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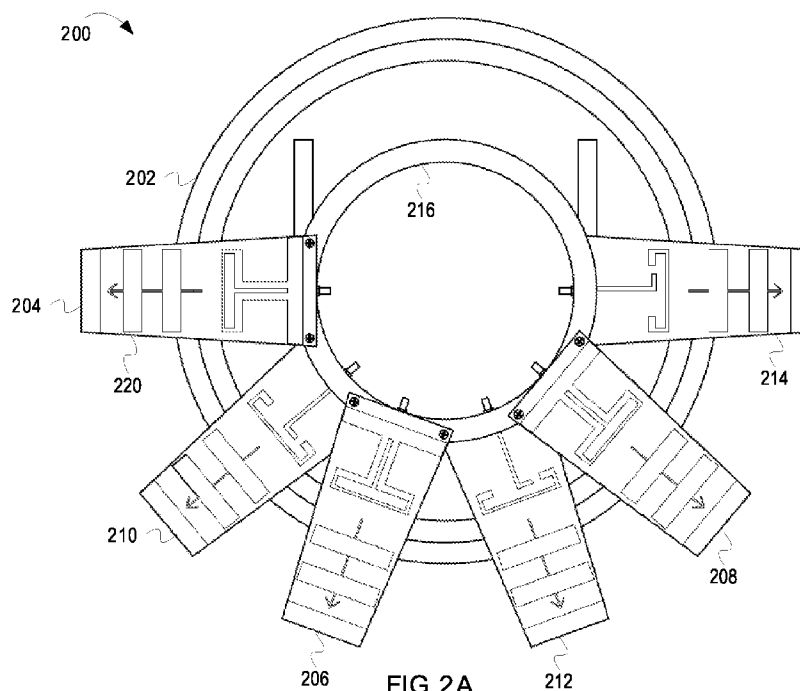
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(54) Title: SYSTEMS AND METHODS FOR LOCATING NODES



(57) Abstract: In some embodiments, apparatuses and methods are provided herein useful to locating a mobile-based node. In some embodiments, a location system comprises a plurality of ground-based nodes, each including a ground-based timing module configured to generate ground-based timing data, a ground-based wireless communications system configured to transmit and receive wireless communications via a first communications protocol and a second communications protocol, the mobile-based node including a mobile-based timing module configured to generate mobile-based timing data and a mobile-based wireless communications system configured to transmit and receive wireless communications via the first communications protocol and the second communications protocol, and a control system configured to calculate a location of the mobile-based node based on (i) wireless communications transmitted by the mobile-based node, (ii) wireless communications received by the mobile-based node, (iii) the timestamp based on the

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mobile-based timing data, and (iv) the respective timestamp based on the ground-based timing data.

SYSTEMS AND METHODS FOR LOCATING NODES

Cross-Reference to Related Applications

[0001] This application claims the benefit of, and priority to, U.S. Provisional Patent Application No. 63/506,904 filed on June 8, 2023, which is hereby incorporated by reference herein in its entirety.

Technical Field

[0002] This invention relates generally to location determination and, more specifically, location determination via wireless communications.

Background

[0003] Typically, locations of objects are determined using satellite navigation signals based on Global Navigation Satellite Systems (GNSS) technology. For example, the location of a vehicle (such as an aircraft, automobile, watercraft), a person, etc. can be determined based on GNSS technology. Global Positioning System (GPS) technology that is part of GNSS is used to locate objects using signals transmitted from geosynchronous satellites. The satellites broadcast signals. The signals include location information and time information. The location information identifies a location of the satellite from which the signal was broadcast. The time information identifies the time at which each signal was broadcast. A receiver (*e.g.*, in a vehicle) receives the communications from the satellites. The receiver then calculates distances to each of the satellites from which a signal was received based on the time at which the signal was received and the time at which the signal was broadcast. If the receiver is receiving signals from a sufficient number of satellites, the receiver can calculate its location with relatively high accuracy (*i.e.*, within several meters).

[0004] While satellite navigation can be used to determine the location of objects with relatively high accuracy, it does have drawbacks. For example, because satellite navigation is one of the most common locating tools used, it could be the target of an attack by a malicious actor. Further, even if not intentionally disrupted, satellite navigation systems can fail and/or operate incorrectly. If satellite navigation systems fail or are operating incorrectly, redundant locating tools must be used. Unfortunately, redundant locating tools are often manual instruments within a vehicle or not automated for ease of use. Accordingly, the loss of satellite navigation places the locating burden on an operator or crewmember of the vehicle, which can

result in errors and inaccuracies. Accordingly, a need exists for an improved locating system that does not require satellite navigation to function properly.

Brief Description of the Drawings

[0005] Disclosed herein are embodiments of systems, apparatuses, and methods pertaining to a location system. This description includes drawings, wherein:

[0006] FIG. 1 is a diagram depicting a vehicle exchanging wireless communications with ground-based nodes, according to some embodiments;

[0007] FIGS. 2A and 2B are top and perspective views, respectively, of a node, according to some embodiments;

[0008] FIG. 3 is a block diagram of a system for aiding in locating an object, according to some embodiments;

[0009] FIG. 4 is a flow chart depicting example operations for locating an object using two-way ranging, according to some embodiments;

[0010] FIG. 5 is a flow chart depicting example operations for locating an object using one-way ranging, according to some embodiments.

[0011] Elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions and/or relative positioning of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of various embodiments of the present disclosure. Also, common but well-understood elements that are useful or necessary in a commercially feasible embodiment are often not depicted in order to facilitate a less obstructed view of these various embodiments of the present disclosure.

Detailed Description

[0012] Generally speaking, pursuant to various embodiments, systems, apparatuses, and methods are provided herein useful to locating a mobile-based node. In some embodiments, a location system for aiding in locating a mobile-based node comprises a plurality of ground-based nodes, each of the ground-based nodes including a ground-based timing module configured to generate ground-based timing data, a ground-based wireless communications system configured to transmit and receive wireless communications via a first communications protocol and a second communications protocol, wherein each of the wireless communications transmitted by a respective one of the ground-based nodes includes a respective timestamp based on the ground-based timing data, the mobile-based node including a mobile-based timing

module configured to generate mobile-based timing data and a mobile-based wireless communications system configured to transmit and receive wireless communications via the first communications protocol and the second communications protocol, wherein each of the wireless communications transmitted by the mobile-based node includes a timestamp based on the mobile-based timing data, and a control system configured to calculate a location of the mobile-based node based on (i) wireless communications transmitted by the mobile-based node, (ii) wireless communications received by the mobile-based node, (iii) the timestamp based on the mobile-based timing data, and (iv) the respective timestamp based on the ground-based timing data.

[0013] As previously discussed, satellite navigation is one of the most common locating/navigational tools used. Satellite navigation systems, like GPS, rely on a series of satellites that broadcast signals to Earth-based receivers. While satellite navigation systems can provide location data with relatively high accuracy, most backup systems are not nearly as effective or useful. Additionally, though satellite navigation systems can provide location data with relatively high accuracy, such location data could be improved with redundant systems. Described herein are systems, methods, and apparatuses that seek minimize, if not eliminate, the drawbacks of current systems.

[0014] In one embodiment, as described herein, a location system includes ground-based nodes and mobile-based nodes. The ground-based nodes are positioned in fixed locations, while the mobile-based nodes are configured to move relative to the ground-based nodes. For example, the ground-based nodes can be located on, or secured to, the ground and the mobile-based nodes can be carried in, or mounted to, a vehicle. The ground-based nodes and mobile-based nodes exchange wireless communications. The wireless communications are used to determine a location of the mobile-based node. An overview of such a system is described with respect to FIG. 1.

[0015] FIG. 1 is a diagram depicting a vehicle 102 exchanging wireless communications with ground-based nodes 108 – 114, according to some embodiments. As depicted in FIG. 1, the vehicle 102 is an aircraft, though it should be noted that the systems, methods, and apparatuses described herein can be used with any suitable type of vehicle. The vehicle 102 is travelling across terrain 116. While the vehicle 102 is travelling across the terrain 116, a mobile-based node 104 is exchanging wireless communications with the ground-based nodes 108 – 114. The exchanged wireless communications are used to aid in locating the mobile-based node 104. Because the mobile-based node 104 is located on and/or within the vehicle 102, the location of

the vehicle 102 may be used interchangeably with location of the mobile-based node 104 herein.

[0016] The locating tool can be used to determine a location of the vehicle 102 in a number of ways. For example, the locating tool can be used to determine the location of the vehicle 102 based on one-way ranging (discussed in more detail with respect to FIG. 5), based on two-way ranging (discussed in more detail with respect to FIG. 4), in concert with other locating tools (*e.g.*, satellite navigation), etc. At a high level, the wireless communications exchanged by the mobile-based node 104 and the ground-based nodes 108 – 114 include timing data (*e.g.*, timestamps). The wireless communications transmitted by the ground-based nodes 108 – 114 also include location data associated with a respective one of the ground-based nodes 108 – 114. The timing data and the location data is used to calculate the location of the vehicle 102.

[0017] Referring to the example depicted in FIG. 1, the mobile-based node 104 is transmitting wireless communications, which are received by four ground-based nodes 108 – 114: 1) a first ground-based node 108; 2) a second ground-based node 110; 3) a third ground-based node 112; and 4) a fourth ground-based node 114. It should be noted that while referred to as “ground-based,” the ground-based nodes 108 – 114 need not be located on the “ground.” Rather, the ground-based nodes 108 – 114 are “ground-based” in that they are relatively stationary (*e.g.*, designed to stay in a single location) and can be located in any suitable position. For example, as depicted in FIG. 1, the second ground-based node 110 is secured to a tower 118.

[0018] The wireless communications transmitted by the mobile-based node 104 include timing data. For example, the wireless communications transmitted by the mobile-based node 104 can include timestamps indicating the time at which the mobile-based node 104 transmitted the wireless communications. In one embodiment, the mobile-based node 104 transmits the wireless communications via multiple communications protocols. For example, the mobile-based node 104 can transmit wireless communications via one or more of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, Zigbee, or any other suitable communications protocol. As one specific example, the mobile-based node 104 can transmit the wireless communications via Wi-Fi and LoRa. The communications protocols used can be selected based on, for example, range, susceptibility to interference, accuracy, power requirements, etc.

[0019] The ground-based nodes 108 – 114 receive the wireless communications transmitted by the mobile-based node 104. The ground-based nodes 108 – 114 receive the wireless communications and log a time (*i.e.*, timing data) at which the wireless communications were received. In one embodiment (*e.g.*, one-way ranging), the timing data from the mobile-based

node 104, the timing data logged by the ground-based nodes 108 – 114, and the locations of the ground-based nodes 108 – 114 can be used to calculate a location of the mobile-based node 104. For example, if the location of the ground-based nodes 108 – 114 is known and the time of flight (TOF) for the wireless communications can be calculated, the distance from a respective one of the ground-based nodes 108 – 114 can be calculated. However, a single absolute distance is not sufficient to determine a location of the mobile-based node 104 in three dimensions. Rather, distances of the mobile-based node 104 from multiple of the ground-based nodes 108 – 114 are used to triangulate the location of the mobile-based node 104. However, leveraging the multi-element array of FIG. 2A it is possible to generate Angle-of-Arrival (AoA) estimates in 2D with orthogonal orientations of FIG. 2A. With an absolute distance, 3D positioning is now possible.

[0020] Further, in some embodiments (*e.g.*, two-way ranging), the ground-based nodes 108 – 114 respond to the wireless communications transmitted by the mobile-based node 104. In such embodiments, the ground-based nodes 108 – 114 transmit ground-based communications back to the mobile-based node 104. The ground-based communications include location data and timing data. The location data indicates a location of a respective one of the ground-based nodes 108 – 114. For example, the ground-based communication transmitted by the first ground-based node 108 includes location data indicating a location of the first ground-based node, the ground-based communication transmitted by the second ground-based node 110 includes location data indicating a location of the second ground-based node 110, etc. The timing data indicates a time at which the ground-based communication was transmitted by a respective one of the ground-based nodes 108 – 114. For example, the ground-based communication transmitted by the first ground-based node 108 includes timing data indicating a time at which the first ground-based node transmitted the ground-based communication, the ground-based communication transmitted by the second ground-based node 110 includes timing data indicating a time at which the second ground-based node 110 transmitted the ground-based communication, etc. The timing data and location data can be used to calculate the location of the mobile-based node 104. For example, a calculation can be performed based on the timing data for transmission of the wireless communications by the mobile-based node 104, the timing data for transmission of the wireless communications by the ground-based nodes 108 – 114, and locations of the ground-based nodes 108 – 114.

[0021] It should be noted that the calculation of the location of the mobile-based node 104 can be performed by any suitable component and such component can be located or associated with

any other suitable component. For example, the location calculation can be performed by a control system, as described in more detail with respect to FIG. 3. The control system can be located and/or associated with the mobile-based node 104, one or more of the ground-based nodes 108 – 114, a remote component (*e.g.*, a cloud-based component), etc.

[0022] While the discussion of FIG. 1 provides an overview of locating system, the discussion of FIG. 2 provides additional detail regarding nodes of the locating system.

[0023] FIGS. 2A and 2B are top and perspective views, respectively, of a node 200, according to some embodiments. The node 200 (*e.g.*, a ground-based node or mobile-based node) generally includes a housing 202, a frame 216, and various wireless communication system components. In the example depicted in FIGS. 2A and 2B, the frame 216 is generally secured to the housing 202, and the wireless communication system components are secured to the frame 216. In some embodiments, though not shown in FIGS. 2A and 2B, the node 200 can include a cover portion. The cover portion can be secured to one or both of the housing 202 and the frame 216 to cover and/or otherwise protect or enclose the components of the node 200. The cover portion can take any suitable form (*e.g.*, domed, polygonal, etc.) and can be secured to one or both of the housing 202 and the frame 216 in any suitable manner (*e.g.*, via fasteners, clips, adhesive, etc.). Further, in some embodiments, the cover portion can include a door or other feature that allows the components of the node 200 to be accessed.

[0024] The wireless communication system components generally include antennas and chipsets (*e.g.*, wireless communications chipsets). The antennas can take any suitable form. In the example depicted in FIGS. 2A and 2B, the antennas are Yagi-style antennas formed into printed circuit boards (PCBs). Additionally, as depicted in FIGS. 2A and 2B, the chipsets are integrated into the PCBs, though such is not required. For example, in some embodiments, the antennas can be communicatively coupled to the chipsets (*i.e.*, the antennas and chipsets are not integrated into a common PCB). Further, in some embodiments, the antennas are directional antennas.

[0025] With reference to the example depicted in FIGS. 2A and 2B, the node 200 includes six PCBs: 1) a first PCB 204, 2) a second PCB 206; 3) a third PCB 208; 4) a fourth PCB 210; 5) a fifth PCB 212; and 6) a sixth PCB 214. Though the example depicted in FIGS. 2A and 2B includes six PCBs (or antennas), such is not required. For example, the node 200 can include greater, or fewer, than six PCBs (or antennas). Further, the PCBs (or antennas if not embodied in PCBs) can be arranged in any suitable manner. For example, the PCBs (or antennas) can be arranged symmetrically about the frame 216, asymmetrically about the frame 216, evenly

spaced about the frame 216, unevenly spaced about the frame 216, etc. In the example depicted in FIGS. 2A and 2B, the PCBs are arranged asymmetrically about the frame 216 but are evenly spaced with respect to one another. Additionally, the PCBs (or antennas) can be of any suitable length. For example, ends of the PCBs (or antennas) can extend to touch a cover portion of the node 200. Further, though the antennas depicted in FIGS. 2A and 2B are arranged such that they do not completely surround the frame 216, embodiments are not so limited. For example, in some embodiments, the antennas can be positioned such that they surround the entirety of the frame 216.

[0026] In the example depicted in FIGS. 2A and 2B, the node 200 includes wireless communications systems to transmit and/or receive wireless communications via multiple communications protocols. For example, a first group of PCBs including the first PCB 204, the second PCB 206, and third PCB 208 can be configured to transmit and/or receive wireless communications via a first communications protocol, and a second group of PCBs including the fourth PCB 210, the fifth PCB 212, and the sixth PCB 214 can be configured to transmit and/or receive wireless communications via a second communications protocol. Accordingly, the PCBs in the first group of PCBs can include a first type of wireless communications chipset (*i.e.*, a wireless communications chipset configured to transmit and/or receive wireless communications via the first communications protocol) and the PCBs in the second group of PCBs can include a second type of wireless communications chipset (*i.e.*, a wireless communications chipset configured to transmit and/or receive wireless communications via the second communications protocol). Alternatively, in some embodiments, the ground-based node may include only two wireless communications chipsets (*e.g.*, a first wireless communications chipset configured to transmit and/or receive wireless communications via the first communications protocol and a second wireless communications chipset configured to transmit and/or receive wireless communications via the second communications protocol). In this example, each PCB in the first group of PCBs would be communicatively coupled to the first wireless communications chipset and each PCB in the second group of PCBs would be communicatively coupled to the second wireless communications chipset. In further embodiments, the ground-based node 200 may include only one wireless communications chipset to which all, or some, of the PCBs are communicatively coupled. In such embodiments, the wireless communications chipset can be configured to transmit and/or receive wireless communications via both the first communications protocol and the second communications protocol.

[0027] As previously noted, the PCBs of the node 200 depicted in FIGS. 2A and 2B act as antennas. For example, longitudinal traces 220 can act as parallel elements of a Yagi-style antenna. It should be noted that while the example depicted in FIGS. 2A and 2B includes six PCBs (or antennas), such is not required. For example, the ground-based node 200 can include great, or fewer, than six PCBs (or antennas). Further, the PCBs (or antennas) need not be specific to a single communications protocol. That is, in some embodiments, one or more of the PCBs or antennas can modulate or otherwise alternate between transmitting and/or receiving wireless communications via the first communications protocol and the second communications protocol.

[0028] While the discussion of FIG. 2 provides additional detail regarding nodes of a locating system, the discussion of FIG. 3 provides additional detail regarding the locating system.

[0029] FIG. 3 is a block diagram of a system 300 for aiding in locating an object, according to some embodiments. The system 300 includes a control system 302, ground-based nodes 304, a network 310, a satellite navigation system 312, and a mobile-based node 314. One or more of the control system 302, the ground-based nodes 304, the satellite navigation system 312, and the mobile-based node 314 are communicatively coupled via the network 310. Accordingly, the network 310 can take any suitable form and include wired and/or wireless links. For example, the network 310 can be capable of transmitting data through a variety of communications protocols and a combination of multiple networks (*e.g.*, wireless wide area networks (WWANs), wide area networks (WANs), local area networks (LANs), etc.).

[0030] The ground-based nodes 304 are “ground-based” in that they are relatively stationary (*e.g.*, designed to stay in a single location) and can be located in any suitable position. In one embodiment, the ground-based nodes 304 are arranged as an array, different portions of the array covering different geographic regions. For example, in some embodiments, a first portion of the array of ground-based nodes 304 can handoff communications with the mobile-based node 314 to a second portion of the array of ground-based nodes 304 as the mobile-based node 314 travels with respect to the ground-based nodes 304.

[0031] Each of the ground-based nodes 304 generally includes a power system 306, a wireless communications system 308 (*i.e.*, a ground-based wireless communications system), and a timing module 322 (*i.e.*, a ground-based timing module). The power system 306 acts to provide power to the ground-based node 304 and can take any suitable form. For example, the power system 306 can interface with ground-based power (*e.g.*, hardwired to an electrical grid), include a battery, include a solar cell and power store, etc. The wireless communications

system 308 is generally configured to transmit and/or receive wireless communications. In some embodiments, the wireless communications system 308 is configured to transmit and/or receive wireless communications via multiple communications protocols. As one example, the ground-based node can be configured to transmit and/or receive wireless communications via both Wi-Fi and LoRa. The ground-based nodes 304 also include a timing module, such as a clock. The ground-based nodes 304 can synchronize timing with one another and/or with other external systems (*e.g.*, the satellite navigation system 312). In one embodiment, each of the ground-based nodes 304 synchronizes its timing module with the satellite navigation system 312. If there is a loss of signal from the satellite navigation system 312 or the signal from the satellite navigation system is compromised, the ground-based nodes 304 can perform a negotiation to determine which one or more of the ground-based nodes 304 will act as the reference node with respect to timing. This negotiation can be performed in any suitable manner and based on any suitable criteria. For example, the ground-based node 304 with the newest or most recently updated hardware and/or software can be chosen as the reference node, the ground-based node 304 with the greatest accuracy (*e.g.*, based on logging timing data provided by the satellite navigation system compared to the ground-based nodes 304 local timing data) can be chosen as the reference node, the ground-based node 304 chosen as the reference node can be based on locations and/or geography (*e.g.*, the most central ground-based node 304, the ground-based node 304 with the clearest line of sight, etc.), etc. In embodiments in which the ground-based nodes 304 transmit wireless communications, the ground-based nodes 304 can include timing data (*e.g.*, timestamps) in the transmitted wireless communications.

[0032] The satellite navigation system 312 can be any suitable system, such as a GPS system. It should be noted that, in some embodiments, the satellite navigation system is not required. For example, in such embodiments, the location of the mobile-based node 314 can be calculated based on communications between the mobile-based node 314 and the ground-based nodes 304. However, in systems that include the satellite navigation system 312, the satellite navigation system 312 can be used in concert with mobile-based node 314 and the ground-based nodes 304 to calculate the location of the mobile-based node with high precision based on Real-Time Kinematics (RTK). As one example, the satellite navigation system 312 can be used as the primary source for location calculations, and the mobile-based node 314 and the ground-based nodes 304 can be used for redundancy and/or error-checking purposes. Similarly, the mobile-based node 314 and the ground-based nodes 304 can be used as the

primary source of location calculations, and the satellite navigation system 312 can be used for redundancy and/or error-checking purposes. In some embodiments, the satellite navigation system 312 is the primary source of location calculations, and the mobile-based node 314 and the ground based nodes 304 are used when a trigger condition has occurred. That is, upon occurrence of the trigger condition, data from the mobile-based node 314 and the ground-based nodes 304 can be used to calculate a location of the mobile-based node 314. The trigger condition can be any suitable condition. For example, the trigger condition can be a loss of satellite navigation signal, a loss of satellite navigation signal for a threshold period of time, quality of a satellite navigation signal, an inability to determine a location based on satellite navigation signal, a known location of the mobile-based station, an estimated location of the mobile-based station, etc.

[0033] The mobile-based node 314 is configured to move relative to the ground-based nodes 304. The mobile-based node 314 generally includes a power system 316, a wireless communications system 318 (*i.e.*, a mobile-based wireless communications module), and a timing module 320 (*i.e.*, a mobile-based timing module). The power system 316 acts to provide power to the mobile-based node 314 and can take any suitable form. For example, the power system 316 can draw power from a vehicle on, or within, which the mobile-based node 314 is located, include a battery or other power store, etc. The wireless communications system 318 is generally configured to transmit and/or receive wireless communications. In some embodiments, the wireless communications system 318 is configured to transmit and/or receive wireless communications via multiple communications protocols. As one example, the ground-based node can be configured to transmit and/or receive wireless communications via both Wi-Fi and LoRa. The mobile-based node 314 also includes the timing module 320, such as a clock. The timing module 320 is generally configured to generate timing data for the mobile-based node 314. For example, the timing data generated by the timing module 320 can be used to include timing data, such as timestamps, in the wireless communications transmitted by the mobile-based node 314. Additionally, in some embodiments, the timing module 320 includes a GNSS receiver (or other satellite receiver). In such embodiments, the GNSS received can be used to perform RTK calculations for the mobile-based node 314.

[0034] The control system 302 can comprise a fixed-purpose hard-wired hardware platform (including but not limited to an application-specific integrated circuit (ASIC) (which is an integrated circuit that is customized by design for a particular use, rather than intended for general-purpose use), a field-programmable gate array (FPGA), and the like) or can comprise

a partially or wholly-programmable hardware platform (including but not limited to microcontrollers, microprocessors, and the like). These architectural options for such structures are well known and understood in the art and require no further description here. The control system 302 is configured (for example, by using corresponding programming as will be well understood by those skilled in the art) to carry out one or more of the steps, actions, and/or functions described herein.

[0035] By one optional approach the control system 302 operably couples to a memory. The memory may be integral to the control system 302 or can be physically discrete (in whole or in part) from the control system 302 as desired. This memory can also be local with respect to the control system 302 (where, for example, both share a common circuit board, chassis, power supply, and/or housing) or can be partially or wholly remote with respect to the control system 302 (where, for example, the memory is physically located in another facility, metropolitan area, or even country as compared to the control system 302).

[0036] This memory can serve, for example, to non-transitorily store the computer instructions that, when executed by the control system 302, cause the control system 302 to behave as described herein. As used herein, this reference to “non-transitorily” will be understood to refer to a non-ephemeral state for the stored contents (and hence excludes when the stored contents merely constitute signals or waves) rather than volatility of the storage media itself and hence includes both non-volatile memory (such as read-only memory (ROM) as well as volatile memory (such as an erasable programmable read-only memory (EPROM)).

[0037] The control system is generally configured to calculate a location of the mobile-based node. The control system 302 can perform location calculations based on any suitable data or communication mode. For example, the control system 302 can perform location calculations based on one-way and/or two-way ranging. Accordingly, the control system 302 can be located and/or associated with any other components of the system. For example, the control system 302 can be integrated and/or associated with one or more of the ground-based nodes 304, the mobile-based node 314, located remotely from the ground-based nodes 304 and the mobile-based node 314 (*e.g.*, in the cloud), etc. The control system 302 generally calculates the location of the mobile-based node 314 based locations of the ground-based nodes 304, timing data provided by one or more of the ground-based nodes 304, and/or timing data provided by the mobile-based node 314. In some embodiments, the control system 302 includes a navigation fusion filter 320. The navigation fusion filter generally aggregates data from sensors and systems associated with the system 300. For example, the navigation fusion filter

320 can aggregate data from the ground-based nodes 304 (e.g., timing data, location data, etc.), the mobile-based node 314 (e.g., timing data, location data, etc.), inertial measurement units (IMUs), etc. In such embodiments, the navigation fusion filter 320 can calculate the location of the mobile-based unit 314 based on the aggregated data. As with the control system 302, the navigation fusion filter 320 can be located and/or associated with any other components of the system. For example, the navigation fusion filter 320 can be integrated and/or associated with one or more of the ground-based nodes 304, the mobile-based node 314, located remotely from the ground-based nodes 304 and the mobile-based node 314 (e.g., in the cloud), etc.

[0038] While the discussion of FIG. 3 provides additional detail regarding a locating system, the discussion of FIGS. 4 and 5 provide additional detail regarding example operations for calculating the location of an object.

[0039] FIG. 4 is a flow chart depicting example operations for locating an object using two-way ranging, according to some embodiments. The flow begins at block 402.

[0040] At block 402, a first wireless communication is transmitted. For example, a wireless communications system of a mobile-based node can transmit the first wireless communication. In one embodiment, the first wireless communication is transmitted via multiple communications protocols. For example, the mobile-based node can transmit the first wireless communication via one or more of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, Zigbee, etc. In one embodiment, the mobile-based node transmits the first wireless communication via a first communications protocol (e.g., Wi-Fi) and a second communications protocol (e.g., LoRa). In some embodiments, the first wireless communication includes timing data, such as a timestamp. The timing data indicates the time at which the first wireless communication was transmitted by the mobile-based node. In such embodiments, a mobile-based timing module can generate the timing data upon which the timestamp is generated. The flow continues at block 404.

[0041] At block 404, the first wireless communication is received. For example, the first wireless communication can be received by ground-based nodes in an array of ground-based nodes. The ground-based nodes can receive the first wireless communication via one or both of the first communications protocol and the second communications protocol. The flow continues at block 406.

[0042] At block 406, ground-based communications are transmitted. For example, one or more of the ground-based nodes in the array of ground-based nodes can transmit a ground-based communication. In some embodiments, the ground-based nodes transmit the ground-based

communications via multiple communications protocols (*e.g.*, a first communications protocol and a second communications protocol). Further, in some embodiments, the ground-based communications include timing data, such as timestamps. In such embodiments, one or more of the ground-based nodes can have ground-based timing modules that generate the timing data. In addition to the timing data, the ground-based communications include location data. The location data includes an indication of the location of the ground-based node that transmitted the ground-based communication. Additionally, or alternatively, the timing data can include an indication of when the first wireless communication was received by a respective one of the ground-based nodes. The ground-based nodes can transmit the ground-based communications in response to receiving the first wireless communication. Additionally, or alternatively, the ground-based nodes can transmit ground-based communications periodically or in response to any suitable event or condition. The flow continues at block 408.

[0043] At block 408, a location of the mobile-based node is calculated. For example, a control system can calculate the location of the mobile-based node. The control system calculates the location of the mobile-based node based on the timing data associated with the first wireless communication, location data associated with each of the ground-based nodes from which a ground-based communication was received, and the timing data associated with each ground-based communication transmitted by a ground-based node. The control system can be associated with, or located with, any suitable component of the system. As one example, the control circuit can be associated with, or part of, the mobile-based node. In such embodiments, the mobile-based node receives the ground-based communications from the ground-based nodes and calculates its location. As another example, the control system can be located remotely from the mobile-based node and the ground-based nodes. In such embodiments, the mobile-based node and/or the ground-based node transmit wireless communications (*e.g.*, the first wireless communication, the ground-based communications, the timing data associated with the first wireless communication, the timing data associated with the ground-based communications, and/or the location data associated with the ground-based nodes) to the control system. As another example, one or more of the ground-based nodes can include the control system. In such embodiments, one or more of the ground-based nodes calculates the location of the mobile-based node. Additionally, in some embodiments, the system may include multiple control systems. For example, the mobile-based node can include a control system, one or more of the ground-based nodes can include a control system, and/or the control

system can be cloud-based. In such embodiments, multiple locations for the mobile-based node can be calculated. The multiple locations can be used, for example, for redundancy and/or error correction. Additionally, in some embodiments, the control system can automatically correct for errors. For example, if a satellite navigation system consistently calculates a location of the mobile-based node to be X but the control system consistently calculated the same location to be Y, the control system can error correct to know that the location Y is really the location X. In such embodiments, the control system can apply a machine learning algorithm to perform such error correction.

[0044] While the discussion of FIG. 4 provides additional detail regarding example operations for location determinations based on two-way ranging, the discussion of FIG. 5 provides additional detail regarding location determination based on one-way ranging.

[0045] FIG. 5 is a flow chart depicting example operations for locating an object using one-way ranging, according to some embodiments. The flow begins at block 502.

[0046] At block 502, a first wireless communication is transmitted. For example, a wireless communications system of a mobile-based node can transmit the first wireless communication. In one embodiment, the first wireless communication is transmitted via multiple communications protocols. For example, the mobile-based node can transmit the first wireless communication via one or more of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, Zigbee, etc. In one embodiment, the mobile-based node transmits the first wireless communication via a first communications protocol (*e.g.*, Wi-Fi) and a second communications protocol (*e.g.*, LoRa). In some embodiments, the first wireless communication includes timing data, such as a timestamp. The timing data indicates the time at which the first wireless communication was transmitted by the mobile-based node. In such embodiments, a mobile-based timing module can generate the timing data upon which the timestamp is generated. The flow continues at block 504.

[0047] At block 504, the first wireless communication is received. For example, the first wireless communication can be received by ground-based nodes in an array of ground-based nodes. The ground-based nodes can receive the first wireless communication via one or both of the first communications protocol and the second communications protocol. The flow continues at block 506.

[0048] At block 506, a location of the mobile-based node is calculated. For example, a control system can calculate the location of the mobile-based node. The control system calculates the location of the mobile-based node based on the timing data associated with the first wireless

communication, location data associated with each of the ground-based nodes from which a ground-based communication was received, and the timing data associated with when the first wireless communication was received by each ground-based node. The control system can be associated with, or located with, any suitable component of the system. As one example, the control system can be located remotely from the mobile-based node and the ground-based nodes. In such embodiments, the mobile-based node and/or the ground-based node transmit wireless communications (*e.g.*, the first wireless communication, the timing data associated with the first wireless communication, the timing data associated with the ground-based communications, and/or the location data associated with the ground-based nodes) to the control system. As another example, one or more of the ground-based nodes can include the control system. In such embodiments, one or more of the ground-based nodes calculates the location of the mobile-based node. Additionally, in some embodiments, the system may include multiple control systems. For example, the mobile-based node can include a control system, one or more of the ground-based nodes can include a control system, and/or the control system can be cloud-based. In such embodiments, multiple locations for the mobile-based node can be calculated. The multiple locations can be used, for example, for redundancy and/or error correction. Additionally, in some embodiments, the control system can automatically correct for errors. For example, if a satellite navigation system consistently calculates a location of the mobile-based node to be X but the control system consistently calculated the same location to be Y, the control system can error correct to know that the location Y is really the location X. In such embodiments, the control system can apply a machine learning algorithm to perform such error correction.

[0049] In some embodiments, a location system for aiding in locating a mobile-based node comprises a plurality of ground-based nodes, each of the ground-based nodes including a ground-based timing module configured to generate ground-based timing data, a ground-based wireless communications system configured to transmit and receive wireless communications via a first communications protocol and a second communications protocol, wherein each of the wireless communications transmitted by a respective one of the ground-based nodes includes a respective timestamp based on the ground-based timing data, the mobile-based node including a mobile-based timing module configured to generate mobile-based timing data and a mobile-based wireless communications system configured to transmit and receive wireless communications via the first communications protocol and the second communications protocol, wherein each of the wireless communications transmitted by the mobile-based node

includes a timestamp based on the mobile-based timing data, and a control system configured to calculate a location of the mobile-based node based on (i) wireless communications transmitted by the mobile-based node, (ii) wireless communications received by the mobile-based node, (iii) the timestamp based on the mobile-based timing data, and (iv) the respective timestamp based on the ground-based timing data.

[0050] In some embodiments, a location system for aiding in locating a mobile-based node comprises a plurality of ground-based nodes, each of the ground-based nodes including a ground-based timing module configured to generate ground-based timing data, a ground-based wireless communications system configured to receive wireless communications via a first communications protocol and a second communications protocol, the mobile-based node including a mobile-based timing module configured to generate mobile-based timing data, and a mobile-based wireless communications system configured to transmit wireless communications via the first communications protocol and the second communications protocol, wherein each of the wireless communications transmitted by the mobile-based node includes a timestamp based on the mobile-based timing data, and a control system configured to calculate a location of the mobile-based node based on (i) location data associated with each of the ground-based nodes, (ii) the timestamp based on the mobile-based timing data, and (iii) the ground-based timing data.

[0051] In some embodiments, an apparatus and a corresponding method performed by the apparatus comprises transmitting, by a wireless communications system of the mobile-based node, a first wireless communication, wherein the first wireless communication is transmitted via a first communications protocol and a second communications protocol, and wherein the first wireless communication includes a first timestamp, receiving, by a plurality of ground-based nodes, the first wireless communication, transmitting, by each of the plurality of ground-based nodes in response to receipt of the first wireless communication, ground-based communications, wherein the ground-based communications are transmitted via the first communications protocol and the second communications protocol, and wherein each of the ground-based communications includes a timestamp, and calculating, by a control system, a location of the mobile-based node based on (i) the first timestamp, (ii) locations of each ground-based node of the plurality of ground-based nodes, and (iii) the timestamp included in each of the ground-based communications.

[0052] In some embodiments, an apparatus and a corresponding method performed by the apparatus comprises transmitting, by a wireless communications system of the mobile-based

node, a first wireless communication, wherein the first wireless communication is transmitted via a first communications protocol and a second communications protocol, and wherein the first wireless communication includes a first timestamp, receiving, by a plurality of ground-based nodes, the first wireless communication, and calculating, by a control system, a location of the mobile-based node based on (i) the first timestamp, (ii) locations of each ground-based node of the plurality of ground-based nodes, and (iii) a time at which the first wireless communication was received by each ground-based node in the plurality of ground-based node.

[0053] Those skilled in the art will recognize that a wide variety of other modifications, alterations, and combinations can also be made with respect to the above described embodiments without departing from the scope of the disclosure, and that such modifications, alterations, and combinations are to be viewed as being within the ambit of the inventive concept.

CLAIMS

What is claimed is:

1. A location system for aiding in locating a mobile-based node, the system comprising:
a plurality of ground-based nodes, each of the ground-based nodes including:
 - a ground-based timing module configured to generate ground-based timing data;
 - a ground-based wireless communications system configured to transmit and receive wireless communications via a first communications protocol and a second communications protocol, wherein each of the wireless communications transmitted by a respective one of the ground-based nodes includes a respective timestamp based on the ground-based timing data;the mobile-based node including:
 - a mobile-based timing module configured to generate mobile-based timing data;
 - and
 - a mobile-based wireless communications system configured to transmit and receive wireless communications via the first communications protocol and the second communications protocol, wherein each of the wireless communications transmitted by the mobile-based node includes a timestamp based on the mobile-based timing data; anda control system configured to:
 - calculate a location of the mobile-based node based on (i) wireless communications transmitted by the mobile-based node, (ii) wireless communications received by the mobile-based node, (iii) the timestamp based on the mobile-based timing data, and (iv) the respective timestamp based on the ground-based timing data.
2. The location system of claim 1, wherein the control system is further configured to:
determine, based on the location of the mobile-based node and a known location, that
the location of the mobile-based node includes an error; and
apply a trained machine learning algorithm to the location of the mobile-based node;
and

correct, based on the application of the trained machine learning algorithm to the location of the mobile-based node, the location of the mobile-based node.

3. The location system of claim 1 or claim 2, wherein the first communications protocol is one of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, and Zigbee, and wherein the second communications protocol is one of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, and Zigbee.
4. The location system of any one of claims 1 – 3, wherein the plurality of ground-based nodes includes at least three ground-based nodes.
5. The location system of any one of claims 1 – 4, further comprising:
a satellite navigation transceiver, wherein the satellite navigation transceiver is configured to receive satellite navigation signals from one or more satellites.
6. The location system of claim 5, wherein the control system additionally calculates the location of the mobile-based node based on the received satellite navigation signals.
7. The location system of claim 5, wherein the control system is further configured to:
determine that a trigger condition has occurred;
wherein the control system calculates the location of the mobile-based node in response to the determination that the trigger condition has occurred.
8. The location system of claim 7, wherein the trigger condition is one or more of a loss of satellite navigation signal, a loss of satellite navigation signal for a threshold period of time, quality of a satellite navigation signal, an inability to determine a location based on satellite navigation signal, a known location of the mobile-based station, and an estimated location of the mobile-based station.
9. The location system of any one of claims 1 – 8, wherein the first communications protocol has a first range and the second communications protocol has a second range, and wherein the first range is different than the second range.

10. The location system of claim 9, wherein the first range is approximately 100 meters and wherein the second range is at least 5 kilometers.
11. The location system of any one of claims 1 – 10, wherein the mobile-based station further comprises a navigation fusion filter, wherein the navigation fusion filter is configured to perform a second calculation of the location of the mobile-based node based on (i) wireless communications transmitted by the mobile-based node, (ii) wireless communications received by the mobile-based node, (iii) the timestamp based on the mobile-based timing data, (iv) the respective timestamp based on the ground-based timing data, (v) data from an inertial measurement unit (IMU), or (vi) any combination of (i) – (v).
12. The location system of any one of claims 1 – 11, wherein the mobile-based station includes a plurality of modules, wherein the transmitter and the receiver are included in each of the modules.
13. The location system of claim 12, wherein the control circuit calculates the location of the mobile-based station based on communications transmitted from two or more of the modules.
14. The location system of any one of claims 1 – 13, wherein the location of the mobile-based station is a geographic location.
15. The location system of any one of claims 1 – 14, wherein the mobile-based station is located on a vehicle.
16. The location system of claim 15, wherein the vehicle is one of an automobile, an aircraft, a watercraft, and a train.
17. The location system of claim 15, wherein the vehicle is unmanned.
18. The location system of any one of claims 1 – 17, wherein each of the ground-based nodes further includes:
at least one antenna; and

at least one wireless communications system.

19. The location system of claim 18, wherein the at least one wireless communications system includes a plurality of wireless communications chipsets, and wherein a first portion of the plurality of wireless communications chipsets is configured to transmit and receive via the first communications protocol and a second portion of the plurality of wireless communications chipsets is configured to transmit and receive via the second wireless communications protocol.

20. The location system of claim 19, wherein each of the plurality of wireless communications chipsets is communicatively coupled to one of the at least one antenna.

21. The location system of claim 18, wherein the at least one antenna includes a first number of antennas and the at least one wireless communications system includes a second number of wireless communications chipsets, wherein the first number is equal to the second number.

22. The location system of claim 18, wherein the at least one antenna includes a first number of antennas and the at least one wireless communications system includes a second number of wireless communications chipsets, wherein the first number is smaller than the second number.

23. The location system of claim 22, wherein the at least one antenna is configured to modulate between broadcasting via the first communications protocol and the second communications protocol.

24. The location system of claim 18, wherein the at least one antenna is located on a printed circuit board (PCB).

25. The location system of claim 18, wherein each of the at least one antenna is directional antenna including two or more parallel antenna elements.

26. The location system of any one of claims 1 – 25, wherein the mobile-based node includes the control system.

27. The location system of claim 26, wherein each ground-based node in the array of ground-based nodes further includes a processor, and wherein the processor is configured to:
- receive, from the mobile-based node, wireless communications via one or more of the first communications protocol and the second communications protocol including the timestamp based on the mobile-based timing data; and
 - calculate a reference location of the mobile-based node based at least in part on (i) a location of a respective ground-based node, (ii) the timestamp based on the mobile-based timing data, (iii) the ground-based timing data.
28. The location system of claim 27, wherein the control system is further configured to:
- receive, from each of the ground-based nodes, a plurality of reference locations;
 - wherein the location of the mobile-based station is further calculated based on at least a portion of the plurality of reference locations.
29. The location system of any one of claims 1 – 28, wherein at least one of the ground-based nodes comprises the control system.
30. The location system of claim 29, wherein the mobile-based wireless communication system is further configured to receive, from the at least one of the ground-based nodes, an indication of the location of the mobile-based node.
31. A location system for aiding in locating a mobile-based node, the system comprising:
- a plurality of ground-based nodes, each of the ground-based nodes including:
 - a ground-based timing module configured to generate ground-based timing data;
 - a ground-based wireless communications system configured to receive wireless communications via a first communications protocol and a second communications protocol;
 - the mobile-based node including:
 - a mobile-based timing module configured to generate mobile-based timing data;
 - and

- a mobile-based wireless communications system configured to transmit wireless communications via the first communications protocol and the second communications protocol, wherein each of the wireless communications transmitted by the mobile-based node includes a timestamp based on the mobile-based timing data; and
- a control system configured to:
- calculate a location of the mobile-based node based on (i) location data associated with each of the ground-based nodes, (ii) the timestamp based on the mobile-based timing data, and (iii) the ground-based timing data.
32. The location system of claim 31, wherein the control system is further configured to:
- determine, based on the location of the mobile-based node and a known location, that the location of the mobile-based node includes an error; and
- apply a trained machine learning algorithm to the location of the mobile-based node; and
- correct, based on the application of the trained machine learning algorithm to the location of the mobile-based node, the location of the mobile-based node.
33. The location system of claim 31 or claim 32, wherein the first communications protocol is one of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, and Zigbee, and wherein the second communications protocol is one of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, and Zigbee.
34. The location system of any one of claims 31 – 33, wherein the plurality of ground-based nodes includes at least three ground-based nodes.
35. The location system of any one of claims 31 – 34, further comprising:
- a satellite navigation transceiver, wherein the satellite navigation transceiver is configured to receive satellite navigation signals from one or more satellites.
36. The location system of claim 35, wherein the control system additionally calculates the location of the mobile-based node based on the received satellite navigation signals.
37. The location system of claim 35, wherein the control system is further configured to:

determine that a trigger condition has occurred;
wherein the control system calculates the location of the mobile-based node in response to the determination that the trigger condition has occurred.

38. The location system of claim 37, wherein the trigger condition is one or more of a loss of satellite navigation signal, a loss of satellite navigation signal for a threshold period of time, quality of a satellite navigation signal, an inability to determine a location based on satellite navigation signal, a known location of the mobile-based station, and an estimated location of the mobile-based station.

39. The location system of any one of claims 31 – 38, wherein the first communications protocol has a first range and the second communications protocol has a second range, and wherein the first range is different than the second range.

40. The location system of claim 39, wherein the first range is approximately 100 meters and wherein the second range is at least 5 kilometers.

41. The location system of any one of claims 31 – 40, wherein the mobile-based station further comprises a navigation fusion filter, wherein the navigation fusion filter is configured to perform a second calculation of the location of the mobile-based node based on (i) wireless communications transmitted by the mobile-based node, (ii) wireless communications received by the mobile-based node, (iii) the timestamp based on the mobile-based timing data, (iv) the respective timestamp based on the ground-based timing data, (v) data from an inertial measurement unit (IMU), or (vi) any combination of (i) – (v).

42. The location system of any one of claims 31 – 40, wherein the mobile-based station includes a plurality of modules, wherein the transmitter and the receiver are included in each of the modules.

43. The location system of claim 42, wherein the control circuit calculates the location of the mobile-based station based on communications transmitted from two or more of the modules.

44. The location system of any one of claims 31 – 43, wherein the location of the mobile-based station is a geographic location.
45. The location system of any one of claims 31 – 44, wherein the mobile-based station is located on a vehicle.
46. The location system of claim 45, wherein the vehicle is one of an automobile, an aircraft, a watercraft, and a train.
47. The location system of claim 45, wherein the vehicle is unmanned.
48. The location system of any one of claims 31 – 47, wherein each of the ground-based nodes further includes:
at least one antenna; and
at least one wireless communications system.
49. The location system of claim 48, wherein the at least one wireless communications system includes a plurality of wireless communications chipsets, and wherein a first portion of the plurality of wireless communications chipsets is configured to transmit and receive via the first communications protocol and a second portion of the plurality of wireless communications chipsets is configured to transmit and receive via the second wireless communications protocol.
50. The location system of claim 49, wherein each of the plurality of wireless communications chipsets is communicatively coupled to one of the at least one antenna.
51. The location system of claim 48, wherein the at least one antenna includes a first number of antennas and the at least one wireless communications system includes a second number of wireless communications chipsets, wherein the first number is equal to the second number.
52. The location system of claim 48, wherein the at least one antenna includes a first number of antennas and the at least one wireless communications system includes a second

number of wireless communications chipsets, wherein the first number is smaller than the second number.

53. The location system of claim 52, wherein the at least one antenna is configured to modulate between broadcasting via the first communications protocol and the second communications protocol.

54. The location system of claim 48, wherein the at least one antenna is located on a printed circuit board (PCB).

55. The location system of claim 48, wherein each of the at least one antenna is directional antenna including two or more parallel antenna elements.

56. The location system of any one of claims 31 – 55, wherein the mobile-based node includes the control system.

57. The location system of claim 56, wherein each ground-based node in the array of ground-based nodes further includes a processor, and wherein the processor is configured to:
receive, from the mobile-based node, wireless communications via one or more of the first communications protocol and the second communications protocol including the timestamp based on the mobile-based timing data; and
calculate a reference location of the mobile-based node based at least in part on (i) a location of a respective ground-based node, (ii) the timestamp based on the mobile-based timing data, (iii) the ground-based timing data.

58. The location system of claim 57, wherein the control system is further configured to:
receive, from each of the ground-based nodes, a plurality of reference locations;
wherein the location of the mobile-based station is further calculated based on at least a portion of the plurality of reference locations.

59. The location system of any one of claims 31 – 58, wherein at least one of the ground-based nodes comprises the control system.

60. The location system of claim 59, wherein the mobile-based wireless communication system is further configured to receive, from the at least one of the ground-based nodes, an indication of the location of the mobile-based node.
61. A method for aiding in locating a mobile-based node, the method comprising:
transmitting, by a wireless communications system of the mobile-based node, a first wireless communication, wherein the first wireless communication is transmitted via a first communications protocol and a second communications protocol, and wherein the first wireless communication includes a first timestamp;
receiving, by a plurality of ground-based nodes, the first wireless communication;
transmitting, by each of the plurality of ground-based nodes in response to receipt of the first wireless communication, ground-based communications, wherein the ground-based communications are transmitted via the first communications protocol and the second communications protocol, and wherein each of the ground-based communications includes a timestamp; and
calculating, by a control system, a location of the mobile-based node based on (i) the first timestamp, (ii) locations of each ground-based node of the plurality of ground-based nodes, and (iii) the timestamp included in each of the ground-based communications.
62. The method of claim 61, further comprising:
determining, based on the location of the mobile-based node and a known location, that the location of the mobile-based node includes an error; and
applying a trained machine learning algorithm to the location of the mobile-based node;
and
correcting, based on the application of the trained machine learning algorithm to the location of the mobile-based node, the location of the mobile-based node.
63. The method of claim 61 or claim 62, wherein the first communications protocol is one of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, and Zigbee, and wherein the second communications protocol is one of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, and Zigbee.

64. The method of any one of claims 61 – 63, wherein the plurality of ground-based nodes includes at least three ground-based nodes.
65. The method of any one of claims 61 – 64, further comprising:
a satellite navigation transceiver, wherein the satellite navigation transceiver is configured to receive satellite navigation signals from one or more satellites.
66. The method of claim 65, wherein the control system additionally calculates the location of the mobile-based node based on the received satellite navigation signals.
67. The method of claim 65, further comprising:
determining that a trigger condition has occurred;
wherein the control system calculates the location of the mobile-based node in response to the determination that the trigger condition has occurred.
68. The method of claim 67, wherein the trigger condition is one or more of a loss of satellite navigation signal, a loss of satellite navigation signal for a threshold period of time, quality of a satellite navigation signal, an inability to determine a location based on satellite navigation signal, a known location of the mobile-based station, and an estimated location of the mobile-based station.
69. The method of any one of claims 61 – 68, wherein the first communications protocol has a first range and the second communications protocol has a second range, and wherein the first range is different than the second range.
70. The method of claim 69, wherein the first range is approximately 100 meters and wherein the second range is at least 5 kilometers.
71. The method of any one of claims 61 – 70, wherein the mobile-based station further comprises a navigation fusion filter, wherein the navigation fusion filter is configured to perform a second calculation of the location of the mobile-based node based on (i) the first timestamp, (ii) locations of each ground-based node of the plurality of ground-based nodes,

and (iii) the timestamp included in each of the ground-based communications, (iv) data from an inertial measurement unit (IMU), or (v) any combination of (i) – (iv).

72. The method of any one of claims 61 – 71, wherein the mobile-based station includes a plurality of modules, wherein the transmitter and the receiver are included in each of the modules.

73. The method of claim 72, wherein the control circuit calculates the location of the mobile-based station based on communications transmitted from two or more of the modules.

74. The method of any one of claims 61 – 73, wherein the location of the mobile-based station is a geographic location.

75. The method of any one of claims 61 – 74, wherein the mobile-based station is located on a vehicle.

76. The method of claim 75, wherein the vehicle is one of an automobile, an aircraft, a watercraft, and a train.

77. The method of claim 75, wherein the vehicle is unmanned.

78. The method of any one of claims 61 – 77, wherein each of the ground-based nodes further includes
at least one antenna, and at least one wireless communications system.

79. The method of claim 78, wherein the at least one wireless communications system includes a plurality of wireless communications chipsets, and wherein a first portion of the plurality of wireless communications chipsets is configured to transmit and receive via the first communications protocol and a second portion of the plurality of wireless communications chipsets is configured to transmit and receive via the second wireless communications protocol.

80. The method of claim 79, wherein each of the plurality of wireless communications chipsets is communicatively coupled to one of the at least one antenna.

81. The method of claim 78, wherein the at least one antenna includes a first number of antennas and the at least one wireless communications system includes a second number of wireless communications chipsets, wherein the first number is equal to the second number.
82. The method of claim 78, wherein the at least one antenna includes a first number of antennas and the at least one wireless communications system includes a second number of wireless communications chipsets, wherein the first number is smaller than the second number.
83. The method of claim 82, wherein the at least one antenna is configured to modulate between broadcasting via the first communications protocol and the second communications protocol.
84. The method of claim 78, wherein the at least one antenna is located on a printed circuit board (PCB).
85. The method of claim 78, wherein each of the at least one antenna is directional antenna including two or more parallel antenna elements.
86. The method of any one of claims 61 – 85, wherein the mobile-based node includes the control system.
87. The method of claim 86, wherein each ground-based node in the array of ground-based nodes further includes a processor, to the method further comprising:
receiving, from the mobile-based node via a processor, wireless communications via one or more of the first communications protocol and the second communications protocol including the first timestamp; and
calculating, by the processor, a reference location of the mobile-based node based at least in part on (i) a location of a respective ground-based node, (ii) the first timestamp, and (iii) each of the timestamps included in the ground-based communications.
88. The method of claim 87, further comprising:

receiving, from each of the ground-based nodes, a plurality of reference locations;
wherein the location of the mobile-based station is further calculated based on at least
a portion of the plurality of reference locations.

89. The method of any one of claims 61 – 88, wherein at least one of the ground-based nodes comprises the control system.

90. The method of claim 89, wherein the mobile-based wireless communication system is further configured to receive, from the at least one of the ground-based nodes, an indication of the location of the mobile-based node.

91. A method for aiding in locating a mobile-based node, the method comprising:
transmitting, by a wireless communications system of the mobile-based node, a first wireless communication, wherein the first wireless communication is transmitted via a first communications protocol and a second communications protocol, and wherein the first wireless communication includes a first timestamp;
receiving, by a plurality of ground-based nodes, the first wireless communication; and
calculating, by a control system, a location of the mobile-based node based on (i) the first timestamp, (ii) locations of each ground-based node of the plurality of ground-based nodes, and (iii) a time at which the first wireless communication was received by each ground-based node in the plurality of ground-based nodes.

92. The method of claim 91, further comprising:
determining, based on the location of the mobile-based node and a known location, that the location of the mobile-based node includes an error; and
applying a trained machine learning algorithm to the location of the mobile-based node;
and
correcting, based on the application of the trained machine learning algorithm to the location of the mobile-based node, the location of the mobile-based node.

93. The method of claim 91 or claim 92, wherein the first communications protocol is one of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, and Zigbee, and wherein the second communications protocol is one of Wi-Fi, LoRa, Bluetooth, Ultrawide Band, and Zigbee.
94. The method of any one of claims 91 – 93, wherein the plurality of ground-based nodes includes at least three ground-based nodes.
95. The method of any one of claims 91 – 94, further comprising:
receiving, via a satellite navigation transceiver, satellite navigation signals from one or more satellites.
96. The method of claim 95, wherein the control system additionally calculates the location of the mobile-based node based on the received satellite navigation signals.
97. The method of claim 95, further comprising:
determining that a trigger condition has occurred;
wherein the control system calculates the location of the mobile-based node in response to the determination that the trigger condition has occurred.
98. The method of claim 97, wherein the trigger condition is one or more of a loss of satellite navigation signal, a loss of satellite navigation signal for a threshold period of time, quality of a satellite navigation signal, an inability to determine a location based on satellite navigation signal, a known location of the mobile-based station, and an estimated location of the mobile-based station.
99. The method of any one of claims 91 – 98, wherein the first communications protocol has a first range and the second communications protocol has a second range, and wherein the first range is different than the second range.
100. The method of claim 99, wherein the first range is approximately 100 meters and wherein the second range is at least 5 kilometers.

101. The method of any one of claims 91 – 100, wherein the mobile-based station further comprises a navigation fusion filter, wherein the navigation fusion filter is configured to perform a second calculation of the location of the mobile-based node based on (i) the first timestamp, (ii) locations of each ground-based node of the plurality of ground-based nodes, and (iii) a time at which the first wireless communication was received by each ground-based node in the plurality of ground-based nodes, (iv) data from an inertial measurement unit (IMU), or (v) any combination of (i) – (iv).

102. The method of any one of claims 91 – 101, wherein the mobile-based station includes a plurality of modules, wherein the transmitter and the receiver are included in each of the modules.

103. The method of claim 102, wherein the control circuit calculates the location of the mobile-based station based on communications transmitted from two or more of the modules.

104. The method of any one of claims 91 – 103, wherein the location of the mobile-based station is a geographic location.

105. The method of any one of claims 91 – 104, wherein the mobile-based station is located on a vehicle.

106. The method of claim 105, wherein the vehicle is one of an automobile, an aircraft, a watercraft, and a train.

107. The method of claim 105, wherein the vehicle is unmanned.

108. The method of any one of claims 91 – 107, wherein each of the ground-based nodes include at least one antenna, and at least one wireless communications system.

109. The method of claim 108, wherein the at least one wireless communications system includes a plurality of wireless communications chipsets, and wherein a first portion of the plurality of wireless communications chipsets is configured to transmit and receive via the first

communications protocol and a second portion of the plurality of wireless communications chipsets is configured to transmit and receive via the second wireless communications protocol.

110. The method of claim 109, wherein each of the plurality of wireless communications chipsets is communicatively coupled to one of the at least one antenna.

111. The method of claim 108, wherein the at least one antenna includes a first number of antennas and the at least one wireless communications system includes a second number of wireless communications chipsets, wherein the first number is equal to the second number.

112. The method of claim 108, wherein the at least one antenna includes a first number of antennas and the at least one wireless communications system includes a second number of wireless communications chipsets, wherein the first number is smaller than the second number.

113. The method of claim 112, wherein the at least one antenna is configured to modulate between broadcasting via the first communications protocol and the second communications protocol.

114. The method of claim 108, wherein the at least one antenna is located on a printed circuit board (PCB).

115. The method of claim 108, wherein each of the at least one antenna is directional antenna including two or more parallel antenna elements.

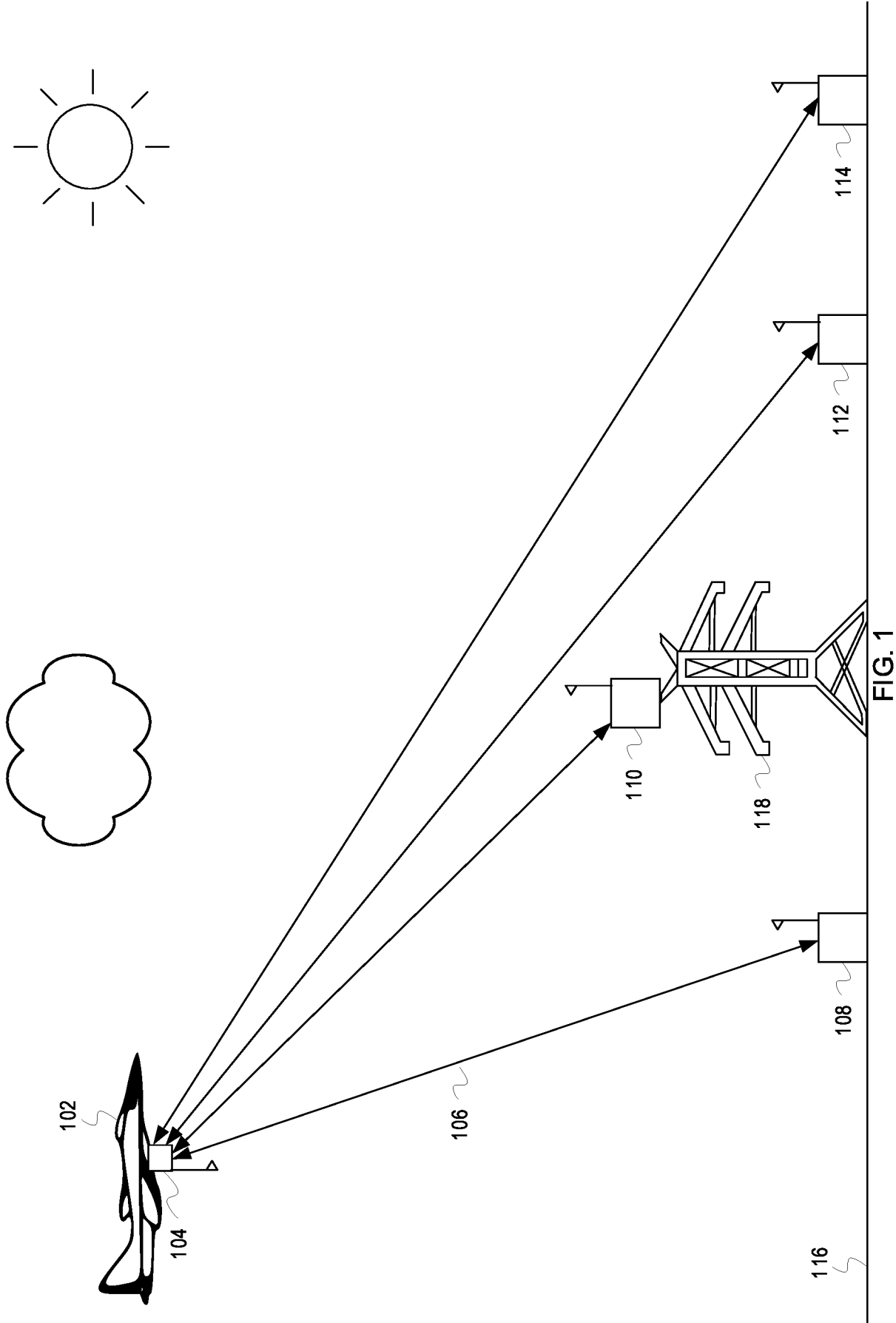
116. The method of any one of claims 91 – 115, wherein the mobile-based node includes the control system.

117. The method of claim 116, wherein each ground-based node in the array of ground-based nodes further includes a processor, to the method further comprising:

receiving, from the mobile-based node via a processor, wireless communications via one or more of the first communications protocol and the second communications protocol including the first timestamp; and

calculating, by the processor, a reference location of the mobile-based node based at least in part on (i) a location of a respective ground-based node, (ii) the first timestamp, and (iii) each of the timestamps included in the ground-based communications.

118. The method of claim 117, further comprising:
receiving, from each of the ground-based nodes, a plurality of reference locations;
wherein the location of the mobile-based station is further calculated based on at least a portion of the plurality of reference locations.
119. The method of any one of claims 91 – 118, wherein at least one of the ground-based nodes comprises the control system.
120. The method of claim 119, wherein the mobile-based wireless communication system is further configured to receive, from the at least one of the ground-based nodes, an indication of the location of the mobile-based node.



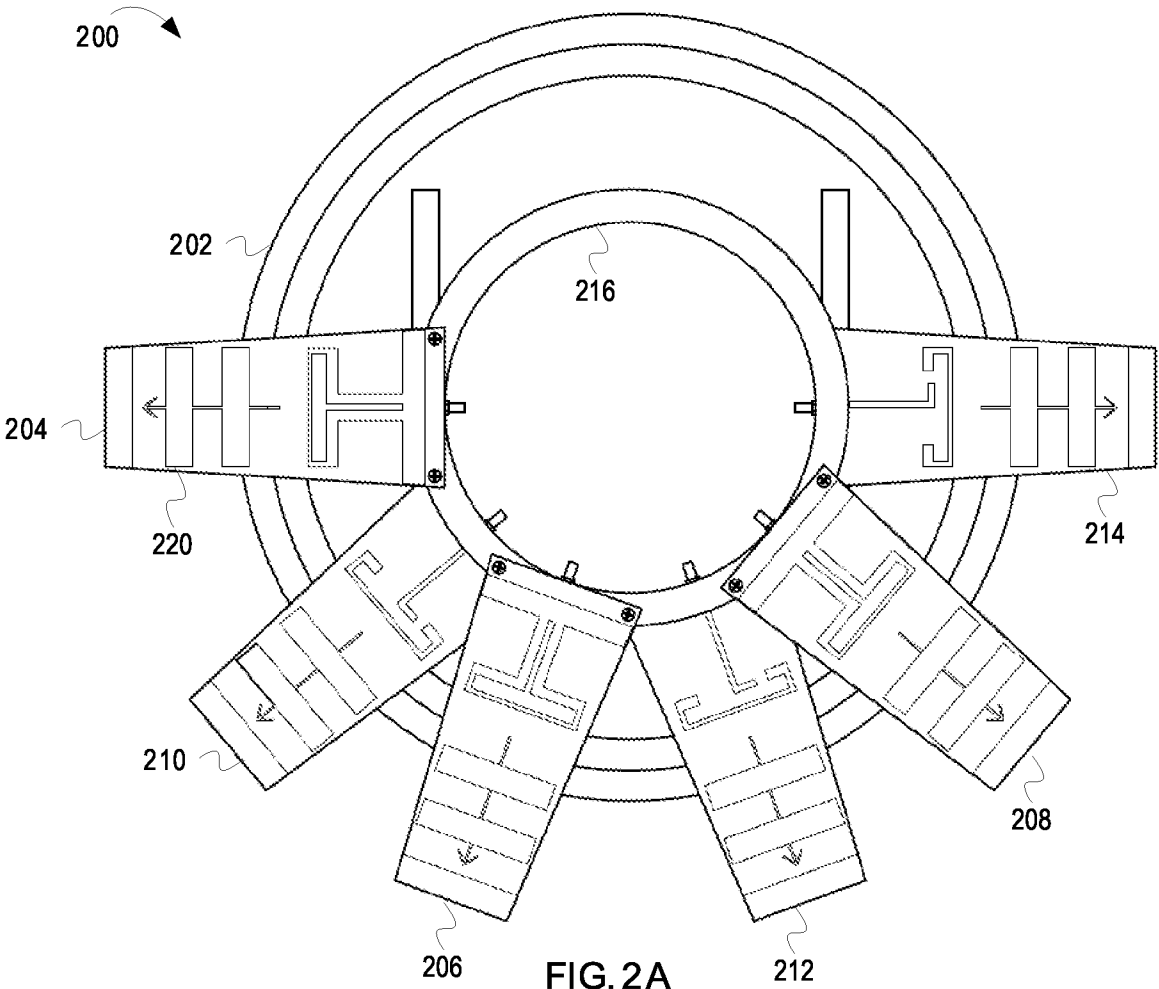


FIG. 2A

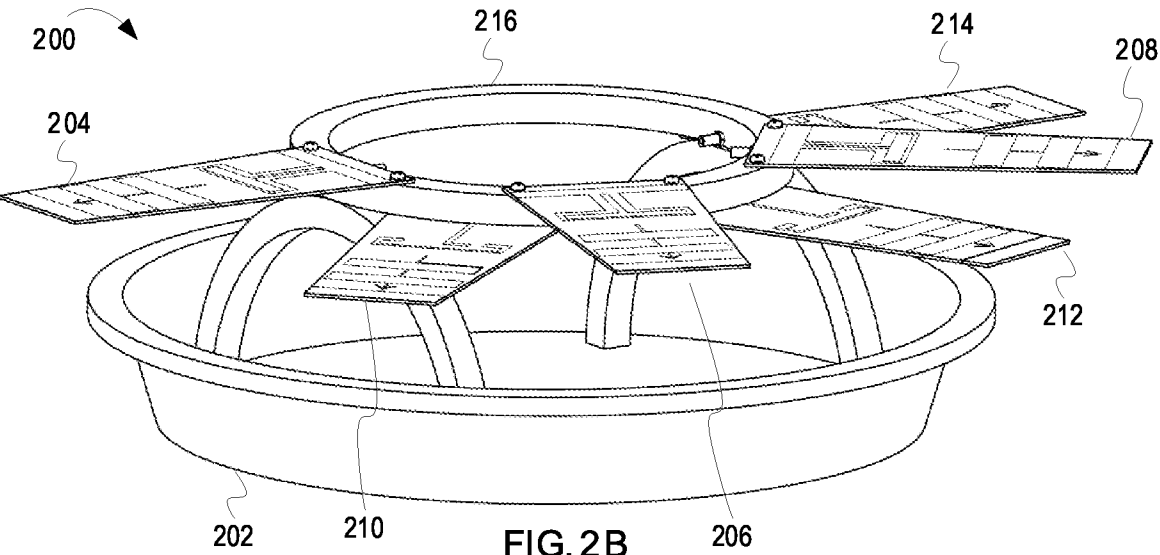
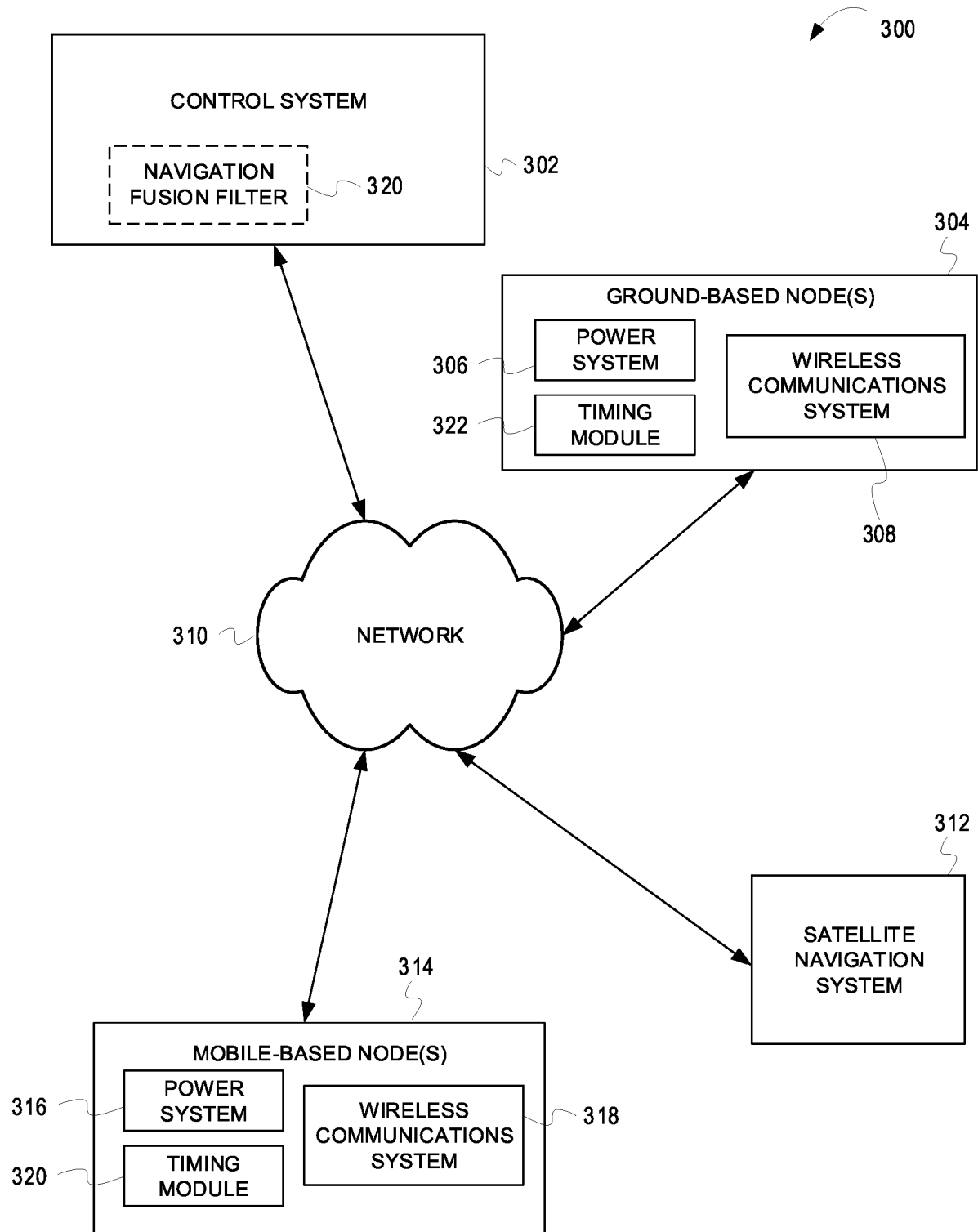


FIG. 2B

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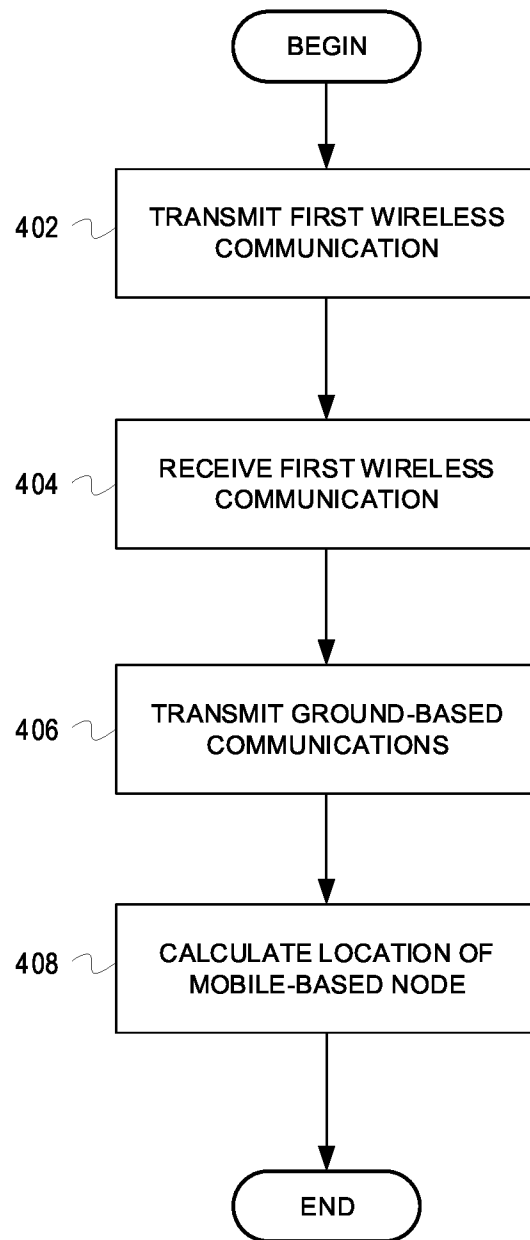


FIG. 4

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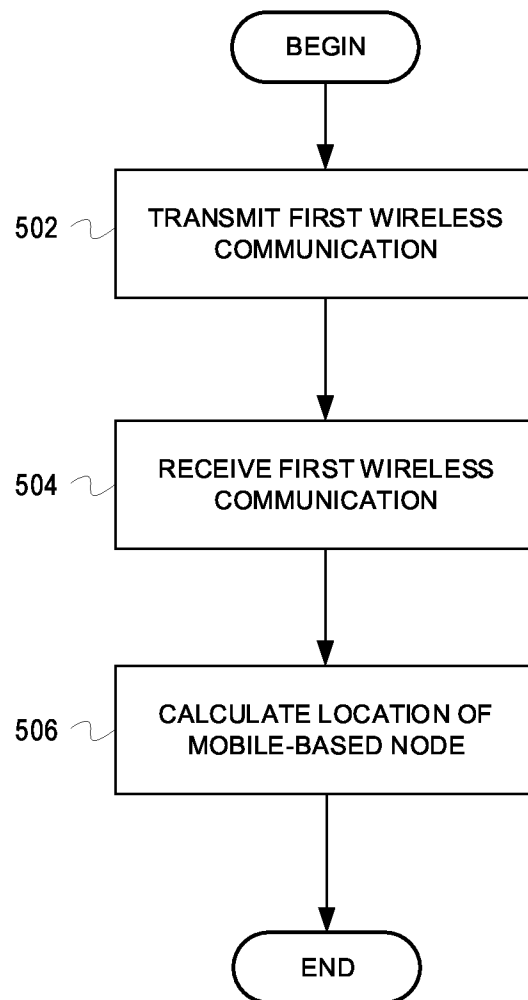


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/032738

A. CLASSIFICATION OF SUBJECT MATTER		
INV.	G01S5/00	G01S13/76 G01S19/48
ADD.	G01S19/15	G01S5/14
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) G01S		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2023/034500 A1 (INTEL CORP [US]) 9 March 2023 (2023-03-09) figures 13-14, 35 Equation 235 paragraph [0201] - paragraph [0205] paragraph [0002] paragraph [0081] - paragraph [0113] paragraph [0136] paragraph [0230] - paragraph [0234] paragraph [0262] - paragraph [0263] paragraph [0356] - paragraph [0365] -----	1 - 120
A	WO 2022/125393 A1 (QUALCOMM INC [US]) 16 June 2022 (2022-06-16) paragraph [0066] - paragraph [0068] paragraph [0085] ----- - / - -	11,30, 41,60, 71,90, 101,120
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 20 September 2024		Date of mailing of the international search report 10/10/2024
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Bomart, Sébastien

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/032738

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 3 790 328 A1 (ROKUBUN S L [ES]) 10 March 2021 (2021-03-10) paragraph [0028] -----	27,28, 57,58, 87,88, 117,118

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2024/032738

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2023034500 A1	09-03-2023	EP 4396597 A1 NL 2032942 A WO 2023034500 A1	10-07-2024 10-03-2023 09-03-2023
WO 2022125393 A1	16-06-2022	CN 116848938 A EP 4260620 A1 JP 2023554263 A KR 20230118829 A TW 202231082 A US 2023422200 A1 WO 2022125393 A1	03-10-2023 18-10-2023 27-12-2023 14-08-2023 01-08-2022 28-12-2023 16-06-2022
EP 3790328 A1	10-03-2021	NONE	