instructions to control

the functional elements of the UE to perform the described functions. Additionally, or alternatively, the UE may perform aspects of the described functions using special-purpose hardware.

At **1605**, the method may include transmitting an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure. The operations of **1605** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1605** may be performed by a switch indication component **925** as described with reference to FIG. **9**.

At **1610**, the method may include receiving, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, a control signal that allocates one or more resources for one or more reference signals. The operations of **1610** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1610** may be performed by a control signal component **940** as described with reference to FIG. **9**.

At **1615**, the method may include receiving the one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, where the one or more reference signals are received based on the control signal. The operations of **1615** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1615** may be performed by a reference signal component **930** as described with reference to FIG. **9**.

At **1620**, the method may include communicating in accordance with one or more beam weights selected based on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals. The operations of **1620** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1620** may be performed by an adaptive beam weight communication component **935** as described with reference to FIG. **9**.

FIG. **17** shows a flowchart illustrating a method **1700** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The operations of the method **1700** may be implemented by a network entity or its components as described herein. For example, the operations of the method **1700** may be performed by a network entity as described with reference to FIGS. **1** through **6** and **11** through **14**. In some examples, a network entity may execute a set of instructions to control the functional elements of the network entity to perform the described functions. Additionally, or alternatively, the network entity may perform aspects of the described functions using special-purpose hardware.

At **1705**, the method may include obtaining an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE. The operations of **1705** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1705** may be performed by a switch indication manager **1325** as described with reference to FIG. **13**.

At **1710**, the method may include outputting, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals. The operations of **1710** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1710** may be performed by a control signal manager **1330** as described with reference to FIG. **13**.

At **1715**, the method may include outputting the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based on the control signal. The operations of **1715** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1715** may be performed by a reference signal manager **1335** as described with reference to FIG. **13**.

FIG. **18** shows a flowchart illustrating a method **1800** that supports techniques for managing an adaptive beam weight-based hybrid beamforming procedure in accordance with one or more aspects of the present disclosure. The operations of the method **1800** may be implemented by a network entity or its components as described herein. For example, the operations of the method **1800** may be performed by a network entity as described with reference to FIGS. **1** through **6** and **11** through **14**. In some examples, a network entity may execute a set of instructions to control the functional elements of the network entity to perform the described functions. Additionally, or alternatively, the network entity may perform aspects of the described functions using special-purpose hardware.

At **1805**, the method may include outputting assistance information that indicates a set of multiple material types for classification, where an indication of a switch to an adaptive beam weight-based hybrid beamforming procedure for a UE is based on the set of multiple material types for classification. The operations of **1805** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1805** may be performed by a material classification manager **1340** as described with reference to FIG. **13**.

At **1810**, the method may include obtaining the indication of the switch from a codebook-based hybrid beamforming procedure to the adaptive beam weight-based hybrid beamforming procedure for the UE. The operations of **1810** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1810** may be performed by a switch indication manager **1325** as described with reference to FIG. **13**.

At **1815**, the method may include outputting, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals. The operations of **1815** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1815** may be performed by a control signal manager **1330** as described with reference to FIG. **13**.

At **1820**, the method may include outputting the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based on the control signal. The operations of **1820** may be performed in accordance with examples as disclosed herein. In some examples, aspects of the operations of **1820** may be performed by a reference signal manager **1335** as described with reference to FIG. **13**.

The following provides an overview of aspects of the present disclosure:

Aspect 1: An apparatus for wireless communications at a UE, comprising: a processor; and memory coupled with the processor, the processor configured to: transmit an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beam-

forming procedure; receive one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure; and communicate in accordance with one or more beam weights selected based at least in part on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

Aspect 2: The apparatus of aspect 1, wherein the processor is further configured to: receive, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, a control signal that allocates one or more resources for the one or more reference signals, wherein the one or more reference signals are received based at least in part on the control signal.

Aspect 3: The apparatus of aspect 2, wherein the processor configured to receive the one or more reference signals is configured to: receive one or more CSI-RSs, one or more SRSs, or a combination thereof for beam weight estimation and selection.

Aspect 4: The apparatus of any of aspects 1 through 3, wherein the processor is further configured to: dynamically perform beam weight estimation based at least in part on the one or more reference signals, wherein the one or more beam weights are based at least in part on the beam weight estimation.

Aspect 5: The apparatus of any of aspects 1 through 4, wherein the processor is further configured to: detect a dielectric property, a conductivity property, or both for a material within a threshold distance from the UE; and communicate using the adaptive beam weight-based hybrid beamforming procedure based at least in part on the detected dielectric property, the detected conductivity property, or both.

Aspect 6: The apparatus of aspect 5, wherein the processor is further configured to: classify the material with a material type from a plurality of material types based at least in part on the detected dielectric property, the detected conductivity property, or both, wherein communicating using the adaptive beam weight-based hybrid beamforming procedure is based at least in part on the material type.

Aspect 7: The apparatus of aspect 6, wherein the processor is further configured to: receive assistance information that indicates the plurality of material types for classification, wherein the material is classified with the material type based at least in part on the assistance information.

Aspect 8: The apparatus of any of aspects 5 through 7, wherein the processor is further configured to: transmit a radar waveform; and receive, in response to the radar waveform, a reflection of the radar waveform from the material within the threshold distance from the UE, wherein communicating using the adaptive beam weight-based hybrid beamforming procedure is based at least in part on a distortion metric of the reflection of the radar waveform that satisfies a distortion threshold.

Aspect 9: The apparatus of aspect 8, wherein the processor is further configured to: input one or more waveform parameters of the reflection of the radar waveform into a machine learning model, wherein the one or more waveform parameters comprise at least the distortion metric; and classify the material with a material type in accordance with an output of the machine learning model based at least in part on the one or more waveform parameters input into the machine learning model.

Aspect 10: The apparatus of any of aspects 5 through 9, wherein the processor is further configured to: detect a second material property for a second material within the threshold distance from the UE; communicate using the codebook-based hybrid beamforming procedure based at least in part on the second material property for the second material; and select a codebook from a plurality of codebooks based at least in part on the codebook-based hybrid beamforming procedure and the second material property for the second material.

Aspect 11: The apparatus of aspect 10, wherein the plurality of codebooks indicates different quantities of beam weights, different beam properties, different phase quantization for the beam weights, different amplitude quantization for the beam weights, or any combination thereof.

Aspect 12: An apparatus for wireless communications, comprising: a processor; and memory coupled with the processor, the processor configured to: obtain an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE; output, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals; and output the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based at least in part on the control signal.

Aspect 13: The apparatus of aspect 12, wherein the processor is further configured to: output assistance information that indicates a plurality of material types for classification, wherein the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE is based at least in part on the plurality of material types for classification.

Aspect 14: The apparatus of any of aspects 12 through 13, wherein the processor is further configured to: obtain or output one or more communications based at least in part on the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE.

Aspect 15: The apparatus of any of aspects 12 through 14, wherein the processor configured to output the one or more reference signals is configured to: output one or more CSI-RSs, one or more SRSs, or a combination thereof for beam weight estimation and selection.

Aspect 16: A method for wireless communications at a UE, comprising: transmitting an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure; receiving one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure; and communicating in accordance with one or more beam weights selected based at least in part on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

Aspect 17: The method of aspect 16, further comprising: receiving, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, a control signal that allocates one or more resources for the one or more reference signals, wherein the one or more reference signals are received based at least in part on the control signal.

Aspect 18: The method of aspect 17, wherein receiving the one or more reference signals comprises: receiving one or more CSI-RSs, one or more SRSs, or a combination thereof for beam weight estimation and selection.

Aspect 19: The method of any of aspects 16 through 18, further comprising: dynamically performing beam weight estimation based at least in part on the one or more reference

signals, wherein the one or more beam weights are based at least in part on the beam weight estimation.

Aspect 20: The method of any of aspects 16 through 19, further comprising: detecting a dielectric property, a conductivity property, or both for a material within a threshold distance from the UE; and communicating using the adaptive beam weight-based hybrid beamforming procedure based at least in part on the detected dielectric property, the detected conductivity property, or both.

Aspect 21: The method of aspect 20, further comprising: classifying the material with a material type from a plurality of material types based at least in part on the detected dielectric property, the detected conductivity property, or both, wherein communicating using the adaptive beam weight-based hybrid beamforming procedure is based at least in part on the material type.

Aspect 22: The method of aspect 21, further comprising: receiving assistance information that indicates the plurality of material types for classification, wherein the material is classified with the material type based at least in part on the assistance information.

Aspect 23: The method of any of aspects 20 through 22, further comprising: transmitting a radar waveform; and receiving, in response to the radar waveform, a reflection of the radar waveform from the material within the threshold distance from the UE, wherein communicating using the adaptive beam weight-based hybrid beamforming procedure is based at least in part on a distortion metric of the reflection of the radar waveform that satisfies a distortion threshold.

Aspect 24: The method of aspect 23, further comprising: inputting one or more waveform parameters of the reflection of the radar waveform into a machine learning model, wherein the one or more waveform parameters comprise at least the distortion metric; and classifying the material with a material type in accordance with an output of the machine learning model based at least in part on the one or more waveform parameters input into the machine learning model.

Aspect 25: The method of any of aspects 20 through 24, further comprising: detecting a second material property for a second material within the threshold distance from the UE; communicating using the codebook-based hybrid beamforming procedure based at least in part on the second material property for the second material; and selecting a codebook from a plurality of codebooks based at least in part on the codebook-based hybrid beamforming procedure and the second material property for the second material.

Aspect 26: The method of aspect 25, wherein the plurality of codebooks indicates different quantities of beam weights, different beam properties, different phase quantization for the beam weights, different amplitude quantization for the beam weights, or any combination thereof.

Aspect 27: A method for wireless communications, comprising: obtaining an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a UE; outputting, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals; and outputting the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based at least in part on the control signal.

Aspect 28: The method of aspect 27, further comprising: outputting assistance information that indicates a plurality of material types for classification, wherein the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE is based at least in part on the plurality of material types for classification.

Aspect 29: The method of any of aspects 27 through 28, further comprising: obtaining or outputting one or more communications based at least in part on the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE.

Aspect 30: The method of any of aspects 27 through 29, wherein outputting the one or more reference signals comprises: outputting one or more CSI-RSs, one or more SRSs, or a combination thereof for beam weight estimation and selection.

Aspect 31: An apparatus for wireless communications at a UE, comprising at least one means for performing a method of any of aspects 16 through 26.

Aspect 32: A non-transitory computer-readable medium storing code for wireless communications at a UE, the code comprising instructions executable by a processor to perform a method of any of aspects 16 through 26.

Aspect 33: An apparatus for wireless communications, comprising at least one means for performing a method of any of aspects 27 through 30.

Aspect 34: A non-transitory computer-readable medium storing code, the code comprising instructions executable by a processor to perform a method of any of aspects 27 through 30.

It should be noted that the methods described herein describe possible implementations, and that the operations and the steps may be rearranged or otherwise modified and that other implementations are possible. Further, aspects from two or more of the methods may be combined.

Although aspects of an LTE, LTE-A, LTE-A Pro, or NR system may be described for purposes of example, and LTE, LTE-A, LTE-A Pro, or NR terminology may be used in much of the description, the techniques described herein are applicable beyond LTE, LTE-A, LTE-A Pro, or NR networks. For example, the described techniques may be applicable to various other wireless communications systems such as Ultra Mobile Broadband (UMB), Institute of Electrical and Electronics Engineers (IEEE) 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20, Flash-OFDM, as well as other systems and radio technologies not explicitly mentioned herein.

Information and signals described herein may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

The various illustrative blocks and components described in connection with the disclosure herein may be implemented or performed using a general-purpose processor, a DSP, an ASIC, a CPU, an FPGA or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor but, in the alternative, the processor may be any processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices (e.g., a combination of a DSP and a microprocessor, multiple microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration).

The functions described herein may be implemented using hardware, software executed by a processor, firmware, or any combination thereof. If implemented using software executed by a processor, the functions may be stored as or transmitted using one or more instructions or code of a computer-readable medium. Other examples and implementations are within the scope of the disclosure and appended claims. For example, due to the nature of software, functions described herein may be implemented using software executed by a processor, hardware, firmware, hardwiring, or combinations of any of these. Features implementing functions may also be physically located at various positions, including being distributed such that portions of functions are implemented at different physical locations.

Computer-readable media includes both non-transitory computer storage media and communication media including any medium that facilitates transfer of a computer program from one location to another. A non-transitory storage medium may be any available medium that may be accessed by a general-purpose or special-purpose computer. By way of example, and not limitation, non-transitory computer-readable media may include RAM, ROM, electrically erasable programmable ROM (EEPROM), flash memory, compact disk (CD) ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other non-transitory medium that may be used to carry or store desired program code means in the form of instructions or data structures and that may be accessed by a general-purpose or special-purpose computer, or a general-purpose or special-purpose processor. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of computer-readable medium. Disk and disc, as used herein, include CD, laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc. Disks may reproduce data magnetically, and discs may reproduce data optically using lasers. Combinations of the above are also included within the scope of computer-readable media.

As used herein, including in the claims, "or" as used in a list of items (e.g., a list of items prefaced by a phrase such as "at least one of" or "one or more of") indicates an inclusive list such that, for example, a list of at least one of A, B, or C means A or B or C or AB or AC or BC or ABC (i.e., A and B and C). Also, as used herein, the phrase "based on" shall not be construed as a reference to a closed set of conditions. For example, an example step that is described as "based on condition A" may be based on both a condition A and a condition B without departing from the scope of the present disclosure. In other words, as used herein, the phrase "based on" shall be construed in the same manner as the phrase "based at least in part on."

The term "determine" or "determining" encompasses a variety of actions and, therefore, "determining" can include calculating, computing, processing, deriving, investigating, looking up (such as via looking up in a table, a database or another data structure), ascertaining and the like. Also, "determining" can include receiving (e.g., receiving information), accessing (e.g., accessing data stored in memory) and the like. Also, "determining" can include resolving, obtaining, selecting, choosing, establishing, and other such similar actions.

In the appended figures, similar components or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label by a dash and a second label that distinguishes among the similar components. If just the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the second reference label, or other subsequent reference label.

The description set forth herein, in connection with the appended drawings, describes example configurations and does not represent all the examples that may be implemented or that are within the scope of the claims. The term "example" used herein means "serving as an example, instance, or illustration," and not "preferred" or "advantageous over other examples." The detailed description includes specific details for the purpose of providing an understanding of the described techniques. These techniques, however, may be practiced without these specific details. In some instances, known structures and devices are shown in block diagram form in order to avoid obscuring the concepts of the described examples.

The description herein is provided to enable a person having ordinary skill in the art to make or use the disclosure. Various modifications to the disclosure will be apparent to a person having ordinary skill in the art, and the generic principles defined herein may be applied to other variations without departing from the scope of the disclosure. Thus, the disclosure is not limited to the examples and designs described herein but is to be accorded the broadest scope consistent with the principles and novel features disclosed herein.

What is claimed is:

1. An apparatus for wireless communications at a user equipment (UE), comprising:

one or more memories; and

one or more processors coupled with the one or more memories and configured to cause the UE to:

transmit an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure at the UE;

receive one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure; and

communicate in accordance with one or more beam weights selected based at least in part on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

2. The apparatus of claim **1**, wherein the one or more processors are further configured to cause the UE to:

receive, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, a control signal that allocates one or more resources for the one or more reference signals, wherein the one or more reference signals are received based at least in part on the control signal.

3. The apparatus of claim **2**, wherein, to receive the one or more reference signals, the one or more processors are configured to cause the UE to:

receive one or more channel state information reference signals (CSI-RSs), one or more sounding reference signals (SRSs), or a combination thereof for beam weight estimation and selection.

4. The apparatus of claim **1**, wherein the one or more processors are further configured to cause the UE to:

dynamically perform beam weight estimation based at least in part on the one or more reference signals, wherein the one or more beam weights are based at least in part on the beam weight estimation.

5. The apparatus of claim **1**, wherein the one or more processors are further configured to cause the UE to:

detect a dielectric property, a conductivity property, or both for a material within a threshold distance from the UE; and

communicate in accordance with the adaptive beam weight-based hybrid beamforming procedure based at least in part on the detected dielectric property, the detected conductivity property, or both.

6. The apparatus of claim **5**, wherein the one or more processors are further configured to cause the UE to:

classify the material with a material type from a plurality of material types based at least in part on the detected dielectric property, the detected conductivity property, or both, wherein the communication in accordance with the adaptive beam weight-based hybrid beamforming procedure is based at least in part on the material type.

7. The apparatus of claim **6**, wherein the one or more processors are further configured to cause the UE to:

receive assistance information that indicates the plurality of material types for classification, wherein the material is classified with the material type based at least in part on the assistance information.

8. The apparatus of claim **5**, wherein the one or more processors are further configured to cause the UE to:

transmit a radar waveform; and

receive, in response to the radar waveform, a reflection of the radar waveform from the material within the threshold distance from the UE, wherein the communication in accordance with the adaptive beam weight-based hybrid beamforming procedure is based at least in part on a distortion metric of the reflection of the radar waveform that satisfies a distortion threshold.

9. The apparatus of claim **8**, wherein the one or more processors are further configured to cause the UE to:

input one or more waveform parameters of the reflection of the radar waveform into a machine learning model, wherein the one or more waveform parameters comprise at least the distortion metric; and

classify the material with a material type in accordance with an output of the machine learning model based at least in part on the one or more waveform parameters input into the machine learning model.

10. The apparatus of claim **5**, wherein the one or more processors are further configured to cause the UE to:

detect a second material property for a second material within the threshold distance from the UE;

communicate in accordance with the codebook-based hybrid beamforming procedure based at least in part on the second material property for the second material; and

select a codebook from a plurality of codebooks based at least in part on the codebook-based hybrid beamforming procedure and the second material property for the second material.

11. The apparatus of claim **10**, wherein the plurality of codebooks indicates different quantities of beam weights, different beam properties, different phase quantization for the beam weights, different amplitude quantization for the beam weights, or any combination thereof.

12. The apparatus of claim **1**, further comprising:

one or more antennas, wherein the indication of the switch is transmitted via the one or more antennas, the one or more reference signals are received via the one or more antennas, the communication is via the one or more antennas, or any combination thereof.

13. An apparatus for wireless communications at a network entity, comprising:

one or more memories; and

one or more processors coupled with the one or more memories and configured to cause the network entity to:

obtain an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a user equipment (UE);

output, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals; and

output the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based at least in part on the control signal.

14. The apparatus of claim **13**, wherein the one or more processors are further configured to cause the network entity to:

output assistance information that indicates a plurality of material types for classification, wherein the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE is based at least in part on the plurality of material types for classification.

15. The apparatus of claim **13**, wherein the one or more processors are further configured to cause the network entity to:

obtain or output one or more communications based at least in part on the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE.

16. The apparatus of claim **13**, wherein, to output the one or more reference signals, the one or more processors are configured to cause the network entity to:

output one or more channel state information reference signals (CSI-RSs), one or more sounding reference signals (SRSs), or a combination thereof for beam weight estimation and selection.

17. The apparatus of claim **13**, further comprising:

one or more antennas, wherein the indication of the switch is obtained via the one or more antennas, the control signal is outputted via the one or more antennas, the one or more reference signals are outputted via the one or more antennas, or any combination thereof.

18. A method for wireless communications at a user equipment (UE), comprising:

transmitting an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure at the UE;

receiving one or more reference signals in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure; and

communicating in accordance with one or more beam weights selected based at least in part on the adaptive beam weight-based hybrid beamforming procedure and the one or more reference signals.

19. The method of claim **18**, further comprising:

receiving, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure, a control signal that allocates one or more

resources for the one or more reference signals, wherein the one or more reference signals are received based at least in part on the control signal.

20. The method of claim **19**, the receiving the one or more reference signals comprising:

receiving one or more channel state information reference signals (CSI-RSs), one or more sounding reference signals (SRSs), or a combination thereof for beam weight estimation and selection.

21. The method of claim **18**, further comprising:

dynamically performing beam weight estimation based at least in part on the one or more reference signals, wherein the one or more beam weights are based at least in part on the beam weight estimation.

22. The method of claim **18**, further comprising:

detecting a dielectric property, a conductivity property, or both for a material within a threshold distance from the UE; and

communicating using the adaptive beam weight-based hybrid beamforming procedure based at least in part on the detected dielectric property, the detected conductivity property, or both.

23. A method for wireless communications at a network entity, comprising:

obtaining an indication of a switch from a codebook-based hybrid beamforming procedure to an adaptive beam weight-based hybrid beamforming procedure for a user equipment (UE);

outputting, in response to the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE, a control signal that allocates one or more resources for one or more reference signals; and

outputting the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE via the one or more resources based at least in part on the control signal.

24. The method of claim **23**, further comprising:

outputting assistance information that indicates a plurality of material types for classification, wherein the indication of the switch to the adaptive beam weight-based hybrid beamforming procedure for the UE is based at least in part on the plurality of material types for classification.

25. The method of claim **23**, further comprising:

obtaining or outputting one or more communications based at least in part on the one or more reference signals associated with the adaptive beam weight-based hybrid beamforming procedure for the UE.

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