US012389238B2

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

(10) **Patent No.: US 12,389,238 B2**
(45) **Date of Patent: Aug. 12, 2025**

(54) **SIGNALING FOR BIDIRECTIONAL PERCEPTION-ASSISTANCE**

(71) Applicant: **QUALCOMM Incorporated**, San Diego, CA (US)

(72) Inventors: **Vasanthan Raghavan**, West Windsor Township, NJ (US); **Junyi Li**, Fairless Hills, PA (US); **Kapil Gulati**, Belle Mead, NJ (US)

(73) Assignee: **QUALCOMM Incorporated**, San Diego, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 293 days.

(21) Appl. No.: **18/062,378**

(22) Filed: **Dec. 6, 2022**

(65) **Prior Publication Data**

US 2024/0187871 A1 Jun. 6, 2024

(51) **Int. Cl.**
H04W 16/28 (2009.01)
H04L 41/16 (2022.01)
H04W 72/044 (2023.01)

(52) **U.S. Cl.**
CPC ***H04W 16/28*** (2013.01); ***H04L 41/16*** (2013.01); ***H04W 72/046*** (2013.01)

(58) **Field of Classification Search**
CPC H04W 16/28; H04W 72/046; H04L 41/16; H04B 7/0695
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

10,666,342	B1 *	5/2020	Landis	H04B 17/318
2018/0063693	A1 *	3/2018	Chakraborty	H04W 8/005
2018/0227024	A1 *	8/2018	Xia	H04B 7/0695
2019/0191425	A1 *	6/2019	Zhu	H04B 7/088
2020/0358514	A1 *	11/2020	Landis	G06N 3/088
2022/0272626	A1	8/2022	Balasubramanian et al.	
2022/0368393	A1 *	11/2022	Lee	H04B 7/0634
2023/0262520	A1 *	8/2023	Sarkar	H04B 7/0617 370/235

FOREIGN PATENT DOCUMENTS

WO	2022133933	A1	6/2022

OTHER PUBLICATIONS

International Search Report and Written Opinion—PCT/US2023/075389—ISA/EPO—Mar. 1, 2024.
Partial International Search Report—PCT/US2023/075389—ISA/EPO—Feb. 2, 2024.

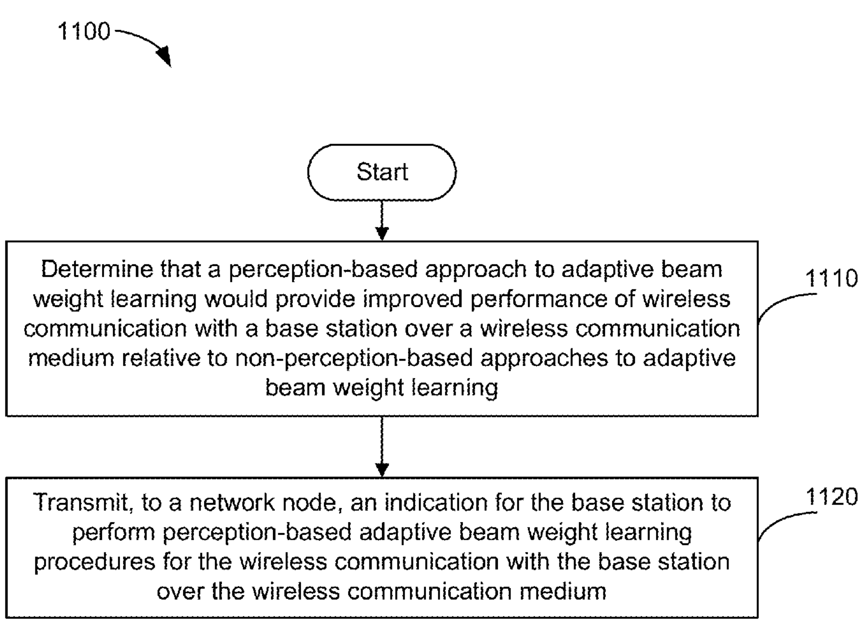
* cited by examiner

Primary Examiner — Kenneth T Lam
(74) *Attorney, Agent, or Firm* — Thien T. Nguyen

(57) **ABSTRACT**

Disclosed are techniques for wireless communication. In an aspect, a user equipment (UE) determines that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning, and transmits, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

18 Claims, 18 Drawing Sheets



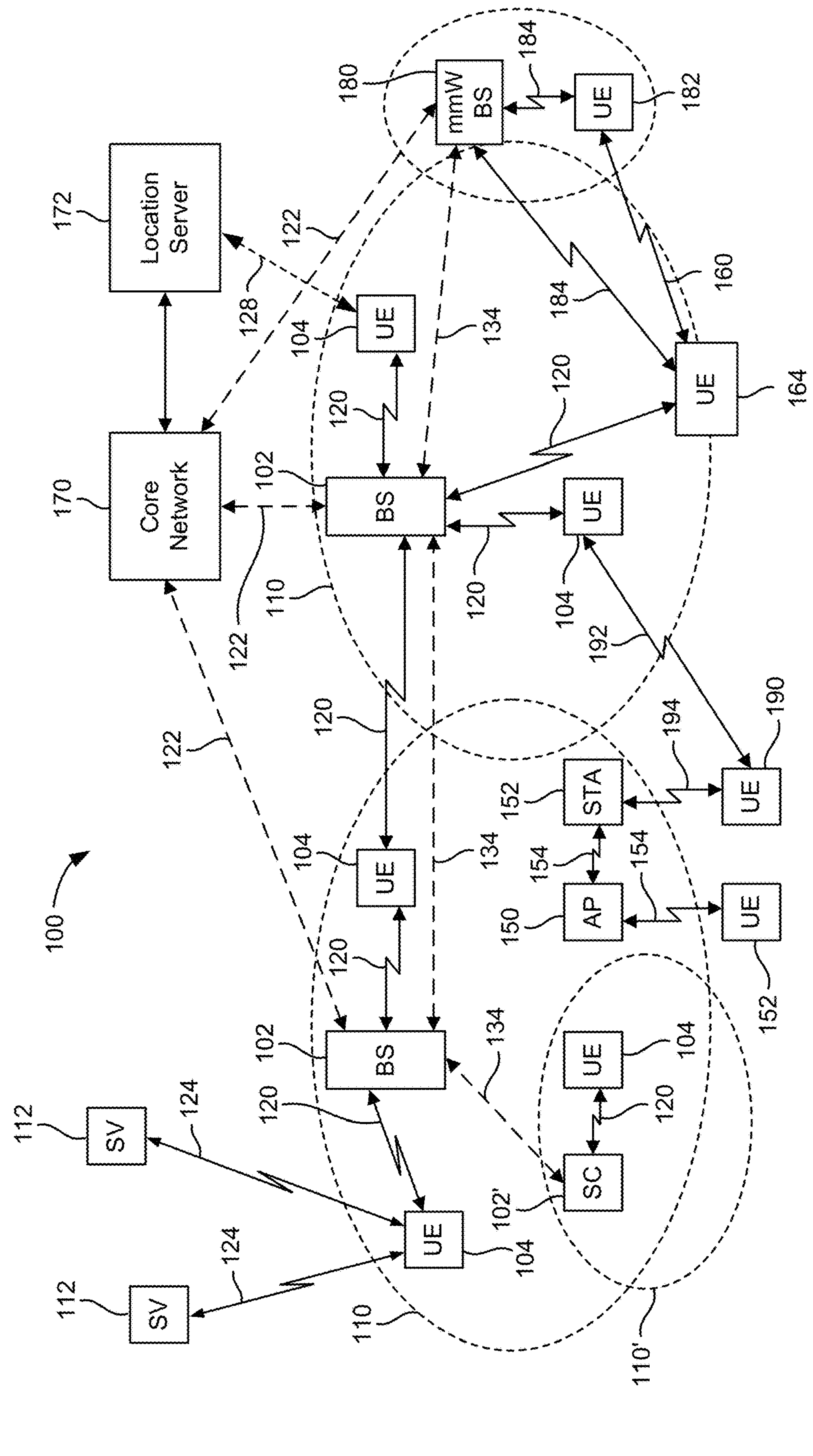

100
Location Server
172
Core Network
170
mmW BS
180
UE
182
184
122
128
134
104
102
BS
120
110
164
160
192
190
194
STA
152
154
AP
150
SC
102'
110'
SV
112
124

FIG. 1

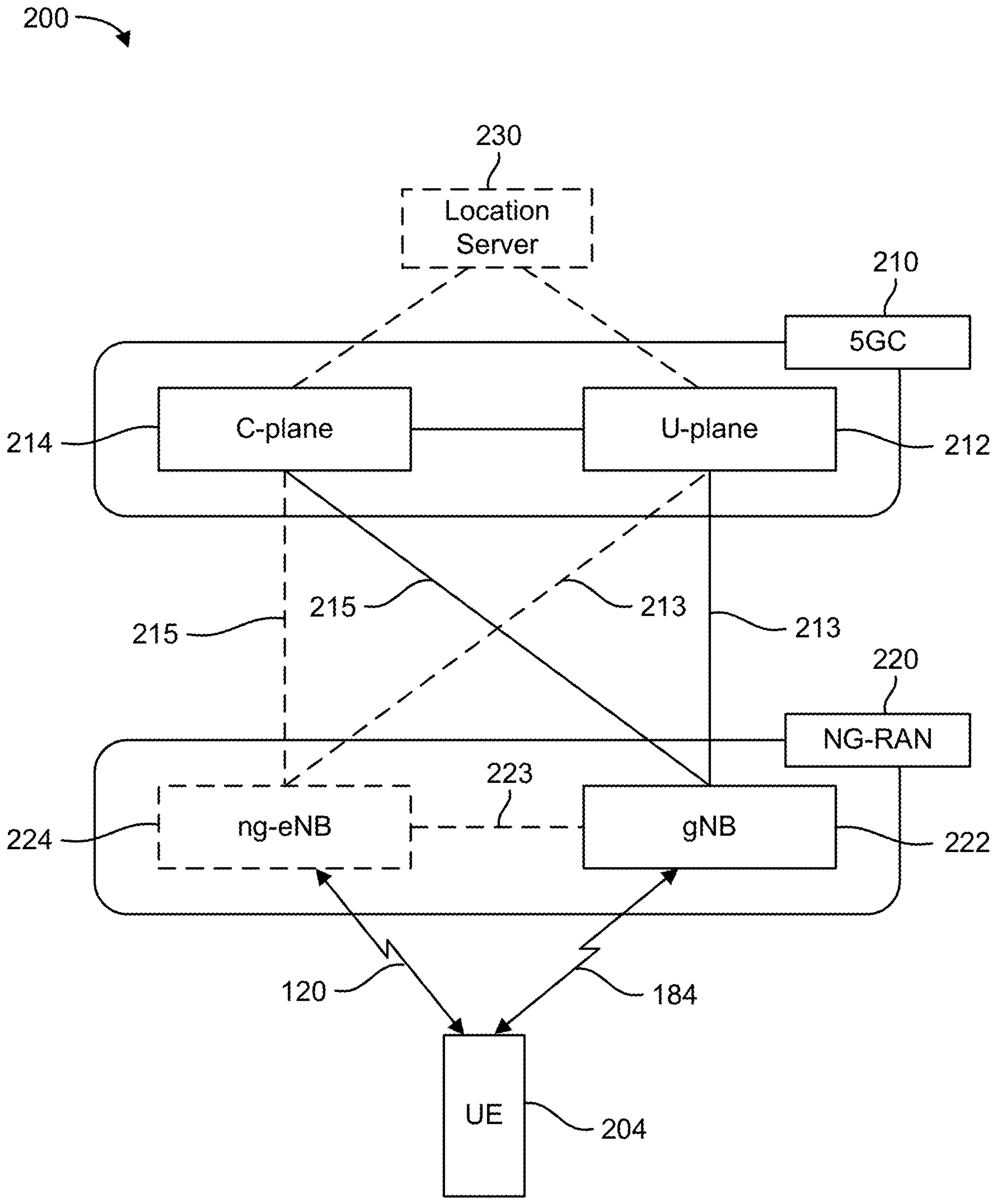
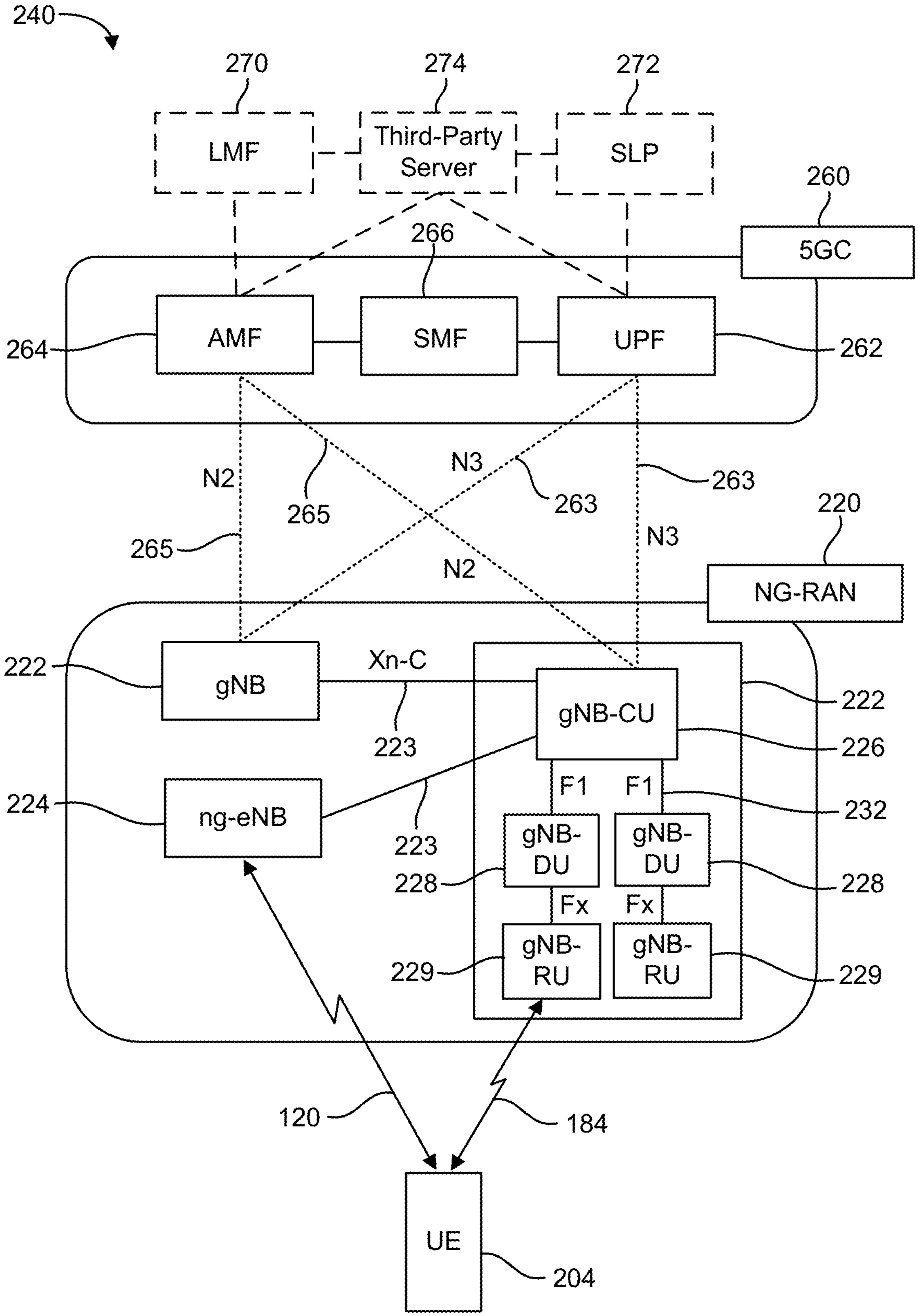
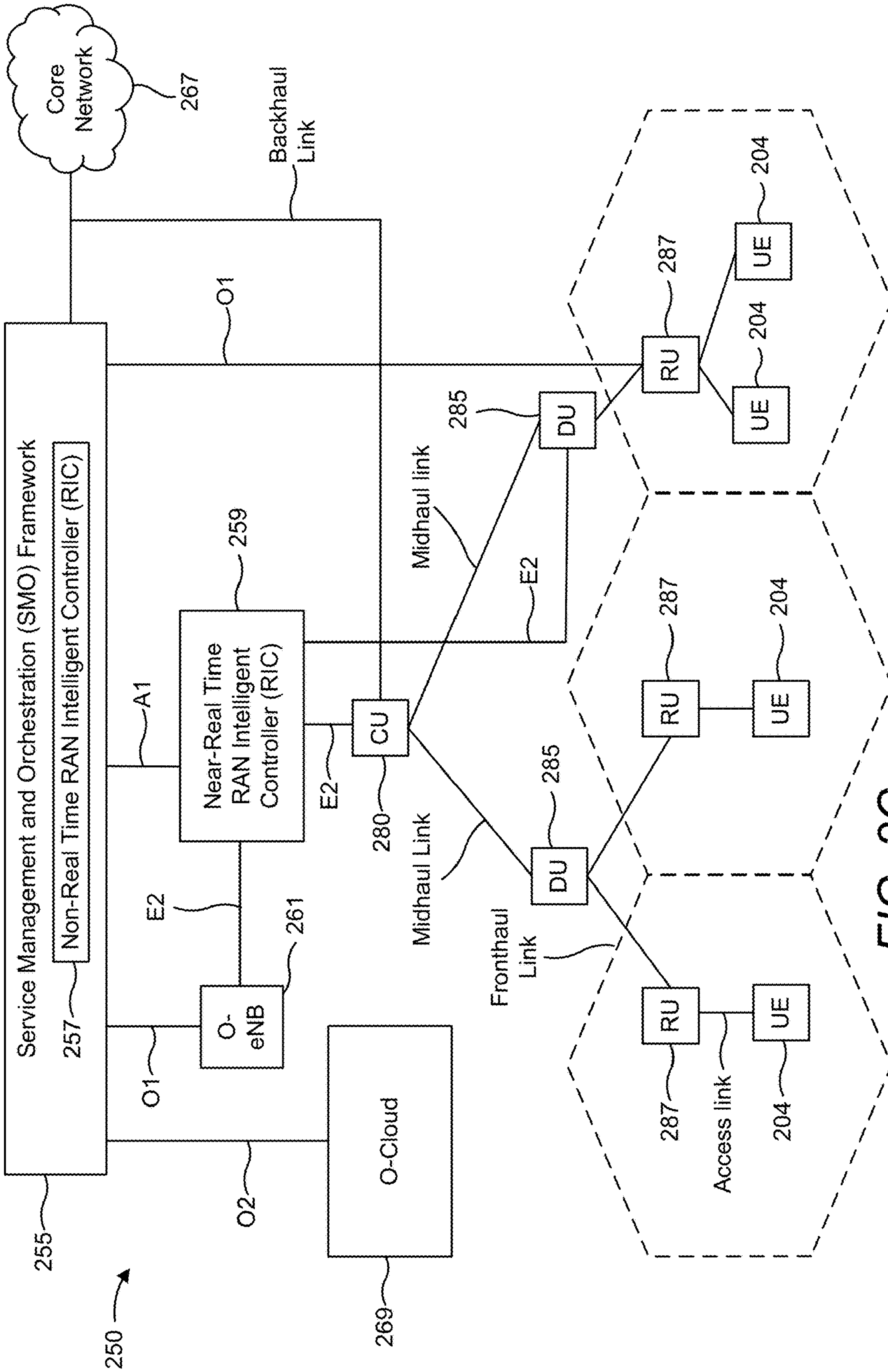

200
230
Location Server
210
5GC
214
C-plane
U-plane
212
215
215
213
213
220
NG-RAN
223
224
ng-eNB
gNB
222
120
184
UE
204

FIG. 2A



240
270
274
272
LMF
Third-Party Server
SLP
260
5GC
266
AMF
SMF
UPF
264
262
N2
265
N3
263
263
265
N3
N2
220
NG-RAN
222
gNB
Xn-C
gNB-CU
222
223
226
224
ng-eNB
F1
F1
232
223
gNB-DU
gNB-DU
228
228
Fx
Fx
229
gNB-RU
gNB-RU
229
120
184
UE
204

FIG. 2B



Core Network
267
Backhaul Link
Service Management and Orchestration (SMO) Framework
Non-Real Time RAN Intelligent Controller (RIC)
257
255
250
O1
A1
O1
O2
Near-Real Time RAN Intelligent Controller (RIC)
259
E2
E2
E2
O-eNB
261
O-Cloud
269
CU
280
Midhaul link
Midhaul Link
DU
285
DU
285
Fronthaul Link
RU
287
RU
287
RU
287
UE
204
UE
204
UE
204
UE
204
Access link

FIG. 2C

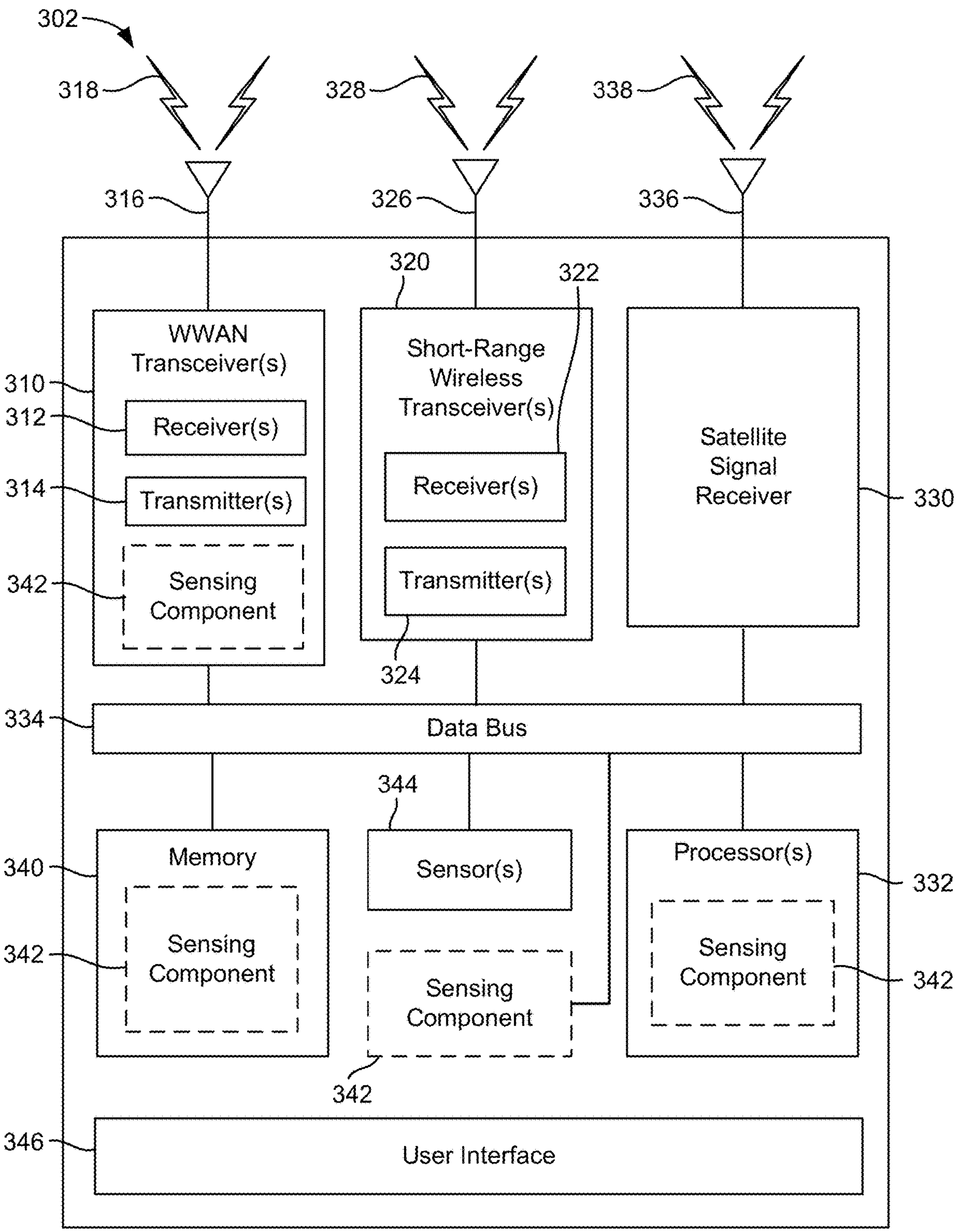

302
318
328
338
316
326
336
320
322
WWAN Transceiver(s)
310
312
Receiver(s)
314
Transmitter(s)
342
Sensing Component
Short-Range Wireless Transceiver(s)
Receiver(s)
Transmitter(s)
324
Satellite Signal Receiver
330
334
Data Bus
344
340
Memory
342
Sensing Component
Sensor(s)
Sensing Component
342
Processor(s)
332
Sensing Component
342
346
User Interface

FIG. 3A

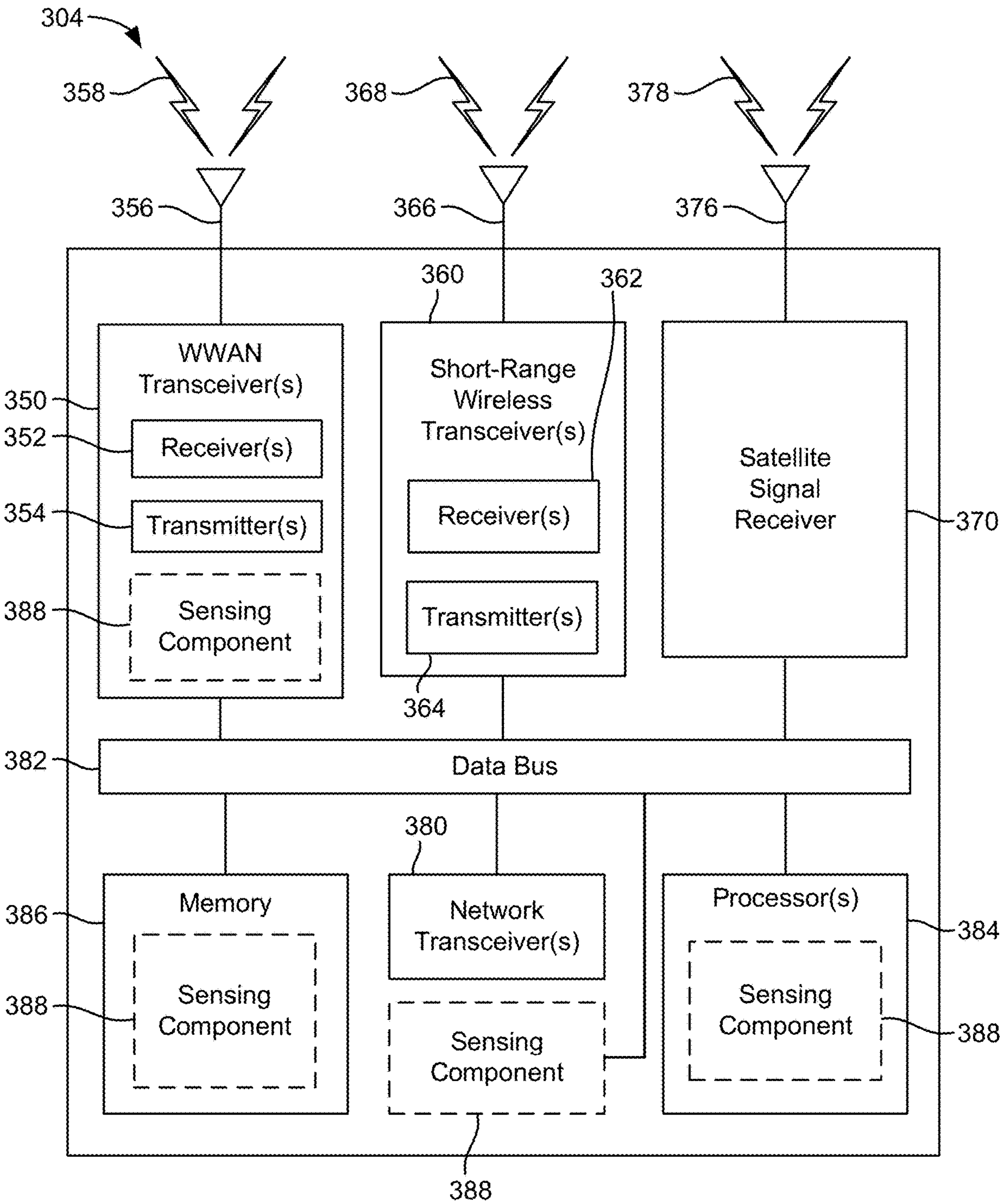

304
358
368
378
356
366
376
360
362
WWAN
Transceiver(s)
350
352
Receiver(s)
354
Transmitter(s)
388
Sensing
Component
Short-Range
Wireless
Transceiver(s)
Receiver(s)
Transmitter(s)
364
Satellite
Signal
Receiver
370
382
Data Bus
380
386
Memory
Sensing
Component
388
Network
Transceiver(s)
Sensing
Component
388
Processor(s)
384
Sensing
Component
388

FIG. 3B

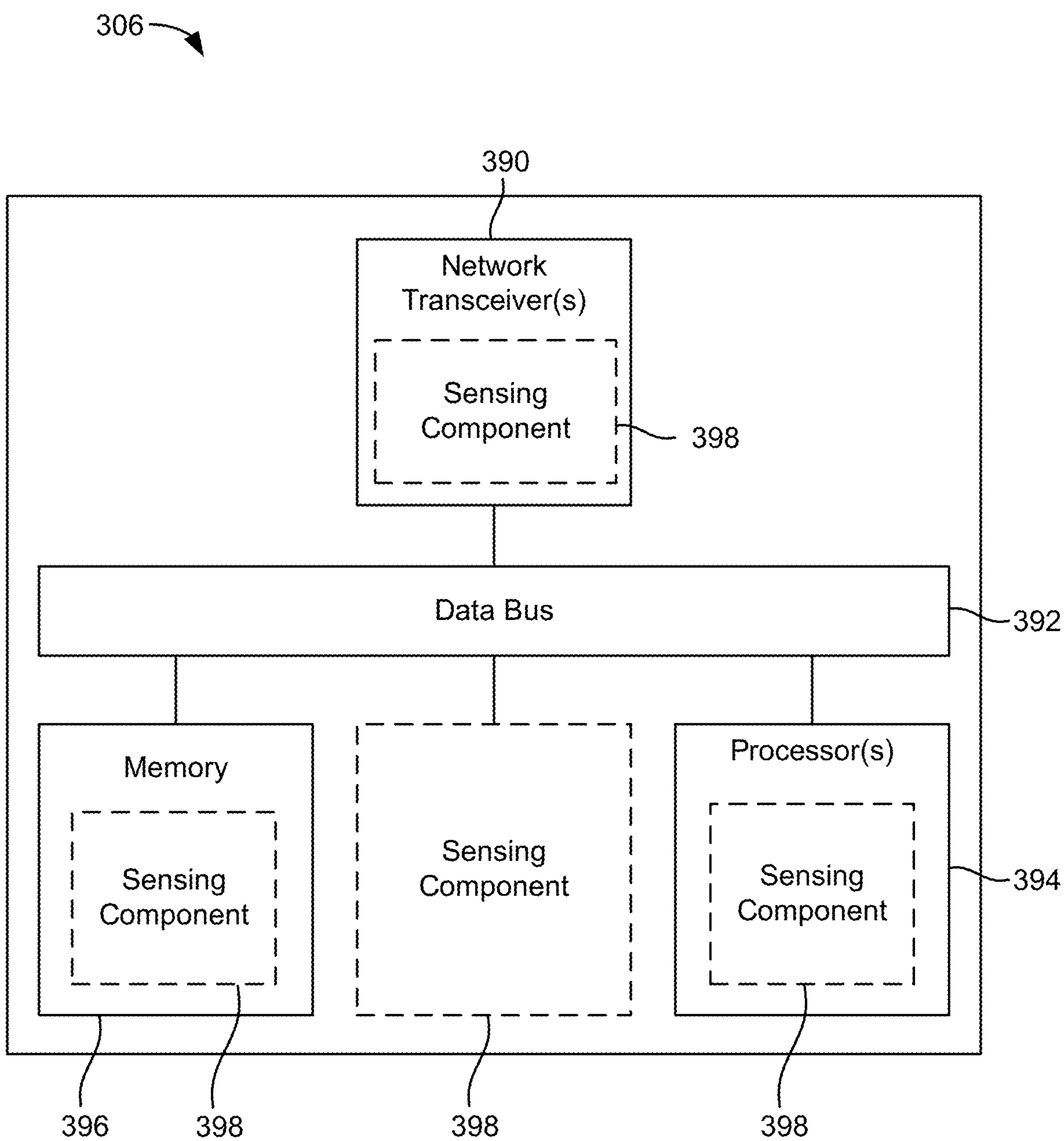

306
390
Network Transceiver(s)
Sensing Component
398
Data Bus
392
Memory
Sensing Component
Sensing Component
Processor(s)
Sensing Component
394
396
398
398
398

FIG. 3C

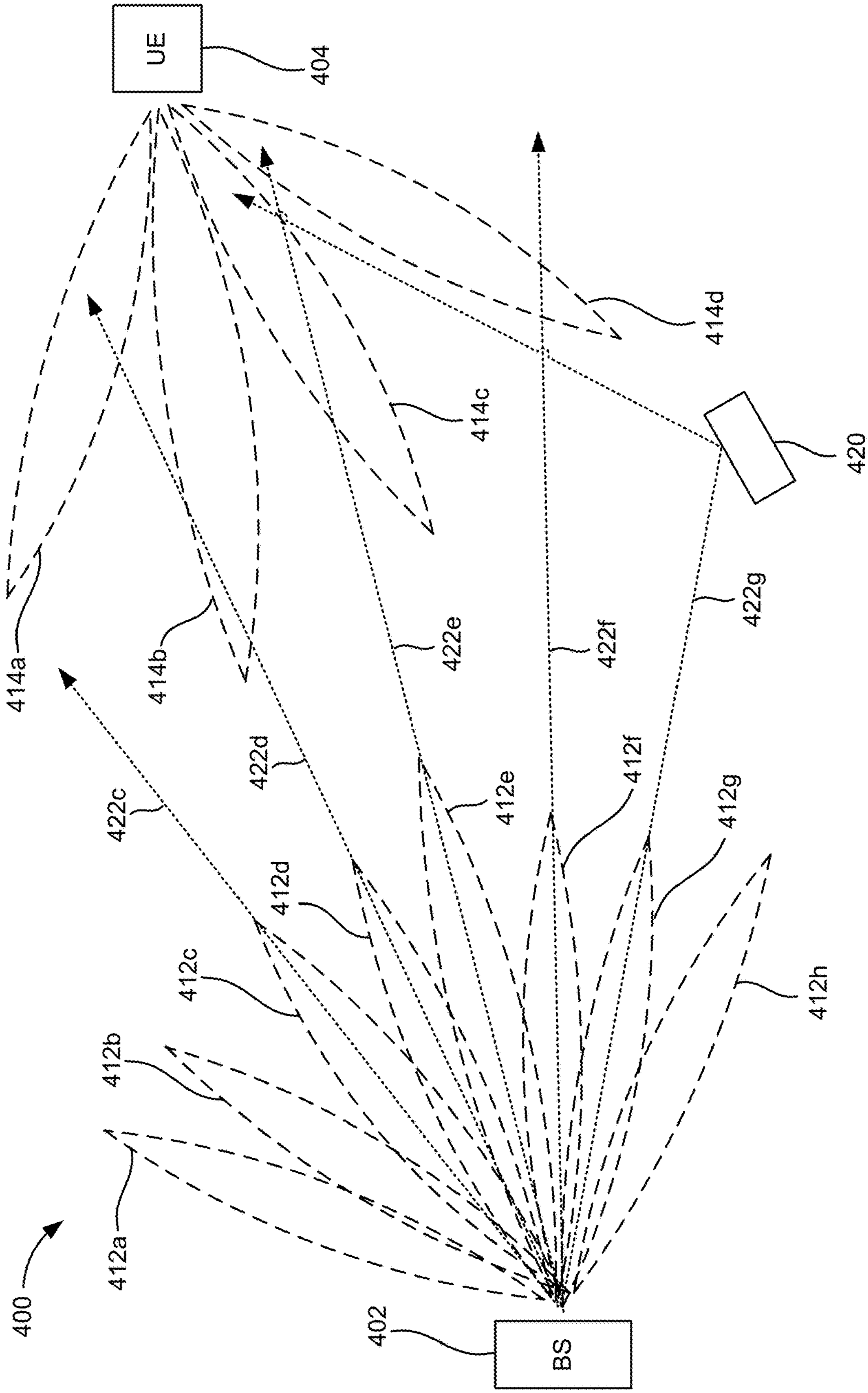

UE
404
414d
414c
420
414a
414b
422e
422f
422g
422d
422c
412e
412f
412g
412d
412c
412h
412b
412a
400
402
BS

FIG. 4

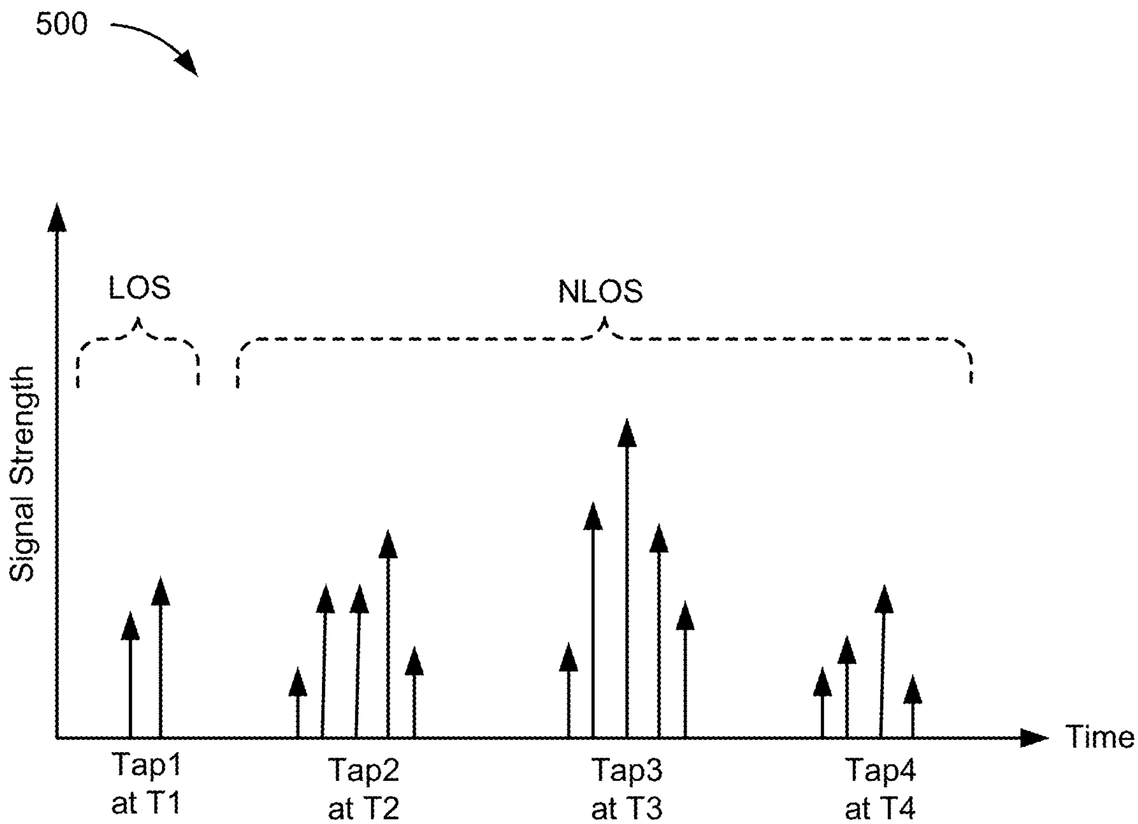

500
LOS
NLOS
Signal Strength
Time
Tap1
at T1
Tap2
at T2
Tap3
at T3
Tap4
at T4

FIG. 5

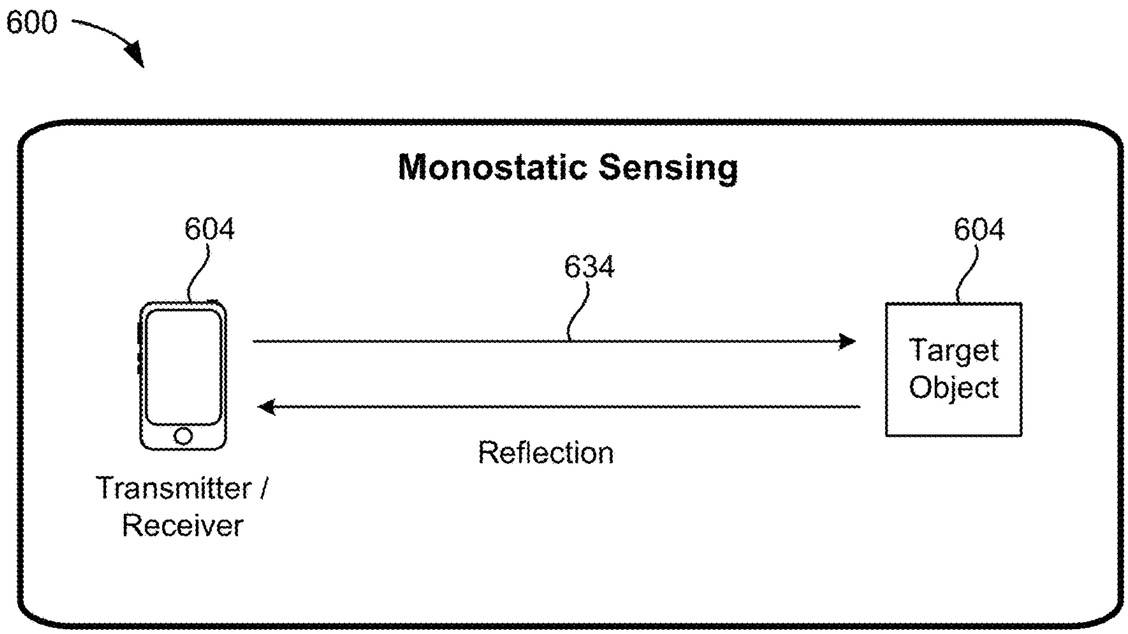

600
Monostatic Sensing
604
634
604
Target Object
Reflection
Transmitter / Receiver

FIG. 6A

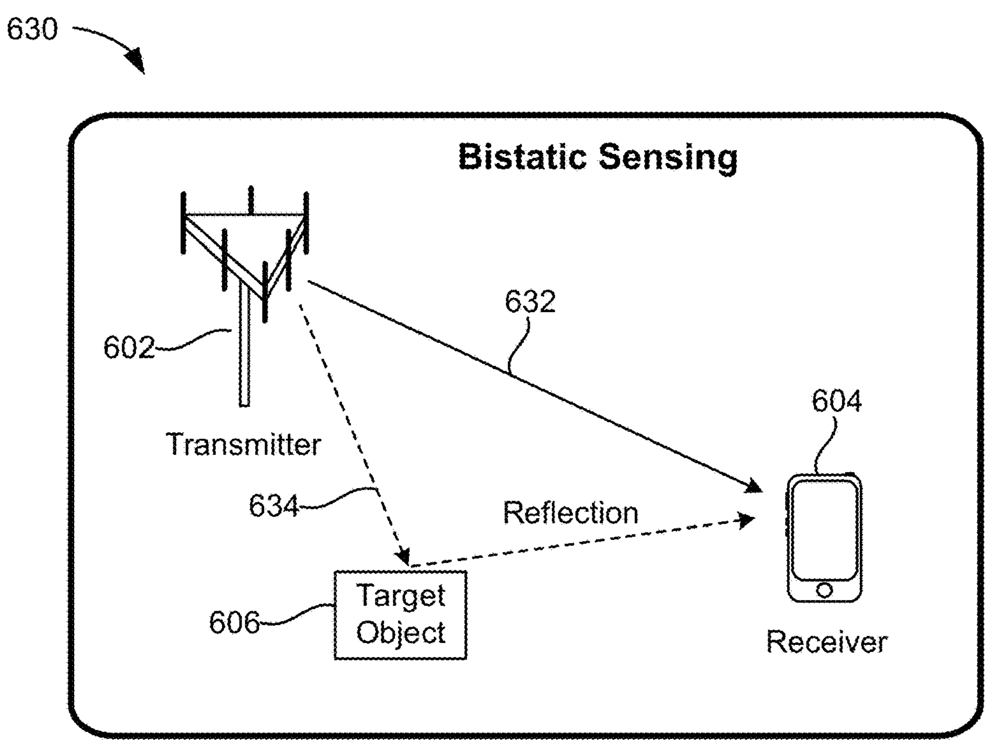

630
Bistatic Sensing
632
602
604
Transmitter
634
Reflection
606
Target Object
Receiver

FIG. 6B

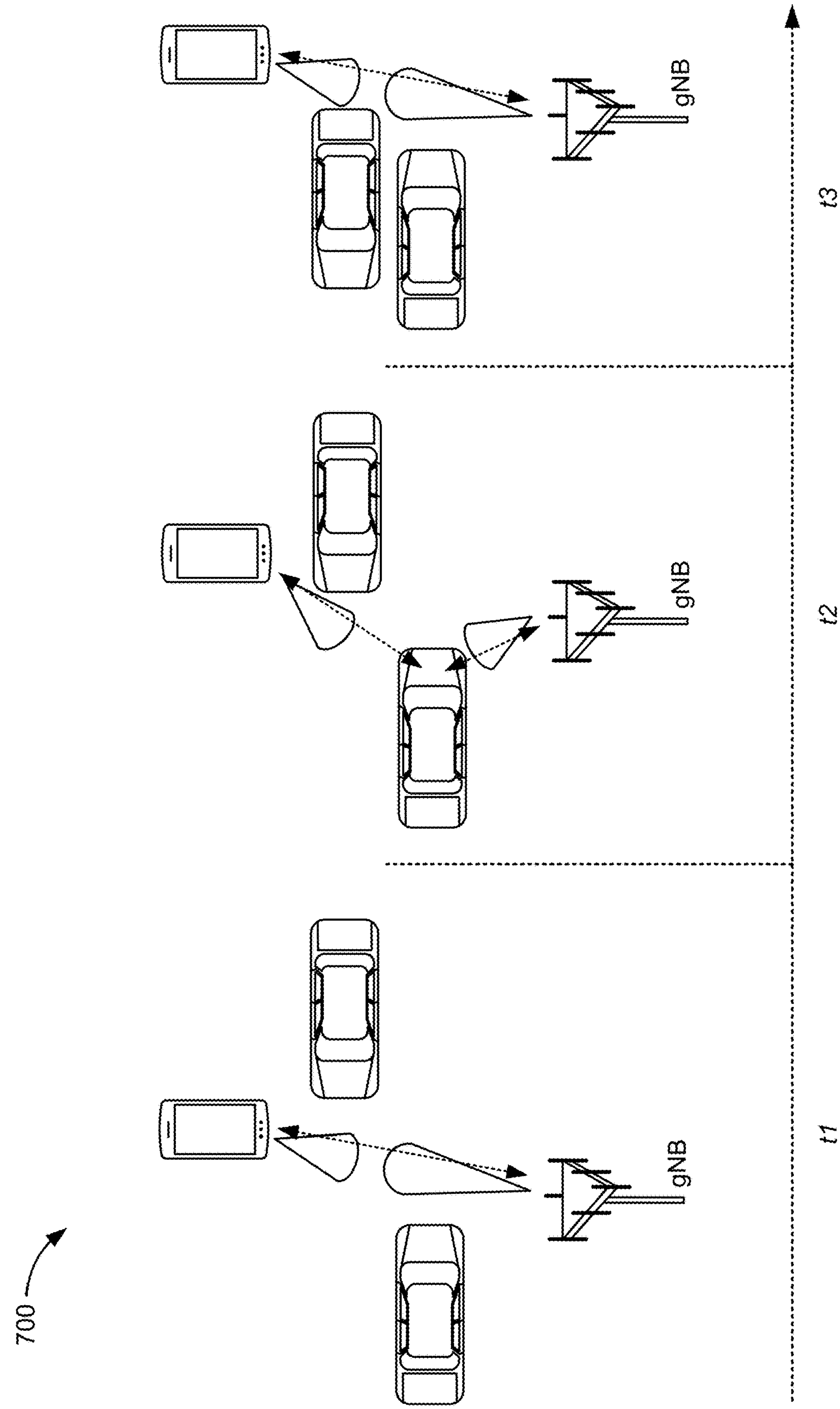


FIG. 7

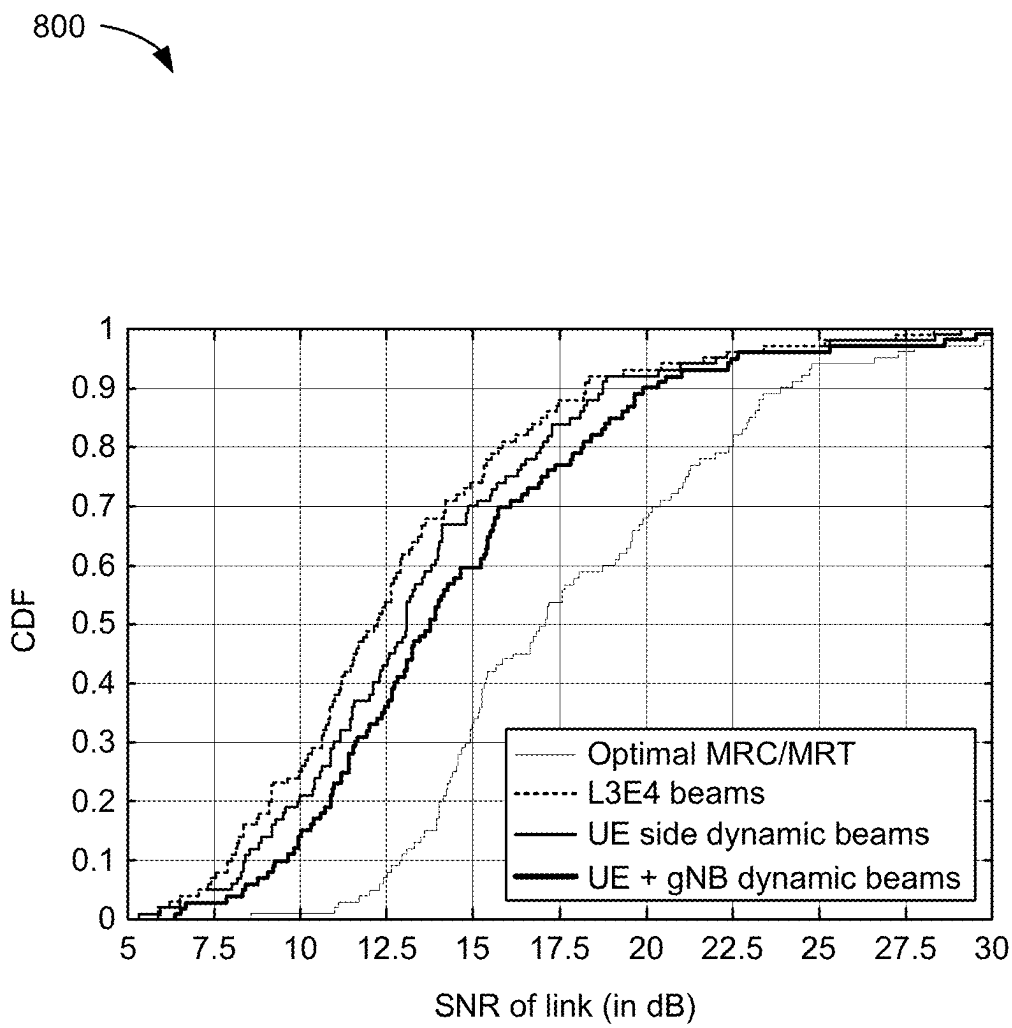

800
CDF
SNR of link (in dB)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
7.5
10
12.5
15
17.5
20
22.5
25
27.5
30
Optimal MRC/MRT
L3E4 beams
UE side dynamic beams
UE + gNB dynamic beams

FIG. 8

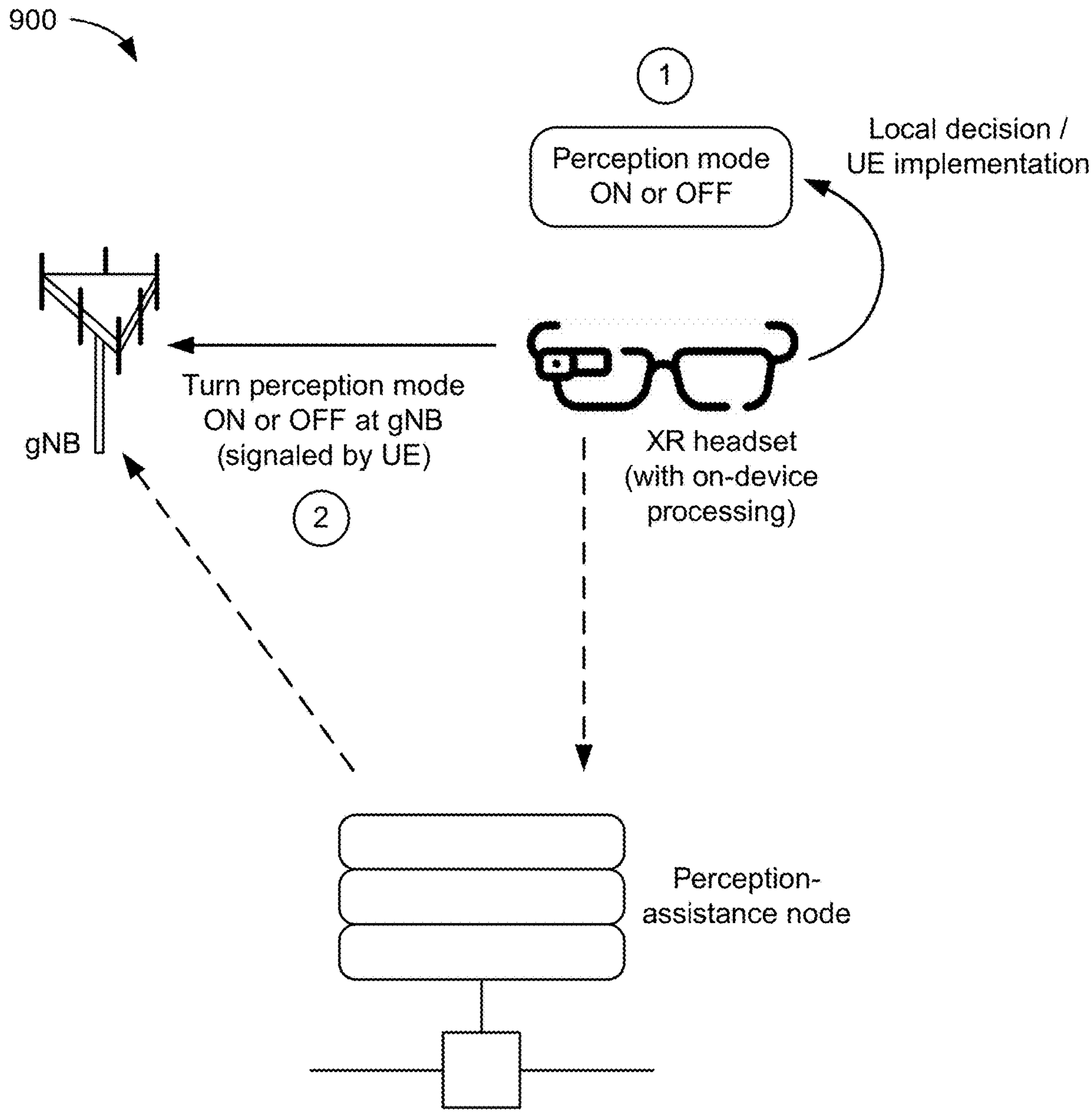

900
1
Perception mode ON or OFF
Local decision / UE implementation
gNB
Turn perception mode ON or OFF at gNB (signaled by UE)
2
XR headset (with on-device processing)
Perception-assistance node

FIG. 9

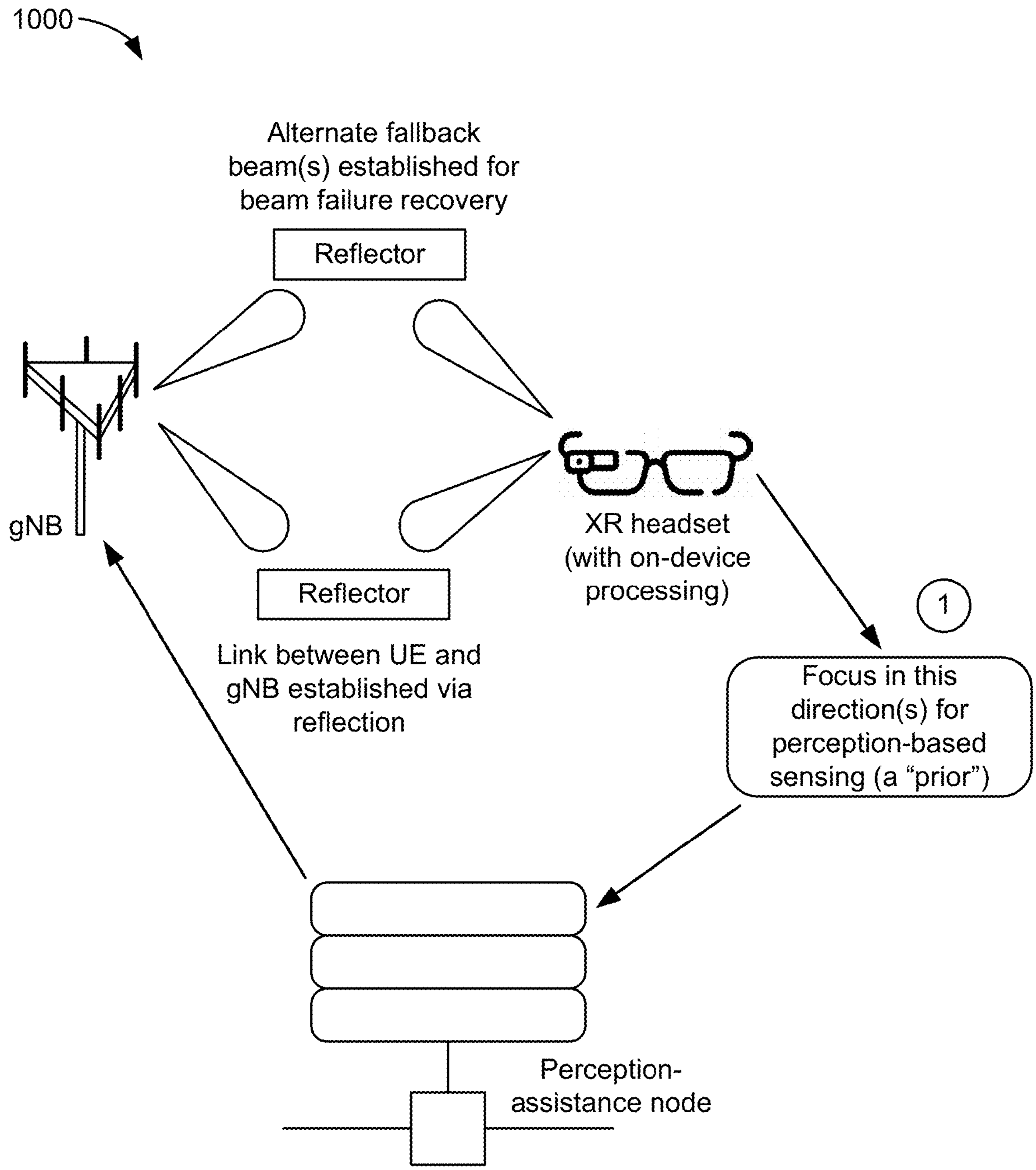

1000
Alternate fallback beam(s) established for beam failure recovery
Reflector
gNB
XR headset (with on-device processing)
Reflector
Link between UE and gNB established via reflection
1
Focus in this direction(s) for perception-based sensing (a "prior")
Perception-assistance node

FIG. 10

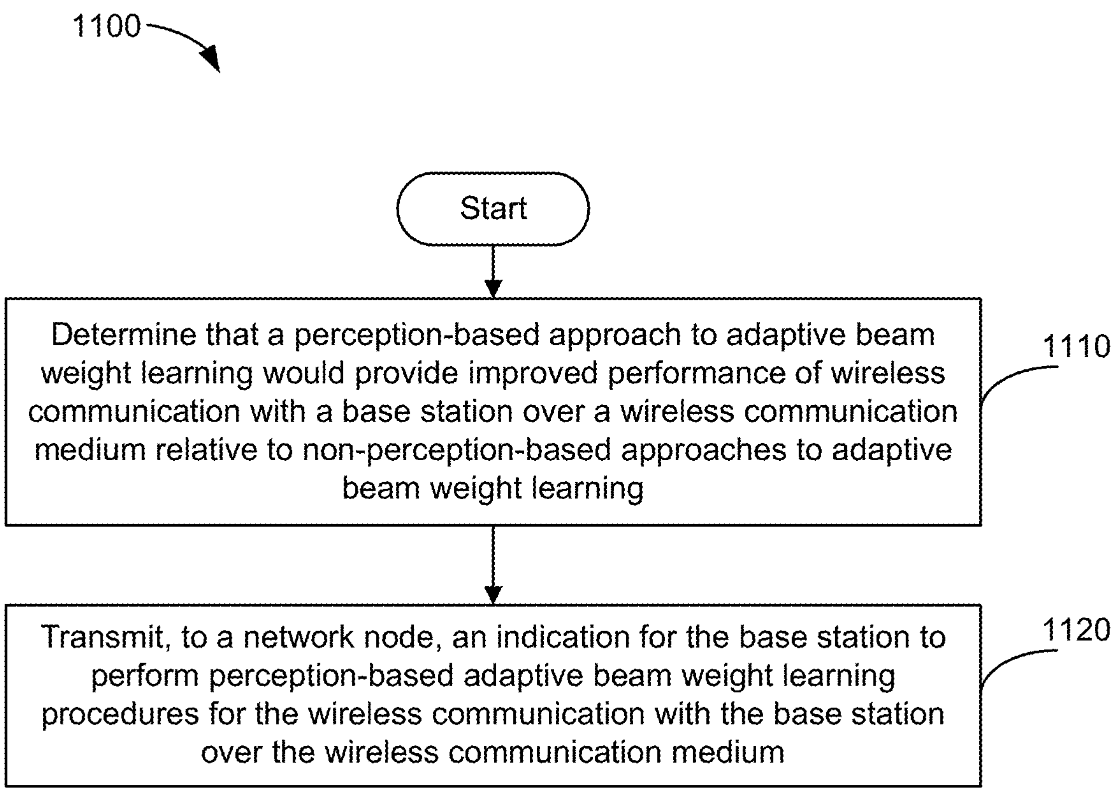

1100
Start
Determine that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning
1110
Transmit, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium
1120

FIG. 11

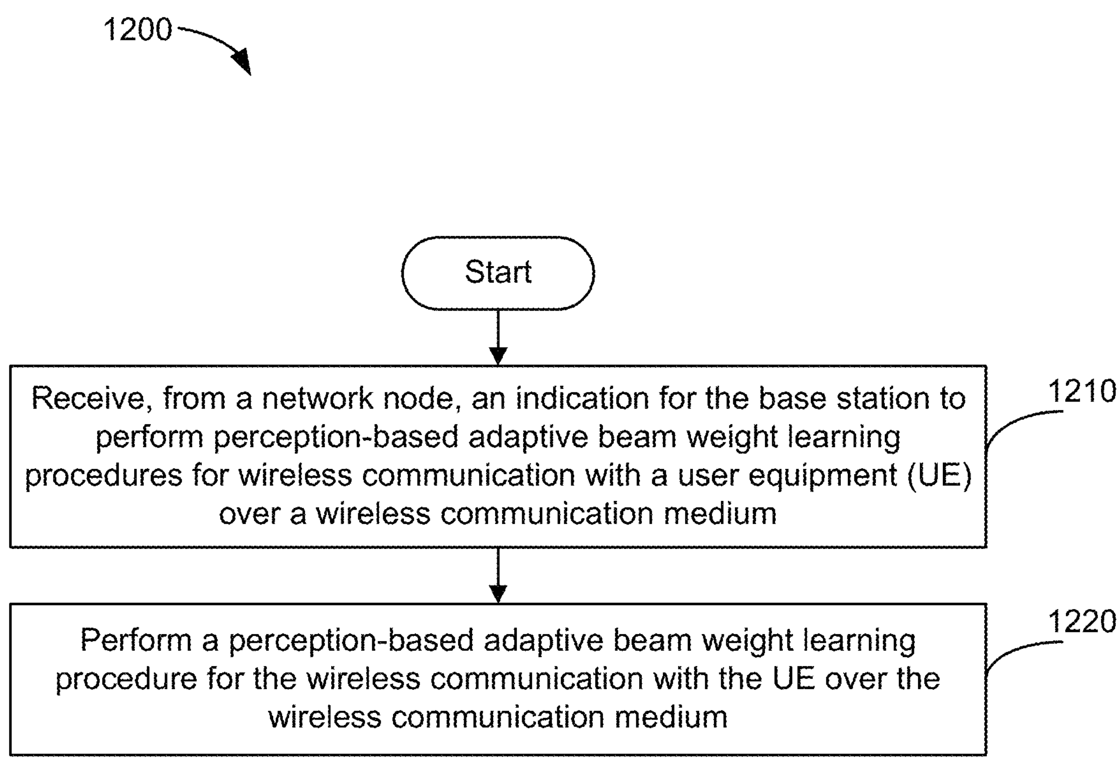

1200
Start
Receive, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium
1210
Perform a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium
1220

FIG. 12

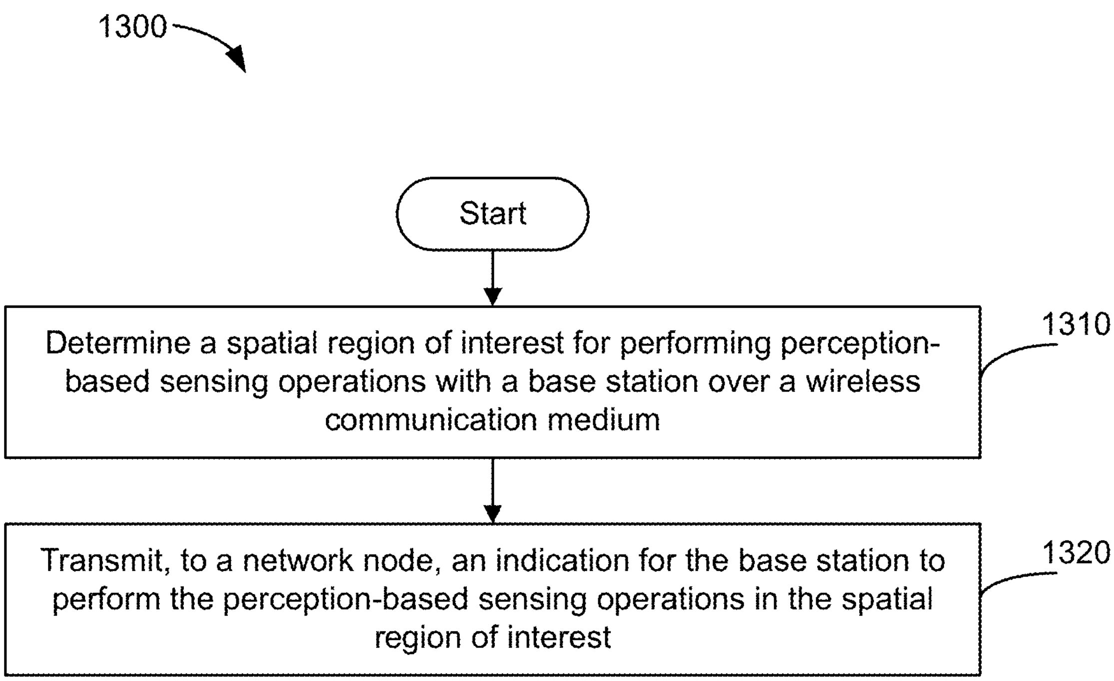

1300
Start
Determine a spatial region of interest for performing perception-based sensing operations with a base station over a wireless communication medium
1310
Transmit, to a network node, an indication for the base station to perform the perception-based sensing operations in the spatial region of interest
1320

FIG. 13

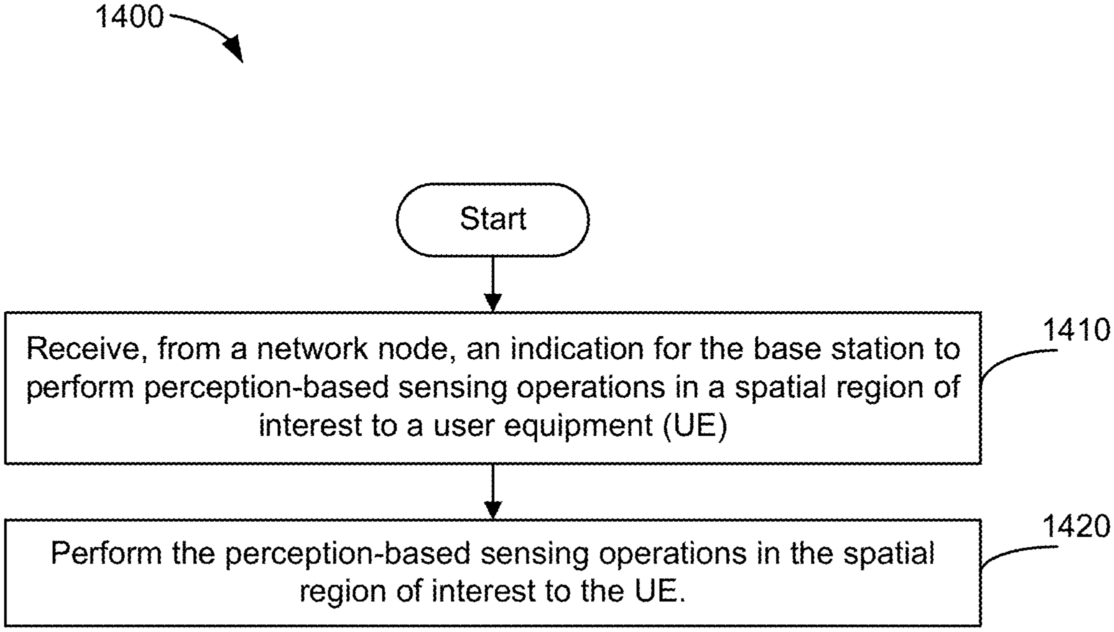

1400
Start
Receive, from a network node, an indication for the base station to perform perception-based sensing operations in a spatial region of interest to a user equipment (UE)
1410
Perform the perception-based sensing operations in the spatial region of interest to the UE.
1420

FIG. 14

SIGNALING FOR BIDIRECTIONAL PERCEPTION-ASSISTANCE

BACKGROUND OF THE DISCLOSURE

1. Field of the Disclosure

Aspects of the disclosure relate generally to wireless communications.

2. Description of the Related Art

Wireless communication systems have developed through various generations, including a first-generation analog wireless phone service (1G), a second-generation (2G) digital wireless phone service (including interim 2.5G and 2.75G networks), a third-generation (3G) high speed data, Internet-capable wireless service and a fourth-generation (4G) service (e.g., Long Term Evolution (LTE) or WiMax). There are presently many different types of wireless communication systems in use, including cellular and personal communications service (PCS) systems. Examples of known cellular systems include the cellular analog advanced mobile phone system (AMPS), and digital cellular systems based on code division multiple access (CDMA), frequency division multiple access (FDMA), time division multiple access (TDMA), the Global System for Mobile communications (GSM), etc.

A fifth generation (5G) wireless standard, referred to as New Radio (NR), enables higher data transfer speeds, greater numbers of connections, and better coverage, among other improvements. The 5G standard, according to the Next Generation Mobile Networks Alliance, is designed to provide higher data rates as compared to previous standards, more accurate positioning (e.g., based on reference signals for positioning (RS-P), such as downlink, uplink, or sidelink positioning reference signals (PRS)), and other technical enhancements. These enhancements, as well as the use of higher frequency bands, advances in PRS processes and technology, and high-density deployments for 5G, enable highly accurate 5G-based positioning.

SUMMARY

The following presents a simplified summary relating to one or more aspects disclosed herein. Thus, the following summary should not be considered an extensive overview relating to all contemplated aspects, nor should the following summary be considered to identify key or critical elements relating to all contemplated aspects or to delineate the scope associated with any particular aspect. Accordingly, the following summary has the sole purpose to present certain concepts relating to one or more aspects relating to the mechanisms disclosed herein in a simplified form to precede the detailed description presented below.

In an aspect, a method of wireless communication performed by a user equipment (UE) includes determining that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning; and transmitting, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

In an aspect, a method of wireless communication performed by a base station includes receiving, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium; and performing a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

In an aspect, a method of wireless communication performed by a user equipment (UE) includes determining a spatial region of interest for performing perception-based sensing operations with a base station over a wireless communication medium; and transmitting, to a network node, an indication for the base station to perform the perception-based sensing operations in the spatial region of interest.

In an aspect, a method of wireless communication performed by a base station includes receiving, from a network node, an indication for the base station to perform perception-based sensing operations in a spatial region of interest to a user equipment (UE); and performing the perception-based sensing operations in the spatial region of interest to the UE.

In an aspect, a user equipment (UE) includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: determine that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning; and transmit, via the at least one transceiver, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

In an aspect, a base station includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: receive, via the at least one transceiver, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium; and perform a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

In an aspect, a user equipment (UE) includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: determine a spatial region of interest for performing perception-based sensing operations with a base station over a wireless communication medium; and transmit, via the at least one transceiver, to a network node, an indication for the base station to perform the perception-based sensing operations in the spatial region of interest.

In an aspect, a base station includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: receive, via the at least one transceiver, from a network node, an indication for the base station to perform perception-based sensing operations in a spatial region of interest to a user equipment (UE); and

perform the perception-based sensing operations in the spatial region of interest to the UE.

In an aspect, a user equipment (UE) includes means for determining that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning; and means for transmitting, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

In an aspect, a base station includes means for receiving, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium; and means for performing a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

In an aspect, a user equipment (UE) includes means for determining a spatial region of interest for performing perception-based sensing operations with a base station over a wireless communication medium; and means for transmitting, to a network node, an indication for the base station to perform the perception-based sensing operations in the spatial region of interest.

In an aspect, a base station includes means for receiving, from a network node, an indication for the base station to perform perception-based sensing operations in a spatial region of interest to a user equipment (UE); and means for performing the perception-based sensing operations in the spatial region of interest to the UE.

In an aspect, a non-transitory computer-readable medium stores computer-executable instructions that, when executed by a user equipment (UE), cause the UE to: determine that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning; and transmit, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

In an aspect, a non-transitory computer-readable medium stores computer-executable instructions that, when executed by a base station, cause the base station to: receive, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium; and perform a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

In an aspect, a non-transitory computer-readable medium stores computer-executable instructions that, when executed by a user equipment (UE), cause the UE to: determine a spatial region of interest for performing perception-based sensing operations with a base station over a wireless communication medium; and transmit, to a network node, an indication for the base station to perform the perception-based sensing operations in the spatial region of interest.

In an aspect, a non-transitory computer-readable medium stores computer-executable instructions that, when executed by a base station, cause the base station to: receive, from a network node, an indication for the base station to perform perception-based sensing operations in a spatial region of interest to a user equipment (UE); and perform the perception-based sensing operations in the spatial region of interest to the UE.

Other objects and advantages associated with the aspects disclosed herein will be apparent to those skilled in the art based on the accompanying drawings and detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are presented to aid in the description of various aspects of the disclosure and are provided solely for illustration of the aspects and not limitation thereof.

FIG. **1** illustrates an example wireless communications system, according to aspects of the disclosure.

FIGS. **2**A, **2**B, and **2**C illustrate example wireless network structures, according to aspects of the disclosure.

FIGS. **3**A, **3**B, and **3**C are simplified block diagrams of several sample aspects of components that may be employed in a user equipment (UE), a base station, and a network entity, respectively, and configured to support communications as taught herein.

FIG. **4** is a diagram illustrating an example base station in communication with an example UE, according to aspects of the disclosure.

FIG. **5** is a graph representing an example channel estimate of a multipath channel between a receiver device and a transmitter device, according to aspects of the disclosure.

FIGS. **6**A and **6**B illustrate different types of radar.

FIG. **7** is a diagram illustrating an example of beam management using perception-assisted sensing, according to aspects of the disclosure.

FIG. **8** is a graph illustrating an example of gains with bidirectional adaptive beam weights, according to aspects of the disclosure.

FIG. **9** is a diagram illustrating a technique for signaling perception-assisted adaptive beam weight learning, according to aspects of the disclosure.

FIG. **10** is a diagram illustrating a technique for signaling a direction of interest for perception-based sensing, according to aspects of the disclosure.

FIGS. **11** to **14** illustrate example methods of wireless communication, according to aspects of the disclosure.

DETAILED DESCRIPTION

Aspects of the disclosure are provided in the following description and related drawings directed to various examples provided for illustration purposes. Alternate aspects may be devised without departing from the scope of the disclosure. Additionally, well-known elements of the disclosure will not be described in detail or will be omitted so as not to obscure the relevant details of the disclosure.

The words "exemplary" and/or "example" are used herein to mean "serving as an example, instance, or illustration." Any aspect described herein as "exemplary" and/or "example" is not necessarily to be construed as preferred or advantageous over other aspects. Likewise, the term "aspects of the disclosure" does not require that all aspects of the disclosure include the discussed feature, advantage or mode of operation.

Those of skill in the art will appreciate that the information and signals described below 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 below may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof, depending in part on the particular application, in part on the desired design, in part on the corresponding technology, etc.

Further, many aspects are described in terms of sequences of actions to be performed by, for example, elements of a computing device. It will be recognized that various actions described herein can be performed by specific circuits (e.g., application specific integrated circuits (ASICs)), by program instructions being executed by one or more processors, or by a combination of both. Additionally, the sequence(s) of actions described herein can be considered to be embodied entirely within any form of non-transitory computer-readable storage medium having stored therein a corresponding set of computer instructions that, upon execution, would cause or instruct an associated processor of a device to perform the functionality described herein. Thus, the various aspects of the disclosure may be embodied in a number of different forms, all of which have been contemplated to be within the scope of the claimed subject matter. In addition, for each of the aspects described herein, the corresponding form of any such aspects may be described herein as, for example, "logic configured to" perform the described action.

As used herein, the terms "user equipment" (UE) and "base station" are not intended to be specific or otherwise limited to any particular radio access technology (RAT), unless otherwise noted. In general, a UE may be any wireless communication device (e.g., a mobile phone, router, tablet computer, laptop computer, consumer asset locating device, wearable (e.g., smartwatch, glasses, augmented reality (AR)/virtual reality (VR)/extended reality (XR) headset, etc.), vehicle (e.g., automobile, motorcycle, bicycle, etc.), Internet of Things (IoT) device, etc.) used by a user to communicate over a wireless communications network. A UE may be mobile or may (e.g., at certain times) be stationary, and may communicate with a radio access network (RAN). As used herein, the term "UE" may be referred to interchangeably as an "access terminal" or "AT," a "client device," a "wireless device," a "subscriber device," a "subscriber terminal," a "subscriber station," a "user terminal" or "UT," a "mobile device," a "mobile terminal," a "mobile station," or variations thereof. Generally, UEs can communicate with a core network via a RAN, and through the core network the UEs can be connected with external networks such as the Internet and with other UEs. Of course, other mechanisms of connecting to the core network and/or the Internet are also possible for the UEs, such as over wired access networks, wireless local area network (WLAN) networks (e.g., based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 specification, etc.) and so on.

A base station may operate according to one of several RATs in communication with UEs depending on the network in which it is deployed, and may be alternatively referred to as an access point (AP), a network node, a NodeB, an evolved NodeB (eNB), a next generation eNB (ng-eNB), a New Radio (NR) Node B (also referred to as a gNB or gNodeB), etc. A base station may be used primarily to support wireless access by UEs, including supporting data, voice, and/or signaling connections for the supported UEs. In some systems a base station may provide purely edge node signaling functions while in other systems it may provide additional control and/or network management functions.

A communication link through which UEs can send signals to a base station is called an uplink (UL) channel (e.g., a reverse traffic channel, a reverse control channel, an access channel, etc.). A communication link through which the base station can send signals to UEs is called a downlink (DL) or forward link channel (e.g., a paging channel, a control channel, a broadcast channel, a forward traffic channel, etc.). As used herein the term traffic channel (TCH) can refer to either an uplink/reverse or downlink/forward traffic channel.

The term "base station" may refer to a single physical transmission-reception point (TRP) or to multiple physical TRPs that may or may not be co-located. For example, where the term "base station" refers to a single physical TRP, the physical TRP may be an antenna of the base station corresponding to a cell (or several cell sectors) of the base station. Where the term "base station" refers to multiple co-located physical TRPs, the physical TRPs may be an array of antennas (e.g., as in a multiple-input multiple-output (MIMO) system or where the base station employs beamforming) of the base station. Where the term "base station" refers to multiple non-co-located physical TRPs, the physical TRPs may be a distributed antenna system (DAS) (a network of spatially separated antennas connected to a common source via a transport medium) or a remote radio head (RRH) (a remote base station connected to a serving base station). Alternatively, the non-co-located physical TRPs may be the serving base station receiving the measurement report from the UE and a neighbor base station whose reference radio frequency (RF) signals the UE is measuring. Because a TRP is the point from which a base station transmits and receives wireless signals, as used herein, references to transmission from or reception at a base station are to be understood as referring to a particular TRP of the base station.

In some implementations that support positioning of UEs, a base station may not support wireless access by UEs (e.g., may not support data, voice, and/or signaling connections for UEs), but may instead transmit reference signals to UEs to be measured by the UEs, and/or may receive and measure signals transmitted by the UEs. Such a base station may be referred to as a positioning beacon (e.g., when transmitting signals to UEs) and/or as a location measurement unit (e.g., when receiving and measuring signals from UEs).

An "RF signal" comprises an electromagnetic wave of a given frequency that transports information through the space between a transmitter and a receiver. As used herein, a transmitter may transmit a single "RF signal" or multiple "RF signals" to a receiver. However, the receiver may receive multiple "RF signals" corresponding to each transmitted RF signal due to the propagation characteristics of RF signals through multipath channels. The same transmitted RF signal on different paths between the transmitter and receiver may be referred to as a "multipath" RF signal. As used herein, an RF signal may also be referred to as a "wireless signal" or simply a "signal" where it is clear from the context that the term "signal" refers to a wireless signal or an RF signal.

FIG. **1** illustrates an example wireless communications system **100**, according to aspects of the disclosure. The wireless communications system **100** (which may also be referred to as a wireless wide area network (WWAN)) may include various base stations **102** (labeled "BS") and various UEs **104**. The base stations **102** may include macro cell base stations (high power cellular base stations) and/or small cell base stations (low power cellular base stations). In an aspect, the macro cell base stations may include eNBs and/or ng-eNBs where the wireless communications system **100** corresponds to an LTE network, or gNBs where the wireless communications system **100** corresponds to a NR network, or a combination of both, and the small cell base stations may include femtocells, picocells, microcells, etc.

The base stations **102** may collectively form a RAN and interface with a core network **170** (e.g., an evolved packet core (EPC) or a 5G core (5GC)) through backhaul links **122**, and through the core network **170** to one or more location servers **172** (e.g., a location management function (LMF) or a secure user plane location (SUPL) location platform (SLP)). The location server(s) **172** may be part of core network **170** or may be external to core network **170**. A location server **172** may be integrated with a base station **102**. A UE **104** may communicate with a location server **172** directly or indirectly. For example, a UE **104** may communicate with a location server **172** via the base station **102** that is currently serving that UE **104**. A UE **104** may also communicate with a location server **172** through another path, such as via an application server (not shown), via another network, such as via a wireless local area network (WLAN) access point (AP) (e.g., AP **150** described below), and so on. For signaling purposes, communication between a UE **104** and a location server **172** may be represented as an indirect connection (e.g., through the core network **170**, etc.) or a direct connection (e.g., as shown via direct connection **128**), with the intervening nodes (if any) omitted from a signaling diagram for clarity.

In addition to other functions, the base stations **102** may perform functions that relate to one or more of transferring user data, radio channel ciphering and deciphering, integrity protection, header compression, mobility control functions (e.g., handover, dual connectivity), inter-cell interference coordination, connection setup and release, load balancing, distribution for non-access stratum (NAS) messages, NAS node selection, synchronization, RAN sharing, multimedia broadcast multicast service (MBMS), subscriber and equipment trace, RAN information management (RIM), paging, positioning, and delivery of warning messages. The base stations **102** may communicate with each other directly or indirectly (e.g., through the EPC/5GC) over backhaul links **134**, which may be wired or wireless.

The base stations **102** may wirelessly communicate with the UEs **104**. Each of the base stations **102** may provide communication coverage for a respective geographic coverage area **110**. In an aspect, one or more cells may be supported by a base station **102** in each geographic coverage area **110**. A "cell" is a logical communication entity used for communication with a base station (e.g., over some frequency resource, referred to as a carrier frequency, component carrier, carrier, band, or the like), and may be associated with an identifier (e.g., a physical cell identifier (PCI), an enhanced cell identifier (ECI), a virtual cell identifier (VCI), a cell global identifier (CGI), etc.) for distinguishing cells operating via the same or a different carrier frequency. In some cases, different cells may be configured according to different protocol types (e.g., machine-type communication (MTC), narrowband IoT (NB-IoT), enhanced mobile broadband (eMBB), or others) that may provide access for different types of UEs. Because a cell is supported by a specific base station, the term "cell" may refer to either or both of the logical communication entity and the base station that supports it, depending on the context. In addition, because a TRP is typically the physical transmission point of a cell, the terms "cell" and "TRP" may be used interchangeably. In some cases, the term "cell" may also refer to a geographic coverage area of a base station (e.g., a sector), insofar as a carrier frequency can be detected and used for communication within some portion of geographic coverage areas **110**.

While neighboring macro cell base station **102** geographic coverage areas **110** may partially overlap (e.g., in a handover region), some of the geographic coverage areas **110** may be substantially overlapped by a larger geographic coverage area **110**. For example, a small cell base station **102'** (labeled "SC" for "small cell") may have a geographic coverage area **110'** that substantially overlaps with the geographic coverage area **110** of one or more macro cell base stations **102**. A network that includes both small cell and macro cell base stations may be known as a heterogeneous network. A heterogeneous network may also include home eNBs (HeNBs), which may provide service to a restricted group known as a closed subscriber group (CSG).

The communication links **120** between the base stations **102** and the UEs **104** may include uplink (also referred to as reverse link) transmissions from a UE **104** to a base station **102** and/or downlink (DL) (also referred to as forward link) transmissions from a base station **102** to a UE **104**. The communication links **120** may use MIMO antenna technology, including spatial multiplexing, beamforming, and/or transmit diversity. The communication links **120** may be through one or more carrier frequencies. Allocation of carriers may be asymmetric with respect to downlink and uplink (e.g., more or less carriers may be allocated for downlink than for uplink).

The wireless communications system **100** may further include a wireless local area network (WLAN) access point (AP) **150** in communication with WLAN stations (STAs) **152** via communication links **154** in an unlicensed frequency spectrum (e.g., 5 GHz). When communicating in an unlicensed frequency spectrum, the WLAN STAs **152** and/or the WLAN AP **150** may perform a clear channel assessment (CCA) or listen before talk (LBT) procedure prior to communicating in order to determine whether the channel is available.

The small cell base station **102'** may operate in a licensed and/or an unlicensed frequency spectrum. When operating in an unlicensed frequency spectrum, the small cell base station **102'** may employ LTE or NR technology and use the same 5 GHz unlicensed frequency spectrum as used by the WLAN AP **150**. The small cell base station **102'**, employing LTE/5G in an unlicensed frequency spectrum, may boost coverage to and/or increase capacity of the access network. NR in unlicensed spectrum may be referred to as NR-U. LTE in an unlicensed spectrum may be referred to as LTE-U, licensed assisted access (LAA), or MulteFire.

The wireless communications system **100** may further include a millimeter wave (mmW) base station **180** that may operate in mmW frequencies and/or near mmW frequencies in communication with a UE **182**. Extremely high frequency (EHF) is part of the RF in the electromagnetic spectrum. EHF has a range of 30 GHz to 300 GHz and a wavelength between 1 millimeter and 10 millimeters. Radio waves in this band may be referred to as a millimeter wave. Near mmW may extend down to a frequency of 3 GHz with a wavelength of 100 millimeters. The super high frequency (SHF) band extends between 3 GHz and 30 GHz, also referred to as centimeter wave. Communications using the mmW/near mmW radio frequency band have high path loss and a relatively short range. The mmW base station **180** and the UE **182** may utilize beamforming (transmit and/or receive) over a mmW communication link **184** to compensate for the extremely high path loss and short range. Further, it will be appreciated that in alternative configurations, one or more base stations **102** may also transmit using mmW or near mmW and beamforming. Accordingly, it will be appreciated that the foregoing illustrations are merely examples and should not be construed to limit the various aspects disclosed herein.

Transmit beamforming is a technique for focusing an RF signal in a specific direction. Traditionally, when a network node (e.g., a base station) broadcasts an RF signal, it broadcasts the signal in all directions (omni-directionally). With transmit beamforming, the network node determines where a given target device (e.g., a UE) is located (relative to the transmitting network node) and projects a stronger downlink RF signal in that specific direction, thereby providing a faster (in terms of data rate) and stronger RF signal for the receiving device(s). To change the directionality of the RF signal when transmitting, a network node can control the phase and relative amplitude of the RF signal at each of the one or more transmitters that are broadcasting the RF signal. For example, a network node may use an array of antennas (referred to as a "phased array" or an "antenna array") that creates a beam of RF waves that can be "steered" to point in different directions, without actually moving the antennas. Specifically, the RF current from the transmitter is fed to the individual antennas with the correct phase relationship so that the radio waves from the separate antennas add together to increase the radiation in a desired direction, while cancelling to suppress radiation in undesired directions.

Transmit beams may be quasi-co-located, meaning that they appear to the receiver (e.g., a UE) as having the same parameters, regardless of whether or not the transmitting antennas of the network node themselves are physically co-located. In NR, there are four types of quasi-co-location (QCL) relations. Specifically, a QCL relation of a given type means that certain parameters about a second reference RF signal on a second beam can be derived from information about a source reference RF signal on a source beam. Thus, if the source reference RF signal is QCL Type A, the receiver can use the source reference RF signal to estimate the Doppler shift, Doppler spread, average delay, and delay spread of a second reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type B, the receiver can use the source reference RF signal to estimate the Doppler shift and Doppler spread of a second reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type C, the receiver can use the source reference RF signal to estimate the Doppler shift and average delay of a second reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type D, the receiver can use the source reference RF signal to estimate the spatial receive parameter of a second reference RF signal transmitted on the same channel.

In receive beamforming, the receiver uses a receive beam to amplify RF signals detected on a given channel. For example, the receiver can increase the gain setting and/or adjust the phase setting of an array of antennas in a particular direction to amplify (e.g., to increase the gain level of) the RF signals received from that direction. Thus, when a receiver is said to beamform in a certain direction, it means the beam gain in that direction is high relative to the beam gain along other directions, or the beam gain in that direction is the highest compared to the beam gain in that direction of all other receive beams available to the receiver. This results in a stronger received signal strength (e.g., reference signal received power (RSRP), reference signal received quality (RSRQ), signal-to-interference-plus-noise ratio (SINR), etc.) of the RF signals received from that direction.

Transmit and receive beams may be spatially related. A spatial relation means that parameters for a second beam (e.g., a transmit or receive beam) for a second reference signal can be derived from information about a first beam (e.g., a receive beam or a transmit beam) for a first reference signal. For example, a UE may use a particular receive beam to receive a reference downlink reference signal (e.g., synchronization signal block (SSB)) from a base station. The UE can then form a transmit beam for sending an uplink reference signal (e.g., sounding reference signal (SRS)) to that base station based on the parameters of the receive beam.

Note that a "downlink" beam may be either a transmit beam or a receive beam, depending on the entity forming it. For example, if a base station is forming the downlink beam to transmit a reference signal to a UE, the downlink beam is a transmit beam. If the UE is forming the downlink beam, however, it is a receive beam to receive the downlink reference signal. Similarly, an "uplink" beam may be either a transmit beam or a receive beam, depending on the entity forming it. For example, if a base station is forming the uplink beam, it is an uplink receive beam, and if a UE is forming the uplink beam, it is an uplink transmit beam.

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 and/or FR2 characteristics, and thus may effectively extend features of FR1 and/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, and/or FR5, or may be within the EHF band.

In a multi-carrier system, such as 5G, one of the carrier frequencies is referred to as the "primary carrier" or "anchor carrier" or "primary serving cell" or "PCell," and the remaining carrier frequencies are referred to as "secondary carriers" or "secondary serving cells" or "SCells." In carrier aggregation, the anchor carrier is the carrier operating on the primary frequency (e.g., FR1) utilized by a UE **104/182** and the cell in which the UE **104/182** either performs the initial radio resource control (RRC) connection establishment procedure or initiates the RRC connection re-establishment procedure. The primary carrier carries all common and UE-specific control channels, and may be a carrier in a licensed frequency (however, this is not always the case). A secondary carrier is a carrier operating on a second frequency (e.g., FR2) that may be configured once the RRC connection is established between the UE **104** and the anchor carrier and that may be used to provide additional radio resources. In some cases, the secondary carrier may be a carrier in an unlicensed frequency. The secondary carrier may contain only necessary signaling information and signals, for example, those that are UE-specific may not be present in the secondary carrier, since both primary uplink and downlink carriers are typically UE-specific. This means that different UEs **104/182** in a cell may have different downlink primary carriers. The same is true for the uplink primary carriers. The network is able to change the primary carrier of any UE **104/182** at any time. This is done, for example, to balance the load on different carriers. Because a "serving cell" (whether a PCell or an SCell) corresponds to a carrier frequency/component carrier over which some base station is communicating, the term "cell," "serving cell," "component carrier," "carrier frequency," and the like can be used interchangeably.

For example, still referring to FIG. **1**, one of the frequencies utilized by the macro cell base stations **102** may be an anchor carrier (or "PCell") and other frequencies utilized by the macro cell base stations **102** and/or the mmW base station **180** may be secondary carriers ("SCells"). The simultaneous transmission and/or reception of multiple carriers enables the UE **104/182** to significantly increase its data transmission and/or reception rates. For example, two 20 MHz aggregated carriers in a multi-carrier system would theoretically lead to a two-fold increase in data rate (i.e., 40 MHz), compared to that attained by a single 20 MHz carrier.

The wireless communications system **100** may further include a UE **164** that may communicate with a macro cell base station **102** over a communication link **120** and/or the mmW base station **180** over a mmW communication link **184**. For example, the macro cell base station **102** may support a PCell and one or more SCells for the UE **164** and the mmW base station **180** may support one or more SCells for the UE **164**.

In some cases, the UE **164** and the UE **182** may be capable of sidelink communication. Sidelink-capable UEs (SL-UEs) may communicate with base stations **102** over communication links **120** using the Uu interface (i.e., the air interface between a UE and a base station). SL-UEs (e.g., UE **164**, UE **182**) may also communicate directly with each other over a wireless sidelink **160** using the PC5 interface (i.e., the air interface between sidelink-capable UEs). A wireless sidelink (or just "sidelink") is an adaptation of the core cellular (e.g., LTE, NR) standard that allows direct communication between two or more UEs without the communication needing to go through a base station. Sidelink communication may be unicast or multicast, and may be used for device-to-device (D2D) media-sharing, vehicle-to-vehicle (V2V) communication, vehicle-to-everything (V2X) communication (e.g., cellular V2X (cV2X) communication, enhanced V2X (eV2X) communication, etc.), emergency rescue applications, etc. One or more of a group of SL-UEs utilizing sidelink communications may be within the geographic coverage area **110** of a base station **102**. Other SL-UEs in such a group may be outside the geographic coverage area **110** of a base station **102** or be otherwise unable to receive transmissions from a base station **102**. In some cases, groups of SL-UEs communicating via sidelink communications may utilize a one-to-many (1:M) system in which each SL-UE transmits to every other SL-UE in the group. In some cases, a base station **102** facilitates the scheduling of resources for sidelink communications. In other cases, sidelink communications are carried out between SL-UEs without the involvement of a base station **102**.

In an aspect, the sidelink **160** may operate over a wireless communication medium of interest, which may be shared with other wireless communications between other vehicles and/or infrastructure access points, as well as other RATs. A "medium" may be composed of one or more time, frequency, and/or space communication resources (e.g., encompassing one or more channels across one or more carriers) associated with wireless communication between one or more transmitter/receiver pairs. In an aspect, the medium of interest may correspond to at least a portion of an unlicensed frequency band shared among various RATs. Although different licensed frequency bands have been reserved for certain communication systems (e.g., by a government entity such as the Federal Communications Commission (FCC) in the United States), these systems, in particular those employing small cell access points, have recently extended operation into unlicensed frequency bands such as the Unlicensed National Information Infrastructure (U-NII) band used by wireless local area network (WLAN) technologies, most notably IEEE 802.11x WLAN technologies generally referred to as "Wi-Fi." Example systems of this type include different variants of CDMA systems, TDMA systems, FDMA systems, orthogonal FDMA (OFDMA) systems, single-carrier FDMA (SC-FDMA) systems, and so on.

Note that although FIG. **1** only illustrates two of the UEs as SL-UEs (i.e., UEs **164** and **182**), any of the illustrated UEs may be SL-UEs. Further, although only UE **182** was described as being capable of beamforming, any of the illustrated UEs, including UE **164**, may be capable of beamforming. Where SL-UEs are capable of beamforming, they may beamform towards each other (i.e., towards other SL-UEs), towards other UEs (e.g., UEs **104**), towards base stations (e.g., base stations **102**, **180**, small cell **102'**, access point **150**), etc. Thus, in some cases, UEs **164** and **182** may utilize beamforming over sidelink **160**.

In the example of FIG. **1**, any of the illustrated UEs (shown in FIG. **1** as a single UE **104** for simplicity) may receive signals **124** from one or more Earth orbiting space vehicles (SVs) **112** (e.g., satellites). In an aspect, the SVs **112** may be part of a satellite positioning system that a UE **104** can use as an independent source of location information. A satellite positioning system typically includes a system of transmitters (e.g., SVs **112**) positioned to enable receivers (e.g., UEs **104**) to determine their location on or above the Earth based, at least in part, on positioning signals (e.g., signals **124**) received from the transmitters. Such a transmitter typically transmits a signal marked with a repeating pseudo-random noise (PN) code of a set number of chips. While typically located in SVs **112**, transmitters may sometimes be located on ground-based control stations, base stations **102**, and/or other UEs **104**. A UE **104** may include one or more dedicated receivers specifically designed to receive signals **124** for deriving geo location information from the SVs **112**.

In a satellite positioning system, the use of signals **124** can be augmented by various satellite-based augmentation systems (SBAS) that may be associated with or otherwise enabled for use with one or more global and/or regional navigation satellite systems. For example an SBAS may include an augmentation system(s) that provides integrity information, differential corrections, etc., such as the Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay Service (EGNOS), the Multifunctional Satellite Augmentation System (MSAS), the Global Positioning System (GPS) Aided Geo Augmented Navigation or GPS and Geo Augmented Navigation system (GAGAN), and/or the like. Thus, as used herein, a satellite positioning system may include any combination of one or more global and/or regional navigation satellites associated with such one or more satellite positioning systems.

In an aspect, SVs **112** may additionally or alternatively be part of one or more non-terrestrial networks (NTNs). In an NTN, an SV **112** is connected to an earth station (also referred to as a ground station, NTN gateway, or gateway), which in turn is connected to an element in a 5G network, such as a modified base station **102** (without a terrestrial antenna) or a network node in a 5GC. This element would in turn provide access to other elements in the 5G network and ultimately to entities external to the 5G network, such as Internet web servers and other user devices. In that way, a UE **104** may receive communication signals (e.g., signals **124**) from an SV **112** instead of, or in addition to, communication signals from a terrestrial base station **102**.

The wireless communications system **100** may further include one or more UEs, such as UE **190**, that connects indirectly to one or more communication networks via one or more device-to-device (D2D) peer-to-peer (P2P) links (referred to as "sidelinks"). In the example of FIG. **1**, UE **190** has a D2D P2P link **192** with one of the UEs **104** connected to one of the base stations **102** (e.g., through which UE **190** may indirectly obtain cellular connectivity) and a D2D P2P link **194** with WLAN STA **152** connected to the WLAN AP **150** (through which UE **190** may indirectly obtain WLAN-based Internet connectivity). In an example, the D2D P2P links **192** and **194** may be supported with any well-known D2D RAT, such as LTE Direct (LTE-D), WiFi Direct (WiFi-D), Bluetooth®, and so on.

FIG. **2**A illustrates an example wireless network structure **200**. For example, a 5GC **210** (also referred to as a Next Generation Core (NGC)) can be viewed functionally as control plane (C-plane) functions **214** (e.g., UE registration, authentication, network access, gateway selection, etc.) and user plane (U-plane) functions **212**, (e.g., UE gateway function, access to data networks, IP routing, etc.) which operate cooperatively to form the core network. User plane interface (NG-U) **213** and control plane interface (NG-C) **215** connect the gNB **222** to the 5GC **210** and specifically to the user plane functions **212** and control plane functions **214**, respectively. In an additional configuration, an ng-eNB **224** may also be connected to the 5GC **210** via NG-C **215** to the control plane functions **214** and NG-U **213** to user plane functions **212**. Further, ng-eNB **224** may directly communicate with gNB **222** via a backhaul connection **223**. In some configurations, a Next Generation RAN (NG-RAN) **220** may have one or more gNBs **222**, while other configurations include one or more of both ng-eNBs **224** and gNBs **222**. Either (or both) gNB **222** or ng-eNB **224** may communicate with one or more UEs **204** (e.g., any of the UEs described herein).

Another optional aspect may include a location server **230**, which may be in communication with the 5GC **210** to provide location assistance for UE(s) **204**. The location server **230** can be implemented as a plurality of separate servers (e.g., physically separate servers, different software modules on a single server, different software modules spread across multiple physical servers, etc.), or alternately may each correspond to a single server. The location server **230** can be configured to support one or more location services for UEs **204** that can connect to the location server **230** via the core network, 5GC **210**, and/or via the Internet (not illustrated). Further, the location server **230** may be integrated into a component of the core network, or alternatively may be external to the core network (e.g., a third party server, such as an original equipment manufacturer (OEM) server or service server).

FIG. **2**B illustrates another example wireless network structure **240**. A 5GC **260** (which may correspond to 5GC **210** in FIG. **2**A) can be viewed functionally as control plane functions, provided by an access and mobility management function (AMF) **264**, and user plane functions, provided by a user plane function (UPF) **262**, which operate cooperatively to form the core network (i.e., 5GC **260**). The functions of the AMF **264** include registration management, connection management, reachability management, mobility management, lawful interception, transport for session management (SM) messages between one or more UEs **204** (e.g., any of the UEs described herein) and a session management function (SMF) **266**, transparent proxy services for routing SM messages, access authentication and access authorization, transport for short message service (SMS) messages between the UE **204** and the short message service function (SMSF) (not shown), and security anchor functionality (SEAF). The AMF **264** also interacts with an authentication server function (AUSF) (not shown) and the UE **204**, and receives the intermediate key that was established as a result of the UE **204** authentication process. In the case of authentication based on a UMTS (universal mobile telecommunications system) subscriber identity module (USIM), the AMF **264** retrieves the security material from the AUSF. The functions of the AMF **264** also include security context management (SCM). The SCM receives a key from the SEAF that it uses to derive access-network specific keys. The functionality of the AMF **264** also includes location services management for regulatory services, transport for location services messages between the UE **204** and a location management function (LMF) **270** (which acts as a location server **230**), transport for location services messages between the NG-RAN **220** and the LMF **270**, evolved packet system (EPS) bearer identifier allocation for interworking with the EPS, and UE **204** mobility event notification. In addition, the AMF **264** also supports functionalities for non-3GPP (Third Generation Partnership Project) access networks.

Functions of the UPF **262** include acting as an anchor point for intra-/inter-RAT mobility (when applicable), acting as an external protocol data unit (PDU) session point of interconnect to a data network (not shown), providing packet routing and forwarding, packet inspection, user plane policy rule enforcement (e.g., gating, redirection, traffic steering), lawful interception (user plane collection), traffic usage reporting, quality of service (QoS) handling for the user plane (e.g., uplink/downlink rate enforcement, reflective QoS marking in the downlink), uplink traffic verification (service data flow (SDF) to QoS flow mapping), transport level packet marking in the uplink and downlink, downlink packet buffering and downlink data notification triggering, and sending and forwarding of one or more "end markers" to the source RAN node. The UPF **262** may also support transfer of location services messages over a user plane between the UE **204** and a location server, such as an SLP **272**.

The functions of the SMF **266** include session management, UE Internet protocol (IP) address allocation and management, selection and control of user plane functions, configuration of traffic steering at the UPF **262** to route traffic to the proper destination, control of part of policy enforcement and QoS, and downlink data notification. The interface over which the SMF **266** communicates with the AMF **264** is referred to as the N11 interface.

Another optional aspect may include an LMF **270**, which may be in communication with the 5GC **260** to provide location assistance for UEs **204**. The LMF **270** can be implemented as a plurality of separate servers (e.g., physically separate servers, different software modules on a single server, different software modules spread across multiple physical servers, etc.), or alternately may each correspond to a single server. The LMF **270** can be configured to support one or more location services for UEs **204** that can connect to the LMF **270** via the core network, 5GC **260**, and/or via the Internet (not illustrated). The SLP **272** may support similar functions to the LMF **270**, but whereas the LMF **270** may communicate with the AMF **264**, NG-RAN **220**, and UEs **204** over a control plane (e.g., using interfaces and protocols intended to convey signaling messages and not voice or data), the SLP **272** may communicate with UEs **204** and external clients (e.g., third-party server **274**) over a user plane (e.g., using protocols intended to carry voice and/or data like the transmission control protocol (TCP) and/or IP).

Yet another optional aspect may include a third-party server **274**, which may be in communication with the LMF **270**, the SLP **272**, the 5GC **260** (e.g., via the AMF **264** and/or the UPF **262**), the NG-RAN **220**, and/or the UE **204** to obtain location information (e.g., a location estimate) for the UE **204**. As such, in some cases, the third-party server **274** may be referred to as a location services (LCS) client or an external client. The third-party server **274** can be implemented as a plurality of separate servers (e.g., physically separate servers, different software modules on a single server, different software modules spread across multiple physical servers, etc.), or alternately may each correspond to a single server.

User plane interface **263** and control plane interface **265** connect the 5GC **260**, and specifically the UPF **262** and AMF **264**, respectively, to one or more gNBs **222** and/or ng-eNBs **224** in the NG-RAN **220**. The interface between gNB(s) **222** and/or ng-eNB(s) **224** and the AMF **264** is referred to as the "N2" interface, and the interface between gNB(s) **222** and/or ng-eNB(s) **224** and the UPF **262** is referred to as the "N3" interface. The gNB(s) **222** and/or ng-eNB(s) **224** of the NG-RAN **220** may communicate directly with each other via backhaul connections **223**, referred to as the "Xn-C" interface. One or more of gNBs **222** and/or ng-eNBs **224** may communicate with one or more UEs **204** over a wireless interface, referred to as the "Uu" interface.

The functionality of a gNB **222** may be divided between a gNB central unit (gNB-CU) **226**, one or more gNB distributed units (gNB-DUs) **228**, and one or more gNB radio units (gNB-RUs) **229**. A gNB-CU **226** is a logical node that includes the base station functions of transferring user data, mobility control, radio access network sharing, positioning, session management, and the like, except for those functions allocated exclusively to the gNB-DU(s) **228**. More specifically, the gNB-CU **226** generally host the radio resource control (RRC), service data adaptation protocol (SDAP), and packet data convergence protocol (PDCP) protocols of the gNB **222**. A gNB-DU **228** is a logical node that generally hosts the radio link control (RLC) and medium access control (MAC) layer of the gNB **222**. Its operation is controlled by the gNB-CU **226**. One gNB-DU **228** can support one or more cells, and one cell is supported by only one gNB-DU **228**. The interface **232** between the gNB-CU **226** and the one or more gNB-DUs **228** is referred to as the "F1" interface. The physical (PHY) layer functionality of a gNB **222** is generally hosted by one or more standalone gNB-RUs **229** that perform functions such as power amplification and signal transmission/reception. The interface between a gNB-DU **228** and a gNB-RU **229** is referred to as the "Fx" interface. Thus, a UE **204** communicates with the gNB-CU **226** via the RRC, SDAP, and PDCP layers, with a gNB-DU **228** via the RLC and MAC layers, and with a gNB-RU **229** via the PHY layer.

Deployment of communication systems, such as 5G NR systems, may be arranged in multiple manners with various components or constituent parts. In a 5G NR system, or network, a network node, a network entity, a mobility element of a network, a RAN node, a core network node, a network element, or a network equipment, such as a base station, or one or more units (or one or more components) performing base station functionality, may be implemented in an aggregated or disaggregated architecture. For example, a base station (such as a Node B (NB), evolved NB (eNB), NR base station, 5G NB, access point (AP), a transmit receive point (TRP), or a cell, etc.) may be implemented as an aggregated base station (also known as a standalone base station or a monolithic base station) or a disaggregated base station.

An aggregated base station may be configured to utilize a radio protocol stack that is physically or logically integrated within a single RAN node. A disaggregated base station may be configured to utilize a protocol stack that is physically or logically distributed among two or more units (such as one or more central or centralized units (CUs), one or more distributed units (DUs), or one or more radio units (RUs)). In some aspects, a CU may be implemented within a RAN node, and one or more DUs may be co-located with the CU, or alternatively, may be geographically or virtually distributed throughout one or multiple other RAN nodes. The DUs may be implemented to communicate with one or more RUs. Each of the CU, DU and RU also can be implemented as virtual units, i.e., a virtual central unit (VCU), a virtual distributed unit (VDU), or a virtual radio unit (VRU).

Base station-type operation or network design may consider aggregation characteristics of base station functionality. For example, disaggregated base stations may be utilized in an integrated access backhaul (IAB) network, an open radio access network (O-RAN (such as the network configuration sponsored by the O-RAN Alliance)), or a virtualized radio access network (vRAN, also known as a cloud radio access network (C-RAN)). Disaggregation may include distributing functionality across two or more units at various physical locations, as well as distributing functionality for at least one unit virtually, which can enable flexibility in network design. The various units of the disaggregated base station, or disaggregated RAN architecture, can be configured for wired or wireless communication with at least one other unit.

FIG. 2C is a diagram 250 illustrating an example disaggregated base station architecture, according to aspects of the disclosure. The disaggregated base station 250 architecture may include one or more central units (CUs) 280 (e.g., gNB-CU 226) that can communicate directly with a core network 267 (e.g., 5GC 210, 5GC 260) via a backhaul link, or indirectly with the core network 267 through one or more disaggregated base station units (such as a Near-Real Time (Near-RT) RAN Intelligent Controller (RIC) 259 via an E2 link, or a Non-Real Time (Non-RT) RIC 257 associated with a Service Management and Orchestration (SMO) Framework 255, or both). A CU 280 may communicate with one or more distributed units (DUs) 285 (e.g., gNB-DUs 228) via respective midhaul links, such as an F1 interface. The DUs 285 may communicate with one or more radio units (RUs) 287 (e.g., gNB-RUs 229) via respective fronthaul links. The RUs 287 may communicate with respective UEs 204 via one or more radio frequency (RF) access links. In some implementations, the UE 204 may be simultaneously served by multiple RUs 287.

Each of the units, i.e., the CUs 280, the DUs 285, the RUs 287, as well as the Near-RT RICs 259, the Non-RT RICs 257 and the SMO Framework 255, may include one or more interfaces or be coupled to one or more interfaces configured to receive or transmit signals, data, or information (collectively, signals) via a wired or wireless transmission medium. Each of the units, or an associated processor or controller providing instructions to the communication interfaces of the units, can be configured to communicate with one or more of the other units via the transmission medium. For example, the units can include a wired interface configured to receive or transmit signals over a wired transmission medium to one or more of the other units. Additionally, the units can include a wireless interface, which may include a receiver, a transmitter or transceiver (such as a radio frequency (RF) transceiver), configured to receive or transmit signals, or both, over a wireless transmission medium to one or more of the other units.

In some aspects, the CU 280 may host one or more higher layer control functions. Such control functions can include radio resource control (RRC), packet data convergence protocol (PDCP), service data adaptation protocol (SDAP), or the like. Each control function can be implemented with an interface configured to communicate signals with other control functions hosted by the CU 280. The CU 280 may be configured to handle user plane functionality (i.e., Central Unit-User Plane (CU-UP)), control plane functionality (i.e., Central Unit-Control Plane (CU-CP)), or a combination thereof. In some implementations, the CU 280 can be logically split into one or more CU-UP units and one or more CU-CP units. The CU-UP unit can communicate bidirectionally with the CU-CP unit via an interface, such as the E1 interface when implemented in an O-RAN configuration. The CU 280 can be implemented to communicate with the DU 285, as necessary, for network control and signaling.

The DU 285 may correspond to a logical unit that includes one or more base station functions to control the operation of one or more RUs 287. In some aspects, the DU 285 may host one or more of a radio link control (RLC) layer, a medium access control (MAC) layer, and one or more high physical (PHY) layers (such as modules for forward error correction (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 aspects, the DU 285 may further host one or more low PHY layers. Each layer (or module) can be implemented with an interface configured to communicate signals with other layers (and modules) hosted by the DU 285, or with the control functions hosted by the CU 280.

Lower-layer functionality can be implemented by one or more RUs 287. In some deployments, an RU 287, controlled by a DU 285, may correspond to a logical node that hosts RF processing functions, or low-PHY layer functions (such as performing fast Fourier transform (FFT), inverse FFT (iFFT), digital beamforming, physical random access channel (PRACH) extraction and filtering, or the like), or both, based at least in part on the functional split, such as a lower layer functional split. In such an architecture, the RU(s) 287 can be implemented to handle over the air (OTA) communication with one or more UEs 204. In some implementations, real-time and non-real-time aspects of control and user plane communication with the RU(s) 287 can be controlled by the corresponding DU 285. In some scenarios, this configuration can enable the DU(s) 285 and the CU 280 to be implemented in a cloud-based RAN architecture, such as a vRAN architecture.

The SMO Framework 255 may be configured to support RAN deployment and provisioning of non-virtualized and virtualized network elements. For non-virtualized network elements, the SMO Framework 255 may be configured to support the deployment of dedicated physical resources for RAN coverage requirements which may be managed via an operations and maintenance interface (such as an O1 interface). For virtualized network elements, the SMO Framework 255 may be configured to interact with a cloud computing platform (such as an open cloud (O-Cloud) 269) to perform network element life cycle management (such as to instantiate virtualized network elements) via a cloud computing platform interface (such as an O2 interface). Such virtualized network elements can include, but are not limited to, CUs 280, DUs 285, RUs 287 and Near-RT RICs 259. In some implementations, the SMO Framework 255 can communicate with a hardware aspect of a 4G RAN, such as an open eNB (O-eNB) 261, via an O1 interface. Additionally, in some implementations, the SMO Framework 255 can communicate directly with one or more RUs 287 via an O1 interface. The SMO Framework 255 also may include a Non-RT RIC 257 configured to support functionality of the SMO Framework 255.

The Non-RT RIC 257 may be configured to include a logical function that enables non-real-time control and optimization of RAN elements and resources, Artificial Intelligence/Machine Learning (AI/ML) workflows including model training and updates, or policy-based guidance of applications/features in the Near-RT RIC 259. The Non-RT RIC 257 may be coupled to or communicate with (such as via an A1 interface) the Near-RT RIC 259. The Near-RT RIC 259 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 (such as via an E2 interface) connecting one or more CUs 280, one or more DUs 285, or both, as well as an O-eNB, with the Near-RT RIC 259.

In some implementations, to generate AI/ML models to be deployed in the Near-RT RIC 259, the Non-RT RIC 257 may receive parameters or external enrichment information from external servers. Such information may be utilized by the Near-RT RIC 259 and may be received at the SMO Framework 255 or the Non-RT RIC 257 from non-network data sources or from network functions. In some examples, the Non-RT RIC 257 or the Near-RT RIC 259 may be configured to tune RAN behavior or performance. For example, the Non-RT RIC 257 may monitor long-term trends and patterns for performance and employ AI/ML models to perform corrective actions through the SMO Framework **255** (such as reconfiguration via O1) or via creation of RAN management policies (such as A1 policies).

FIGS. **3**A, **3**B, and **3**C illustrate several example components (represented by corresponding blocks) that may be incorporated into a UE **302** (which may correspond to any of the UEs described herein), a base station **304** (which may correspond to any of the base stations described herein), and a network entity **306** (which may correspond to or embody any of the network functions described herein, including the location server **230** and the LMF **270**, or alternatively may be independent from the NG-RAN **220** and/or 5GC **210**/**260** infrastructure depicted in FIGS. **2**A and **2**B, such as a private network) to support the operations described herein. It will be appreciated that these components may be implemented in different types of apparatuses in different implementations (e.g., in an ASIC, in a system-on-chip (SoC), etc.). The illustrated components may also be incorporated into other apparatuses in a communication system. For example, other apparatuses in a system may include components similar to those described to provide similar functionality. Also, a given apparatus may contain one or more of the components. For example, an apparatus may include multiple transceiver components that enable the apparatus to operate on multiple carriers and/or communicate via different technologies.

The UE **302** and the base station **304** each include one or more wireless wide area network (WWAN) transceivers **310** and **350**, respectively, providing means for communicating (e.g., means for transmitting, means for receiving, means for measuring, means for tuning, means for refraining from transmitting, etc.) via one or more wireless communication networks (not shown), such as an NR network, an LTE network, a GSM network, and/or the like. The WWAN transceivers **310** and **350** may each be connected to one or more antennas **316** and **356**, respectively, for communicating with other network nodes, such as other UEs, access points, base stations (e.g., eNBs, gNBs), etc., via at least one designated RAT (e.g., NR, LTE, GSM, etc.) over a wireless communication medium of interest (e.g., some set of time/frequency resources in a particular frequency spectrum). The WWAN transceivers **310** and **350** may be variously configured for transmitting and encoding signals **318** and **358** (e.g., messages, indications, information, and so on), respectively, and, conversely, for receiving and decoding signals **318** and **358** (e.g., messages, indications, information, pilots, and so on), respectively, in accordance with the designated RAT. Specifically, the WWAN transceivers **310** and **350** include one or more transmitters **314** and **354**, respectively, for transmitting and encoding signals **318** and **358**, respectively, and one or more receivers **312** and **352**, respectively, for receiving and decoding signals **318** and **358**, respectively.

The UE **302** and the base station **304** each also include, at least in some cases, one or more short-range wireless transceivers **320** and **360**, respectively. The short-range wireless transceivers **320** and **360** may be connected to one or more antennas **326** and **366**, respectively, and provide means for communicating (e.g., means for transmitting, means for receiving, means for measuring, means for tuning, means for refraining from transmitting, etc.) with other network nodes, such as other UEs, access points, base stations, etc., via at least one designated RAT (e.g., WiFi, LTE-D, Bluetooth®, Zigbee®, Z-Wave®, PC5, dedicated short-range communications (DSRC), wireless access for vehicular environments (WAVE), near-field communication (NFC), etc.) over a wireless communication medium of interest. The short-range wireless transceivers **320** and **360** may be variously configured for transmitting and encoding signals **328** and **368** (e.g., messages, indications, information, and so on), respectively, and, conversely, for receiving and decoding signals **328** and **368** (e.g., messages, indications, information, pilots, and so on), respectively, in accordance with the designated RAT. Specifically, the short-range wireless transceivers **320** and **360** include one or more transmitters **324** and **364**, respectively, for transmitting and encoding signals **328** and **368**, respectively, and one or more receivers **322** and **362**, respectively, for receiving and decoding signals **328** and **368**, respectively. As specific examples, the short-range wireless transceivers **320** and **360** may be WiFi transceivers, Bluetooth® transceivers, Zigbee® and/or Z-Wave® transceivers, NFC transceivers, or vehicle-to-vehicle (V2V) and/or vehicle-to-everything (V2X) transceivers.

The UE **302** and the base station **304** also include, at least in some cases, satellite signal receivers **330** and **370**. The satellite signal receivers **330** and **370** may be connected to one or more antennas **336** and **376**, respectively, and may provide means for receiving and/or measuring satellite positioning/communication signals **338** and **378**, respectively. Where the satellite signal receivers **330** and **370** are satellite positioning system receivers, the satellite positioning/communication signals **338** and **378** may be global positioning system (GPS) signals, global navigation satellite system (GLONASS) signals, Galileo signals, Beidou signals, Indian Regional Navigation Satellite System (NAVIC), Quasi-Zenith Satellite System (QZSS), etc. Where the satellite signal receivers **330** and **370** are non-terrestrial network (NTN) receivers, the satellite positioning/communication signals **338** and **378** may be communication signals (e.g., carrying control and/or user data) originating from a 5G network. The satellite signal receivers **330** and **370** may comprise any suitable hardware and/or software for receiving and processing satellite positioning/communication signals **338** and **378**, respectively. The satellite signal receivers **330** and **370** may request information and operations as appropriate from the other systems, and, at least in some cases, perform calculations to determine locations of the UE **302** and the base station **304**, respectively, using measurements obtained by any suitable satellite positioning system algorithm.

The base station **304** and the network entity **306** each include one or more network transceivers **380** and **390**, respectively, providing means for communicating (e.g., means for transmitting, means for receiving, etc.) with other network entities (e.g., other base stations **304**, other network entities **306**). For example, the base station **304** may employ the one or more network transceivers **380** to communicate with other base stations **304** or network entities **306** over one or more wired or wireless backhaul links. As another example, the network entity **306** may employ the one or more network transceivers **390** to communicate with one or more base station **304** over one or more wired or wireless backhaul links, or with other network entities **306** over one or more wired or wireless core network interfaces.

A transceiver may be configured to communicate over a wired or wireless link. A transceiver (whether a wired transceiver or a wireless transceiver) includes transmitter circuitry (e.g., transmitters **314**, **324**, **354**, **364**) and receiver circuitry (e.g., receivers **312**, **322**, **352**, **362**). A transceiver may be an integrated device (e.g., embodying transmitter circuitry and receiver circuitry in a single device) in some implementations, may comprise separate transmitter circuitry and separate receiver circuitry in some implementations, or may be embodied in other ways in other implementations. The transmitter circuitry and receiver circuitry of a wired transceiver (e.g., network transceivers **380** and **390** in some implementations) may be coupled to one or more wired network interface ports. Wireless transmitter circuitry (e.g., transmitters **314**, **324**, **354**, **364**) may include or be coupled to a plurality of antennas (e.g., antennas **316**, **326**, **356**, **366**), such as an antenna array, that permits the respective apparatus (e.g., UE **302**, base station **304**) to perform transmit "beamforming," as described herein. Similarly, wireless receiver circuitry (e.g., receivers **312**, **322**, **352**, **362**) may include or be coupled to a plurality of antennas (e.g., antennas **316**, **326**, **356**, **366**), such as an antenna array, that permits the respective apparatus (e.g., UE **302**, base station **304**) to perform receive beamforming, as described herein. In an aspect, the transmitter circuitry and receiver circuitry may share the same plurality of antennas (e.g., antennas **316**, **326**, **356**, **366**), such that the respective apparatus can only receive or transmit at a given time, not both at the same time. A wireless transceiver (e.g., WWAN transceivers **310** and **350**, short-range wireless transceivers **320** and **360**) may also include a network listen module (NLM) or the like for performing various measurements.

As used herein, the various wireless transceivers (e.g., transceivers **310**, **320**, **350**, and **360**, and network transceivers **380** and **390** in some implementations) and wired transceivers (e.g., network transceivers **380** and **390** in some implementations) may generally be characterized as "a transceiver," "at least one transceiver," or "one or more transceivers." As such, whether a particular transceiver is a wired or wireless transceiver may be inferred from the type of communication performed. For example, backhaul communication between network devices or servers will generally relate to signaling via a wired transceiver, whereas wireless communication between a UE (e.g., UE **302**) and a base station (e.g., base station **304**) will generally relate to signaling via a wireless transceiver.

The UE **302**, the base station **304**, and the network entity **306** also include other components that may be used in conjunction with the operations as disclosed herein. The UE **302**, the base station **304**, and the network entity **306** include one or more processors **332**, **384**, and **394**, respectively, for providing functionality relating to, for example, wireless communication, and for providing other processing functionality. The processors **332**, **384**, and **394** may therefore provide means for processing, such as means for determining, means for calculating, means for receiving, means for transmitting, means for indicating, etc. In an aspect, the processors **332**, **384**, and **394** may include, for example, one or more general purpose processors, multi-core processors, central processing units (CPUs), ASICs, digital signal processors (DSPs), field programmable gate arrays (FPGAs), other programmable logic devices or processing circuitry, or various combinations thereof.

The UE **302**, the base station **304**, and the network entity **306** include memory circuitry implementing memories **340**, **386**, and **396** (e.g., each including a memory device), respectively, for maintaining information (e.g., information indicative of reserved resources, thresholds, parameters, and so on). The memories **340**, **386**, and **396** may therefore provide means for storing, means for retrieving, means for maintaining, etc. In some cases, the UE **302**, the base station **304**, and the network entity **306** may include sensing component **342**, **388**, and **398**, respectively. The sensing component **342**, **388**, and **398** may be hardware circuits that are part of or coupled to the processors **332**, **384**, and **394**, respectively, that, when executed, cause the UE **302**, the base station **304**, and the network entity **306** to perform the functionality described herein. In other aspects, the sensing component **342**, **388**, and **398** may be external to the processors **332**, **384**, and **394** (e.g., part of a modem processing system, integrated with another processing system, etc.). Alternatively, the sensing component **342**, **388**, and **398** may be memory modules stored in the memories **340**, **386**, and **396**, respectively, that, when executed by the processors **332**, **384**, and **394** (or a modem processing system, another processing system, etc.), cause the UE **302**, the base station **304**, and the network entity **306** to perform the functionality described herein. FIG. **3**A illustrates possible locations of the sensing component **342**, which may be, for example, part of the one or more WWAN transceivers **310**, the memory **340**, the one or more processors **332**, or any combination thereof, or may be a standalone component. FIG. **3**B illustrates possible locations of the sensing component **388**, which may be, for example, part of the one or more WWAN transceivers **350**, the memory **386**, the one or more processors **384**, or any combination thereof, or may be a standalone component. FIG. **3**C illustrates possible locations of the sensing component **398**, which may be, for example, part of the one or more network transceivers **390**, the memory **396**, the one or more processors **394**, or any combination thereof, or may be a standalone component.

The UE **302** may include one or more sensors **344** coupled to the one or more processors **332** to provide means for sensing or detecting movement and/or orientation information that is independent of motion data derived from signals received by the one or more WWAN transceivers **310**, the one or more short-range wireless transceivers **320**, and/or the satellite signal receiver **330**. By way of example, the sensor(s) **344** may include an accelerometer (e.g., a micro-electrical mechanical systems (MEMS) device), a gyroscope, a geomagnetic sensor (e.g., a compass), an altimeter (e.g., a barometric pressure altimeter), and/or any other type of movement detection sensor. Moreover, the sensor(s) **344** may include a plurality of different types of devices and combine their outputs in order to provide motion information. For example, the sensor(s) **344** may use a combination of a multi-axis accelerometer and orientation sensors to provide the ability to compute positions in two-dimensional (2D) and/or three-dimensional (3D) coordinate systems.

In addition, the UE **302** includes a user interface **346** providing means for providing indications (e.g., audible and/or visual indications) to a user and/or for receiving user input (e.g., upon user actuation of a sensing device such a keypad, a touch screen, a microphone, and so on). Although not shown, the base station **304** and the network entity **306** may also include user interfaces.

Referring to the one or more processors **384** in more detail, in the downlink, IP packets from the network entity **306** may be provided to the processor **384**. The one or more processors **384** may implement functionality for an RRC layer, a packet data convergence protocol (PDCP) layer, a radio link control (RLC) layer, and a medium access control (MAC) layer. The one or more processors **384** may provide RRC layer functionality associated with broadcasting of system information (e.g., master information block (MIB), system information blocks (SIBs)), RRC connection control (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), inter-RAT mobility, and measurement configuration for UE measurement reporting; PDCP layer functionality associated with header compression/decompression, security (ciphering, deciphering, integrity protection, integrity verification), and handover support functions; RLC layer functionality associated with the transfer of upper layer

PDUs, error correction through automatic repeat request (ARQ), concatenation, segmentation, and reassembly of RLC service data units (SDUs), re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, scheduling information reporting, error correction, priority handling, and logical channel prioritization.

The transmitter **354** and the receiver **352** may implement Layer-1 (L1) functionality associated with various signal processing functions. Layer-1, which includes a physical (PHY) layer, may include error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, interleaving, rate matching, mapping onto physical channels, modulation/demodulation of physical channels, and MIMO antenna processing. The transmitter **354** handles mapping to signal constellations based on various modulation schemes (e.g., binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), M-phase-shift keying (M-PSK), M-quadrature amplitude modulation (M-QAM)). The coded and modulated symbols may then be split into parallel streams. Each stream may then be mapped to an orthogonal frequency division multiplexing (OFDM) subcarrier, multiplexed with a reference signal (e.g., pilot) in the time and/or frequency domain, and then combined together using an inverse fast Fourier transform (IFFT) to produce a physical channel carrying a time domain OFDM symbol stream. The OFDM symbol stream is spatially precoded to produce multiple spatial streams. Channel estimates from a channel estimator may be used to determine the coding and modulation scheme, as well as for spatial processing. The channel estimate may be derived from a reference signal and/or channel condition feedback transmitted by the UE **302**. Each spatial stream may then be provided to one or more different antennas **356**. The transmitter **354** may modulate an RF carrier with a respective spatial stream for transmission.

At the UE **302**, the receiver **312** receives a signal through its respective antenna(s) **316**. The receiver **312** recovers information modulated onto an RF carrier and provides the information to the one or more processors **332**. The transmitter **314** and the receiver **312** implement Layer-1 functionality associated with various signal processing functions. The receiver **312** may perform spatial processing on the information to recover any spatial streams destined for the UE **302**. If multiple spatial streams are destined for the UE **302**, they may be combined by the receiver **312** into a single OFDM symbol stream. The receiver **312** then converts the OFDM symbol stream from the time-domain to the frequency domain using a fast Fourier transform (FFT). The frequency domain signal comprises a separate OFDM symbol stream for each subcarrier of the OFDM signal. The symbols on each subcarrier, and the reference signal, are recovered and demodulated by determining the most likely signal constellation points transmitted by the base station **304**. These soft decisions may be based on channel estimates computed by a channel estimator. The soft decisions are then decoded and de-interleaved to recover the data and control signals that were originally transmitted by the base station **304** on the physical channel. The data and control signals are then provided to the one or more processors **332**, which implements Layer-3 (L3) and Layer-2 (L2) functionality.

In the uplink, the one or more processors **332** provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, and control signal processing to recover IP packets from the core network. The one or more processors **332** are also responsible for error detection.

Similar to the functionality described in connection with the downlink transmission by the base station **304**, the one or more processors **332** provides RRC layer functionality associated with system information (e.g., MIB, SIBs) acquisition, RRC connections, and measurement reporting; PDCP layer functionality associated with header compression/decompression, and security (ciphering, deciphering, integrity protection, integrity verification); RLC layer functionality associated with the transfer of upper layer PDUs, error correction through ARQ, concatenation, segmentation, and reassembly of RLC SDUs, re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, multiplexing of MAC SDUs onto transport blocks (TBs), demultiplexing of MAC SDUs from TBs, scheduling information reporting, error correction through hybrid automatic repeat request (HARQ), priority handling, and logical channel prioritization.

Channel estimates derived by the channel estimator from a reference signal or feedback transmitted by the base station **304** may be used by the transmitter **314** to select the appropriate coding and modulation schemes, and to facilitate spatial processing. The spatial streams generated by the transmitter **314** may be provided to different antenna(s) **316**. The transmitter **314** may modulate an RF carrier with a respective spatial stream for transmission.

The uplink transmission is processed at the base station **304** in a manner similar to that described in connection with the receiver function at the UE **302**. The receiver **352** receives a signal through its respective antenna(s) **356**. The receiver **352** recovers information modulated onto an RF carrier and provides the information to the one or more processors **384**.

In the uplink, the one or more processors **384** provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, control signal processing to recover IP packets from the UE **302**. IP packets from the one or more processors **384** may be provided to the core network. The one or more processors **384** are also responsible for error detection.

For convenience, the UE **302**, the base station **304**, and/or the network entity **306** are shown in FIGS. **3**A, **3**B, and **3**C as including various components that may be configured according to the various examples described herein. It will be appreciated, however, that the illustrated components may have different functionality in different designs. In particular, various components in FIGS. **3**A to **3**C are optional in alternative configurations and the various aspects include configurations that may vary due to design choice, costs, use of the device, or other considerations. For example, in case of FIG. **3**A, a particular implementation of UE **302** may omit the WWAN transceiver(s) **310** (e.g., a wearable device or tablet computer or PC or laptop may have Wi-Fi and/or Bluetooth capability without cellular capability), or may omit the short-range wireless transceiver (s) **320** (e.g., cellular-only, etc.), or may omit the satellite signal receiver **330**, or may omit the sensor(s) **344**, and so on. In another example, in case of FIG. **3**B, a particular implementation of the base station **304** may omit the WWAN transceiver(s) **350** (e.g., a Wi-Fi "hotspot" access point without cellular capability), or may omit the short-range wireless transceiver(s) **360** (e.g., cellular-only, etc.), or may omit the satellite receiver **370**, and so on. For brevity, illustration of the various alternative configurations is not provided herein, but would be readily understandable to one skilled in the art.

The various components of the UE **302**, the base station **304**, and the network entity **306** may be communicatively coupled to each other over data buses **334**, **382**, and **392**, respectively. In an aspect, the data buses **334**, **382**, and **392** may form, or be part of, a communication interface of the UE **302**, the base station **304**, and the network entity **306**, respectively. For example, where different logical entities are embodied in the same device (e.g., gNB and location server functionality incorporated into the same base station **304**), the data buses **334**, **382**, and **392** may provide communication between them.

The components of FIGS. **3**A, **3**B, and **3**C may be implemented in various ways. In some implementations, the components of FIGS. **3**A, **3**B, and **3**C may be implemented in one or more circuits such as, for example, one or more processors and/or one or more ASICs (which may include one or more processors). Here, each circuit may use and/or incorporate at least one memory component for storing information or executable code used by the circuit to provide this functionality. For example, some or all of the functionality represented by blocks **310** to **346** may be implemented by processor and memory component(s) of the UE **302** (e.g., by execution of appropriate code and/or by appropriate configuration of processor components). Similarly, some or all of the functionality represented by blocks **350** to **388** may be implemented by processor and memory component(s) of the base station **304** (e.g., by execution of appropriate code and/or by appropriate configuration of processor components). Also, some or all of the functionality represented by blocks **390** to **398** may be implemented by processor and memory component(s) of the network entity **306** (e.g., by execution of appropriate code and/or by appropriate configuration of processor components). For simplicity, various operations, acts, and/or functions are described herein as being performed "by a UE," "by a base station," "by a network entity," etc. However, as will be appreciated, such operations, acts, and/or functions may actually be performed by specific components or combinations of components of the UE **302**, base station **304**, network entity **306**, etc., such as the processors **332**, **384**, **394**, the transceivers **310**, **320**, **350**, and **360**, the memories **340**, **386**, and **396**, the sensing component **342**, **388**, and **398**, etc.

In some designs, the network entity **306** may be implemented as a core network component. In other designs, the network entity **306** may be distinct from a network operator or operation of the cellular network infrastructure (e.g., NG RAN **220** and/or 5GC **210**/**260**). For example, the network entity **306** may be a component of a private network that may be configured to communicate with the UE **302** via the base station **304** or independently from the base station **304** (e.g., over a non-cellular communication link, such as WiFi).

Wireless communication signals (e.g., RF signals configured to carry OFDM symbols in accordance with a wireless communications standard, such as LTE, NR, etc.) transmitted between a UE and a base station can be used for environment sensing (also referred to as "RF sensing" or "radar"). Using wireless communication signals for environment sensing can be regarded as consumer-level radar with advanced detection capabilities that enable, among other things, touchless/device-free interaction with a device/system. The wireless communication signals may be cellular communication signals, such as LTE or NR signals, WLAN signals, such as Wi-Fi signals, etc. As a particular example, the wireless communication signals may be an OFDM waveform as utilized in LTE and NR. High-frequency communication signals, such as mmW RF signals, are especially beneficial to use as radar signals because the higher frequency provides, at least, more accurate range (distance) detection.

Possible use cases of RF sensing include health monitoring use cases, such as heartbeat detection, respiration rate monitoring, and the like, gesture recognition use cases, such as human activity recognition, keystroke detection, sign language recognition, and the like, contextual information acquisition use cases, such as location detection/tracking, direction finding, range estimation, and the like, and automotive radar use cases, such as smart cruise control, collision avoidance, and the like.

FIG. **4** is a diagram **400** illustrating a base station (BS) **402** (which may correspond to any of the base stations described herein) in communication with a UE **404** (which may correspond to any of the UEs described herein). Referring to FIG. **4**, the base station **402** may transmit a beamformed signal to the UE **404** on one or more transmit beams **412***a*, **412***b*, **412***c*, **412***d*, **412***e*, **412***f*, **412***g*, **412***h* (collectively, beams **412**), each having a beam identifier that can be used by the UE **404** to identify the respective beam. Where the base station **402** is beamforming towards the UE **404** with a single array of antennas (e.g., a single TRP/cell), the base station **402** may perform a "beam sweep" by transmitting first beam **412***a*, then beam **412***b*, and so on until lastly transmitting beam **412***h*. Alternatively, the base station **402** may transmit beams **412** in some pattern, such as beam **412***a*, then beam **412***h*, then beam **412***b*, then beam **412***g*, and so on. Where the base station **402** is beamforming towards the UE **404** using multiple arrays of antennas (e.g., multiple TRPs/cells), each antenna array may perform a beam sweep of a subset of the beams **412**. Alternatively, each of beams **412** may correspond to a single antenna or antenna array.

FIG. **4** further illustrates the paths **422***c*, **422***d*, **422***e*, **422***f*, and **422***g* followed by the beamformed signal transmitted on beams **412***c*, **412***d*, **412***e*, **412***f*, and **412***g*, respectively. Each path **422***c*, **422***d*, **422***e*, **422***f*, **422***g* may correspond to a single "multipath" or, due to the propagation characteristics of radio frequency (RF) signals through the environment, may be comprised of a plurality (a cluster) of "multipaths." Note that although only the paths **422***c*-**422***g* for beams **412***c*-**412***g* are shown, this is for simplicity, and the signal transmitted on each of beams **412** will follow some path. In the example shown, the paths **422***c*, **422***d*, **422***e*, and **422***f* are straight lines, while path **422***g* reflects off an obstacle **420** (e.g., a building, vehicle, terrain feature, etc.).

The UE **404** may receive the beamformed signal from the base station **402** on one or more receive beams **414***a*, **414***b*, **414***c*, **414***d* (collectively, beams **414**). Note that for simplicity, the beams illustrated in FIG. **4** represent either transmit beams or receive beams, depending on which of the base station **402** and the UE **404** is transmitting and which is receiving. Thus, the UE **404** may also transmit a beamformed signal to the base station **402** on one or more of the beams **414**, and the base station **402** may receive the beamformed signal from the UE **404** on one or more of the beams **412**.

In an aspect, the base station **402** and the UE **404** may perform beam training to align the transmit and receive beams of the base station **402** and the UE **404**. For example, depending on environmental conditions and other factors, the base station **402** and the UE **404** may determine that the best transmit and receive beams are **412***d* and **414***b*, respectively, or beams **412***e* and **414***c*, respectively. The direction of the best transmit beam for the base station **402** may or may not be the same as the direction of the best receive beam, and likewise, the direction of the best receive beam for the UE **404** may or may not be the same as the direction of the best transmit beam.

FIG. **5** is a graph **500** representing an example channel estimate of a multipath channel between a receiver device (e.g., any of the UEs or base stations described herein) and a transmitter device (e.g., any other of the UEs or base stations described herein), according to aspects of the disclosure. The channel estimate represents the intensity of a radio frequency (RF) signal (e.g., a positioning reference signal (PRS)) received through a multipath channel as a function of time delay, and may be referred to as the channel energy response (CER), channel impulse response (CIR), or power delay profile (PDP) of the channel. Thus, the horizontal axis represents time (e.g., milliseconds) and the vertical axis represents signal strength (e.g., decibels). Note that a multipath channel is a channel between a transmitter and a receiver over which an RF signal follows multiple paths, or multipaths, due to transmission of the RF signal on multiple beams and/or to the propagation characteristics of the RF signal (e.g., reflection, refraction, etc.).

In the example of FIG. **5**, the receiver detects/measures multiple (four) channel taps of the RF signal. Each channel tap is a cluster of one or more rays and corresponds to a multipath that the RF signal followed between the transmitter and the receiver. Thus, a channel tap represents the time of arrival and signal strength of an RF signal over a multipath. There may be multiple channel taps due to the RF signal being transmitted on different transmit beams (and therefore at different angles), or because of the propagation characteristics of RF signals (e.g., potentially following different paths due to reflections), or both. Note that although FIG. **5** illustrates channel taps of two to five rays, as will be appreciated, the channel taps may have more or fewer than the illustrated number of rays.

In the example of FIG. **5**, the channel tap detected at time T**3** is composed of stronger rays than the channel tap detected at time T**1**. This may be due to an obstruction on the LOS path between the transmitter and the receiver. Alternatively or additionally, there may be a strong reflector along the NLOS path corresponding to the channel tap detected at time T**3**.

There are different types of sensing, including monostatic sensing (also referred to as "active sensing") and bistatic sensing (also referred to as "passive sensing"). FIGS. **6**A and **6**B illustrate these different types of sensing. Specifically, FIG. **6**A is a diagram **600** illustrating a monostatic sensing scenario and FIG. **6**B is a diagram **630** illustrating a bistatic sensing scenario. In FIG. **6**A, the transmitter (Tx) and receiver (Rx) are co-located in the same device **604** (e.g., a UE). The sensing device **604** transmits one or more RF sensing signals **634** (e.g., uplink or sidelink positioning reference signals (PRS) where the device **604** is a UE), and some of the RF sensing signals **634** reflect off a target object **606**. The sensing device **604** can measure various properties (e.g., times of arrival (ToAs), angles of arrival (AoAs), phase shift, etc.) of the reflections of the RF sensing signals **634** to determine characteristics of the target object **606** (e.g., size, shape, speed, motion state, etc.).

In FIG. **6**B, the transmitter (Tx) and receiver (Rx) are not co-located, that is, they are separate devices (e.g., a UE and a base station). Note that while FIG. **6**B illustrates using a downlink RF signal as the RF sensing signal **632**, uplink RF signals or sidelink RF signals can also be used as RF sensing signals **632**. In a downlink scenario, as shown, the transmitter is a base station and the receiver is a UE, whereas in an uplink scenario, the transmitter is a UE and the receiver is a base station.

Referring to FIG. **6**B in greater detail, the transmitter device **602** transmits RF sensing signals **632** and **634** (e.g., positioning reference signals (PRS)) to the receiver device **604**, but some of the RF sensing signals **634** reflect off a target object **606**. The receiver device **604** (also referred to as the "sensing device") can measure the ToAs of the RF sensing signals **632** received directly from the transmitter device and the ToAs of the RF sensing signals **634** reflected from the target object **606**.

More specifically, as described above with reference to FIG. **5**, a transmitter device (e.g., a base station) may transmit a single RF signal or multiple RF signals to a receiver device (e.g., a UE). However, the receiver may receive multiple channel taps corresponding to each transmitted RF signal due to the propagation characteristics of RF signals through multipath channels. Each channel tap may be associated with a cluster of one or more rays and correspond to a multipath that the RF signal followed between the transmitter and the receiver. Thus, a channel tap represents the time of arrival and signal strength of an RF signal over a multipath. Generally, the time at which the receiver detects the first channel tap is considered the ToA of the RF signal on the line-of-site (LOS) path (i.e., the shortest path between the transmitter and the receiver). Later channel taps are considered to have reflected off objects between the transmitter and the receiver and therefore to have followed non-LOS (NLOS) paths between the transmitter and the receiver.

Thus, referring back to FIG. **6**B, the RF sensing signals **632** followed the LOS path between the transmitter device **602** and the receiver device **604**, and the RF sensing signals **634** followed an NLOS path between the transmitter device **602** and the receiver device **604** due to reflecting off the target object **606**. The transmitter device **602** may have transmitted multiple RF sensing signals **632**, **634**, some of which followed the LOS path and others of which followed the NLOS path. Alternatively, the transmitter device **602** may have transmitted a single RF sensing signal in a broad enough beam that a portion of the RF sensing signal followed the LOS path (RF sensing signal **632**) and a portion of the RF sensing signal followed the NLOS path (RF sensing signal **634**).

Based on the ToA of the LOS path, the ToA of the NLOS path, and the speed of light, the receiver device can determine the distance to the target object(s). For example, the receiver device can calculate the distance to the target object as the difference between the ToA of the LOS path and the ToA of the NLOS path multiplied by the speed of light. In addition, if the receiver device is capable of receive beamforming, the receiver device may be able to determine the general direction to a target object as the direction (angle) of the receive beam on which the RF sensing signal following the NLOS path was received. That is, the receiver device may determine the direction to the target object as the angle of arrival (AoA) of the RF sensing signal, which is the angle of the receive beam used to receive the RF sensing signal. The receiver device may then optionally report this information to the transmitter device, its serving base station, an application server associated with the core network, an external client, a third-party application, or some other sensing entity. Alternatively, the receiver device may report the ToA measurements to the transmitter device, or other sensing entity (e.g., if the receiver device does not have the processing capability to perform the calculations itself), and the transmitter device may determine the distance and, optionally, the direction to the target object.

Note that if the RF sensing signals are uplink RF signals transmitted by a UE to a base station, the base station would perform object detection based on the uplink RF signals just like the UE does based on the downlink RF signals.

Millimeter wave systems are maturing, with first-generation systems already deployed in the market. Current carrier frequencies of interest are in the "28," "39," and "48" GHz bands, but there is an increased focus on upper millimeter wave (greater than 52.6 GHz) bands and sub-Terahertz (greater than 114.25 GHz) bands. Based on the availability of these bands, communications for vehicular systems and AR/VR/XR systems have taken prominence as the sixth generation (6G) of cellular communications standards evolve.

Perception-assisted sensing is also increasingly discussed in these systems to assist with speeding up different aspects of PHY communication. Examples of perception assistance include speeding up beam management aspects (e.g., bidirectional beam refinement, such as P2-P3 operational modes, beam switching, beamwidth adaptation, etc.) based on changes in environment (such as blockage or fading). Typically, perception assistance happens at a specific node (e.g., a UE), where assistance is based on internal perception (e.g., use of cameras, lidar, radar, motion sensors) or external perception (e.g., based on signaling to/from the node from/to a perception-assistance node).

In both vehicular and AR/VR/XR systems, perception-assisted sensing is performed at the device (UE) itself. Perception information collected by the device may be based on sensor information from cameras, radar, lidar, motion sensors (e.g., accelerometers, gyroscope, compass, barometer, etc.), and the like. For example, based on the sensor information, the perception information may include beamforming-related information (e.g., adaptive beam weights that have worked best in the last few time slots), the orientation of the device (e.g., relative to a global coordinate system (GCS)), the field-of-view (FOV) of the device, the motion state of the device (e.g., moving, stationary), the periodicity of movement (e.g., in a gaming/industrial setting), the velocity of the device, and the like.

With specific reference to perception-assisted sensing for vehicular systems, vehicle-aided sensing of the physical world can be used to improve communication. Higher bands (e.g., mmW bands) are more impacted by environmental changes than lower bands. Vehicles and RSUs are good candidates for sensing due to their always "on" sensors, well-known location and orientation, and street-level sensing. There is also a rich set of potential applications for vehicle-aided sensing, such as predictive beam management, handover prediction, predictive rate adaptation, robust RF fingerprinting in dynamic environments, dynamic network management, channel state information (CSI) compression, and the like.

The present disclosure provides techniques to enable a UE to indicate the turning ON of perception assistance at another node in the network. Currently, there is no such signaling, since perception-based assistance is limited to the node itself. The other node may be a base station (e.g., a gNB) with which the UE is communicating, or another type of node, such as a sidelink UE or an explicit perception-assistance node, with which the UE can communicate to signal changes/requirements to the base station. Such bidirectional perception assistance can significantly speed up PHY aspects and improve beamforming gains.

FIG. **7** is a diagram **700** illustrating an example of beam management using perception-assisted sensing, according to aspects of the disclosure. As shown in FIG. **7**, the line-of-sight (LOS) path over which the UE-gNB link is established at time t**1** is blocked by a moving vehicle. This forces the UE to switch to a different (reflected) path via another moving vehicle at time t**2**. As the first moving vehicle unblocks the original path, the link over the LOS path can be reestablished at time t**3**. Cameras and other sensors (at the UE, vehicle, and/or gNB) can provide perception information to assist with the illustrated beam establishment, beam switching, and beam recovery.

Beam establishment, beam switching, and/or beam recovery may be based on adaptive beam weight learning. The basic concept behind the generation and tracking of adaptive (dynamic) beam weights has a few constituent steps. First, a specific set of beam weights (that are a priori designed with a specific objective) are used for channel sounding. Channel sounding is a technique that evaluates the radio environment for wireless communication based on the reception/measurement of certain reference signals, such as SSBs and/or channel state information reference signals (CSI-RS). Second, the receiver (e.g., the UE) measures the RSRPs of the reference signals received with the set of beam weights (phase measurements are generally not possible due to stability issues). Third, the beam weights to use for reception are determined (learned). These beam weights are also typically used for transmission as well. Fourth, the beam weights are updated (adapted) as the channel environment changes (e.g., due to blockage, fading, etc.).

Typically, adaptive/dynamic beam weights are designed as the dominant eigenvector of the channel covariance matrix as seen at the UE side. The covariance matrix is learned either over SSBs (an always-present reference signal) or over aperiodic CSI-RS (configured by the base station). The number of such reference signals grows as N^2, where N is the array dimension, since this is the degrees of freedom associated with an N×N covariance matrix. This can be onerous for both the UE (where $N \geq 4$) as well as the customer premises equipment (CPE) (where $N \geq 64$).

Adaptive/dynamic beam weights are often used at one end (e.g., UE), while the other end (e.g., gNB) uses non-adaptive/directional beam weights. In this scenario, most changes occur at the UE end with minimal requirement for coordination of beam switches (the gNB beam remains the same). However, there is a broad utility to using adaptive/dynamic beam weights at both ends of the link, as described below with reference to FIG. **8**.

FIG. **8** is a graph **800** illustrating an example of gains with bidirectional adaptive beam weights, according to aspects of the disclosure. The graph **800** illustrates the performance of beam refinement at the receiver node only (P3 based) versus at both the transmitter and receiver nodes (P2-P3 based). Plotted is the sum of the signal-to-noise ratio (SNR) across 2L/polarizations with different schemes. P2 is based on simple addition of the two best narrow beams from a size-32 codebook for an 8×4 array. P3 is based on per-antenna co-phasing for a 4×1 array to generate good beamforming structures. The baseline beams are based on a P1 beam sweep at both ends (32 beams at the gNB side and four beams at the UE side). As shown in the graph **800**, an SNR improvement on the order of one to two decibels (dB) is seen with this simple strategy. More complicated/involved strategies can lead to even more improvement over the baseline—making an even better case for bidirectional beam refinement.

Perception-assisted adaptive beam weight learning can be faster than non-perception-based approaches and can lead to better performance gains. The tradeoff is in terms of more control signaling for the coordination of such approaches. Perception can assist with reference signal reduction as well as search space (over all possible beam weights) reduction.

FIG. **9** is a diagram **900** illustrating a technique for signaling perception-assisted adaptive beam weight learning, according to aspects of the disclosure. In a first stage, the UE (illustrated as an XR headset) determines that a perception-based approach to adaptive beam weight learning would work better (e.g., provide improved performance of wireless communication with the gNB) at its end relative to a non-perception-based approach. The UE may determine that a perception-based approach would work better based on the signal strengths (e.g., RSRPs, SNRs, etc.) of reference signals (e.g., SSBs, CSI-RS) received on different receive beams and/or other perception information obtained by the UE. Based on this determination, at a second stage, the UE can request the gNB to perform perception-based approaches for adaptive beam weight learning. This can be indicated to the gNB by a "turn ON perception mode" signal. The signal can be sent directly to the gNB itself (e.g., via RRC, MAC control element (MAC-CE), or uplink control information (UCI)), as shown by the solid line, or via a coordinating node (e.g., a sidelink UE or a perception-assistance node that communicates with the gNB), as shown by the dashed line.

At some point, the UE may determine that a perception-based approach to adaptive beam weight learning would not work better at its end relative to a non-perception-based approach. The UE can then request the gNB to cease perception-based approaches for adaptive beam weight learning. This can be indicated to the gNB by a "turn OFF perception mode" signal.

FIG. **10** is a diagram **1000** illustrating a technique for signaling a direction of interest for perception-based sensing, according to aspects of the disclosure. In this technique, the UE (illustrated as an XR headset) can request perception-based sensing with a "prior" over the beamspace provided (i.e., the directions/beam weights in which the UE is capable of beamforming). The prior indicates that certain angular regions of space are more important or relevant for perception-based sensing. The indication of the prior could be based on UE-based perception of which angles appear to correspond to better clusters (e.g., multipaths with higher signal strength) in the channel estimate. For example, the UE may determine the best transmission configuration indicator (TCI) state during a beam training procedure with the gNB. This allows the UE to explore specific areas of its beamspace and indicate this via specific choices of prior at the gNB beamspace.

The UE may transmit an indication to the base station (directly or via a coordinating node) requesting it to perform perception-based sensing operations (as described above with reference to FIGS. **6**A and **6**B) in the direction of interest. The signaling may be via RRC, MAC-CE, or UCI.

FIG. **11** illustrates an example method **1100** of wireless communication, according to aspects of the disclosure. In an aspect, method **1100** may be performed by a UE (e.g., any of the UEs described herein).

At **1110**, the UE determines that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning. In an aspect, operation **1110** may be performed by the one or more WWAN transceivers **310**, the one or more short-range wireless transceivers **320**, the one or more processors **332**, memory **340**, and/or sensing component **342**, any or all of which may be considered means for performing this operation.

In an aspect, the determination that the perception-based approach to adaptive beam weight learning would provide improved performance of the wireless communication with the base station may be based on perception information obtained by the UE. The perception information may include motion sensor information of the UE, radar-based sensing information of the UE, lidar-based sensing information of the UE, images or video captured by one or more cameras of the UE, beamforming information of the UE, an orientation of the UE, a periodicity of movement of the UE, a channel estimate of the wireless communication medium, signal strengths of reference signals received on different receive beams, or any combination thereof.

In an aspect, the improved performance may include higher signal strength of a wireless channel between the UE and the base station, increased reliability of the channel between the UE and the base station, or any combination thereof.

At **1120**, the UE transmits, to a network node (e.g., the base station or a coordinating node), an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium. In an aspect, operation **1120** may be performed by the one or more WWAN transceivers **310**, the one or more short-range wireless transceivers **320**, the one or more processors **332**, memory **340**, and/or sensing component **342**, any or all of which may be considered means for performing this operation.

In an aspect, the indication may transmitted to the network node via RRC signaling, MAC-CE signaling, or UCI.

In an aspect, the method **1100** may further include (not shown) performing a perception-based adaptive beam weight learning procedure for the wireless communication with the base station. Performing the perception-based adaptive beam weight learning procedure may include (1) determining a direction of interest for the wireless communication with the base station based on perception information obtained by the UE, (2) using a set of beam weights to sound the wireless communication medium in the direction of interest, (3) measuring signal strengths of reference signals transmitted by the base station on the wireless communication medium, and (4) determining a subset of beam weights of the set of beam weights to use for the wireless communication with the based station over the wireless communication medium.

In an aspect, the method **1100** may further include (not shown) determining that the perception-based approach to adaptive beam weight learning would no longer provide improved performance of the wireless communication with the base station over the wireless communication medium relative to the non-perception-based approaches to adaptive beam weight learning, and transmitting, to the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

In an aspect, the network node may be a sidelink UE, a perception-assistance node, or the base station.

In an aspect, the UE may be an extended reality device, a virtual reality device, an augmented reality device, a gaming device, an Internet of Things (IoT) device, or a vehicle.

FIG. **12** illustrates an example method **1200** of wireless communication, according to aspects of the disclosure. In an aspect, method **1200** may be performed by a base station (e.g., any of the base stations or base station entities described herein)

At **1210**, the base station receives, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a UE over a wireless communication medium. In an aspect, operation **1210** may be performed by the one or more WWAN transceivers **350**, the one or more short-range wireless transceivers **360**, the one or more processors **384**, memory **386**, and/or sensing component **388**, any or all of which may be considered means for performing this operation.

In an aspect, the indication may be received from the network node via RRC signaling, MAC-CE signaling, or UCI signaling.

At **1220**, the base station performs a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium. In an aspect, operation **1220** may be performed by the one or more WWAN transceivers **350**, the one or more short-range wireless transceivers **360**, the one or more processors **384**, memory **386**, and/or sensing component **388**, any or all of which may be considered means for performing this operation.

In an aspect, performing the perception-based adaptive beam weight learning procedure may include (1) determining a direction of interest for the wireless communication with the UE based on perception information obtained by the base station, (2) using a set of beam weights to sound the wireless communication medium in the direction of interest, (3) measuring signal strengths of reference signals transmitted by the UE on the wireless communication medium, and (4) determining a subset of beam weights of the set of beam weights to use for the wireless communication with the UE on the wireless communication medium.

In an aspect, the perception information may include radar-based sensing information of the base station, lidar-based sensing information of the base station, images or video captured by one or more cameras of the base station, beamforming information of the base station, signal strengths of reference signals received on different receive beams, a channel estimate of the wireless communication medium, or any combination thereof.

In an aspect, the method **1200** may further include (not shown) receiving, from the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the UE over the wireless communication medium, and ceasing to perform the perception-based adaptive beam weight learning procedure for the communication with the UE over the wireless communication medium.

In an aspect, the network node may be the UE, a sidelink UE in communication with the UE, or a perception-assistance node.

As will be appreciated, a technical advantage of the methods **1100** and **1200** is enabling bidirectional perception-based adaptive beam weight learning.

FIG. **13** illustrates an example method **1300** of wireless communication, according to aspects of the disclosure. In an aspect, method **1300** may be performed by a UE (e.g., any of the UEs described herein)

At **1310**, the UE determines a spatial region of interest for performing perception-based sensing operations with a base station over a wireless communication medium. In an aspect, operation **1310** may be performed by the one or more WWAN transceivers **310**, the one or more short-range wireless transceivers **320**, the one or more processors **332**, memory **340**, and/or sensing component **342**, any or all of which may be considered means for performing this operation.

In an aspect, the spatial region of interest may be determined based on perception information obtained by the UE. In an aspect, the perception information may include motion sensor information of the UE, radar-based sensing information of the UE, lidar-based sensing information of the UE, images or video captured by one or more cameras of the UE, beamforming information of the UE, an orientation of the UE, a periodicity of movement of the UE, a channel estimate of the wireless communication medium, signal strengths of reference signals received on different receive beams, or any combination thereof.

In an aspect, the spatial region of interest may be determined based on a determination that signal strength of reference signals received from the base station over the wireless communication medium is higher in the spatial region of interest than in other spatial regions. In an aspect, the determination that the signal strength of the reference signals received from the base station is higher in the spatial region of interest may be based on a channel estimate of the wireless communication medium.

In an aspect, the spatial region of interest may be within a beamspace of the UE.

At **1320**, the UE transmits, to a network node, an indication for the base station to perform the perception-based sensing operations in the spatial region of interest. In an aspect, operation **1320** may be performed by the one or more WWAN transceivers **310**, the one or more short-range wireless transceivers **320**, the one or more processors **332**, memory **340**, and/or sensing component **342**, any or all of which may be considered means for performing this operation.

In an aspect, the network node may be a sidelink UE, a perception-assistance node, or the base station.

In an aspect, the UE may be an extended reality device, a virtual reality device, an augmented reality device, a gaming device, an Internet of Things (IoT) device, or a vehicle.

In an aspect, the indication may be transmitted to the network node via RRC signaling, MAC-CE signaling, or UCI signaling.

FIG. **14** illustrates an example method **1400** of wireless communication, according to aspects of the disclosure. In an aspect, method **1400** may be performed by a base station (e.g., any of the base stations or base station entities described herein)

At **1410**, the base station receives, from a network node, an indication for the base station to perform perception-based sensing operations in a spatial region of interest to a UE. In an aspect, operation **1410** may be performed by the one or more WWAN transceivers **350**, the one or more short-range wireless transceivers **360**, the one or more processors **384**, memory **386**, and/or sensing component **388**, any or all of which may be considered means for performing this operation.

In an aspect, the indication may be received from the network node via RRC signaling, MAC-CE signaling, or UCI signaling.

At **1420**, the base station performs the perception-based sensing operations in the spatial region of interest to the UE. In an aspect, operation **1420** may be performed by the one or more WWAN transceivers **350**, the one or more short-range wireless transceivers **360**, the one or more processors **384**, memory **386**, and/or sensing component **388**, any or all of which may be considered means for performing this operation.

In an aspect, performing the perception-based sensing operations may include performing a beam sweep within the spatial region of interest to the UE.

In an aspect, the spatial region of interest may be within a beamspace of the UE.

In an aspect, the network node may be a sidelink UE, a perception-assistance node, or the base station.

As will be appreciated, a technical advantage of the methods **1300** and **1400** is improved perception-based sensing by providing a direction of interest for the perception-based sensing.

In the detailed description above it can be seen that different features are grouped together in examples. This manner of disclosure should not be understood as an intention that the example clauses have more features than are explicitly mentioned in each clause. Rather, the various aspects of the disclosure may include fewer than all features of an individual example clause disclosed. Therefore, the following clauses should hereby be deemed to be incorporated in the description, wherein each clause by itself can stand as a separate example. Although each dependent clause can refer in the clauses to a specific combination with one of the other clauses, the aspect(s) of that dependent clause are not limited to the specific combination. It will be appreciated that other example clauses can also include a combination of the dependent clause aspect(s) with the subject matter of any other dependent clause or independent clause or a combination of any feature with other dependent and independent clauses. The various aspects disclosed herein expressly include these combinations, unless it is explicitly expressed or can be readily inferred that a specific combination is not intended (e.g., contradictory aspects, such as defining an element as both an electrical insulator and an electrical conductor). Furthermore, it is also intended that aspects of a clause can be included in any other independent clause, even if the clause is not directly dependent on the independent clause.

Implementation examples are described in the following numbered clauses:

Clause 1. A method of wireless communication performed by a user equipment (UE), comprising: determining that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning; and transmitting, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

Clause 2. The method of clause 1, wherein the determination that the perception-based approach to adaptive beam weight learning would provide improved performance of the wireless communication with the base station is based on perception information obtained by the UE.

Clause 3. The method of clause 2, wherein the perception information comprises: motion sensor information of the UE, radar-based sensing information of the UE, lidar-based sensing information of the UE, images or video captured by one or more cameras of the UE, beamforming information of the UE, an orientation of the UE, a periodicity of movement of the UE, a channel estimate of the wireless communication medium, signal strengths of reference signals received on different receive beams, or any combination thereof.

Clause 4. The method of any of clauses 1 to 3, further comprising: performing a perception-based adaptive beam weight learning procedure for the wireless communication with the base station.

Clause 5. The method of clause 4, wherein performing the perception-based adaptive beam weight learning procedure comprises: determining a direction of interest for the wireless communication with the base station based on perception information obtained by the UE; using a set of beam weights to sound the wireless communication medium in the direction of interest; measuring signal strengths of reference signals transmitted by the base station on the wireless communication medium; and determining a subset of beam weights of the set of beam weights to use for the wireless communication with the based station over the wireless communication medium.

Clause 6. The method of any of clauses 1 to 5, further comprising: determining that the perception-based approach to adaptive beam weight learning would no longer provide improved performance of the wireless communication with the base station over the wireless communication medium relative to the non-perception-based approaches to adaptive beam weight learning; and transmitting, to the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

Clause 7. The method of any of clauses 1 to 6, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 8. The method of any of clauses 1 to 7, wherein the improved performance comprises: higher signal strength of a wireless channel between the UE and the base station, increased reliability of the wireless channel between the UE and the base station, or any combination thereof.

Clause 9. The method of any of clauses 1 to 8, wherein the UE comprises: an extended reality device, a virtual reality device, an augmented reality device, a gaming device, an Internet of Things (IoT) device, or a vehicle.

Clause 10. The method of any of clauses 1 to 9, wherein the indication is transmitted to the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 11. A method of wireless communication performed by a base station, comprising: receiving, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium; and performing a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

Clause 12. The method of clause 11, wherein performing the perception-based adaptive beam weight learning procedure comprises: determining a direction of interest for the wireless communication with the UE based on perception information obtained by the base station; using a set of beam weights to sound the wireless communication medium in the direction of interest; measuring signal strengths of reference signals transmitted by the UE on the wireless communication medium; and determining a subset of beam weights of the set of beam weights to use for the wireless communication with the UE on the wireless communication medium.

Clause 13. The method of clause 12, wherein the perception information comprises: radar-based sensing information of the base station, lidar-based sensing information of the base station, images or video captured by one or more cameras of the base station, beamforming information of the base station, signal strengths of reference signals received on different receive beams, a channel estimate of the wireless communication medium, or any combination thereof.

Clause 14. The method of any of clauses 11 to 13, further comprising: receiving, from the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the UE over the wireless communication medium; and ceasing to perform the perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

Clause 15. The method of any of clauses 11 to 14, wherein the network node comprises: the UE, a sidelink UE in communication with the UE, or a perception-assistance node.

Clause 16. The method of any of clauses 11 to 15, wherein the indication is received from the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 17. A method of wireless communication performed by a user equipment (UE), comprising: determining a spatial region of interest for performing perception-based sensing operations with a base station over a wireless communication medium; and transmitting, to a network node, an indication for the base station to perform the perception-based sensing operations in the spatial region of interest.

Clause 18. The method of clause 17, wherein the spatial region of interest is determined based on a determination that signal strength of reference signals received from the base station over the wireless communication medium is higher in the spatial region of interest than in other spatial regions.

Clause 19. The method of clause 18, wherein the determination that the signal strength of the reference signals received from the base station is higher in the spatial region of interest is based on a channel estimate of the wireless communication medium.

Clause 20. The method of any of clauses 17 to 19, wherein the spatial region of interest is determined based on perception information obtained by the UE.

Clause 21. The method of clause 20, wherein the perception information comprises: motion sensor information of the UE, radar-based sensing information of the UE, lidar-based sensing information of the UE, images or video captured by one or more cameras of the UE, beamforming information of the UE, an orientation of the UE, a periodicity of movement of the UE, a channel estimate of the wireless communication medium, signal strengths of reference signals received on different receive beams, or any combination thereof.

Clause 22. The method of any of clauses 17 to 21, wherein the spatial region of interest is within a beamspace of the UE.

Clause 23. The method of any of clauses 17 to 22, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 24. The method of any of clauses 17 to 23, wherein the UE comprises: an extended reality device, a virtual reality device, an augmented reality device, a gaming device, an Internet of Things (IoT) device, or a vehicle.

Clause 25. The method of any of clauses 17 to 24, wherein the indication is transmitted to the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 26. A method of wireless communication performed by a base station, comprising: receiving, from a network node, an indication for the base station to perform perception-based sensing operations in a spatial region of interest to a user equipment (UE); and performing the perception-based sensing operations in the spatial region of interest to the UE.

Clause 27. The method of clause 26, wherein the spatial region of interest is within a beamspace of the UE.

Clause 28. The method of any of clauses 26 to 27, wherein performing the perception-based sensing operations comprises: performing a beam sweep within the spatial region of interest to the UE.

Clause 29. The method of any of clauses 26 to 28, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 30. The method of any of clauses 26 to 29, wherein the indication is received from the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 31. A user equipment (UE), comprising: a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: determine that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning; and transmit, via the at least one transceiver, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

Clause 32. The UE of clause 31, wherein the determination that the perception-based approach to adaptive beam weight learning would provide improved performance of the wireless communication with the base station is based on perception information obtained by the UE.

Clause 33. The UE of clause 32, wherein the perception information comprises: motion sensor information of the UE, radar-based sensing information of the UE, lidar-based sensing information of the UE, images or video captured by one or more cameras of the UE, beamforming information of the UE, an orientation of the UE, a periodicity of movement of the UE, a channel estimate of the wireless communication medium, signal strengths of reference signals received on different receive beams, or any combination thereof.

Clause 34. The UE of any of clauses 31 to 33, wherein the at least one processor is further configured to: perform a perception-based adaptive beam weight learning procedure for the wireless communication with the base station.

Clause 35. The UE of clause 34, wherein the at least one processor configured to perform the perception-based adaptive beam weight learning procedure comprises the at least one processor configured to: determine a direction of interest for the wireless communication with the base station based on perception information obtained by the UE; use a set of beam weights to sound the wireless communication medium in the direction of interest; measure signal strengths of reference signals transmitted by the base station on the wireless communication medium; and determine a subset of beam weights of the set of beam weights to use for the wireless communication with the based station over the wireless communication medium.

Clause 36. The UE of any of clauses 31 to 35, wherein the at least one processor is further configured to: determine that the perception-based approach to adaptive beam weight learning would no longer provide improved performance of the wireless communication with the base station over the wireless communication medium relative to the non-perception-based approaches to adaptive beam weight learning; and transmit, via the at least one transceiver, to the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

Clause 37. The UE of any of clauses 31 to 36, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 38. The UE of any of clauses 31 to 37, wherein the improved performance comprises: higher signal strength of a wireless channel between the UE and the base station, increased reliability of the wireless channel between the UE and the base station, or any combination thereof.

Clause 39. The UE of any of clauses 31 to 38, wherein the UE comprises: an extended reality device, a virtual reality device, an augmented reality device, a gaming device, an Internet of Things (IoT) device, or a vehicle.

Clause 40. The UE of any of clauses 31 to 39, wherein the indication is transmitted to the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 41. A base station, comprising: a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: receive, via the at least one transceiver, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium; and perform a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

Clause 42. The base station of clause 41, wherein the at least one processor configured to perform the perception-based adaptive beam weight learning procedure comprises the at least one processor configured to: determine a direction of interest for the wireless communication with the UE based on perception information obtained by the base station; use a set of beam weights to sound the wireless communication medium in the direction of interest; measure signal strengths of reference signals transmitted by the UE on the wireless communication medium; and determine a subset of beam weights of the set of beam weights to use for the wireless communication with the UE on the wireless communication medium.

Clause 43. The base station of clause 42, wherein the perception information comprises: radar-based sensing information of the base station, lidar-based sensing information of the base station, images or video captured by one or more cameras of the base station, beamforming information of the base station, signal strengths of reference signals received on different receive beams, a channel estimate of the wireless communication medium, or any combination thereof.

Clause 44. The base station of any of clauses 41 to 43, wherein the at least one processor is further configured to: receive, via the at least one transceiver, from the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the UE over the wireless communication medium; and cease to perform the perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

Clause 45. The base station of any of clauses 41 to 44, wherein the network node comprises: the UE, a sidelink UE in communication with the UE, or a perception-assistance node.

Clause 46. The base station of any of clauses 41 to 45, wherein the indication is received from the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 47. A user equipment (UE), comprising: a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: determine a spatial region of interest for performing perception-based sensing operations with a base station over a wireless communication medium; and transmit, via the at least one transceiver, to a network node, an indication for the base station to perform the perception-based sensing operations in the spatial region of interest.

Clause 48. The UE of clause 47, wherein the spatial region of interest is determined based on a determination that signal strength of reference signals received from the base station over the wireless communication medium is higher in the spatial region of interest than in other spatial regions.

Clause 49. The UE of clause 48, wherein the determination that the signal strength of the reference signals received from the base station is higher in the spatial region of interest is based on a channel estimate of the wireless communication medium.

Clause 50. The UE of any of clauses 47 to 49, wherein the spatial region of interest is determined based on perception information obtained by the UE.

Clause 51. The UE of clause 50, wherein the perception information comprises: motion sensor information of the UE, radar-based sensing information of the UE, lidar-based sensing information of the UE, images or video captured by one or more cameras of the UE, beamforming information of the UE, an orientation of the UE, a periodicity of movement of the UE, a channel estimate of the wireless communication medium, signal strengths of reference signals received on different receive beams, or any combination thereof.

Clause 52. The UE of any of clauses 47 to 51, wherein the spatial region of interest is within a beamspace of the UE.

Clause 53. The UE of any of clauses 47 to 52, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 54. The UE of any of clauses 47 to 53, wherein the UE comprises: an extended reality device, a virtual reality device, an augmented reality device, a gaming device, an Internet of Things (IoT) device, or a vehicle.

Clause 55. The UE of any of clauses 47 to 54, wherein the indication is transmitted to the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 56. A base station, comprising: a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: receive, via the at least one transceiver, from a network node, an indication for the base station to perform perception-based sensing operations in a spatial region of interest to a user equipment (UE); and perform the perception-based sensing operations in the spatial region of interest to the UE.

Clause 57. The base station of clause 56, wherein the spatial region of interest is within a beamspace of the UE.

Clause 58. The base station of any of clauses 56 to 57, wherein the at least one processor configured to perform the perception-based sensing operations comprises the at least one processor configured to: perform a beam sweep within the spatial region of interest to the UE.

Clause 59. The base station of any of clauses 56 to 58, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 60. The base station of any of clauses 56 to 59, wherein the indication is received from the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 61. A user equipment (UE), comprising: means for determining that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning; and means for transmitting, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

Clause 62. The UE of clause 61, wherein the determination that the perception-based approach to adaptive beam weight learning would provide improved performance of the wireless communication with the base station is based on perception information obtained by the UE.

Clause 63. The UE of clause 62, wherein the perception information comprises: motion sensor information of the UE, radar-based sensing information of the UE, lidar-based sensing information of the UE, images or video captured by one or more cameras of the UE, beamforming information of the UE, an orientation of the UE, a periodicity of movement of the UE, a channel estimate of the wireless communication medium, signal strengths of reference signals received on different receive beams, or any combination thereof.

Clause 64. The UE of any of clauses 61 to 63, further comprising: means for performing a perception-based adaptive beam weight learning procedure for the wireless communication with the base station.

Clause 65. The UE of clause 64, wherein the means for performing the perception-based adaptive beam weight learning procedure comprises: means for determining a direction of interest for the wireless communication with the base station based on perception information obtained by the UE; means for using a set of beam weights to sound the wireless communication medium in the direction of interest; means for measuring signal strengths of reference signals transmitted by the base station on the wireless communication medium; and means for determining a subset of beam weights of the set of beam weights to use for the wireless communication with the based station over the wireless communication medium.

Clause 66. The UE of any of clauses 61 to 65, further comprising: means for determining that the perception-based approach to adaptive beam weight learning would no longer provide improved performance of the wireless communication with the base station over the wireless communication medium relative to the non-perception-based approaches to adaptive beam weight learning; and means for transmitting, to the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

Clause 67. The UE of any of clauses 61 to 66, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 68. The UE of any of clauses 61 to 67, wherein the improved performance comprises: higher signal strength of a wireless channel between the UE and the base station, increased reliability of the wireless channel between the UE and the base station, or any combination thereof.

Clause 69. The UE of any of clauses 61 to 68, wherein the UE comprises: an extended reality device, a virtual reality device, an augmented reality device, a gaming device, an Internet of Things (IoT) device, or a vehicle.

Clause 70. The UE of any of clauses 61 to 69, wherein the indication is transmitted to the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 71. A base station, comprising: means for receiving, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium; and means for performing a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

Clause 72. The base station of clause 71, wherein the means for performing the perception-based adaptive beam weight learning procedure comprises: means for determining a direction of interest for the wireless communication with the UE based on perception information obtained by the base station; means for using a set of beam weights to sound the wireless communication medium in the direction of interest; means for measuring signal strengths of reference signals transmitted by the UE on the wireless communication medium; and means for determining a subset of beam weights of the set of beam weights to use for the wireless communication with the UE on the wireless communication medium.

Clause 73. The base station of clause 72, wherein the perception information comprises: radar-based sensing information of the base station, lidar-based sensing information of the base station, images or video captured by one or more cameras of the base station, beamforming information of the base station, signal strengths of reference signals received on different receive beams, a channel estimate of the wireless communication medium, or any combination thereof.

Clause 74. The base station of any of clauses 71 to 73, further comprising: means for receiving, from the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the UE over the wireless communication medium; and means for ceasing to perform the perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

Clause 75. The base station of any of clauses 71 to 74, wherein the network node comprises: the UE, a sidelink UE in communication with the UE, or a perception-assistance node.

Clause 76. The base station of any of clauses 71 to 75, wherein the indication is received from the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 77. A user equipment (UE), comprising: means for determining a spatial region of interest for performing perception-based sensing operations with a base station over a wireless communication medium; and means for transmitting, to a network node, an indication for the base station to perform the perception-based sensing operations in the spatial region of interest.

Clause 78. The UE of clause 77, wherein the spatial region of interest is determined based on a determination that signal strength of reference signals received from the base station over the wireless communication medium is higher in the spatial region of interest than in other spatial regions.

Clause 79. The UE of clause 78, wherein the determination that the signal strength of the reference signals received from the base station is higher in the spatial region of interest is based on a channel estimate of the wireless communication medium.

Clause 80. The UE of any of clauses 77 to 79, wherein the spatial region of interest is determined based on perception information obtained by the UE.

Clause 81. The UE of clause 80, wherein the perception information comprises: motion sensor information of the UE, radar-based sensing information of the UE, lidar-based sensing information of the UE, images or video captured by one or more cameras of the UE, beamforming information of the UE, an orientation of the UE, a periodicity of movement of the UE, a channel estimate of the wireless communication medium, signal strengths of reference signals received on different receive beams, or any combination thereof.

Clause 82. The UE of any of clauses 77 to 81, wherein the spatial region of interest is within a beamspace of the UE.

Clause 83. The UE of any of clauses 77 to 82, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 84. The UE of any of clauses 77 to 83, wherein the UE comprises: an extended reality device, a virtual reality device, an augmented reality device, a gaming device, an Internet of Things (IoT) device, or a vehicle.

Clause 85. The UE of any of clauses 77 to 84, wherein the indication is transmitted to the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 86. A base station, comprising: means for receiving, from a network node, an indication for the base station to perform perception-based sensing operations in a spatial region of interest to a user equipment (UE); and means for performing the perception-based sensing operations in the spatial region of interest to the UE.

Clause 87. The base station of clause 86, wherein the spatial region of interest is within a beamspace of the UE.

Clause 88. The base station of any of clauses 86 to 87, wherein the means for performing the perception-based sensing operations comprises: means for performing a beam sweep within the spatial region of interest to the UE.

Clause 89. The base station of any of clauses 86 to 88, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 90. The base station of any of clauses 86 to 89, wherein the indication is received from the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 91. A non-transitory computer-readable medium storing computer-executable instructions that, when executed by a user equipment (UE), cause the UE to: determine that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning; and transmit, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

Clause 92. The non-transitory computer-readable medium of clause 91, wherein the determination that the perception-based approach to adaptive beam weight learning would provide improved performance of the wireless communication with the base station is based on perception information obtained by the UE.

Clause 93. The non-transitory computer-readable medium of clause 92, wherein the perception information comprises: motion sensor information of the UE, radar-based sensing information of the UE, lidar-based sensing information of the UE, images or video captured by one or more cameras of the UE, beamforming information of the UE, an orientation of the UE, a periodicity of movement of the UE, a channel estimate of the wireless communication medium, signal strengths of reference signals received on different receive beams, or any combination thereof.

Clause 94. The non-transitory computer-readable medium of any of clauses 91 to 93, further comprising computer-executable instructions that, when executed by the UE, cause the UE to: perform a perception-based adaptive beam weight learning procedure for the wireless communication with the base station.

Clause 95. The non-transitory computer-readable medium of clause 94, wherein the computer-executable instructions that, when executed by the UE, cause the UE to perform the perception-based adaptive beam weight learning procedure comprise computer-executable instructions that, when executed by the UE, cause the UE to: determine a direction of interest for the wireless communication with the base station based on perception information obtained by the UE; use a set of beam weights to sound the wireless communication medium in the direction of interest; measure signal strengths of reference signals transmitted by the base station on the wireless communication medium; and determine a subset of beam weights of the set of beam weights to use for the wireless communication with the based station over the wireless communication medium.

Clause 96. The non-transitory computer-readable medium of any of clauses 91 to 95, further comprising computer-executable instructions that, when executed by the UE, cause the UE to: determine that the perception-based approach to adaptive beam weight learning would no longer provide improved performance of the wireless communication with the base station over the wireless communication medium relative to the non-perception-based approaches to adaptive beam weight learning; and transmit, to the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

Clause 97. The non-transitory computer-readable medium of any of clauses 91 to 96, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 98. The non-transitory computer-readable medium of any of clauses 91 to 97, wherein the improved performance comprises: higher signal strength of a wireless channel between the UE and the base station, increased reliability of the wireless channel between the UE and the base station, or any combination thereof.

Clause 99. The non-transitory computer-readable medium of any of clauses 91 to 98, wherein the UE comprises: an extended reality device, a virtual reality device, an augmented reality device, a gaming device, an Internet of Things (IoT) device, or a vehicle.

Clause 100. The non-transitory computer-readable medium of any of clauses 91 to 99, wherein the indication is transmitted to the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 101. A non-transitory computer-readable medium storing computer-executable instructions that, when executed by a base station, cause the base station to: receive, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium; and perform a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

Clause 102. The non-transitory computer-readable medium of clause 101, wherein the computer-executable instructions that, when executed by the base station, cause the base station to perform the perception-based adaptive beam weight learning procedure comprise computer-executable instructions that, when executed by the base station, cause the base station to: determine a direction of interest for the wireless communication with the UE based on perception information obtained by the base station; use a set of beam weights to sound the wireless communication medium in the direction of interest; measure signal strengths of reference signals transmitted by the UE on the wireless communication medium; and determine a subset of beam weights of the set of beam weights to use for the wireless communication with the UE on the wireless communication medium.

Clause 103. The non-transitory computer-readable medium of clause 102, wherein the perception information comprises: radar-based sensing information of the base station, lidar-based sensing information of the base station, images or video captured by one or more cameras of the base station, beamforming information of the base station, signal strengths of reference signals received on different receive beams, a channel estimate of the wireless communication medium, or any combination thereof.

Clause 104. The non-transitory computer-readable medium of any of clauses 101 to 103, further comprising computer-executable instructions that, when executed by the base station, cause the base station to: receive, from the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the UE over the wireless communication medium; and cease to perform the perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

Clause 105. The non-transitory computer-readable medium of any of clauses 101 to 104, wherein the network node comprises: the UE, a sidelink UE in communication with the UE, or a perception-assistance node.

Clause 106. The non-transitory computer-readable medium of any of clauses 101 to 105, wherein the indication is received from the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 107. A non-transitory computer-readable medium storing computer-executable instructions that, when executed by a user equipment (UE), cause the UE to: determine a spatial region of interest for performing perception-based sensing operations with a base station over a wireless communication medium; and transmit, to a network node, an indication for the base station to perform the perception-based sensing operations in the spatial region of interest.

Clause 108. The non-transitory computer-readable medium of clause 107, wherein the spatial region of interest is determined based on a determination that signal strength of reference signals received from the base station over the wireless communication medium is higher in the spatial region of interest than in other spatial regions.

Clause 109. The non-transitory computer-readable medium of clause 108, wherein the determination that the signal strength of the reference signals received from the base station is higher in the spatial region of interest is based on a channel estimate of the wireless communication medium.

Clause 110. The non-transitory computer-readable medium of any of clauses 107 to 109, wherein the spatial region of interest is determined based on perception information obtained by the UE.

Clause 111. The non-transitory computer-readable medium of clause 110, wherein the perception information comprises: motion sensor information of the UE, radar-based sensing information of the UE, lidar-based sensing information of the UE, images or video captured by one or more cameras of the UE, beamforming information of the UE, an orientation of the UE, a periodicity of movement of the UE, a channel estimate of the wireless communication medium, signal strengths of reference signals received on different receive beams, or any combination thereof.

Clause 112. The non-transitory computer-readable medium of any of clauses 107 to 111, wherein the spatial region of interest is within a beamspace of the UE.

Clause 113. The non-transitory computer-readable medium of any of clauses 107 to 112, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 114. The non-transitory computer-readable medium of any of clauses 107 to 113, wherein the UE comprises: an extended reality device, a virtual reality device, an augmented reality device, a gaming device, an Internet of Things (IoT) device, or a vehicle.

Clause 115. The non-transitory computer-readable medium of any of clauses 107 to 114, wherein the indication is transmitted to the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Clause 116. A non-transitory computer-readable medium storing computer-executable instructions that, when executed by a base station, cause the base station to: receive, from a network node, an indication for the base station to perform perception-based sensing operations in a spatial region of interest to a user equipment (UE); and perform the perception-based sensing operations in the spatial region of interest to the UE.

Clause 117. The non-transitory computer-readable medium of clause 116, wherein the spatial region of interest is within a beamspace of the UE.

Clause 118. The non-transitory computer-readable medium of any of clauses 116 to 117, wherein the computer-executable instructions that, when executed by the base station, cause the base station to perform the perception-based sensing operations comprise computer-executable instructions that, when executed by the base station, cause the base station to: perform a beam sweep within the spatial region of interest to the UE.

Clause 119. The non-transitory computer-readable medium of any of clauses 116 to 118, wherein the network node comprises: a sidelink UE, a perception-assistance node, or the base station.

Clause 120. The non-transitory computer-readable medium of any of clauses 116 to 119, wherein the indication is received from the network node via: radio resource control (RRC) signaling, medium access control control element (MAC-CE) signaling, or uplink control information (UCI) signaling.

Those of skill in the art will appreciate that information and signals 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 above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

Further, those of skill in the art will appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the aspects disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

The various illustrative logical blocks, modules, and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an ASIC, a field-programmable gate array (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 conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, for example, a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The methods, sequences and/or algorithms described in connection with the aspects disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in random access memory (RAM), flash memory, read-only memory (ROM), erasable programmable ROM (EPROM), electrically erasable programmable ROM (EEPROM), registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An example storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal (e.g., UE). In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

In one or more example aspects, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. 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 medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

While the foregoing disclosure shows illustrative aspects of the disclosure, it should be noted that various changes and modifications could be made herein without departing from the scope of the disclosure as defined by the appended claims. The functions, steps and/or actions of the method claims in accordance with the aspects of the disclosure described herein need not be performed in any particular order. Furthermore, although elements of the disclosure may be described or claimed in the singular, the plural is contemplated unless limitation to the singular is explicitly stated.

What is claimed is:

1. A method of wireless communication performed by a user equipment (UE), comprising:
   determining that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning;
   transmitting, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium;
   determining that the perception-based approach to adaptive beam weight learning would no longer provide improved performance of the wireless communication with the base station over the wireless communication medium relative to the non-perception-based approaches to adaptive beam weight learning; and
   transmitting, to the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

2. The method of claim **1**, wherein the determination that the perception-based approach to adaptive beam weight learning would provide improved performance of the wireless communication with the base station is based on perception information obtained by the UE.

3. The method of claim **2**, wherein the perception information comprises:
   motion sensor information of the UE,
   radar-based sensing information of the UE,
   lidar-based sensing information of the UE,
   images or video captured by one or more cameras of the UE,
   beamforming information of the UE,
   an orientation of the UE,
   a periodicity of movement of the UE,
   a channel estimate of the wireless communication medium,
   signal strengths of reference signals received on different receive beams, or
   any combination thereof.

4. The method of claim **1**, further comprising:
   performing a perception-based adaptive beam weight learning procedure for the wireless communication with the base station.

5. The method of claim **4**, wherein performing the perception-based adaptive beam weight learning procedure comprises:
   determining a direction of interest for the wireless communication with the base station based on perception information obtained by the UE;
   using a set of beam weights to sound the wireless communication medium in the direction of interest;
   measuring signal strengths of reference signals transmitted by the base station on the wireless communication medium; and
   determining a subset of beam weights of the set of beam weights to use for the wireless communication with the based station over the wireless communication medium.

6. The method of claim **1**, wherein the network node comprises:
   a sidelink UE,
   a perception-assistance node, or
   the base station.

7. The method of claim **1**, wherein the improved performance comprises:
   higher signal strength of a wireless channel between the UE and the base station,
   increased reliability of the wireless channel between the UE and the base station, or
   any combination thereof.

8. The method of claim **1**, wherein the UE comprises:
   an extended reality device,
   a virtual reality device,
   an augmented reality device,
   a gaming device,
   an Internet of Things (IoT) device, or
   a vehicle.

9. The method of claim **1**, wherein the indication is transmitted to the network node via:
   radio resource control (RRC) signaling,
   medium access control control element (MAC-CE) signaling, or
   uplink control information (UCI) signaling.

10. A method of wireless communication performed by a base station, comprising:
   receiving, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium;
   performing a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium;
   receiving, from the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the UE over the wireless communication medium; and
   ceasing to perform the perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

11. The method of claim **10**, wherein performing the perception-based adaptive beam weight learning procedure comprises:
   determining a direction of interest for the wireless communication with the UE based on perception information obtained by the base station;
   using a set of beam weights to sound the wireless communication medium in the direction of interest;
   measuring signal strengths of reference signals transmitted by the UE on the wireless communication medium; and
   determining a subset of beam weights of the set of beam weights to use for the wireless communication with the UE on the wireless communication medium.

12. The method of claim 11, wherein the perception information comprises:
radar-based sensing information of the base station,
lidar-based sensing information of the base station,
images or video captured by one or more cameras of the base station,
beamforming information of the base station,
signal strengths of reference signals received on different receive beams,
a channel estimate of the wireless communication medium, or
any combination thereof.

13. The method of claim 10, wherein the network node comprises:
the UE,
a sidelink UE in communication with the UE, or
a perception-assistance node.

14. The method of claim 10, wherein the indication is received from the network node via:
radio resource control (RRC) signaling,
medium access control control element (MAC-CE) signaling, or
uplink control information (UCI) signaling.

15. A user equipment (UE), comprising:
a memory;
at least one transceiver; and
at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to:
determine that a perception-based approach to adaptive beam weight learning would provide improved performance of wireless communication with a base station over a wireless communication medium relative to non-perception-based approaches to adaptive beam weight learning;
transmit, via the at least one transceiver, to a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium;
determine that the perception-based approach to adaptive beam weight learning would no longer provide improved performance of the wireless communication with the base station over the wireless communication medium relative to the non-perception-based approaches to adaptive beam weight learning; and
transmit, via the at least one transceiver, to the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the base station over the wireless communication medium.

16. The UE of claim 15, wherein the at least one processor is further configured to:
perform a perception-based adaptive beam weight learning procedure for the wireless communication with the base station.

17. A base station, comprising:
a memory;
at least one transceiver; and
at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to:
receive, via the at least one transceiver, from a network node, an indication for the base station to perform perception-based adaptive beam weight learning procedures for wireless communication with a user equipment (UE) over a wireless communication medium;
perform a perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium;
receive, via the at least one transceiver, from the network node, an indication for the base station to cease performing the perception-based adaptive beam weight learning procedures for the wireless communication with the UE over the wireless communication medium; and
cease to perform the perception-based adaptive beam weight learning procedure for the wireless communication with the UE over the wireless communication medium.

18. The base station of claim 17, wherein the at least one processor configured to perform the perception-based adaptive beam weight learning procedure comprises the at least one processor configured to:
determine a direction of interest for the wireless communication with the UE based on perception information obtained by the base station;
use a set of beam weights to sound the wireless communication medium in the direction of interest;
measure signal strengths of reference signals transmitted by the UE on the wireless communication medium; and
determine a subset of beam weights of the set of beam weights to use for the wireless communication with the UE on the wireless communication medium.

* * * * *