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Newman et al.

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(54) **PRECISION LOCALIZATION OF MOBILE 5G/6G TERMINALS BY COORDINATED GNSS RECEPTION**

(52) **U.S. Cl.**  
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(57) **ABSTRACT**

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Mobile wireless terminals, such as vehicles in traffic, can determine the relative positions of other vehicles with improved precision by arranging to acquire GNSS (global navigational satellite system) signals simultaneously, and then analyzing the various data sets differentially. Simultaneous acquisition can cancel many important errors such as motional errors of the vehicles, atmospheric distortions, and satellite timebase errors. Differential analysis to determine the relative positions of vehicles (as opposed to their overall geographical coordinates) can reduce errors related to satellite ephemeris and velocity, as well as roundoff errors. Localization with a precision of less than 1 meter can greatly improve collision avoidance while discriminating near-miss scenarios from imminent collisions, according to some embodiments. Messaging examples, in 5G and 6G, to manage the simultaneous acquisition and differential analysis, are provided in examples. Many other aspects are disclosed.

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(Continued)

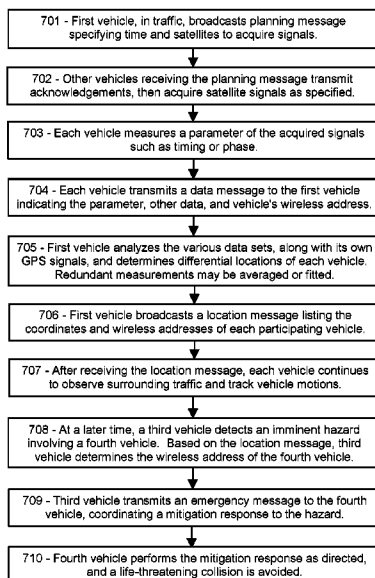
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See application file for complete search history.

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**FIG. 1** (prior art)

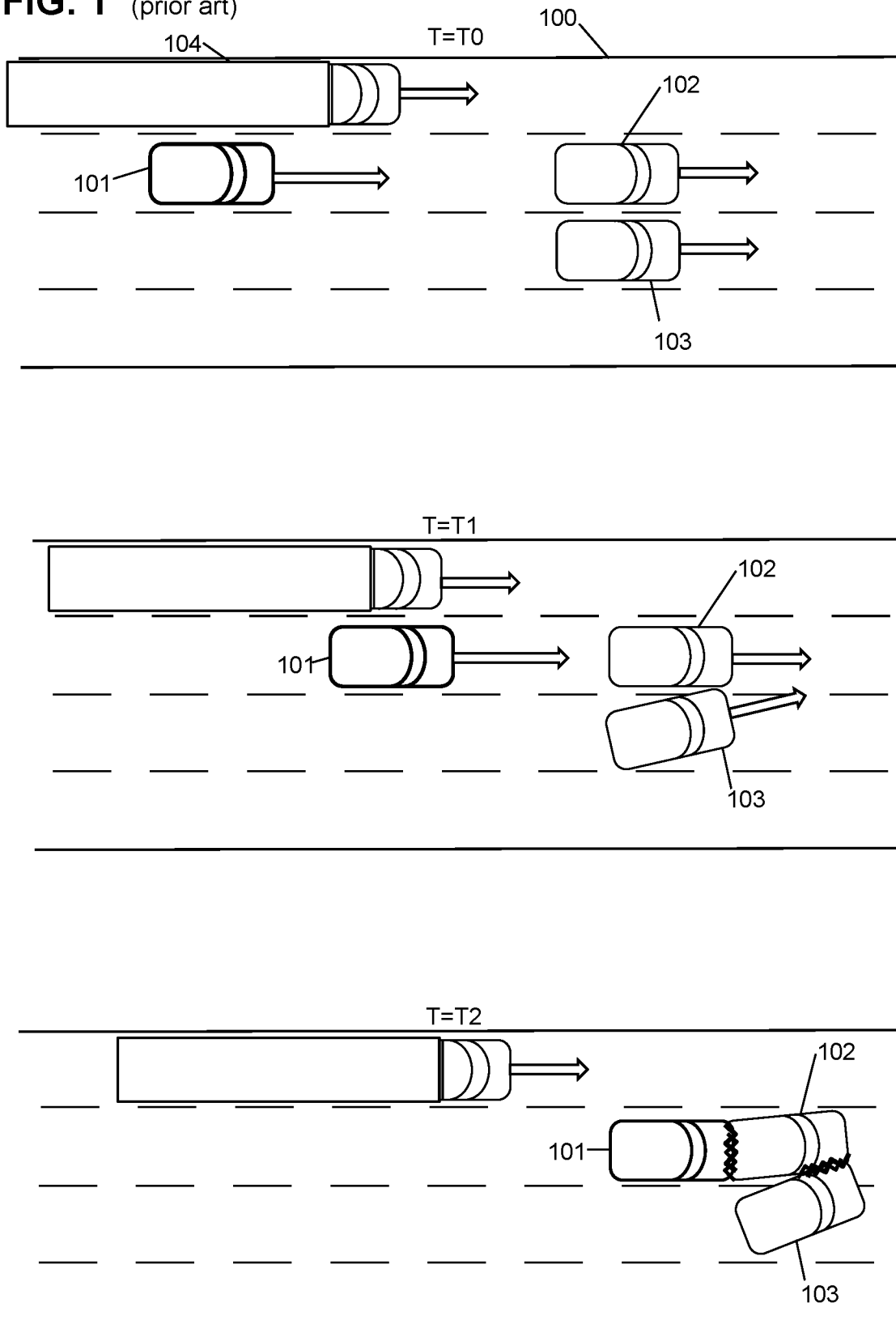


FIG. 2

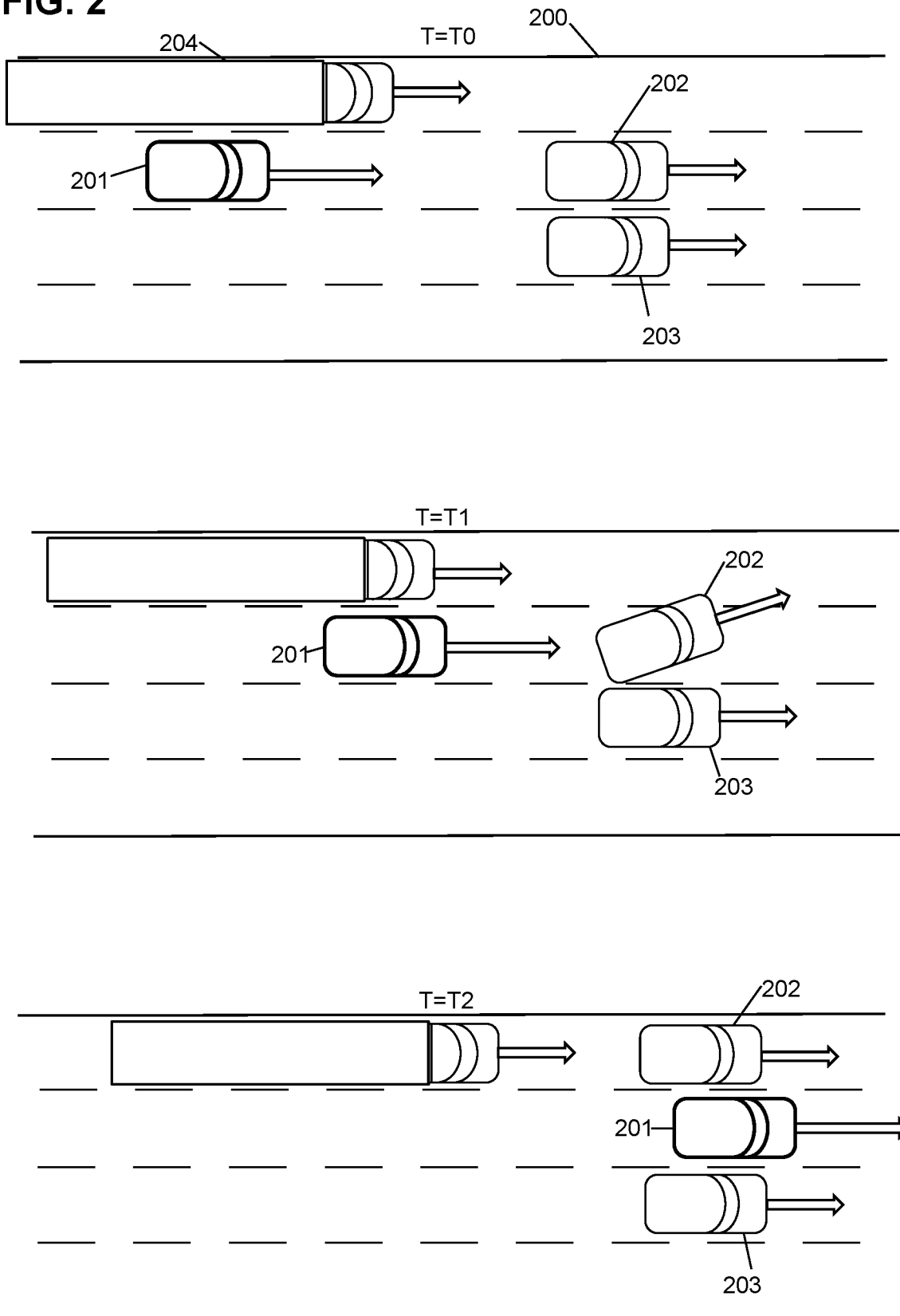


FIG. 3 (prior art)

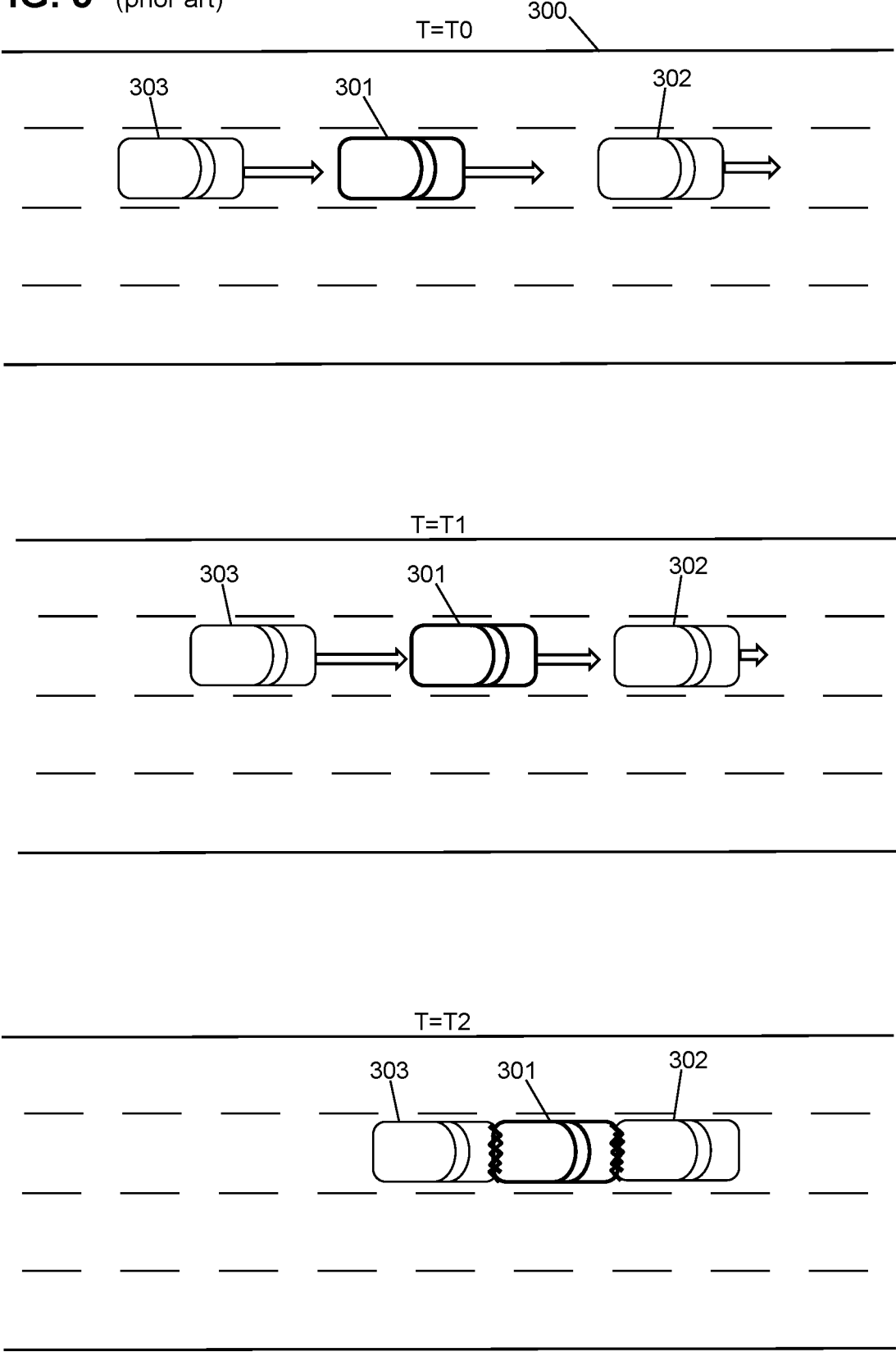


FIG. 4

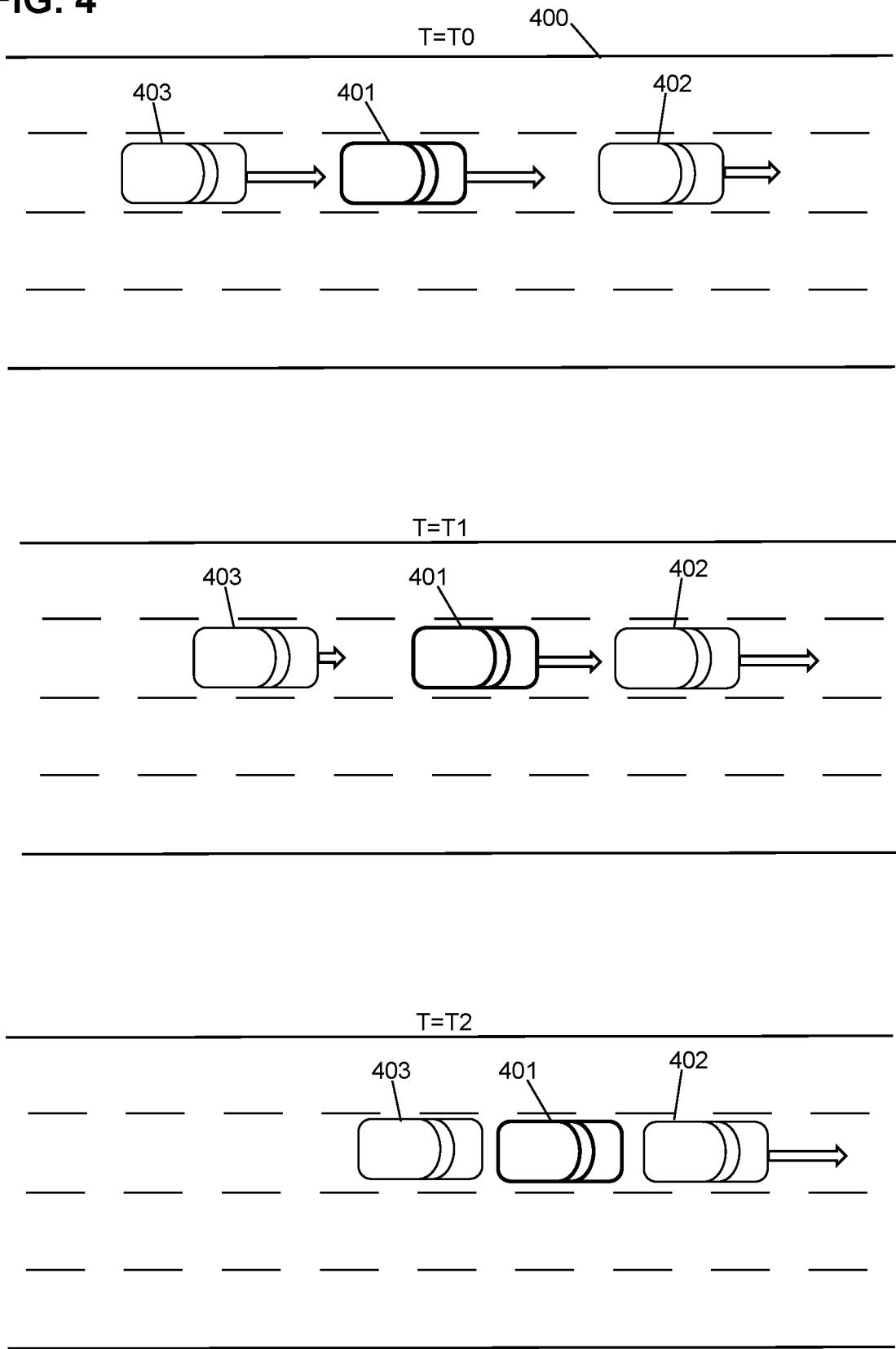


FIG. 5

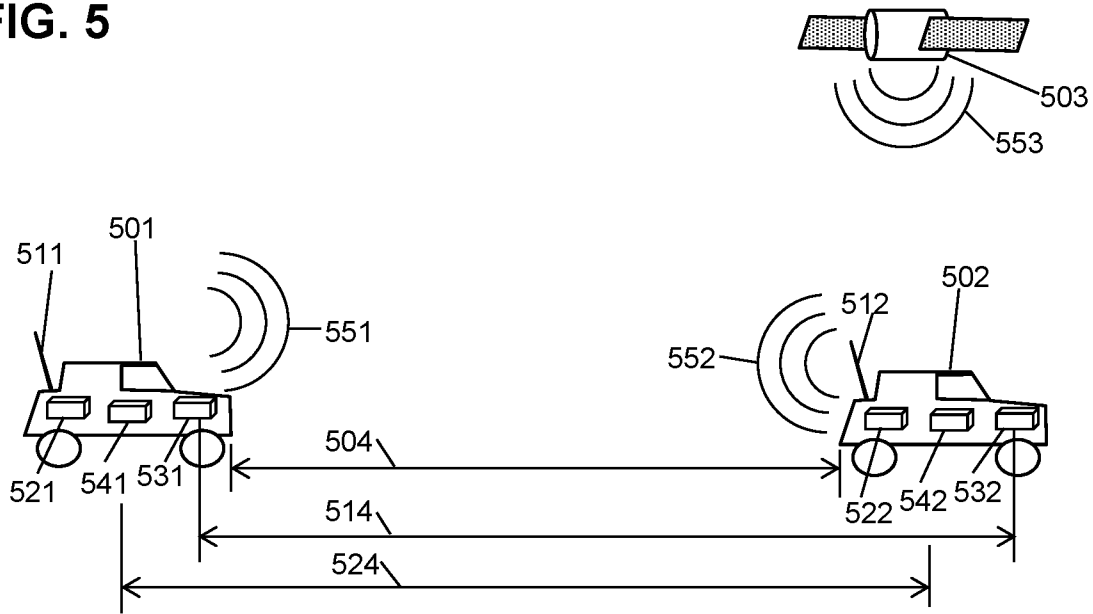


FIG. 6

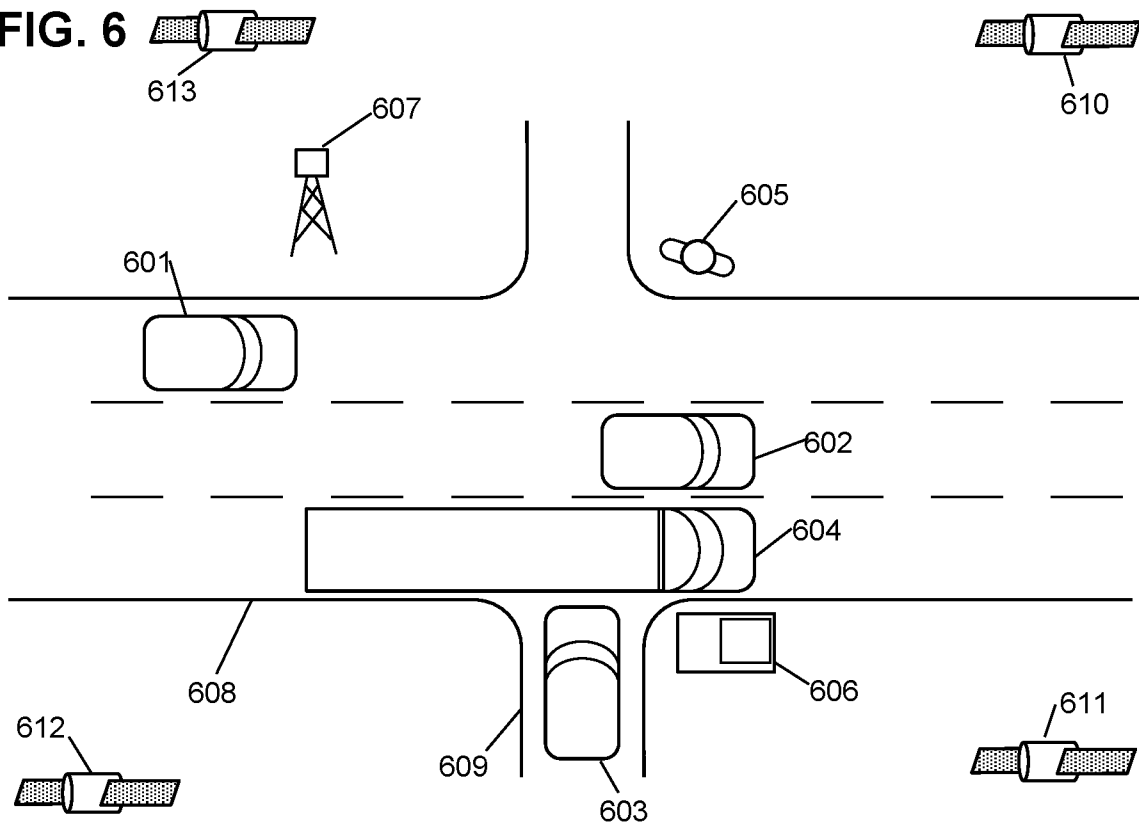
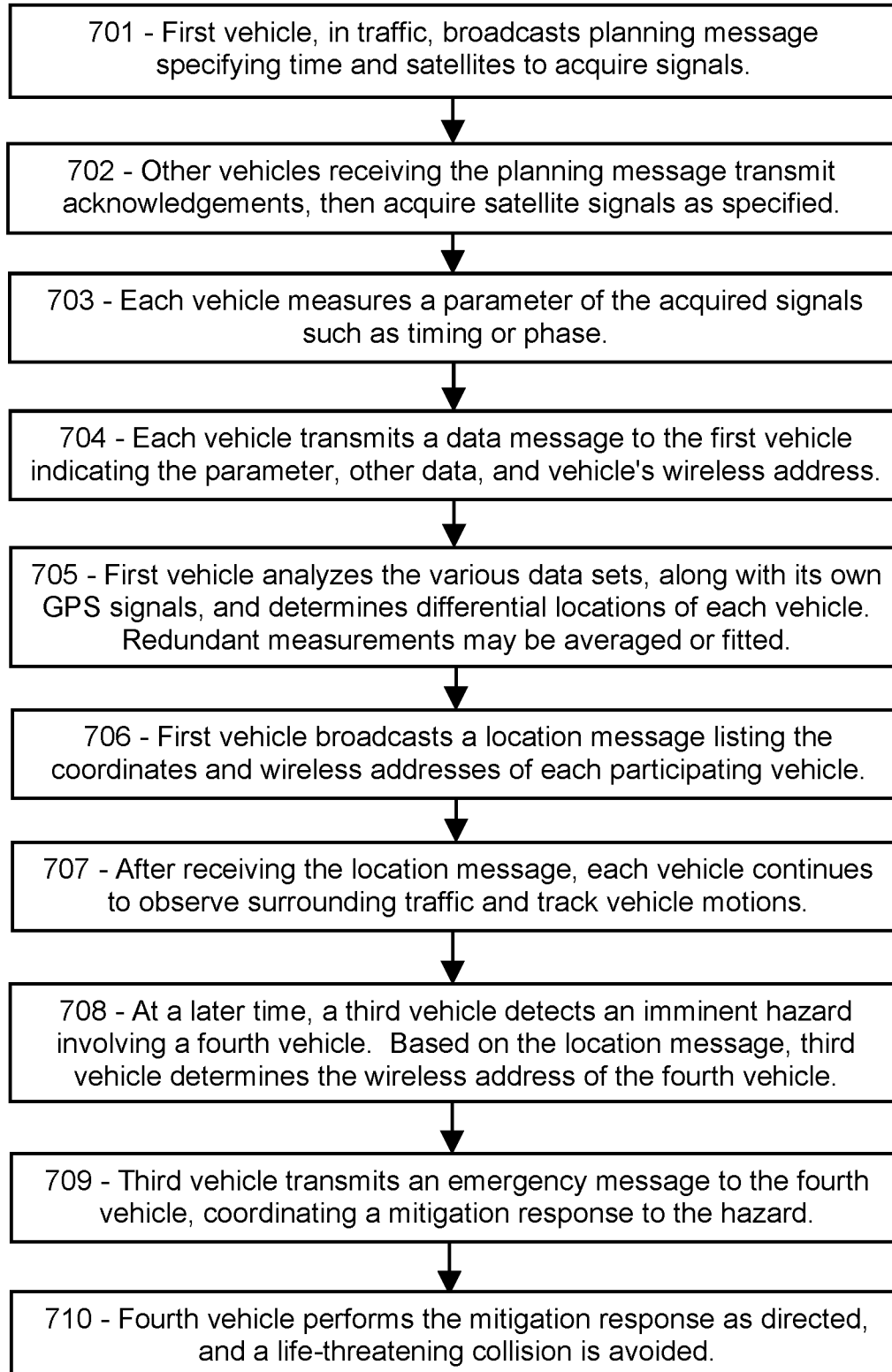


FIG. 7





**PRECISION LOCALIZATION OF MOBILE  
5G/6G TERMINALS BY COORDINATED  
GNSS RECEPTION**

PRIORITY CLAIMS AND RELATED  
APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 17/583,386, entitled “V2X Messaging in 5G/6G with Simultaneous GPS Reception”, filed Jan. 25, 2022, which claims the benefit of U.S. Provisional Patent Application Ser. No. 63/260,814, entitled “Localization and Identification of Vehicles in Traffic by 5G Messaging”, filed Sep. 1, 2021, and U.S. Provisional Patent Application Ser. No. 63/243,437, entitled “V2X Messaging in 5G with Simultaneous GPS Reception”, filed Sep. 13, 2021, and U.S. Provisional Patent Application Ser. No. 63/245,227, entitled “V2X with 5G Image Exchange and AI-Based Viewpoint Fusion”, filed Sep. 17, 2021, and U.S. Provisional Patent Application Ser. No. 63/246,000, entitled “V2X Connectivity Matrix with 5G Sidelink”, filed Sep. 20, 2021, and U.S. Provisional Patent Application Ser. No. 63/256,042, entitled “Hailing Procedure for V2R, V2V and V2X Initial Contact in 5G”, filed Oct. 15, 2021, and U.S. Provisional Patent Application Ser. No. 63/271,335, entitled “Semaphore Messages for Rapid 5G and 6G Network Selection”, filed Oct. 25, 2021, and U.S. Provisional Patent Application Ser. No. 63/272,352, entitled “Sidelink V2V, V2X, and Low-Complexity IoT Communications in 5G and 6G”, filed Oct. 27, 2021, and US Provisional Patent Application Ser. No. 63/287,428, entitled “V2X and Vehicle Localization by Local Map Exchange in 5G/6G”, filed Dec. 8, 2021, and U.S. Provisional Patent Application Ser. No. 63/288,237, entitled “V2X with 5G/6G Image Exchange and AI-Based Viewpoint Fusion”, filed Dec. 10, 2021, and U.S. Provisional Patent Application Ser. No. 63/288,807, entitled “V2X Messaging in 5G/6G with Simultaneous GPS Reception”, filed Dec. 13, 2021, and U.S. Provisional Patent Application Ser. No. 63/290,731, entitled “Vehicle Connectivity, V2X Communication, and 5G/6G Sidelink Messaging”, filed Dec. 17, 2021, all of which are hereby incorporated by reference in their entireties.

FIELD OF THE INVENTION

The invention relates to systems and methods for localizing wireless entities by satellite-based navigation signals.

BACKGROUND OF THE INVENTION

Vehicles and other mobile wireless terminals are expected to cooperate in managing traffic and other benefits in 5G and 6G. However, such cooperation generally requires that each communicating user be localized, by identifying each terminal and its wireless address among other users in vicinity. Prior art includes a variety of GNSS (global navigational satellite system) methods for determining positions, but it is generally difficult for moving vehicles to obtain a spatial resolution better than a few meters due to motional errors in the satellite signals. For example, the spatial resolution may be limited due to the motion of the vehicle while acquiring signals from multiple satellites, preventing the averaging of successive acquisitions, among other error sources. Many promising and valuable applications are thereby inhibited, if not prevented altogether.

What is needed is means for a vehicle in motion to determine its location, and thereby the positions of proximate vehicles, and other roadside transmitters, with improved precision.

This Background is provided to introduce a brief context for the Summary and Detailed Description that follow. This Background is not intended to be an aid in determining the scope of the claimed subject matter nor be viewed as limiting the claimed subject matter to implementations that solve any or all of the disadvantages or problems presented above.

SUMMARY OF THE INVENTION

In a first aspect, there is a method for a first wireless entity to determine a position of a second wireless entity relative to the first wireless entity, the method comprising: at a predetermined time, acquiring a first set of navigation satellite signals; receiving, from the second wireless entity, a wireless data message comprising data related to a second set of navigation satellite signals acquired by the second vehicle at the predetermined time; differentially analyzing the first set of navigation satellite signals and the data related to the second set of navigation satellite signals; and determining, according to the differential analysis, a distance and a direction between the first and second wireless entities.

In another aspect, there is non-transitory computer-readable media in a second vehicle in traffic, the traffic comprising a first vehicle and at least one other vehicle, the media containing instructions that when implemented by a computing environment cause a method to be performed, the method comprising: receiving, from the first vehicle, a planning message specifying a particular time and a particular satellite or satellites, and further specifying that navigation satellite signals from the particular satellite or satellites are to be acquired at the particular time; acquiring the navigation satellite signals at the particular time; determining, from the navigation satellite signals, a value of a parameter; and transmitting or broadcasting a data message indicating the value of the parameter and further indicating a second wireless address of the second vehicle.

In another aspect, there is a roadside access point of a wireless network, the access point configured to: broadcast a planning message, the planning message specifying one or more particular navigation satellites, a particular time for acquiring signals from the particular navigation satellites, and a wireless address of the access point; acquire, at the particular time, from the particular navigation satellites, a first set of the navigation satellite signals; receive, from a vehicle, a data message comprising a wireless address of the vehicle and data related to a second set of the navigation satellite signals, the second set of the navigation satellite signals acquired by the vehicle at the particular time from the particular navigation satellites; and determine, according to the first set of navigation satellite signals and the data related to the second set of navigation satellite signals, a location of the vehicle at the particular time.

This Summary is provided to introduce a selection of concepts in a simplified form. The concepts are further described in the Detailed Description section. Elements or steps other than those described in this Summary are possible, and no element or step is necessarily required. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended for use as an aid in determining the scope of the claimed subject

matter. The claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

These and other embodiments are described in further detail with reference to the figures and accompanying detailed description as provided below.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sketch showing a vehicle collision, according to prior art.

FIG. 2 is a sketch showing an exemplary embodiment of a procedure for vehicles to avoid a collision, according to some embodiments.

FIG. 3 is a sketch showing three vehicles colliding, according to prior art.

FIG. 4 is a sketch showing an exemplary embodiment of a procedure for three vehicles to avoid a collision, according to some embodiments.

FIG. 5 is a schematic sketch showing an exemplary embodiment of vehicles cooperating to determine the distance between them, according to some embodiments.

FIG. 6 is a schematic sketch showing an exemplary embodiment of a traffic scene including wireless entities configured to determine locations by simultaneous acquisition of satellite signals, according to some embodiments.

FIG. 7 is a flowchart showing an exemplary embodiment of a procedure for vehicles to avoid a collision, according to some embodiments.

Like reference numerals refer to like elements throughout.

#### DETAILED DESCRIPTION

Disclosed herein are procedures enabling vehicles in traffic to determine the locations of other proximate vehicles, as well as non-vehicle transmitters such as pedestrians, toll booths, safety gates, roadside access points, and the like. Systems and methods disclosed herein (the “systems” and “methods”, also occasionally termed “embodiments” or “arrangements”, generally according to present principles) can provide urgently needed wireless communication protocols to reduce traffic fatalities, facilitate traffic flow, and provide V2V and V2X communication options appropriate for 5G and 6G technologies, according to some embodiments.

As disclosed in more detail below, vehicles in motion can determine the relative locations of other vehicles or wireless entities, relative to each other, with improved precision by synchronizing their reception of satellite navigation signals. One of the vehicles, or a roadside access point, can broadcast a planning message specifying a particular time at which the vehicles will acquire the same signals from the same satellites simultaneously. The participating vehicles then transmit their raw data to the planning entity, which can then analyze the signals differentially. The planning entity thereby determines the relative distances between the vehicles, as opposed to calculating their global coordinates. The differential analysis and simultaneous acquisitions may cause major uncertainties to cancel. For example, by acquiring the same satellite signals at the same time, the participating entities can negate, or greatly reduce, errors due to the relative motion of the vehicles, satellite ephemeris and clock errors, atmospheric propagation errors, and others. The planning entity can correlate the various arrival-time parameters and optionally the signal phases, and can then analyze the data differentially to determine the distance between the vehicles at the time of data acquisition. Due to the simul-

aneous acquisition, and resulting cancellation of certain errors, the cooperating entities can determine the distances between them more precisely than by separately acquiring geographical coordinates, according to some embodiments. Various resolution-improving schemes such as “precise point positioning” generally rely on extensive averaging including multiple acquisitions of satellite data, spanning minutes to hours, and thus are not feasible when the vehicles are traveling in traffic.

In one embodiment, vehicles in traffic may exchange messages agreeing to acquire navigation signals, from certain specified satellites, at a specified time, and to exchange data based on the signals thus acquired, as well as their wireless addresses. The vehicles (or one of them, or a roadside processor) can then analyze the two sets of data to determine the position of each vehicle relative to the others, including distances between the vehicles. The vehicles (or the planning entity) can then broadcast the calculation results as a position map or coordinate listing, including the wireless addresses of the participating vehicles. The participating vehicles, or any other entities receiving the position map or listing, can then determine which vehicles in traffic have which wireless addresses, so that the vehicles can communicate with each other thereafter.

With primary sources of error canceled or reduced according to the simultaneous acquisitions and the differential analysis, the vehicles may obtain improved spatial resolution, such as a resolution of less than 1 meter in the relative distances and locations, in some embodiments. Such precise locations may enable vehicles to identify specific other vehicles in dense traffic, and thereby to communicate with another vehicle individually, thereby allowing them to cooperate in ways not possible absent the specific identification and localization of the vehicles. For example, the vehicles can cooperate more effectively to avoid collisions and to facilitate efficient flow of traffic. In addition, the precise location data may enable collision-avoidance software to calculate trajectories more accurately, discriminate near-miss events from imminent collisions more accurately, and devise mitigation strategies more accurately than possible without the high-resolution location results.

Following are examples of traffic situations in which lives can be saved by improved vehicle location determination.

FIG. 1 is a sketch showing a vehicle collision, according to prior art. A four-lane highway **100** is shown at three times **T0**, **T1**, and **T2**, occupied by a first, second, and third vehicle **101-102-103** depicted as cars, and a semi-trailer **104**. All vehicles are traveling to the right, as indicated by arrows. The first vehicle **101** is outlined in bold to indicate that it is the one transmitting. All three cars **101-103** are autonomous vehicles and all are in radio contact with each other on a sidelink or V2V channel.

At **T0**, the first vehicle **101** recognizes that it is traveling too fast and is likely to hit the second vehicle **102**. The first vehicle **101** cannot switch to the left lane because the truck **104** is in the way. It doesn’t make sense to shift to the right because then the third vehicle **103** is in the way, and there is no time to reach the rightmost lane. Therefore vehicle **101** transmits an emergency message, intended for the second vehicle **102**, instructing it to immediately and forcefully shift to the left, to avoid a collision. Unfortunately, the first vehicle **101** has incorrectly determined the wireless address of the second vehicle due to the poor spatial resolution of GPS and the poor angular precision of directional beamforming. The wireless address which the first vehicle **101** thinks belongs to the second vehicle **102**, instead belongs to the third vehicle **103**. Therefore, when the first vehicle **101**

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transmitted the collision-avoidance instruction, it was actually addressed to the third vehicle **103** instead of the second vehicle **102**. Consequently, at **T1** the third vehicle **103** immediately performs the instructed left-turn emergency maneuver, and strikes the second vehicle **102**. At **T3**, the first vehicle **101** collides with the second vehicle **102** since the second vehicle **102** is still blocking the way. All three vehicles are badly damaged, as indicated by crunch marks. In fact, they will be lucky if they avoid being hit again by the approaching truck **104**. The cause of the collision was the mistaken determination, by the first vehicle **101**, of which of the second and third vehicles **102**, **103** had which wireless address. The ultimate source of the collision was the insufficient spatial resolution of GPS which often cannot reliably discriminate two adjacent vehicles traveling at high speed on a freeway.

FIG. **2** is a sketch showing an exemplary embodiment of a procedure for vehicles to avoid a collision, according to some embodiments. As depicted in this non-limiting example, the freeway **200**, first second and third vehicles **201-202-203** and the truck **204** are as described with FIG. **1**, however this time the first vehicle **201** exchanged messages with the second vehicle **202** according to the systems and methods disclosed herein, and therefore has determined the correct wireless addresses for the second and third vehicles **202-203**. At **T0**, the first vehicle **201** transmits the emergency collision-avoidance message for an immediate left shift, but this time using the correct wireless address of the second vehicle **202**. Accordingly, at **T1**, the second vehicle **202** dodges left into the leftmost lane. At **T2**, the second vehicle has completed the change, and the first vehicle passes safely through the gap. The third vehicle **203** then sends the first vehicle **201** a message expressing gratitude for using an effective technology to correctly identify and localize each vehicle, instead of relying on an ineffective means for determining which wireless address belongs to which vehicle.

FIG. **3** is a sketch showing three vehicles colliding, according to prior art. A highway **300** includes a first, second, and third vehicle **301-302-303** in line. At **T0**, the first vehicle determines that it is traveling faster than the second vehicle **302** and immediately begins to slow down. To avoid being rear-ended by the third vehicle **303**, the first vehicle **301** transmits an emergency message “slow down immediately!” to the wireless address that the first vehicle **301** thinks belongs to the third vehicle **303**, and another emergency message “speed up immediately” to the wireless address that the first vehicle **301** thinks belongs to the second vehicle **302**. Unfortunately, in this case those addresses were misallocated, and they actually belong to the opposite vehicles. The error is due to the poor longitudinal resolution achievable in a moving GPS receiver. Consequently, the third vehicle **303** received an emergency command to speed up and the second vehicle **302** got an emergency command to slow down.

At **T1**, the second vehicle **302** has obligingly slowed down further, as directed by the emergency message it mistakenly received, while the third vehicle **303** has accelerated to high speed, as instructed in its mistaken message. At **T2**, the first vehicle **301** has smashed into the second vehicle **302** and the third vehicle **303** has smashed into the first vehicle **301**. The cause of this accident was that the first vehicle **301** had misallocated the wireless addresses to the two other vehicles, resulting in sending the emergency messages to the wrong vehicles. The ultimate source was the poor longitudinal resolution of satellite-based locations when moving at high speed.

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FIG. **4** is a sketch showing an exemplary embodiment of a procedure for three vehicles to avoid a collision, according to some embodiments. As depicted in this non-limiting example, a first, second, and third vehicle **401-402-403** are in line on a highway **400** when, at **T0**, the first vehicle **401** determines that it is going faster than the second vehicle **402** and begins to slow down. To avoid being rear-ended, the first vehicle **401** sends an emergency message to the third vehicle **403** to slow down, and another emergency message to the second vehicle **402** to speed up. The first vehicle **401** knows the correct wireless address of the second and third vehicles **402-403** because, at an earlier time, all three vehicles acquired GPS signals simultaneously and they, or one of them, analyzed those signals differentially to determine each vehicle’s position in association with the vehicle’s wireless address. Accordingly, the third vehicle **403** receives the emergency message correctly addressed to it and, at **T1**, has begun slowing down as directed. Likewise, the second vehicle **402** has received the acceleration request and has speeded up, giving the others crucial extra seconds to decelerate.

At time **T2**, the first and third vehicles **401-403** have decelerated to match the second vehicle **402**, thereby avoiding colliding. Thus a collision can be avoided (or at least mitigated) in almost every case by cooperative action among the participants, but only if each participant knows which wireless address belongs to which other vehicle.

Systems and methods for simultaneous GPS reception are described in the following examples.

FIG. **5** is a schematic sketch showing an exemplary embodiment of vehicles cooperating to determine the distances between them, according to some embodiments. As depicted in this non-limiting example, a first vehicle **501** and a second vehicle **502** are configured for wireless communication, reception of satellite navigation signals, and processing of localization data. The first vehicle **501** includes a first antenna **511**, a first wireless transceiver **521**, a first processor **541**, and a first GPS (or other navigation type) receiver **531**, while the second vehicle **502** includes a second antenna **512**, a second transceiver **522**, a second processor **542**, and a second GPS receiver **532**. The first vehicle **501** is configured to transmit a first wireless message **551** symbolized by waves, the second vehicle **502** is configured to transmit a second wireless message **552**, and the navigation satellite **503** is configured to transmit GPS (or other navigation) signals **553**.

Three distances between the vehicles are defined as follows: A distance **Dmin 504** is the distance between the closest parts of the two vehicles **501-502**, a distance **Dnav 514** is the distance between the GPS (or other navigation) receivers **531-532**, and a distance **Dcentroid 524** is the distance between geometric centroids of the two vehicles **501-502**. From a traffic-safety perspective, the important distance is **Dmin 504**, while for GPS signals the relevant distance is **Dnav 514**, and for visual scene interpretation, **Dcentroid 524** may be most natural. Each vehicle **501-502** may include correction factors that translate between measurements based on the three distances **504-514-524**, and other distances based on other sensors. Although such corrections have not been significant with prior-art low-resolution localization, the improved precision enabled by the systems and methods disclosed herein may necessitate such distance corrections, according to some embodiments.

In the depicted example, the first and second vehicles **501-502** may initially communicate to agree upon a plan to simultaneously receive GPS signals **553**. For example, the first vehicle **501** (the “planning” vehicle) may broadcast a

first message **551** indicating, for example, a particular time at which the vehicles **501-502** may receive GPS signals **553** from a particular satellite **503**. The second vehicle **502** may reply with a message **552** agreeing to the plan. Alternatively, the second vehicle **502** may remain silent and not respond, since there is no need to clutter the bandwidth with unnecessary messaging. If the second vehicle **502** cannot comply with the original plan, it can propose a different plan, or decline to participate, or otherwise respond, or not respond.

The first and second vehicles **501-502** then receive (or attempt to receive) the same satellite signal **553** at their respective GPS receivers **531-532** at the specified time, and then exchange messages **551** or **552** including data derived from the received satellite signals **553**. For example, the second entity **502** may determine timing data from the received satellite signal **553**, and may then transmit a message including that data to the first vehicle **501**. Then, using the processor **541**, the first vehicle may analyze the data received from the second vehicle **502** along with data derived from its own reception of the satellite signals **553**, determining a differential between the two data sets, and may thereby derive a distance, such as  $D_{nav}$  **514**, related to that differential.

The analysis of the combined data may be configured to negate errors. For example, the first processor **541** may be configured to calculate a differential or difference between the signals received by the first and second **501-502** vehicles, and may derive a distance between the vehicles (or a component of that distance) from the observed difference between the two signals. For example, the data may include a time of arrival, or a difference in the times of arrival, of a particular signal feature in signals from two different satellites positioned at opposite sides of the sky. The arrival times of those two signal features, and their differential, may be different for the first and second vehicles **501-502**, due to their different distances from the satellite **503**. The distance  $D_{nav}$  **514** is related to that time difference by trigonometry. For example, if a particular satellite **503** is positioned along the line between the two vehicles **501-502**, then  $D_{nav}$  may equal that time difference divided by the speed of light. If the satellite **503** is positioned at an angle relative to the line between the vehicles, then the distance is related trigonometrically to that angle. In addition, by simultaneously receiving further signals from other navigation satellites (at least three, preferably four satellites), the vehicles can differentially analyze those signals as well, and thereby determine a two-dimensional location of the second vehicle **502** relative to the first vehicle **501**.

If the two vehicles **501-502** acquire satellite navigation signals at the same time from the same satellites, then improved precision may be obtained by subtracting the time of arrival of a particular signal feature at the first and second GPS receivers **531-532** for the satellites received. In some embodiments, it may not be necessary for the vehicles to include a precision time-base because the differences between arrival times of satellites at various positions in the sky are sufficient to determine the relative positions of the vehicles. Differential analysis is often more precise than calculating a first distance of the first vehicle **501** from the satellite **503** and a second distance of the second vehicle **502** from the satellite **503**, and then subtracting those two large distances to obtain the small distance between the vehicles. In addition, other errors may cancel each other in the differential calculation, such as errors due to satellite motion or satellite time-base errors, which are the same for the two vehicles' data sets, and therefore cancel in the differential. Since it is not necessary, in this example, to determine the

absolute latitude and longitude of the vehicles, the differential distance  $D_{nav}$  may be determined to greater precision as a result of the cancellation of the common distortions when the signals are acquired at the same time from the same satellite signals. In addition, it may not be necessary to calculate the distance to the satellite **503**, nor to determine other parameters related to absolute location, thereby saving time and canceling further sources of uncertainty such as errors due to vehicle motion and satellite motion, vehicle time-base errors and satellite clock errors, uncertainties in satellite position and its motion versus time, and many others that cancel in the differential. The simultaneous acquisition may thereby enable a more precise determination of the relative distance between the two vehicles **501-502**, and in their two-dimensional location of the second vehicle **502** relative to the first vehicle **501**, than provided by separate uncoordinated acquisitions, according to some embodiments.

As used herein, the two entities detect satellite signals "simultaneously" if the entities detect the same signals as closely in time as possible, given the finite speed of the signals. For example, if the vehicles are **300** meters apart, and if a satellite is in line with the vehicles, then the satellite signal will reach one of the vehicles about 1 microsecond later than the other vehicle. If both vehicles detect the same feature of the same signal from the same satellite, then the vehicles are said to have detected simultaneously, notwithstanding the signal propagation time between vehicles. However, that timing differential is directly related to the distance between the vehicles, and this relationship is independent of the distance to the satellite, the motion of the vehicles, the motion of the satellite, the stability of the satellite's time-base, and many other cancelling uncertainties.

In some embodiments of the systems and methods, any number of vehicles (or other wireless entities) may be in radio range of each other, and may be configured to exchange messages specifying data from three or more data sets acquired from three or more navigation satellites. For example, a first vehicle may broadcast a planning message specifying a time at which the vehicles will acquire signals from each of those satellites. The participating vehicles can then acquire the various signals from the specified satellites at the specified time in the specified order. Each of the vehicles may then derive data from the signals that they individually detect, and may transmit their reply messages to the first vehicle (or to another calculating entity such as a roadside access point), specifying that data. For example, each vehicle can include, in the data, a time difference between the arrival of a specific feature of the signals from each of the satellites, the time difference being measured to sufficient precision (such as 1-2 nanoseconds, for example) that the planning entity can derive relative positions of the vehicles by comparing those time differences. The vehicles may also include, in the planning message and the reply messages, each entity's wireless address, so that the vehicles can communicate with each other thereafter.

The first vehicle (or multiple vehicles, or a fixed entity) can then calculate the locations of each other participating vehicle, relative to the first vehicle or a central vehicle or some other basis, for example. The first vehicle may then broadcast a "locations" message including the calculated position map showing each participating vehicle's position along with its wireless address. Then, after receiving the locations message, the participating vehicles can then refer to the position map to determine which wireless address

goes with which physical vehicle, and can thereby communicate with and coordinate with the other vehicles.

The coordinate system of the position map may be related to a geographical coordinate system such as north and south, or it may be based on the direction of travel of the first vehicle, or it may be relative to the direction of the road that the vehicles are on. The position map may be a list of Cartesian coordinates and wireless addresses, for example. The coordinates may be the (X,Y) coordinates of each participating vehicle, in meters or in 10-cm units, relative to the first vehicle, with the X coordinate measured parallel to the road and the Y coordinate perpendicular to the road, for example. Alternatively, or in addition, the first vehicle (or other entity) may broadcast a message including a coordinate listing of the vehicle positions. Alternatively, the calculating entity may prepare a two-dimensional map as an image for example, or other format.

Calculating the location of a vehicle, relative to another vehicle, based on differential analysis of the simultaneously acquired data, may include a fitting step. When a location is determined redundantly by multiple independent measurements, the separate determinations generally disagree with each other due to measurement uncertainty and roundoff errors and the like. The first vehicle (or other calculating entity, such as a roadside computer) may process the measurements using a fitting function such as averaging the values, or performing a least-squares fit, or a maximum-likelihood fit, or an outlier-free mean-value fit, or other type of combination of the values. An artificial intelligence model, trained by machine learning using a large number of traffic location scenarios, may be employed to perform the location analysis based on the individually measured satellite data sets, including fitting the over-determined coordinates of the vehicles and other participating entities. A land-based access point or base station, or a remote supercomputer in communication with the roadside assets, may assist by solving the location fit rapidly.

Differentially analyzing the data acquired from multiple vehicles, and adjusting the two-dimensional fitting function for each vehicle's coordinates relative to the first vehicle, for example, is a complex problem. Artificial intelligence (AI) may be well-suited to determining the relative positions of the vehicles according to the satellite signals, due to the ability of some AI models to account for a wide range of parameters that may be mutually under- or over-determined or otherwise conflicted. For example, a software AI structure, such as a neural net, may be configured in a supercomputer, to accept as inputs the data acquired by each of the vehicles for each of the satellites, and to calculate a maximum-likelihood (or other fitting type) solution for the relative positions of the vehicles. Adjustable variables in the AI structure may be varied to incrementally and iteratively improve the accuracy of a predicted distance, for example, by comparing the predicted distance to the actual measured distance between vehicles. When adjusted to provide sufficiently accurate relative position measurements, the AI structure may be termed an AI model since it can then perform a useful task.

In some embodiments, the AI model may be too large and unwieldy for use by a busy vehicle processor. Therefore, a smaller and simpler algorithm may be derived from the successful AI model, by freezing the adjustable variables in beneficial values, and/or removing ("pruning") the non-productive inputs and functions. Alternatively, the algorithm may be configured as a different type of calculation tool, such as a table of values that can be interpolated, a computer program that emulates the AI model, an analytic function or

set of functions, or other way of calculating the relative positions of the vehicles according to the satellite data.

Due to the potentially large number of inputs and adjustable variables in the model, and the very large amount of training data likely needed for convergence of the model, the AI structure is preferably prepared in a supercomputer. The supercomputer may be a classical semiconductor-based computer, with sufficient speed and thread count and processor count to perform the model training in a feasible amount of time. Alternatively, the supercomputer may be a quantum computer having "qbits" or quantum bits as its working elements. Quantum computers may provide special advantages to solving AI models because they can very rapidly explore a complex terrain of values, such as the highly interrelated effects of the various inputs on the output results. Therefore, the systems and methods include a quantum computer programmed to include an AI structure and trained on a large number of traffic scenarios in which vehicles acquire navigation-satellite signals synchronously and perform differential analysis on the data sets.

The participating vehicles, after receiving the location message in which the vehicle locations are associated with their wireless addresses, can then communicate with each other "specifically", that is, transmitting messages unicast to a particular vehicle selected from the surrounding traffic. In addition, the location data may assist a hazard-avoidance program in each vehicle, for detecting imminent collisions and devising evasion strategies. In addition, with knowledge of the wireless addresses of each participating vehicle in proximity, the vehicles may thereby cooperate for collision avoidance and traffic management, in ways that may not be possible absent the disclosed systems and methods.

FIG. 6 is a schematic sketch showing an exemplary embodiment of a traffic scene including wireless entities configured to determine locations by simultaneous acquisition of satellite signals, according to some embodiments. As depicted in this non-limiting example, a multi-lane highway 608 includes vehicles rendered as cars 601 and 602, and a truck 604. On a connecting street 609 is another vehicle 603. Near the highway 608 is a pedestrian 605 with a mobile phone, an automatic wireless tollbooth 606, and a roadside access point or base station 607. All of those entities 601-607 are in wireless communication with each other on, for example, a sidelink or other predetermined frequency, and are also configured to detect signals, such as GPS (or other satellite) signals. Overhead at various angles are four navigation satellites 610, 611, 612, and 613, such as GPS satellites.

A planning entity, such as vehicle 601 or the access point 607, initially broadcasts a planning message to all receivers in range, suggesting a synchronized acquisition of satellite signals at a particular time relative to the planning message, such as 100 microseconds or 10 milliseconds after the planning message ends, for example. The planning message may specify that signals are to be acquired from particular satellites, such as satellites 610-613, receiving each satellite's signal at a particular time according to the satellite's transmission schedule. The planning message may include specifications about how the signals are to be analyzed (such as detecting and relative timing a particular feature of the signals) and how the data (such as the timing of the feature) is to be returned to the planning entity. The entities 601-607 may then acquire the satellite signals from the specified satellites 610-613 at the specified times. Each entity may then reduce the received signals to specific data values of parameters needed for the relative location determination, such as the arrival times (or time differences) of a particular

feature or phase of each satellite signal. The entities may then transmit data messages indicating the data thereby obtained. To avoid message interference among the data messages, the entities may monitor the channel during an LBT (listen-before-talk) interval before transmitting. The LBT interval may be a randomly selected interval, within a predetermined maximum time interval. Alternatively, the entities may have agreed as to the order in which they will report their data values, or they may have been assigned separate frequencies or bands for each entity, among other ways to avoid message interference. If a message interference occurs, then the planning entity or other entity may request a retransmission.

After receiving the data messages from the participating entities, the planning entity may analyze the various data sets to determine the relative positions of the entities. The planning entity may be configured to perform the location calculations in a differential manner, configured to cause certain errors or uncertainties to cancel each other. For example, the planning entity may be configured to subtract corresponding data values from two (or more) of the entities to obtain a differential value, and may then calculate a relative distance, or coordinate displacement, between those two entities according to the differential value (along with other data, such as angles to satellites). In addition, if multiple participating entities are present, the planning entity may be configured to perform a fit or weighted average or the like, in which the location of each entity may be determined by combining multiple distance measurements according to each of the participating entities and each of the satellites. The planning entity may thereby derive a maximum-likelihood or other improved location determination for each participating entity, which may be more precise than any of the contributing values individually, according to some embodiments. The planning entity may then assemble the various positions relative to, for example, the planning vehicle, as a position map, and may broadcast the position map with locations thus obtained. In addition, each vehicle's coordinates in the coordinate listing (or its location in the position map) may be annotated with that vehicle's wireless address.

Many advantages may result from the improved relative position determinations. For example, in the depicted scenario, vehicle **601** may be prepared to take violent evasive actions if the pedestrian **605** is in the roadway **608**. However, if a precision determination of the pedestrian's location indicates it is not encroaching the highway **608**, then the vehicle **601** may proceed safely in lane and avoid a risky swerve maneuver. If the precision location determination reveals that the pedestrian **605** has indeed stepped onto the highway **608**, then the precision location determination may provide the approaching vehicle **601** with sufficient time to swerve or stop safely. Sufficiently precise data may enable the vehicle **601** to manage the maneuver with minimum risk to itself, and may thereby save the errant pedestrian's life. Ordinary GPS signals, with a resolution of a few meters typically for moving vehicles, may not be sufficient in general to indicate whether the pedestrian is in the lane or on the side. Therefore it is essential that the oncoming vehicles obtain sufficiently precise location information as soon as possible, so that an emergency avoidance maneuver (with its risks) can be executed in time.

The precision location determination may also be necessary to separate closely-spaced entities. For example, the nearest surfaces of the truck **604** and the passing car **602** may be less than a meter of each other, which is below the resolution normally provided by non-differential, non-si-

multaneous, individual GPS. Improved spatial resolution, and especially improved determination of distances between entities, may be necessary to separate them, without which it may be impossible to form an accurate map of the local traffic.

Autonomous or semi-autonomous vehicles depend on continuous traffic situation awareness for control and safety. But in the present example, at least some of the entities are obscured from the sensors and cameras of other entities, and therefore cannot be included accurately in the local traffic map. Vehicle **601** is unable to detect the waiting car **603** or the toll booth **606**, for example. The location message may list the coordinates of all those entities, thereby revealing hidden entities and providing a more complete map of the traffic scenario.

In some embodiments, the access point **607** may be the planning entity, configured to transmit the planning message, acquire satellite signals at the specified time, and receive the data messages of the other entities. The access point **607** may perform differential analysis on the vehicles' data relative to the access point's received signals, determining the spatial distribution of the vehicles and other entities relative to the location of the access point. The access point **607** can also perform fitting on the overdetermined values, such as a maximum-likelihood fitting for example, and can then broadcast the location results to the other entities. Since the computing power of the land-based and stationary access point **607** is likely far better than most mobile processors, the access point **607** may be able to provide a more accurate determination, and faster, than the mobile entities could. In addition, the access point can broadcast the coordinate listing formatted as the geographical latitude and longitude of each vehicle, by adding the access point's previously determined coordinates to the relative position coordinates of each vehicle. In addition, the access point **607** may be in communication with other fixed assets, such as other base stations or access points upstream and downstream on the highway, and can compare the current traffic distribution with earlier traffic determinations upstream. This may reveal problems or emerging hazards, and may provide improved location resolution at the current site, for example. In addition, the access point **607** may be able to communicate with one of the vehicles according to the location and address information thus determined, for example to warn the vehicle of a hazard. A further advantage of the access point **607** doing the analysis may be that the vehicles would be minimally distracted, since they would be required only to acquire the satellite signals at the specified time and transmit the data results or timing parameters to the access point **607**. Assisted by the roadside access point's computers, the vehicles may obtain traffic awareness including localization and identification of surrounding vehicles, while focusing primarily on operating the vehicle instead of analyzing group data.

FIG. 7 is a flowchart showing an exemplary embodiment of a procedure for vehicles to avoid a collision, according to some embodiments. As depicted in this non-limiting example, at **701** a first vehicle (or other entity such as a roadside access point) broadcasts a planning message specifying particular navigation satellites and a particular time at which the satellite signals can be acquired. For example, the specified acquisition time may be in the range of 10 microseconds to 1 second following the start or end of the planning message, or other delay time configured to match a scheduled transmission time of the satellite or satellites. At **702**, the other vehicles in proximity receive the planning message. The other vehicles may acknowledge or they may

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remain silent. Acknowledgement may be unnecessary in most cases. At the specified time, each vehicle acquires the satellite signals as directed. At **703**, each vehicle analyzes the satellite signals to determine a characteristic parameter such as a timing or phase or other feature of the signals, related to the vehicle's location. At **704**, each vehicle transmits a data message indicating the characteristic parameter (or parameters) as well as the wireless address of that vehicle. At **705**, the first vehicle analyzes the various data sets. For example, the first vehicle may subtract or differentially compare the characteristic parameters determined by each of the vehicles, and thereby determines a relative location for each of the vehicles instead of a global geographic location. For example, the location of one vehicle may be determined relative to, say, the planning entity or other reference point, thereby canceling many uncertainties and measurement errors.

The orientation of the location distribution may be relative to the direction of the road or the travel direction of the first vehicle or a geographical direction, for example. In addition, if multiple vehicles are participating, each location coordinate is likely to be overdetermined by multiple independent measurements. In that case, the first vehicle may apply an averaging or fitting function to obtain a self-consistent distribution of locations of the vehicles. In addition, optionally, the vehicle locations may be adjusted to indicate the locations of the vehicle centroids instead of the location of the GPS receiver (the vehicles may indicate this correction in their data messages so that the first vehicle can add or subtract it from the values in the position map or coordinate listing). At **706**, the first vehicle broadcasts a location message indicating the location coordinates of each vehicle (relative to the first vehicle in this case) along with each vehicle's wireless address.

At **707**, the vehicles continue to monitor the positions of proximate vehicles as they proceed along the road using, for example, cameras or other sensors, and may thereby keep track of which vehicle has which wireless address as they move. Later, at **708**, a third vehicle detects an imminent hazard such as a collision involving a fourth vehicle. The third vehicle knows the wireless address of the fourth vehicle because they were both listed in the location message, and therefore at **709** the third vehicle transmits an emergency message to the fourth vehicle requesting immediate evasion to avoid the collision. At **710**, the fourth vehicle complies, the collision is avoided, and a life is saved as a result of precisely determining vehicle locations by simultaneous GPS as disclosed herein.

In general, the systems and methods disclosed herein are configured to provide relative distance and/or location determinations of vehicles and other wireless entities, using procedures in which common errors and uncertainties cancel. The procedures can provide improved localization precision and thereby identify each vehicle in proximity when combined with the determined wireless address of the vehicle. Such high-precision localization can greatly assist a collision-avoidance software by enabling improved trajectory calculations and improved near-miss determination, according to some embodiments. Higher localization precision can also provide earlier detection of imminent collisions, and therefore additional time to implement an avoidance or mitigation strategy, with lower risk involved in that strategy. Hence, fewer accidents may ensue, and less harm in each remaining collision, than would be possible absent the disclosed methods and systems.

The wireless embodiments of this disclosure may be aptly suited for cloud backup protection, according to some

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embodiments. Furthermore, the cloud backup can be provided cyber-security, such as blockchain, to lock or protect data, thereby preventing malevolent actors from making changes. The cyber-security may thereby avoid changes that, in some applications, could result in hazards including lethal hazards, such as in applications related to traffic safety, electric grid management, law enforcement, or national security.

In some embodiments, non-transitory computer-readable media may include instructions that, when executed by a computing environment, cause a method to be performed, the method according to the principles disclosed herein. In some embodiments, the instructions (such as software or firmware) may be upgradable or updatable, to provide additional capabilities and/or to fix errors and/or to remove security vulnerabilities, among many other reasons for updating software. In some embodiments, the updates may be provided monthly, quarterly, annually, every 2 or 3 or 4 years, or upon other interval, or at the convenience of the owner, for example. In some embodiments, the updates (especially updates providing added capabilities) may be provided on a fee basis. The intent of the updates may be to cause the updated software to perform better than previously, and to thereby provide additional user satisfaction.

The system and method may be fully implemented in any number of computing devices. Typically, instructions are laid out on computer readable media, generally non-transitory, and these instructions are sufficient to allow a processor in the computing device to implement the method of the invention. The computer readable medium may be a hard drive or solid state storage having instructions that, when run, or sooner, are loaded into random access memory. Inputs to the application, e.g., from the plurality of users or from any one user, may be by any number of appropriate computer input devices. For example, users may employ vehicular controls, as well as a keyboard, mouse, touch-screen, joystick, trackpad, other pointing device, or any other such computer input device to input data relevant to the calculations. Data may also be input by way of one or more sensors on the vehicle, an inserted memory chip, hard drive, flash drives, flash memory, optical media, magnetic media, or any other type of file—storing medium. The outputs may be delivered to a user by way of signals transmitted to vehicle steering and throttle controls, a video graphics card or integrated graphics chipset coupled to a display that maybe seen by a user. Given this teaching, any number of other tangible outputs will also be understood to be contemplated by the invention. For example, outputs may be stored on a memory chip, hard drive, flash drives, flash memory, optical media, magnetic media, or any other type of output. It should also be noted that the invention may be implemented on any number of different types of computing devices, e.g., embedded systems and processors, personal computers, laptop computers, notebook computers, net book computers, handheld computers, personal digital assistants, mobile phones, smart phones, tablet computers, and also on devices specifically designed for these purposes. In one implementation, a user of a smart phone or WiFi-connected device downloads a copy of the application to their device from a server using a wireless Internet connection. An appropriate authentication procedure and secure transaction process may provide for payment to be made to the seller. The application may download over the mobile connection, or over the WiFi or other wireless network connection. The application may then be run by the user. Such a networked system may provide a suitable computing environment for an implementation in which a plurality of users provide

separate inputs to the system and method. In the below system where vehicle controls are contemplated, the plural inputs may allow plural users to input relevant data at the same time.

It is to be understood that the foregoing description is not a definition of the invention but is a description of one or more preferred exemplary embodiments of the invention. The invention is not limited to the particular embodiments(s) disclosed herein, but rather is defined solely by the claims below. Furthermore, the statements contained in the foregoing description relate to particular embodiments and are not to be construed as limitations on the scope of the invention or on the definition of terms used in the claims, except where a term or phrase is expressly defined above. Various other embodiments and various changes and modifications to the disclosed embodiment(s) will become apparent to those skilled in the art. For example, the specific combination and order of steps is just one possibility, as the present method may include a combination of steps that has fewer, greater, or different steps than that shown here. All such other embodiments, changes, and modifications are intended to come within the scope of the appended claims.

As used in this specification and claims, the terms “for example”, “e.g.”, “for instance”, “such as”, and “like” and the terms “comprising”, “having”, “including”, and their other verb forms, when used in conjunction with a listing of one or more components or other items, are each to be construed as open-ended, meaning that the listing is not to be considered as excluding other additional components or items. Other terms are to be construed using their broadest reasonable meaning unless they are used in a context that requires a different interpretation.

The invention claimed is:

1. A method for a first wireless entity to determine a position of a second wireless entity relative to the first wireless entity, the method comprising:

- a) at a predetermined time, acquiring a first set of navigation satellite signals;
- b) receiving, from the second wireless entity, a wireless data message comprising data related to a second set of navigation satellite signals acquired by a second vehicle at the predetermined time;
- c) differentially analyzing the first set of navigation satellite signals and the data related to the second set of navigation satellite signals; and
- d) determining, according to the differential analysis, a distance and a direction between the first and second wireless entities.

2. The method of claim 1, wherein the wireless data message is transmitted according to 5G or 6G technology.

3. The method of claim 1, further comprising specifying, by the first wireless entity, the predetermined time and one or more particular satellites, wherein the first and second sets of navigation satellite signals are to be acquired at the predetermined time from the particular satellites.

4. The method of claim 1, further comprising receiving, from the second wireless entity, concatenated with or included in the wireless data message, a wireless address or identification code of the second wireless entity.

5. The method of claim 1, further comprising transmitting or broadcasting a location message indicating the wireless address or identification code of the first and second wireless

entities, and the position of the second wireless entity relative to the first wireless entity.

6. The method of claim 5, wherein the location message further indicates a latitude and a longitude of the first wireless entity.

7. The method of claim 5, wherein the location message further indicates the position of the second wireless entity relative to the first wireless entity in a Cartesian coordinate system.

8. The method of claim 7, wherein the Cartesian coordinate system comprises a first axis parallel to a road occupied by the first and second wireless entities, and a second axis perpendicular to the road.

9. The method of claim 5, further comprising:

- a) receiving, by a third wireless entity, the location message;
- b) determining, by the third wireless entity, that a collision is imminent between the third wireless entity and a fourth wireless entity;
- c) determining, by the third wireless entity, according to the location message, a wireless address of the fourth wireless entity; and
- d) transmitting, by the third wireless entity, to the fourth wireless entity, an emergency message.

10. The method of claim 1, wherein:

- a) the second wireless entity is not visible to the first wireless entity and to a camera of the first wireless entity; and
- b) the first wireless entity is not visible to the second wireless entity and to a camera of the second wireless entity.

11. The method of claim 1, wherein the differentially analyzing comprises:

- a) determining a first value of a particular parameter according to the first set of navigation satellite signals;
- b) determining a second value of the particular parameter according to the data related to the second set of navigation satellite signals;
- c) determining a differential by subtracting the first and second values; and
- d) determining the position of the second wireless entity relative to the first wireless entity based at least in part on the differential.

12. The method of claim 1, wherein the differentially analyzing is configured to cancel at least one measurement error that is present in both the first and second sets of satellite signals.

13. The method of claim 1, wherein the wireless data message further indicates a position of a centroid of the second vehicle relative to a navigation antenna of the second vehicle, the navigation antenna configured to receive the second set of navigation satellite signals.

14. The method of claim 13, further comprising transmitting or broadcasting a location message indicating the wireless address or identification code of the first and second wireless entities, the position of the second wireless entity relative to the first wireless entity, the position of the centroid of the second vehicle relative to the navigation antenna of the second vehicle, and a position of a centroid of a first vehicle relative to a navigation antenna of the first vehicle.