



(51) International Patent Classification:

H04B 17/391 (2015.01) *H04W 16/18* (2009.01)
H04B 17/309 (2015.01)

(21) International Application Number:

PCT/IB2018/001272

(22) International Filing Date:

11 October 2018 (11.10.2018)

(25) Filing Language:

English

(26) Publication Language:

English

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(81) Designated States (*unless otherwise indicated, for every
kind of national protection available*): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every
kind of regional protection available*): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

(54) Title: SYSTEM AND METHOD FOR GENERATING A DIFFRACTION PATTERN IN ORDER TO OPTIMIZE SENSOR
LOCATION IN A 3D ENVIRONMENT

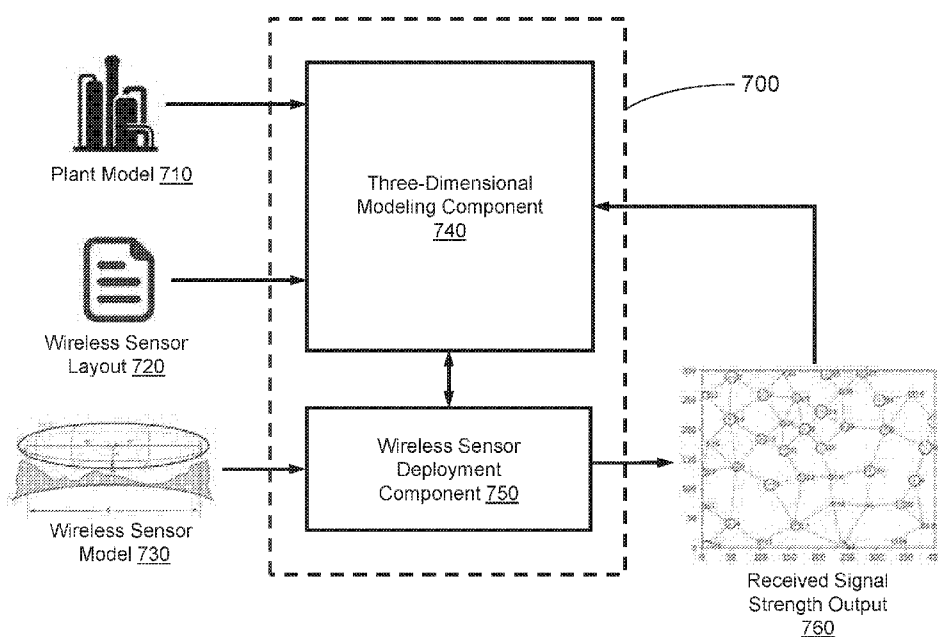


FIG. 7

(57) Abstract: A wireless sensor deployment component 750 determines a diffraction pattern for wireless signals propagating between various pairs of wireless sensors deployed in an environment, and determines accordingly the path loss to design an improved wireless network for the environment and subsequently deploy a plurality of wireless sensors that form the improved wireless network. For each Fresnel zone 210, a three-dimensional modeling component 740 determines which, if any, obstacles 110 in the environment 100 intersect Fresnel zone 210. For each intersecting obstacle 110Z, a three-dimensional modeling component 740 determines projection 550 of intersecting obstacle 110Z into diffraction plane 540, where diffraction plane 540 is perpendicular to line-of-sight 220. Once all projections 550 and their respective diffraction planes 540 are determined, wireless sensor deployment component 750 determines a

MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

SYSTEM AND METHOD FOR GENERATING A DIFFRACTION PATTERN IN
ORDER TO OPTIMIZE SENSOR LOCATION IN A 3D ENVIRONMENT

Technical Field

[0001] The present disclosure relates generally to determining path loss between a transmitter and a receiver. In some embodiments, the path loss is determined using a Fresnel diffraction formula and three-dimensional models of each obstacle disposed between the transmitter and the receiver to improve deployment of a wireless sensor network in a metal-rich environment.

Description of Related Art

[0002] Modern industrial environments, such as, but not limited to, manufacturing plants, oil refineries, etc., require reliable wireless networks. Such industrial environments are typically considered harsh environments for wireless networks due to a large amount of metal and/or concrete structures that typically absorb, and thus attenuate, and interfere with wireless signals (e.g., radio frequency (RF) signals, etc.) transmitted between a wireless transmitter and a wireless receiver, or between wireless sensors, for example, when transmit and receive functions are combined in a single sensor device. Improper deployment of these wireless sensors in the industrial environment impacts a reliability of communications between wireless sensors, and hence, an overall reliability of the wireless network.

[0003] Propagation of wireless signals, including RF signals, in free space is well understood and described by various known theoretical equations and approximated by various empirical formulas. However, due to complexities in resolving boundary conditions, obstacles in the industrial environment are typically approximated as one-dimensional geometries when determining attenuation of wireless signals propagating in the industrial

environment. Conventional techniques model obstacles in a path of propagating signals using a so-called “knife edge diffraction” model from the Fresnel-Kirchhoff diffraction formula in order to approximate signal loss, or path loss, due to diffraction caused by the obstacles. See e.g., Jacques Deygout, “Multiple Knife-Edge Diffraction of Microwaves,” *IEEE Trans. Antennas Propagation*, vol. AP-14, no. 4, 480, 1966; Carlos Lopez Giovaneli, “An Analysis of Simplified Solutions for Multiple Knife-Edge Diffraction,” *IEEE Trans. Antennas Propagation*, vol. AP-32, no. 3, 297, 1984. However, these techniques tend to over simplify models of the obstacles, thereby causing degradations in accuracy of any analysis or quantitative computation.

[0004] Today, many industrial environments have their structure and equipment layouts digitized and stored as computerized three-dimensional “3D” models. With such 3D models, various geometric information between any two points in the industrial environment, such as the distance between the two points, any structures and/or equipment (i.e., “obstacles”) that block a line-of-sight (LOS) between the two points, the shape, dimension, orientation, and location of these obstacles, etc., may be accurately extracted for subsequent analysis. In some instances, 3D models of the obstacles have been used to estimate signal loss using improved approximations over conventional knife edge diffraction techniques. See e.g., Stefano Savazzi, *et al.*, “Wireless Sensor Network Modeling and Deployment Challenges in Oil and Gas Refinery Plants,” *Int. J. Distributed Sensor Networks*, vol. 2013, article ID 383168. However, these techniques still oversimplify the effects of the obstacles on the wireless signals propagating between wireless sensors in the wireless network.

Brief Summary of the Disclosure

[0005] In some embodiments of the disclosure, a method comprises: receiving a three-dimensional model of an environment, wherein the three-dimensional model comprises an obstacle model and an obstacle location for each of a plurality of obstacles in the environment; receiving a wireless sensor layout for the environment, wherein the wireless sensor layout comprises a sensor location and sensor parameters for each of plurality

of wireless sensors for the environment; generating a diffraction pattern at a wireless receiver for a wireless transmitter, wherein the wireless transmitter and the wireless receiver are each wireless sensors included among the plurality of wireless sensors; and adjusting the sensor location in the wireless sensor layout of either the wireless transmitter or the wireless receiver based on the diffraction pattern. In some embodiments, the generating the diffraction pattern comprises: determining a line-of-sight between a sensor location of the wireless receiver and a sensor location of the wireless transmitter; generating a Fresnel zone using the line of sight, the sensor location of the wireless transmitter, the sensor location of the wireless receiver, and a frequency or wavelength of the wireless transmitter; determining an interfering obstacle, from among the plurality of obstacles, that intersects the Fresnel zone based on the obstacle model and the obstacle location of each of the plurality of obstacles; generating, using the obstacle model and the obstacle location of the interfering obstacle, a two-dimensional projection of the interfering obstacle onto a diffraction plane that is between the wireless transmitter and the wireless receiver and that is perpendicular to the line-of-sight; and generating, using Fresnel diffraction and the two-dimensional projection of the interfering obstacle, the diffraction pattern at the wireless receiver.

[0006] In some embodiments of the disclosure, generating a diffraction pattern at a wireless receiver for a wireless transmitter comprises generating a diffraction pattern for each pair of wireless sensors among the plurality of wireless sensors in the wireless sensor layout.

[0007] In some embodiments of the disclosure, determining an interfering obstacle that intersects the Fresnel zone comprises determining a plurality of interfering obstacles that intersect the Fresnel zone, each of the plurality of interfering obstacles among the plurality of obstacles.

[0008] In some embodiments of the disclosure, generating a two-dimensional projection of the interfering obstacle onto a diffraction plane that is perpendicular to the line-of-sight comprises generating a two-dimensional projection onto a respective diffraction plane for each of the plurality of interfering obstacles.

[0009] In some embodiments of the disclosure, generating a two-dimensional

projection of the interfering obstacle onto a diffraction plane that is perpendicular to the line-of-sight comprises generating a two-dimensional projection of the interfering obstacle onto the diffraction plane that is perpendicular to the line-of-sight, wherein the diffraction plane includes a location of a center of mass of the interfering obstacle.

[0010] Some embodiments of the disclosure further comprise generating a three-dimensional rendering of the three-dimensional model of the environment, wherein the rendering comprises either a Fresnel zone between the wireless transmitter and the wireless receiver or the line-of-sight between the wireless transmitter and the wireless receiver.

[0011] In some embodiments of the disclosure, the rendering comprises both the Fresnel zone and the line-of-sight.

[0012] In some embodiments of the disclosure, the rendering further comprises information regarding a strength or relative strength of wireless signals received at the wireless receiver.

[0013] In some embodiments of the disclosure, the rendering further comprises information regarding a strength or relative strength of a connection between the wireless transmitter and the wireless receiver.

[0014] Some embodiments of the disclosure comprise a computing processor configured to implement various aspects of the disclosure.

Brief Description of the Drawings

[0015] The present disclosure, in accordance with one or more various embodiments, is described in detail with reference to the following figures. The figures are provided for purposes of illustration only and merely depict typical or example embodiments.

[0016] FIG. 1 illustrates an example industrial environment in which a wireless network is deployed (or to be deployed) in accordance with various embodiments of the present disclosure.

[0017] FIG. 2 illustrates an example pair of wireless sensors of a wireless network in an industrial environment with an interfering obstacle disposed between them in accordance with various embodiments of the present disclosure.

[0018] FIG. 3A illustrates a geometry with a single obstacle (i.e., blockage) useful for discussing Fresnel diffraction in accordance with various embodiments of the present disclosure.

[0019] FIG. 3B illustrates a geometry with multiple obstacles (i.e., blockages) useful for discussing Fresnel diffraction in accordance with various embodiments of the present disclosure.

[0020] FIG. 3C illustrates an annotated geometry with multiple obstacles useful for discussing Fresnel diffraction in accordance with various embodiments of the present disclosure.

[0021] FIG. 4 illustrates a computational flowchart for determining an attenuation pattern at a wireless receiver with multiple obstacles (i.e., blockages) disposed along a line-of-sight from a wireless transmitter in accordance with various embodiments of the present disclosure.

[0022] FIG. 5A illustrates a two-dimensional representation of an arbitrary three-dimensional obstacle in accordance with conventional embodiments.

[0023] FIG. 5B illustrates a two-dimensional representation of an arbitrary three-dimensional obstacle in accordance with various embodiments of the present disclosure.

[0024] FIG. 6A illustrates a line-of-sight perspective of a Fresnel zone for an example pair of wireless sensors with an interfering obstacle disposed between them in accordance with various embodiments of the present disclosure.

[0025] FIG. 6B illustrates a projection of an interfering obstacle in a diffraction plane in accordance with various embodiments of the present disclosure.

[0026] FIG. 6C illustrates a line-of-sight perspective of a Fresnel zone for an example pair of wireless sensors with an interfering obstacle disposed between them, wherein the

interfering obstacle is offset from a line-of-sight, in accordance with various embodiments of the present disclosure.

[0027] FIG. 6D illustrates a projection of an interfering obstacle in a diffraction plane, where the interfering obstacle is offset from a line-of-sight, in accordance with various embodiments of the present disclosure.

[0028] FIG. 7 is a functional block diagram illustrating a system useful for determining path loss between wireless sensors in an industrial environment in accordance with various embodiments of the present disclosure.

[0029] FIG. 8 illustrates an operation of various embodiments of the present disclosure.

[0030] FIG. 9 illustrates various aspects of an operation of various embodiments of the present disclosure in further detail.

[0031] FIG. 10 illustrates a rendering of obstacles and Fresnel zones between various pairs of wireless sensors in an industrial environment in accordance with various embodiments of the present disclosure.

[0032] FIG. 11 is an example computing component that may be used to implement various features of embodiments described in the present disclosure.

[0033] The figures are not exhaustive and do not limit the present disclosure to the precise form disclosed.

Detailed Description

[0034] Various embodiments of the present disclosure are directed to determining path loss, or signal loss, of wireless signals propagating between various pairs of wireless sensors deployed (actual or planned) in an industrial environment. Such path loss between a transmitting wireless sensor and a receiving wireless sensor are caused by two primary factors: 1) a propagation loss caused by free space expansion of a wavefront of the wireless signals; and 2) an absorption and/or scatter loss caused by the obstacles absorbing and/or

scattering the wireless signals. In some embodiments, determination of the path loss may be used to design an improved wireless network for the industrial environment and subsequently deploy a plurality of wireless sensors that form the improved wireless network in the industrial environment. Significant costs savings and increased network reliability may be achieved by designing the wireless network in advance of deployment rather than by trial-and-error on-site.

[0035] FIG. 1 illustrates an example industrial environment 100 in which a wireless network is deployed (or to be deployed) in accordance with various embodiments of the present disclosure. While this disclosure refers to industrial environment 100 as being “industrial,” industrial environment 100 is not intended to be so limited; in fact, industrial environment 100 may include any obstacle-rich environment in which the wireless network is deployed (or to be deployed), such as, but not limited to, an urban environment, an office environment, a home environment, a manufacturing environment, or any other interior or exterior obstacle-rich environment. Industrial environment 100 includes various structures, equipment or other components that may occur in such corresponding environment and are collectively referred to herein as obstacles 110 (illustrated as various three-dimensional shapes in FIG. 1, including an obstacle 110A, an obstacle 110B, an obstacle 110C, and an obstacle 110D specifically, as well as other obstacles generally). Industrial environment 100 includes various wireless sensors 120 (illustrated as “stars” in FIG. 1, including a wireless sensor 120A, a wireless sensor 120B, a wireless sensor 120C, and a wireless sensor 120D specifically, as well as other wireless sensors generally). Wireless sensors 120 are deployed (either actual or planned) throughout industrial environment 100; and collectively, wireless sensors 120, along with other equipment not otherwise illustrated, form a wireless network 130. While wireless sensors 120 are depicted in FIG.1 as being mounted on obstacles 110 (e.g., wireless sensor 120A is mounted on obstacle 110A, etc.), other locations for mounting wireless sensors 120 may be used. In various embodiments of this disclosure, wireless sensors 120 are communications devices configured to both transmit and receive wireless signals. In the description below, a particular wireless sensor 120 may be described as a

wireless transmitter 120 when transmitting wireless signals while another wireless sensor 120 may be described as a wireless receiver 120 when receiving wireless signals.

[0036] FIG. 2 illustrates an example pair of wireless sensors 120 (illustrated as a wireless sensor 120T_x mounted on an obstacle 110X (or any other mounting point) and a wireless sensor 120R_x mounted on an obstacle 110Y (or any other mounting point)) of wireless network 130 in industrial environment 100 with an interfering obstacle 110Z disposed between them 120T_x, 120R_x in accordance with various embodiments of the present disclosure. For purposes of this disclosure, wireless sensor 120T_x is referred to as wireless transmitter 120T_x, and wireless sensor 120R_x is referred to as wireless receiver 120R_x. As illustrated in FIG. 2, a Fresnel zone 210 is depicted between wireless transmitter 120T_x and wireless receiver 120R_x. Fresnel zone 210 is a prolate spheroid-shaped (i.e., an ellipsoid of revolution) region in space, centered around a line-of-sight “LOS” 220 between wireless transmitter 120T_x and wireless receiver 120R_x. Fresnel zone 210 is a construct used to generally characterize propagation of electromagnetic waves, such as wireless signals, between wireless transmitter 120T_x and wireless receiver 120R_x; and more specifically, to aid in calculation of an impact on the wireless signals of obstacles 110 occurring within Fresnel zone 210.

[0037] FIG. 3A illustrates a geometry 300A with a single obstacle useful for discussing Fresnel diffraction in accordance with various embodiments of the present disclosure. Geometry 300A includes wireless transmitter 120T_x and a two-dimensional blockage 310 (i.e., a two-dimensional representation of the obstacle) disposed in a diffraction plane 330 at a distance d_1 from wireless transmitter 120T_x and along line-of-sight 220, where diffraction plane 330 is perpendicular to line-of-sight 220. For purposes of this description, wireless transmitter 120T_x is considered to be a point source transmitter of wireless signals. A Fresnel diffraction formula describes an impact of blockage 310 on wireless signals propagating from wireless transmitter 120T_x when they reach an observation plane 340 at a distance d_2 from diffraction plane 330 perpendicular to and along line-of-sight 220. More specifically, the Fresnel diffraction formula describes a diffraction pattern 350 in observation plane 340

caused by blockage 310 impacting wireless signals propagating from wireless transmitter 120T_x. The Fresnel diffraction formula is expressed as:

$$U(x, y) = i \frac{ae^{ik(d_1+d_2)}}{\lambda \cdot d_1 \cdot d_2} \iint A(x', y') \exp \left\{ -ik \frac{d_1 + d_2}{2d_1 d_2} [(x - x')^2 + (y - y')^2] \right\} dx' dy' \quad (1)$$

where $U(x, y)$ is a complex amplitude of a wavefront at observation plane 340; $A(x', y')$ is an area in diffraction plane 330 including blockage 310; d_1 is a distance between wireless transmitter 120T_x and diffraction plane 330; d_2 is a distance between diffraction plane 330 and observation plane 340; a is a constant representing an amplitude of an initial wavefront; and λ and k are a wavelength and an angular wavenumber ($k = 2\pi / \lambda$) of the wireless signal, respectively.

[0038] FIG. 3B illustrates a geometry 300B with multiple obstacles useful for describing Fresnel diffraction in accordance with various embodiments of the present disclosure. Geometry 300B includes multiple two-dimensional blockages 310B (illustrated in FIG. 3B as a blockage 310B₁, a blockage 310B₂, and a blockage 310B₃) each disposed in a respective diffraction plane 330B (illustrated in FIG. 3B as a diffraction plane 330B₁, a diffraction plane 330B₂, and a diffraction plane 330B₃) perpendicular to and along line-of-sight 220. When multiple blockages 310B exist between wireless transmitter 120T_x and wireless receiver 120R_x along line-of-sight 220, each blockage 310B is described as a two-dimensional attenuation pattern that generates diffractions of the incident wavefront at the corresponding diffraction plane 330B perpendicular to line-of-sight 220. A total attenuation experienced by wireless signals propagating from wireless transmitter 120T_x to wireless receiver 120R_x in the presence of blockages 310B may be determined by combining all attenuations from consecutive planes by applying the Fresnel Diffraction formula from each plane to the next.

[0039] FIG. 3C illustrates an annotated geometry 300C, which is a version of geometry 300B annotated with various path intervals 350, 370 useful for describing propagation of wireless signals from wireless transmitter 120T_x to wireless receiver 120R_x,

where multiple blockages 310 are disposed between them in their respective diffraction planes 330 along line-of-sight 220, in accordance with various embodiments of the present disclosure.

[0040] Referring to FIG. 3C, during a path interval 350 along line-of-sight 220 between wireless transmitter 120T_x and a first blockage 310B₁, wireless signals propagate in free space according to the following Equation (2):

$$U(r) = \frac{a \cdot e^{-ikr}}{r} \quad (2)$$

where

$$r^2 = x_1^2 + y_1^2 + z_1^2 \quad (3)$$

and

$$U_1(x_1, y_1, z_1) = \frac{a \cdot e^{-ik\sqrt{x_1^2 + y_1^2 + z_1^2}}}{\sqrt{x_1^2 + y_1^2 + z_1^2}} \quad (4)$$

[0041] At plane 330B₁, wireless signals experience attenuation due to first blockage 310B₁ absorbing such wireless signals according to the following Equation (5):

$$U'_i(x_i, y_i, z_i) = U_i(x_i, y_i, z_i) \cdot a_i(x_i, y_i) \quad (5)$$

where $i = 1$.

[0042] During a path interval 370A along line-of-sight 220 between first blockage 310B₁ and a second blockage 310B₂, wireless signals are impacted by Fresnel diffraction caused by first blockage 310B₁ according to the following modified form of Fresnel Diffraction in Equation (6):

$$\mathcal{D}\{U, z\} \equiv -\frac{e^{ikz}}{i\lambda z} \iint U(x', y', 0) \exp\left\{\frac{-ik}{2z}[(x-x')^2 + (y-y')^2]\right\} dx' dy' \quad (6)$$

where $U(x', y', 0)$ represent an initial wavefront and z is a propagation distance.

[0043] At plane 330B₂, wireless signals experience attenuation from second blockage 310B₂ absorbing the wireless signals according to Equation (5), where $i = 2$. During a path

interval 370B along line-of-sight 220 between second blockage 310B₂ and a third blockage 310B₃, wireless signals are further impacted by Fresnel diffraction caused by second blockage 310B₂ according to Equation (6).

[0044] With each additional blockage 310B_i, wireless signals experience attenuation (expressed by Equation (5)) followed by Fresnel diffraction (expressed by Equation (6)). These two equations may be iteratively applied as described above for each additional blockage 310B_i along line-of-sight 220 in order to determine the diffraction pattern in the observation plane of wireless receiver 120R_x.

[0045] FIG. 4 illustrates a computational flowchart 400 for determining a diffraction pattern in an observation plane at wireless receiver 120R_x as a result of multiple obstacles 310 (i.e., blockages) disposed along a line-of-sight 220 from wireless transmitter 120T_x in accordance with various embodiments of the present disclosure. In operation 410, when wireless signals are propagating in free space along line-of-sight 220 during interval 350, Equation (2) is evaluated. In operation 420, when wireless signals experience attenuation caused by the ith-blockage (e.g., blockage 310B_i), Equation (5) is evaluated. In operation 430, when wireless signals are impacted by Fresnel diffraction caused by the ith-blockage, Equation (6) is evaluated. As illustrated, Equation (5) and Equation (6) are iteratively evaluated for each blockage 310B_i along line-of-sight 220. In operation 440, the final diffraction pattern determined in operation 430 is evaluated at the observation plane at wireless receiver 120R_x. In some embodiments, the final diffraction pattern at the observation plane with blockages 310 may be normalized with free space propagation as:

$$attenuation(x, y) = 20 \log_{10} \left| \frac{U(x, y, z)}{U_{free}(x, y, z)} \right|, \quad (7)$$

where $U(x, y, z)$ is the complex amplitude considering blockages 310 and $U_{free}(x, y, z)$ is the complex amplitude of free space propagation of the wireless signals without any blockages 310.

[0046] In some embodiments, a total signal strength of wireless signals received at wireless receiver 120R_x (i.e., RSS) from wireless transmitter 120T_x may be expressed (in dB) as:

$$RSS|_{dB} = g_0 - 20\log_{10}\left(\frac{1+d}{d_0}\right) - \sigma, \quad (8)$$

where g_0 is a channel gain function of the transmit power measured at a reference distance d_0 (typically d_0 is set at 2m, though other values may be used). The logarithm term in equation (8) is the propagation losses experienced by the wireless signals; and σ is the attenuation experienced by the wireless signals from the absorption losses.

[0047] The description above with regard to FIG. 3A, FIG. 3B, and FIG. 3C referenced two-dimensional blockages 310 disposed along line-of-sight 220. However, obstacles 110 occurring between wireless sensors in industrial environment 100 are not typically “two-dimensional.” According to various embodiments of the present disclosure, three-dimensional obstacles 110 are approximated as two-dimensional blockages 310 in order to determine diffraction patterns using Equation (5) and Equation (6).

[0048] Some conventional solutions approximate a three-dimensional obstacle as a two-dimensional blockage by determining a cross-section of the three-dimensional obstacle at a center of mass (or center of volume) of the obstacle, and subsequently use this cross-section as the two-dimensional blockage. However, this cross-section approximation is inadequate for irregularly-shaped objects in occurring in a line-of-sight path between a pair of wireless sensors as would typically be found in most industrial environments 100. FIG. 5A illustrates a two-dimensional representation 530 of an arbitrary three-dimensional obstacle 510 (illustrated in FIG. 5A as a three-sided pyramid 510) in accordance with conventional techniques. In FIG. 5A, two-dimensional representation 530 is determined as a cross-section 530 of obstacle 510 at a plane 520 located at a center of mass of obstacle 510. FIG. 5B illustrates a two-dimensional representation 550 of three-dimensional obstacle 510 in accordance with various embodiments of the present disclosure. In FIG. 5B, two-dimensional

representation 550 is determined as a projection 550 of obstacle 510 into plane 540 perpendicular to line-of-sight 220. As illustrated in FIG. 5A and 5B, projection 550 is substantially larger than cross-section 530, because projection 550 more accurately represents three-dimensional obstacle 510 than does cross-section 530.

[0049] Once projection 550 is determined, a location of plane 540 along line-of-sight 220 may be determined. Projection 550 and plane 540 correspond to blockage 310 and diffraction plane 330, respectively, for purposes of evaluating Fresnel diffraction as described above. In some embodiments, plane 540 may be located along line-of-sight 220 corresponding to a point on obstacle 510 nearest to wireless transmitter 120T_x. In some embodiments, plane 540 may be located along line-of-sight 220 corresponding to a point on obstacle 510 farthest from wireless transmitter 120T_x. In some embodiments, plane 540 may be located along line-of-sight 220 corresponding to an average of the points on obstacle 510 that are nearest to and farthest from wireless transmitter 120T_x. In some embodiments, plane 540 may be located along line-of-sight 220 corresponding to a center of mass or a center of volume of obstacle 510. In some embodiments, plane 540 may be located along line-of-sight 220 anywhere between points on obstacle 510 that are nearest to and farthest from wireless transmitter 120T_x.

[0050] Referring back to FIG. 2, according to various embodiments of the present disclosure, those obstacles 110 (e.g., obstacle 110Z) that intersect Fresnel zone 210 constructed around line-of-sight 220 between wireless transmitter 120T_x and wireless receiver 120R_x are approximated as projections 550 in planes 540 and located along line-of-sight 220.

[0051] FIG. 6A illustrates the example pair of wireless sensors 120T_x, 120R_x with an interfering obstacle 110Z disposed between them 120T_x, 120R_x as illustrated in FIG. 2 from a perspective viewing down line-of-sight 220 from wireless transmitter 120T_x (not illustrated in FIG. 6A) toward wireless receiver 120R_x in accordance with various embodiments of the present disclosure. As illustrated in FIG. 6A, interfering obstacle 110Z completely occludes both obstacle 110Y and wireless transmitter 120R_x. (Wireless transmitter 120R_x is illustrated

in FIG. 6A as a white star to indicate its presence, albeit obscured, behind interfering obstacle 110Z.) As also illustrated in FIG. 6A, interfering obstacle 110Z intersects Fresnel zone 210.

[0052] FIG. 6B illustrates a projection 550B, into diffraction plane 540, of interfering obstacle 110Z that intersects Fresnel zone 210 in accordance with various embodiments of the present disclosure. As discussed above, that portion of obstacle 110Z that intersects Fresnel zone 210 is projected into diffraction plane 540, which is a plane perpendicular to line-of-sight 220, to determine projection 550B. As also discussed above, projection 550B may be used as a two-dimensional blockage 310 for purposes of evaluating Fresnel diffraction in accordance with various embodiments of the present disclosure.

[0053] FIG. 6C illustrates the example pair of wireless sensors 120T_x, 120R_x with an interfering obstacle 110Z disposed between them 120T_x, 120R_x as illustrated in FIG. 2 from a perspective viewing down line-of-sight 220 from wireless transmitter 120T_x (not illustrated in FIG. 6A) toward wireless receiver 120R_x in accordance with various embodiments of the present disclosure. As illustrated in FIG. 6C, interfering obstacle 110Z is offset from line-of-sight 220 and thus, only partially occludes obstacle 110Y. As also illustrated in FIG. 6C, even though interfering obstacle 110Z only partially occludes obstacle 110 and doesn't occlude wireless receiver 120R_x at all, interfering obstacle 110Z still intersects Fresnel zone 210.

[0054] FIG. 6D illustrates a projection 550D, into diffraction plane 540, of interfering obstacle 110Z that intersects Fresnel zone 210 in accordance with various embodiments of the present disclosure. As discussed above, that portion of obstacle 110Z that intersects Fresnel zone 210 is projected into diffraction plane 540, which is a plane perpendicular to line-of-sight 220, to determine projection 550D. Again, projection 550D may be used as a two-dimensional blockage 310 for purposes of evaluating Fresnel diffraction in accordance with various embodiments of the present disclosure.

[0055] FIG. 7 is a functional block diagram illustrating a system 700 useful for determining path loss between wireless sensors 120 in an industrial environment 100 in accordance with various embodiments of the present disclosure. In some embodiments, system 100 includes a three-dimensional modeling component 740 and a wireless sensor

deployment component 750. In some embodiments, three-dimensional modeling component 740 and wireless sensor deployment component 750 may be integrated as a single system. In some embodiments, three-dimensional modeling component 740 and wireless sensor deployment component 750 are separate systems, for example, when three-dimensional modeling component 740 is a consumer-off-the-self modeling component, such as, but not limited to, SolidWorks® 3D CAD Software available from Dassault Systèmes.

[0056] Three-dimensional modeling component 740 receives a plant model 710 and a wireless sensor layout 720. Plant model 710 includes three-dimensional models of various structures and equipment, and their respective locations, within industrial environment 100. In some embodiments, plant model 710 includes sufficient information such that a distance and direction between any two points in industrial environment 100 may be determined. In some embodiments, plant model 710 includes a shape, a dimension, an orientation, and a location for each obstacle 110 in industrial environment 100; in some embodiments, the shape, dimension, orientation, and/or location are expressed in three dimensions.

[0057] Wireless sensor layout 720 includes a location of each wireless sensor 120 of wireless network 130 in industrial environment 100; in some embodiments, the sensor location is expressed in three dimensions. In some embodiments, wireless sensor layout 720 corresponds to an existing layout of wireless sensors 120 in industrial environment 100. In some embodiments, wireless sensor layout 720 corresponds to an initial plan for a layout of wireless sensors 120 in industrial environment 100. In some embodiments, a user may use three-dimensional modeling component 740 to enter and position wireless sensors 120 in plant model 710 of industrial environment 100, for example, via a three-dimensional graphical user interface of three-dimensional modeling component 740.

[0058] With plant model 710 and wireless sensor layout 720, three-dimensional modeling component 740 may determine relative positions between various pairs of wireless sensors 120 in industrial environment 100. In some embodiments, three-dimensional modeling component 740 may determine a line-of-sight 220 between various pairs of wireless sensors 120. In some embodiments, three-dimensional modeling component 740 may

determine a line-of-sight 220 between each pair of wireless sensors 120. In some embodiments, three-dimensional modeling component 740 provides this information to wireless sensor deployment component 750.

[0059] Wireless sensor deployment component 750 receives a sensor model 730 for various ones of wireless sensors 120 deployed, or to be deployed, as wireless network 130 in industrial environment 100. In some embodiments, sensor model 730 includes an operational frequency (or wavelength) and a power level of each wireless sensor 120 in wireless network. In some embodiments, wireless sensor deployment component 750 determines a Fresnel zone 210 for each line-of-sight 220 determined by three-dimensional modeling component 740.

[0060] In some embodiments, for each Fresnel zone 210, three-dimensional modeling component 740 determines which, if any, obstacles 110 in industrial environment 100 intersect Fresnel zone 210. For each intersecting obstacle 110Z, three-dimensional modeling component 740 determines projection 550 of intersecting obstacle 110Z into diffraction plane 540, where diffraction plane 540 is perpendicular to line-of-sight 220. Once all projections 550 and their respective diffraction planes 540 are determined, wireless sensor deployment component 750 determines a quantitative diffraction pattern at wireless receiver 120R_x using projection(s) 550 lying along line-of-sight 220 as described above.

[0061] In some embodiments, wireless sensor deployment component 750 determines a diffraction pattern for various pairs of wireless sensors 120 as described above. In some embodiments, wireless sensor deployment component 750 determines the diffraction pattern for each pair of wireless sensors 120 in wireless network 130 as described above. In some embodiments, wireless sensor deployment component 750 provides the diffractions patterns to three-dimensional modeling component 740 for subsequent display to a user, for example, in a three-dimensional rendering of industrial environment 100.

[0062] In some embodiments, wireless sensor deployment component 750 determines a received signal strength (RSS) 760 for various pairs of wireless sensors 120 as described above. In some embodiments, wireless sensor deployment component 750

determines the received signal strength 760 for each pair of wireless sensors 120 in wireless network 130 as described above. In some embodiments, wireless sensor deployment component 750 provides received signal strength 760 to three-dimensional modeling component 740 for subsequent display to the user, for example, in a three-dimensional rendering of industrial environment 100.

[0063] In some embodiments, a connection between given pairs of wireless sensors 120 may be categorized based on received signal strength 760. For example, in some embodiments, connections may be characterized, for example when channel gain function of the transmit power measured at a reference distance, g_0 , is -47dBm, as: 1) an excellent connection when RSS is > -75 dBm; 2) a good connection when RSS is between -80 to -75 dBm; a poor connection when RSS is between -85 to -80 dBm; and a bad connection when RSS is < -85 dBm. Other categories, descriptors, and/or received signal strength boundaries may be used as would be appreciated.

[0064] In some embodiments, three-dimensional modeling component 740 displays a three-dimensional rendering of industrial environment 100 that provides information regarding received signal strength 760 for various pairs of wireless sensors 120. For example, FIG. 10 illustrates a rendering 1000 of obstacles 110 and Fresnel zones 1010 between various pairs of sensors 120 in industrial environment 100. Fresnel zones 1010 may provide a user with some relative understanding or appreciation of an impact of various obstacles 110 on locations of wireless sensors 120. In some embodiments, line-of-sight 220 may be rendered instead of, or in addition to, Fresnel zones 1010. In some embodiments, Fresnel zones 1010 may be color-coded to indicate a relative strength of wireless signals received at wireless receiver 120R_x. In some embodiments, Fresnel zones 1010 (and/or lines-of-sight 220) may be annotated to indicate a received signal strength of wireless signals received at wireless receiver 120R_x. As would be appreciated, a user may subsequently use rendering 1000 to relocate or reposition various wireless sensors 120 to improve communications between various pairs of wireless sensors 120 and/or an overall reliability of wireless network 130.

[0065] In some embodiments, after any relocating or repositioning of wireless sensors 120, updated locations of wireless sensors 120 may be generated as a wireless sensor layout. This wireless sensor layout may subsequently be used on-site at industrial environment 100 to deploy wireless sensors 120 as would be appreciated.

[0066] FIG. 8 illustrates an operation 800 of various embodiments of the present disclosure. In an operation 810, system 700 receives a three-dimensional model (e.g., plant model 710) of industrial environment 100. In some embodiments, three-dimensional model includes a three-dimensional obstacle model and a three dimensional obstacle location for each obstacle 110 in industrial environment 100.

[0067] In an operation 820, system 700 receives a sensor location and sensor parameters for each wireless sensor 120 in industrial environment 100. In some embodiments, three-dimensional modeling component 740 receives the sensor locations and wireless sensor deployment component 750 receives the sensor parameters.

[0068] In an operation 830, system 700 generates a diffraction pattern at wireless receiver 120R_x of wireless signals propagating from wireless transmitter 120T_x based on the respective locations of wireless transmitter 120T_x and wireless receiver 120R_x, the sensor parameters, and any obstacles located between wireless transmitter 120T_x and wireless receiver 120R_x. FIG. 9 illustrates various aspects of operation 830 in further detail.

[0069] In an operation 910, system 700 determines line-of-sight 220 between the sensor location of wireless transmitter 120T_x and the sensor location of wireless receiver 120R_x. In an operation 920, system 700 determines Fresnel zone 210 using line-of-sight 220, the sensor locations of wireless transmitter 120T_x and wireless receiver 120R_x, and the sensor parameters of wireless transmitter 120T_x. In an operation 930, system 700 determines which, if any, obstacles 110 intersect Fresnel zone 210 based on the respective obstacle model(s) and obstacle location(s). In an operation 940, system 700 generates two-dimensional projection 550 of intersecting obstacle 110Z onto diffraction plane 540, where diffraction plane 540 is perpendicular to line-of-sight 220. In an operation 950, system 700 generates

the diffraction pattern at wireless receiver 120R_x using Fresnel diffraction (e.g., operation 400) and two-dimensional projection 550.

[0070] Returning to FIG. 8, in an operation 840, system 700 adjusts the sensor location of either wireless transmitter 120T_x or wireless receiver 120R_x based on the diffraction pattern.

[0071] As used herein, the term “component” may describe a given unit of functionality that may be performed in accordance with one or more embodiments of the present application. As used herein, a component may be implemented utilizing any form of hardware, software, or a combination thereof. For example, one or more processors, controllers, ASICs, PLAs, PALs, CPLDs, FPGAs, logical components, software routines or other mechanisms may be implemented to make up a component. Various components described herein may be implemented as discrete components or described functions and features may be shared in part or in total among one or more components. In other words, as would be apparent to one of ordinary skill in the art after reading this description, the various features and functionality described herein may be implemented in any given application. They may be implemented in one or more separate or shared components in various combinations and permutations. Although various features or functional elements may be individually described or claimed as separate components, it should be understood that these features/functionality may be shared among one or more common software and hardware elements. Such a description shall not require or imply that separate hardware or software components are used to implement such features or functionality.

[0072] Where components are implemented in whole or in part using software, these software elements may be implemented to operate with a computing or processing component capable of carrying out the functionality described with respect thereto. One such example computing component is illustrated in FIG. 11. Various embodiments are described in terms of this example-computing component 1100. After reading this description, it will become apparent to a person skilled in the relevant art how to implement the application using other computing components or architectures.

[0073] Referring now to FIG. 11, computing component 1100 may represent, for example, computing or processing capabilities found within computer processing units or any other type of special-purpose or general-purpose computing devices as may be desirable or appropriate for a given application or environment. Computing component 1100 may also represent computing capabilities embedded within or otherwise available to a given device. For example, a computing component may be found in other electronic devices such as, for example, electronic devices that may include some form of processing capability.

[0074] Computing component 1100 may include, for example, one or more processors, controllers, control components, or other processing devices such as a processor 1104. Processor 1104 may be implemented using a general-purpose or special-purpose processing engine such as, for example, a microprocessor, controller, or other control logic. Processor 1104 may be connected to a bus 1102. However, any communication medium may be used to facilitate interaction with other components of computing component 1100 or to communicate externally.

[0075] Computing component 1100 may also include one or more memory components, simply referred to herein as main memory 1108. For example, random access memory (RAM) or other dynamic memory, may be used for storing information and instructions to be executed by processor 1104. Main memory 1108 may also be used for storing temporary variables or other intermediate information during execution of instructions to be executed by processor 1104. Computing component 1100 may likewise include a read only memory ("ROM") or other static device coupled to bus 1102 for storing static information and instructions for processor 1104.

[0076] The computing component 1100 may also include one or more various forms of information storage mechanism 1110, which may include, for example, a media drive 1112 and a storage unit interface 1120. The media drive 1112 may include a drive or other mechanism to support fixed or removable storage media 1114. For example, a hard disk drive, a solid state drive, a magnetic tape drive, an optical drive, a compact disc (CD) or digital video disc (DVD) drive (R or RW), or other removable or fixed media drive may be provided.

Storage media 1114 may include, for example, a hard disk, an integrated circuit assembly, magnetic tape, cartridge, optical disk, a CD or DVD. Storage media 1114 may be any other fixed or removable medium that is read by, written to or accessed by media drive 1112. As these examples illustrate, the storage media 1114 may include a computer usable storage medium having stored therein computer software or data.

[0077] In alternative embodiments, information storage mechanism 1110 may include other similar instrumentalities for allowing computer programs or other instructions or data to be loaded into computing component 1100. Such instrumentalities may include, for example, a fixed or removable storage unit 1122 and an interface 1120. Examples of such storage units 1122 and interfaces 1120 may include a program cartridge and cartridge interface, a removable memory (for example, a flash memory or other removable memory component) and memory slot. Other examples may include a PCMCIA slot and card, and other fixed or removable storage units 1122 and interfaces 1120 that allow software and data to be transferred from storage unit 1122 to computing component 1100.

[0078] Computing component 1100 may also include a communications interface 1124. Communications interface 1124 may be used to allow software and data to be transferred between computing component 1100 and external devices. Examples of communications interface 1124 may include a modem or softmodem, a network interface (such as an Ethernet, network interface card, WiMedia, IEEE 802.XX or other interface). Other examples include a communications port (such as for example, a USB port, IR port, RS232 port Bluetooth® interface, or other port), or other communications interface. Software/data transferred via communications interface 1124 may be carried on signals, which may be electronic, electromagnetic (which includes optical) or other signals capable of being exchanged by a given communications interface 1124. These signals may be provided to communications interface 1124 via a channel 1128. Channel 1128 may carry signals and may be implemented using a wired or wireless communication medium. Some examples of a channel may include a phone line, a cellular link, an RF link, an optical link, a network interface, a local or wide area network, and other wired or wireless communications channels.

[0079] In this document, the terms "computer program medium" and "computer usable medium" are used to generally refer to transitory or non-transitory media. Such media may be, e.g., memory 1108, storage unit 1120, media 1114, and channel 1128. These and other various forms of computer program media or computer usable media may be involved in carrying one or more sequences of one or more instructions to a processing device for execution. Such instructions embodied on the medium, are generally referred to as "computer program code" or a "computer program product" (which may be grouped in the form of computer programs or other groupings). When executed, such instructions may enable the computing component 1100 to perform features or functions of the present application as discussed herein.

[0080] It should be understood that the various features, aspects and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described. Instead, they may be applied, alone or in various combinations, to one or more other embodiments, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus, the breadth and scope of the present application should not be limited by any of the above-described exemplary embodiments.

[0081] Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing, the term "including" should be read as meaning "including, without limitation" or the like. The term "example" is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof. The terms "a" or "an" should be read as meaning "at least one," "one or more" or the like; and adjectives such as "conventional," "traditional," "normal," "standard," "known." Terms of similar meaning should not be construed as limiting the item described to a given time period or to an item available as of a given time. Instead, they should be read to encompass conventional, traditional, normal, or standard technologies that may be available or known now or at any time in the future. Where this document refers to technologies that would be apparent or

known to one of ordinary skill in the art, such technologies encompass those apparent or known to the skilled artisan now or at any time in the future.

[0082] The presence of broadening words and phrases such as “one or more,” “at least,” “but not limited to” or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent. The use of the term “component” does not imply that the aspects or functionality described or claimed as part of the component are all configured in a common package. Indeed, any or all of the various aspects of a component, whether control logic or other components, may be combined in a single package or separately maintained and may further be distributed in multiple groupings or packages or across multiple locations.

[0083] Additionally, the various embodiments set forth herein are described in terms of exemplary block diagrams, flow charts and other illustrations. As will become apparent to one of ordinary skill in the art after reading this document, the illustrated embodiments and their various alternatives may be implemented without confinement to the illustrated examples. For example, block diagrams and their accompanying description should not be construed as mandating a particular architecture or configuration.

Claims

What is claimed is:

1. A method comprising:

receiving a three-dimensional model of an environment, wherein the three-dimensional model comprises an obstacle model and an obstacle location for each of a plurality of obstacles in the environment;

receiving a wireless sensor layout for the environment, wherein the wireless sensor layout comprises a sensor location and sensor parameters for each of plurality of wireless sensors for the environment;

generating a diffraction pattern at a wireless receiver for a wireless transmitter, wherein the wireless transmitter and the wireless receiver are each wireless sensors included among the plurality of wireless sensors, wherein the generating the diffraction pattern comprises:

determining a line-of-sight between a sensor location of the wireless receiver and a sensor location of the wireless transmitter,

generating a Fresnel zone using the line of sight, the sensor location of the wireless transmitter, the sensor location of the wireless receiver, and a frequency or a wavelength of the wireless transmitter,

determining an interfering obstacle, from among the plurality of obstacles, that intersects the Fresnel zone based on the obstacle model and the obstacle location of each of the plurality of obstacles,

generating, using the obstacle model and the obstacle location of the interfering obstacle, a two-dimensional projection of the interfering obstacle onto a diffraction plane that is between the wireless transmitter and the wireless receiver and that is perpendicular to the line-of-sight, and

generating, using Fresnel diffraction and the two-dimensional projection of the interfering obstacle, the diffraction pattern at the wireless receiver; and

adjusting the sensor location in the wireless sensor layout of either the wireless transmitter or the wireless receiver based on the diffraction pattern.

2. The method of claim 1, wherein generating a diffraction pattern at a wireless receiver for a wireless transmitter comprises generating a diffraction pattern for each pair of wireless sensors among the plurality of wireless sensors in the wireless sensor layout.
3. The method of claim 1, wherein determining an interfering obstacle that intersects the Fresnel zone comprises determining a plurality of interfering obstacles that intersect the Fresnel zone, each of the plurality of interfering obstacles among the plurality of obstacles.
4. The method of claim 3, wherein generating a two-dimensional projection of the interfering obstacle onto a diffraction plane that is perpendicular to the line-of-sight comprises generating a two-dimensional projection onto a respective diffraction plane for each of the plurality of interfering obstacles.
5. The method of claim 1, wherein generating a two-dimensional projection of the interfering obstacle onto a diffraction plane that is perpendicular to the line-of-sight comprises generating a two-dimensional projection of the interfering obstacle onto the diffraction plane that is perpendicular to the line-of-sight, wherein the diffraction plane includes a location of a center of mass of the interfering obstacle.
6. The method of claim 1, further comprising:
generating a three-dimensional rendering of the three-dimensional model of the environment, wherein the rendering comprises either a Fresnel zone between the wireless transmitter and the wireless receiver or the line-of-sight between the wireless transmitter and the wireless receiver.

7. The method of claim 6, wherein the rendering comprises both the Fresnel zone and the line-of-sight.
8. The method of claim 6, wherein the rendering further comprises information regarding a strength or relative strength of wireless signals received at the wireless receiver.
9. The method of claim 6, wherein the rendering further comprises information regarding a strength or relative strength of a connection between the wireless transmitter and the wireless receiver.
10. A system comprising a computing processor configured to:
 - receive a three-dimensional model of an environment, wherein the three-dimensional model comprises an obstacle model and an obstacle location for each of a plurality of obstacles in the environment;
 - receive a wireless sensor layout for the environment, wherein the wireless sensor layout comprises a sensor location and sensor parameters for each of plurality of wireless sensors for the environment;
 - generate a diffraction pattern at a wireless receiver for a wireless transmitter, wherein the wireless transmitter and the wireless receiver are each wireless sensors included among the plurality of wireless sensors, wherein the generate the diffraction pattern comprises:
 - determine a line-of-sight between a sensor location of the wireless receiver and a sensor location of the wireless transmitter,
 - generate a Fresnel zone using the line of sight, the sensor location of the wireless transmitter, the sensor location of the wireless receiver, and a frequency or a wavelength of the wireless transmitter,

determine an interfering obstacle, from among the plurality of obstacles, that intersects the Fresnel zone based on the obstacle model and the obstacle location of each of the plurality of obstacles,

generate, using the obstacle model and the obstacle location of the interfering obstacle, a two-dimensional projection of the interfering obstacle onto a diffraction plane that is between the wireless transmitter and the wireless receiver and that is perpendicular to the line-of-sight, and

generate, using Fresnel diffraction and the two-dimensional projection of the interfering obstacle, the diffraction pattern at the wireless receiver; and

adjust the sensor location in the wireless sensor layout of either the wireless transmitter or the wireless receiver based on the diffraction pattern.

11. The system of claim 10, wherein generate a diffraction pattern at a wireless receiver for a wireless transmitter comprises generate a diffraction pattern for each pair of wireless sensors among the plurality of wireless sensors in the wireless sensor layout.

12. The system of claim 10, wherein determine an interfering obstacle that intersects the Fresnel zone comprises determine a plurality of interfering obstacles that intersect the Fresnel zone, each of the plurality of interfering obstacles among the plurality of obstacles.

13. The system of claim 12, wherein generate a two-dimensional projection of the interfering obstacle onto a diffraction plane that is perpendicular to the line-of-sight comprises generate a two-dimensional projection onto a respective diffraction plane for each of the plurality of interfering obstacles.

14. The system of claim 10, wherein generate a two-dimensional projection of the interfering obstacle onto a diffraction plane that is perpendicular to the line-of-sight comprises generate a two-dimensional projection of the interfering obstacle onto the

diffraction plane that is perpendicular to the line-of-sight, wherein the diffraction plane includes a location of a center of mass of the interfering obstacle.

15. The system of claim 10, wherein the computing processor is further configured to:
generate a three-dimensional rendering of the three-dimensional model of the environment, wherein the rendering comprises either a Fresnel zone between the wireless transmitter and the wireless receiver or the line-of-sight between the wireless transmitter and the wireless receiver.

16. The system of claim 15, wherein the rendering comprises both the Fresnel zone and the line-of-sight.

17. The system of claim 15, wherein the rendering further comprises information regarding a strength or relative strength of wireless signals received at the wireless receiver.

18. The system of claim 15, wherein the rendering further comprises information regarding a strength or relative strength of a connection between the wireless transmitter and the wireless receiver.

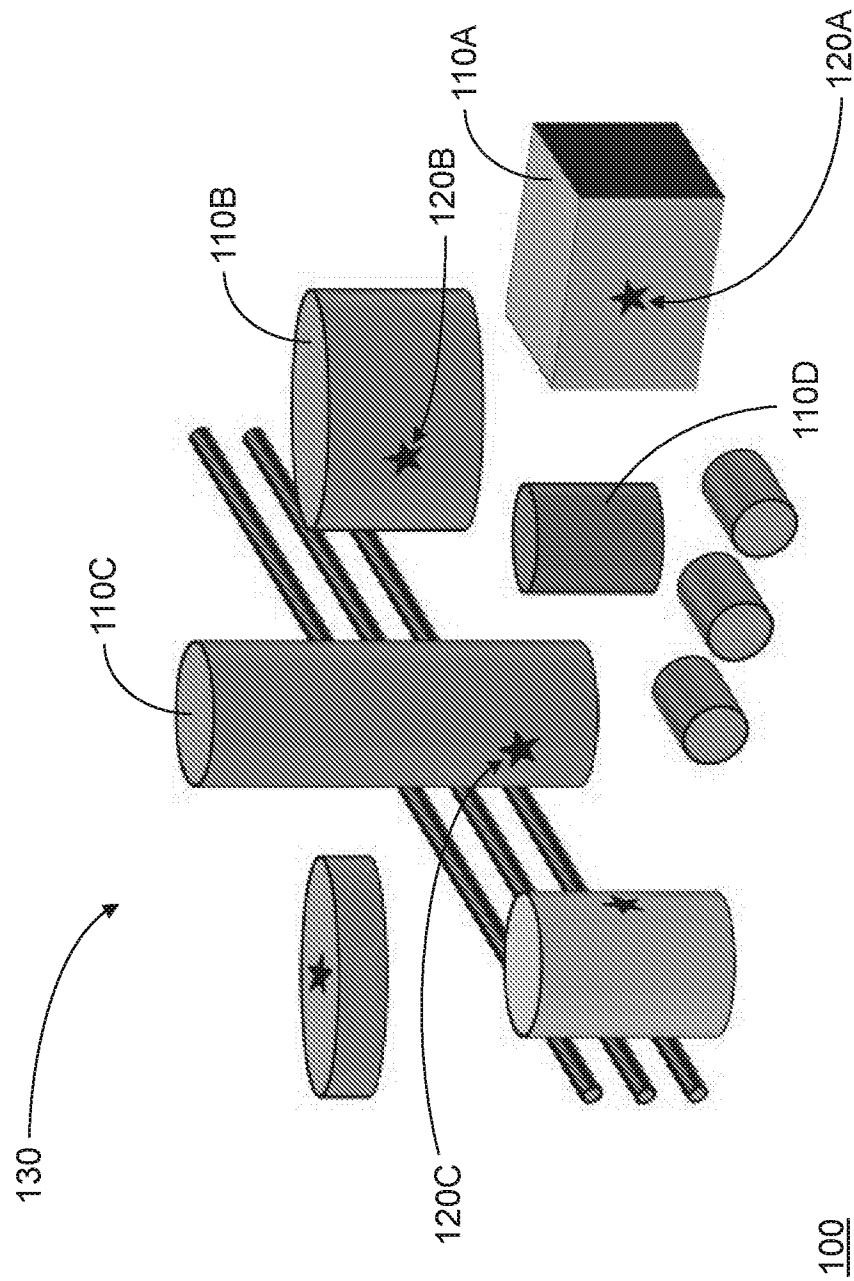
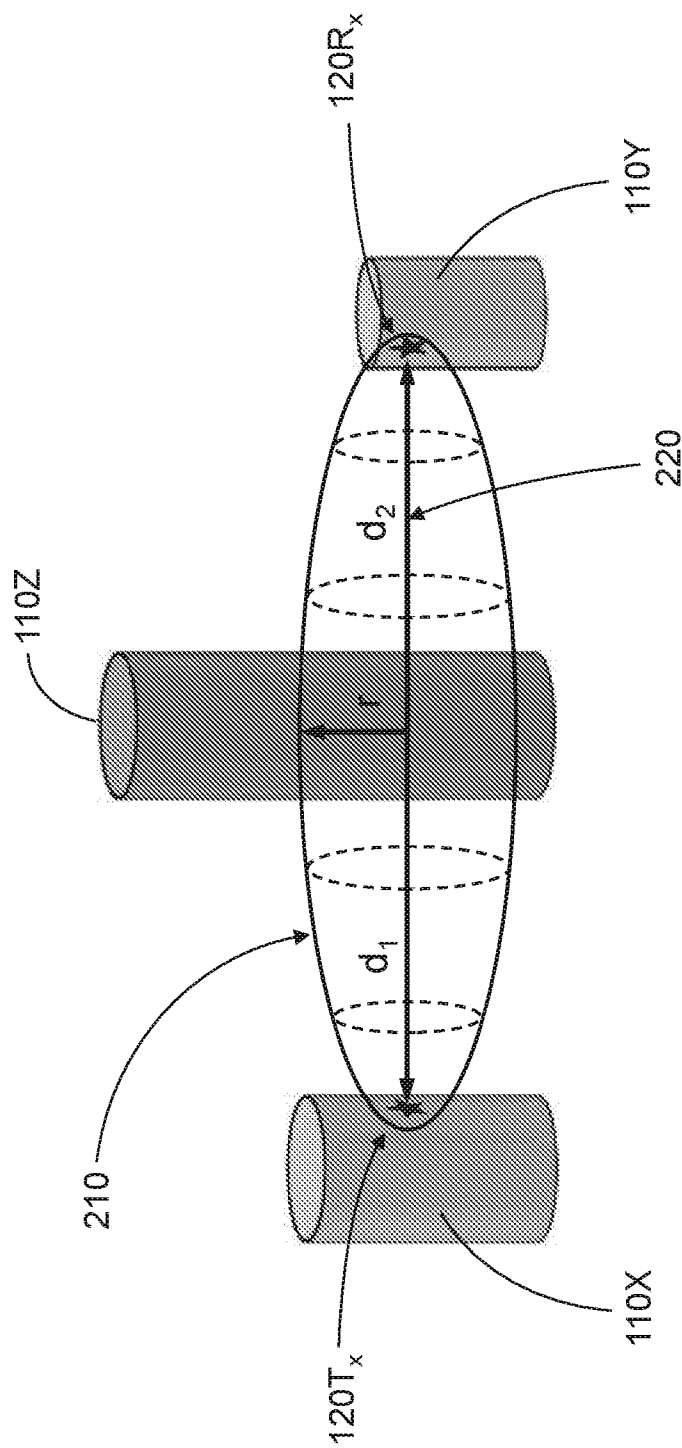


FIG. 1



130

FIG. 2A

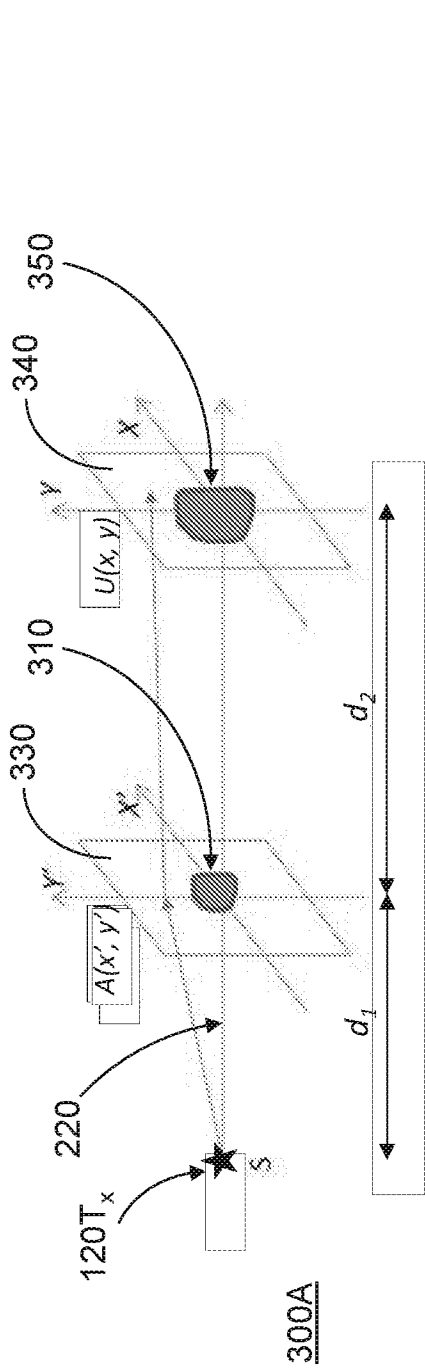


FIG. 3A

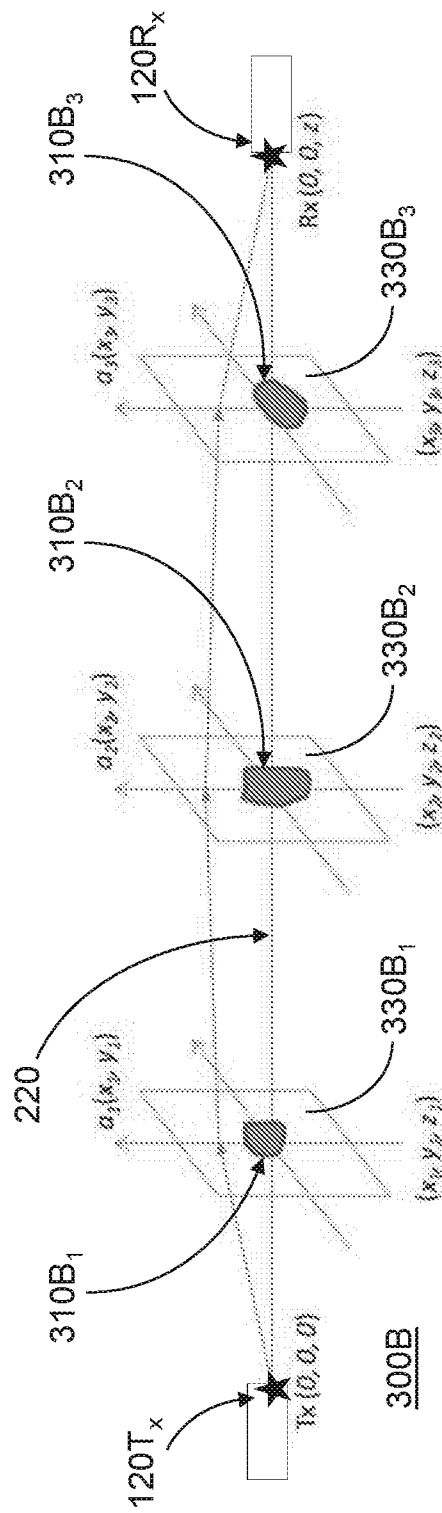
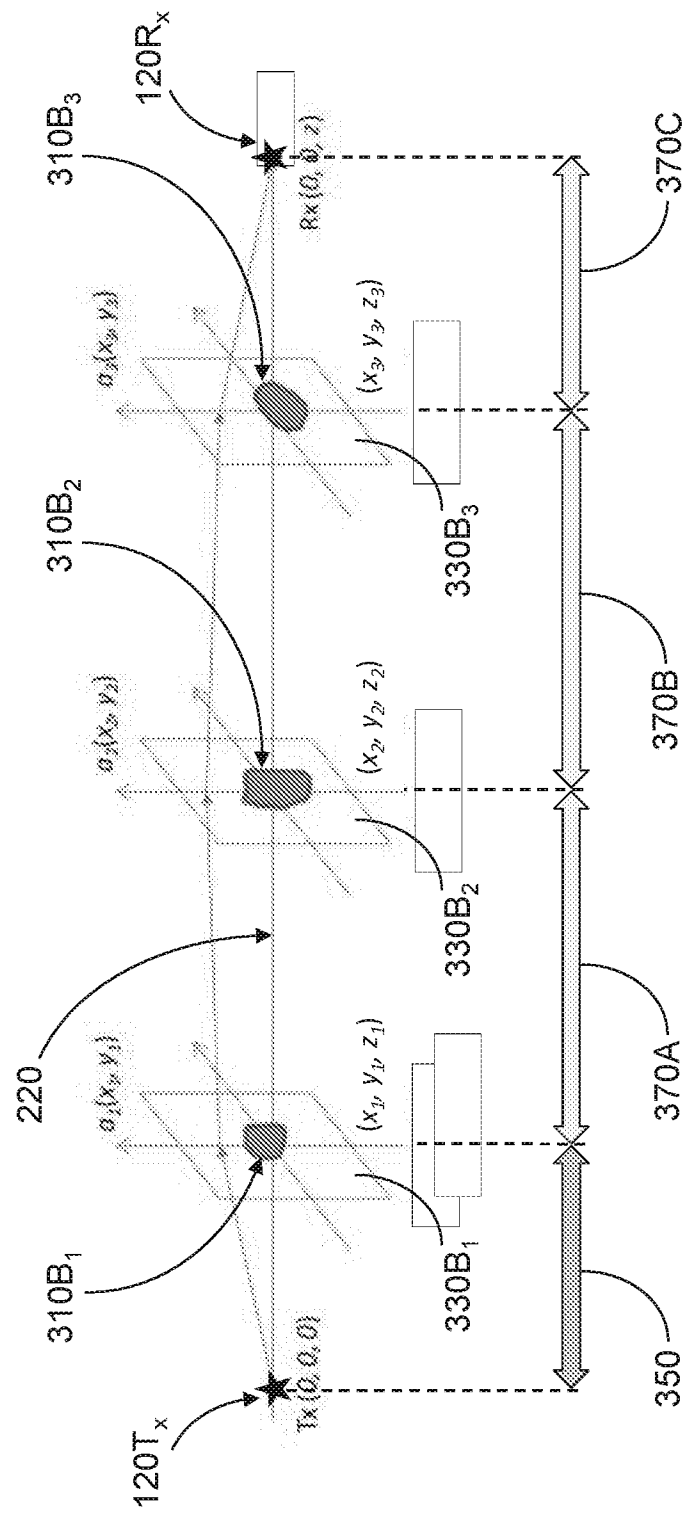
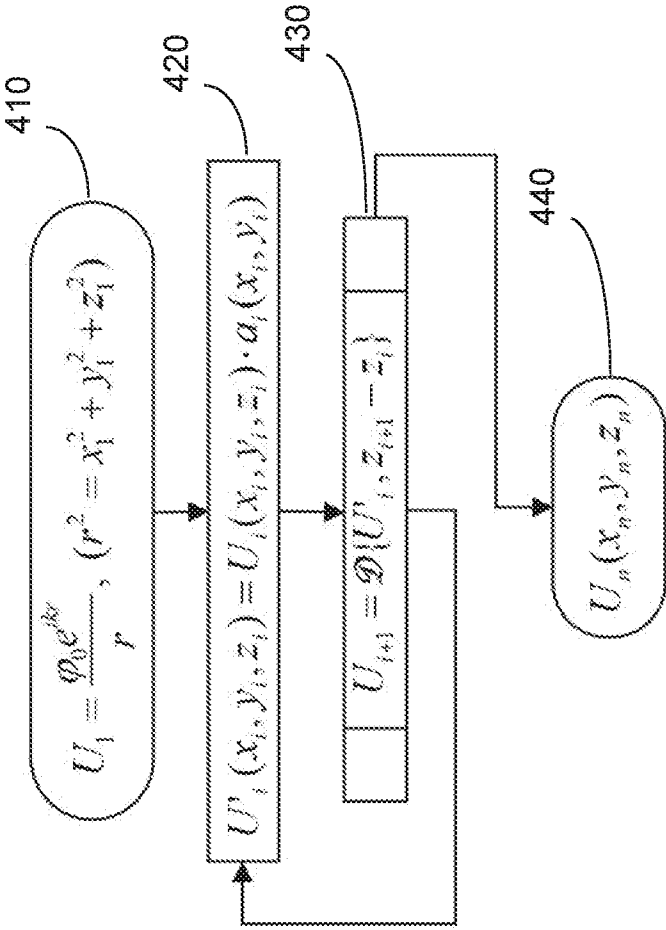


FIG. 3B



300C

FIG. 3C



400

FIG. 4

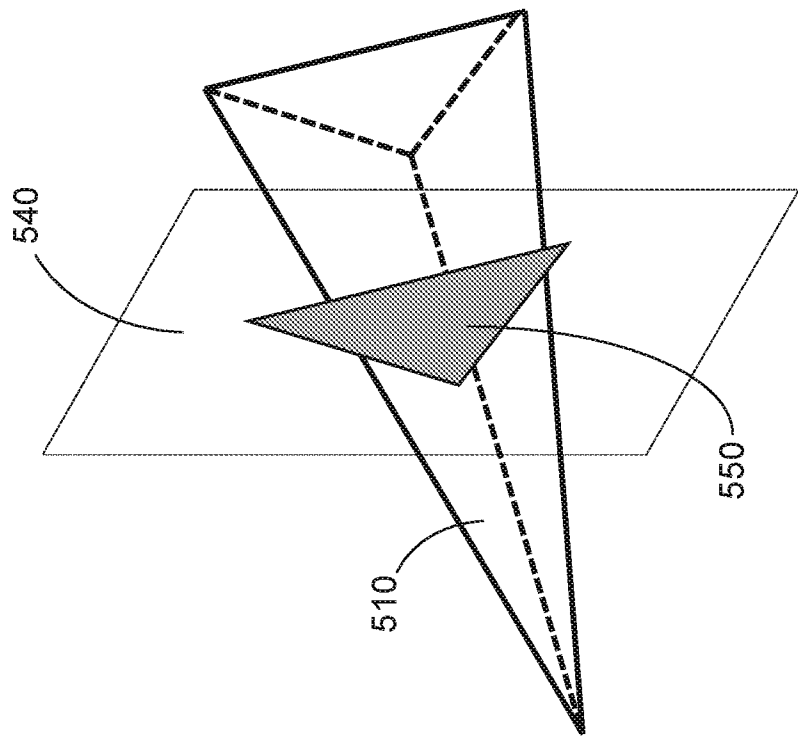


FIG. 5B

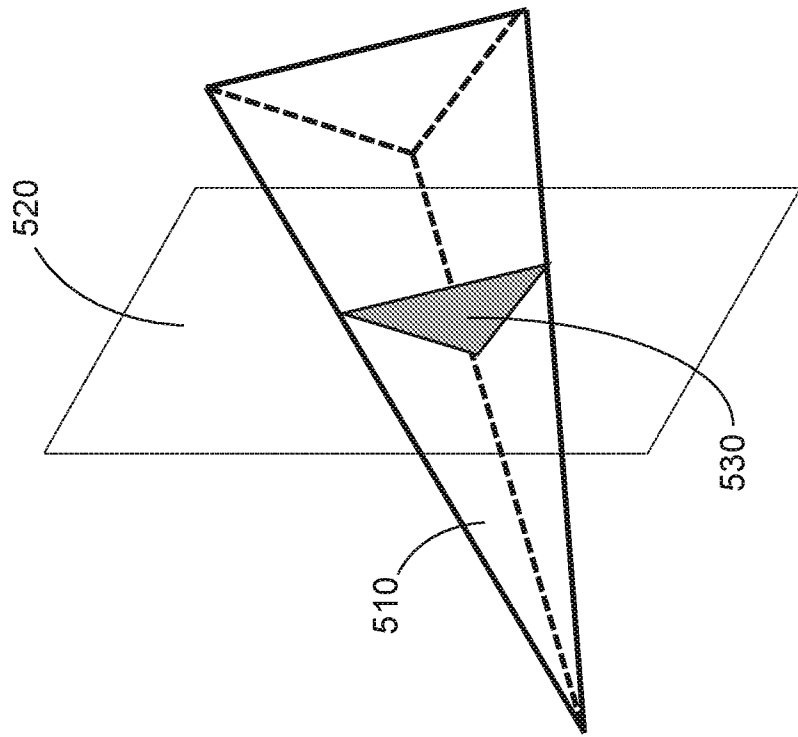


FIG. 5A

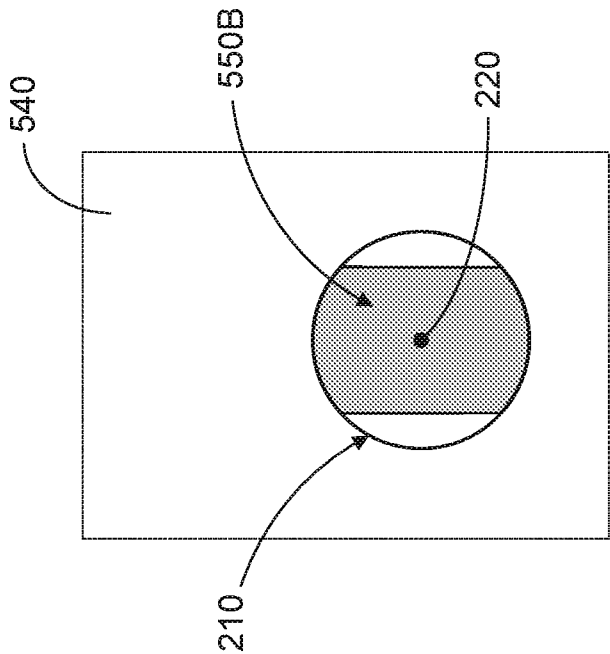


FIG. 6B

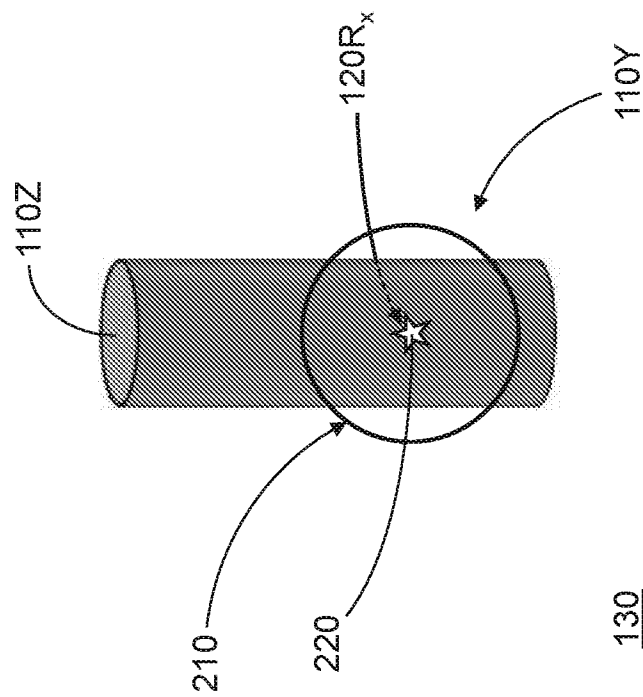


FIG. 6A

130

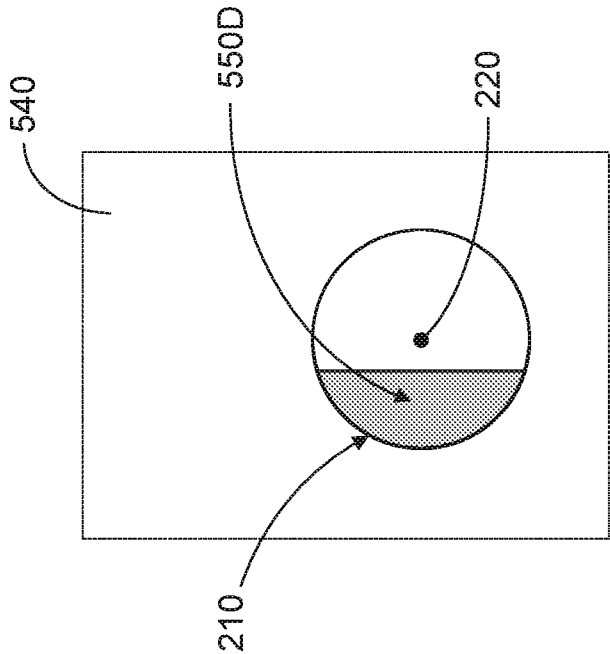


FIG. 6D

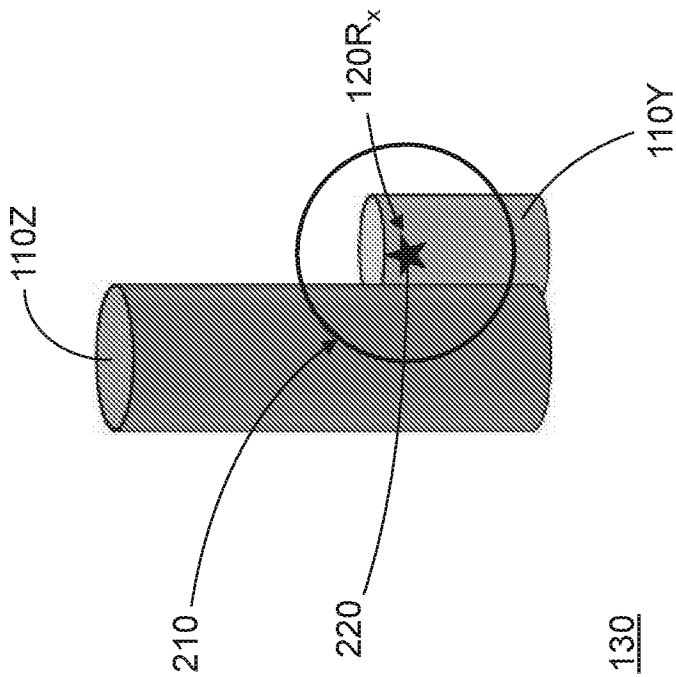


FIG. 6C

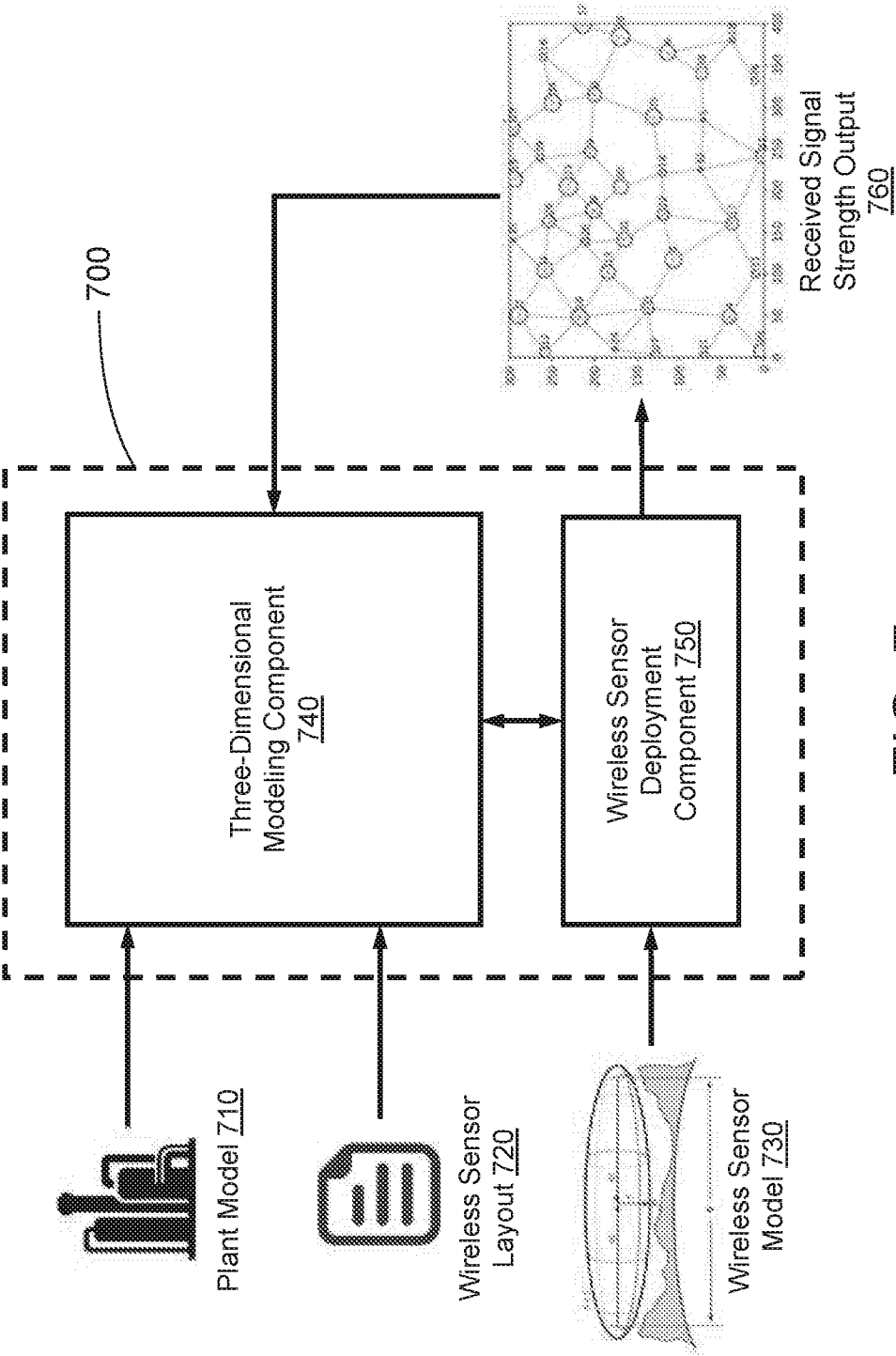


FIG. 7

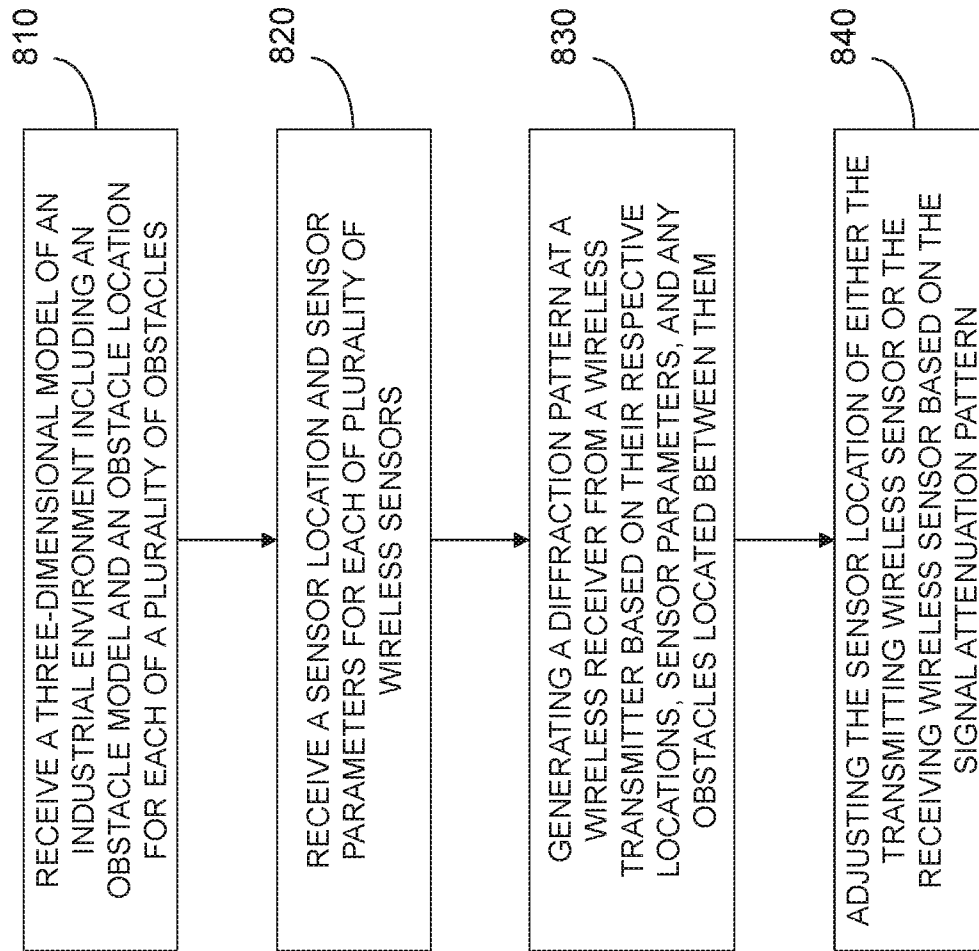


FIG. 8

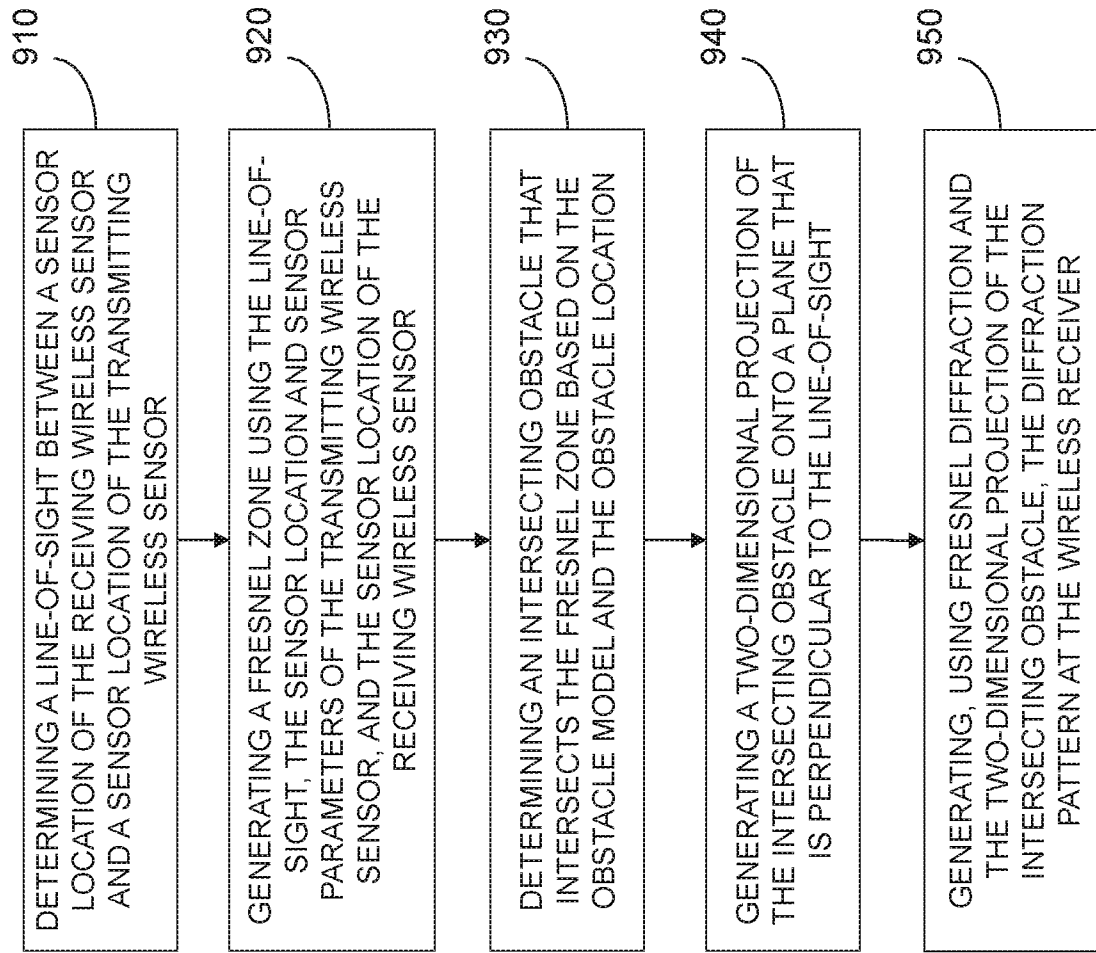


FIG. 9

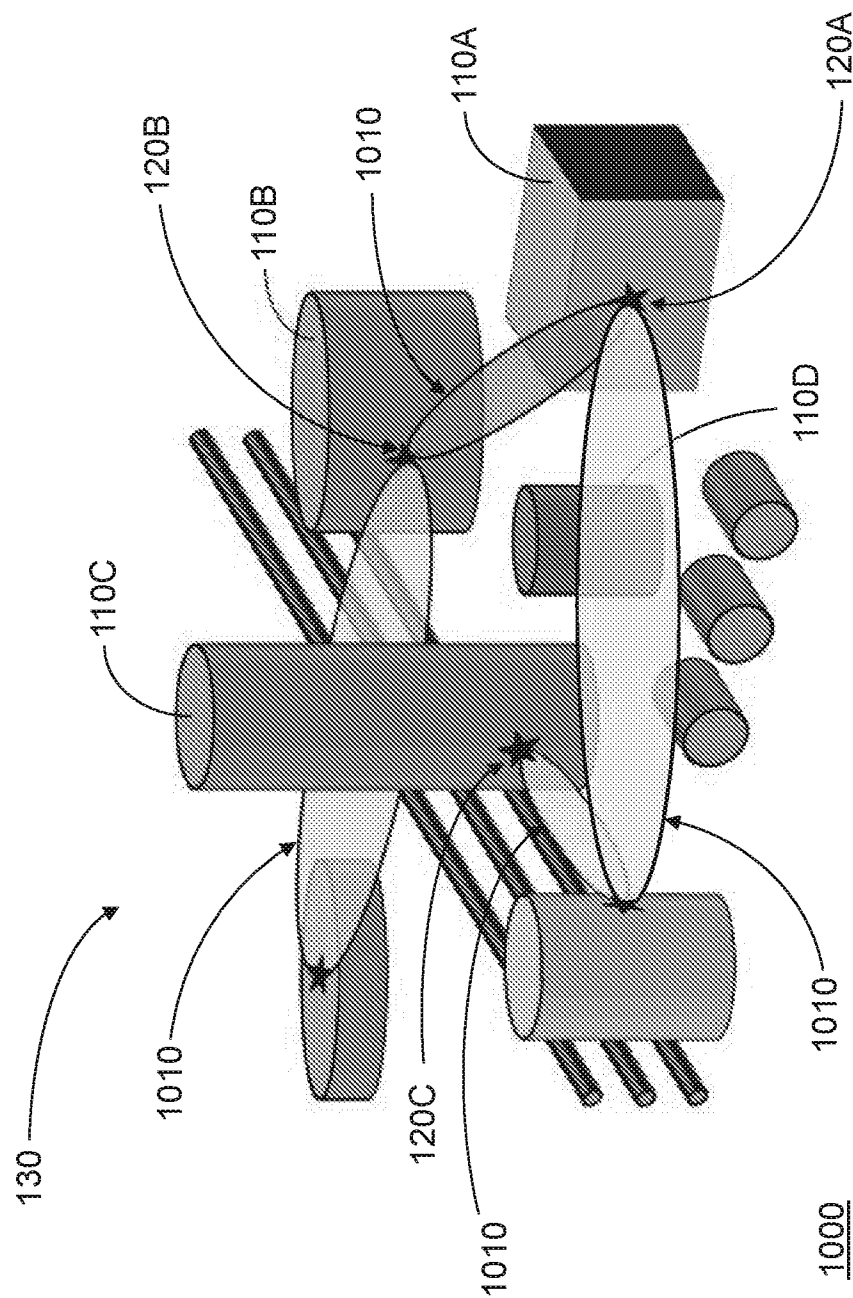


FIG. 10

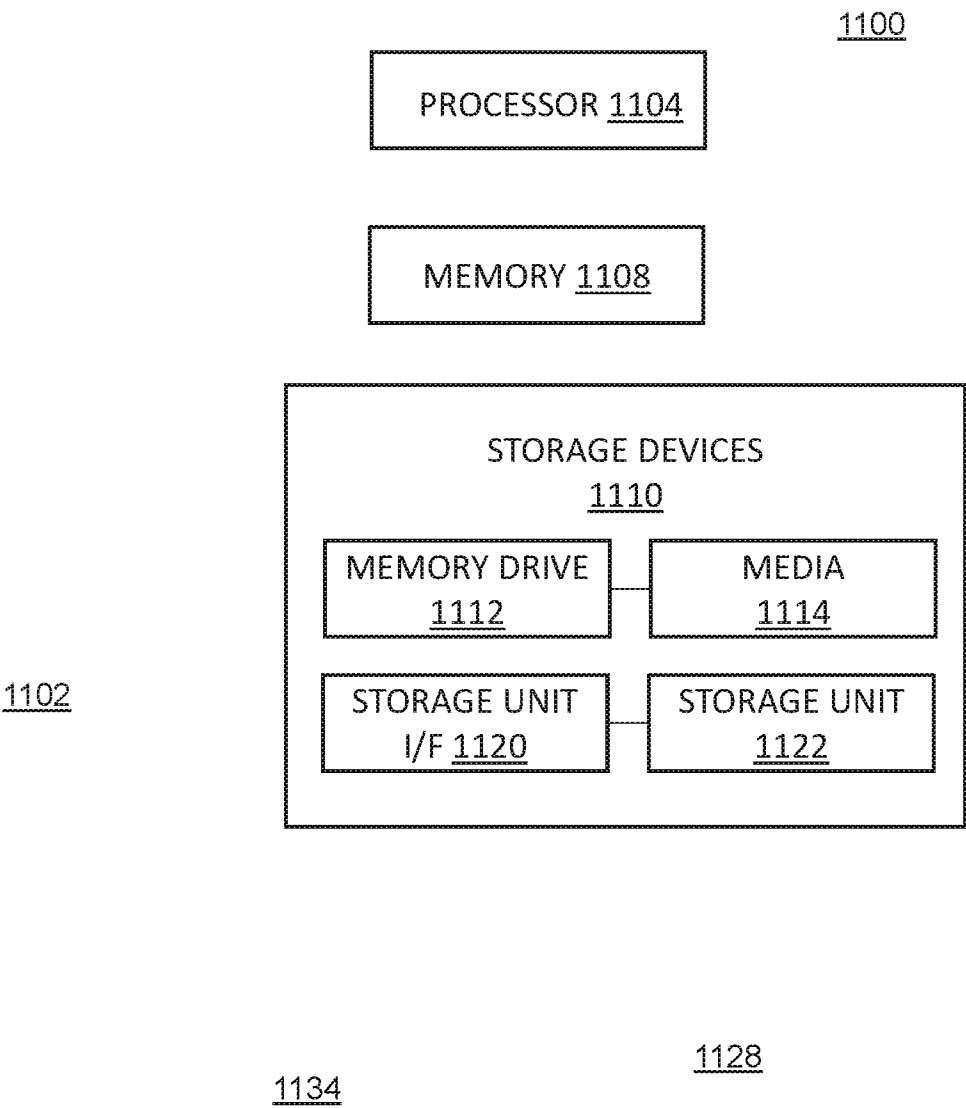


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2018/001272

A. CLASSIFICATION OF SUBJECT MATTER INV. H04B17/391 H04B17/309 H04W16/18 ADD.				
According to International Patent Classification (IPC) or to both national classification and IPC				
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H04B H04W				
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched				
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EP0-Internal, WPI Data				
C. DOCUMENTS CONSIDERED TO BE RELEVANT				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
Y	EP 2 315 377 A1 (MENTUM [FR]) 27 April 2011 (2011-04-27) abstract paragraphs [0015], [0043], [0050] - [0056], [0068] - [0069] figures 1A,1B,2-5	1-18		
Y	----- US 8 264 672 B1 (COLE JOSHUA R [US]) 11 September 2012 (2012-09-11) abstract column 5, lines 31-41 figures 1-3 -----	1-18		
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.				
* Special categories of cited documents :				
<table style="width: 100%; border: none;"> <tr> <td style="width: 50%; vertical-align: top; border: none;"> "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed </td> <td style="width: 50%; vertical-align: top; border: none;"> "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family </td> </tr> </table>			"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family
"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family			
Date of the actual completion of the international search 17 June 2019	Date of mailing of the international search report 27/06/2019			
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Yang, Betty			

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2018/001272

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 2315377	A1	27-04-2011	EP 2315377 A1	27-04-2011
			FR 2951584 A1	22-04-2011

US 8264672	B1	11-09-2012	NONE	
