(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 October 2016 (06.10.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/159874 A1

(51) International Patent Classification:
G01S 5/02 (2010.01) *G07B 15/06* (2011.01)
G01S 5/14 (2006.01) *H04W 64/00* (2009.01)

(21) International Application Number:
PCT/SG2016/050146

(22) International Filing Date:
28 March 2016 (28.03.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10201502450V 27 March 2015 (27.03.2015) SG

(71) Applicant: **AGENCY FOR SCIENCE, TECHNOLOGY AND RESEARCH** [SG/SG]; 1 Fusionopolis Way, #20-10 Connexis, Singapore 138632 (SG).

(72) Inventor: **PATHMASUNTHARAM, Jaya Shankar S/O**; c/o PKM, Institute for Infocomm Research, 1 Fusionopolis Way, #21-01 Connexis, South Tower, Singapore 138632 (SG).

(74) Agent: **VIERING, JENTSCHURA & PARTNER LLP**; P.O. Box 1088, Rochor Post Office, Rochor Road, Singapore 911833 (SG).

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

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,

[Continued on next page]

(54) Title: METHOD AND DEVICE FOR VEHICLE DETECTION

(57) Abstract: Various embodiments provide a method of detecting a vehicle within a road segment. The method may include determining a round trip time for a communication signal exchange between the vehicle and an access point based on a predetermined time delay in the communication signal exchange; estimating a distance between the vehicle and the access point based on the determined round trip time; and determining whether the vehicle is within the road segment based on a comparison between the estimated distance and a predetermined range of distances. The predetermined range of distance is determined based on distances between the road segment and the access point.

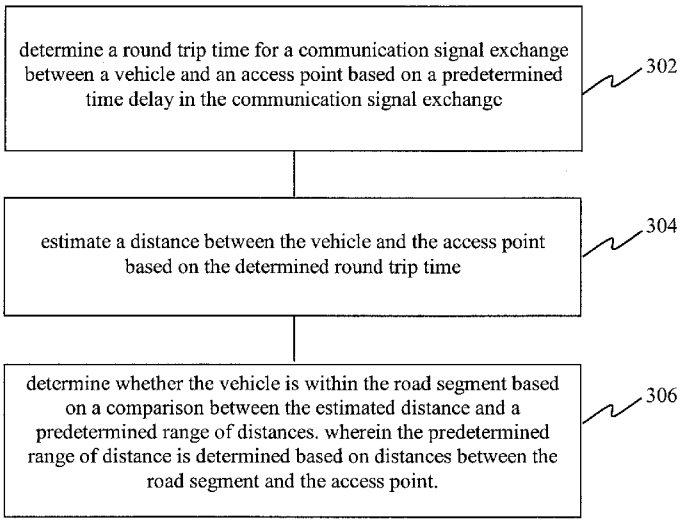


Fig. 3

WO 2016/159874 A1

SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

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

METHOD AND DEVICE FOR VEHICLE DETECTION

Cross-reference to Related Applications

[0001] The present application claims the benefit of the Singapore patent application 10201502450V filed on 27 March 2015, the entire contents of which are incorporated herein by reference for all purposes.

Technical Field

[0002] Embodiments generally relate to methods and devices for detection of a mobile communication device. Specifically, embodiments relate to methods and devices for detection of a vehicle.

Background

[0003] Next generation tolling system will be implemented using the upcoming connected vehicle infrastructure with V2V (vehicle-to-vehicle) and V2I (vehicle-to-infrastructure) capabilities. Cars are likely to be fitted with on board units (OBU) that carry sensors and radios such as Gyro, Accelerometer, GNSS (Global Navigation Satellite System), DSRC (Dedicated Short Range Communications), 3G, etc. New generation tolling can be implemented based on positions obtained by GNSS. However, GNSS positions are difficult to obtain in urban canyons, underground or areas with thick foliage. In such cases, charging zones in road tolling systems will have to rely on other techniques to provide accurate positioning.

[0004] Barrier-less car parks can also be implemented using GNSS. However, GNSS will suffer from the same issues mentioned above.

[0005] DSRC radio beacons which communicate to vehicles can be used as a means to localize the vehicle. Current beaconing approach uses a beam-forming approach to localize and track a vehicle within a given zone. However, using a beam-forming approach may also introduce errors in the positioning, and also restrict the antenna beam-width pattern in the on-board-unit to be narrow and restrictive for use in other applications such as car-to-car communications.

[0006] Point based charging and distance based charging in road tolling systems require segments in the road to be accurately designated. Besides this, vehicles need to be accurately identified in the zones or segments to give the drivers the sense that the system is accurately charging them. When a radio transceiver is used to implement a charging zone, there can be many complications. Charging zones implemented with DSRC or radio beam forming require the position of antenna, beam width and power to be controlled properly. If the setup is not done properly, signals will get reflected beyond the charging zone and cause charging transaction to occur outside the charging zone. Because of this complex setup, DSRC or radio antenna of the on-board unit may have to be designed with restricted beam width and direction as opposed to omni-directional antenna.

[0007] The new connected vehicle paradigm requires a V2V connection in all direction and therefore requires an omni-directional antenna setup in the vehicles. By restricting the antenna coverage, this feature cannot be implemented. In the future tolling system, besides the requirement of accurate charging, new requirements to disseminate charging information accurately before the driver enters the charging zone are also required. This again necessitates the need for omni-directional antenna.

[0008] The current approach for charging vehicles in the zone can be based on GPS positioning or radio beam forming approach. GPS is prone to error under poor satellite geometry conditions, urban canyons, multi-path reflections, etc. Under such circumstances,

it is difficult to totally eliminate false positive charging especially if the zone forming the road segment is smaller than the possible error distances of GPS.

[0009] The current DSRC-based charging zones 102 may be implemented using a set of directional antennas 104, 106 as shown in Fig. 1. The directional antennas 102 are normally angled downwards from tall gantries to point towards the zones on interest. To make the charging zone 102 more defined, the gantries are implemented with good height and antennas 104 are directed almost vertically downwards. To provide accurate localization of the vehicle in the zone, another set of antennas 106 behind the first gantry is also used to provide extra detection. To enhance the charging process, the antenna 112 of the OBU in the vehicle is also implemented using directional antennas and angled towards the gantry as shown Fig. 1. These proprietary DSRC radios have to be implemented with very fast communication protocols to ensure that the vehicles are charged in the zone 102 accurately.

[0010] More recently, IEEE 802.11p radios are also proposed for tolling use. With 802.11p, the communication protocol has some latency in completing the transaction, especially if the transaction needs to be secured. Due to this reason, road toll charging may need to be implemented with larger charging zones. Implementing larger zones with 802.11p or DSRC is tricky as the antenna beams from high gantries have to be spread horizontally and are difficult to adjust. The beam width and propagation can be irregular causing communication with vehicle to happen outside the zone. Using such methods, false positives will be very difficult to eliminate. Due to this, vehicles may be charged in the wrong location.

[0011] Conventional car parks are implemented with barriers and some form of payment and identification method at the entrance. In some cases, the identification method is based on DSRC. This method of DSRC identification is normally based on the use of directional antenna in the base station to communicate to the on-board-unit of vehicles. The use of the

directional antenna is to accurately distinguish the front vehicle queuing at the car park entrance.

[0012] Fig. 2 shows a current electronic parking detection and charging system 200. A directional antenna 202 is placed right before the car park barrier 204 and has an antenna beam that helps distinguishing the first and subsequent cars queuing at the entrance. Such a configuration is used to ensure that the wrong car is not charged during the fee deduction. Due to the directional nature of the antenna 202, the opportunity for communication is time limited if a vehicle is moving too fast. When there is a barrier 204, the vehicle comes to a halt and it is easy for the antenna to carry out the communication with the desired vehicle. If the barrier is removed and the same system is used to detect and charge the vehicle, the communication with the vehicle will fail.

Summary

[0013] Various embodiments provide a method of detecting a vehicle within a road segment. The method may include determining a round trip time for a communication signal exchange between the vehicle and an access point based on a predetermined time delay in the communication signal exchange; estimating a distance between the vehicle and the access point based on the determined round trip time; and determining whether the vehicle is within the road segment based on a comparison between the estimated distance and a predetermined range of distances. The predetermined range of distance is determined based on distances between the road segment and the access point.

Brief Description of the Drawings

[0014] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead

generally being placed upon illustrating the principles of the invention. In the following description, various embodiments are described with reference to the following drawings, in which:

Fig. 1 shows DSRC-based charging zones implemented using a set of directional antennas.

Fig. 2 shows an electronic parking detection and charging system.

Fig. 3 shows a flowchart illustrating a method of detecting a vehicle in a road segment according to various embodiments.

Fig. 4 shows a flowchart illustrating a method of detecting a vehicle in a road segment according to various embodiments.

Fig. 5 shows a flowchart illustrating a method of detecting a vehicle in a road segment according to various embodiments.

Fig. 6 shows a detection device for detecting a vehicle in a road segment according to various embodiments.

Fig. 7 shows a message flow diagram of a 4-way handshake process and a 2-way handshake process according to various embodiments.

Fig. 8 shows a diagram in which a radio access point is placed along a road according to various embodiments.

Fig. 9 shows a 4-way handshake between an access point and a mobile station (MS) according to various embodiments.

Fig. 10 shows a 2-way handshake between two devices according to various embodiments.

Fig. 11 shows a diagram illustrating detection of a vehicle in a charging zone of a road segment according to various embodiments.

Fig. 12 shows an exemplary single lane road segment bounded by lines A-A' and B-B' according to various embodiments.

Fig. 13 shows a configuration of an access point according to various embodiments.

Fig. 14 shows a 2-way handshake between the vehicle and the access point of Fig. 13 according to various embodiments.

Fig. 15 illustrates a diagram for tracking the relative location of the vehicle within the charging zone using the trilateration method according to various embodiments.

Fig. 16 illustrates a diagram for tracking the relative location of the vehicle when the vehicle is outside the charging zone according to various embodiments.

Fig. 17 illustrates a diagram for tracking the relative location of the vehicle when the vehicle is within the charging zone according to various embodiments.

Fig. 18 shows an exemplary embodiment wherein six receivers are used for vehicle detection in a road segment.

Fig. 19 shows a hardware configuration for vehicle detection according to various embodiments.

Fig. 20 shows a system including a base station and a plurality of transceivers according to various embodiments.

Fig. 21 shows a communication between a vehicle and a base station according to various embodiments.

Fig. 22 shows a communication with a vehicle according to various embodiments.

Fig. 23 shows a possible timing sequence of ACK reception for a vehicle passing through a road segment shown in Fig. 20.

Fig. 24 shows a system including a base station and a plurality of transceivers for tracking a movement of a vehicle within a road segment according to various embodiments.

Fig. 25 shows a possible timing sequence of ACK reception for a vehicle passing through a road segment shown in Fig. 24.

Fig. 26 shows a coverage beyond the charging zone provided by an access point with an omni-directional antenna according to various embodiments.

Fig. 27 shows a coverage provided by more than one access point with omni-directional antenna according to various embodiments.

Fig. 28 shows a coverage provided by an access point with a directional antenna according to various embodiments.

Description

[0015] In a desired toll system, the V2V (vehicle-to-vehicle) communication should not be restricted, and false positive and true negative charging should be eliminated completely. It is acceptable if vehicles are not charged under false negative scenario.

[0016] Table 1 below shows the criteria and requirement for a desired toll system.

Table 1

Criteria	Description	Requirement
False Positive	Vehicle not in the zone but tested positive in the zone	Should not charge vehicle at all
False Negative	Vehicle in the zone but tested negative in the zone	Acceptable if vehicle is not charged
True Positive	Vehicle in the zone and tested positive in the zone	To charge vehicle
Ture Negative	Vehicle not in the zone and tested negative in the zone	Should not charge vehicle at all

[0017] Various embodiments provide methods and devices to accurately identify a vehicle within a road segment, and charge the vehicle according to the requirements mentioned above in Table 1 for road tolling purposes.

[0018] Another application that requires monitoring and detection of vehicle movement across a segment of a road is for entries into car parks. Various embodiments provide a method and a device that accurately track the direction of the vehicle movement and the entry and exit of a road segment. This may be used to implement a barrier-less car park charging system. When applied in the car park charging system, the entry and exit into a car park may need accurate positive crossover across the segment and accurate time stamping when the vehicle crosses over the segment. The methods and devices of various embodiments may be applied to both road toll charging and car park toll charging.

[0019] Fig. 3 shows a flowchart illustrating a method of detecting a vehicle within a road segment according to various embodiments.

[0020] At 302, a round trip time for a communication signal exchange between the vehicle and an access point is determined based on a predetermined time delay in the communication signal exchange.

[0021] At 304, a distance between the vehicle and the access point is estimated based on the determined round trip time.

[0022] At 306, it is determined whether the vehicle is within the road segment based on a comparison between the estimated distance and a predetermined range of distances. The predetermined range of distance is determined based on distances between the road segment and the access point.

[0023] In other words, a time period required for a signal communication between the vehicle and the access point may represent a distance between the vehicle and the access point. Such a time period may be measured by measuring the round trip time, wherein the round trip time represents the length of time it takes for a signal to be sent plus the length of time it takes for an acknowledgment of that signal to be received. The round trip time is measured, taking into account a predetermined or fixed time day that occurs in the signal

communication which may not indicate a physical distance in the transmission/reception path and may be taken out from the entire time spent on the communication exchange. Accordingly, the round trip time may be used to estimate a corresponding distance between the vehicle and the access point. The road segment may be predetermined to have a predetermined range of distances from the access point. Accordingly, by comparing the estimated distance of the vehicle from the access point with the predetermined distance range corresponding to the road segment, it may be determined whether the vehicle is within the road segment.

[0024] In various embodiments, if the estimated distance is within the predetermined range of distances, it is determined that the vehicle is within the road segment. If the estimated distance is out of the predetermined range of distances, it is determined that the vehicle is out of the road segment.

[0025] In various embodiments, the predetermined time delay may include a short inter-frame space (SIFS), which may also be referred to as a short inter-frame sequence. The SIFS represents the amount of time required for a wireless interface to process a received signal and to respond with a response signal, for example, a time delay or gap between reception of a MAC frame and transmission of a response MAC frame. In various embodiments wherein the communication signal exchange is performed in IEEE 802.11 networks, SIFS may be the interframe spacing between reception time of a Request To Send (RTS) frame and transmission time of a Clear To Send (CTS) frame, or the interframe spacing between reception time of a CTS frame and transmission time of a DATA frame, or the interframe spacing between reception time of a DATA frame and transmission time of an ACK frame.

[0026] In various embodiments, the predetermined time delay may further include a time interval between the time at which the vehicle or the access point is enabled for transmission of the communication signal and the time at which the communication signal is transmitted.

In various embodiments wherein IEEE 802.11 radio cards are used in the vehicle and the access point for communication signal exchange, a Transmit Ready Pin (TX_PIN) may be used to enable a RF (radio frequency) front-end chain for transmission or reception of communication signals, e.g., RF signals. During transmission, the RF front-end may be enable prior to a transmission of a MAC frame. The time interval between the enabling of the TX_PIN and the time a MAC frame is sent out may be taken into account as the predetermined time delay in determining the time length for the communication signal exchange.

[0027] In various embodiments, the communication signal exchange may include transmission of a signal and reception of an acknowledgement signal at one of the vehicle or the access point.

[0028] In various embodiments, the communication signal exchange may be performed according to at least one of 802.11 protocol or CSMA-CA (Carrier sense multiple access with collision avoidance) protocol.

[0029] The communication signal exchange may be part of a handshake process, including exchange of a data/control signal and an acknowledgement signal. In various embodiments, the handshake process may include one of a 2-way handshake process or a 4-way handshake process. In an embodiment of 2-way handshake process, the handshake process may include transmission of a DATA message and reception of an ACK message, e.g. according to IEEE 802.11. The DATA message may be understood as a message carrying useful data or user data). In an embodiment of 4-way handshake process, the handshake process may include transmission of a DATA message and reception of an ACK message, and may further include transmission of a RTS message and reception of a CTS message.

[0030] In various embodiments, the access point may be located within the road segment, for example, along the road side of the road segment or in the middle of the road segment. The access point may include an antenna with a coverage at least substantially covering the road segment. The antenna may be an omni-directional antenna or a directional antenna.

[0031] In various embodiments, the access point may be located outside the road segment, for example, outside and near an entrance/exit of the road segment. The access point may include an antenna with a coverage at least substantially covering the road segment. The antenna may be an omni-directional antenna or a directional antenna.

[0032] In various embodiments, the communication signal exchange with the access point may be carried out by a mobile communication device provided in the vehicle, such as a on-board-unit with wireless communication capabilities, for example supporting IEEE 802.11.

[0033] In various embodiments, the method as illustrated with reference to Fig. 3 above may further include detecting the vehicle using an access point with a plurality of receivers located at different locations with respect to the road segment, so as to determine the location of the vehicle relative to the road segment. The movement of the vehicle along the road segment may also be determined based on the comparison of the respective time length determined within a time period.

[0034] According to various embodiments, a respective round trip time may be determined for a communication signal exchange between the vehicle and a respective receiver of the plurality of receivers of the access point. The respective round trip time for respective receiver may be compared with each other, and whether the vehicle is within the road segment may be determined based on the comparison of the respective round trip time. In various embodiments, the access point may include at least a first receiver located within

the road segment and at least a second receiver located outside the road segment, wherein the first receiver and the second receiver have the same distance from one of an entrance line or an exit line of the road segment.

[0035] The entrance line may refer to a line across the width of the road at the entrance of the road segment, and the exit line may refer to another line across the width of the road at the exit of the road segment, such that a portion of the road between the entrance line and the exit line defines the road segment referred to herein. In various embodiments, the first receiver and the second receiver are arranged along a direction parallel to a longitudinal axis of the road. For example, the first receiver and the second receiver may be both arranged at the same road side, or both arranged in the center of the road. Accordingly, any point along the entrance line or exit line is away from the first receiver and the second receiver by the same distance.

[0036] In various embodiments, determining whether the vehicle is within the road segment may include determining a Time Difference of Arrival (TDOA) based on the comparison of the respective round trip time. The TDOA may indicate the difference in the distances of the respective receiver from the vehicle.

[0037] In various embodiments, it is determined that the vehicle is within the road segment, if it is determined that the round trip time determined for the first receiver is shorter than the round trip time determined for the second receiver.

[0038] In various embodiments, the access point may further include at least a third receiver located outside the road segment, wherein the first receiver and the third receiver have the same distance from the other one of the entrance line or the exit line of the road segment. The third receiver is located opposite to the second receiver. For example, if the second receiver is located outside the entrance of the road segment, the third receiver is located at the opposite side outside the exit of the road segment, and vice versa. In various

embodiments, the receivers are arranged along a direction parallel to a longitudinal axis of the road. For example, the three receivers may be arranged at the same road side, or arranged in the center of the road.

[0039] The access point may include more than three receivers in other embodiments.

[0040] In various embodiments, it is determined that the vehicle is within the road segment, if it is determined the round trip time determined for the first receiver is shorter than the round trip time determined for the second receiver, and/or if it is determined that the round trip time determined for the first receiver is shorter than the round trip time determined for the third receiver.

[0041] In various embodiment, a movement direction of the vehicle may be determined based on the comparison of the respective round trip time in a time period. Illustratively, at a first time point in the time period, it is determined that the vehicle is outside the road segment and outside the entrance. At a second time point in the time period, it is determined that the vehicle is within the road segment. At a third point in the time period, it is determined that the vehicle is outside the road segment and outside the exit. Accordingly, it may be determined that the vehicle enters the road segment from the entrance and leaves the road segment from the exit within this time period.

[0042] In various embodiments, the same media access control (MAC) address is assigned to the plurality of receivers and the communication signal is addressed to the same media access control address, such that the communication signal is transmitted from the vehicle to the plurality of receivers.

[0043] In various embodiments, the method as illustrated with reference to Fig. 3 above may further include determining whether a communication signal from the vehicle is received at a plurality of transceivers of an access point, and determining whether the vehicle is within the road segment based on the determined reception of the communication signal at

the respective transceiver. The plurality of transceivers are located at different locations of the road segment to provide different coverage zones, each coverage zone covering at least a portion of the road segment.

[0044] In other words, the vehicle detection method may further provide a plurality of transceivers in an access point, wherein the transceivers are located differently from each other and provide different coverage zones with respect to the road segment. The vehicle detection method may detect the vehicle in the road segment by a determination performed on the communication signals received at the plurality of transceivers.

[0045] In various embodiments, a movement or a movement direction of the vehicle may also be determined. The movement direction of the vehicle in the road segment may be determined based on a time sequence of receiving the communication signal at the plurality of transceivers.

[0046] In various embodiments, the same media access control (MAC) address is assigned to the plurality of transceivers and the communication signal is addressed to the same media access control address, such that the communication signal is transmitted from the vehicle to the plurality of transceivers.

[0047] In various embodiments, the plurality of transceivers may include at least a first transceiver configured to provide a coverage zone covering the entire road segment, a second transceiver configured to provide a coverage zone at an entrance of the road segment, and a third transceiver configured to provide a coverage zone at an exit of the road segment without overlapping with the coverage zone of the second transceiver. In various embodiments, a portion of the road segment between the entrance and the exit may not be covered by the coverage zones of the second transceiver and the third transceiver. According to various embodiments, it is determined that the vehicle moves from the entrance to the exit

of the road segment if the communication signal from the vehicle is sequentially received at the second transceiver, the first transceiver and the third transceiver; and vice versa.

[0048] In various embodiments, the plurality of transceivers may include at least a first transceiver configured to provide a coverage zone covering the entire road segment, a second transceiver configured to provide a coverage zone at an entrance of the road segment, and a third transceiver configured to provide a coverage zone at an exit of the road segment. The coverage zones of the first transceiver, the second transceiver and the third transceiver may overlap at a predetermined charging zone of the road segment. According to various embodiments, it is determined that the vehicle is within the predetermined charging zone of the road segment if the communication signal is simultaneously received at the first transceiver, the second transceiver and the third transceiver.

[0049] In various embodiments, the communication signal exchange with the respective transceivers of the access point may be carried out by a mobile communication device provided in the vehicle, such as a on-board-unit with wireless communication capabilities, for example supporting IEEE 802.11.

[0050] Fig. 4 shows a flowchart illustrating a method of detecting a vehicle within a road segment according to various embodiments.

[0051] At 402, a respective round trip time is determined for a communication signal exchange between the vehicle and a respective receiver of a plurality of receivers of an access point.

[0052] At 404, the respective round trip time is compared with each other.

[0053] At 406, it is determined whether the vehicle is within the road segment based on the comparison of the respective round trip time.

[0054] The access point may include at least a first receiver located within the road segment and at least a second receiver located outside the road segment, wherein the first

receiver and the second receiver have the same distance from one of an entrance line or an exit line of the road segment.

[0055] The entrance line may refer to a line across the width of the road at the entrance of the road segment, and the exit line may refer to another line across the width of the road at the exit of the road segment, such that a portion of the road between the entrance line and the exit line defines the road segment referred to herein. In various embodiments, the first receiver and the second receiver are arranged along a direction parallel to a longitudinal axis of the road. For example, the first receiver and the second receiver may be both arranged at the same road side, or both arranged in the center of the road. Accordingly, any point along the entrance line or exit line is away from the first receiver and the second receiver by the same distance.

[0056] In various embodiments, determining whether the vehicle is within the road segment may include determining a Time Difference of Arrival based on the comparison of the respective round trip time. The TDOA may indicate the difference in the RTTs for the plurality of receivers, and the difference in the distances of the receivers from the vehicle.

[0057] In various embodiments, it is determined that the vehicle is within the road segment, if it is determined that the round trip time determined for the first receiver is shorter than the round trip time determined for the second receiver.

[0058] In various embodiments, the access point may further include at least a third receiver located outside the road segment, wherein the first receiver and the third receiver have the same distance from the other one of the entrance line or the exit line of the road segment. The third receiver is located opposite to the second receiver. For example, if the second receiver is located outside the entrance of the road segment, the third receiver is located at the opposite side outside the exit of the road segment, and vice versa.

[0059] The access point may include more than three receivers in other embodiments.

[0060] In various embodiments, it is determined that the vehicle is within the road segment, if it is determined the round trip time determined for the first receiver is shorter than the round trip time determined for the second receiver, and/or if it is determined that the round trip time determined for the first receiver is shorter than the round trip time determined for the third receiver.

[0061] In various embodiment, a movement direction of the vehicle may be determined based on the comparison of the respective round trip time in a time period. Illustratively, at a first time point in the time period, it is determined that the vehicle is outside the road segment and outside the entrance. At a second point in the time period, it is determined that the vehicle is within the road segment. At a third point in the time period, it is determined that the vehicle is outside the road segment and outside the exit. Accordingly, it may be determined that the vehicle enters the road segment from the entrance and leaves the road segment from the exit within this time period.

[0062] In various embodiments, the same media access control (MAC) address is assigned to the plurality of receivers and the communication signal is addressed to the same media access control address, such that the communication signal is transmitted from the vehicle to the plurality of receivers.

[0063] In other words, by providing a plurality of receivers at different locations with respect to the road segment and by determining a respective time length for communication signal exchange with the respective receivers, the presence of the vehicle within the road segment and/or the location of the vehicle relative to the road segment may be determined. The movement of the vehicle along the road segment may also be determined based on the comparison of the respective time length determined within a time period.

[0064] In various embodiments, The respective RTT may be determined according to various embodiments of Fig. 3 above. In other embodiments, the respective entire time

length for communication signal communication between the vehicle and the respective receivers may be measured and compared to determine the location of the vehicle relative to the road segment. The entire time length may be measured from a starting time of signal transmission to a time of arrival (TOA) of a response signal reception, for example. In other words, instead of using the RTT which takes into account the possible time delay in the communication signal exchange, the entire time length which does not take into account the possible time delay in the communication path may also be used to determine a rough time difference.

[0065] In various embodiments, the communication signal exchange with the access point may be carried out by a mobile communication device provided in the vehicle, such as a on-board-unit with wireless communication capabilities, for example supporting IEEE 802.11.

[0066] Fig. 5 shows a flowchart illustrating a method of detecting a vehicle within a road segment.

[0067] At 502, it is determined whether a communication signal from the vehicle is received at a plurality of transceivers of an access point.

[0068] At 504, it is determined whether the vehicle is within the road segment based on the determined reception of the communication signal at the respective transceiver.

[0069] The plurality of transceivers are located at different locations of the road segment to provide different coverage zones, each coverage zone covering at least a portion of the road segment.

[0070] In other words, by a determination performed on the communication signals received at a plurality of transceivers of an access point which are located differently from each other and provide different coverage zones with respect to the road segment, the presence of the vehicle in the road segment may be determined.

[0071] In various embodiments, a movement or a movement direction of the vehicle may also be determined. The movement direction of the vehicle in the road segment may be determined based on a time sequence of receiving the communication signal at the plurality of transceivers.

[0072] In various embodiments, the same media access control (MAC) address is assigned to the plurality of transceivers and the communication signal is addressed to the same media access control address, such that the communication signal is transmitted from the vehicle to the plurality of transceivers.

[0073] In various embodiments, the plurality of transceivers may include at least a first transceiver configured to provide a coverage zone covering the entire road segment, a second transceiver configured to provide a coverage zone at an entrance of the road segment, and a third transceiver configured to provide a coverage zone at an exit of the road segment without overlapping with the coverage zone of the second transceiver. In various embodiments, a portion of the road segment between the entrance and the exit may not be covered by the coverage zones of the second transceiver and the third transceiver. According to various embodiments, it is determined that the vehicle moves from the entrance to the exit of the road segment if the communication signal from the vehicle is sequentially received at the second transceiver, the first transceiver and the third transceiver; and vice versa.

[0074] In various embodiments, the plurality of transceivers may include at least a first transceiver configured to provide a coverage zone covering the entire road segment, a second transceiver configured to provide a coverage zone at an entrance of the road segment, and a third transceiver configured to provide a coverage zone at an exit of the road segment. The coverage zones of the first transceiver, the second transceiver and the third transceiver may overlap at a predetermined charging zone of the road segment. According to various embodiments, it is determined that the vehicle is within the predetermined charging zone of

the road segment if the communication signal is simultaneously received at the first transceiver, the second transceiver and the third transceiver.

[0075] In various embodiments, the communication signal exchange with the respective transceivers of the access point may be carried out by a mobile communication device provided in the vehicle, such as a on-board-unit with wireless communication capabilities, for example supporting IEEE 802.11.

[0076] The methods described in various embodiments of Figs. 3-5 may be combined in any suitable manner to detect the vehicle in the road segment, and/or detect the location of the vehicle relative to the road segment, and/or detect the movement direction of the vehicle in the road segment. The road segment may also include a segment at the entrance/exit of a car park. For example, the methods described in the embodiments of Fig. 4 and Fig. 5 may be combined for vehicle detection using a plurality of receivers or transceivers in the access point, without estimating the distance between the vehicle and the access point and comparing the estimated distance with the predetermined range of distances as in embodiments of Fig. 3. In another example, the method in the embodiments of Fig. 3 may be combined with the embodiments of Fig. 4, or with the embodiments of Fig. 5, or with the embodiments of both Fig. 4 and Fig. 5.

[0077] Various embodiments further provide a detection device for detecting a vehicle within a road segment. Fig. 6 shows a schematic diagram of a detection device 600 according to various embodiments.

[0078] As shown in Fig. 6, the detection device 600 may include a determiner 602 and a processor 604.

[0079] In various embodiments, the detection device 600 may be configured to carry out the corresponding methods of Fig. 3 as described above. The determiner 602 may be configured to determine a round trip time for a communication signal exchange between the

vehicle and an access point based on a predetermined time delay in the communication signal exchange. The processor 604 may be configured to estimate a distance between the vehicle and the access point based on the determined round trip time, and determine whether the vehicle is within the road segment based on a comparison between the estimated distance and a predetermined range of distances. The predetermined ranges of distance may be determined based on distances between the road segment and the access point.

[0080] In various embodiments, the detection device 600 may be configured to carry out the corresponding methods of Fig. 4 as described above. The determiner 602 may be configured to determine a respective round trip time for a communication signal exchange between the vehicle and a respective receiver of a plurality of receivers of an access point. The processor 604 may be configured to compare the respective round trip time with each other, and determine whether the vehicle is within the road segment based on the comparison of the respective round trip time. In various embodiments, the access point may include at least a first receiver located within the road segment and at least a second receiver located outside the road segment. The first receiver and the second receiver have the same distance from one of an entrance line or an exit line of the road segment.

[0081] In various embodiments, the detection device 600 may be configured to carry out the corresponding methods of Fig. 5 as described above. The determiner 602 may be configured to determine whether a communication signal from the vehicle is received at a plurality of transceivers of an access point. The processor 604 may be configured to determine whether a vehicle is within the road segment based on the determined reception of the communication signal at the respective transceiver. The plurality of transceivers are located at different locations of the road segment to provide different coverage zones, wherein each coverage zone covers at least a portion of the road segment.

[0082] Although the determiner 602 and the processor 604 are shown as separate components in Fig. 6, it is understood that the detection device 600 may include a single processor configured to carry out the processes performed in the determined 602 and the processor 604. In other embodiments, the detection device 600 may be or may include a computer program product, e.g. a non-transitory computer readable medium, storing a program or instructions which when executed by a processor causes the processor to carry out the methods of various embodiments above.

[0083] The detection device 600 may be configured to carry out the corresponding methods of Figs. 3-5 as described in various embodiments above. It should be noted that embodiments described in context with the methods illustrated in Figs. 3-5 are analogously valid for the detection device 600 and vice versa. Similarly, detection device 600 may be configured to carry out the method combining the various embodiments described with respect to Figs. 3-5 above, so as to detect the vehicle in the road segment, and/or detect the location of the vehicle relative to the road segment, and/or detect the movement direction of the vehicle in the road segment.

[0084] In various embodiments, the detection device 600 may be implemented by an access point located in or close to a road segment, and operating according to a wireless communication network standard, such as IEEE 802.11, e.g. WiFi access points. In various embodiments, the detection device 600 may also be implemented by a charging device or a charging system which may communicate with one or more access points.

[0085] The components of the detection device 600 (e.g. the determiner 602 and the processor 604) may for example be implemented by one or more circuits. A "circuit" may be understood as any kind of a logic implementing entity, which may be special purpose circuitry or a processor executing software stored in a memory, firmware, or any combination thereof. Thus, in an embodiment, a "circuit" may be a hard-wired logic circuit

or a programmable logic circuit such as a programmable processor, e.g. a microprocessor (e.g. a Complex Instruction Set Computer (CISC) processor or a Reduced Instruction Set Computer (RISC) processor). A "circuit" may also be a processor executing software, e.g. any kind of computer program, e.g. a computer program using a virtual machine code such as e.g. Java. . Any other kind of implementation of the respective functions which will be described in more detail below may also be understood as a "circuit".

[0086] Methods and Devices according to various embodiments above address the problem of wrongly charging the vehicle outside the charging zone of a road segment. In other words, various embodiments eliminate the false positive charging and true negative charging. Unlike conventional systems which limit the communication to a small area covered by directional antenna, various embodiments allows vehicles that are outside the charging zone of the road segment to freely communicate to the radio access point situated at the gantry of a road tolling system or a barrier of a car park entrance/exit for other purposes.

[0087] Various embodiments above also provide an approach to track a movement of the vehicle passing through the segment of the road, for example, at the entrance/exit of the car park, to positively identify the process of entering or leaving the car park. Accordingly, various embodiments may be used in a barrier-less car park.

[0088] The methods of various embodiments above are further described in more detail with reference to Figs. 7 to 28 below.

[0089] In various embodiments, the methods to detect a vehicle in a road segment so as to carry out toll charging make use of the built-in MAC protocol found in IEEE 802.11 or CSMA-CA protocols. The MAC protocols may be implemented using 2-way handshake or 4-way handshake.

[0090] Fig. 7 shows a message flow diagram of a 4-way handshake process and a 2-way handshake process according to various embodiments.

[0091] The 4-way handshake is illustrated in Fig. 7(a). The message flow illustrates a data transmission from a first device, in this example an access point (AP) 701, to a second device, in this example a mobile terminal 702, which operate according to IEEE 802.11. The mobile terminal may be the on-board-unit in the vehicle as described above.

[0092] Each signal (also referred to as message or frame) transmitted is subjected to a propagation delay 709 when it is transmitted from one device to the other. This is illustrated by the frames being drawn with a slope indicating that a frame arrives later at one device than it is transmitted at the other (assuming time increases along axes 703, 704 from top to bottom). The inter-frame times are normally determined to be a fixed value which is SIFS 705 in IEEE 802.11.

[0093] According to the 4-way handshake, the device transmitting data, in this example AP 701, transmits an RTS (Request to Send) frame 706. The device receiving the data, in this example mobile terminal 702, responds with a CTS (Clear to Send) frame 707. After having received the CTS message 707, the AP 701 transmits a data frame 708 which arrives at the mobile terminal 702 (like also the other frames) with a propagation delay 709. The mobile terminal 702 acknowledges the data reception with an acknowledgement (ACK) frame 710.

[0094] The 2-way handshake is illustrated in Fig. 7(b), which is similar to the 4-way handshake of Fig. 7(b) but without the communications of RTS frame 706 and the CTS frame 707.

[0095] The method of various embodiments makes use of ranging from a radio access point to determine whether a vehicle is within a road segment, wherein the radio access point may be placed along the road segment, or on a gantry above the road segment, or outside the road segment.

[0096] Fig. 8 shows a diagram 800 in which a radio access point 802 is placed along a road according to various embodiments. A range d_i between the radio access point 802 and a vehicle 804 is determined from the communication signal exchange, for example MAC protocol exchange, between the vehicle 804 and the access point 802 according to various embodiments.

[0097] Various embodiments makes use of the fixed timing properties of the gaps between reception of a MAC frame and transmission of a response MAC frame. For example, the time gaps between a reception time of the RTS frame and a transmission time of the CTS frame, between a reception time of the CTS frame and a transmission time of the DATA frame, and between a reception time of the DATA frame and a transmission time of the ACK frame, are well bounded by a fixed amount of MAC clock ticks, which is defined by SIFS 705 shown in Fig. 7.

[0098] Fig. 9 shows a 4-way handshake between the access point and a mobile station (MS), in this example, the vehicle, according to various embodiments.

[0099] In most IEEE 802.11 radio cards, a Transmit Ready Pin (TX_PIN) 802 is used to enable the RF front-end chain for transmission or reception of RF signals. During transmission, the RF front-end is enabled prior to a transmission of a MAC frame. The time interval between the time of enabling the TX_PIN and the time a MAC frame is sent out, is denoted as *t0* in Fig. 9, and is normally consistent for most IEEE 802.11 radios. As shown in Fig. 9, the TX_PIN signal is pulled high when the frame is ready to be sent out.

[00100] A ranging method to determine a distance between the vehicle and the access point according to various embodiment may be implemented in several ways as below.

[00101] In various embodiments, the round trip time (RTT) may be calculated between the transmission of the RTS frame and the reception of the CTS frame on the same radio device, according to the 4-way handshake process shown in Fig. 7(a) and Fig. 9. The 4-way

handshake may be initiated by the MS or the AP. The RTT may be measured by measuring the TX_PIN signal generated prior to the RTS frame and TX_PIN signal generated prior to the DATA frame on the same radio, given by the time measured between points C and D (T_{C-D}) as shown in Fig. 9. The RTT between MS and AP may be determined as follows:

$$RTT = T_{C-D} - T_{RTS} - T_{CTS} - SIFS - SIFS$$

wherein T_{RTS} = RTS frame transmission time

T_{CTS} = CTS frame transmission time

[00102] In various embodiments, the RTT may be calculated between the transmission of the CTS frame and the reception of the DATA frame on the same radio device, according to the 4-way handshake process shown in Fig. 7(a) and Fig. 9. The 4-way handshake may be initiated by the MS or the AP. The RTT can be measured by measuring the TX_PIN signal generated prior to the CTS frame and TX_PIN signal generated prior to the ACK frame on the same radio, which is given by the time measured between points A and B (T_{A-B}) as shown in Fig. 9. The RTT between MS and AP may be determined as follows:

$$RTT = T_{A-B} - T_{CTS} - T_{DATA} - SIFS - SIFS$$

wherein T_{CTS} = CTS frame transmission time

T_{DATA} = DATA frame transmission time

[00103] In various embodiments, the RTT may be calculated from the TX_PIN signal generation to the reception of a MAC frame, according to the 4-way handshake process shown in Fig. 7(a) and Fig. 9. The reception of the MAC frame may be based on a signal processing device that accurately measures the Time Of Arrival of the frame. According to Fig. 9, the RTT may be measured as follows:

$$RTT = T_{C-N} - t0 - T_{RTS} - SIFS; \text{ or}$$

$$RTT = T_{A-M} - t0 - T_{CTS} - SIFS; \text{ or}$$

$$RTT = T_{D-O} - t0 - T_{DATA} - SIFS$$

[00104] In various embodiments, the RTT may be determined according to a 2-way handshake process. Fig. 10 shows a 2-way handshake between two devices, for example, the access point and the vehicle, according to various embodiments. The 2-way handshake of Fig. 10 is similar to the 4-way handshake of Fig. 9, but without the communication of RTS and CTS frames.

[00105] In various embodiments, the RTT may be calculated from TX_PIN signal generation to the reception of a MAC frame, according to the 2−way handshake process shown in Fig. 7(b) and Fig. 10. The reception of the MAC frame may be based on a signal processing device that accurately measures the Time Of Arrival of the frame. For example, according to Fig. 10, the RTT may be measured as follows:

$$RTT = T_{U\text{-}S} - t0 - T_{DATA} - SIFS$$

[00106] In various embodiments above to determine the RTT, the measured RTT is not exactly accurate. Due to the non-synchronized effect of the receiver and transmitter MAC clocks, the reception of the signal at a receiver may be delayed. Other irregularities in the radio front end or digital processing may also cause the signal to be received with more than SIFS plus flight time period. Another source of error is multi-path signals that may cause distortion in the received signal, which may also cause the time of arrival of the signal to be delayed. The method for ranging and positioning the vehicle takes into account these errors. Because the measured RTT will always be equal or greater than the true RTT, the actual distance given by a true RTT can only be the same or lesser than the estimated distance given by the measured RTT/2. Accordingly, the method according to various embodiments above can use the measured RTT to completely avoid the false positive and true negative problem. There may be situations wherein the measured RTT value indicates that the vehicle is outside the charging zone of the road segment, whereas the vehicle is actually inside the

charging zone. In such a case, no charging will occur (i.e., False negative). This satisfies the requirement of Table 1.

[00107] Fig. 11 shows a diagram illustrating detection of a vehicle in a charging zone of a road segment according to various embodiments.

[00108] As shown in Fig. 11, in a road segment 1102 of 90 meters which at the same time defines a charging zone of 90 meters, an access point 1104 is located along the road, for example, in the center of the road segment 1102. The access point 1104 may have an omni-directional antenna which provides a circular coverage. A predetermined range of distances may be determined based on the distances between the road segment 1102 and the access point 1104. In this embodiment, as the access point 1104 is located at the centre of the road segment 1102, the predetermined range of distances may be determined to be 0-45m as shown in the circular zone 1106, which substantially covers the charging zone 1102. The radius of 45 meters from the access point 1104 may be thus used to range the vehicle. The MAC clock synchronization problems and the multi-path signals, etc. which may cause the RTT to be measured erroneously and may give a larger value than the actual distance may be ignored. When the vehicle passes the charging zone 1102, the 4-way or 2-way handshake may be initiated between the vehicle and the AP 1104. In various embodiments, the MAC handshake may be initiated periodically from the vehicle or the AP.

[00109] According to the method of various embodiments above, the RTT value, e.g., returned by the 802.11 radio card at the vehicle or the AP, may be measured. In the embodiment of Fig. 11 when the charging zone 1102 is given by 90 meters, any measured RTT that indicates a distance less than 90 meters will be used to indicate that the vehicle is within the charging zone and to trigger the charging. For example, a distance of a vehicle 1108 from the AP 1104 may be estimated based on the measured RTT, for example, a distance according to RTT/2 as RTT represents a round trip time interval. If the determined

distance of the vehicle 1108 is within the predetermined range of 0-45 meters, the vehicle 1108 will be determined to be within the road segment 1102 and will be charged. In an embodiment, the measured RTT for a vehicle 1110 may indicate a distance greater than 45 meters from the AP 1104, due to reflection of communication signals by a reflector, but the vehicle 1110 is actually within the 45 radius of the circular zone 1106 and within the road segment 1102. In such a case, the vehicle 1110 will be determined to be outside the road segment 1102 due to the estimated distance greater than 45 meters, and the vehicle 1110 will not be charged. This is an example of a false negative case.

[00110] In various embodiments, to determine the direction of vehicle travel and avoid charging in the opposite lanes, a combination of GPS and/or map matching and/or radio beacons and/or dead reckoning may be used to resolve the direction of travel.

[00111] Various embodiments may also make use of a trilateration approach to determine if a vehicle has crossed into a segment of a road or has left the segment of the road. Fig. 12 shows an exemplary single lane road segment 1202 bounded by lines A-A' and B-B'. The location at lines B-B' and A-A' may respectively correspond to an entrance line and an exit line of the road segment 1202, or vice versa.

[00112] The method for localizing the vehicle in a road segment according to various embodiments makes use of the RTT or the Time Difference Of Arrival (TDOA) information derived from the same MAC protocol exchange between one or several access points along the road to an on-board-unit in a vehicle.

[00113] Fig. 13 shows a configuration of an access point according to various embodiments.

[00114] The access point may be used to perform the trilateration based on TDOA localization. The access point 1300 may include a micro-controller 1302 configured to interface and control a radio device, such as a DSRC 802.11p device. The radio device is

shown as a transmitter TX 1304 in Fig. 13. The access point 1300 may further include a plurality of receivers 1306 configured to process the time of arrival signals of the MAC frame. The time of arrival signal may be used to determine TDOA values.

[00115] In the embodiments of Fig. 13, three receivers RX1, RX2, RX3 included in the access point 1300. The positions of the receivers 1306 are spatially distributed to obtain the TDOA values. The receivers 1306 may be configured to collect the signals and pass them to a signal processing unit 1308 which computes the time of arrival of the signal. A vehicle 1310 has an on-board- unit (OBU), including a matching 802.11 radio, may be configured to perform the communication signal exchange with the access point 1300. In Fig. 13, the TX_PIN trigger from the TX device 1304 in the access point 1300 is connected to the signal processing device 1308 to time stamp the start of the TDOA calculation. In the embodiments of Fig. 13, an example of a 2-way handshake may be used to calculate the TDOA information. The DATA frame may be sent from the access point 1300 and the vehicle 1310 replies with the ACK frame. Alternatively, the 4-way handshake may also be used to compute the TDOA values.

[00116] In Fig. 13, the configuration to compute the TDOA values simultaneously using one set of 2-way or 4-way handshake is shown. This is important as it keeps the temporal integrity of the measured TDOA value. This is as oppose to other systems that may use several access points located at different locations to compute the TDOA values based on more than one MAC protocol exchange. Due to the TDMA (time division multiple access) nature of the 802.11 MAC protocol and mobility of the vehicle, it may be difficult to ensure the location of the tracked object accurately with measurement using several MAC protocol exchanges.

[00117] In various embodiments, the TDOA values may also be computed simultaneously using one MAC protocol exchange according to the method described in PCT publication

WO2015012767. The method to compute TDOA values simultaneously uses a set of transceivers to process the MAC protocol exchange between the transceivers and the mobile station (e.g. the vehicle). The MAC protocol exchange in this case may be based on the 2-way or 4-way exchange. The set of transceivers may include a master transceiver and several slave transceivers. All the transceivers (except the transceivers at the vehicle) are configured with the same MAC address, and when the transceiver of the vehicle initiates the MAC protocol exchange with the master transceiver, all other transceivers will also be activated because of the same MAC address being assigned with. The transmissions from the master transceiver is allowed to be sent over the air to complete the MAC protocol exchange with the vehicle, but the transmission by the slave transceivers are suppressed. Although the messages from the slave devices are suppressed, the MAC protocol exchange is still perceived to be complete from the viewpoint of the slave devices. During this single MAC protocol exchange, the TDOA values of the respective transceivers to the vehicle can be computed simultaneously because the MAC protocol exchange is essentially completed in all the transceivers.

[00118] Fig. 14 shows a 2-way handshake between the vehicle and the access point of Fig. 13 according to various embodiments.

[00119] In Fig. 14, an exemplary MAC protocol timing sequence is shown. The TX_PIN of AP 1402 is triggered at point A to start the measurement of the RTT or TDOA values. The measured values T1, T2 and T3 represent the time lengths from point A to the reception times of the ACK frame at the receivers RX1, RX2 and RX3. The values of T1, T2 and T3 may be used in a trilateration algorithm, and used to calculate the relative location and/or exact location of the vehicle with respect to the access point. The location of the TX device with respect to the receivers RX1, RX2 and RX3 of the AP determines the range calculation measured by these receivers. The TX device's location with respect to the receivers RX1,

RX2 and RX3 are fixed. The measured values T1, T2 and T3 may also be used for measuring distance values or the round trip time (RTT). The measured distance values may not directly give the distance of the AP to the vehicle as the TX device may not necessarily be collocated with the RX device. If they are not collocated, the distance value or RTT will be the total time between the TX-to-MS and MS-to-RX transaction, which is used to determine the TDOA value. In another embodiment, instead of using the TX_PIN trigger, the T1, T2, T3 may be measured from the start of the DATA frame transmission, which may also be used to obtain the RTT or TDOA values.

[00120] The TDOA values can be computed in several ways when 2 - way and 4 - way MAC handshakes are used.

[00121] In various embodiments of the 4-way handshake, the round trip time (RTT), which can be used as the basis of TDOA computation may be calculated between the transmission of the RTS frame and the reception of the CTS frame on the same radio device. The 4-way handshake may be initiated by the MS or the AP. TDOA values can be derived from the RTT that may be measured by measuring the TX_PIN signal generated prior to the RTS frame and the first signal of the received CTS frame on the same radio device, which may be given by the time measured between points C and N (T_{C-N}) as shown in Fig. 9. Similar to the embodiments of RTT determination described above, the RTT value between MS and AP may be determined as follows:

$$RTT = T_{C-N} - T_{RTS} - SIFS - t0$$

wherein T_{RTS} = RTS frame transmission time

[00122] In various embodiments of the 4-way handshake, the RTT which can be used as the basis to compute TDOA may also be calculated between the transmission of the CTS frame and the reception of the DATA frame on the same radio device. The 4-way handshake may be initiated by the MS or the AP. The RTT value can be measured by measuring the

TX_PIN signal generated prior to the CTS frame and the first signal of the received DATA frame on the same radio device, which may be given by the time measured between points A and M (T_{A-M}) as shown in Fig. 9. Similar to the embodiments of RTT determination described above, the RTT value between MS and AP may be determined as follows:

$$RTT = T_{A-M} - T_{CTS} - SIFS - t0$$

wherein T_{CTS} = CTS frame transmission time.

[00123] In various embodiments of the 2-way handshake or the 4-way handshake, the RTT value which can be used to derive the TDOA may be calculated between the transmission of the DATA frame and the reception of the ACK frame on the same radio device. The 4−way handshake may be initiated by the AP. The RTT value may be measured by measuring the TX_PIN signal generated prior to the DATA frame and the first signal of the received ACK frame on the same radio device. This is given by the time measured between points D and O (T_{D-O}) as shown in Fig. 9 for the 4-way handshake. For the 2-way handshake, the RTT value which can be used as the basis to measure TDOA may be measured between points U and S (T_{U-S}) as shown in Fig. 10. Similar to the embodiments of RTT determination described above, the RTT value between MS and AP may be determined as follows:

$$RTT = T_{D-O} - T_{DATA} - SIFS - t0; \text{ or}$$

$$RTT = T_{U-S} - T_{DATA} - SIFS - t0$$

wherein T_{DATA} = DATA frame transmission time.

[00124] The method to measure RTT as shown above may not be exactly accurate. Due to the non-synchronized effect of the receiver and transmitter MAC clocks, the reception of the signal at a receiver may be delayed. Other irregularities in the radio front end or digital processing may also cause the signal to be received with more than SIFS plus flight time period. The RTT time measured for example may be off by 1-2 MAC clock period due to

just the non-synchronized MAC clocks. Another source of error may be multi-path signals that may cause distortion in the received signal. This may also cause the time of arrival of the frame to be delayed. Accordingly, the TDOA values may be used for the trilateration process.

[00125] Fig. 15 illustrates a diagram for tracking the relative location of the vehicle within the charging zone using the trilateration method according to various embodiments, when the access point configuration in Fig. 13 is used. The lines A–A' and B–B' represent the exit line and entry line of the charging zone 1502 of the road segment 1502.

[00126] For illustration purposes, the transceiver TX of the access point may be collocated with the receiver RX1, and may be located outside the exit of the road segment 1502 at 1504. The receiver RX2 may be located within the road segment 1502 at 1506, and the receiver RX3 may be located outside the entrance of the road segment 1502 at 1508. In the embodiments shown in Fig. 15, the receivers RX1, RX2 and RX3 used for measure the TDOA values are placed along the road side, e.g., along the same side of the road. In other embodiments, the receivers RX1, RX2 and RX3 may also be placed in other locations of the road, e.g. at the center of the road, as long as these receivers are arranged along a direction parallel to a longitudinal axis of the road. The receivers RX2 and RX3 may have the same distance x from the line B–B'. The receivers RX2 and RX1 may have the same distance y from line A–A'.

[00127] The relative location of the vehicles crossing the entrance at line B–B' may be detected based on the TDOA values determined for RX2 and RX3. When a vehicle MS1 1510 is at the entrance B–B', the RTT values received at the receivers RX2 and RX3 are the same, and the TDOA value may be zero. This indicates that it takes the same amount of time for the DATA transmission from TX to MS1, and for the ACK transmission from MS1 to RX2 and from MS1 to RX3, respectively. Similarly, when another vehicle MS2 1512 is

located along any point on line B–B', the RTT values for RX2 and RX3 will be the same and will indicate that the vehicle MS2 is at the entrance of the road segment 1502.

[00128] Fig. 16 illustrates a diagram for tracking the relative location of the vehicle when the vehicle is outside the charging zone according to various embodiments.

[00129] In Fig. 16, the vehicle MS1 1510 may be outside the line B–B' of the road segment 1502 and has not entered the charging zone 1502. The RTT values determined for receivers RX2 and RX3 can be compared to derive this relative location. If the vehicle MS1 is outside the line B–B', the RTT value for RX2 will be larger than the RTT value for RX3, and the TDOA value may be determined based on this comparison. By comparing the RTT values for RX2 and RX3, i.e. by the TDOA value, it can be determined that the vehicle MS1 is outside the road segment 1502.

[00130] Fig. 17 illustrates a diagram for tracking the relative location of the vehicle when the vehicle is within the charging zone according to various embodiments.

[00131] When the MS1 1510 has crossed over line B–B' into the road segment 1502, the RTT values for RX2 will be smaller than the RTT values for RX3. This may be used to determine the TDOA to indicate that the vehicle 1510 is within the road segment 1502. If the RTT values determined for receivers RX1 and RX2 shows that the RTT value is greater for RX1 compared to RX2, and/or if the RTT values determined for receivers RX2 and RX3 shows that the RTT value is greater for RX3 compared to RX2, then the vehicle MS1 can be determined to be within the charging zone.

[00132] In the car park application, the receivers RX1, RX2 and RX3, may be used to positively identify a vehicle prior to entering the zone (before B–B') , within the zone, and after the zone (after A–A') to appropriately track and charge the vehicle.

[00133] In the exemplary embodiments shown in Figs. 15-17, three receivers are used and located at different locations with respect to the road segment to achieve detection of

vehicles at and through the boundaries A−A' and B−B'. The three receivers may also be used to detect a movement direction of the vehicles. The exact position, e.g. geographical position, of the vehicle may be determined using three or more receivers according to the existing trilateration method.

[00134] In various embodiments, only two receivers, for example, RX2 and RX3 in Figs. 15-17, may be used to detect whether the vehicle passes the line B-B' and whether the vehicle is in the road segment 1502.

[00135] In various embodiments, more than three receivers may also be used for redundancy and improvement in the location tracking of the vehicles.

[00136] Fig. 18 shows an exemplary embodiment wherein six receivers are used for vehicle detection in a road segment 1802. In the embodiment of Fig. 18, a receiver pair RX2 − RX6 both having a distance z away from line B−B' and a receiver pair RX3 −RX5 both having a distance x away from line B−B', may be used to track if the vehicle crossed over the line B−B'.

[00137] Various embodiments further provide a method to detect and track a movement of a vehicle passing through a road segment using a set of transceivers with different antenna coverage.

[00138] Fig. 19 shows a hardware configuration for vehicle detection according to various embodiments. The base station BS1 1902, for example an access point, includes a DSRC transceiver 1904 and a micro-controller. Further transceivers RX1 1912 and RX2 1922 are also provided, which may be DSRC transceivers (e.g. 802.11p devices). All transceivers may be assigned with the same MAC address. The assignment of the same MAC address helps the micro-controller to receive and process the time of arrival of the ACK frame for all the transceivers. The antenna for the base station 1902 may be a longer distance and wider coverage antenna, which may be omni-directional or directional. The transceivers RX1 and

RX2 may have a smaller antenna footprint, which may be omni-directional or directional. The operation to detect the vehicle in the road segment makes use of a 4-way or 2-way handshake protocol between the base station and the vehicle. The micro-controller in Fig. 19 is shown to be connected either by wired or wireless connection to indicate that time of arrival of the ACK frames are compared between various transceivers to help correlate the position of the vehicle.

[00139] Fig. 20 shows a system including a base station and a plurality of transceivers according to various embodiments. The setup of Fig. 20 may be used in a barrier-less electronic parking system.

[00140] The movement of a vehicle may be tracked and detected through a series of coverage zones to positively identify if a vehicle has moved through a segment of a road. Zones A, B and C are the coverage of the antenna for transceivers BS1 1902, RX1 1912, and RX2 1822, respectively. As shown in Fig. 20, zone A covers the entire road segment 1932, Zone B covers an entrance area of the road segment 1932, and Zone C covers an exit area of the road segment 1932. Zone B does not overlap with Zone C. In an example, when it is detected that a vehicle passes through the zones in the sequence of A - B - C - A or A - B - A - C - A, it can be determined that a vehicle has passed through this segment of the road.

[00141] When a vehicle enters zone A, it starts to communicate with the base station BS1. This communication signal exchange may be initiated via a beacon sent out by BS1. Once the vehicle is detected in zone A, the BS1 device may periodically poll the vehicle to track its movement with 2-way handshake, 4-way handshake or a beacon.

[00142] Fig. 21 shows a communication between a vehicle and a base station according to various embodiments. When the vehicle is in zone A only, a DATA–ACK communication according to 2-way handshake is carried out between the vehicle and the 1942 and the base

station 1902. The other transceivers RX1 and RX2 will not receive the ACK frame since the vehicle is not within Zone B and Zone C.

[00143] Fig. 22 shows a communication with a vehicle according to various embodiments.

[00144] As shown in Fig. 22, the ACK frame is received by the transceiver RX1 when the vehicle is in zone B. Both transceivers BS1 and RX1 receive the ACK frame, which may be determined that the vehicle is within both Zone A and Zone B. Because the MAC addresses are the same, the frames can be processed and compared by the respective micro-controllers of BS1 and RX1.

[00145] Fig. 23 shows a possible timing sequence of ACK reception for a vehicle passing through a road segment 1932 shown in Fig. 20. As the vehicle passes through, it can be determined that at T1, the vehicle is likely entering the zone A from the right. At T2 and T3, the vehicle enters zone B as the transceiver RX1 also receives the ACK frame from the vehicle. At T4, it may be determined that the vehicle is still in zone A but between zone B and C, as only the base station BS1 receives the ACK frame. At T5 and T6, it may be determined that the vehicle enters zone C as the transceiver RX2 also receives the ACK frame from the vehicle. At T7, it may be determined that the vehicle leaves zone C and remains in zone A, as the transceiver RX2 stops receiving the ACK frame and the base station BS1 still receives the ACK frame.

[00146] According to the embodiments described with regard to Figs. 20-23 above, the movement direction of a vehicle relative to a road segment, e.g. relative to the car park entrance/exit may be determined.

[00147] Fig. 24 shows a system including a base station and a plurality of transceivers for tracking a movement of a vehicle within a road segment according to various embodiments. The hardware setup of Fig. 20 may be used in the embodiments of Fig. 24.

[00148] In the embodiments of Fig. 24, an exemplary setup of the coverage zones using omni-directional and directional antennas are illustrated. Other antenna variations to achieve the zones may also be used in other embodiments. Zones A, B and C are the coverage zones of the antennas for transceivers BS1 1902, RX1 1912, and RX2 1822, respectively. As shown in Fig. 24, zone A covers the entire road segment 1932, Zone B covers an entrance area of the road segment 1932, and Zone C covers an exit area of the road segment 1932. Zone B overlaps with Zone C at a central portion of the road segment 1932, which may be determined to be a charging zone of the road segment 1932. The embodiments of Fig. 24 may be used to implement the road tolling application.

[00149] When transceivers BS1, RX1 and RX2 receives the ACK frame simultaneously, it may be determined that the vehicle is in zone D, which may be designed to fall within the road segment F 1932 and defines a critical charging zone for road tolling. Zone D may be an overlap region of Zone B and Zone C, as well as Zone A. In this manner, the vehicle can be positively identified within road segment F 1932.

[00150] Fig. 25 shows a possible timing sequence of ACK reception for a vehicle passing through a road segment 1932 shown in Fig. 24.

[00151] As the vehicle passes through at T1, it may be determined that the vehicle is likely entering the zone A from the right. At T2, it may be determined that the vehicle enters zone B which still overlaps with zone A, as both BS1 and RX1 receive the ACK frame at T2. At T3 and T4, it may be determined that the vehicle is likely in zone D as BS1, RX2 and RX1 receives the ACK frame from MS1. Charging for the road tolling application may start at time T3.

[00152] Various embodiments above provide various methods and devices for detecting the vehicle within the road segment, which includes determination of the distance of the vehicle to the access point, determination of location and/or movement of vehicle using a

plurality of transceivers according to trilateration, and determination of location and/or movement of vehicle using different antenna coverage zones using narrow beam antennas. Various embodiments may be applied separately or combined to improve the performance of the vehicle detection.

[00153] The method for vehicle detection based on an estimation of the distance between the vehicle and the access point may allow the access point, e.g., the base station radios, to communicate with the vehicle beyond the charging zone of the road segment for other purposes, e.g. for broadcast of tariff data, etc. Different antenna setup may be possible when implementing the charging zone.

[00154] Fig. 26 shows a coverage beyond the charging zone provided by an access point with an omni-directional antenna according to various embodiments.

[00155] The access point AP1 may be placed along the road and at the centre of the road segment, using an omni-directional antenna with a coverage zone 2602 as shown in Fig. 26. The coverage zone 2602 may cover the charging zone 2604 and is wider than the charging zone 2604. A valid range2606 for triggering a tolling charge falls within the semi-circle that substantially overlaps with the charging zone 2604. The valid range 2606 represents a range of distances from the AP1, which may be determined based on the distances of the charging zone 2604 from the AP1. When a distance between the vehicle and the AP1 is determined to be within this range 2606, the vehicle is determined to be within the charging zone 2604 of the road segment. In this antenna setup, the lane that is the farthest from the AP may have less coverage by the valid range 2606.

[00156] According to the embodiments of Fig. 26, when the vehicle is outside the charging zone 2604 but within AP's coverage zone 2602, the vehicle can communicate to the AP1. The AP1 may periodically broadcast its MAC address to the oncoming vehicle.

During this phase, the vehicle's OBU will identify the MAC address of AP1 and periodically communicate with the AP1. The range 2606 may be calculated in the OBU or at the AP1.

[00157] Fig. 27 shows a coverage provided by more than one access point with omni-directional antenna according to various embodiments.

[00158] As shown in Fig. 27, more than one AP is used to enhance the coverage and reliability of ranging the vehicle within the charging zone 2702 of the road segment. In the embodiments of Fig. 27, a first access point AP1 and a second access point AP2 are positioned at the road side in the center of the road segment, and on the opposite sides of the road.

[00159] AP1 is configured to provide a coverage zone bound by arc A 2704, and AP2 is configured to provide the coverage bounded by arc B 2706. Compared to Fig. 26, the embodiment of Fig. 27 will allow vehicles travelling in the lane farthest away from AP1 to have equally good coverage by another access point.

[00160] In various embodiments, AP2 may have a different MAC address from AP1. To realize the accurate positioning of the approaching vehicle, the vehicle may perform the MAC handshake with both the APs periodically. By comparing the range values determined either at the AP or the OBU of the vehicle, the trigger point for charging the vehicle within the charging zone may be determined. Alternatively, to save bandwidth and allow more vehicles to be tracked, the closer AP may be chosen for the vehicle after checking the ranging distance from the two APs. The vehicle will then constantly perform the MAC protocol exchange with one AP only.

[00161] Although Fig. 26 and Fig. 27 show access points with an omni-directional antenna, it is understood that the access points may also use directional antenna to provide a directional coverage zone in other embodiments.

[00162] Fig. 28 shows a coverage provided by an access point with a directional antenna according to various embodiments.

[00163] In the embodiments of Fig. 28, the access point AP1 with a directional antenna may be placed outside a charging zone 2802 and at the exit of the charging zone 2802. In this case, the directional antenna may be pointed towards the entrance of the charging zone, and provide a coverage zone 2804 covering and greater than the charging zone 2802 as shown in Fig. 28. Based on the setup in Fig. 28, only a certain vehicles will be allowed to trigger the charging. Arc 1 and Arc 2 are circular arcs with respect to AP1, which is determined by an overlapping between the charging zone 2802 and the coverage zone 2804. The distance of Arc 1 to AP1 and the distance of Arc 2 to AP1 may determine the range of the distances, such that the vehicle having a distance from the AP1 within this range will be determined to be within the charging zone 2802. In other words, vehicles that are found in the overlapping zone defined by the zone 2804 between Arc 1 and Arc 2, and overlapping with the charging zone 2802 will be allowed be charged. To improve the coverage, more access points, such as AP2 as shown in Fig. 28 with directional antenna facing the entrance may be placed at the opposite side of the road or other suitable locations.

[00164] Radio technologies, such as IEEE 802.11p, allow the use of multiple radio channels for communication. To track and charge multiple vehicles in the charging zone, the detection device, e.g. the access point, or the detection system including a plurality of access points, according to various embodiment described above may communicate with the vehicle via the control channel before the vehicle enters the zone. A vehicle can be assigned to communicate on a specific channel for charging and tracking purpose. In this manner, more vehicles can be tracked and charged accordingly. On the base station or access point, multiple radio cards may be used to handle communication in different channels simultaneously.

[00165] According to various embodiment above, a method of detecting a vehicle within a road segment includes estimating a distance between a moving vehicle and an interrogating device, e.g. an access point, based on a time delay in communication signal exchange between the moving vehicle and interrogating device. The estimated distance is then used for determining whether a vehicle is within a specific range of distance (including a certain degree of tolerance) from the interrogating device to represent a positive indication. This positive indication in turn can be used to send a further signal to the vehicle to notify of the positive indication at the interrogating device.

[00166] The method of various embodiments may estimate the distance between the vehicle and the access point based on TOA or RTT in the communication signal exchange, in particular, communication frames associated with the handshaking protocol of a 802.11 radio.

[00167] A vehicle detection system may be provided to perform the detection methods of various embodiments above. The vehicle detection system may be an access point including one or more transceivers along with one or more antenna as described in various embodiments above. The vehicle detection system may also include a plurality of access points so arranged to communicate with a transceiver installed in a moving vehicle within a predefined range of distances between the access points and the transceiver installed in the vehicle. Each access point may include one or more antennas and a communication module configured to receive and transmit communication signals with the transceiver in the moving vehicle. The transceiver installed in the vehicle is capable to exchange communication signals with one or more access points.

[00168] The vehicle detection system as described above may further include one or more image capturing devices that are configured to capture an image upon receiving a trigger

signal from the access point. The vehicle detection system as described in the above embodiments may be applied to or incorporated in an electronic tolling system.

[00169] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

What is claimed is:

1. A method of detecting a vehicle within a road segment, the method comprising:

determining a round trip time for a communication signal exchange between the vehicle and an access point based on a predetermined time delay in the communication signal exchange;

estimating a distance between the vehicle and the access point based on the determined round trip time;

determining whether the vehicle is within the road segment based on a comparison between the estimated distance and a predetermined range of distances, the predetermined range of distance being determined based on distances between the road segment and the access point.

2. The method according to claim 1, further comprising:

determining that the vehicle is within the road segment, if the estimated distance is within the predetermined range of distances; and

determining that the vehicle is out of the road segment, if the estimated distance is out of the predetermined range of distances.

3. The method according to claim 1 or 2, wherein the predetermined time delay comprises a short inter-frame space.

4. The method of any one of claims 1 to 3, wherein the predetermined time delay further comprises a time interval between the time at which the vehicle or the access point is enabled for transmission of the communication signal and the time at which the communication signal is transmitted.

5. The method according to any one of claims 1 to 4, wherein the communication signal exchange comprises transmission of a signal and reception of an acknowledgement signal at one of the vehicle or the access point,

6. The method according to any one of claims 1 to 5, wherein the communication signal exchange is part of a handshake process comprising one of a 2-way handshake process or a 4-way handshake process.

7. The method according to any one of claims 1 to 6, wherein the communication signal exchange is performed according to at least one of 802.11 protocol or CSMA-CA protocol.

8. The method according to any one of claims 1 to 7, wherein the access point is located within or outside the road segment, and comprises an antenna with a coverage at least substantially covering the road segment.

9. The method according to claim 8, wherein the antenna is one of an omni-directional antenna or a directional antenna.

10. The method according to any one of claims 1 to 9, further comprising:

determining a respective round trip time for a communication signal exchange between the vehicle and a respective receiver of a plurality of receivers of the access point;

comparing the respective round trip time with each other; and

determining whether the vehicle is within the road segment based on the comparison of the respective round trip time;

wherein the access point comprises at least a first receiver located within the road segment and at least a second receiver located outside the road segment, wherein the first receiver and the second receiver have the same distance from one of an entrance line or an exit line of the road segment.

11. The method according to claim 10, wherein determining whether the vehicle is within the road segment comprising determining a Time Difference of Arrival based on the comparison of the respective round trip time.

12. The method according to claim 10 or 11, further comprising

determining that the vehicle is within the road segment if the round trip time determined for the first receiver is shorter than the round trip time determined for the second receiver.

13. The method according to any one of claims 10 to 12, further comprising

assigning the same media access control address to the plurality of receivers and addressing the communication signal to the same media access control address.

14. The method according to any one of claims 10 to 13, wherein the access point comprises at least a third receiver located outside the road segment, wherein the first receiver and the third receiver have the same distance from the other one of the entrance line or the exit line of the road segment.

15. The method according to claim 14, further comprising

determining a movement direction of the vehicle based on the comparison of the respective round trip time.

16. The method according to any one of claims 1 to 15, further comprising:

determining whether a communication signal from the vehicle is received at a plurality of transceivers of the access point;

determining whether the vehicle is within the road segment based on the determined reception of the communication signal at the respective transceiver;

wherein the plurality of transceivers are located at different locations of the road segment to provide different coverage zones, each coverage zone covering at least a portion of the road segment.

17. The method according to claim 16, further comprising:

determining a movement direction of the vehicle in the road segment based on a time sequence of receiving the communication signal at the plurality of transceivers.

18. The method according to claim 16 or 17, further comprising

assigning the same media access control address to the plurality of transceivers and addressing the communication signal to the same media access control address.

19. The method according to any one of claims 16 to 18, wherein the plurality of transceivers comprises a first transceiver configured to provide a coverage zone covering the entire road segment, a second transceiver configured to provide a coverage zone at an entrance of the road segment, and a third transceiver configured to provide a coverage zone at an exit of the road segment without overlapping with the coverage zone of the second transceiver.

20. The method according to claim 19, further comprising:

determining that the vehicle moves from the entrance to the exit of the road segment if the communication signal from the vehicle is sequentially received at the second transceiver, the first transceiver and the third transceiver; and vice versa.

21. The method according to any one of claims 16 to 18, wherein the plurality of transceivers comprises a first transceiver configured to provide a coverage zone covering the entire road segment, a second transceiver configured to provide a coverage zone at an entrance of the road segment, and a third transceiver configured to provide a coverage zone at an exit of the road segment,

wherein the coverage zones of the first transceiver, the second transceiver and the third transceiver overlap at a predetermined charging zone of the road segment.

22. The method according to claim 21, further comprising:

determining that the vehicle is within the predetermined charging zone of the road segment if the communication signal is simultaneously received at the first transceiver, the second transceiver and the third transceiver.

23. A detection device for detecting a vehicle within a road segment, comprising:

a determiner configured to determine a round trip time for a communication signal exchange between the vehicle and an access point based on a predetermined time delay in the communication signal exchange; and

a processor configured to

estimate a distance between the vehicle and the access point based on the determined round trip time;

determine whether the vehicle is within the road segment based on a comparison between the estimated distance and a predetermined range of distances, the predetermined ranges of distance being determined based on distances between the road segment and the access point.

24. A non-transitory computer readable medium storing a program which when executed by a processor causes the processor to:

determine a round trip time for a communication signal exchange between a vehicle and an access point based on a predetermined time delay in the communication signal exchange;

estimate a distance between the vehicle and the access point based on the determined round trip time; and

determine whether the vehicle is within a road segment based on a comparison between the estimated distance and a predetermined range of distances, the predetermined range of distance being determined based on distances between the road segment and the access point.

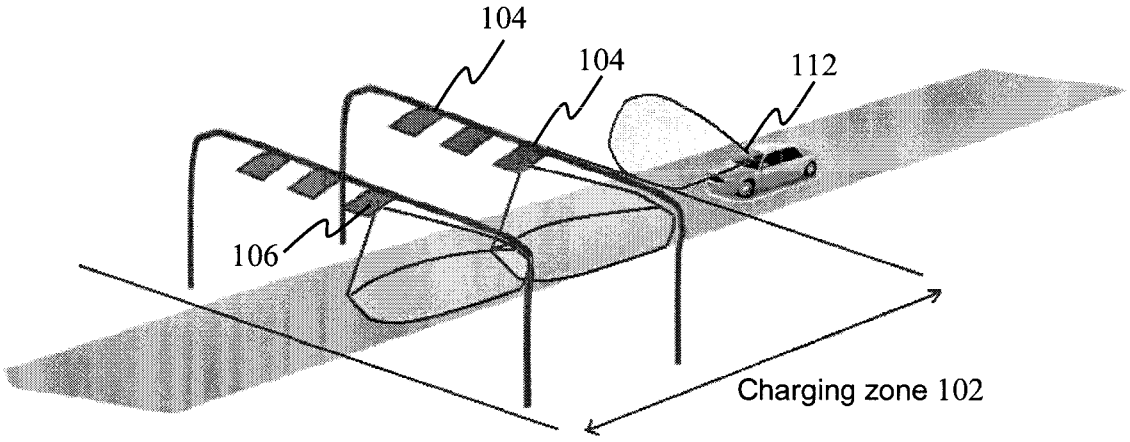

104
104
112
106
Charging zone 102

Fig. 1

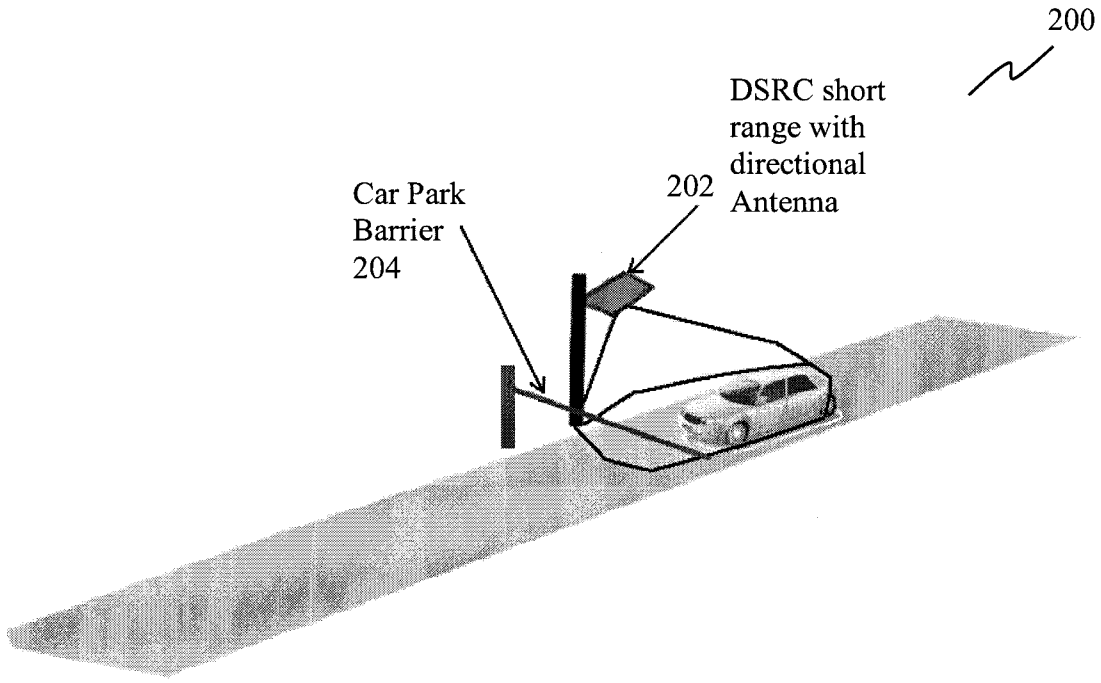

200
DSRC short range with directional Antenna
202
Car Park Barrier 204

Fig. 2

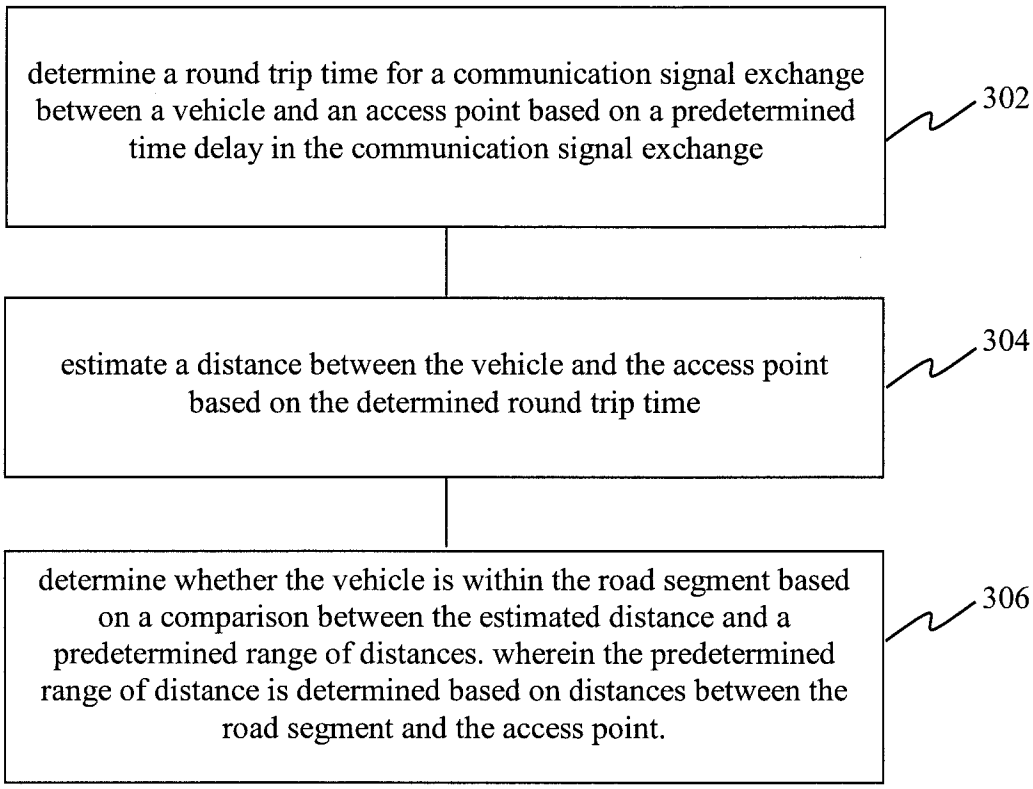

determine a round trip time for a communication signal exchange between a vehicle and an access point based on a predetermined time delay in the communication signal exchange
302
estimate a distance between the vehicle and the access point based on the determined round trip time
304
determine whether the vehicle is within the road segment based on a comparison between the estimated distance and a predetermined range of distances. wherein the predetermined range of distance is determined based on distances between the road segment and the access point.
306

Fig. 3

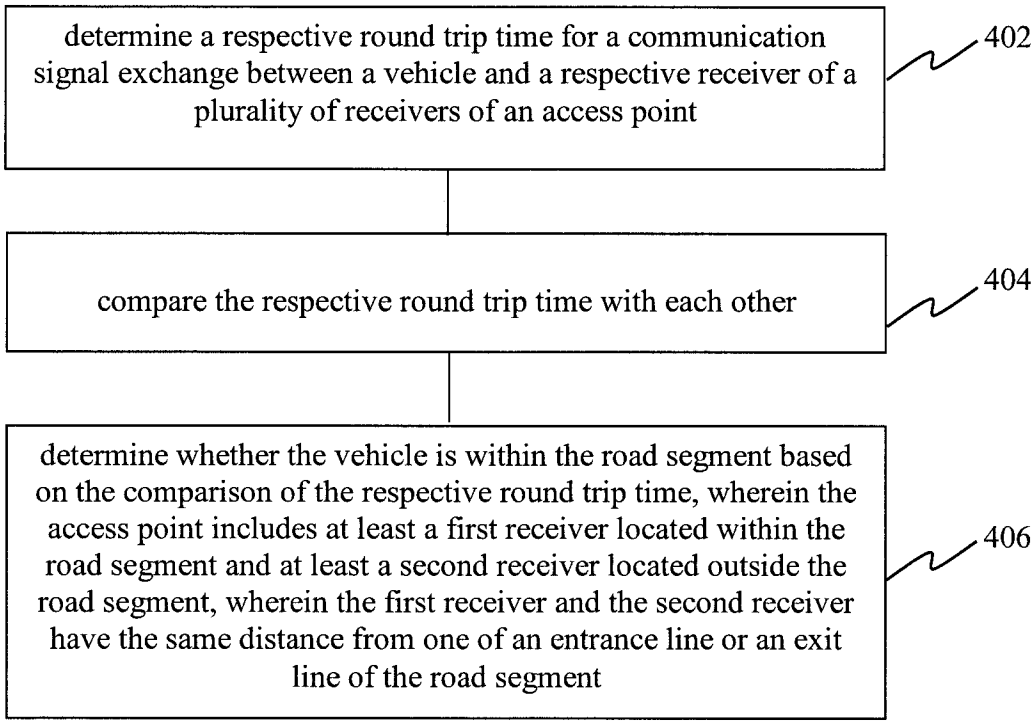

determine a respective round trip time for a communication signal exchange between a vehicle and a respective receiver of a plurality of receivers of an access point
402
compare the respective round trip time with each other
404
determine whether the vehicle is within the road segment based on the comparison of the respective round trip time, wherein the access point includes at least a first receiver located within the road segment and at least a second receiver located outside the road segment, wherein the first receiver and the second receiver have the same distance from one of an entrance line or an exit line of the road segment
406

Fig. 4

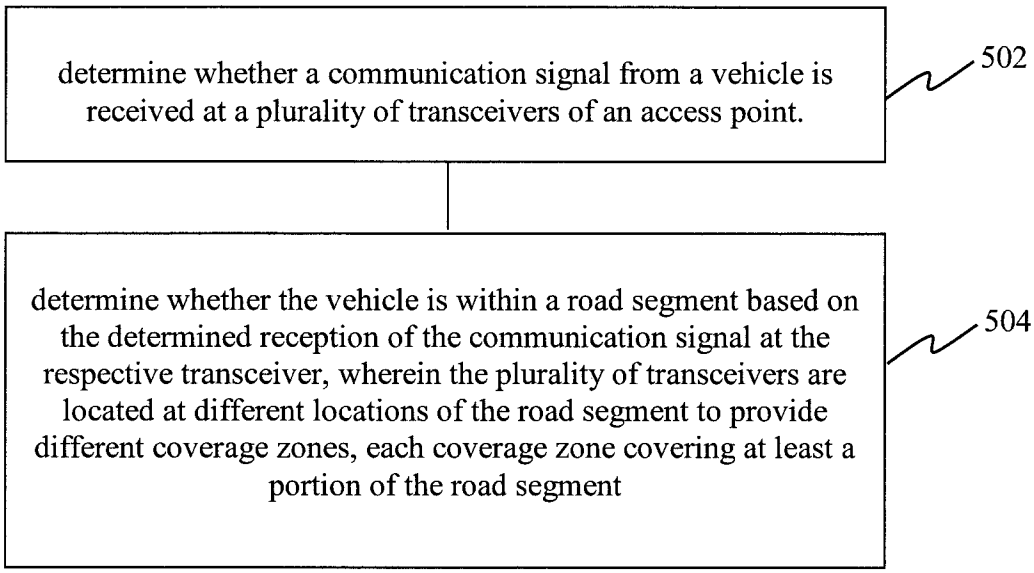

determine whether a communication signal from a vehicle is received at a plurality of transceivers of an access point.
502
determine whether the vehicle is within a road segment based on the determined reception of the communication signal at the respective transceiver, wherein the plurality of transceivers are located at different locations of the road segment to provide different coverage zones, each coverage zone covering at least a portion of the road segment
504

Fig. 5

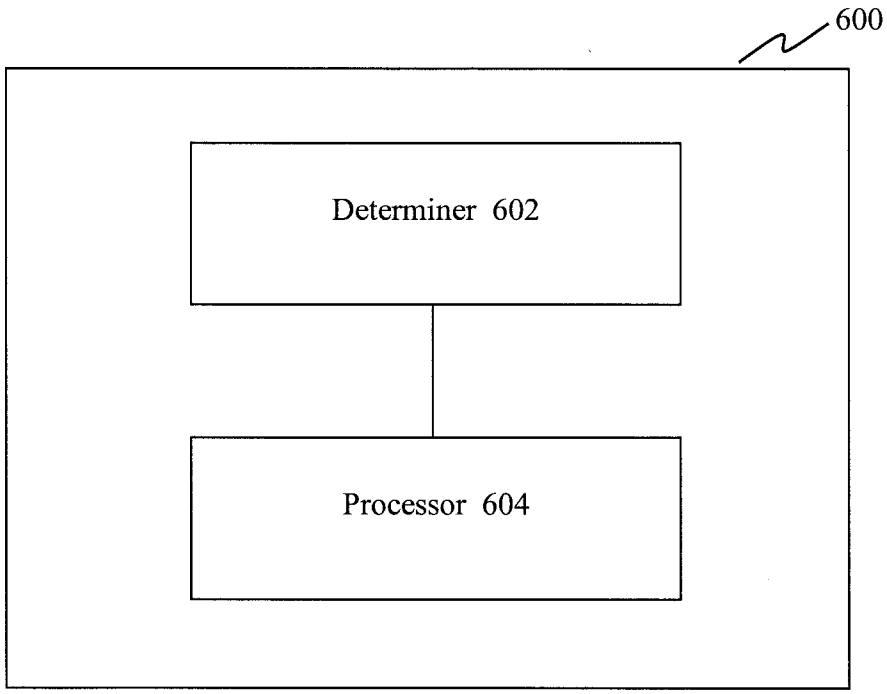

600
Determiner 602
Processor 604

Fig. 6

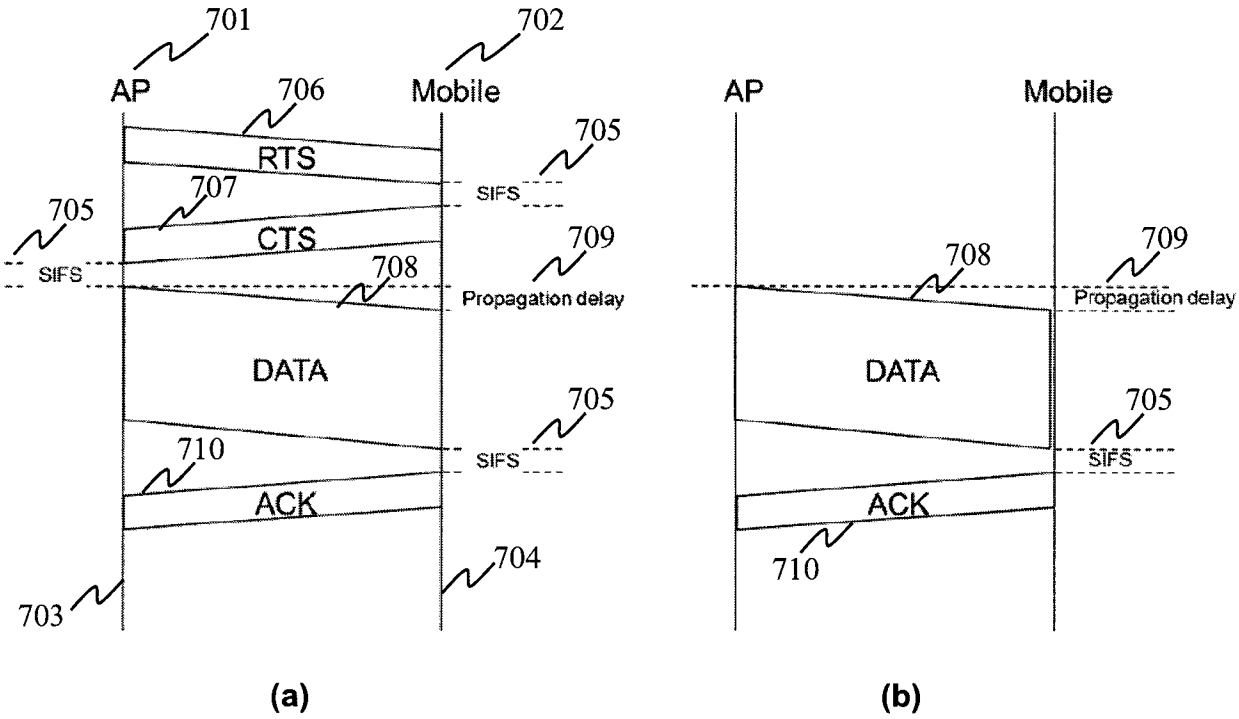

701
AP
706
Mobile
702
RTS
705
SIFS
707
CTS
705
SIFS
708
709
Propagation delay
DATA
705
SIFS
710
ACK
703
704
(a)
AP
Mobile
708
709
Propagation delay
DATA
705
SIFS
ACK
710
(b)

Fig. 7

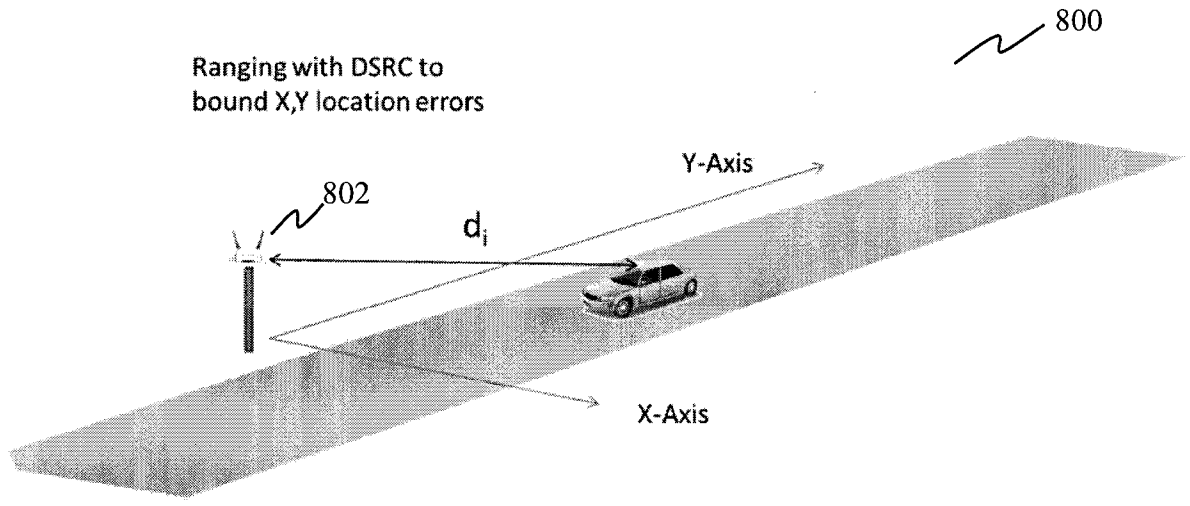

800
Ranging with DSRC to
bound X,Y location errors
Y-Axis
802
d_i
X-Axis

Fig. 8

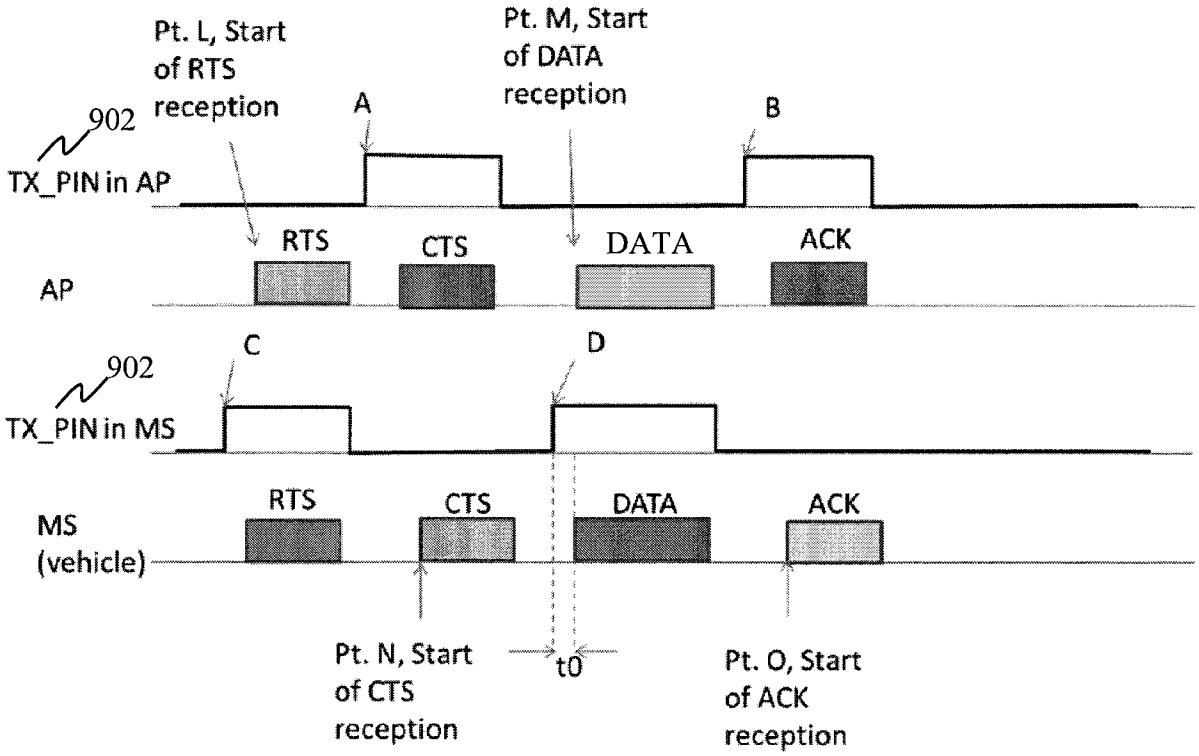

Pt. L, Start of RTS reception
Pt. M, Start of DATA reception
902
A
B
TX_PIN in AP
RTS
CTS
DATA
ACK
AP
C
D
902
TX_PIN in MS
RTS
CTS
DATA
ACK
MS (vehicle)
Pt. N, Start of CTS reception
t0
Pt. O, Start of ACK reception

Fig. 9

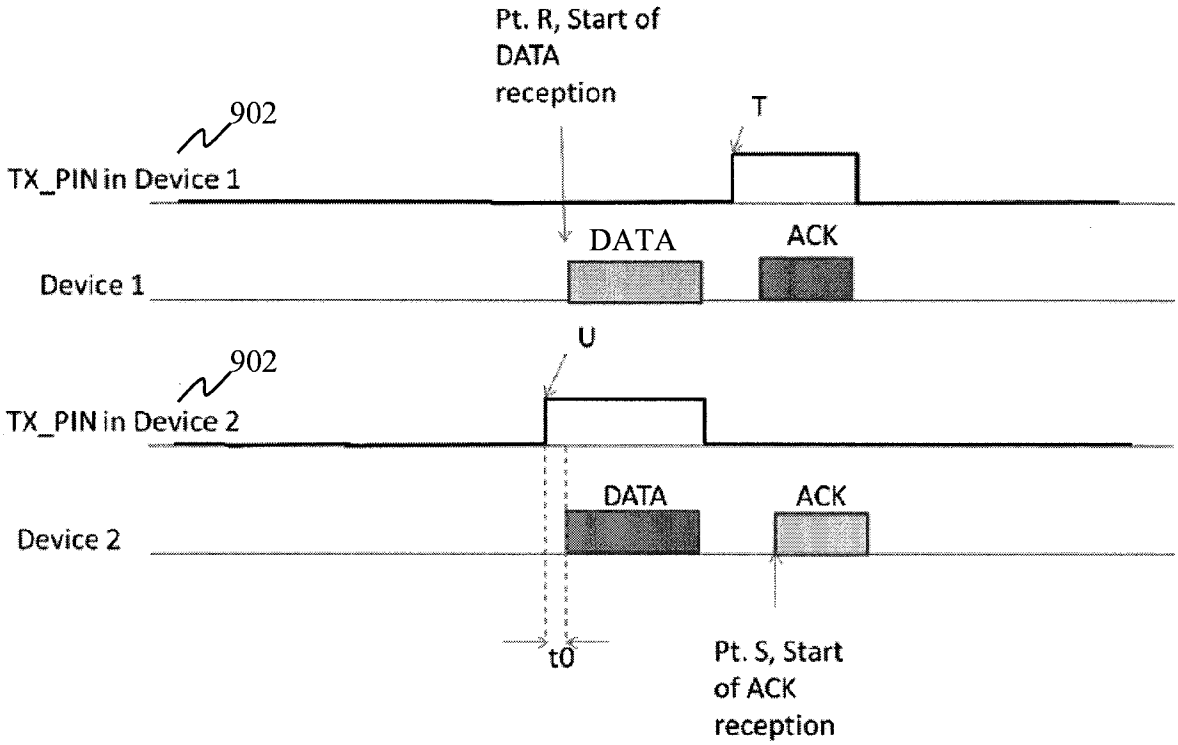

Pt. R, Start of DATA reception
902
T
TX_PIN in Device 1
DATA
ACK
Device 1
U
902
TX_PIN in Device 2
DATA
ACK
Device 2
t0
Pt. S, Start of ACK reception

Fig. 10

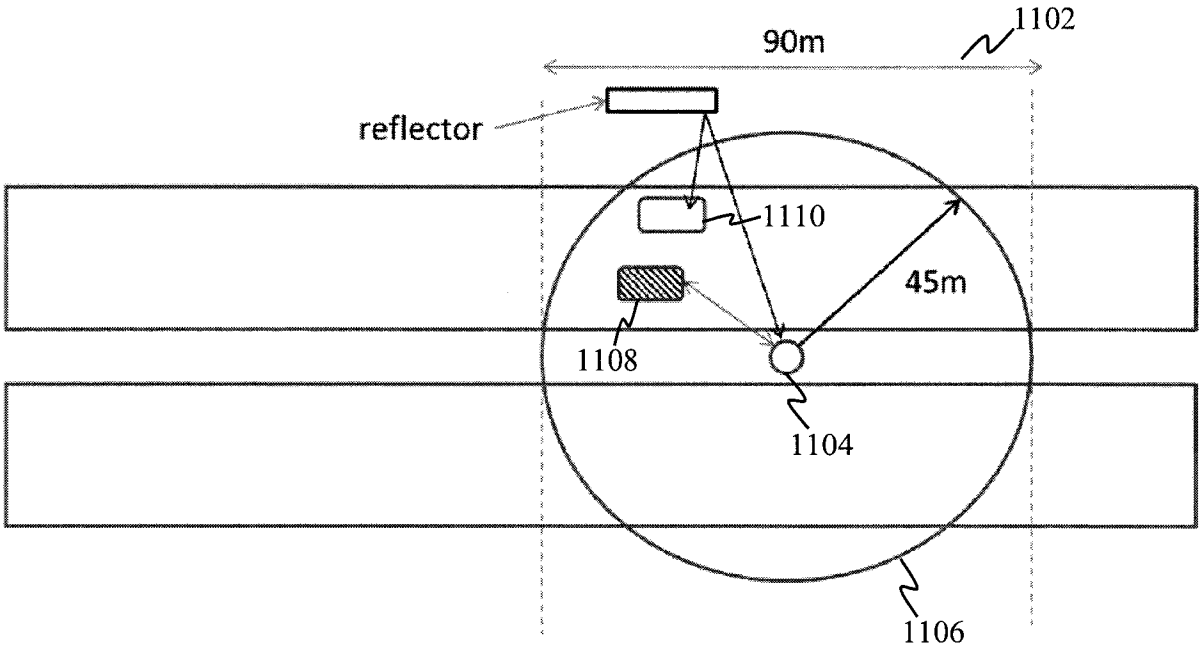

90m
1102
reflector
1110
45m
1108
1104
1106

Fig. 11

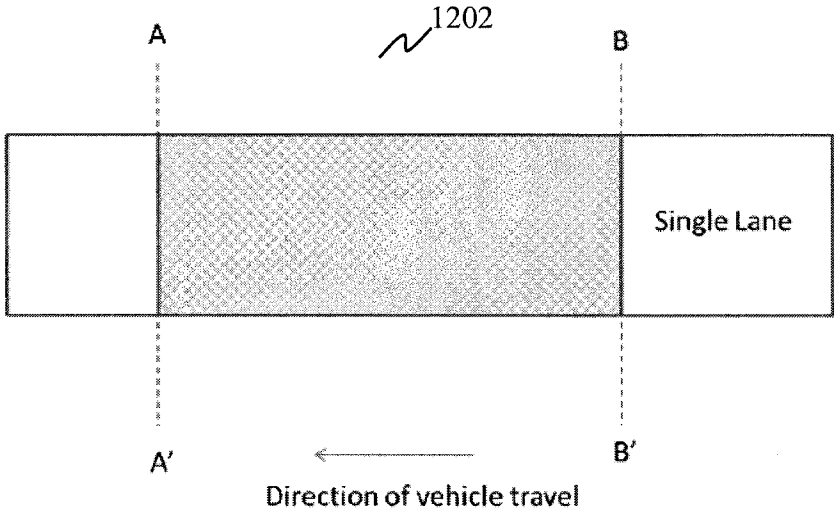

A
1202
B
Single Lane
A'
B'
Direction of vehicle travel

Fig. 12

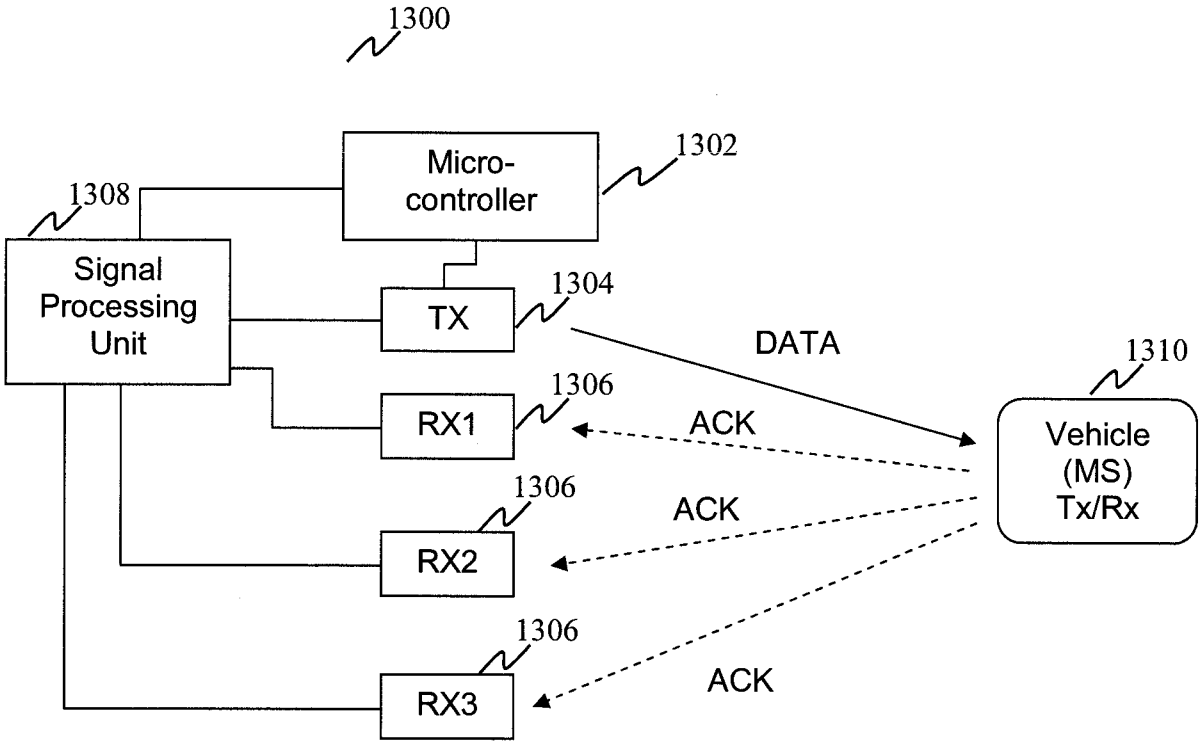

1300
Micro-controller
1302
1308
Signal Processing Unit
TX
1304
DATA
1310
1306
RX1
ACK
Vehicle (MS) Tx/Rx
1306
RX2
ACK
1306
RX3
ACK

Fig. 13

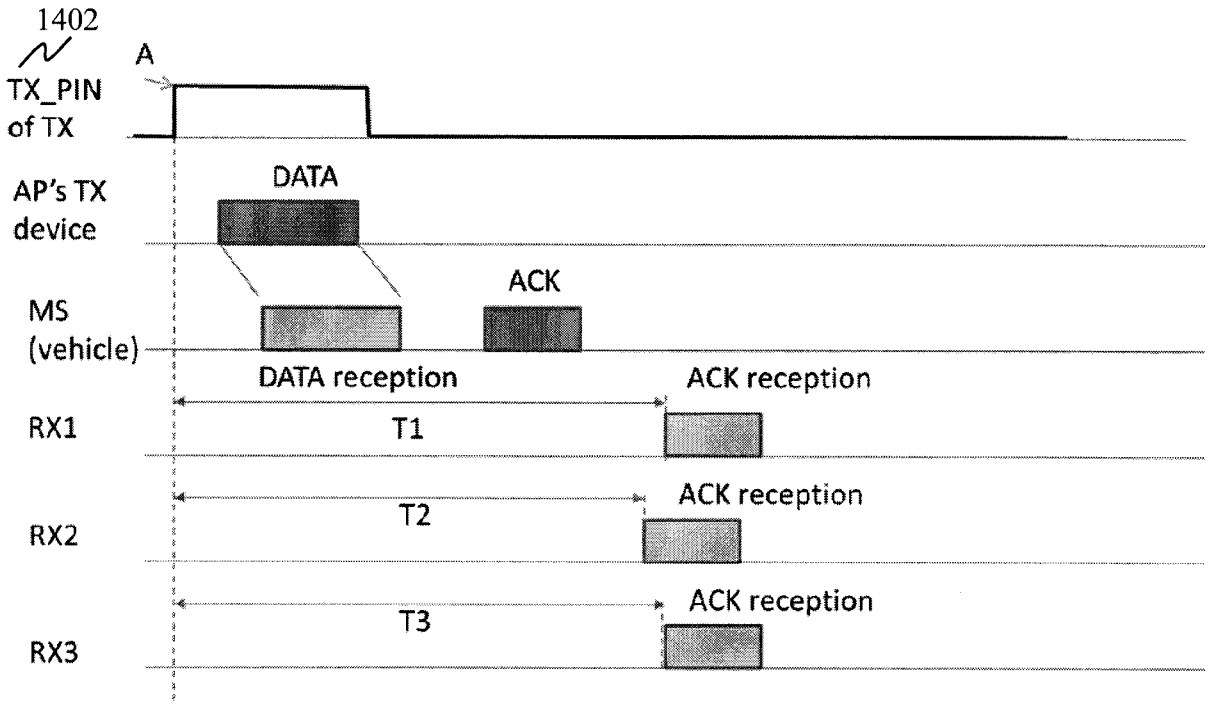

1402
A
TX_PIN of TX
AP's TX device
DATA
ACK
MS (vehicle)
DATA reception
ACK reception
RX1
T1
ACK reception
RX2
T2
ACK reception
RX3
T3

Fig. 14

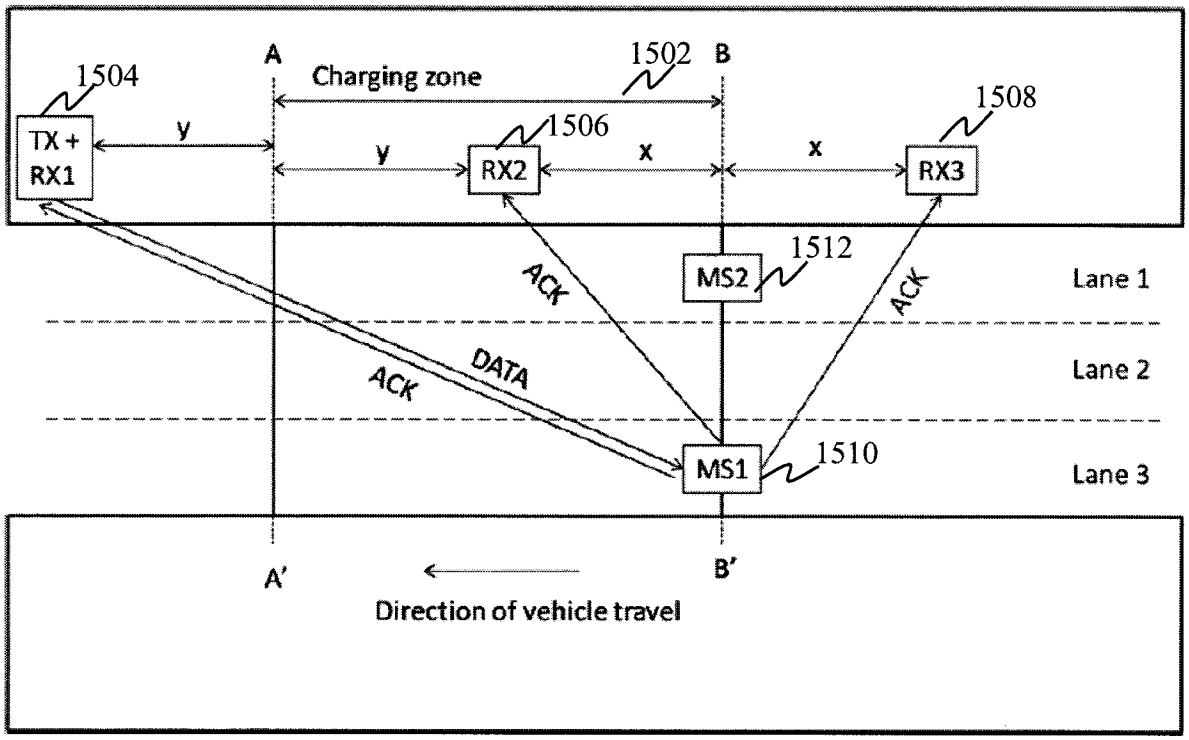

A
Charging zone
1502
B
1504
1508
TX +
RX1
y
y
1506
RX2
x
x
RX3
1512
MS2
ACK
ACK
Lane 1
DATA
Lane 2
ACK
MS1
1510
Lane 3
A'
B'
Direction of vehicle travel

Fig. 15

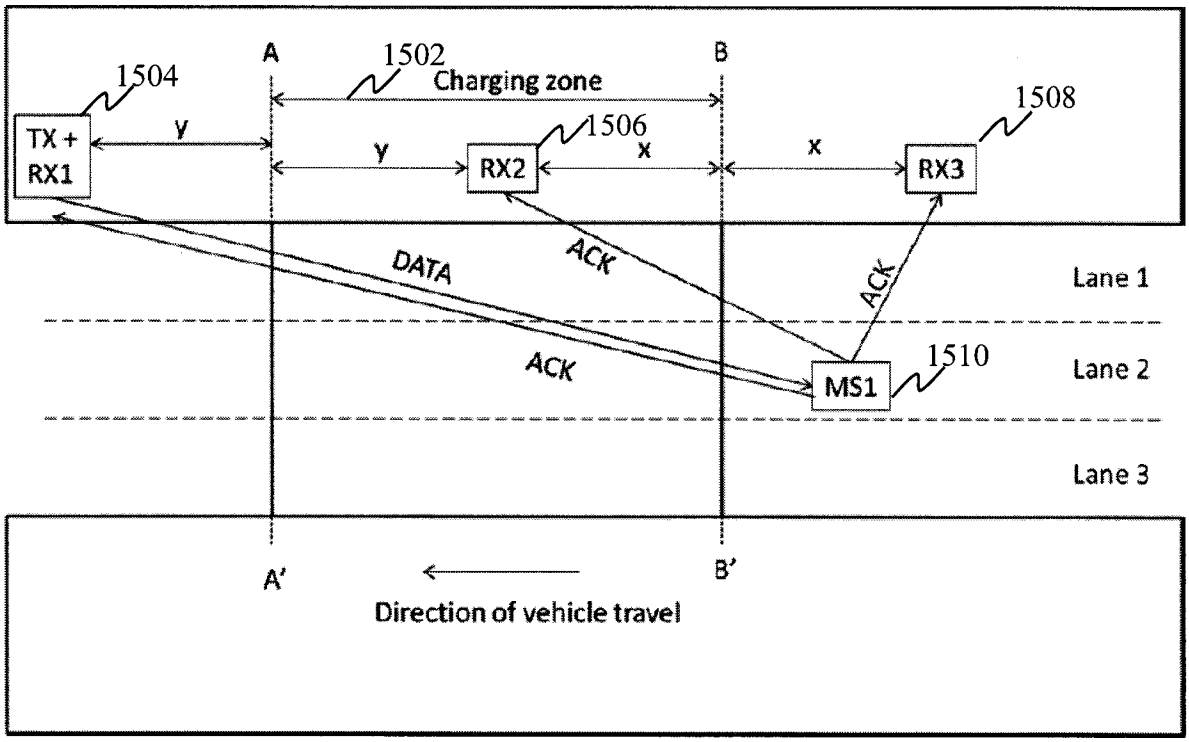

A
1502
Charging zone
B
1504
1508
TX +
RX1
y
y
1506
RX2
x
x
RX3
ACK
DATA
ACK
Lane 1
Lane 2
MS1
1510
Lane 3
A'
B'
Direction of vehicle travel

Fig. 16

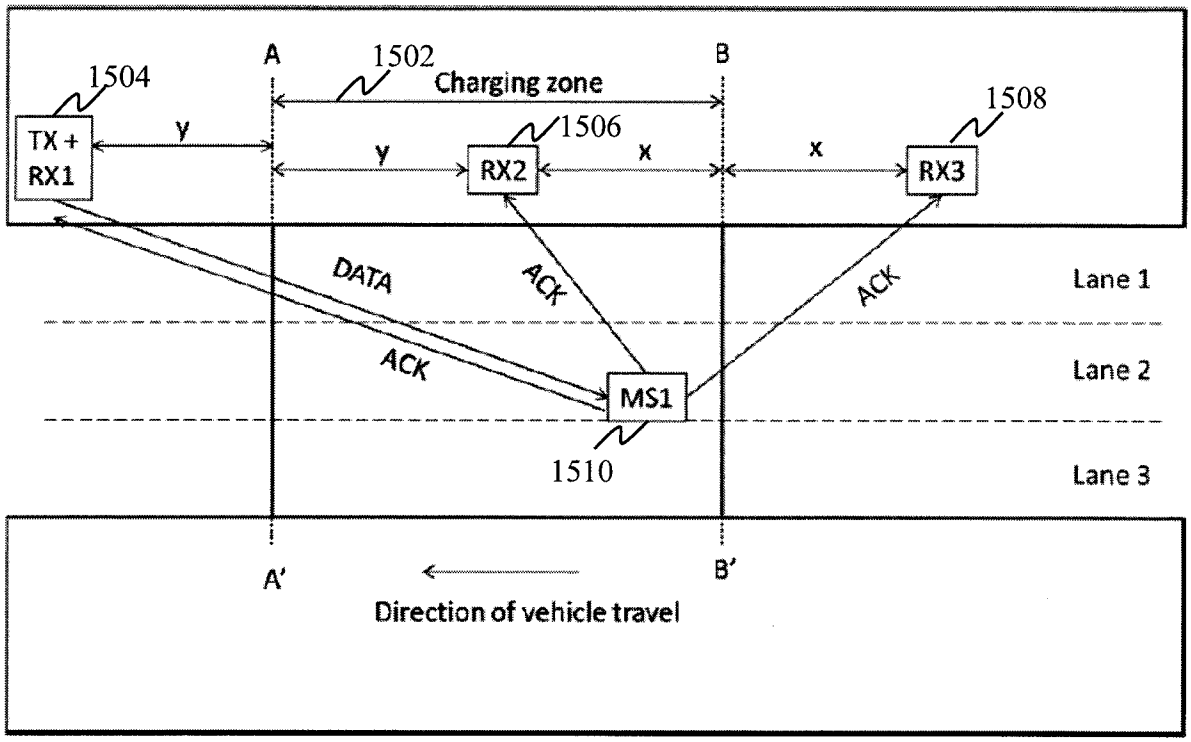

A
1502
Charging zone
B
1504
1508
TX +
RX1
y
y
1506
RX2
x
x
RX3
DATA
ACK
ACK
Lane 1
Lane 2
MS1
1510
Lane 3
A'
B'
Direction of vehicle travel

Fig. 17

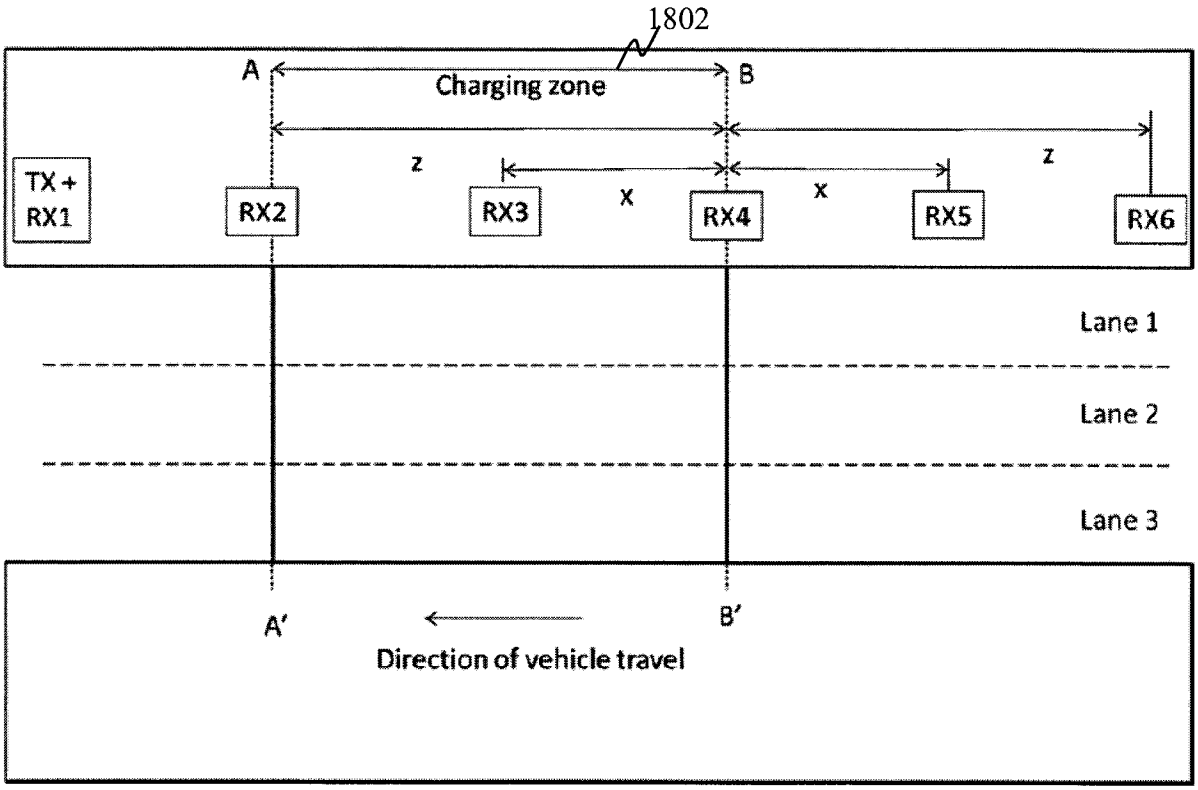

1802
A
Charging zone
B
z
z
TX +
RX1
RX2
RX3
x
RX4
x
RX5
RX6
Lane 1
Lane 2
Lane 3
A'
B'
Direction of vehicle travel

Fig. 18

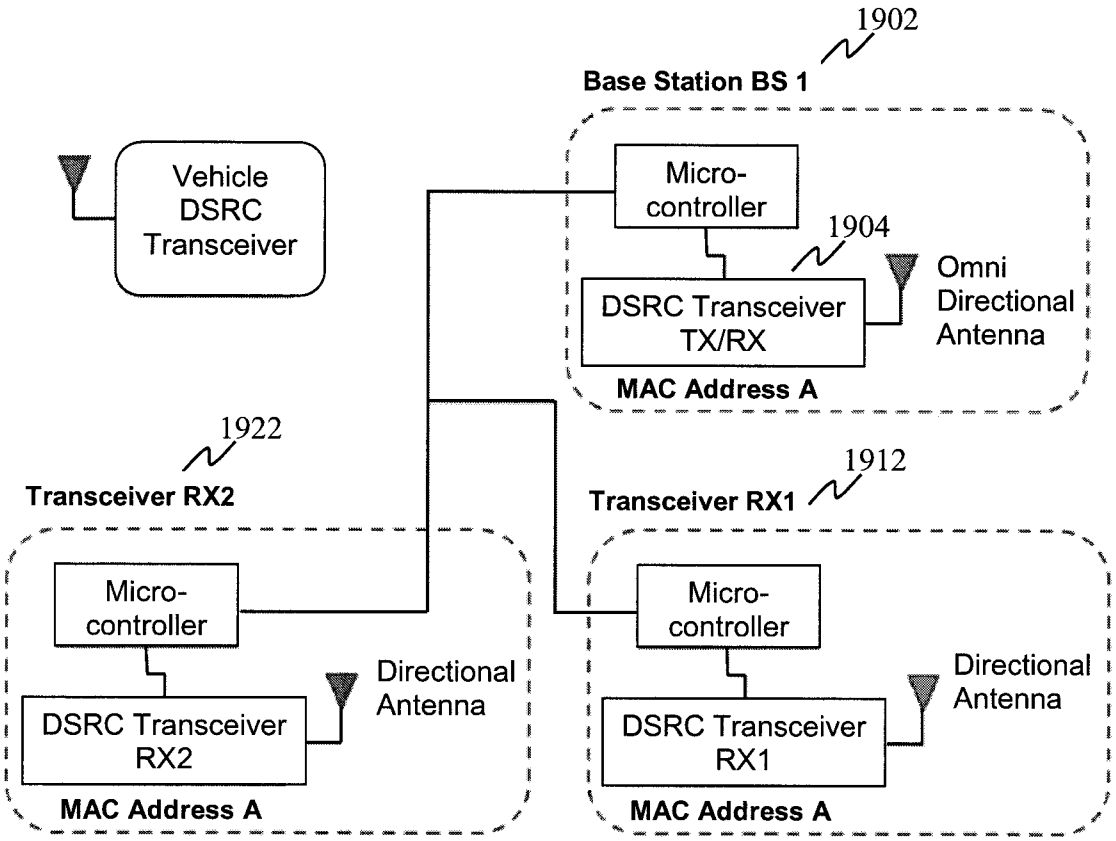

1902
Base Station BS 1
Vehicle DSRC Transceiver
Micro-controller
1904
DSRC Transceiver TX/RX
Omni Directional Antenna
MAC Address A
1922
Transceiver RX2
1912
Transceiver RX1
Micro-controller
DSRC Transceiver RX2
Directional Antenna
MAC Address A
Micro-controller
DSRC Transceiver RX1
Directional Antenna
MAC Address A

Fig. 19

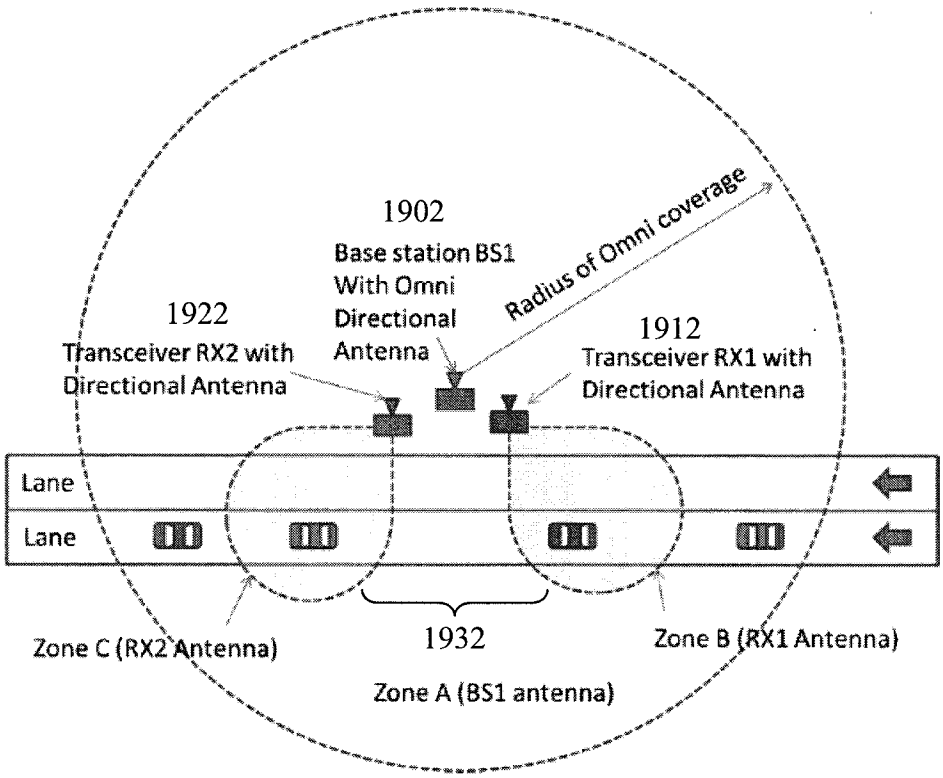

1902
Base station BS1
With Omni
Directional
Antenna
Radius of Omni coverage
1922
Transceiver RX2 with
Directional Antenna
1912
Transceiver RX1 with
Directional Antenna
Lane
Lane
Zone C (RX2 Antenna)
1932
Zone B (RX1 Antenna)
Zone A (BS1 antenna)

Fig. 20

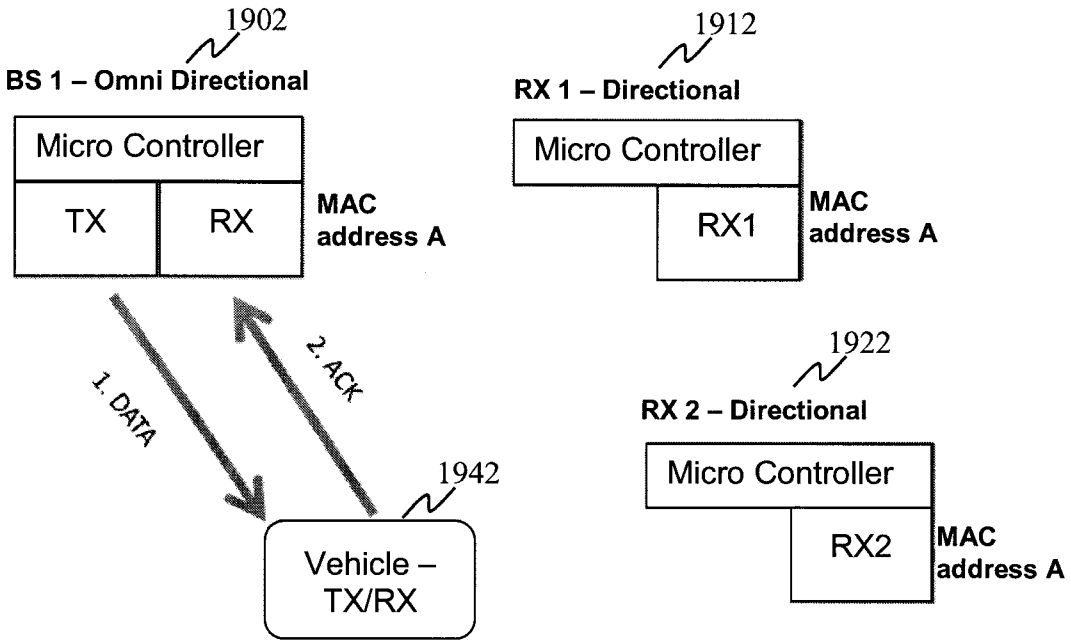

1902
BS 1 – Omni Directional
Micro Controller
TX
RX
MAC address A
1912
RX 1 – Directional
Micro Controller
RX1
MAC address A
1922
RX 2 – Directional
Micro Controller
RX2
MAC address A
1. DATA
2. ACK
1942
Vehicle – TX/RX

Fig. 21

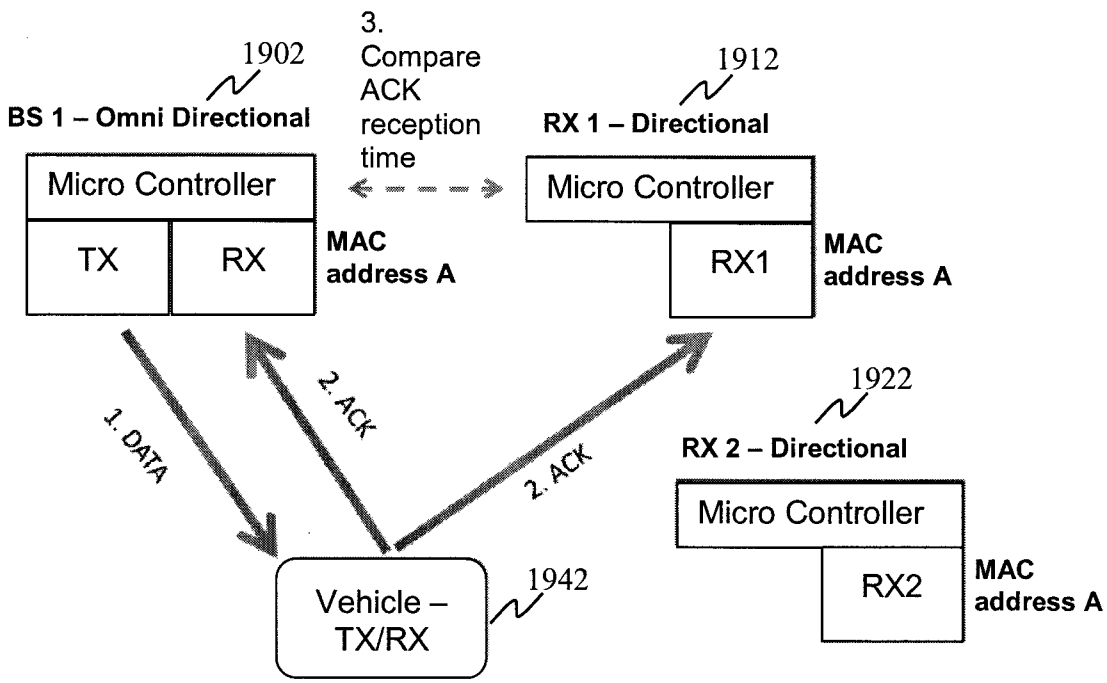

3. Compare ACK reception time
1902
BS 1 – Omni Directional
Micro Controller
TX
RX
MAC address A
1912
RX 1 – Directional
Micro Controller
RX1
MAC address A
1922
RX 2 – Directional
Micro Controller
RX2
MAC address A
1. DATA
2. ACK
2. ACK
1942
Vehicle – TX/RX

Fig. 22

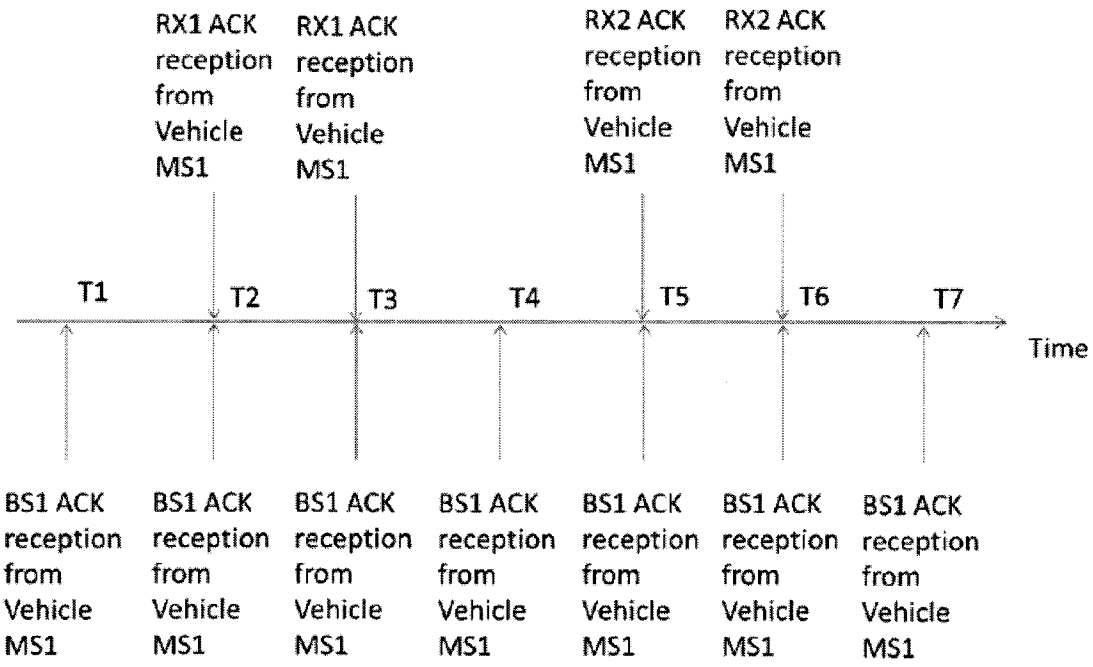

RX1 ACK reception from Vehicle MS1
RX1 ACK reception from Vehicle MS1
RX2 ACK reception from Vehicle MS1
RX2 ACK reception from Vehicle MS1
T1
T2
T3
T4
T5
T6
T7
Time
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1

Fig. 23

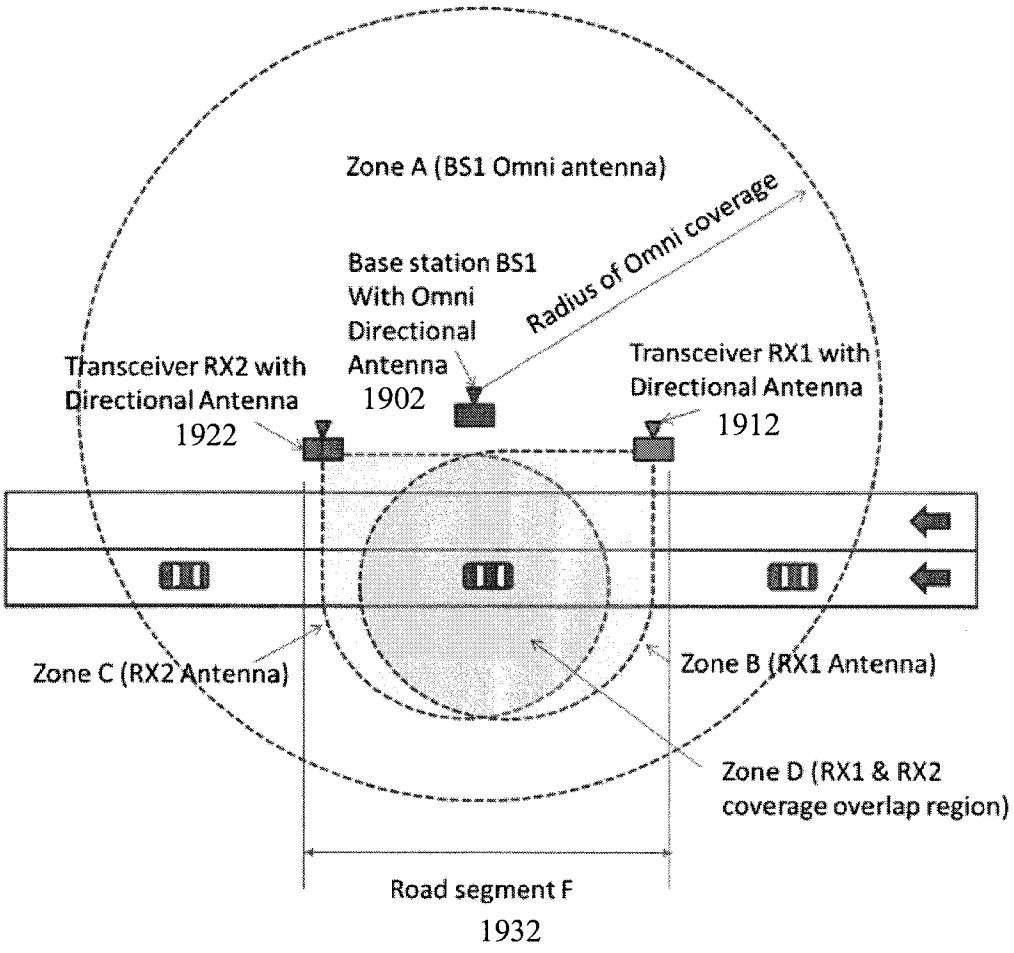

Zone A (BS1 Omni antenna)
Radius of Omni coverage
Base station BS1
With Omni
Directional
Antenna
1902
Transceiver RX2 with
Directional Antenna
1922
Transceiver RX1 with
Directional Antenna
1912
Zone C (RX2 Antenna)
Zone B (RX1 Antenna)
Zone D (RX1 & RX2
coverage overlap region)
Road segment F
1932

Fig. 24

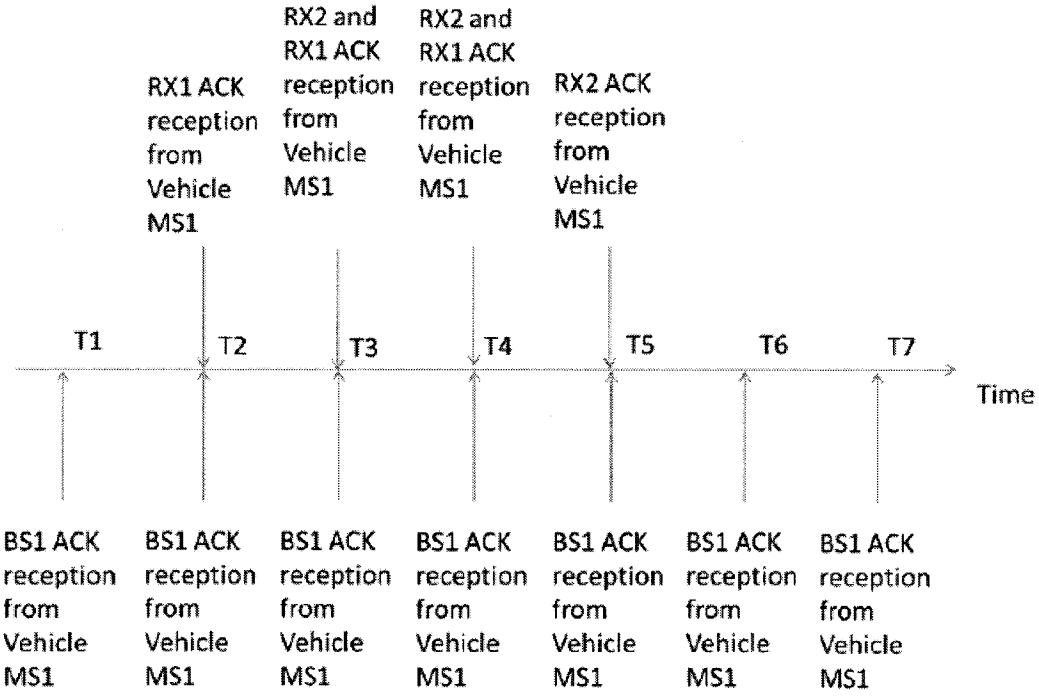

RX1 ACK reception from Vehicle MS1
RX2 and RX1 ACK reception from Vehicle MS1
RX2 and RX1 ACK reception from Vehicle MS1
RX2 ACK reception from Vehicle MS1
T1
T2
T3
T4
T5
T6
T7
Time
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1
BS1 ACK reception from Vehicle MS1

Fig. 25

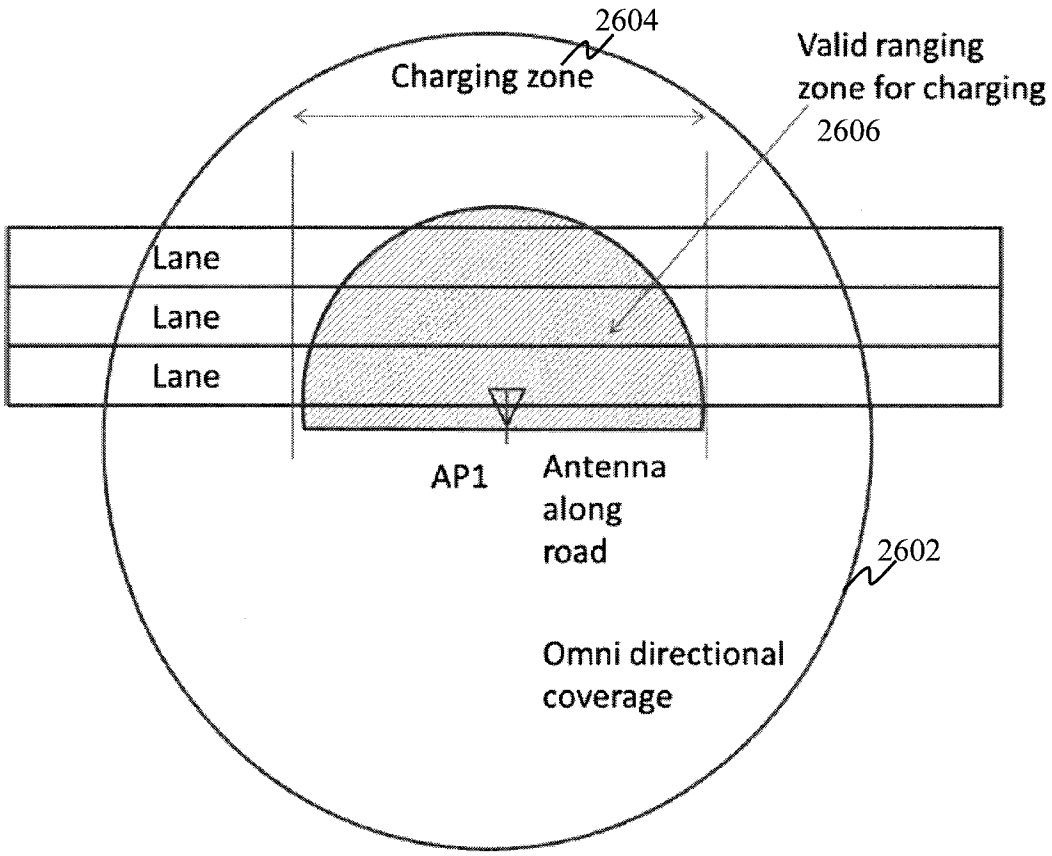

2604
Charging zone
Valid ranging
zone for charging
2606
Lane
Lane
Lane
AP1
Antenna
along
road
2602
Omni directional
coverage

Fig. 26

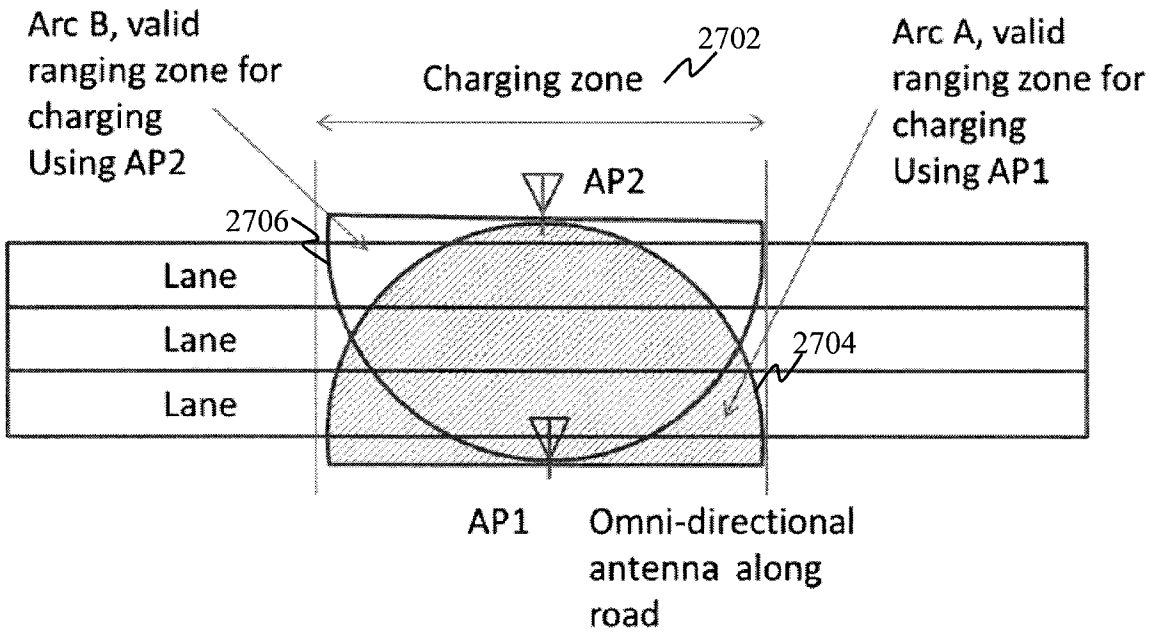

Arc B, valid
ranging zone for
charging
Using AP2
2702
Charging zone
Arc A, valid
ranging zone for
charging
Using AP1
AP2
2706
Lane
Lane
Lane
2704
AP1
Omni-directional
antenna along
road

Fig. 27

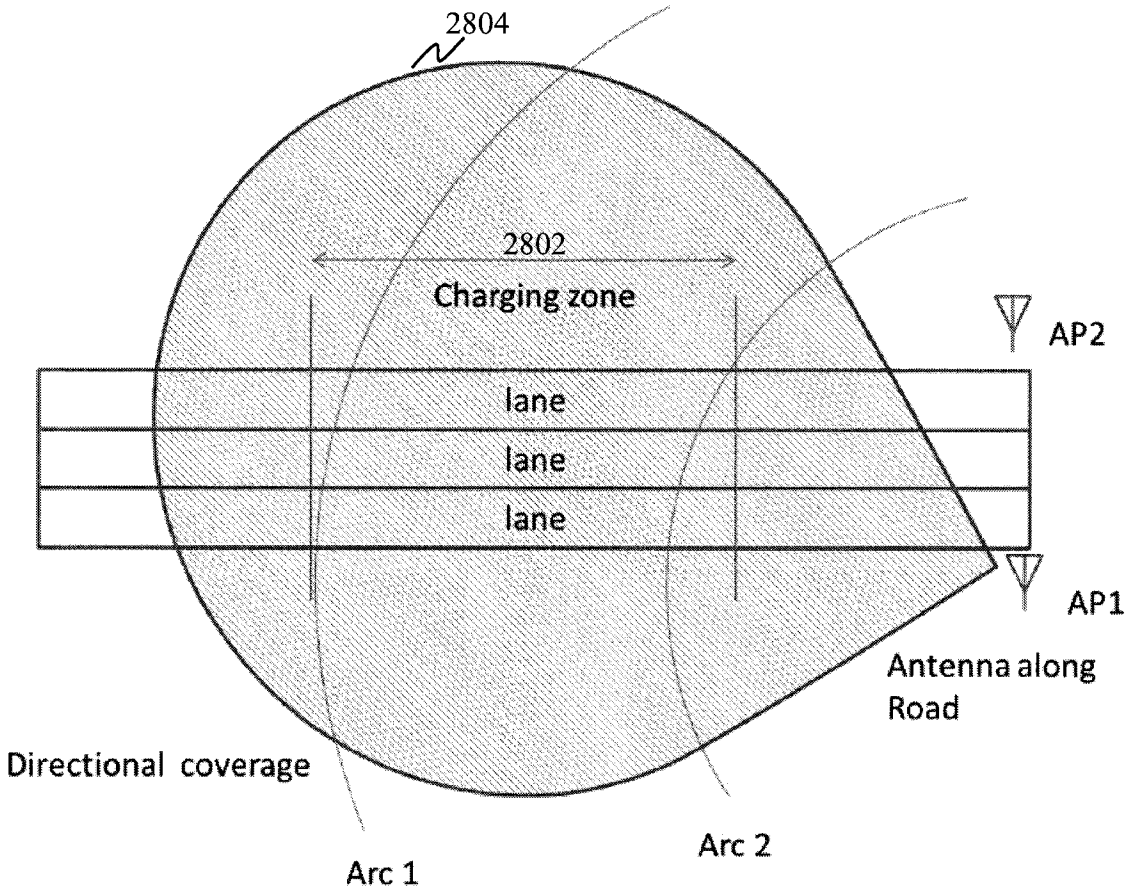

2804
2802
Charging zone
AP2
lane
lane
lane
AP1
Antenna along Road
Directional coverage
Arc 1
Arc 2

Fig. 28

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2016/050146

A. CLASSIFICATION OF SUBJECT MATTER

G01S 5/02 (2010.01) ***G01S 5/14 (2006.01)*** *G07B 15/06 (2011.01)* *H04W 64/00 (2009.01)*

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01S, G07B

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)

FAMPAT and SCOPUS: round trip time, RTT, access point, road segment, vehicle, car, toll, car park, distance estimation and other related terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/0022920 A1 (DUA, P. AND GARIN, L. J.) 23 January 2014 paragraphs [0005], [0046], [0060]-[0062], [0114], [0127]-[0128], figures 3 and 4	1-24
A	US 2014/0253389 A1 (BEAUREGARD, S. J.) 11 September 2014 paragraph [0003]	-
A	US 2012/0314587 A1 (CURTICAPEAN, F.) 13 December 2012 paragraph [0002]	-

☐ 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	Date of mailing of the international search report
20/06/2016 *(day/month/year)*	24/06/2016 *(day/month/year)*

Name and mailing address of the ISA/SG

IPOS INTELLECTUAL PROPERTY OFFICE OF SINGAPORE

Intellectual Property Office of Singapore
51 Bras Basah Road
#01-01 Manulife Centre
Singapore 189554

Email: pct@ipos.gov.sg

Authorized officer

Lee Yi Chau

IPOS Customer Service Tel. No.: (+65) 6339 8616

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2016/050146

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014/0022920 A1	23/01/2014	CN 104471966 A	25/03/2015
		EP 2875654 A2	27/05/2015
		US 2014/0022050 A1	23/01/2014
		US 8933776 B2	13/01/2015
		WO 2014/014572 A2	23/01/2014
US 2014/0253389 A1	11/09/2014	WO 2014/137698 A1	12/09/2014
US 2012/0314587 A1	13/12/2012	US 8547870 B2	01/10/2013
		WO 2012/170046 A1	13/12/2012