US 20220011398A1

(19) **United States**

(12) **Patent Application Publication**

Duan et al.

(10) **Pub. No.: US 2022/0011398 A1**

(43) **Pub. Date: Jan. 13, 2022**

(54) **METHOD AND APPARATUS FOR DETERMINING RELATIVE POSITIONING BETWEEN DEVICES**

(71) Applicant: **Red Point Positioning Corporation**, Boston, MA (US)

(72) Inventors: **Chunjie Duan**, Brookline, MA (US); **Georgiy Pekhteryev**, Kharkiv (UA); **Serhii Rybalko**, Kharkiv (UA); **Zhenzhen Ye**, Westford, MA (US)

(73) Assignee: **Red Point Positioning Corporation**, Boston, MA (US)

(21) Appl. No.: **17/368,378**

(22) Filed: **Jul. 6, 2021**

Related U.S. Application Data

(60) Provisional application No. 63/050,144, filed on Jul. 10, 2020, provisional application No. 63/052,188, filed on Jul. 15, 2020.

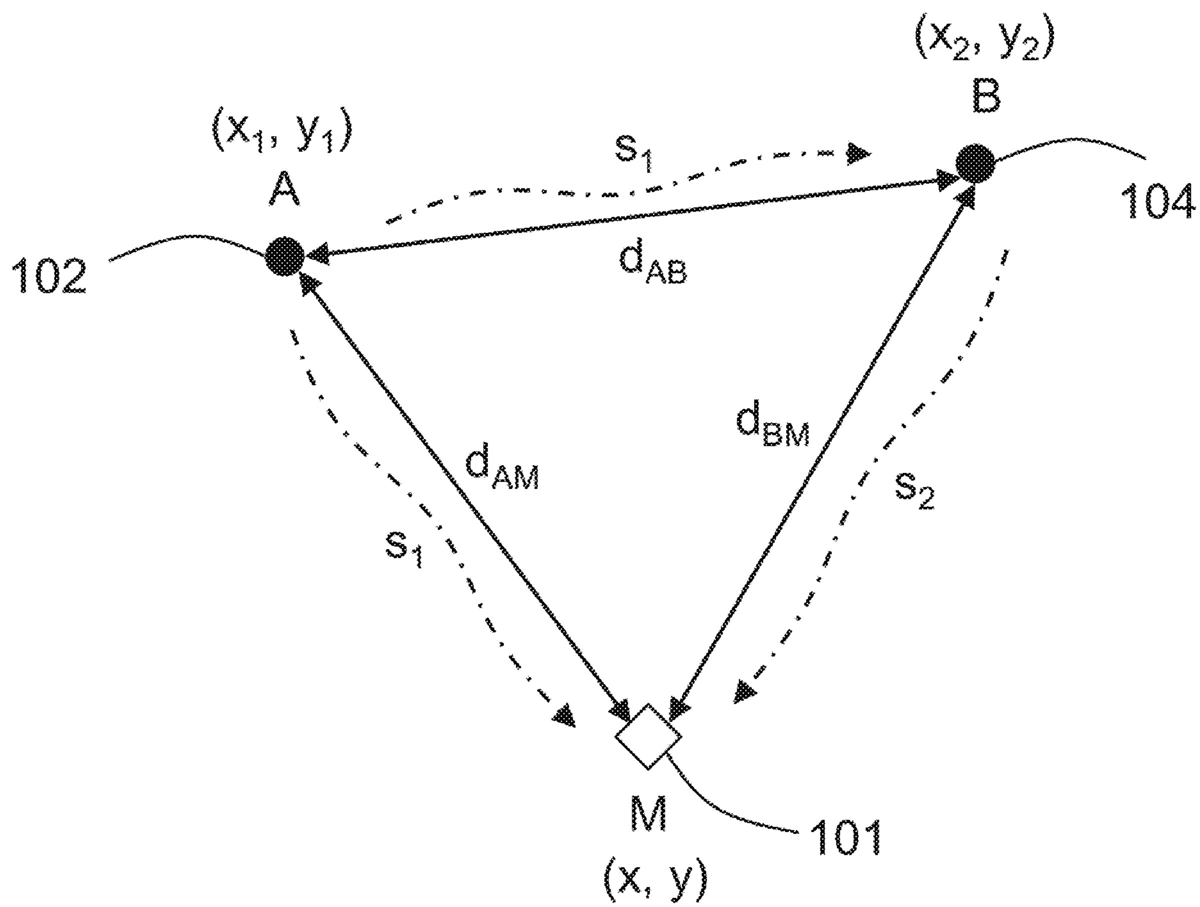
Publication Classification

(51) **Int. Cl.**
G01S 5/02 (2006.01)
G08B 21/18 (2006.01)

(52) **U.S. Cl.**
CPC ***G01S 5/0289*** (2013.01); ***G08B 21/18*** (2013.01)

(57) **ABSTRACT**

Aspects of the subject disclosure may include, for example, transmitting, by a first transmitter of a first device, a first wireless signal, wherein the first wireless signal utilizes a first signaling technology, receiving, by a second receiver of the first device, a second wireless signal generated by a second device, wherein the second wireless signal utilizes a second signaling technology that differs from the first signaling technology, and transmitting, by a second transmitter of the first device, a third wireless signal responsive to receiving the second wireless signal, wherein the third wireless signal utilizes the second signaling technology, and wherein the third wireless signal enables the second device to determine location information associated with the first device and the second device. Other embodiments are disclosed.



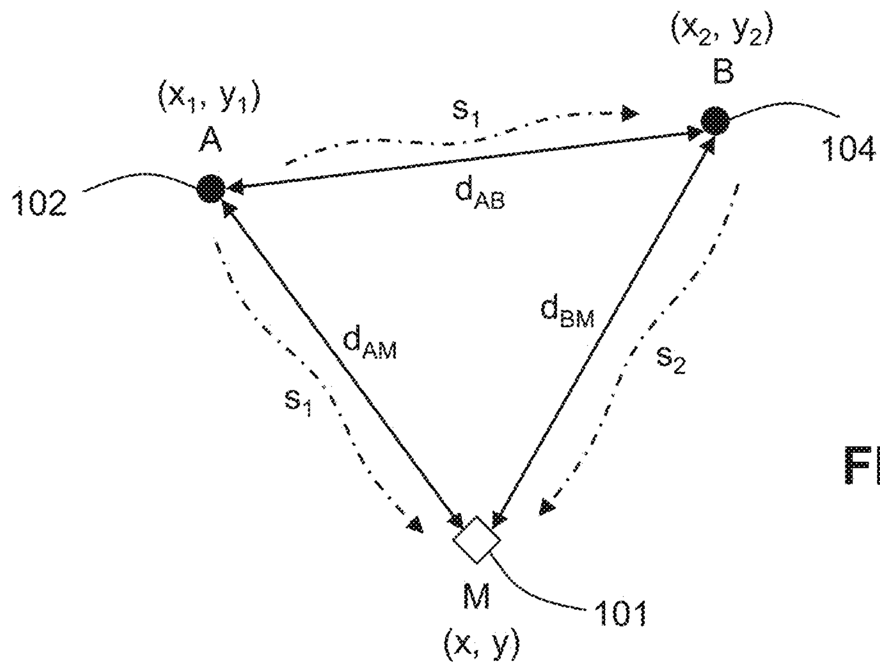

(x2, y2)
B
(x1, y1)
A
s1
104
102
dAB
dBM
dAM
s2
s1
M
101
(x, y)

FIG. 1

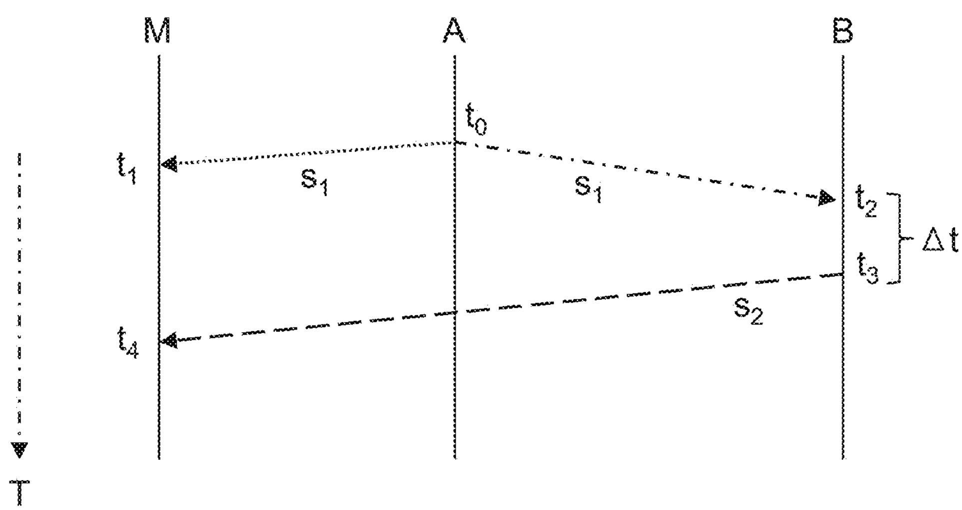

M
A
B
t0
t1
s1
s1
t2
Δt
t3
s2
t4
T

FIG. 2

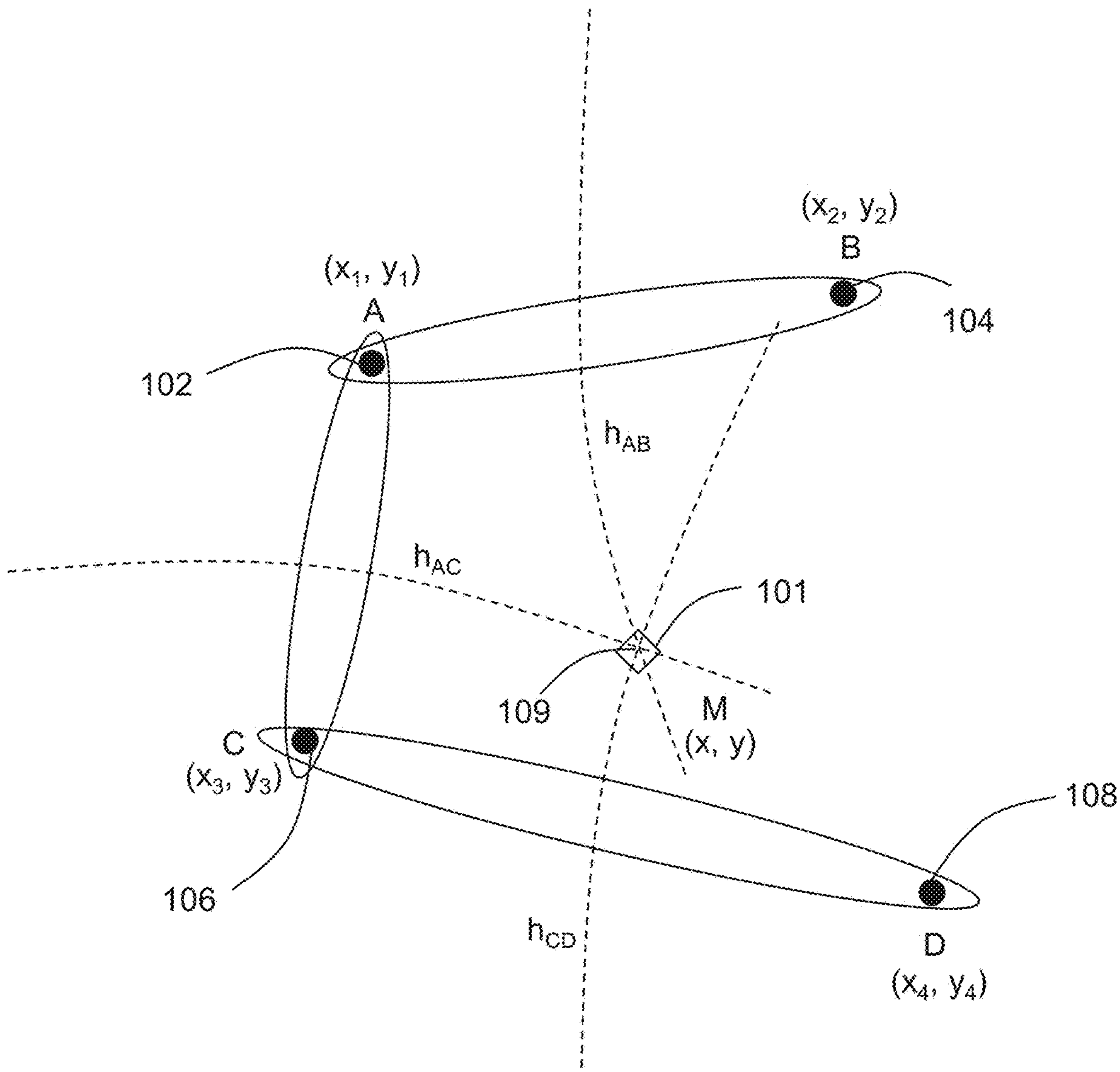

(x2, y2)
B
104
(x1, y1)
A
102
hAB
hAC
101
109
M
(x, y)
C
(x3, y3)
108
106
hCD
D
(x4, y4)

FIG. 3

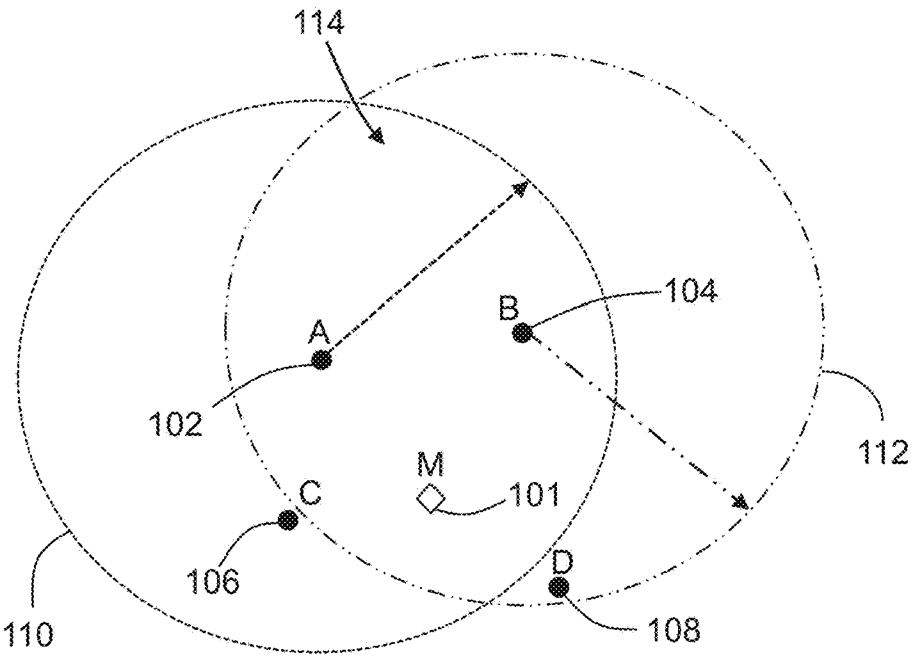

114
104
B
A
102
112
M
C
101
106
D
110
108

FIG. 4A

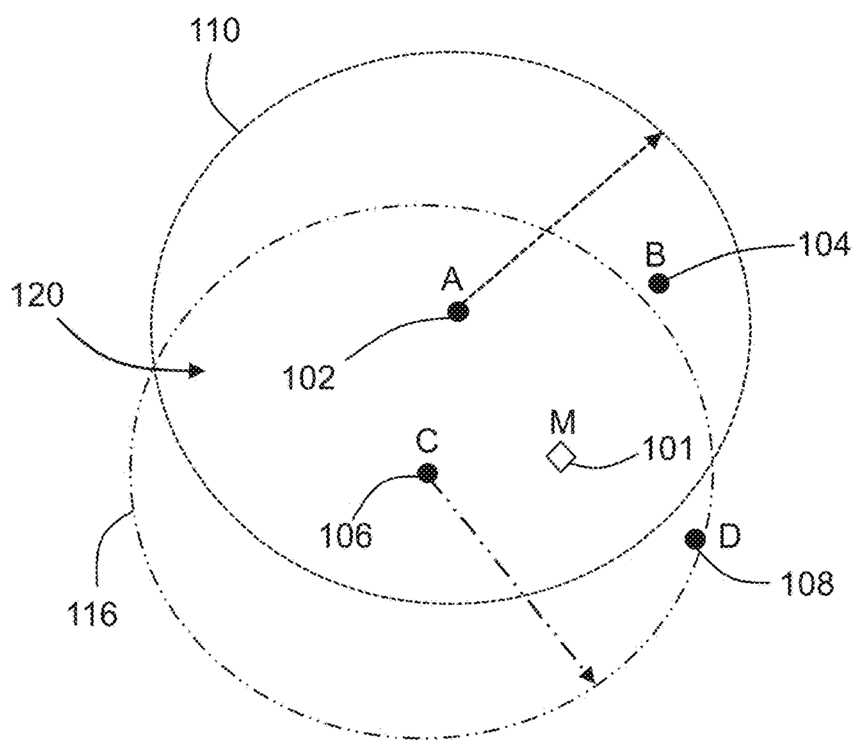

110
104
B
A
120
102
M
C
101
106
D
108
116

FIG. 4B

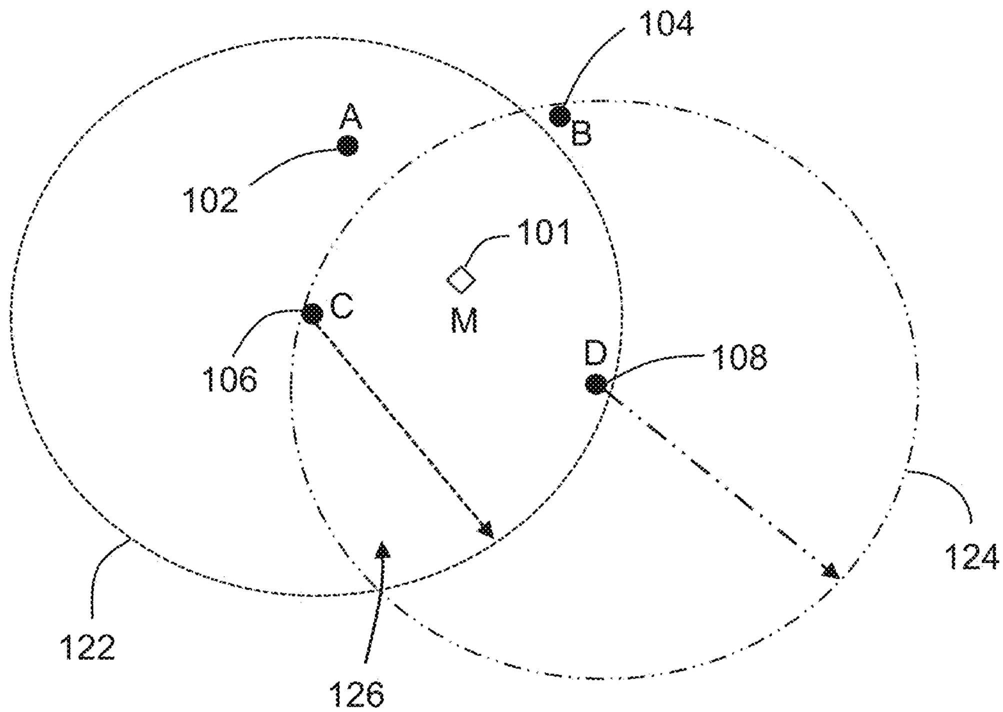


FIG. 4C

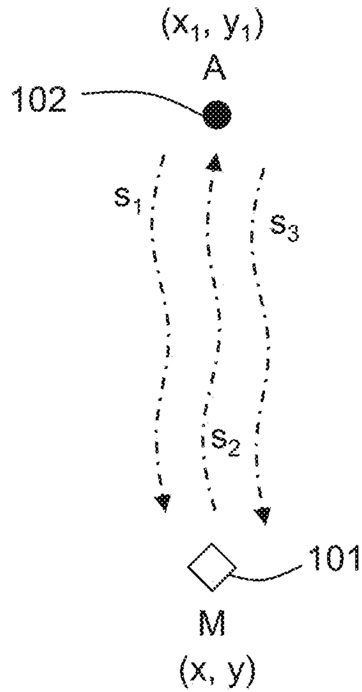

(x1, y1)
A
102
s1
s2
s3
101
M
(x, y)

FIG. 5

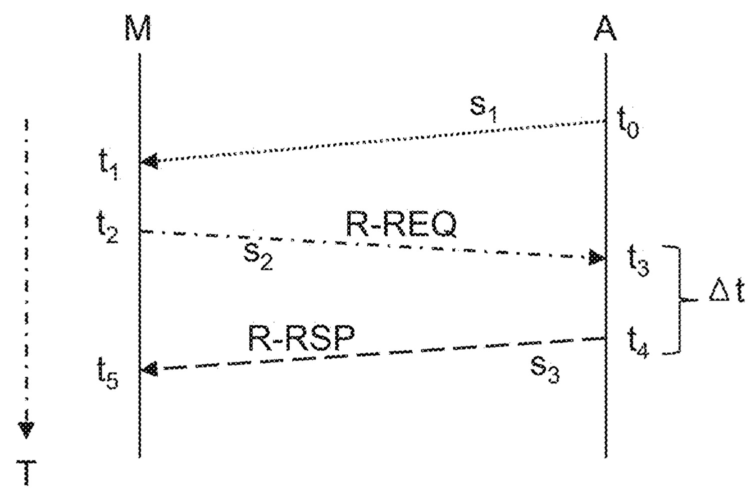

M
A
s1
t0
t1
t2
R-REQ
s2
t3
Δt
R-RSP
t4
t5
s3
T

FIG. 6

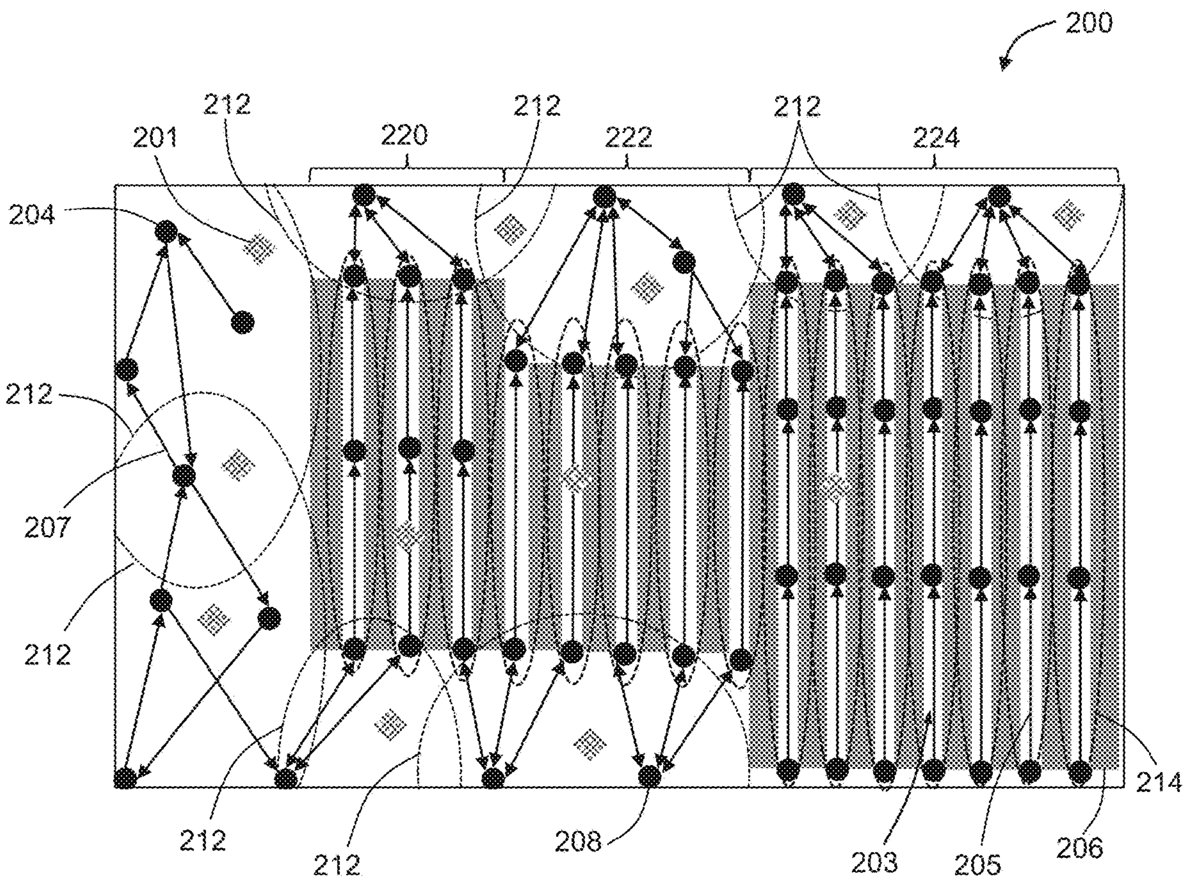
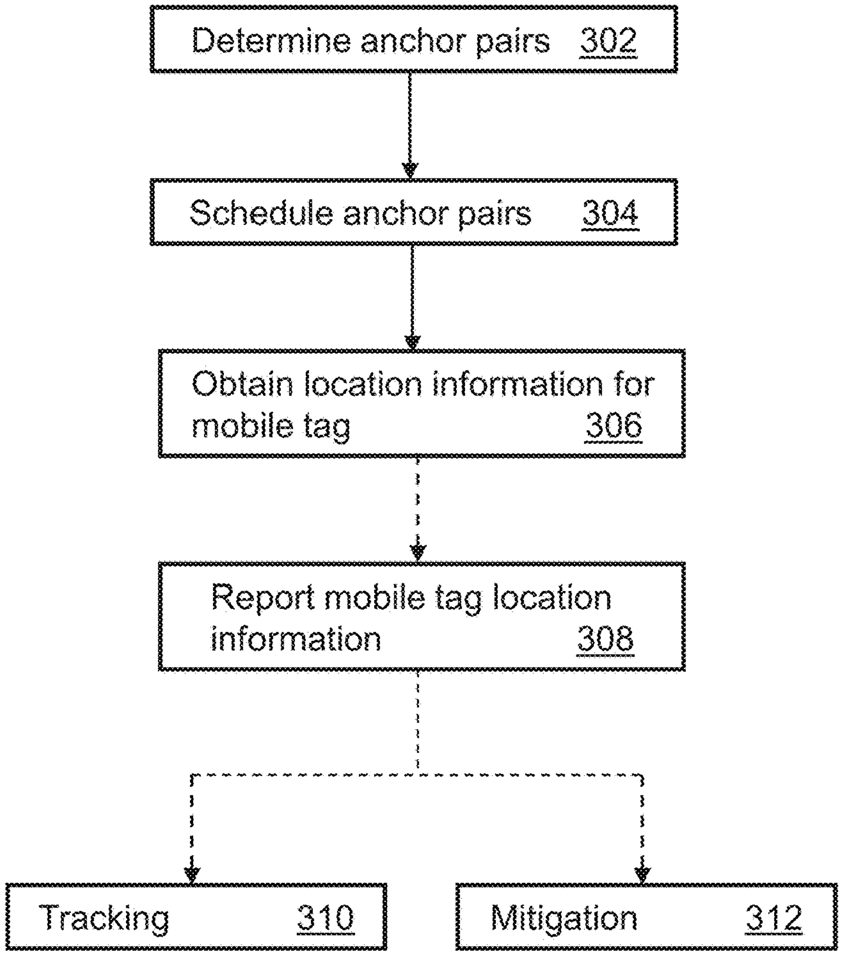

200
212
212
212
201
220
222
224
204
212
207
212
212
212
208
203
205
206
214

FIG. 7



300

FIG. 8

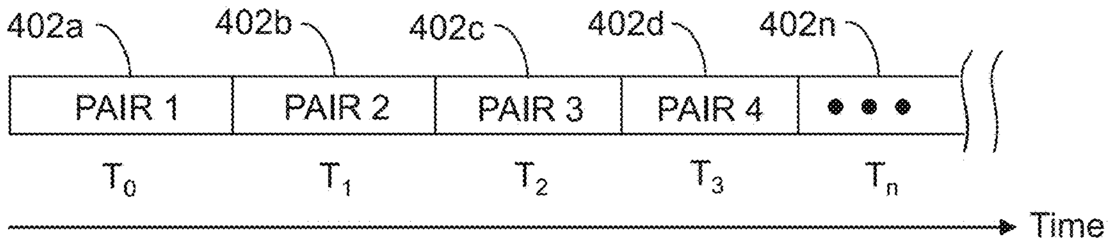


FIG. 9

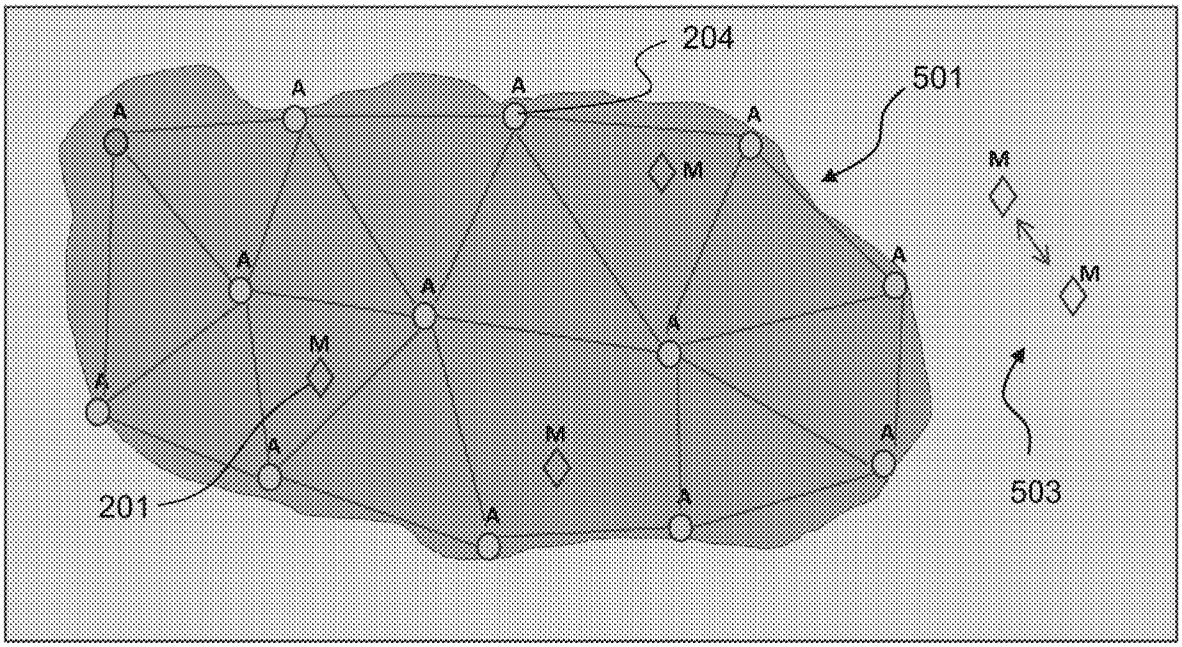


FIG. 10

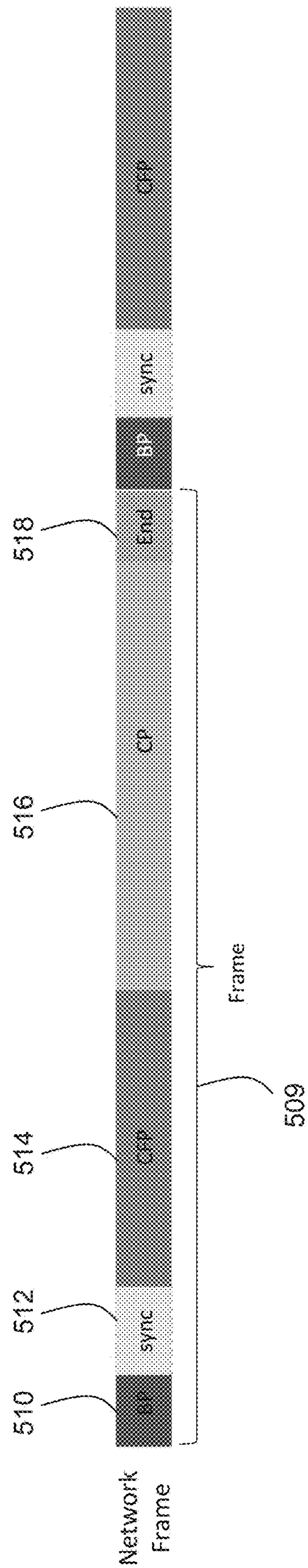

Network Frame
510
BP
512
sync
514
CFP
509
Frame
516
CP
518
End
BP
sync
CFP

FIG. 11

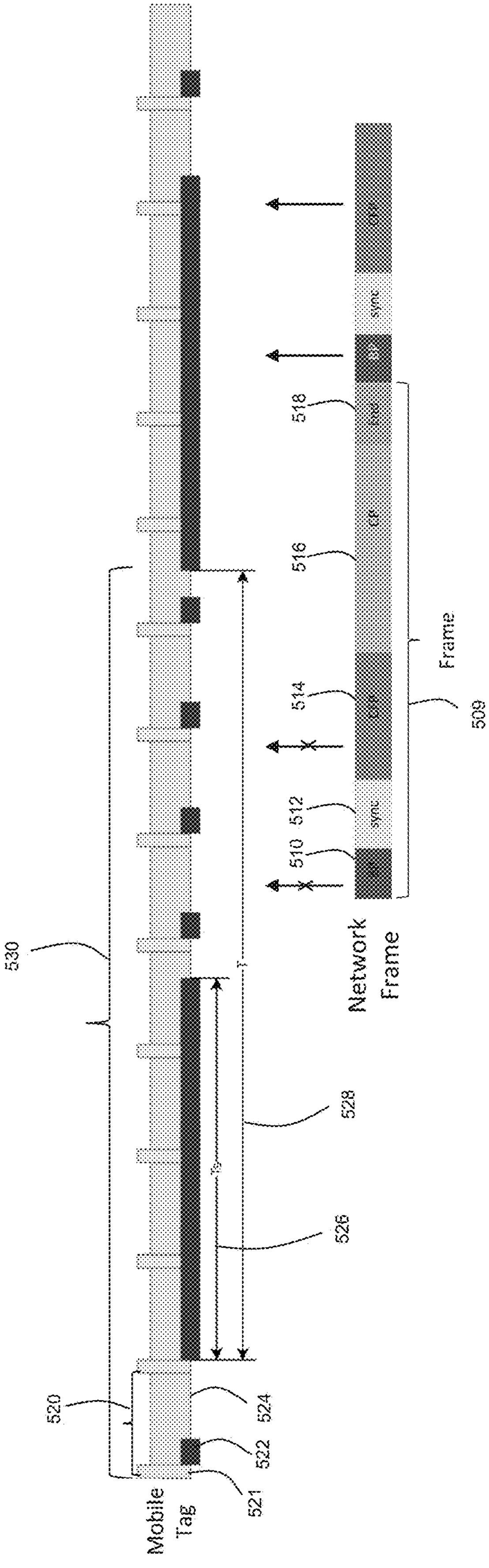
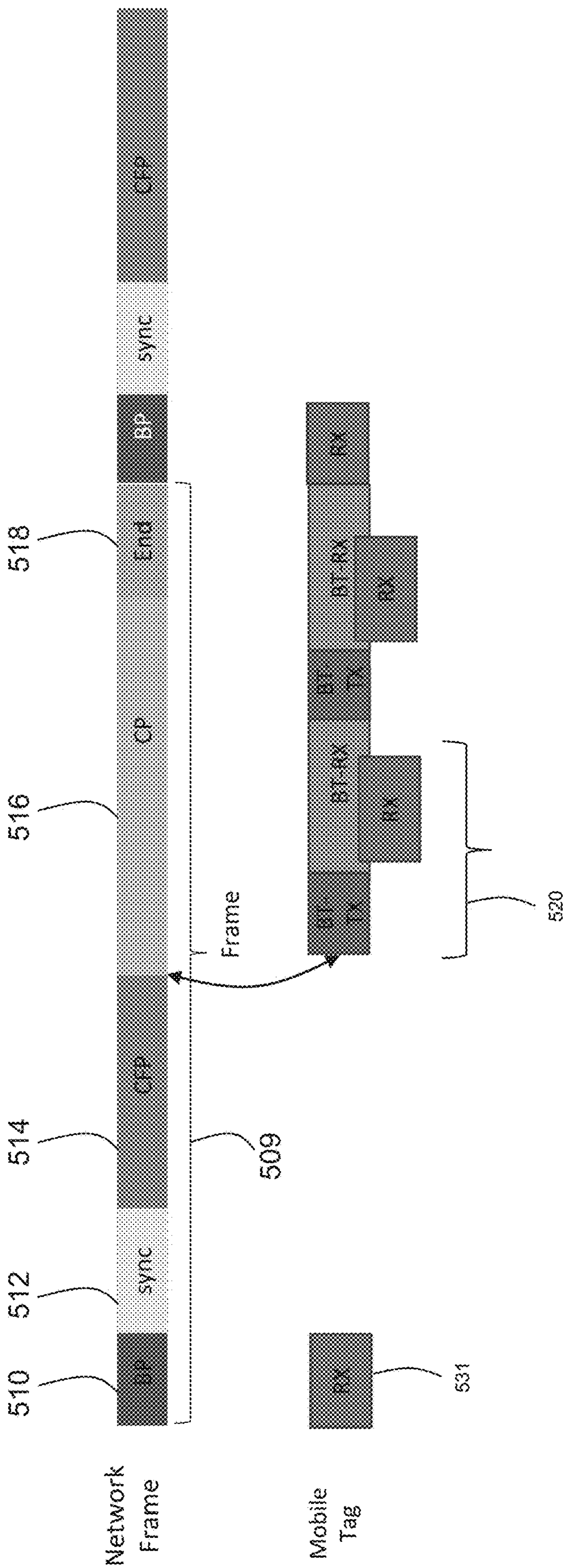

530
520
Mobile Tag
521
522
524
526
528
T
Network Frame
510
512
514
516
518
sync
sync
Frame
509

FIG. 12



Network Frame
Mobile Tag
510
512
514
516
518
509
520
531
BP
sync
CFP
CP
End
BP
sync
CFP
Frame
RX
BT-TX
BT-RX
RX
BT-TX
BT-RX
RX
RX

FIG. 13

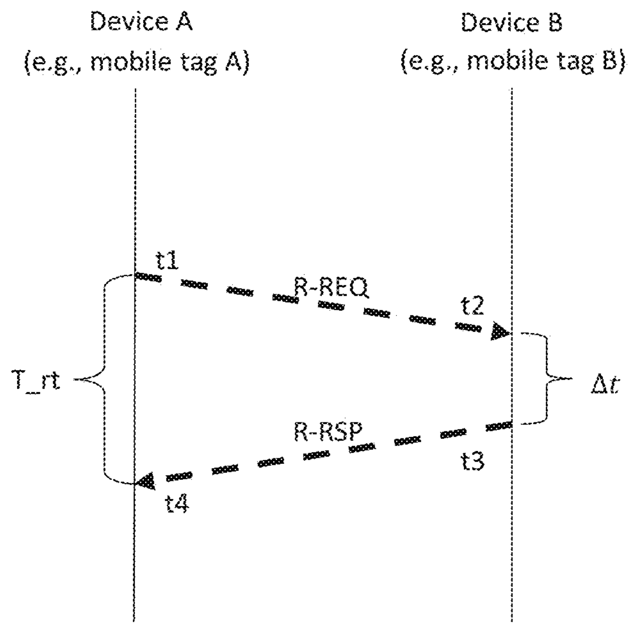


FIG. 14A

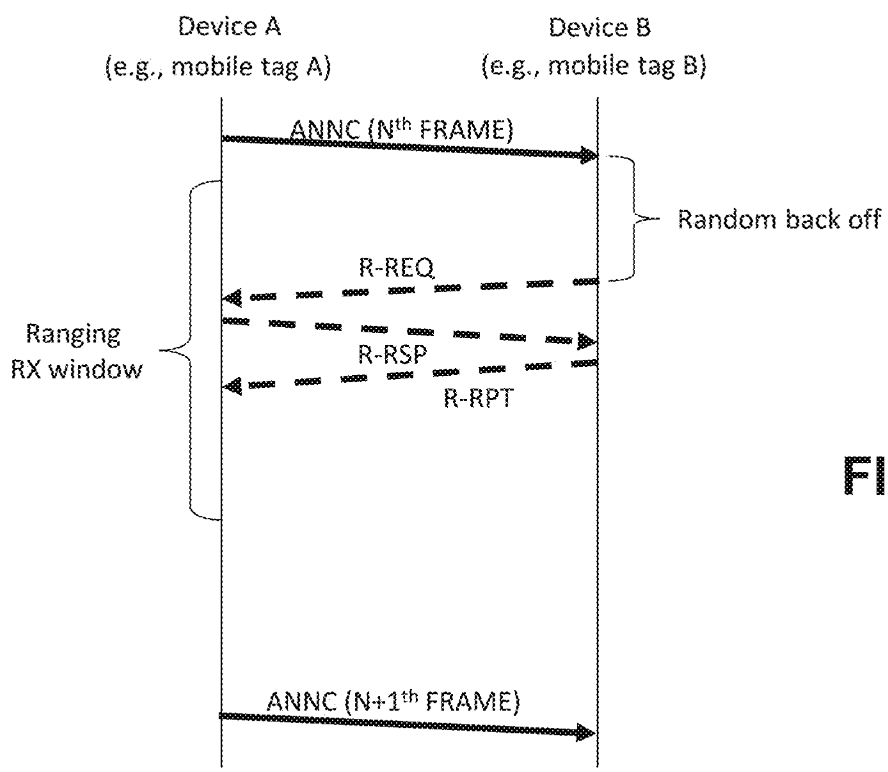


FIG. 14B

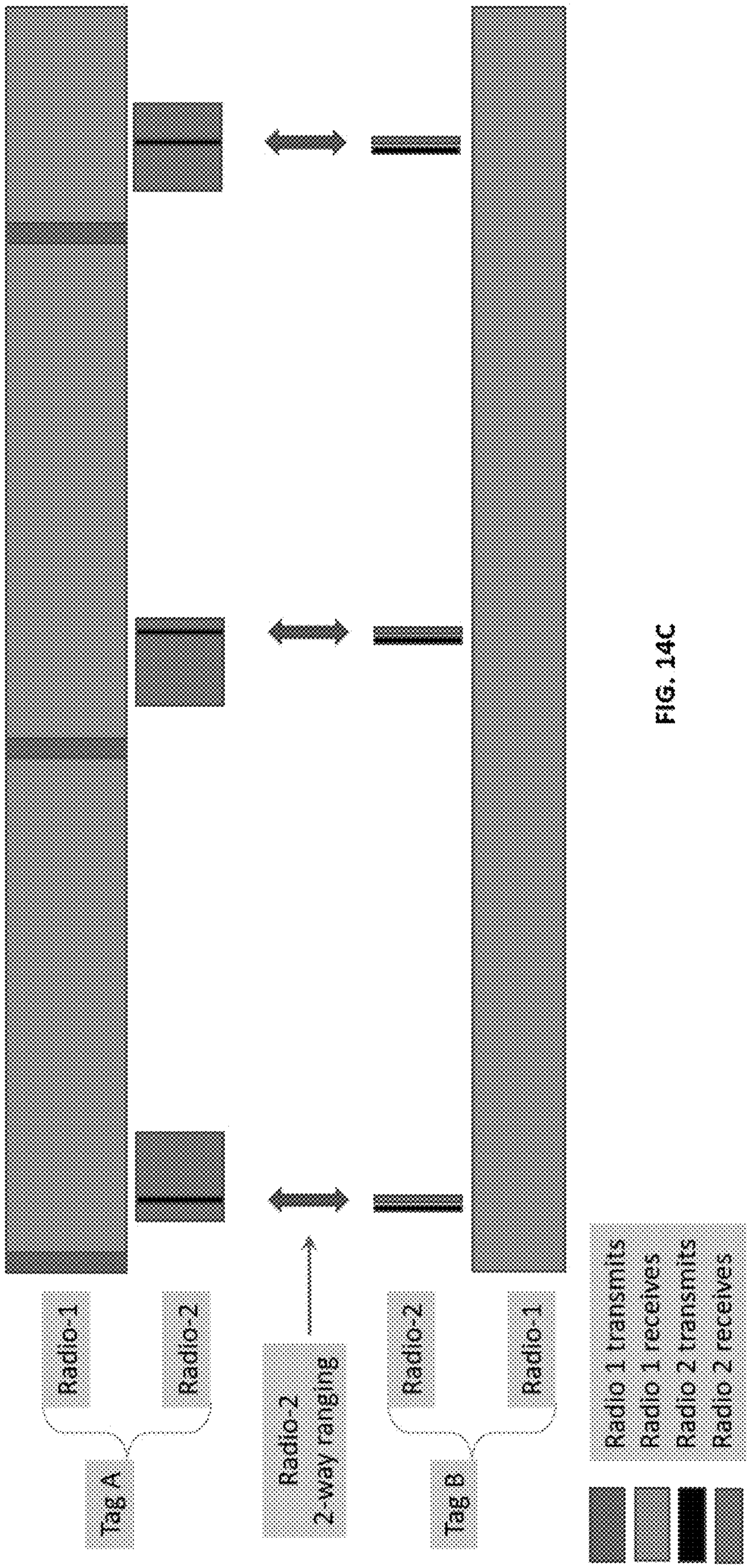
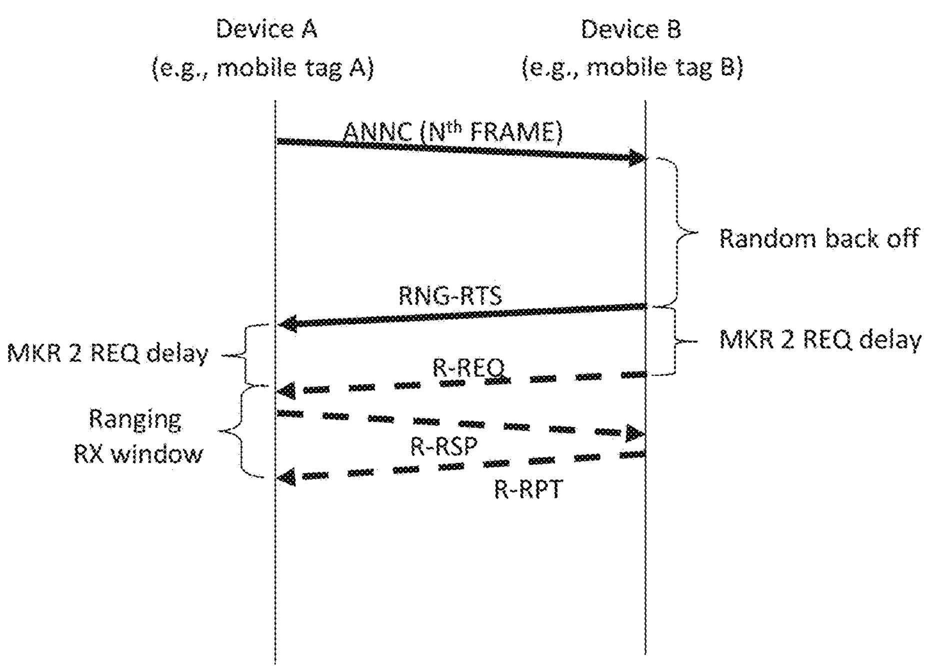

Radio-1
Radio-2
Tag A
Radio-2
2 way ranging
Radio-2
Radio-1
Tag B
Radio 1 transmits
Radio 1 receives
Radio 2 transmits
Radio 2 receives

FIG. 14C



Device A
(e.g., mobile tag A)
Device B
(e.g., mobile tag B)
ANNC (Nth FRAME)
Random back off
RNG-RTS
MKR 2 REQ delay
MKR 2 REQ delay
R-REQ
Ranging
RX window
R-RSP
R-RPT

FIG. 14D

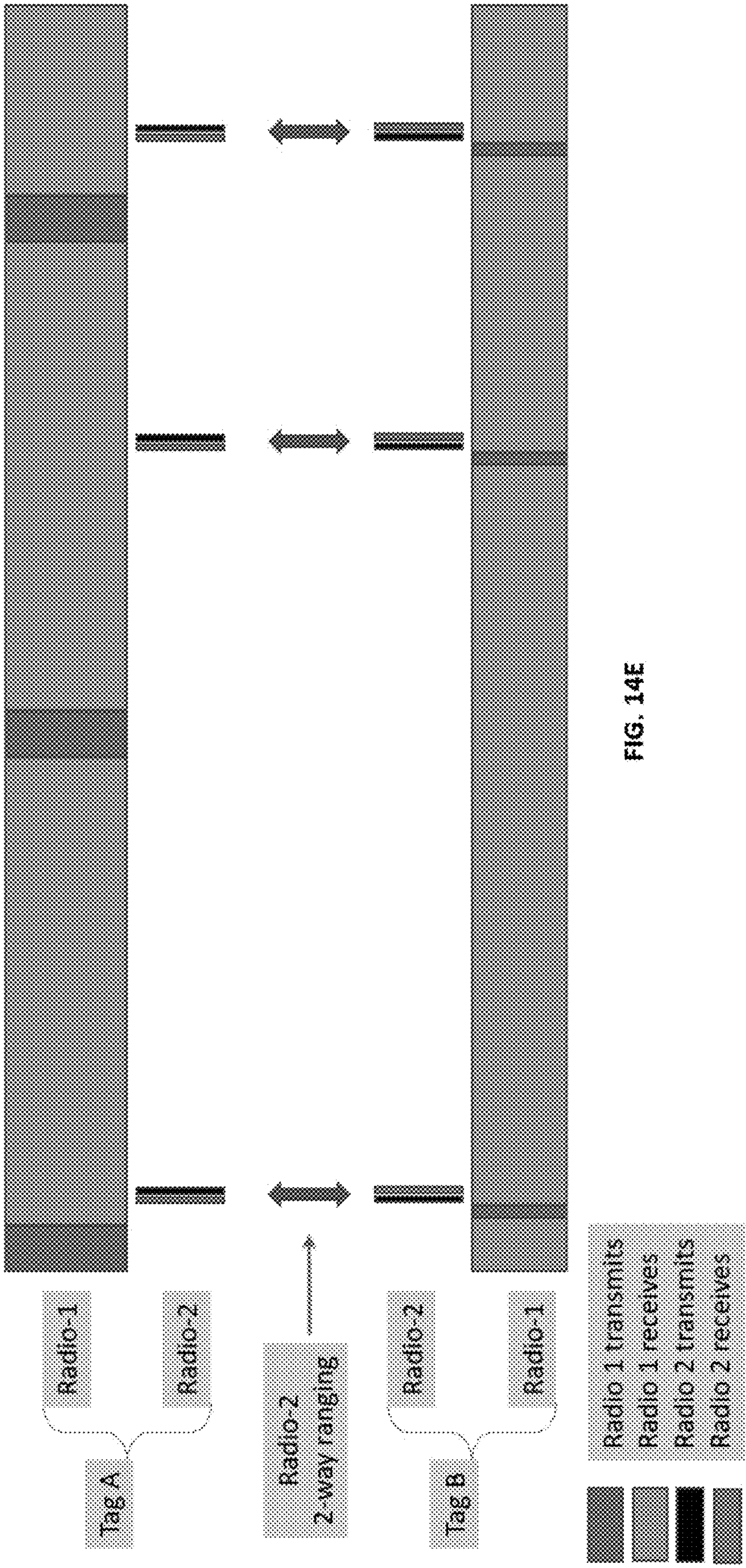

Tag A
Radio-1
Radio-2
Radio-2
2 way ranging
Tag B
Radio-2
Radio-1
Radio 1 transmits
Radio 1 receives
Radio 2 transmits
Radio 2 receives

FIG. 14E

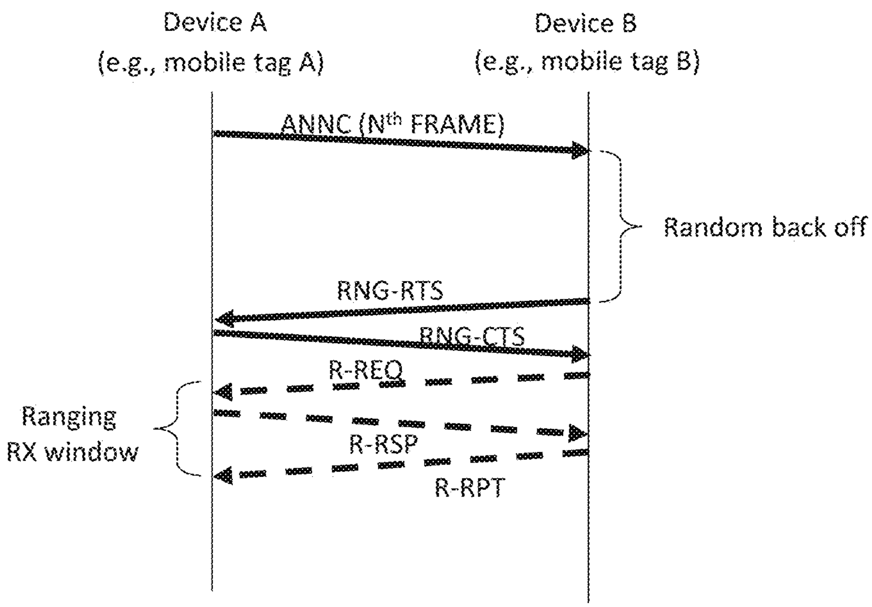

Device A
(e.g., mobile tag A)
Device B
(e.g., mobile tag B)
ANNC (N^th FRAME)
Random back off
RNG-RTS
RNG-CTS
R-REQ
Ranging
RX window
R-RSP
R-RPT

FIG. 14F

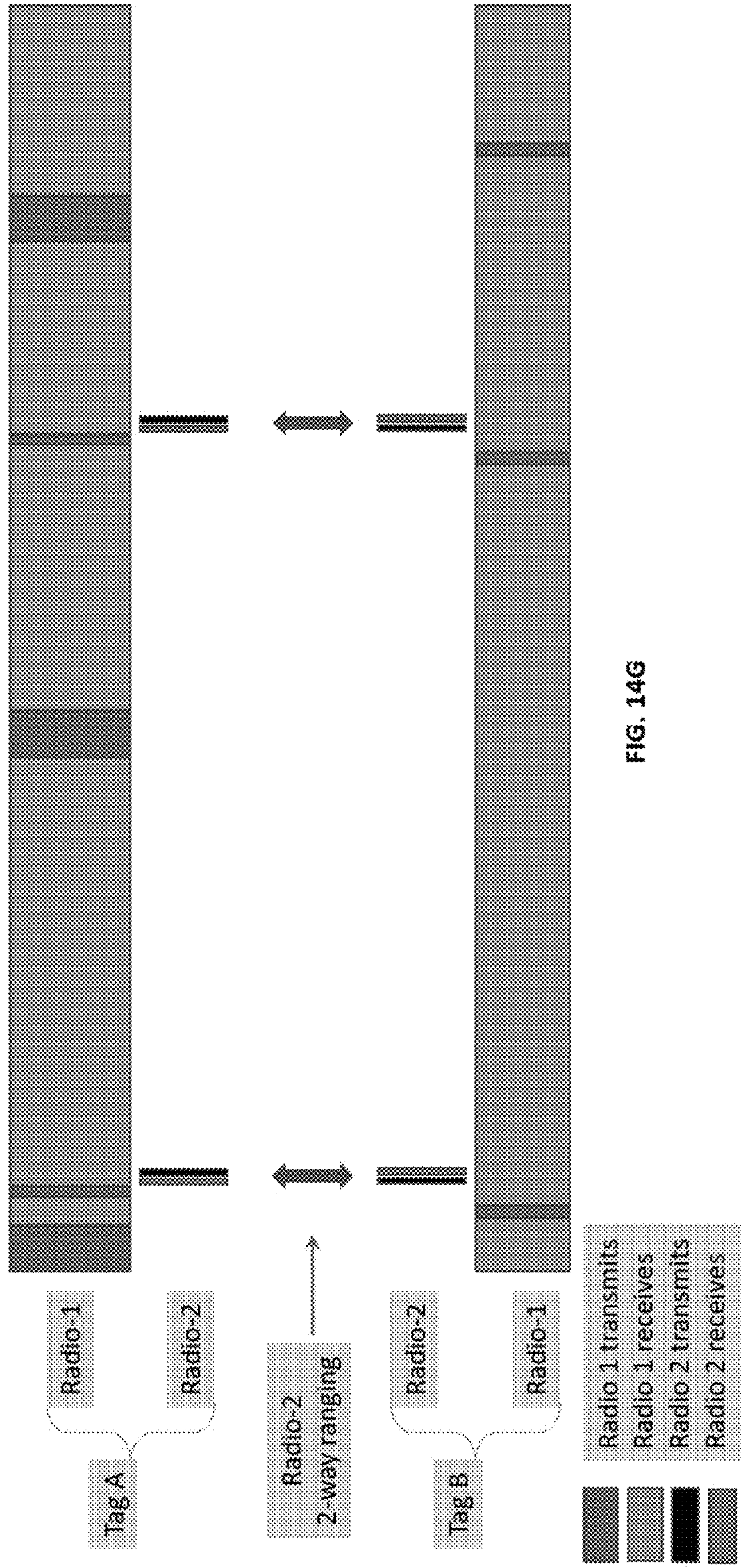
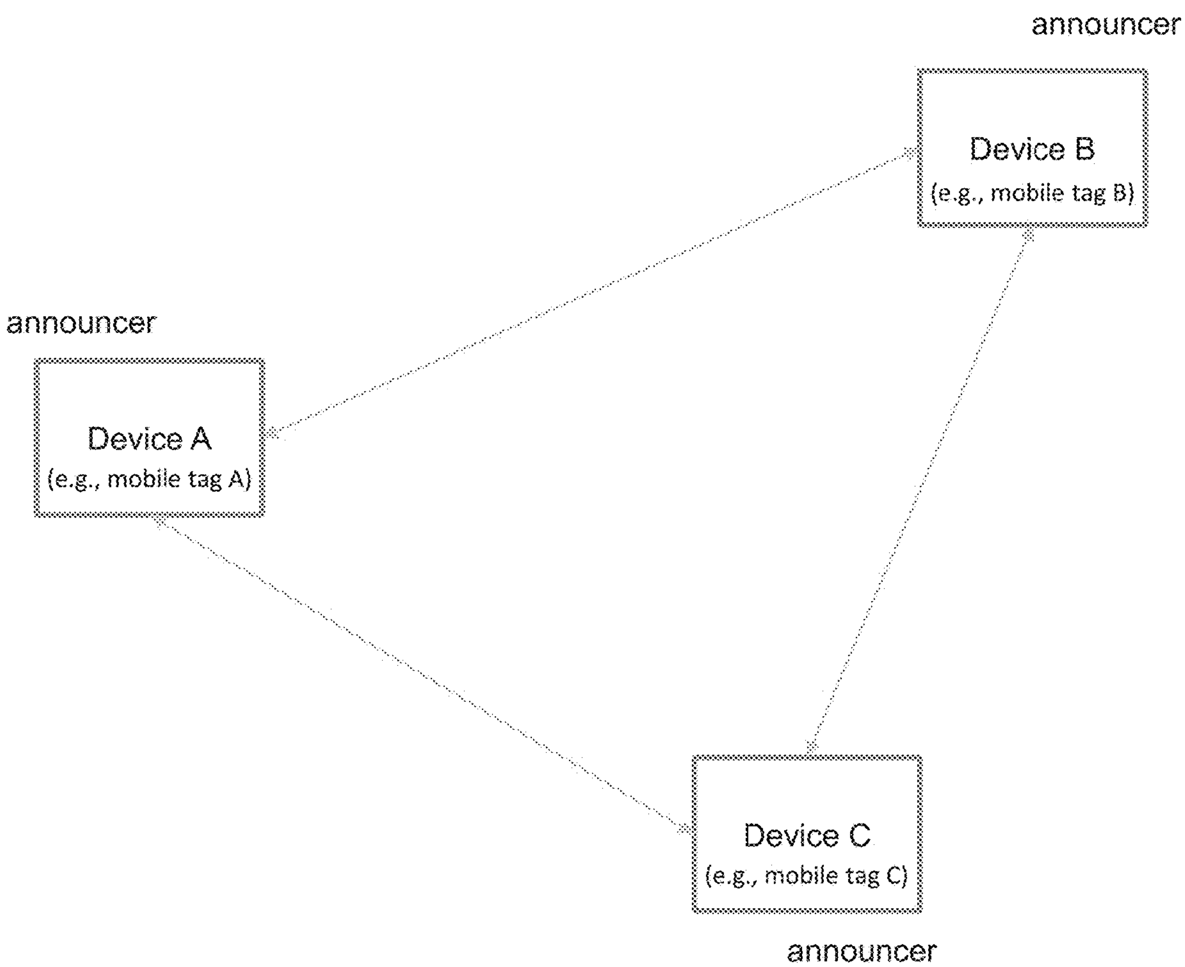

Tag A
Radio-1
Radio-2
Radio-2
2-way ranging
Tag B
Radio-2
Radio-1
Radio 1 transmits
Radio 1 receives
Radio 2 transmits
Radio 2 receives

FIG. 14G



announcer
Device B
(e.g., mobile tag B)
announcer
Device A
(e.g., mobile tag A)
Device C
(e.g., mobile tag C)
announcer

FIG. 14H

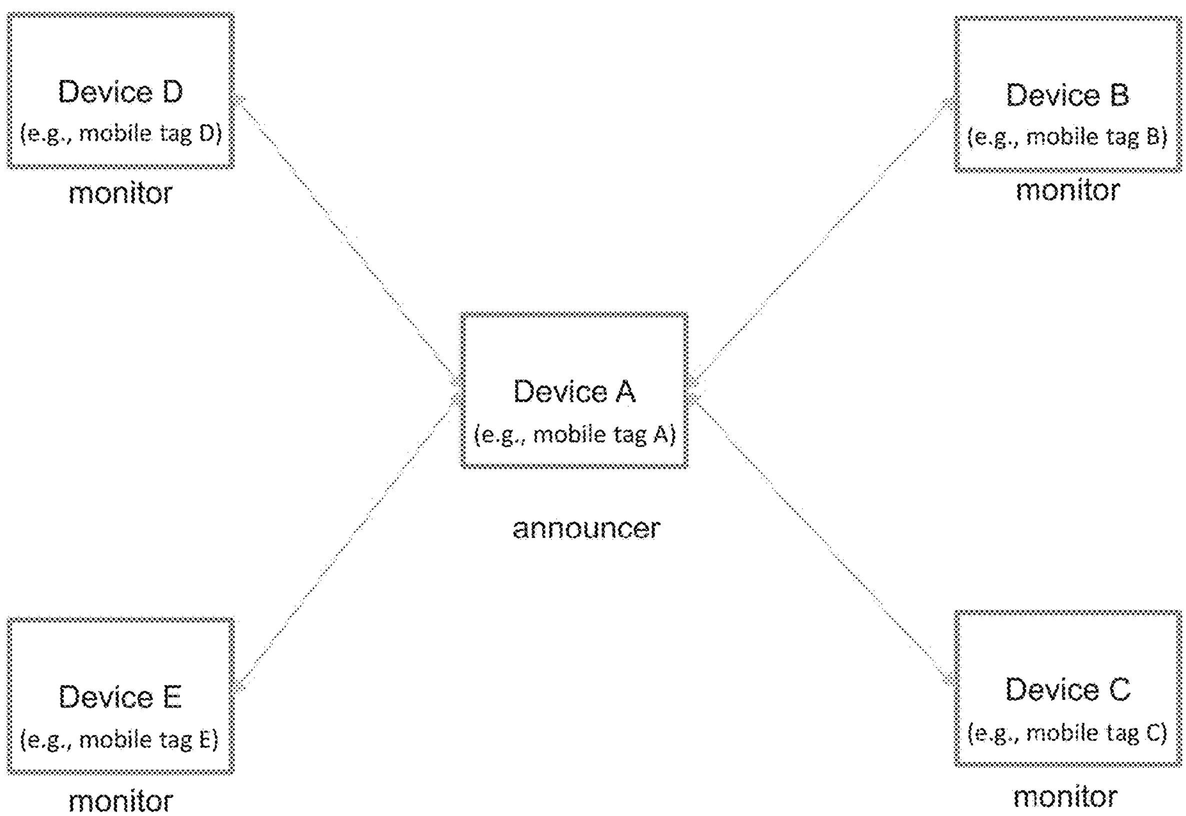

Device D
(e.g., mobile tag D)
monitor
Device B
(e.g., mobile tag B)
monitor
Device A
(e.g., mobile tag A)
announcer
Device E
(e.g., mobile tag E)
monitor
Device C
(e.g., mobile tag C)
monitor

FIG. 14J

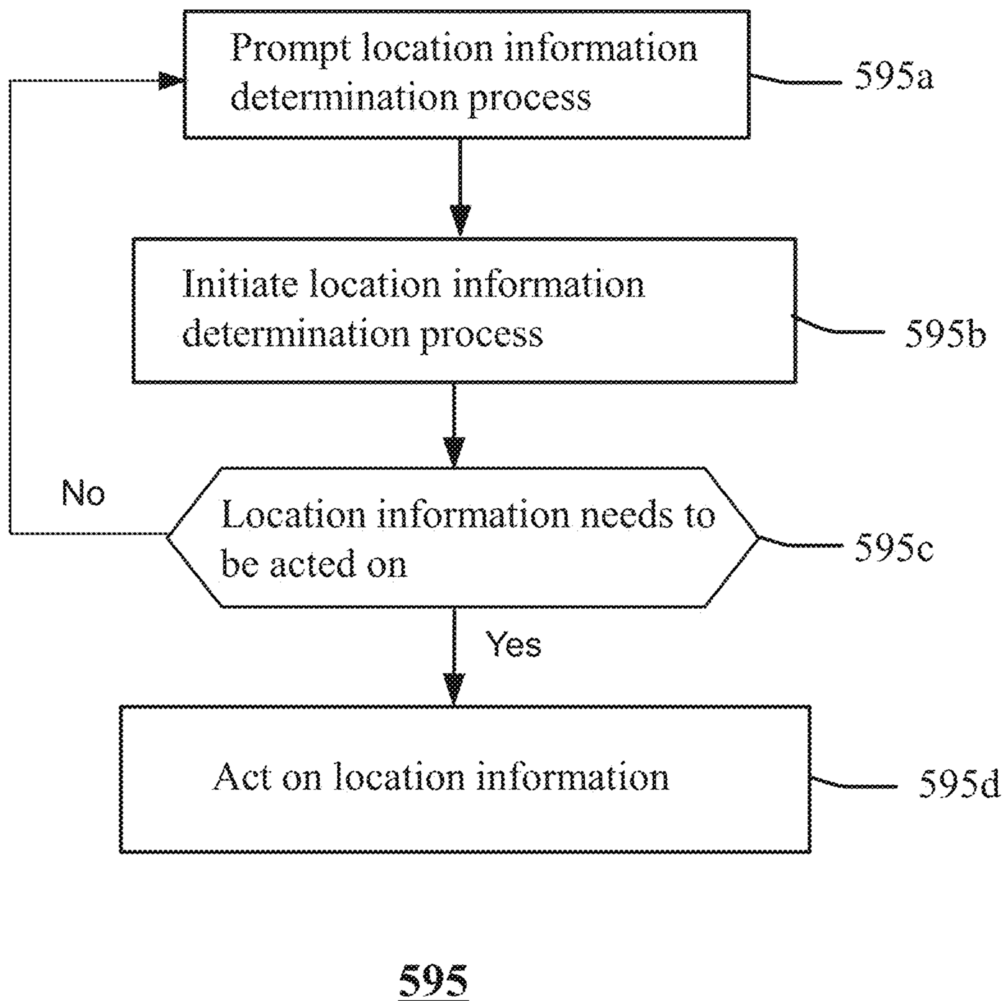

Prompt location information determination process
595a
Initiate location information determination process
595b
No
Location information needs to be acted on
595c
Yes
Act on location information
595d
595

FIG. 14K

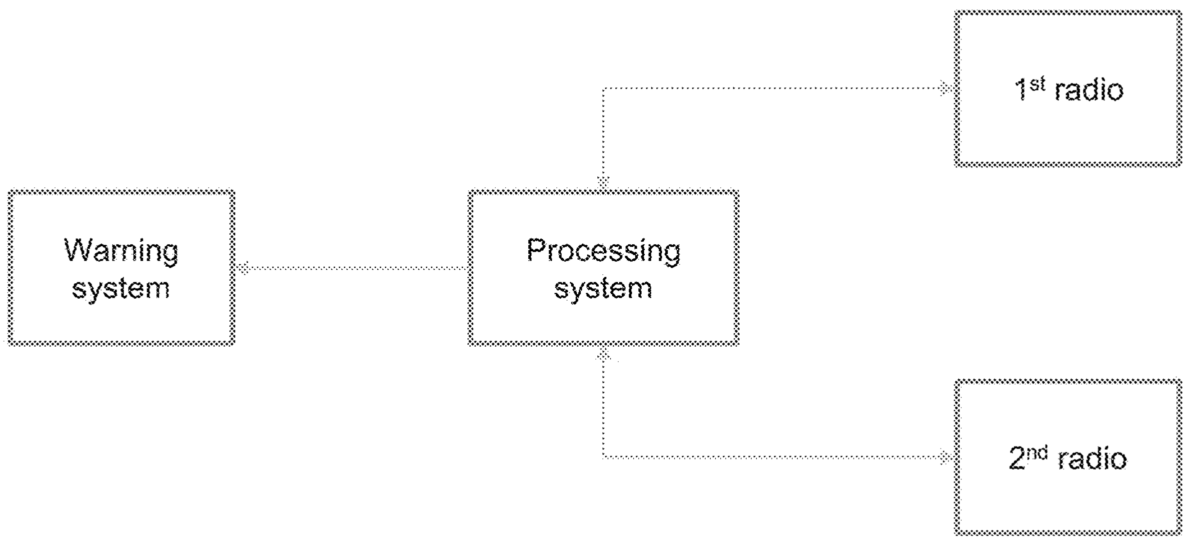


FIG. 14L

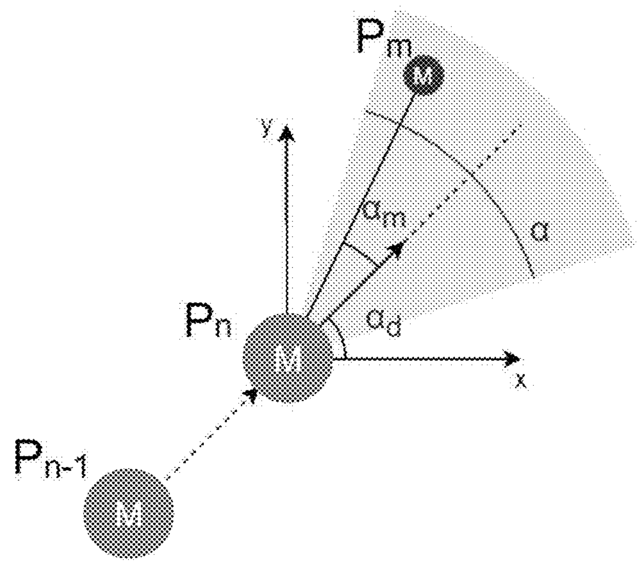


FIG. 15

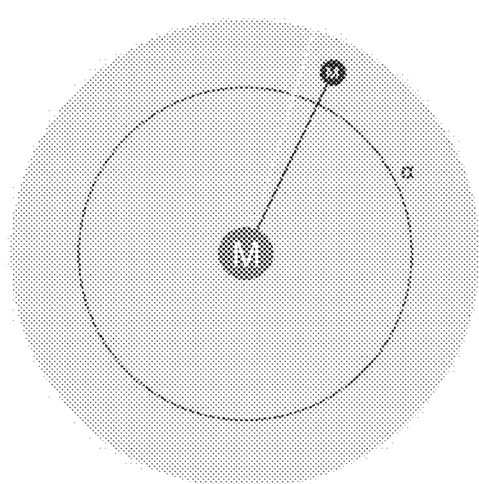
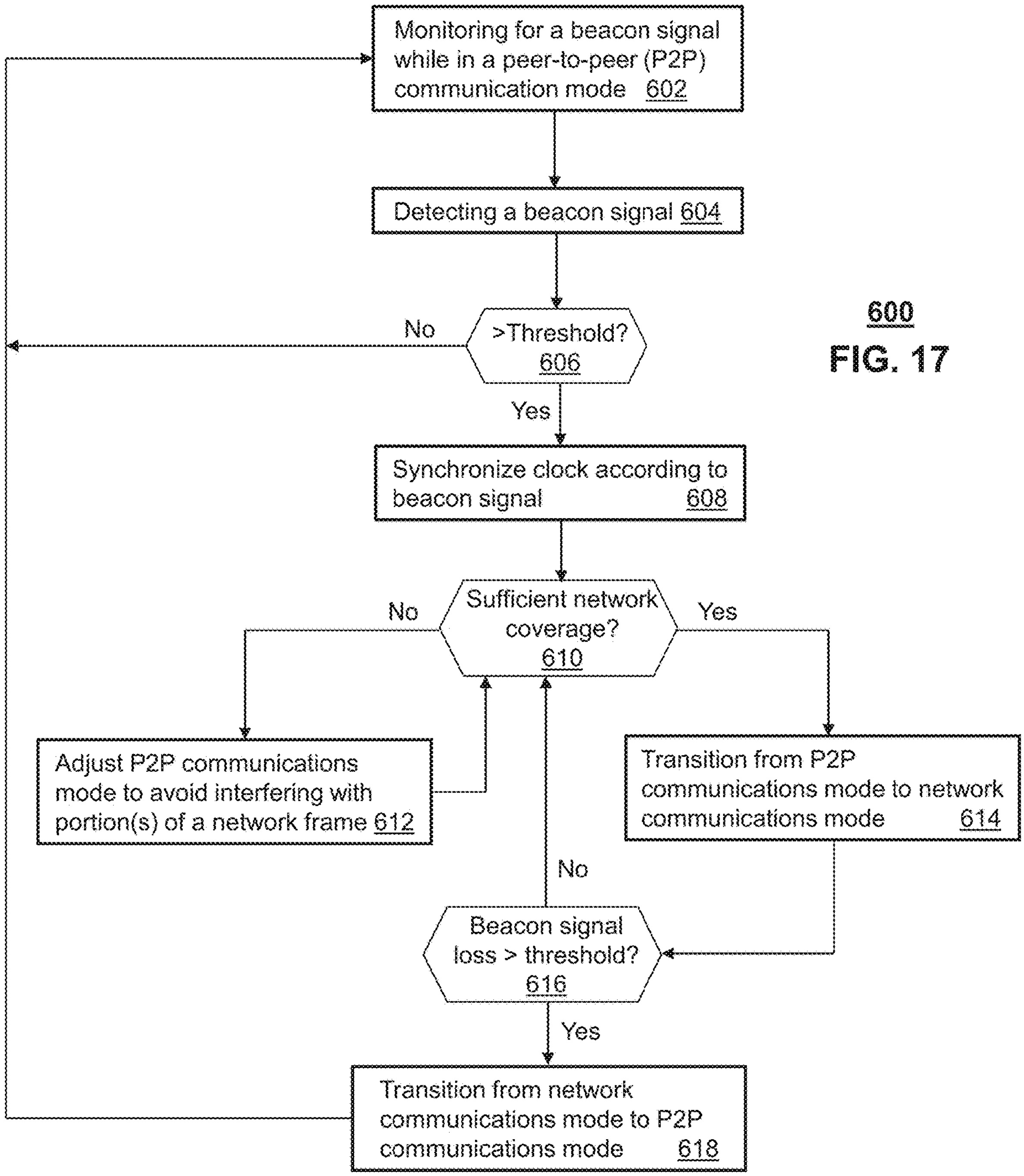
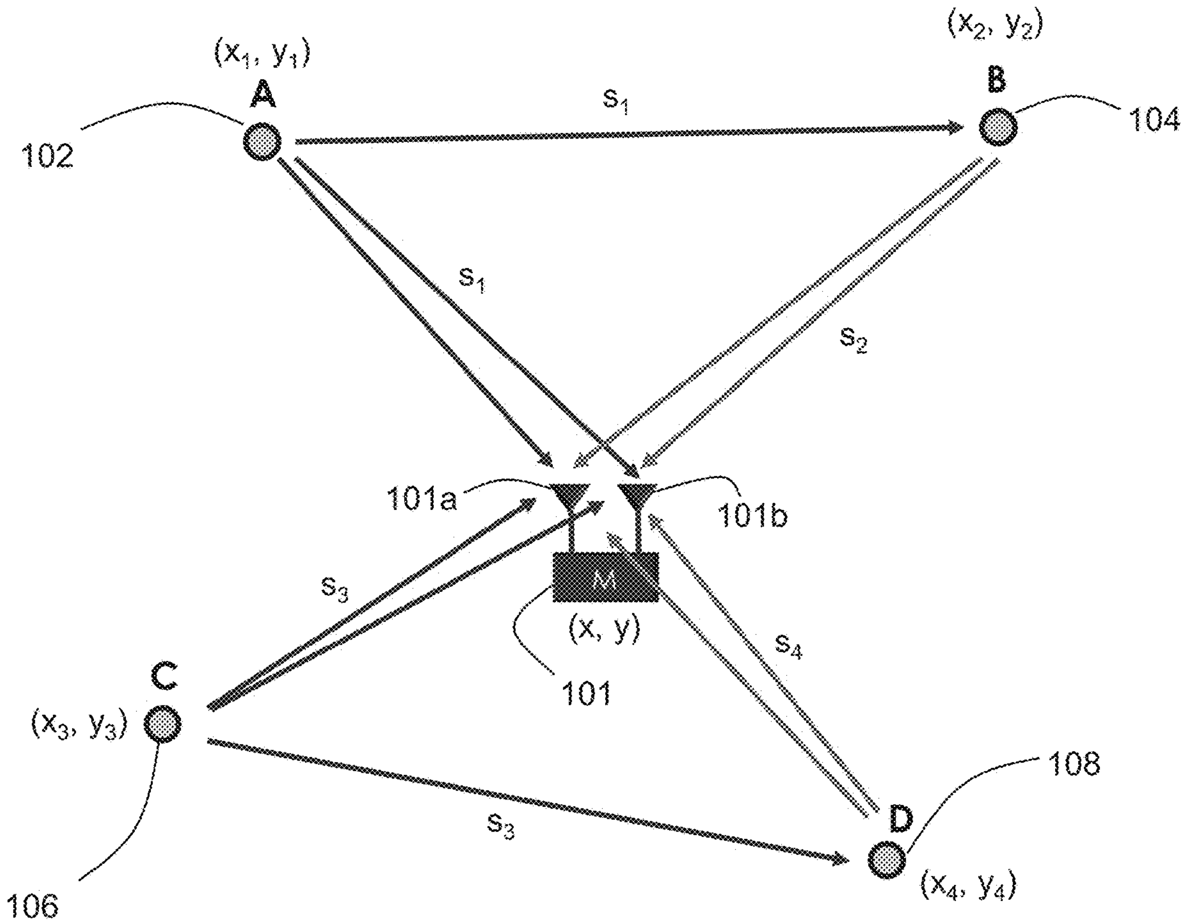


FIG. 16


Monitoring for a beacon signal while in a peer-to-peer (P2P) communication mode 602
Detecting a beacon signal 604
No
>Threshold? 606
Yes
Synchronize clock according to beacon signal 608
No
Sufficient network coverage? 610
Yes
Adjust P2P communications mode to avoid interfering with portion(s) of a network frame 612
Transition from P2P communications mode to network communications mode 614
No
Beacon signal loss > threshold? 616
Yes
Transition from network communications mode to P2P communications mode 618

600

FIG. 17



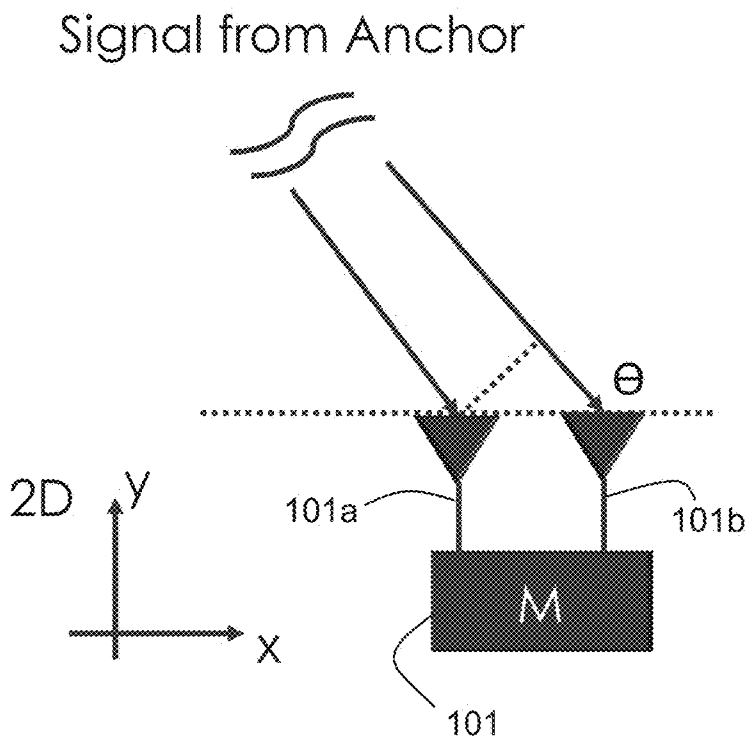
(x1, y1)
A
(x2, y2)
B
s1
102
104
s1
s2
101a
101b
s3
M
(x, y)
s4
101
C
(x3, y3)
108
D
s3
(x4, y4)
106

700

FIG. 18A

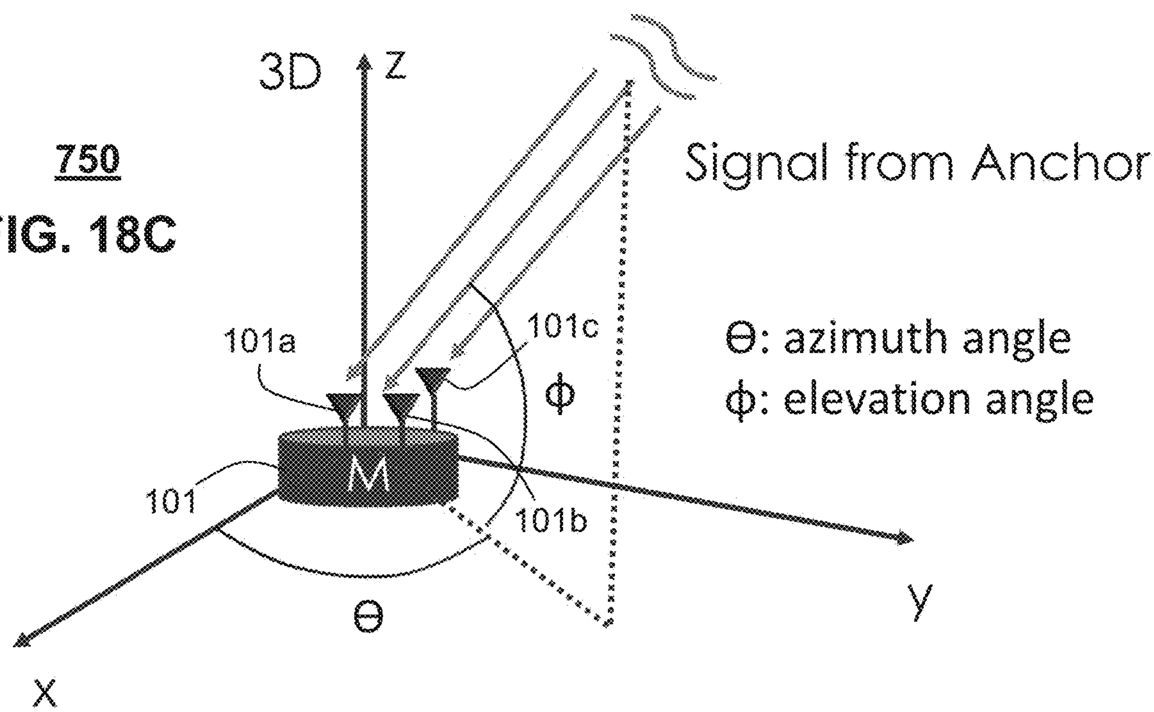
725

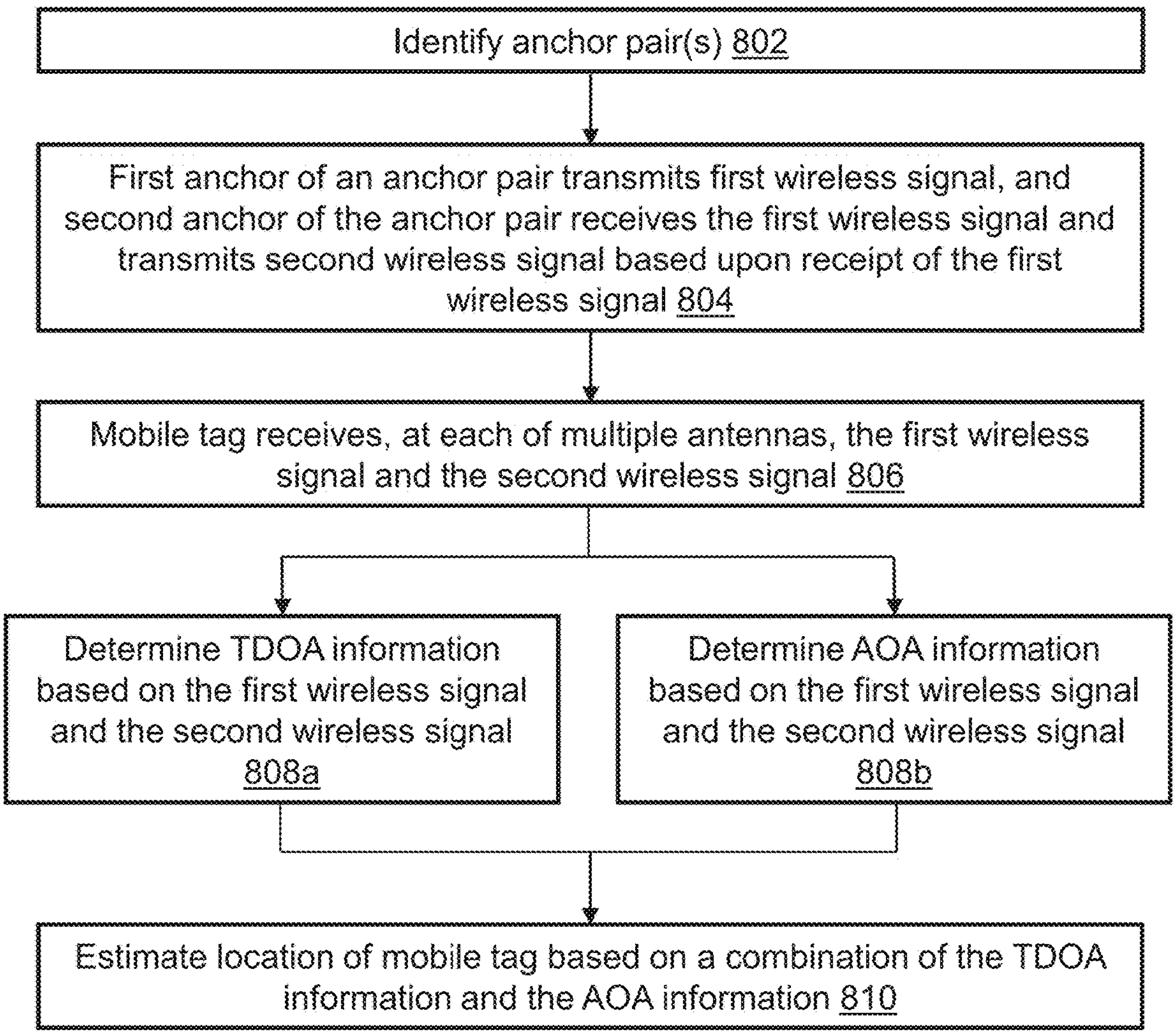
FIG. 18B



750

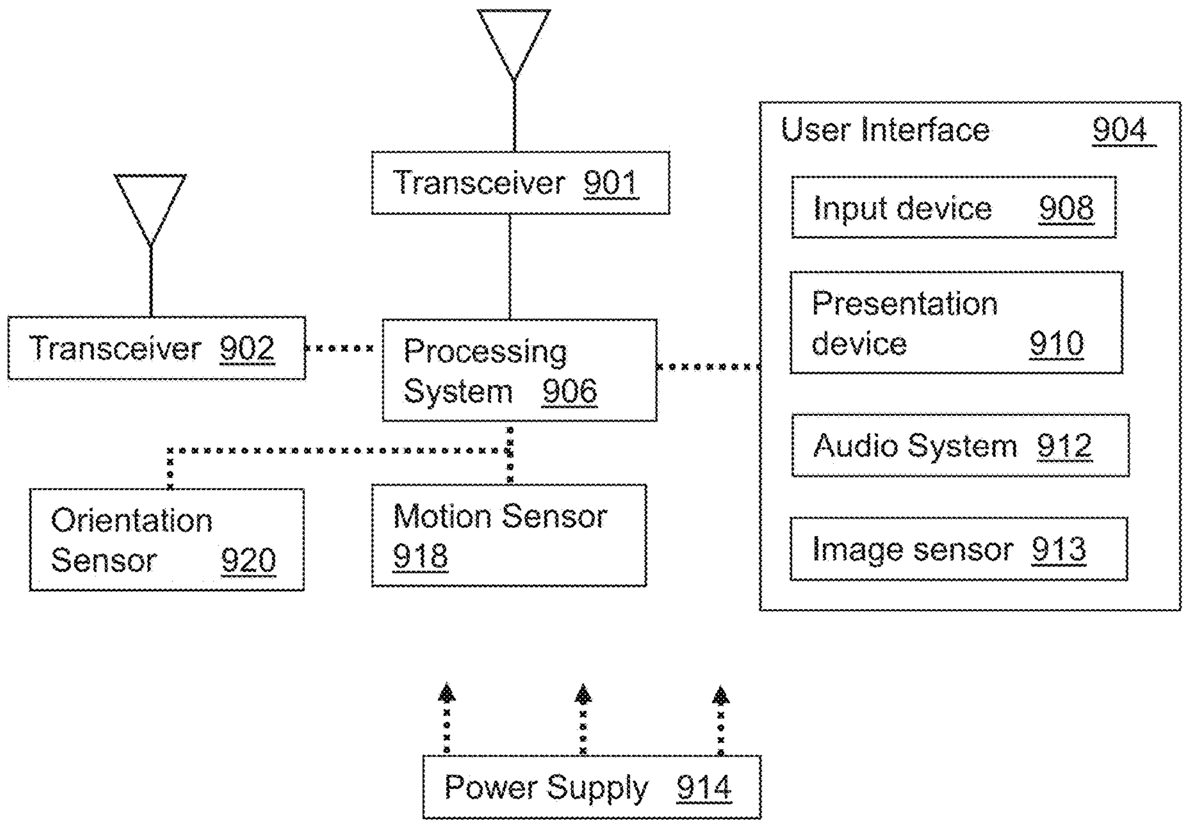
FIG. 18C




Identify anchor pair(s) 802
First anchor of an anchor pair transmits first wireless signal, and second anchor of the anchor pair receives the first wireless signal and transmits second wireless signal based upon receipt of the first wireless signal 804
Mobile tag receives, at each of multiple antennas, the first wireless signal and the second wireless signal 806
Determine TDOA information based on the first wireless signal and the second wireless signal 808a
Determine AOA information based on the first wireless signal and the second wireless signal 808b
Estimate location of mobile tag based on a combination of the TDOA information and the AOA information 810

800

FIG. 19


Transceiver 901
User Interface 904
Input device 908
Transceiver 902
Processing System 906
Presentation device 910
Audio System 912
Orientation Sensor 920
Motion Sensor 918
Image sensor 913
Power Supply 914

900
FIG. 20

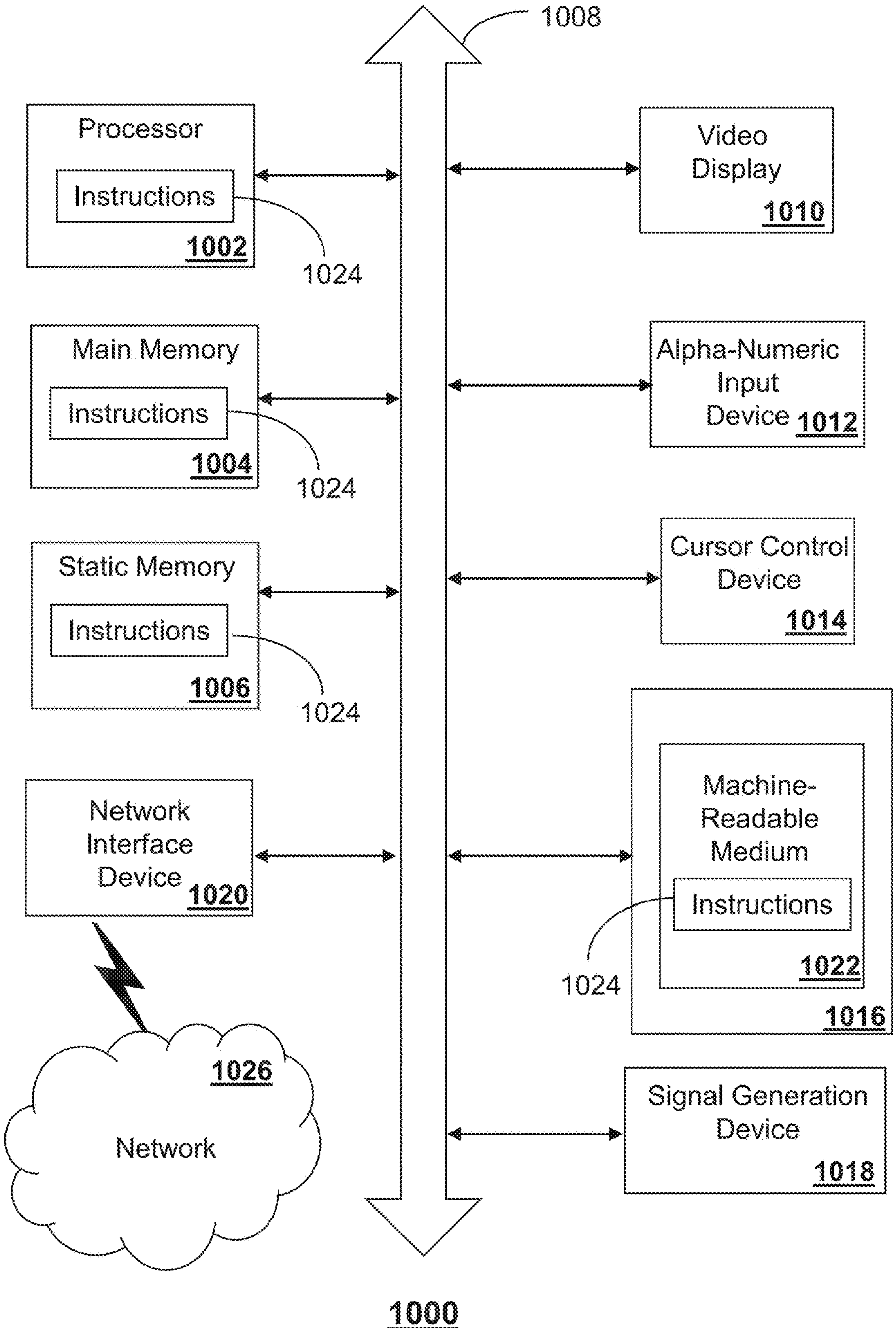

1008
Processor
Instructions
1002
1024
Main Memory
Instructions
1004
1024
Static Memory
Instructions
1006
1024
Network Interface Device 1020
1026
Network
Video Display
1010
Alpha-Numeric Input Device 1012
Cursor Control Device
1014
Machine-Readable Medium
Instructions
1022
1024
1016
Signal Generation Device
1018
1000

FIG. 21

METHOD AND APPARATUS FOR DETERMINING RELATIVE POSITIONING BETWEEN DEVICES

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims priority to U.S. Provisional Ser. No. 63/050,144, filed Jul. 10, 2020. This application also claims priority to U.S. Provisional Ser. No. 63/052,188, filed Jul. 15, 2020. The contents of each of the foregoing are hereby incorporated by reference into this application as if set forth herein in full.

FIELD OF THE DISCLOSURE

[0002] The subject disclosure relates to a method and apparatus for determining relative positioning between devices.

BACKGROUND

[0003] Determining location information between devices can serve multiple purposes, such as predicting and mitigating collisions, tracking distances between devices, or combinations thereof. Location information can correspond to distances between devices, trajectory of devices, positions of devices, or combinations thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

[0005] FIG. **1** is a block diagram illustrating an exemplary, non-limiting embodiment of a mobile tag and anchors for determining location information between the mobile tag and the anchors in accordance with various aspects described herein.

[0006] FIG. **2** is a block diagram illustrating an exemplary, non-limiting embodiment of a timing diagram for determining location information between the mobile tag and the anchors of FIG. **1** in accordance with various aspects described herein.

[0007] FIG. **3** is a block diagram illustrating an exemplary, non-limiting embodiment for determining location information between the mobile tag and pairs of anchors in accordance with various aspects described herein.

[0008] FIGS. **4**A, **4**B and **4**C are block diagrams illustrating exemplary, non-limiting embodiments for selecting pairs of anchors in accordance with various aspects described herein.

[0009] FIG. **5** is a block diagram illustrating an exemplary, non-limiting embodiment of a mobile tag and an anchor for determining location information between the mobile tag and the anchor in accordance with various aspects described herein.

[0010] FIG. **6** is a block diagram illustrating an exemplary, non-limiting embodiment of a timing diagram for determining location information between the mobile tag and the anchor of FIG. **5** in accordance with various aspects described herein.

[0011] FIG. **7** is a block diagram illustrating an exemplary, non-limiting embodiment for determining location information of mobile tags in a demarcated area in accordance with various aspects described herein.

[0012] FIG. **8** depicts an illustrative embodiment of a method for determining location information and uses thereof in accordance with various aspects described herein.

[0013] FIG. **9** is a block diagram illustrating an exemplary, non-limiting embodiment for scheduling a process for determining location information between mobile tags and pairs of anchors in the demarcated area of FIG. **7** in accordance with various aspects described herein.

[0014] FIG. **10** is a block diagram illustrating an exemplary, non-limiting embodiment of environments where mobile tags can operate from in accordance with various aspects described herein.

[0015] FIG. **11** is a block diagram illustrating an exemplary, non-limiting embodiment of a network frame in accordance with various aspects described herein.

[0016] FIG. **12** is a block diagram illustrating an exemplary, non-limiting embodiment of a peer-to-peer frame configured for monitoring a presence of a network frame in accordance with various aspects described herein.

[0017] FIG. **13** is a block diagram illustrating an exemplary, non-limiting embodiment of a mobile tag configured to utilize peer-to-peer communications in a manner that avoids interfering with portions of a network frame in accordance with various aspects described herein.

[0018] FIG. **14**A is a block diagram illustrating an exemplary, non-limiting embodiment of a two-way time of arrival process in accordance with various aspects described herein.

[0019] FIGS. **14**B and **14**C are block diagrams illustrating exemplary, non-limiting embodiments of a process for determining location data between devices (e.g., mobile tags) in accordance with various aspects described herein.

[0020] FIGS. **14**D and **14**E are block diagrams illustrating exemplary, non-limiting embodiments of a process for determining location data between devices (e.g., mobile tags) in accordance with various aspects described herein.

[0021] FIGS. **14**F and **14**G are block diagrams illustrating exemplary, non-limiting embodiments of a process for determining location data between devices (e.g., mobile tags) in accordance with various aspects described herein.

[0022] FIGS. **14**H and **14**J are block diagrams illustrating exemplary, non-limiting embodiments of architectures for communicating between devices (e.g., mobile tags) in accordance with various aspects described herein.

[0023] FIG. **14**K depicts an illustrative embodiment of a method in accordance with various aspects described herein.

[0024] FIG. **14**L is a block diagram illustrating an example, non-limiting embodiment of the components of the devices (e.g., mobile tags) of FIGS. **14**A through **14**J in accordance with various aspects described herein.

[0025] FIG. **15** is a block diagram illustrating an exemplary, non-limiting embodiment of capabilities of a mobile tag to determine its location in a network of anchors providing location services in accordance with various aspects described herein.

[0026] FIG. **16** is a block diagram illustrating an exemplary, non-limiting embodiment of capabilities of a mobile tag to determine its location utilizing peer-to-peer communications with other mobile tags in accordance with various aspects described herein.

[0027] FIG. **17** depicts an illustrative embodiment of a method for transitioning between modes of communications; particularly, peer-to-peer communications mode and network communications mode in accordance with various aspects described herein.

[0028] FIG. **18**A is a block diagram illustrating an exemplary, non-limiting embodiment for determining location information between a mobile tag and pairs of anchors in accordance with various aspects described herein.

[0029] FIG. **18**B is a block diagram illustrating an exemplary, non-limiting embodiment of a mobile tag having two antennas for facilitating determining of location information of the mobile tag in accordance with various aspects described herein.

[0030] FIG. **18**C is a block diagram illustrating an exemplary, non-limiting embodiment of a mobile tag having three antennas for facilitating determining of location information of the mobile tag in accordance with various aspects described herein.

[0031] FIG. **19** depicts an illustrative embodiment of a method for determining location information in accordance with various aspects described herein.

[0032] FIG. **20** is a block diagram of an example, non-limiting embodiment of a communication device in accordance with various aspects described herein.

[0033] FIG. **21** is a block diagram of an example, non-limiting embodiment of a computing system in accordance with various aspects described herein.

DETAILED DESCRIPTION

[0034] The subject disclosure describes, among other things, illustrative embodiments for determining location information in association with devices.

[0035] One or more aspects of the subject disclosure include a method. The method can comprise transmitting, by a first transmitter of a first device, a first wireless signal, wherein the first wireless signal utilizes a first signaling technology. Further, the method can include receiving, by a second receiver of the first device, a second wireless signal generated by a second device, wherein the second wireless signal utilizes a second signaling technology that differs from the first signaling technology. Further, the method can include transmitting, by a second transmitter of the first device, a third wireless signal responsive to receiving the second wireless signal, wherein the third wireless signal utilizes the second signaling technology, and wherein the third wireless signal enables the second device to determine location information associated with the first device and the second device.

[0036] One or more aspects of the subject disclosure include a non-transitory machine-readable medium, comprising executable instructions that, when executed by a processing system of a first device, facilitate performance of operations. The operations can include receiving, by a first receiver of the first device, a first wireless signal generated by a second device, wherein the first wireless signal utilizes a first signaling technology. Further, the operations can include transmitting, by a second transmitter of the first device, a second wireless signal, wherein the second wireless signal utilizes a second signaling technology that differs from the first signaling technology. Further, the operations can include receiving, by a second receiver of the first device, a third wireless signal, wherein the third wireless signal utilizes the second signaling technology. Further, the operations can include determining location information associated with the first device and the second device based on the third wireless signal.

[0037] One or more aspects of the subject disclosure include a first device, comprising a first transmitter, a second transmitter, a second receiver, a processing system including a processor, and a memory that stores executable instructions that, when executed by the processing system, facilitate performance of operations. The operations can include transmitting, by the first transmitter, a first wireless signal, wherein the first wireless signal utilizes a narrowband signaling technology. Further, the operations can include receiving, by the second receiver, a second wireless signal generated by a second device, wherein the second wireless signal utilizes a wideband signaling technology. Further, the operations can include transmitting, by the second transmitter, a third wireless signal, wherein the third wireless signal utilizes the wideband signaling technology, and wherein the third wireless signal enables the second device to determine location information associated with the first device and the second device.

[0038] Other embodiments are described in the subject disclosure.

[0039] FIG. **1** is a block diagram illustrating an exemplary, non-limiting embodiment of a mobile tag **101** and anchors **102** ("A") and **104** ("B") for determining location information between the mobile tag **101** ("M") and the anchors **102** and **104** in accordance with various aspects described herein. In an embodiment, anchor **102** can be configured to transmit a first wireless signal (s_1) that can be received by anchor **104** and the mobile tag **101**. The timing of transmission by anchor **102** and reception by the mobile tag **101** and anchor **104** of the first wireless signal (s_1) is depicted in FIG. **2**.

[0040] In an embodiment, anchor **102** transmits the first wireless signal (s_1) at time t_0, which in turn is received by the mobile tag **101** at time ti and anchor **104** at time t_2. Anchor **104** can be configured to transmit a second wireless signal (s_2) at time t_3, which is received by the mobile tag **101** at time t_4. The mobile tag **101** can be configured to use a time difference of arrival (TDOA) measurement technique based on the first and second wireless signals (s_1, s_2) to determine location information between the mobile tag **101** and the anchors **102** and **104** as will be described below.

[0041] In an embodiment, anchors **102** and **104** are stationary. Accordingly, their x-y coordinates and the distance between anchors **102** and **104** (d_{AB}) can be made known to the mobile tag **101** either by a look-up table provisioned into a memory of the mobile tag **101** or by including such information in the first wireless signal (s_1), which can then be obtained by the mobile tag **101**. Additionally, the mobile tag **101** can be configured to include in its look-up table the receive time and transmit time (t_2, t_3) of anchor **104** and/or a time difference between these times ($\Delta t=t_3-t_2$), or can receive this information in the second wireless signal (s_2) transmitted by anchor **104**. The equations that follow can be used to calculate a first possible location of the mobile tag **101** relative to anchor pair **102**, **104**.

[0042] The distance between anchor **102** and the mobile tag can be represented as,

$$d_{AM}=c(t_1-t_0) \quad \text{(EQ 1)},$$

where c is the speed of light constant. Similarly, the distance from anchor **102** to anchor **104** can be represented as,

$$d_{AB}=c(t_2-t_0) \quad \text{(EQ 2)}.$$

Additionally, the distance from anchor **104** to the mobile tag **101** can be represented as,

$$d_{BM}=c(t_4-t_3) \quad \text{(EQ 3)}.$$

The total distance traveled by the first wireless signal (s_1) from anchor **102** to anchor **104** and the second wireless signals (s_2) from anchor **104** to mobile tag **101** can be represented as,

$$d_{AB}+d_{BM}=c(t_2-t_0+t_4-t_3) \quad \text{(EQ 4A)}.$$

To eliminate variable t_0, equation EQ1 can be subtracted from equation EQ 4A, resulting in,

$$d_{AB}+d_{BM}-d_{AM}=c(t_2-t_1+t_4-t_3) \quad \text{(EQ 4B)}.$$

[0043] Substituting $\Delta t=t_3-t_2$ into EQ 4B results in equation,

$$d_{AB}+d_{BM}-d_{AM}=c(t_4-t_1-\Delta t) \quad \text{(EQ 4C)}.$$

[0044] Since d_{AB} is a constant known to the mobile tag **101** and the time variables of the factor $c(t_4-t_1-\Delta t)$ are also known to the mobile tag **101**, EQ 4C can be rewritten as,

$$d_{BM}-d_{AM}=\Delta d_1 \quad \text{(EQ 5)},$$

where $\Delta d_1=c(t_4-t_1-\Delta t)-d_{AB}$, which are constants known to mobile tag **101**. Furthermore, in an example of two-dimensional (2D) space, the distance between anchor **102** and the mobile tag **101** can be represented as,

$$d_{AM}=\sqrt{(x-x_1)^2+(y-y_1)^2},$$

and the distance between anchor **104** and the mobile tag **101** can be represented as,

$$d_{BM}=\sqrt{(x-x_2)^2+(y-y_2)^2}.$$

Substituting d_{AM} and d_{BM} in EQ 5 results in the following equation,

$$\sqrt{(x-x_2)^2+(y-y_2)^2}-\sqrt{(x-x_1)^2+(y-y_1)^2}=\Delta d_1 \quad \text{(EQ 6)}.$$

[0045] Equation EQ 6 has only two unknown variables (x, y) that can be solved by the mobile tag **101** utilizing a non-linear regression technique (e.g., Nonlinear Least Squares). Such a technique produces a hyperbolic curve of solutions for x and y that is associated with the positions of anchors **102** and **104**. Such a hyperbolic curve can be represented as,

$$h_{AB}=\Delta d_1 \quad \text{(EQ 7A)},$$

where $h_{AB}=\sqrt{(x-x_2)^2+(y-y_2)^2}-\sqrt{(x-x_1)^2+(y-y_1)^2}$. The mobile tag **101** can be further configured to perform the above calculation across other anchor pairs as depicted in FIG. **3**. For example, the mobile tag **101** can be configured to determine a hyperbolic curve between anchors **102** and **106** (i.e., anchors A and C) resulting in equation,

$$h_{AC}=\Delta d_2 \quad \text{(EQ 7B)},$$

where Δd_2 is a constant known to mobile tag **101**, and where $h_{AC}=\sqrt{(x-x_3)^2+(y-y_3)^2}-\sqrt{(x-x_1)^2+(y-y_1)^2}$. Additionally, the mobile tag **101** can be configured to determine a hyperbolic curve between anchors **106** and **108** (i.e., anchors C and D) resulting in equation,

$$h_{CD}=\Delta d_3 \quad \text{(EQ 7C)},$$

where Δd_3 is a constant known to mobile tag **101**, and where $h_{CD}=\sqrt{(x-x_4)^2+(y-y_4)^2}-\sqrt{(x-x_3)^2+(y-y_3)^2}$. The intersection **109** of hyperbolic curves h_{AB}, h_{AC} and h_{CB} corresponding to equations EQ 7A-7C can provide a two-dimensional coordinate location (i.e., x, y) for the mobile tag **101** relative to anchor pairs **102** and **104** (anchors A/B), **102** and **106** (anchors A/C), and **106** and **108** (anchors C/D). It will be appreciated that the mobile tag **101** can also be configured to determine a three-dimensional coordinate (i.e., x, y, z) of its location by utilizing a fourth pair of anchors.

[0046] To enable the above calculations, the pairs of anchors utilized by the mobile tag **101** must satisfy a coverage area that encompasses the anchor pairs and the mobile tag **101**. For example, referring to FIG. **4**A, the coverage area of anchor **102** (anchor "A") is defined by reference **110**, while the coverage area of anchor **104** (anchor "B") is defined by reference **112**. The overlapping region **114** represents the coverage area that is jointly shared by anchors **102** and **104**. Since anchor **104** and the mobile tag **101** must be able to receive the first wireless signal (s_1) generated by anchor **102**, anchor **104** and the mobile tag **101** must be located in the overlapping region **114**. Additionally, the mobile tag **101** must be in the overlapping region **114** in order to receive the second wireless signal (s_2) generated by anchor **104**. Conditions such as described above for anchor pairs **102**, **104** (anchors A/B) must also be satisfied by the other anchor pairs **102**, **106** (anchors A/C) and anchor pairs **106**, **108** (anchors C/D) in order to enable the mobile tag **101** to perform the triangulation calculations described above for hyperbolic curves h_{AB} , h_{AC} and h_{CD}.

[0047] FIG. **4**B shows that the coverage areas **110** and **116** of anchor pair **102**, **106** (anchors A/C) create an overlapping region **120** that encompasses anchors **102** and **106** and the mobile tag **101**, thereby enabling the mobile tag **101** to calculate hyperbolic curve h_{AC}. Additionally, FIG. **4**C shows that the coverage areas **122** and **124** of anchor pair **106**, **108** (anchors C/D) create an overlapping region **126** that encompasses anchors **106** and **108** and the mobile tag **101**, thereby enabling the mobile tag **101** to calculate hyperbolic curve h_{CD}.

[0048] FIG. **5** depicts another embodiment for determining location information between the mobile tag **101** and an anchor **102**. In this embodiment, the mobile tag **101** can be configured to use a two-way time of arrival (TW-TOA) process for determining a distance between itself and the anchor **102**. Optionally, and as depicted in FIG. **6**, the process may begin at anchor **102** which transmits a first wireless signal (s_1), which is received at time t_1. Wireless signal (s_1) can include the x-y coordinates (x_1, y_1) of anchor **102**. Upon receiving the first wireless signal (s_1), the mobile tag **101** can be configured to transmit a second wireless signal (s_2), which can represent a range request (R-REQ) signal directed to anchor **102** initiated at time t_2 and received by anchor **102** at time t_3.

[0049] Upon receiving the R-REQ signal at time t_3, the anchor **102** can process the R-REQ signal and initiate at time t_4 a transmission of a third wireless signal (s_3) representing a range response (R-RSP) signal that is received by the mobile tag **101** at time t_5. The time to process the R-REQ signal and transmit the R-RSP signal can be represented by $\Delta t=t_4-t_3$, which can be communicated to the mobile tag **101** via the third wireless signal (s_3).

[0050] The mobile tag **101** can be configured to determine a roundtrip distance based on the formula,

$$d_{r\text{-}trip}=d_{AM}+d_{MA} \quad \text{(EQ 8)},$$

where $d_{r\text{-}trip}$ is the roundtrip distance from the mobile tag **101** to anchor **102** and back to mobile tag **101**, d_{MA} is the distance from the mobile tag **101** to anchor **102**, and d_{AM} is the distance from anchor **102** to the mobile tag **101**. The distance from the mobile tag **101** to anchor **102** can be determined by,

$$d_{MA}=c(t_3-t_2) \quad \text{(EQ 9).}$$

Similarly, the distance from anchor **102** to the mobile tag **101** can be determined by,

$$d_{AM}=c(t_5-t_4) \quad \text{(EQ 10).}$$

With the above equations, the roundtrip distance can be rewritten as,

$$d_{r\text{-}trip}=c(t_5-t_4+t_3-t_2) \quad \text{(EQ 11).}$$

[0051] As noted earlier, the time to process the R-REQ signal and transmit the R-RSP signal via anchor **102** can be represented as $\Delta t=t_4-t_3$. Anchor **102** can be configured to transmit the value of Δt in the R-RSP signal for use by the mobile tag **101** in calculating $d_{r\text{-}trip}$. Substituting Δt in $d_{r\text{-}trip}$ results in the formula,

$$d_{r\text{-}trip}=c(t_5-t_2-\Delta t) \quad \text{(EQ 12).}$$

Since the values of t_5, t_2, and Δt are known to the mobile tag **101**, the mobile tag **101** can readily calculate $d_{r\text{-}trip}$. The mobile tag **101** can also calculate the distance from the mobile tag **101** to anchor **102** based on the formula,

$$d_{MA}=d_{r\text{-}trip}/2 \quad \text{(EQ 13).}$$

It will be appreciated that the mobile tag **101** can also be configured to know a priori the fixed value of Δt thus eliminating the need to transmit the value of Δt in the R-RSP signal. This knowledge can be based on a pre-provisioning of the mobile tag **101** with this information prior to deployment. In yet another embodiment, the processing time to receive the R-REQ signal and respond with the transmission of the R-RSP signal can be a fixed processing time interval known and used by all devices in a network performing TW-TOA analysis. It will be further appreciated that the R-REQ and the R-RSP signals can be transmitted using ultra-wideband signaling technology to increase the accuracy of the $d_{dr\text{-}trip}$ calculations. Accordingly, the TW-TOA illustrated in FIG. **5** can be used by either the mobile tag **101** or anchors in other embodiments to calculate a relative distance between each other.

[0052] It will be appreciated that the TDOA and TW-TOA processes described above can also be used between mobile tags **101**. For example, FIGS. **1-3**, **4A-4C**, **5**, and **6** can be adapted so that the anchors are replaced with mobile tags **101**. In this embodiment, mobile tags **101** can use TDOA or TW-TOA to obtain location information amongst each other based on the processes described earlier for TDOA and TW-TOA, respectively.

[0053] It will be further appreciated that a mobile tag **101**, depicted in FIGS. **1**, **3**, **4**A-4C, and **5**, can be configured with multiple antennas and phase detectors to calculate an angle of arrival of any wireless signal generated by an anchor and received by the mobile tag **101** based on a phase difference between the antennas determined from the received wireless signal. An angle of arrival calculation can be used to determine an angular orientation between a mobile tag **101** and an anchor. It will be further appreciated that the mobile tags **101** can be configured to determine a speed of travel of the mobile tag **101** by performing multiple location measurements over a time period. With angular orientation and speed of travel, a mobile tag **101** can also determine its trajectory of travel. Alternatively, the mobile tags **101** can be configured with an orientation sensor (e.g., a magnetometer) to determine an angular orientation with an anchor.

[0054] As will be discussed shortly, TDOA, TW-TOA, angular orientation, speed of travel, or combinations thereof can be utilized in an environment such as illustrated in FIG. **7**.

[0055] FIG. **7** is a block diagram illustrating an exemplary, non-limiting embodiment for determining location information of mobile tags **201** in a demarcated area **200** in accordance with various aspects described herein. In the illustration of FIG. **7**, the demarcated area **200** can represent a warehouse with racks or shelves **206** for managing the distribution of products and/or materials. It will be appreciated that the demarcated area **200** can correspond to numerous other use cases, including without limitation, a parking lot for managing parking spots, a commercial or retail environment for monitoring individuals and/or assets, assisted navigation of vehicles and/or machinery such as robots or forklifts, collision detection and avoidance of objects, managing separation between objects and/or individuals, as well as other suitable applications to which the subject disclosure can be applied. For illustration purposes only, the demarcated area **200** of FIG. **7** will be considered a warehouse with racks and/or shelves **206**.

[0056] The measurement technique used by the mobile tags **201** to determine location information within the demarcated area **200** can depend on the location of the mobile tags **201** relative to other anchors **204** in the demarcated area **200**. For example, when a mobile tag **201** is located in sections **212** (i.e., open spaces without shelving **206** and with line-of-site to pairs of anchors **204**), the mobile tag **201** can be configured to perform TDOA measurements among pairs of anchors **204** as described above in relation to FIGS. **1-3** and **4A-4C**. On the other hand, when the mobile tag **201** is located in an aisle **203** between racks/shelves **206**, the mobile tag **201** can be configured to perform TW-TOA measurements among one or more anchors **204** located in the aisle **203** as described above in relation to FIGS. **5** and **6**.

[0057] Additionally, an aisle **203** can be configured with two or more anchors **204**. An aisle **203** can have more than two anchors **204** when the coverage area of a first anchor **204** at one end of the aisle **203** has insufficient coverage to reach a second anchor **204** at the other end of the aisle **203** and vice-versa—see sections **220** and **224** and reference number **205**. However, when the coverage area of a first anchor **204** at one end of the aisle **203** has sufficient coverage to reach a second anchor **204** at the end of the aisle **203** and vice-versa, then no more than two anchors **204** is necessary in the aisle **203**—see region **222**.

[0058] FIG. **8** depicts an illustrative embodiment of a method **300** in accordance with various aspects described herein. Method **300** can begin at step **302** where a computing system, such as a server (described below in relation to FIG. **21**), is configured to identify anchor pairs in the demarcated area **200** of FIG. **7** that provide sufficient coverage to enable TW-TOA or TDOA measurements depending on the location of the mobile tags **201**.

[0059] In the case of open spaces, like region **212** (repeated in several portions of the demarcated area **200** of FIG. **7**), mobile tags **201** are configured to use TDOA measurement techniques to determine location information. To enable TDOA measurements, the server is configured at step **302** to identify, for a certain number of x-y coordinates obtained from a digitization of an open space defined by region **212** where a mobile tag **201** may be located, at least three pairs of anchors **204** that have overlapping coverage that satisfy the condition described earlier in relation to FIGS. **3**, **4**A, **4**B, and **4**C. It will be appreciated that techniques other than digitization of an open space can be used to identify possible x-y coordinates used by the server to perform step **302**. In the case of spaces formed by aisles **203**, like region **214** (repeated in several portions of the demarcated area **200** of FIG. **7**), mobile tags **201** are configured to use TW-TOA measurement techniques to determine location information. To enable TW-TOA measurements, the server is configured at step **302** to identify at least two anchors **204** covering at least a portion of the aisle **203**. The mobile tags **201** can be configured to perform TW-TOA with anchors **204** at opposite ends of an aisle **203** to provide further accuracy or at least validate location information determined by the mobile tag **201**. As noted earlier, pairs of anchors **204** can be located at opposite ends of an aisle **203**, or in between aisles **203** when a pair of anchors **204** is unable to cover for the full-length of an aisle **203**. The mobile tag **201** can be configured to perform TW-TOA measurement according to the embodiments described above in relation to FIGS. **5** and **6**.

[0060] For open spaces such as region **212**, a server can be configured at step **302** to determine optimal pairs of anchors **204** in FIG. **7** that provide sufficient coverage for any mobile tag **201** in the area such as region **212** to perform triangulation with at least three pairs of anchors **204** that satisfy the conditions set forth in FIGS. **4**A-**4**C. The process of selecting anchor pairs for TDOA triangulation and optimal coverage in open spaces defined by region **212** can be performed as an iterative analysis by a server at step **302**, or by other techniques that enable convergence to a solution that provides coverage to mobile tags **201** across most (if not all) open spaces depicted by region **212**. In the case of spaces defined by aisles **203**, the server can identify the anchor pairs **204** in the aisles **203** that provide sufficient coverage to cover the aisle from end-to-end as illustrated by sections **220-224** of FIG. **7**.

[0061] Once the anchor pairs **204** have been identified, the server can proceed to step **304** to identify a schedule for communications between anchor pairs **204** and one or more mobile tags **201**. In one embodiment, the anchors **204** can be configured to transmit and receive wireless signals (e.g., reference number **207**) in a single frequency band. A single frequency band for performing TDOA or TW-TOA measurements can reduce the design complexity of mobile tags **201** and corresponding costs. To avoid collisions between anchor pairs **204** transmitting in a same frequency band near other anchors, the server can be configured to utilize a time-division scheme (timeslots) such as shown in FIG. **9** to enable anchor pairs **204** to communicate with each other and with one or more mobile tags **201** without causing signal interference (i.e., wireless collisions).

[0062] To achieve this, the server can be configured, for example, to determine at step **304** which anchor pairs **204** have overlapping coverage areas with other anchor pairs and schedule the communications between the anchor pairs and the mobile tags **201** during specific timeslots T_0-T_n (e.g., **402***a* through **402***n*). In the case where a pair of anchors **204** does not have an overlapping coverage area with another anchor pair (e.g., anchor pairs at opposite ends of the demarcated area **200**), the server can schedule simultaneous wireless communications of both anchor pairs **204** during a same timeslot (not shown in FIG. **9**). As part of the scheduling process shown in FIG. **9**, the server can be further configured at step **304** to determine which of the anchor pairs **204** will initiate/start a measurement session through a transmission of wireless signal (s_1). Such anchors **204** will be referred to herein as source anchors **204**.

[0063] In one embodiment, the anchor pairs **204** identified by the server at step **302**, and the transmission schedule and source anchors **204** determined by the server at step **304** can be communicated to all anchors **204** via gateway anchors **208** communicatively coupled to the server. Gateway anchors **208** can be located at the edges of the demarcated area **200** or in other locations of the demarcated area **200**. Additionally, the server can also be configured to share the identification of the anchor pairs **204** and transmission schedules with the mobile tags **201**. This information can be conveyed by gateway anchors **208** when the mobile tags **201** are in close vicinity thereto, or by way of other anchors **204** which can be configured to obtain this information from the gateway anchors **208** and relay the information to the mobile tags **201**.

[0064] It will be appreciated that the locations of the anchors **204** in FIG. **7** can be predefined before the implementation of step **302** by the server. That is, the anchors **204** can be placed by one or more individuals managing the placement of shelves/racks, etc. in the demarcated area **200**. The specific x-y coordinate locations of the anchors **204** can be determined by such individuals and communicated to the server via, for example, a look-up table provided to the server, in order to perform step **302**.

[0065] It will be further appreciated that in other embodiments, the location of anchors can instead be determined by the server at step **302**. In this embodiment, the server can be provided with the location of racks/shelves and/or other objects in the demarcated area **200** along with dimensions of the demarcated area **200** and dimensions of the racks/shelves and/or other objects. The server can then be configured to perform an iterative analysis to determine a location for anchors **204** relative to the racks/shelves identified to the server that provide desirable coverage for mobile tags **201** to perform TDOA analysis in open spaces or TW-TOA analysis in aisles **203**. In this embodiment, the server can be configured to report the x-y coordinate locations of anchors **204** to one or more personnel managing the floor space of the demarcated area **200** for placement of the anchors **204** in their corresponding x-y coordinate locations.

[0066] It will be further appreciated that once the anchors **204** have been placed in their designated locations determined by the server, the server can be configured to provide the x-y coordinates to all anchors **204** in the demarcated area **200** via gateway anchors **208** as described above. This information can also be conveyed by gateway anchors **208** when the mobile tags **201** are in close vicinity thereto, or by way of other anchors **204** which can be configured to obtain this information from the gateway anchors **208** and relay the information to the mobile tags **201**.

[0067] Referring back to FIG. **8**, at step **306**, mobile tags **201** can be configured to initiate a process using TDOA or TW-TOA (and in some instances angular orientation measurements) to obtain location information depending on the location of the mobile tag **201** in the demarcated area **200**. In one or more embodiments (although other techniques can be utilized) to assist mobile tags **201** in identifying whether they are in region **212** (i.e., open spaces) or region **214** (i.e., aisles **203**), the source anchors **204** can be configured to transmit in the first wireless signal (s_1) an indication of whether to use TDOA or TW-TOA. The indication may be a flag or message that enables the mobile tag **201** to determine whether it is in region **212** (an open space) or region **214** (an aisle **203**). The first wireless signal (s_1) can also convey to the mobile tag **201** the x-y coordinates of one or both anchor pairs **204**. Alternatively, the mobile tags **201** can be configured with a look-up table that includes the x-y coordinates of all anchors **204** in the demarcated area **200**. The mobile tags **201** can obtain the look-up table from the server via the gateway anchors **208** or during provisioning of the mobile tag **201** by a user before the mobile tag **201** is deployed for use in the demarcated area **200**. It will be further appreciated that step **306** can be adapted to enable mobile tags **101** to measure and thereby obtain location information between each other using TDOA or TW-TOA as described earlier in relation to FIGS. **1-3**, **4A-4C**, **5**, and **6**.

[0068] Once a mobile tag **201** calculates location information via TDOA or TW-TOA measurement techniques, the mobile tag **201** can in turn report, at step **308**, the location information to other devices such as other mobile tags **201**, the anchors **204** in its coverage area, and/or the server by communicating directly to one or more gateway anchors **208** or indirectly via one or more intermediate anchors **204** that can communicate with the one or more gateway anchors **208**. The location information can include without limitation, x-y coordinates of the mobile tag **201** within the demarcated area **200**, a speed of travel of the mobile tag **201** determined from multiple location measurements over a time period, a trajectory of the mobile tag **201**, angular orientation of the mobile tag **201** relative to other anchors **204** and/or other mobile tags **201**, or any combinations thereof. Since sharing location information does not require precision measurements via ultra-wideband signals, the mobile tags **201** can be configured to share location information with other devices using lower power wireless signaling techniques such as Bluetooth®, ZigBee®, WiFi or other suitable wireless signaling protocols.

[0069] Sharing location information of the mobile tags **201** enables the server and/or other devices such as the anchors **204** and other mobile tags **201** to track at step **310** movement and location of the mobile tags **201** and detect and perform mitigation procedures at step **312**. For example, mobile tags **201** can be configured to detect issues such as proximity violations and/or possible collisions between mobile tags **201** from this shared information. Upon detecting such issues, the mobile tags **201** can be configured to assert an alarm (audible and/or visual) and/or take further mitigation action such as slow down or otherwise disable a vehicle (e.g., a forklift, robot, automobile, etc.) that may collide with an individual carrying a mobile tag **201**. The mobile tag **201** may be integrated in an identification badge or embedded in a mobile communication device (e.g., mobile phone, tablet, etc.), clipped on a shirt, integrated into an article of clothing of the individual or otherwise carried by the individual via other suitable methods for carrying the mobile tag **201**.

[0070] It will be appreciated that method **300** can be adapted for other embodiments contemplated by the subject disclosure. For example, at step **306**, a mobile tag **201** can be adapted to obtain location information based on a determination of whether it is in an open space defined by region **212** or an aisle **203** defined by region **214**. A mobile tag **201**, for example, can receive wireless signals from both an anchor **204** in an open space and an anchor **204** in an aisle **203**. To determine whether to perform a TDOA measurement or a TW-TOA measurement, the mobile tag **201** can be configured to obtain from its internal memory a history of locations in the demarcated area **200** that are stored by the mobile tag **201** to determine if the most recent location (or trajectory of the mobile tag **201**) places the mobile tag **201** in an open space, region **212**, or aisle **203**, region **214**.

[0071] If the mobile tag **201** determines it is likely in an open space, region **212**, it can proceed to perform TDOA analysis based on the wireless signals generated by anchor pairs **204** in the open space. Otherwise, if the mobile tag **201** determines it is likely in an aisle, region **214**, it can proceed to perform TW-TOA analysis based on the wireless signals generated by anchor pairs **204** in the aisle **203**. If the mobile tag **201** is unable to make a determination of where it is likely located from a history of locations, the mobile tag **201** can be configured to perform TDOA analysis based on the wireless signals generated by anchor pairs **204** in the open space and TW-TOA analysis based on the wireless signals generated by anchor pairs **204** in the aisle **203**. The mobile tag **201** can be configured to compare the location determined from TDOA and the location determined from TW-TOA to the stored location history and thereby make a determination as to which location to choose that more closely mimics the location history of the mobile tag **201**.

[0072] While for purposes of simplicity of explanation, the respective processes are shown and described as a series of blocks in FIG. **8**, it is to be understood and appreciated that the claimed subject matter is not limited by the order of the blocks, as some blocks may occur in different orders and/or concurrently with other blocks from what is depicted and described herein. Moreover, not all illustrated blocks may be required to implement the methods described herein. For example, steps **308-312** can be optional.

[0073] FIG. **10** is a block diagram illustrating an exemplary, non-limiting embodiment of environments where mobile tags can operate from in accordance with various aspects described herein. Mobile tags **201** can at certain times operate within a network **501** of anchors **204** (such as described above in relation to FIG. **7**) to obtain their location as described above. However, users (or vehicles or other mobile devices) carrying a mobile tag **201** can transition to an open space **503** that is outside of the coverage of the network **501**. When this occurs, the mobile tags **204** can be configured to transition to peer-to-peer communications (i.e., tag-to-tag communications) to continue to obtain location information relative to other mobile tags in the open space **503**.

[0074] FIG. **11** is a block diagram illustrating an exemplary, non-limiting embodiment of a network frame **509** that can be utilized by the network **501** in accordance with various aspects described herein. The network frame **509** can include a beacon signal **510**, a sync period **512**, a contention-free period (CFP) **514**, a contention period (CP) **516**, and an end period **518**. The beacon signal **510** is generated by anchors **204** to provide anchors **204** and mobile tags **201** a means for synchronization. The CFP **514** portion of the frame **509** supports downlink TDOA (DL-TDOA) ranging packets, which in turn also supports the anchor pair scheduling depicted in FIG. **9**. In the present context, the term "downlink" means communications from anchor to mobile tag, while the term "uplink" means communications from mobile tag to anchor. Transmissions during CFP **514** are scheduled to avoid simultaneous transmissions that lead to wireless signal interference. The CP **516** portion of the frame **509** supports uplink TDOA (UL-TDOA), TW-TOA ranging packets and additional data packets/control signaling packets and can be subject to simultaneous transmissions that in turn may interfere with each other.

[0075] The sync period **512** (which can be optional) provides a short buffer period for anchors **204** to synchronize the start of the CFP **514** to each other. The end period **518** (which can be optional) provides a short buffer period for a next frame **509** preparation or can serve as a guard interval for ACK message transmissions. The network frame **509** is periodic as shown by the next repetitive sequence of fields in a subsequent network frame. Various other scheduling and timing, including use of particular frame structures, can be used with the exemplary embodiments of the subject disclosure as described in U.S. Pat. No. 10,779,118, filed Jan. 11, 2019, to Duan et al., the disclosure of which is hereby incorporated by reference herein in its entirety.

[0076] FIG. **12** is a block diagram illustrating an exemplary, non-limiting embodiment of a peer-to-peer frame configured for monitoring a presence of a network frame **509** in accordance with various aspects described herein. The peer-to-peer frame is referred to herein as a peer-to-peer super-frame **530**. The peer-to-peer super-frame **530** can include a peer-to-peer sub-frame **520** and a network sub-frame **528**. The peer-to-peer sub-frame **520** enables a mobile tag **201** located in the open space **503** of FIG. **10** to perform peer-to-peer range measurements (e.g., as described in relation to FIGS. **14**A, **14**B, **14**D, and **14**F below). The peer-to-peer sub-frame **520** can include a peer-to-peer beacon signal **521**, a ranging period **522**, and a listening period **524**.

[0077] The peer-to-peer beacon signal **521** can be a Bluetooth (or ultra-wideband) signal that a mobile tag **201** broadcasts to other mobile tags **201** to initiate a ranging process to determine the relative location of the mobile tag **201** to other mobile tags **201** in its vicinity. The peer-to-peer beacon signal **521** can be an announcement message and/or synchronization signal to enable other mobile tags **201** to properly initiate a ranging process. During the ranging period **522**, the mobile tag **201** can be configured to perform ranging measurements using ultra-wideband signals or other techniques (e.g., RF signal strength indicator (RSSI)). During the listening period **524**, the mobile tag **201** can be configured to monitor response messages from other mobile tags **201** in its communication range using a Bluetooth (or ultra-wideband) receiver. The peer-to-peer sub-frame **520** is periodic as shown in FIG. **12**.

[0078] To detect the presence of the network **501** with anchors **204**, the mobile tag **201** can be configured to monitor during the network sub-frame **528** for a beacon signal **510** generated by one or more anchors **204** in the network **501**. During the network sub-frame **528**, the mobile tag **201** can be configured to turn on the ultra-wideband receiver to monitor a beacon signal **510** generated by one or more anchors **204** using an ultra-wideband transmitter. Generally, the ultra-wideband receiver of the mobile tag **201** draws more current than a Bluetooth narrowband receiver. To extend battery life of the mobile tag **201**, the mobile tag **201** can be configured to maintain the ultra-wideband receiver on for a period **526** (depicted as Ts), which is less than the period (depicted as T) of the network sub-frame **528**. The period **526** (Ts) can be chosen sufficiently large to enable the mobile tag **201** to detect a beacon signal of at least one network frame **509**.

[0079] In the illustration of FIG. **12**, a first instance of the beacon signal **510** is not detected because it occurs outside the period **526** (Ts) in which the ultra-wideband receiver of the mobile tag **201** is enabled to monitor for beacon signals. However, during a second instance of a super-frame **530**, a beacon signal from a second instance of a network frame **509** is detected during the period **526** (Ts) of the network-subframe **528** of the mobile tag **201**. Upon detecting the beacon signal **510**, the mobile tag **201** can be configured to extend the period **526** (Ts) to enable the mobile tag **201** to receive multiple instances of a beacon signal **510** which enables the mobile tag **201** to synchronize its clock to the network frame **509**. Upon achieving synchronization, the mobile tag **201** can be configured to determine whether transitioning from a peer-to-peer communications mode (as depicted in FIG. **12**) to a network communications mode (as depicted in FIG. **11**) is warranted.

[0080] In an embodiment, the mobile tag **201** can be configured to store a coverage map of the network **501**. The coverage map can indicate areas in the network **501** where access to anchors **204** is available and not available. Alternatively, or in combination with the foregoing embodiment, the mobile tag **201** can be configured to receive a message including a coverage map (or portion of the coverage map that represents a vicinity where the mobile tag **201** is located) from at least one anchor **204** after the mobile tag **201** has synchronized to the network frame **509**. The mobile tag **201** can also be configured to track a history of its movements from the time it left the network **501** to an open space **503** not inside the wireless coverage area of the network **501**. The mobile tag **201** can perform this type of tracking by utilizing an accelerometer, gyroscope, and/or magnetometer (compass) to determine a history of positions from inside the network **501** to an open space **503** and back to the network **501**. By tracking a history of positions, the mobile tag **201** can determine where it is in the coverage map of the network **501** and thereby determine whether it is in a communication range of one or more anchors **204** in the network **501**. Alternatively, the mobile tag **201** can be configured to try to communicate with one or more anchors **204** and determine from ranging measurements whether it is located in the network **501**. In yet another embodiment, the mobile tag **201** may receive messages from anchors **204** during a CFP period and based on the number of messages and quality of messages received during the CFP period determine if it is in the communication coverage of anchors **204** in the network **501**.

[0081] If the mobile tag **201** cannot reliably communicate with anchors **204** in the network **501**, or cannot make an accurate measurement of its location relative to one or more anchors, and/or it determines from a coverage map and position history that it is in an area of the network **501** where anchors **204** are not accessible, then the mobile tag **201** can be configured to adjust peer-to-peer mobile tag communications to occur in a position in a network frame **509**, which minimizes the chances of causing wireless signal interference with anchors **204** or other mobile tags **201** engaged in a network communications mode as depicted in FIG. **13**.

[0082] FIG. **13** is a block diagram illustrating an exemplary, non-limiting embodiment of a mobile tag **201** configured to utilize peer-to-peer communications in a manner that avoids interfering with portions of a network frame **509** in accordance with various aspects described herein. To minimize RF interference with anchors **204** and/or other mobile tags **201** operating in a network communications mode, a mobile tag **201** that has insufficient coverage in the network **501** (e.g., cannot access one or more anchors **204**) can be configured to maintain peer-to-peer communications in the CP **516** portion (i.e., contention period) of the network frame **509** and maintain synchronicity with the network frame **509** by monitoring the beacon signal **510** via a short listening period **531**. Since the CP **516** portion allows for contentions (i.e., RF interference due to simultaneous RF transmissions), contentions caused by the mobile tag **201** performing peer-to-peer communications can be tolerated and will not cause issues with RF transmissions by anchors **204** utilizing the CFP portion **514** (contention-free period) of the network frame **509**. The mobile tag **201** can perform this adjustment after it has synchronized its clock to the network frame **509** utilizing the beacon signal **510** as a reference signal. Once the mobile tag **201** has adapted peer-to-peer communications in the CP portion **516** of the network frame **509**, the mobile tag **201** can cease to use timing associated with the peer-to-peer super-frame **530** depicted in FIG. **12**, and instead resort to utilizing only the sub-frame **520** within the CP portion **516** of the network frame **509**.

[0083] If, on the other hand, the mobile tag **201** determines that it is in the communication range of a sufficient number of anchors **204** in the network **501** to adequately determine its location in the network **501**, then the mobile tag **201** can be configured to fully transition to a network communications mode by ceasing to utilize peer-to-peer communications altogether as depicted in FIG. **12** and rely exclusively on communications with anchors **204** utilizing the network frame **509** of FIG. **11**.

[0084] FIG. **14**A depicts a two-way time of arrival (TW-TOA) (e.g., peer-to-peer) process for determining distances between devices (e.g., mobile tags). The process can begin at device A which transmits a range request (R-REQ) signal to device B at time t_1. Device B receives the R-REQ signal at time t_2. Device B processes the R-REQ signal for a period of Δt, and responsive thereto transmits a range response (R-RSP) signal at t_3. Device A receives the R-RSP signal at t_4. Device A can determine a roundtrip distance based on the formula $d_{r\text{-}trip}=d_{AB}+d_{BA}$, where $d_{r\text{-}trip}$ is the roundtrip distance from device A to device B and back to device A, d_{AB} is the distance from device A to device B, and d_{BA} is the distance from device B to device A. The distance from device A to device B can be determined by $d_{AB}=c(t_2-t_1)$, where c is the speed of light. Similarly, the distance from device B to device A can be determined by $d_{BA}=c(t_4-t_3)$. Substituting the above equations, the roundtrip distance can be rewritten as $d_{r\text{-}trip}=c(t_4-t_3+t_2-t_1)$.

[0085] The time to process the R-REQ signal and to transmit the R-RSP signal via device B can be represented as $\Delta t=t_3-t_2$. Device B can be configured to transmit the value of Δt in the R-RSP signal for use by device A in calculating $d_{r\text{-}trip}$. Substituting Δt in $d_{r\text{-}trip}$ results in the formula: $d_{r\text{-}trip}=c(t_4-t_1-\Delta t)$. Since the values of t_4, t_1, and Δt are known to device A, device A can readily calculate $d_{r\text{-}trip}$. Device A can also calculate the distance from device A to device B based on the formula: $d_{AB}=d_{r\text{-}trip}/2$. It will be appreciated that device A can also be configured to know a priori the fixed value of Δt. In yet another embodiment, the processing time to receive the R-REQ signal and respond with the transmission of the R-RSP signal can be a fixed processing time interval known and used by all devices in a network performing TW-TOA analysis. In the foregoing embodiments, the value of Δt would not need to be transmitted in the R-RSP signal. It will be further appreciated that the R-REQ and the R-RSP signals can be transmitted using ultra-wideband signaling technology to increase the accuracy of the $_{dr\text{-}trip}$ calculations or derivatives thereof. Accordingly, the TW-TOA process illustrated in FIG. **14**A can be used by either device A or device B to calculate a relative distance between each other. This process can be utilized in various embodiments that follow below.

[0086] FIGS. **14**B and **14**C depict exemplary, non-limiting embodiments of a (e.g., peer-to-peer) process for determining location data between devices (e.g., mobile tags) in accordance with various aspects described herein. In FIG. **14**B, device A can begin by transmitting an announcement wireless signal (ANNC) utilizing a low power narrow band transmitter (such as a Bluetooth transmitter). Upon receiving at device B, the announcement signal utilizing a narrow band receiver (e.g., Bluetooth receiver), device B can, in response, select a random time to transmit via a wideband transmitter a range request (R-REQ) signal utilizing a wideband signaling technology (e.g., ultra-wideband signal at high frequencies such as 500 MHz). Device A can be configured to turn on a wideband receiver (e.g., for receiving ultra-wideband signals) during a ranging RX window as shown in order to receive the R-REQ signal from device B and/or other devices in a vicinity of device A that are responding to the announcement signal generated by device A.

[0087] Upon receiving the R-REQ signal, device A can be configured to enable a wideband transmitter (e.g., for transmitting ultra-wideband signals) to transmit a range response (R-RSP) signal. Device B can receive the R-RSP signal with a wideband receiver (e.g., for receiving ultra-wideband signals). Upon receiving the R-RSP signal, device B can determine the round-trip time between the R-REQ signal and the R-RSP signal and thereby determine a distance between device B and device A. If the R-RSP signal includes a processing time by device A to receive R-REQ and thereafter transmit R-RSP, such information can be used by device B to more accurately determine the distance between device A and device B (e.g., as described above in relation to FIG. **14**A).

[0088] In addition to measuring a relative distance between devices, device B (or device A) can be configured with multiple antennas to calculate an angle of arrival of the R-RSP signal based on a phase difference between the antennas. Such angle of arrival can be used to determine an angular orientation between device B and device A. By combining the angular orientation with a determination of the distance between devices A and B, device B can also determine a location and angular orientation of device A relative to the location of device B.

[0089] Additionally, the announcement signal can be submitted periodically or asynchronously to prompt multiple measurements by device B (and other devices in a vicinity of device A) utilizing the process shown in FIG. **14**B. Distance and angular orientation can be used by device B (and other devices) to also determine a trajectory of device A relative to device B (and the other devices). Device B can also be configured to report, to device A, location information, such as the measured distance, angular orientation, position, and/or trajectory of device A and/or B via a range report (R-RPT) signal. The R-RPT signal can be a narrow band signal (e.g., Bluetooth) or wideband signal (e.g., ultra-wideband). The trajectory data can be used to predict collisions between devices A and B, enabling each device to take mitigation action(s) such as asserting an alarm at device B and/or device A.

[0090] Additionally, warning conditions can be provisioned at both devices A and B to determine conformance with a required separation between devices A and B. The warning conditions can be separation thresholds and/or trajectory thresholds. If the warning condition is not satisfied, devices A and/or B can be configured to assert alarms. The alarms can be audible alarms, illuminating alarms (e.g., flashing colored light) or a combination thereof. Additionally, the embodiments depicted by FIG. **14**B can also be applied to device B in which device B is the one initiating/originating the announcement signal, and device A (and/or other devices) calculates its location and/or orientation relative to device B as described above (and, for example, shares the same with device B). FIG. **14**C temporally depicts (e.g., peer-to-peer) transmission and reception intervals of the announcement signals and range signals (e.g., described above in relation to FIG. **14**B) utilizing narrow band transmitter(s)/receiver(s) or transceiver(s) (e.g., a Bluetooth transceiver or the like) and ultra-wideband transmitter(s)/receiver(s) or transceiver(s) at each of devices A and B (depicted as Tags A and B, respectively). As shown, each device may be equipped with two radios (a radio-1 and a radio-2). Radio-1 may be configured to transmit and receive narrow band (e.g., Bluetooth) signals, while radio-2 may be configured to transmit and receive ultra-wideband signals. Since use of narrow band signals expends less power than ultra-wideband signals, utilizing a narrow band (e.g., Bluetooth) radio, when possible, can extend battery life of the devices.

[0091] FIG. **14**D depicts an adaptation to the embodiments of FIG. **14**B. In particular, device B can be configured to transmit in response to the announcement signal a range ready-to-send (RNG-RTS) signal using narrow band signaling technology such as Bluetooth. The RNG-RTS signal can include timing information that indicates when device B will transmit the R-REQ signal. By knowing this timing, device A can substantially reduce the ranging RX window (which saves battery life of device A) by knowing the arrival time of the R-REQ signal and a predetermined time for receiving the R-RPT signal. If an R-RPT signal is not expected, device A can shorten the ranging RX window even further and thereby further improve battery life. The location and/or orientation measurements can be performed by device B as previously described in relation to FIG. **14**B. FIG. **14**E temporally depicts (e.g., peer-to-peer) transmission and reception intervals of the announcement signals and range signals (e.g., described above in relation to FIG. **14**D) utilizing narrow band transmitter(s)/receiver(s) or transceiver(s) (e.g., a Bluetooth transceiver or the like) and ultra-wideband transmitter(s)/receiver(s) or transceiver(s) at each of devices A and B (depicted as Tags A and B, respectively).

[0092] FIG. **14**F depicts an adaptation to the embodiments of FIGS. **14**B and **14**D. In this illustration, device A can be configured to transmit, in response to the RNG-RTS signal, a ranging clear-to-send (RNG-CTS) signal using narrow band signaling technology such as Bluetooth. The RNG-CTS signal can include timing information that indicates when device B should transmit the R-REQ signal. In this embodiment, device A can control the initial transmission time of the R-REQ signal thereby enabling device A to limit the size of the ranging RX window, reduce current draw from the ultra-wideband transceiver and thereby improve battery life of device A. The previously described embodiments of FIGS. **14**B and **14**D are applicable to FIG. **14**F (e.g., for performing location and/or orientation measurements by device B and sharing such information with device A via the R-RPT signal). FIG. **14**G temporally depicts (e.g., peer-to-peer) transmission and reception intervals of the announcement signals and range signals (e.g., described above in relation to FIG. **14**F) utilizing narrow band transmitter(s)/receiver(s) or transceiver(s) (e.g., a Bluetooth transceiver or the like) and ultra-wideband transmitter(s)/receiver(s) or transceiver(s) at each of devices A and B (depicted as Tags A and B, respectively).

[0093] FIG. **14**H depicts an architecture in which all devices (e.g., mobile tags) can serve as announcers by initiating a measurement request via announcement signals as described in relation to FIGS. **14**B, **14**D, and **14**F. To reduce communication traffic, the devices illustrated in FIG. **14**H can be configured to share location information measurements with each other, thereby limiting the number of announcement signals transmitted. Additionally, devices A, B and C can be configured to coordinate amongst each other who serves as an announcer and who serves as a measurement device at alternate times to further manage communications traffic. FIG. **14**J depicts an architecture in which one device (device A) can serve as the announcer while the other devices (devices B-E) serve as monitors that perform location information measurements. The devices of FIGS. **14**H and **14**J can include some devices that are mobile and some devices that are stationary (e.g., anchors). In another embodiment, FIGS. **14**H and **14**J can include all mobile devices.

[0094] FIG. **14**K depicts a flowchart illustration of a method **595** relating to devices (e.g., mobile tags). Method **595** can begin with step **595***a* in which a prompt (e.g., announcement signal) sent by one or more devices prompts one or more other devices to initiate, at step **595***b*, a location determination process. In an embodiment, steps **595***a* and **595***b* can be represented by the devices of FIGS. **14**B, **14**D, and **14**F in which an announcement signal is transmitted to prompt other device(s) to initiate a location information measurement process. At step **595***c*, one or more devices that have determined location information based on steps **595***a* and **595***b* can be configured to determine if such location information needs to be acted on at step **595***d*. For example, devices acquiring location information can act by performing collision mitigation of one or more collisions predicted in accordance with the location information. Collision mitigation can include, without limitation, asserting alarms at one or more devices, slowing or stopping mobile devices, and/or submitting warning wireless messages between devices. Similarly, devices acquiring location information can assert warnings at step **595***d* if one or more separation conditions are not satisfied. If devices reviewing location information determine at step **595***c* that action is not required, such devices can proceed to step **595***a* and reinitiate method **595** at step **595***a*.

[0095] While for purposes of simplicity of explanation, the respective processes are shown and described as a series of blocks in FIG. **14**K, it is to be understood and appreciated that the claimed subject matter is not limited by the order of the blocks, as some blocks may occur in different orders and/or concurrently with other blocks from what is depicted and described herein. Moreover, not all illustrated blocks may be required to implement the methods described herein.

[0096] FIG. **14**L depicts hardware components that may be utilized by the devices of FIGS. **14**B-**14**J to perform the embodiments described above. Each device can be configured with a processing system including one or more processors (e.g., microprocessors, digital signal processors, application specific integrated circuits, state machines, etc.) that control operations of the device. The processing system can be coupled to first and second radios, each radio including a transceiver (transmitter and receiver). The first radio can be configured to operate as a low power radio (e.g., narrow band radio configured as a Bluetooth radio). The first radio can thus be used to exchange messages between devices with low power consumption. The second radio can be configured to operate as a high frequency radio (e.g., ultra-wideband radio operating at 500 MHz) to enable the processing system to perform high precision roundtrip time of arrival calculations, which can result in precise distance measurements (distance measurements with accuracy better than +/−20%). The second radio can also be equipped with multiple antennas to enable the processing system to perform angle of arrival measurements via phase difference measurements and/or other suitable measurements, which, when combined with distance measurements, can enable the processing system to determine a relative position between devices.

[0097] The processing system can also be configured to perform the embodiments of FIGS. **14**B, **14**D, and **14**F to determine location information that includes distance measurements, angular measurements, position measurements, and/or trajectory measurements. The processing system can be further configured to compare the location information to warning conditions. When such conditions are not satisfied, the processing system can be configured to assert a warning system that generates an audible alert (e.g., sounds out of a speaker) and/or visual alert (e.g., blinking light from an LED, text message sent to a cell phone or other communication devices, etc.).

[0098] Although not shown, the device components shown in FIG. **14**L can be combined with a battery, memory for storing data and programming information executed by the processing system, and a power management system coupled to the battery for powering the device components of FIG. **14**L.

[0099] FIG. **15** is a block diagram illustrating an exemplary, non-limiting embodiment of capabilities of a mobile tag **201** to determine its location in a network of anchors providing location services in accordance with various aspects described herein. In the illustration of FIG. **15**, a mobile tag **201** located in the network **501** of anchors **204** and operating in a network communications mode (i.e., exclusively performing ranging measurements with anchors **204**) can determine its relative position to another mobile tag **201** and, based on a history of positions (P_{n-1} to P_n), its angular trajectory relative to the other mobile tag **201**. Such angular trajectory can be used to assert alarms to avoid collisions, enforce social distancing, and/or other policies set by an administrator of the mobile tags **201** and/or network **501** of anchors **204**.

[0100] FIG. **16** is a block diagram illustrating an exemplary, non-limiting embodiment of capabilities of a mobile tag **201** to determine its location utilizing peer-to-peer communications with other mobile tags **201** in accordance with various aspects described herein. In the illustration of FIG. **16**, the mobile tag **201** is limited to determining its relative location to another mobile tag **201** without trajectory information or angular orientation. In an alternative embodiment, the mobile tag **201** can perform the functions described in relation to FIG. **15** with instrumentation such as one or more accelerometers, one or more gyroscopes, and/or a magnetometer. With such instrumentation, a mobile tag **201** can utilize as a reference point a last known location of the mobile tag **201** while in the network **501** of anchors **204** and determine thereafter utilizing the instrumentation a history of positions (P_{n-1} to P_n) and its angular trajectory relative to another mobile tag **201** utilizing similar instrumentation.

[0101] FIG. **17** depicts an illustrative embodiment of a method **600** for transitioning between modes of communications; particularly, peer-to-peer communications mode and network communications mode in accordance with various aspects described herein. Method **600** can begin with step **602** where a mobile tag can be configured to monitor a beacon signal while in a peer-to-peer communications mode utilizing, for example, the peer-to-peer superframe **530** (and corresponding network sub-frame **528**) shown in FIG. **12**. As noted earlier, the peer-to-peer communication mode may be invoked when the mobile tag **201** transitions out of the coverage area of the network **501** of anchors **204** into an open space **503** or when the mobile tag **201** is located in the network **501** in an area that lacks coverage from anchors **204**, which causes the mobile tag **201** to resort to the embodiment described in relation to FIG. **13**.

[0102] Upon detecting a beacon signal at step **604** while in a peer-to-peer communications mode, the mobile tag **201** can proceed to step **606** where it determines if a threshold of instances of a beacon signal has been satisfied (e.g., a threshold set to greater than **2** consecutive beacon signals). If the threshold is not satisfied, the mobile tag **201** can be configured to return to step **602** and continue the monitoring process. If the threshold is satisfied, the mobile tag **201** can be configured at step **608** to synchronize its clock to the network frame **509** of FIG. **11** utilizing one or more instances of the beacon signal. In an embodiment, synchronization can take place during one or more instances of the synchronization period **512**. Once synchronized, the mobile tag **201** can proceed to step **610** to determine if there is sufficient coverage in the network **201** to transition to a network communications mode (i.e., performing ranging measurements exclusively with the assistance of one or more anchors **204**).

[0103] In one embodiment, the coverage determination of step **610** can be performed by the mobile tag **201** by comparing its location to a look-up table (or database) of sub-coverage areas in the network **501** (not shown in FIG. **10**). If the mobile tag **201** has instrumentation to reasonably determine where it is located within the network **501**, such location information may be sufficient for the mobile tag **201** to determine from a look-up table (or database) whether it is in an area of the network **501** where it has sufficient access to anchors **204** to safely transition to a network communications mode, or whether it should transition to an adjusted peer-to-peer communications mode as depicted FIG. **13**. The look-up table (or database) can be provided by one or more anchors at a previous time when the mobile tag **201** was located in the network **501** and operating in a network communications mode or from another source (e.g., mobile tag **201** paired with a communication device such as a smartphone that can communicate with a server of the network **501** via a cellular network or other communication means). In another embodiment, the mobile tag **201** can be configured to receive one or more messages from one or more anchors **204** transmitting its location in the network **501**, which the mobile tag **201** can then compare to the look-up table (or database) to determine if it is in a location that supports a safe transition to a network communications mode. In another embodiment, the mobile tag **201** may receive one or more messages from one or more anchors **204** in the network **501** during the CFP period, which the mobile tag **201** can use to determine if it is able to transition to a network communications mode based on the number of messages and/or quality of the received messages from anchors **204** in the network **501** during the CFP period. For example, the quality of messages can be determined from a number of consecutive received messages exceeding a signal strength threshold. Such measurements can enable a mobile tag **201** to determine if there is sufficient (or insufficient) coverage in the network **501** of anchors **204** to transition from peer-to-peer communications to network communications or remain in peer-to-peer communications but operate in the mode shown in FIG. **13**.

[0104] If the mobile tag **201** detects at step **610** that there is insufficient coverage in the network **501** relative to its current location to transition to a network communications mode, then the mobile tag **201** can proceed to step **612** where the mobile tag **201** can transition from a peer-to-peer communications mode as depicted in FIG. **12** to an adjusted peer-to-peer communications mode as shown in FIG. **13** (or maintain this adjusted communications mode if the mobile tag **201** had already previously implemented step **612**). Alternatively, if the mobile tag **201** detects at step **610** that there is sufficient coverage to transition to a network communications mode, the mobile tag **201** can transition from a peer-to-peer communications mode as depicted in FIG. **12** to a network communications mode depicted by FIG. **11** where it performs ranging measurements exclusively with the assistance of anchors **204** of the network **501**.

[0105] Once the transition from a peer-to-peer communications mode to a network communications mode occurs at step **614**, the mobile tag **201** can be configured to monitor a lack of a presence of a beacon signal generated by the anchors **204** of the network **501**. If the number of instances where the mobile tag **201** detects a lack of a beacon signal satisfies a threshold (greater than **2** consecutive lost beacon signals), the mobile tag **201** can transition to step **618** where it transitions from a network communications mode as depicted in FIG. **11** to a peer-to-peer communications mode as depicted by FIG. **12**, and begins to monitor at step **602** for a presence of a beacon signal to transition back to the network communications mode once the instances of beacon signals satisfies the threshold of step **606** as previously described. If no lost beacon signals are detected at step **616**, the mobile tag **201** can proceed to step **610** to determine if there's sufficient coverage to remain in the network communications mode at step **614**. If the mobile tag **201** determines at step **616** that there is insufficient coverage, then the mobile tag **201** can proceed to step **612** and perform peer-to-peer communication as previously described above.

[0106] While for purposes of simplicity of explanation, the respective processes are shown and described as a series of blocks in FIG. **17**, it is to be understood and appreciated that the claimed subject matter is not limited by the order of the blocks, as some blocks may occur in different orders and/or concurrently with other blocks from what is depicted and described herein. Moreover, not all illustrated blocks may be required to implement the methods described herein.

[0107] Exemplary embodiments, described herein, provide a system and method for determining the location of a mobile tag based on TDOA and AOA information (e.g., a combination of TDOA and AOA information). FIG. **18**A is a block diagram illustrating an exemplary, non-limiting embodiment of a system **700** that includes the mobile tag **101** ("M") and the anchors **102** ("A"), **104** ("B"), **106** ("C"), and **108** ("D") (e.g., described above in relation to FIGS. **1-3** and **4**A-**4**C) for determining the location of the mobile tag **101**—e.g., relative to one or more of the anchors **102**, **104**, **106**, and **108**. System **700** can include any number of mobile tags and anchors, and thus the mobile tag and anchors shown in FIG. **18**A is for illustrative purposes only. For example, system **700** may include more mobile tags and/or more or fewer anchors.

[0108] As shown in FIG. **18**A, the mobile tag **101** may include two antennas—e.g., an antenna **101***a* and an antenna **101***b*. In some embodiments, the mobile tag **101** may include additional antennas, such as three antennas (e.g., as depicted in FIG. **18**B and described in more detail below) or more. In certain embodiments, the antennas may be included in an antenna array.

[0109] The antennas **101***a* and **101***b* may be configured to transmit and receive wireless signals (or packets) at a certain frequency or frequency range. In certain embodiments, the antennas **101***a* and **101***b* may be spatially distributed, or spaced apart from one another, on the mobile tag **101** by a distance of less than or equal to half of the wavelength ($\lambda/2$) of the wireless signal frequency.

[0110] Although not shown, the antennas **101***a* and **101***b* may be communicatively coupled to a processing unit (e.g., a radio frequency (RF) front-end or the like). In some embodiments, the antennas **101***a* and **101***b* may be communicatively coupled to a single or common processing unit. In certain embodiments, the antennas **101***a* and **101***b* may be communicatively coupled to different processing units (where, for example, clocks of the processing units may or may not be synchronized).

[0111] As depicted in FIG. **18**A, each of the antennas **101***a* and **101***b* can be configured to receive wireless signals transmitted by the anchors **102** and **104** (e.g., a first pair of anchors), such as the first and second wireless signals (s_1, s_2) described above in relation to FIGS. **1** and **2**, as well as wireless signals transmitted by one or more other anchors or pairs of anchors, such as third and fourth wireless signals (s_3, s_4) transmitted by the anchors **106** and **108** (e.g., a second pair of anchors). In various embodiments, such as in a case where (e.g., only) a single pair of anchors in system **700**, such as anchors **102**, **104**, is selected to transmit wireless signals (e.g., wireless signals (s_1, s_2)) for purposes of estimating a present location of the mobile tag **101**, the antennas **101***a* and **101***b* may receive wireless signals from (e.g., only) that pair of anchors.

[0112] By virtue of the different positions of antennas **101**a and **101**b on the mobile tag **101**, the antennas may receive a given wireless signal from an anchor at (e.g., slightly) different times. This is depicted in FIG. **18**A as two arrows representing a different line-of-sight (LOS) for each of the first, second, third, and fourth wireless signals (s_1, s_2, s_3, s_4). In a case where the antennas **101**a and **101**b are spaced apart by a short distance, such as less than or equal to half of the wavelength (λ/**2**) of the wireless signal frequency, information regarding a direction of an incoming wireless signal, such as an angle of arrival (AOA) of the wireless signal can be estimated or calculated. In exemplary embodiments, and as described in more detail below, AOA information can be further leveraged to determine or estimate a location of the mobile tag **101**.

[0113] FIGS. **18**B and **18**C show example block diagrams of the mobile tag **101** configured with two antennas (block diagram **725**) and three antennas (block diagram **750**), respectively. As shown in FIG. **18**B, a wireless signal, transmitted by an anchor, may be received at each of the two antennas **101**a, **101**b of the mobile tag **101**, which can enable estimation of an AOA of the wireless signal in two-dimensional (2D) space (e.g., an azimuth angle θ in the x-y plane). For a mobile tag **101** that is configured with three or more antennas (e.g., as depicted in FIG. **18**C), a wireless signal, transmitted by an anchor, may be received at each of the three antennas **101**a, **101**b, **101**c, which can enable estimation of additional AOA information—e.g., both an azimuth angle θ (in the x-y plane) and an elevation angle ϕ (with respect to (e.g., above) the x-y plane).

[0114] The AOA of a wireless signal transmitted by an anchor, and received by each of multiple antennas of the mobile tag **101**, can be estimated or determined using any suitable technique. For example, estimation of AOA can be performed using beamforming approaches (e.g., the Bartlett method, the Minimum variance distortionless response (MVDR) beamformer solution, linear prediction, and/or the like), subspace-based approaches (e.g., MUltiple SIgnal Classification (MUSIC) and/or variants thereof, Estimation of Signal Parameters via Rotational Invariant Techniques (ESPRIT), and/or the like), maximum likelihood estimation, etc.

[0115] In various embodiments, AOA information (e.g., azimuth angle θ and/or elevation angle ϕ) for a given anchor, can be estimated or determined individually—that is, where the azimuth angle θ (and/or the elevation angle ϕ) is estimated using only wireless signal information for that anchor. In some embodiments, AOA information (e.g., azimuth angle θ and/or elevation angle ϕ) for each of multiple anchors, can be jointly estimated or determined—that is, where, for example, AOA estimation technique(s) are applied to a combination of the wireless signal information for the multiple anchors, to arrive at individual AOA information (e.g., individual azimuth angle θ and/or elevation angle ϕ) for each of the multiple anchors.

[0116] As briefly described above with respect to FIG. **18**A, estimated AOA information (azimuth angle θ and/or elevation angle ϕ) can be leveraged to determine a location of the mobile tag **101**. This is possible based on geometric relationships that exist between the location of the mobile tag **101** and the azimuth angle θ and/or the elevation angle ϕ.

[0117] In a case where the mobile tag **101** includes two antennas (e.g., as depicted in FIG. **18**B), and using the first and second wireless signals (s_1, s_2) (transmitted by the pair of anchors **102**, **104**) as an example, the relationship between azimuth angle θ of the first wireless signal (s_1) (e.g., azimuth angle θ_1) and the locations of the anchor **102** and the mobile tag **101** in 2D space can be represented as

$$\tan\theta_1 = y_1 - y/x_1 - x \quad \text{(EQ 14)},$$

where θ_1, x_1, and y_1 may be known, and the relationship between azimuth angle θ of the second wireless signal (s_2) (e.g., azimuth angle θ_2) and the locations of the anchor **104** and the mobile tag **101** in 2D space can be similarly represented as

$$\tan\theta_2 = \frac{y_2 - y}{x_2 - x}, \quad \text{(EQ 15)}$$

where θ_2, x_2, and y_2 may be known.

[0118] In a case where the mobile tag **101** includes three or more antennas (e.g., as depicted in FIG. **18**C), and using the first and second wireless signals (s_1, s_2) (transmitted by the pair of anchors **102**, **104**) as another example, both of EQs 14 and 15 may apply for the respective azimuth angles θ_1 and θ_2 of the first and second wireless signals (s_1, s_2), and additional mathematical relationships may exist for the elevation angle ϕ for each of the first and second wireless signals (s_1, s_2). For example, the relationship between an elevation angle ϕ_1 for the first wireless signal (s_1) and the locations of the anchor **102** and the mobile tag **101** in three-dimensional (3D) space can be represented as

$$\tan\phi_1 = \frac{z_1 - z}{\sqrt{(x - x_1)^2 + (y - y_1)^2}}, \quad \text{(EQ 16)}$$

where ϕ_1, x_1, y_1, and z_1 may be known, and the relationship between an elevation angle ϕ_2 for the second wireless signal (s_2) and the locations of the anchor **104** and the mobile tag **101** in 3D space can be similarly represented as

$$\tan\phi_2 = \frac{z_2 - z}{\sqrt{(x - x_2)^2 + (y - y_2)^2}}, \quad \text{(EQ 17)}$$

where ϕ_2, x_2, y_2, and z_2 may be known.

[0119] As described above with respect to FIGS. **1** and **2**, a (e.g., downlink) TDOA measurement technique can be used to determine a location of the mobile tag **101**. In particular, location data relating to a pair of anchors (e.g., the pair of anchors **102** and **104**) and receipt, by the mobile tag **101**, of wireless signals transmitted from the anchors (e.g., the first and second wireless signals (s_1, s_2)), can be mathematically represented by EQs 4C, 5, and 6 above. Substituting a 3D version of Δd_1 in EQ 6 with $c(t_4 - t_1 - \Delta t) - d_{AB}$ (where the location (x_1, y_1, z_1) of anchor **102** and the location (x_2, y_2, z_2) of anchor **104** may be known) results in

$$c(t_4 - t_1 - \Delta t) = \sqrt{(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2} - \sqrt{(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2} + d_{AB} \quad \text{(EQ 18)}.$$

[0120] In exemplary embodiments, a location of the mobile tag **101** can be determined based on a combination of both TDOA information and AOA information. Stated differently, the geometric relationships between the AOA information and the location of the mobile tag **101** can be combined with TDOA information to jointly estimate the location of the mobile tag **101**. In various embodiments, the combination can be implemented by solving a system of equations that includes the relevant equations defined above.

[0121] As an example, in a case where the mobile tag **101** includes two antennas, as depicted in FIG. **18**B, the system of equations can include EQs 14, 15, and 18 above. In this example, distance measurements may be performed in 3D space, a height z (in EQ 18) of the mobile tag **101** may be known, and solving EQs 14, 15, and 18 above can yield a location (x, y) of the mobile tag **101**.

[0122] As another example, in a case where the mobile tag **101** includes three antennas, as depicted in FIG. **18**C, the system of equations can include EQs 14, 15, 16, 17, and 18 above. In this example, a height z of the mobile tag **101** may be unknown, and solving EQs 14, 15, 16, 17, and 18 above can yield a location (x, y, z) of the mobile tag **101**.

[0123] The systems of equations (e.g., the system of EQs 14, 15, and 18 and the system of EQs 14, 15, 16, 17, and 18) can be solved in any suitable manner For example, each system of equations can be solved by utilizing nonlinear least-squares, weighted least squares, Kalman filtering, and/or the like.

[0124] It is to be appreciated and understood that EQs 14, 15, 16, and 17 above are provided only as examples. Other equations (e.g., trigonometric formulas) that represent the same or similar geometric relationships between the mobile tag **101** and the anchors **102** and **104** can be used. For example, in a case where the mobile tag **101** includes two antennas (as depicted in FIG. **18**B), trigonometric formulas other than those based on the tangent function (i.e., EQs 14 and 15) can be used to define the relationships between the azimuth angle θ and the (x, y) coordinate. As another example, in a case where the mobile tag **101** includes three antennas (as depicted in FIG. **18**C), trigonometric formulas other than those based on the tangent function (i.e., EQs 14, 15, 16, and 17) can be used to define the relationships between the azimuth angle θ, the elevation angle ϕ, and the (x, y, z) coordinate.

[0125] Combining TDOA information and AOA information to estimate the location of a mobile tag (such as the mobile tag **101**), as described above, can provide improved (or optimized) accuracy as compared to estimating the location using only TDOA information.

[0126] In some embodiments, additional anchor pairs may be employed to further aid in the estimation of the location of the mobile tag. For example, in a case where the mobile tag **101** includes two antennas (as depicted in FIG. **18**B), and where a second pair of anchors (e.g., anchors **106** and **108**) transmits wireless signals (e.g., wireless signals s_3 and s_4) to the mobile tag **101**, an additional set of equations, similar to EQs 14, 15, and 18, may be defined for the geometric and time-based relationships between the anchors **106**, **108** and the mobile tag **101**. This additional set of equations may, along with EQs 14, 15, 18 (relating to anchors **102**, **104**), be solved—e.g., using nonlinear least-squares, weighted least squares, Kalman filtering, and/or the like—to arrive at an estimated location (x, y) of the mobile tag **101**. It is worth noting, however, that the improved accuracy of the estimated location of the mobile tag **101** provided by employing the above-described combination of TDOA information and AOA information for a single pair of anchors (e.g., just anchors **102** and **104**), may obviate a need to utilize multiple anchor pairs for a particular location estimation. That is, for purposes of determining a present location of a mobile tag (e.g., the mobile tag **101**), wireless signals from other anchor pairs, such as anchors **106**, **108**, may not be necessary. This reduces or eliminates a need to provide vast coverage for a mobile tag, such as may otherwise be required if only TDOA information is used to estimate the location of the mobile tag (e.g., using only TDOA information to estimate the location of a mobile tag may require the use of at least three pairs of anchors, as described above in relation to FIGS. **1**-**3** and **4**A-**4**C). Less restrictive (or less stringent) coverage requirements decreases the quantity of anchors that need to be involved for any given mobile tag location estimation, and thus allows for more efficient scheduling of anchor pairs. This can reduce the quantity of wireless signals being transmitted and received across a network of anchors and mobile tags, which conserves computing resources, power resources, and network resources, and also improves overall network performance.

[0127] Furthermore, obtaining AOA information (e.g., as described above with respect to FIGS. **18**A-**18**C) for a mobile tag can further facilitate collision mitigation between the mobile tag and other mobile tags. For example, in some embodiments, the mobile tag **101** can provide, to a second mobile tag (e.g., as part of peer-to-peer communications described above in relation to FIG. **12**), AOA information estimated based on wireless signals received from anchors **102** and **104**. In this example, the second mobile tag may utilize this information to determine a direction of the mobile tag **101** relative to the second mobile tag, and may, in conjunction with distance and/or speed measurements relating to the mobile tag **101** and the second mobile tag, determine whether there is any risk of collision with the mobile tag **101**.

[0128] FIG. **19** depicts an illustrative embodiment of a method **800** in accordance with various aspects described herein. Method **800** can begin at step **802**, where anchor pair(s) (e.g., anchor pair **102**, **104** of FIG. **18**A), in a network of anchors, are identified. In various embodiments, anchors pairs may be identified in a manner similar to that described above with respect to step **302** of FIG. **8**. Anchors of an anchor pair (e.g., anchor pair **102**, **104**) may be within communication range with one another, where an overlapping coverage region thereof may encompass the two anchors and a mobile tag (e.g., the mobile tag **101** or **201**). In various embodiments, and as described above with respect to step **304** of FIG. **8**, the anchor pair may transmit wireless signals in accordance with a transmission schedule to avoid signal collisions.

[0129] At step **804** of method **800**, a first anchor of the anchor pair may transmit a first wireless signal, where a second anchor of the anchor pair may receive the first wireless signal and transmit a second wireless signal based upon receipt of the first wireless signal. For example, anchor pair **102** may transmit the first wireless signal s_1, where the anchor pair **104** may receive the first wireless signal s_1 and transmit the second wireless signal s_2 based upon receipt of the first wireless signal s_1, as described above with respect to FIGS. **1**, **2**, and **18**A.

[0130] At step **806**, the mobile tag may receive, at multiple antennas, the first wireless signal and the second wireless signal. For example, an embodiment of the mobile tag **101** that includes two antennas **101**_a_ and **101**_b_ (e.g., as described above with respect to FIG. **18**B) may receive, at each of the two antennas **101***a* and **101***b*, the first wireless signal s_1 and the second wireless signal s_2. As another example, an embodiment of the mobile tag **101** that includes three or more antennas **101***a*, **101***b*, **101***c* (e.g., as described above with respect to FIG. **18**C) may receive, at each of the three or more antennas **101***a*, **101***b*, **101***c*, the first wireless signal s_1 and the second wireless signal s_2.

[0131] At step **808***a*, the mobile tag may determine TDOA information based on the first and second wireless signals. For example, the mobile tag **101** may determine TDOA information based on the first wireless signal s_1 and the second wireless signal s_2—e.g., in a manner similar to that described above with respect to FIGS. **18**A-**18**C, such as by using EQ 18. Alternatively, the mobile tag may provide, to an external position estimator device (e.g., the server described above with respect to FIG. **8**), information relating to the first and second wireless signals, which the server may use to determine the TDOA information.

[0132] Independently (e.g., in parallel with step **808***a*), at step **808***b*, the mobile tag may determine AOA information based on the first and second wireless signals. For example, the mobile tag **101** may determine AOA information based on the first wireless signal s_1 and the second wireless signal s_2—e.g., in a manner similar to that described above with respect to FIGS. **18**A-**18**C, such as by using beamforming approaches, subspace-based approaches, maximum likelihood estimation, etc. In various embodiments, the mobile tag may estimate AOA information for each anchor of the anchor pair. For example, the mobile tag **101** may estimate AOA information for anchor **102** based upon receipt of the first wireless signal s_1 at each of multiple antennas, and may estimate AOA information for anchor **104** based upon receipt of the second wireless signal s_2 at each of the multiple antennas. In some embodiments, the mobile tag may provide, to the external position estimator device (e.g., the server described above with respect to FIG. **8**), information relating to the first and second wireless signals, which the server may use to determine the AOA information.

[0133] At step **810**, the location of the mobile tag may be estimated (e.g., jointly estimated) based on a combination of the TDOA information and geometric relationships between the AOA information and the location of the mobile tag. For example, the mobile tag **101**, or the external position estimator device, may estimate the location of the mobile tag **101** based on a combination of the TDOA information and geometric relationships between the AOA information and the location of the mobile tag **101**—e.g., by solving a system of equations that includes EQs 14, 15, and 18 (in a case where the mobile tag **101** includes two antennas) or by solving a system of equations that includes EQs 14, 15, 16, 17, and 18 (in a case where the mobile tag **101** includes three or more antennas).

[0134] While for purposes of simplicity of explanation, the respective processes are shown and described as a series of blocks in FIG. **19**, it is to be understood and appreciated that the claimed subject matter is not limited by the order of the blocks, as some blocks may occur in different orders and/or concurrently with other blocks from what is depicted and described herein. For example, in some embodiments, step **808***a* may alternatively be performed prior to step **808***b* or vice versa. Moreover, not all illustrated blocks may be required to implement the methods described herein.

[0135] FIG. **20** is a block diagram of an example, non-limiting embodiments of a communication device **900** in accordance with various aspects described herein. Communication device **900** can serve, in whole or in part, as an illustrative embodiment of a mobile tag **101**, **201** and an anchor **102**, **104**, **106**, **108**, **204** as depicted in FIGS. **1**-**7** (or of one or more devices shown in FIGS. **14**A-**14**J), and can be configured to perform, in whole or in part, portions of methods **300**, **595**, and **600** of FIGS. **8**, **14**K, and **17**, respectively.

[0136] In an embodiment, communication device **900** can comprise a first wireless transceivers **901**, a user interface (UI) **904**, a power supply **914**, and a processing system **906** for managing operations of the communication device **900**. In another embodiment, communication device **900** can further include a second wireless transceiver **902**, a motion sensor **918**, and an orientation sensor **920**. The first wireless transceiver **901** can be configured to support wideband wireless signals such as ultra-wideband signals (e.g., 500 MHz) for performing precision measurements such as TDOA and TW-TOA as described above and can be further configured for exchanging messages (e.g., x-y coordinates, location flags, etc.).

[0137] The second wireless transceiver **902** can be configured to support wireless access technologies such as Bluetooth®, ZigBee®, or WiFi (Bluetooth® and ZigBee® are trademarks registered by the Bluetooth® Special Interest Group and the ZigBee® Alliance, respectively). The second wireless transceiver **902** can be utilized to conserve power and offload messaging between communication devices by utilizing narrow band signals such as Bluetooth®, ZigBee®, or WiFi, instead of ultra-wideband signals. One or both wireless transceivers **901**, **902** can also be used for obtaining a strength indicator (RSSI). One or both wireless transceivers **901**, **902** can also be equipped with multiple antennas and one or more phase detectors to determine angle of arrival of wireless signals and thereby an orientation of the communication device **900** (e.g., mobile tag **101**) relative to another communication device **900** (e.g., anchor **204**).

[0138] The UI **904** can include an input device **908** that provides at least one of one or more depressible buttons, a tactile keypad, a touch-sensitive keypad, or a navigation mechanism such as a roller ball, a joystick, or a navigation disk for manipulating operations of the communication device **900**. The input device **908** can be an integral part of a housing assembly of the communication device **900** or an independent device operably coupled thereto by a tethered wireline interface (such as a USB cable) or a wireless interface supporting for example Bluetooth®. The UI **904** can further include a presentation device **910**. The presentation device **910** can include a vibrator to generate haptic feedback, an LED (Light Emitting Diode) configurable by the processing system **906** to emit one or more colors, and/or a monochrome or color LCD (Liquid Crystal Display) or OLED (Organic LED) display configurable by the processing system to present alphanumeric characters, icons or other displayable objects.

[0139] The UI **904** can also include an audio system **912** that utilizes audio technology for conveying low volume audio (for proximity listening by a user) and/or high volume audio (for hands free operation). The audio system **912** can further include a microphone for receiving audible signals of an end user. The audio system **912** can also be used for voice recognition applications. The UI **904** can further include an image sensor **913** such as a charged coupled device (CCD) camera for capturing still or moving images in a vicinity of the communication device **900**. The camera can be used for performing facial recognition and user ID recognition that can be combined with embodiments of the subject disclosure.

[0140] The power supply **914** can utilize common power management technologies such as replaceable and rechargeable batteries, supply regulation technologies, and/or charging system technologies for supplying energy to the components of the communication device **900** to facilitate portable applications. Alternatively, or in combination, the charging system can utilize external power sources such as DC power supplied over a physical interface such as a USB port or other suitable tethering technologies.

[0141] The motion sensor **918** can utilize motion sensing technology such as an accelerometer, a gyroscope, or other suitable motion sensing technology to detect motion of the communication device **900** in three-dimensional space. The orientation sensor **920** can utilize orientation sensing technology such as a magnetometer to detect the orientation of the communication device **900** (in degrees, minutes, or other suitable orientation metrics). In some embodiments, the orientation sensor **920** can replace a need for utilizing multiple antennas with the first and/or second wireless transceivers **901**, **902** and a phase detector for performing angle of arrival measurements. In other embodiments, the function of the orientation sensor **920** can be combined with an angle of arrival measurement performed with multiple antennas with the first and/or second wireless transceivers **901**, **902** and a phase detector.

[0142] The processing system **906** can utilize computing technologies such as a microprocessor, a digital signal processor (DSP), programmable gate arrays, application specific integrated circuits (ASICs), and/or a video processor with associated storage memory such as Flash, ROM, RAM, SRAM, DRAM or other storage technologies for executing computer instructions, controlling, and processing data supplied by the aforementioned components of the communication device **900**.

[0143] Other components not shown in FIG. **20** can be used in one or more embodiments of the subject disclosure. For instance, the communication device **900** can include a reset button (not shown). The reset button can be used to reset the controller **906** of the communication device **900**. In yet another embodiment, the communication device **900** can also include a factory default setting button positioned, for example, below a small hole in a housing assembly of the communication device **900** to force the communication device **900** to re-establish factory settings.

[0144] The communication device **900** as described herein can operate with more or less of the circuit components shown in FIG. **20**. These variant embodiments can be used in one or more embodiments of the subject disclosure.

[0145] FIG. **21** depicts an exemplary diagrammatic representation of a machine in the form of a computing system **1000** within which a set of instructions, when executed, may cause the machine to perform any one or more of the methods described above. One or more instances of the machine can operate, for example, as the computing system referred to in methods **300**, **595**, or **600** of FIGS. **8**, **14**K, and **17**. In some embodiments, the machine may be connected (e.g., using a network **1026**) to other machines. In a networked deployment, the machine may operate in the capacity of a server or a client user machine in a server-client user network environment, or as a peer machine in a peer-to-peer (or distributed) network environment.

[0146] The machine may comprise a server computer, a client user computer, a personal computer (PC), a tablet, a smart phone, a laptop computer, a desktop computer, a control system, a network router, switch or bridge, or any machine capable of executing a set of instructions (sequential or otherwise) that specify actions to be taken by that machine. It will be understood that a communication device of the subject disclosure includes broadly any electronic device that provides data communication. Further, while a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines (physical or virtual machines) that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methods discussed herein.

[0147] The computer system **1000** may include a processor (or controller) **1002** (e.g., a central processing unit (CPU)), a graphics processing unit (GPU, or both), a main memory **1004** and a static memory **1006**, which communicate with each other via a bus **1008**. The computer system **1000** may further include a display unit **1010** (e.g., a liquid crystal display (LCD), a flat panel, or a solid state display). The computer system **1000** may include an input device **1012** (e.g., a keyboard), a cursor control device **1014** (e.g., a mouse), a disk drive unit **1016**, a signal generation device **1018** (e.g., a speaker or remote control) and a network interface device **1020**. In distributed environments, the embodiments described in the subject disclosure can be adapted to utilize multiple display units **1010** controlled by two or more computer systems **1000**. In this configuration, presentations described by the subject disclosure may in part be shown in a first of the display units **1010**, while the remaining portion is presented in a second of the display units **1010**.

[0148] The disk drive unit **1016** may include a tangible computer-readable storage medium **1022** on which is stored one or more sets of instructions (e.g., software **1024**) embodying any one or more of the methods or functions described herein, including those methods illustrated above. The instructions **1024** may also reside, completely or at least partially, within the main memory **1004**, the static memory **1006**, and/or within the processor **1002** during execution thereof by the computer system **1000**. The main memory **1004** and the processor **1002** also may constitute tangible computer-readable storage media.

[0149] Dedicated hardware implementations including, but not limited to, application specific integrated circuits, programmable logic arrays and other hardware devices can likewise be constructed to implement the methods described herein. Application specific integrated circuits and programmable logic array can use downloadable instructions for executing state machines and/or circuit configurations to implement embodiments of the subject disclosure. Applications that may include the apparatus and systems of various embodiments broadly include a variety of electronic and computer systems. Some embodiments implement functions in two or more specific interconnected hardware modules or devices with related control and data signals communicated between and through the modules, or as portions of an application-specific integrated circuit. Thus, the example system is applicable to software, firmware, and hardware implementations.

[0150] In accordance with various embodiments of the subject disclosure, the operations or methods described herein are intended for operation as software programs or instructions running on or executed by a computer processor or other computing device, and which may include other forms of instructions manifested as a state machine implemented with logic components in an application specific integrated circuit or field programmable gate array. Furthermore, software implementations (e.g., software programs, instructions, etc.) including, but not limited to, distributed processing or component/object distributed processing, parallel processing, or virtual machine processing can also be constructed to implement the methods described herein. Distributed processing environments can include multiple processors in a single machine, single processors in multiple machines, and/or multiple processors in multiple machines. It is further noted that a computing device such as a processor, a controller, a state machine or other suitable device for executing instructions to perform operations or methods may perform such operations directly or indirectly by way of one or more intermediate devices directed by the computing device.

[0151] While the tangible computer-readable storage medium **1022** is shown in an example embodiment to be a single medium, the term "tangible computer-readable storage medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term "tangible computer-readable storage medium" shall also be taken to include any non-transitory medium that is capable of storing or encoding a set of instructions for execution by the machine and that cause the machine to perform any one or more of the methods of the subject disclosure. The term "non-transitory" as in a non-transitory computer-readable storage includes without limitation memories, drives, devices and anything tangible but not a signal per se.

[0152] The term "tangible computer-readable storage medium" shall accordingly be taken to include, but not be limited to: solid-state memories such as a memory card or other package that houses one or more read-only (non-volatile) memories, random access memories, or other re-writable (volatile) memories, a magneto-optical or optical medium such as a disk or tape, or other tangible media which can be used to store information. Accordingly, the disclosure is considered to include any one or more of a tangible computer-readable storage medium, as listed herein and including art-recognized equivalents and successor media, in which the software implementations herein are stored.

[0153] The foregoing embodiments can be combined in whole or in part with the embodiments described in U.S. Pat. Nos. 9,788,151, 10,444,321, 10,408,917, and 10,200,886 and U.S Patent Application Publication Nos. 2019/0222959 and 2015/0156746. For instance, embodiments of the aforementioned U.S. patents and U.S. patent applications associated with measurement calculation techniques to determine location information, prediction techniques for predicting collisions, and/or mitigation techniques for preventing a collision between individuals and objects that pose a danger to individuals (e.g., a forklift, robot, etc. having a tag attached thereto) can be combined in whole or in part with embodiments of the subject disclosure. Accordingly, all sections of the aforementioned patents and patent applications are incorporated herein by reference in their entirety.

[0154] As employed herein, the term "processor" can refer to substantially any computing processing unit or device comprising, but not limited to comprising, single-core processors; single-processors with software multithread execution capability; multi-core processors; multi-core processors with software multithread execution capability; multi-core processors with hardware multithread technology; parallel platforms; and parallel platforms with distributed shared memory. Additionally, a processor can refer to an integrated circuit, an application specific integrated circuit (ASIC), a digital signal processor (DSP), a field programmable gate array (FPGA), a programmable logic controller (PLC), a complex programmable logic device (CPLD), a discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. Processors can exploit nano-scale architectures such as, but not limited to, molecular and quantum-dot based transistors, switches and gates, in order to optimize space usage or enhance performance of user equipment. A processor can also be implemented as a combination of computing processing units.

[0155] As used herein, terms such as "data storage," data storage," "database," and substantially any other information storage component relevant to operation and functionality of a component, refer to "memory components," or entities embodied in a "memory" or components comprising the memory. It will be appreciated that the memory components or computer-readable storage media, described herein can be either volatile memory or nonvolatile memory or can include both volatile and nonvolatile memory.

[0156] Although the present specification describes components and functions implemented in the embodiments with reference to particular standards and protocols, the disclosure is not limited to such standards and protocols. Standards for Internet and other packet switched network transmission (e.g., TCP/IP, UDP/IP, HTML, HTTP, Bluetooth, etc.) represent examples of the state of the art. Such standards are from time-to-time superseded by faster or more efficient equivalents having essentially the same functions.

[0157] In addition, a flow diagram may include a "start" and/or "continue" indication. The "start" and "continue" indications reflect that the steps presented can optionally be incorporated in or otherwise used in conjunction with other routines. In this context, "start" indicates the beginning of the first step presented and may be preceded by other activities not specifically shown. Further, the "continue" indication reflects that the steps presented may be performed multiple times and/or may be succeeded by other activities not specifically shown. Further, while a flow diagram indicates a particular ordering of steps, other orderings are likewise possible provided that the principles of causality are maintained.

[0158] As may also be used herein, the term(s) "operably coupled to", "coupled to", and/or "coupling" includes direct coupling between items and/or indirect coupling between items via one or more intervening items. Such items and intervening items include, but are not limited to, junctions, communication paths, components, circuit elements, circuits, functional blocks, and/or devices. As an example of indirect coupling, a signal conveyed from a first item to a second item may be modified by one or more intervening items by modifying the form, nature or format of information in a signal, while one or more elements of the information in the signal are nevertheless conveyed in a manner than can be recognized by the second item. In a further example of indirect coupling, an action in a first item can cause a reaction on the second item, as a result of actions and/or reactions in one or more intervening items.

[0159] The illustrations of embodiments described herein are intended to provide a general understanding of the structure of various embodiments, and they are not intended to serve as a complete description of all the elements and features of apparatus and systems that might make use of the structures described herein. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The exemplary embodiments can include combinations of features and/or steps from multiple embodiments. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. Figures are also merely representational and may not be drawn to scale. Certain proportions thereof may be exaggerated, while others may be minimized Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

[0160] What has been described above includes mere examples of various embodiments. It is, of course, not possible to describe every conceivable combination of components or methodologies for purposes of describing these examples, but one of ordinary skill in the art can recognize that many further combinations and permutations of the present embodiments are possible. Accordingly, the embodiments disclosed and/or claimed herein are intended to embrace all such alterations, modifications and variations that fall within the spirit and scope of the appended claims. Furthermore, to the extent that the term "includes" is used in either the detailed description or the claims, such term is intended to be inclusive in a manner similar to the term "comprising" as "comprising" is interpreted when employed as a transitional word in a claim.

[0161] Although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement which achieves the same or similar purpose may be substituted for the embodiments described or shown by the subject disclosure. The subject disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, can be used in the subject disclosure. For instance, one or more features from one or more embodiments can be combined with one or more features of one or more other embodiments. In one or more embodiments, features that are positively recited can also be negatively recited and excluded from the embodiment with or without replacement by another structural and/or functional feature. The steps or functions described with respect to the embodiments of the subject disclosure can be performed in any order. The steps or functions described with respect to the embodiments of the subject disclosure can be performed alone or in combination with other steps or functions of the subject disclosure, as well as from other embodiments or from other steps that have not been described in the subject disclosure. Further, more than or less than all of the features described with respect to an embodiment can also be utilized.

[0162] Less than all of the steps or functions described with respect to the exemplary processes or methods can also be performed in one or more of the exemplary embodiments. Further, the use of numerical terms to describe a device, component, step or function, such as first, second, third, and so forth, is not intended to describe an order or function unless expressly stated so. The use of the terms first, second, third and so forth, is generally to distinguish between devices, components, steps or functions unless expressly stated otherwise. Additionally, one or more devices or components described with respect to the exemplary embodiments can facilitate one or more functions, where the facilitating (e.g., facilitating access or facilitating establishing a connection) can include less than every step needed to perform the function or can include all of the steps needed to perform the function.

[0163] The Abstract of the Disclosure is provided with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separately claimed subject matter.

What is claimed is:

1. A method, comprising:

transmitting, by a first transmitter of a first device, a first wireless signal, wherein the first wireless signal utilizes a first signaling technology;

receiving, by a second receiver of the first device, a second wireless signal generated by a second device, wherein the second wireless signal utilizes a second signaling technology that differs from the first signaling technology; and

transmitting, by a second transmitter of the first device, a third wireless signal responsive to receiving the second wireless signal, wherein the third wireless signal utilizes the second signaling technology, and wherein the third wireless signal enables the second device to determine location information associated with the first device and the second device.

2. The method of claim **1**, wherein the first signaling technology comprises a narrowband signaling protocol, and wherein the second signaling technology comprises a wideband signaling technology.

3. The method of claim **1**, wherein the first device or the second device generates an alarm when the location information does not conform to a warning condition, and wherein the location information comprises a distance measured between the first device and the second device, an angular orientation between the first device and the second device, a first position of the first device relative to a second position of the second device, a trajectory of the first device, a trajectory of the second device, or any combinations thereof.

4. The method of claim **1**, wherein the second device is configured to select, responsive to receiving the first wireless signal, a random time to transmit the second wireless signal to avoid interfering with a transmission of another device.

5. The method of claim **1**, further comprising enabling the second receiver for a time interval for receiving at least the second wireless signal transmitted by the second device, wherein the time interval begins after transmitting the first wireless signal and ends at a time for at least receiving the second wireless signal.

6. The method of claim **1**, wherein the second wireless signal is received by the second receiver after receiving, by a first receiver of the first device, a fourth wireless signal that is generated by the second device, wherein the fourth wireless signal utilizes the first signaling technology, wherein the fourth wireless signal includes information for configuring the second receiver, the second transmitter, or a combination thereof, and wherein the receiving the fourth wireless signal permits the first device to shorten a window of time that the second receiver, the second transmitter, or the combination thereof is enabled.

7. The method of claim **1**, further comprising receiving, by a first receiver utilizing the first signaling technology or by the second receiver utilizing the second signaling technology, a fourth wireless signal generated by the second device, wherein the fourth wireless signal includes data comprising the location information associated with the first device and the second device as determined by the second device.

8. The method of claim **1**, further comprising retransmitting, by the first transmitter of the first device, the first wireless signal to prompt one or more devices to initiate a process for determining location information associated with the first device and the one or more devices.

9. The method of claim **1**, wherein the first wireless signal comprises an announcement signal for prompting a determination of the location information by the second device, and wherein the method further comprises:

receiving, by a first receiver of the first device, a fourth wireless signal generated by the second device, wherein the fourth wireless signal utilizes the first signaling technology; and

transmitting, by the first transmitter of the first device, a fifth wireless signal directed to the second device, wherein the fifth wireless signal indicates a time for transmitting the second wireless signal by the second device.

10. The method of claim **1**, wherein the second device is configured to transmit wireless signals for prompting location information measurements between the second device and other devices, and wherein the other devices include the first device.

11. A non-transitory machine-readable medium, comprising executable instructions that, when executed by a processing system of a first device, facilitate performance of operations, the operations comprising:

receiving, by a first receiver of the first device, a first wireless signal generated by a second device, wherein the first wireless signal utilizes a first signaling technology;

transmitting, by a second transmitter of the first device, a second wireless signal, wherein the second wireless signal utilizes a second signaling technology that differs from the first signaling technology;

receiving, by a second receiver of the first device, a third wireless signal, wherein the third wireless signal utilizes the second signaling technology; and

determining location information associated with the first device and the second device based on the third wireless signal.

12. The non-transitory machine-readable medium of claim **11**, wherein the first signaling technology comprises a Bluetooth signaling technology.

13. The non-transitory machine-readable medium of claim **11**, wherein the second signaling technology comprises an ultra-wideband signaling technology.

14. The non-transitory machine-readable medium of claim **11**, wherein the determining the location information includes determining a distance between the first device and the second device according to a time difference between a transmission of the second wireless signal and a reception of the third wireless signal.

15. The non-transitory machine-readable medium of claim **14**, wherein the determining the distance further includes adjusting the time difference according to a processing time by the second device to receive the second wireless signal and transmit the third wireless signal.

16. A first device, comprising:

a first transmitter;

a second transmitter;

a second receiver;

a processing system including a processor; and

a memory that stores executable instructions that, when executed by the processing system, facilitate performance of operations, the operations comprising:

transmitting, by the first transmitter, a first wireless signal, wherein the first wireless signal utilizes a narrowband signaling technology;

receiving, by the second receiver, a second wireless signal generated by a second device, wherein the second wireless signal utilizes a wideband signaling technology; and

transmitting, by the second transmitter, a third wireless signal, wherein the third wireless signal utilizes the wideband signaling technology, and wherein the third wireless signal enables the second device to determine location information associated with the first device and the second device.

17. The first device of claim **16**, wherein the first device and the second device correspond to a first mobile tag device and second mobile tag device, respectively.

18. The first device of claim **16**, wherein the location information associated with the first device and the second device is determined according to a time of arrival technique, an angle of arrival technique, signal strength technique, or any combinations thereof.

19. The first device of claim **16**, wherein the operations further comprise receiving a fourth wireless signal transmitted by the second device, and wherein the fourth wireless signal includes information associated with a distance between the first device and the second device.

20. The first device of claim **19**, wherein the fourth wireless signal utilizes the narrowband signaling technology or the wideband signaling technology.

* * * * *