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(54) **VEHICLE SOFTWARE DEPLOYMENT SERVICE**

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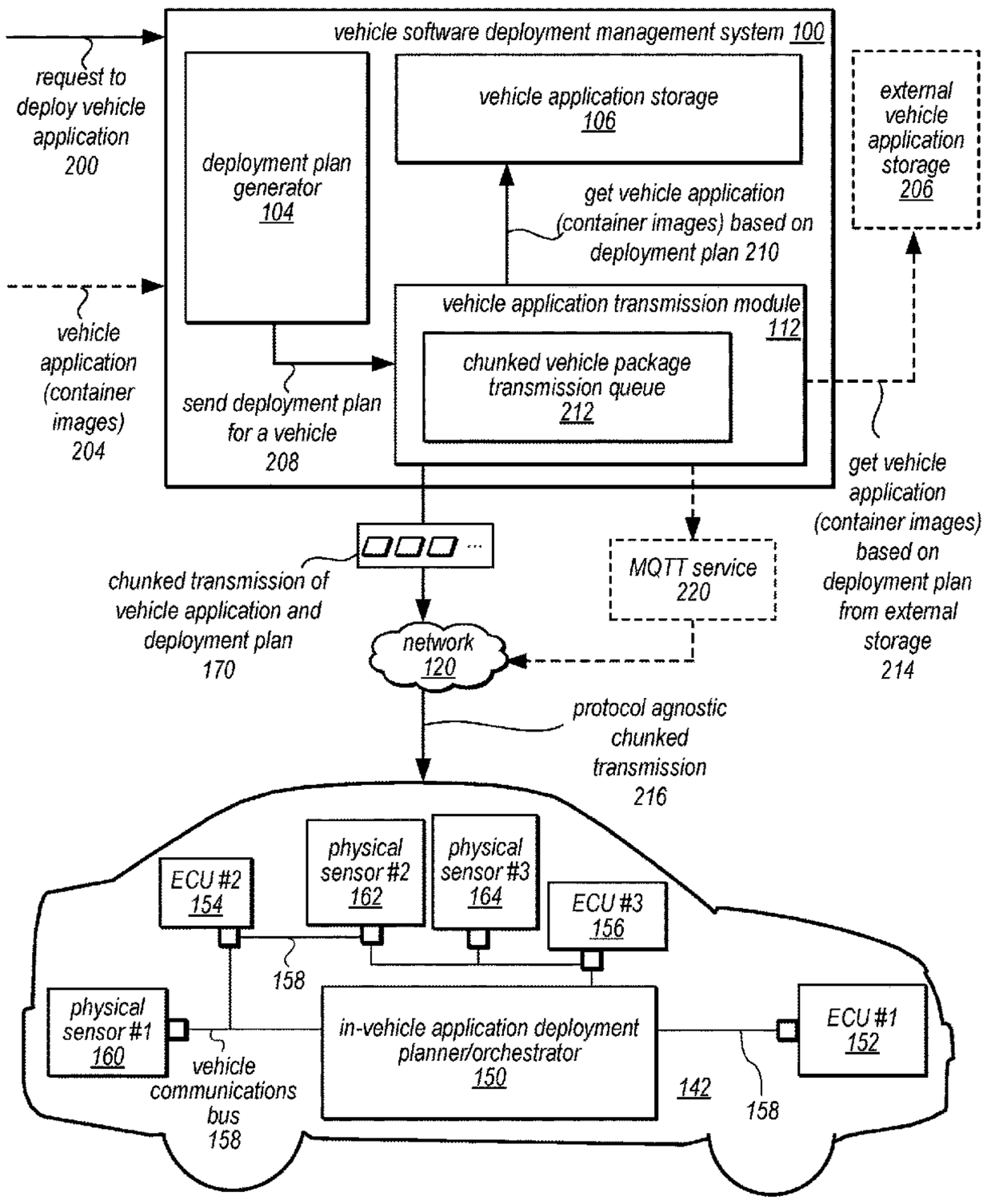
CPC ***G06F 8/61*** (2013.01); ***H04L 67/12*** (2013.01); ***H04L 67/34*** (2013.01)

(57) **ABSTRACT**

A system comprising one or more computing devices implements a vehicle software deployment management system. The vehicle software deployment management system enables clients to send signed serialized data chunks of a vehicle software application and a deployment plan for the software application to vehicles using a protocol agnostic transmission format. The vehicle software deployment management system may generate a deployment plan that may be processed by an in-vehicle application deployment planner/orchestrator of the vehicle to deploy the particular vehicle software application. The vehicle software deployment management system may send the vehicle software application using containers to be used by ECU agents of various ECUs of the vehicle. Furthermore, the vehicle software deployment management system may utilize received vehicle information to dynamically generate one or more updated vehicle deployment plans to send to respective vehicles.



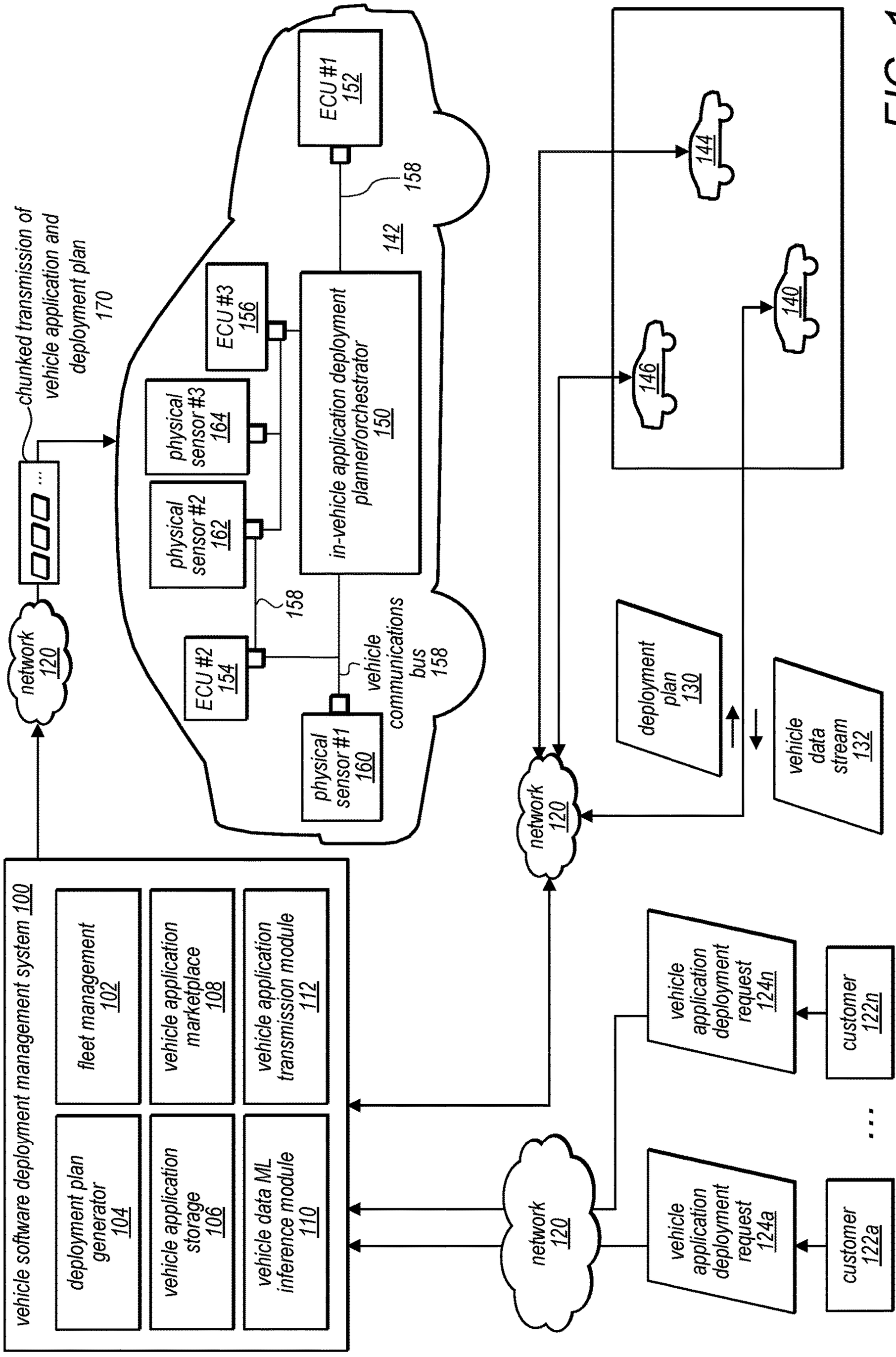

vehicle software deployment management system 100
fleet management 102
deployment plan generator 104
vehicle application marketplace 108
vehicle application storage 106
vehicle application transmission module 112
vehicle data ML inference module 110
network 120
chunked transmission of vehicle application and deployment plan 170
network 120
ECU #1 152
ECU #2 154
ECU #3 156
physical sensor #1 160
physical sensor #2 162
physical sensor #3 164
in-vehicle application deployment planner/orchestrator 150
vehicle communications bus 158
158
142
network 120
deployment plan 130
vehicle data stream 132
144
146
140
vehicle application deployment request 124a
vehicle application deployment request 124n
customer 122a
customer 122n

FIG. 1

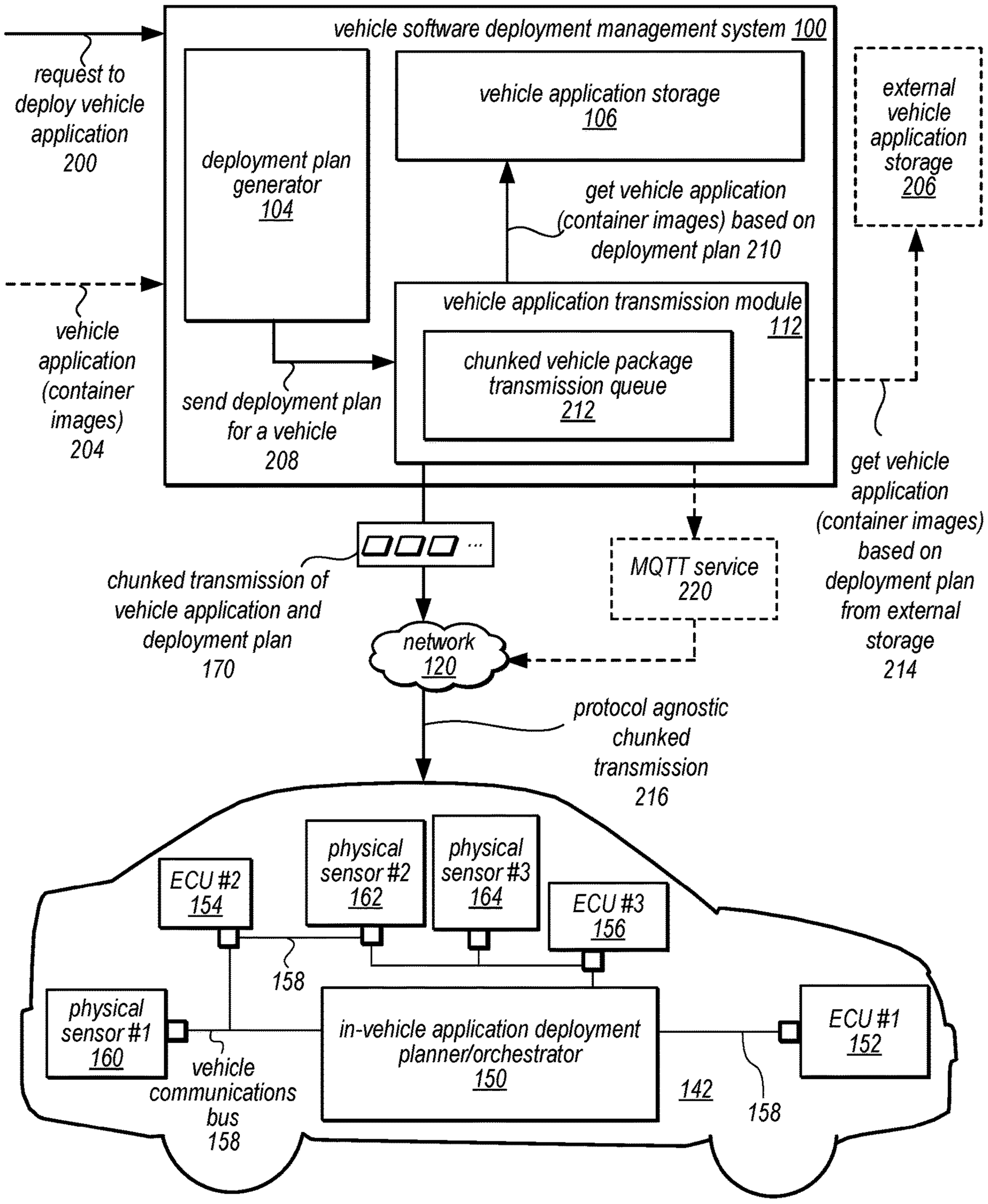

vehicle software deployment management system 100
request to deploy vehicle application 200
deployment plan generator 104
vehicle application storage 106
external vehicle application storage 206
get vehicle application (container images) based on deployment plan 210
vehicle application transmission module 112
chunked vehicle package transmission queue 212
vehicle application (container images) 204
send deployment plan for a vehicle 208
get vehicle application (container images) based on deployment plan from external storage 214
chunked transmission of vehicle application and deployment plan 170
MQTT service 220
network 120
protocol agnostic chunked transmission 216
ECU #2 154
physical sensor #2 162
physical sensor #3 164
ECU #3 156
158
physical sensor #1 160
vehicle communications bus 158
in-vehicle application deployment planner/orchestrator 150
142
ECU #1 152
158

FIG. 2

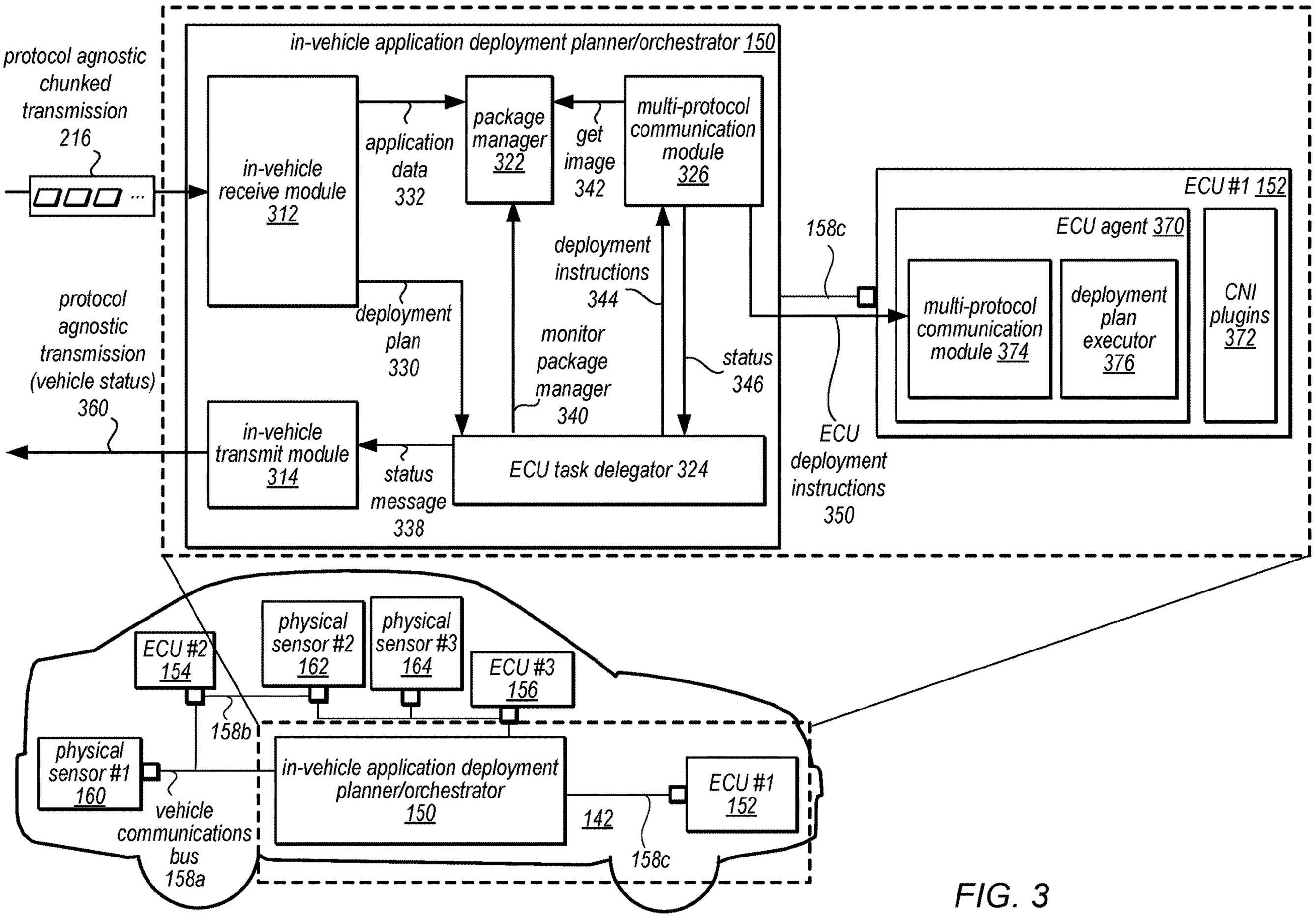

protocol agnostic chunked transmission 216
in-vehicle application deployment planner/orchestrator 150
in-vehicle receive module 312
application data 332
package manager 322
get image 342
multi-protocol communication module 326
ECU #1 152
ECU agent 370
158c
multi-protocol communication module 374
deployment plan executor 376
CNI plugins 372
deployment instructions 344
deployment plan 330
monitor package manager 340
status 346
protocol agnostic transmission (vehicle status) 360
in-vehicle transmit module 314
status message 338
ECU task delegator 324
ECU deployment instructions 350
physical sensor #2 162
physical sensor #3 164
ECU #2 154
ECU #3 156
158b
physical sensor #1 160
vehicle communications bus 158a
in-vehicle application deployment planner/orchestrator 150
142
ECU #1 152
158c

FIG. 3

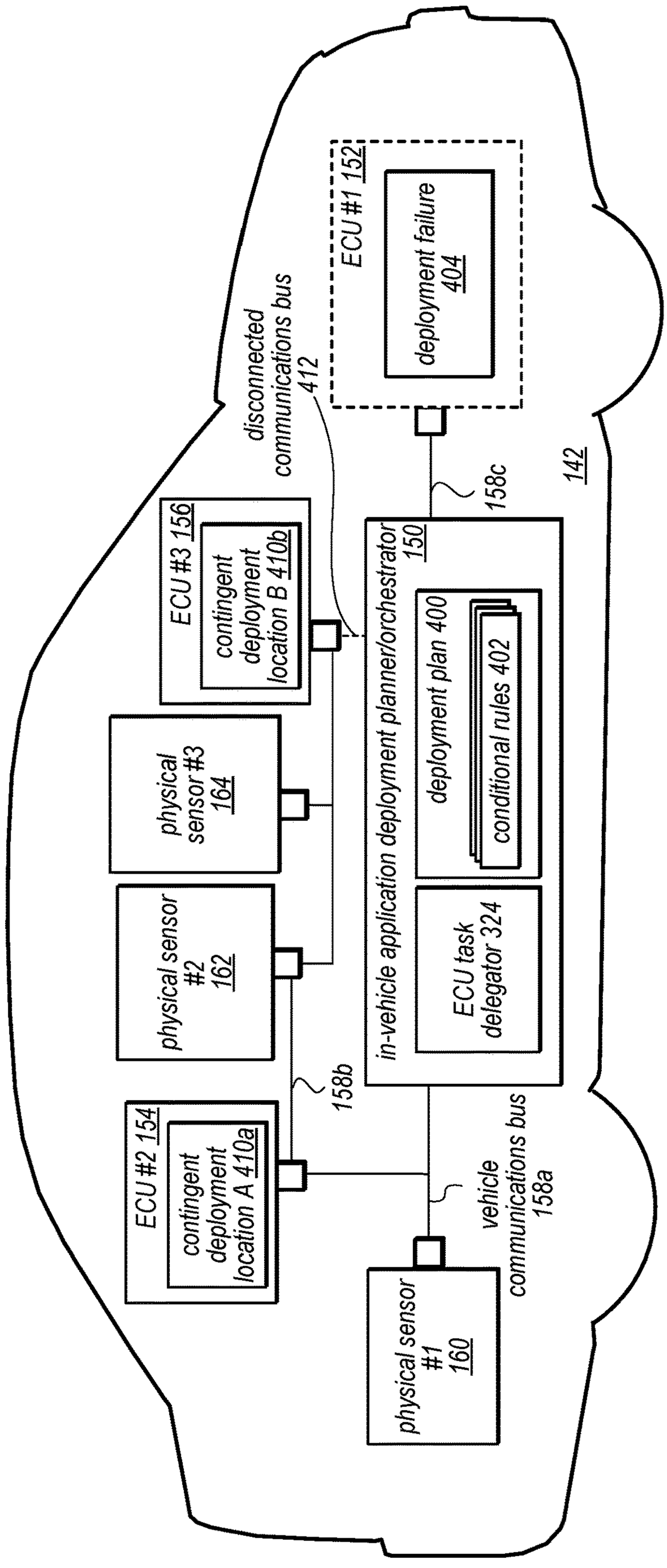

ECU #1 152
deployment failure 404
disconnected communications bus 412
158c
142
in-vehicle application deployment planner/orchestrator 150
deployment plan 400
conditional rules 402
ECU task delegator 324
ECU #3 156
contingent deployment location B 410b
physical sensor #3 164
physical sensor #2 162
158b
ECU #2 154
contingent deployment location A 410a
physical sensor #1 160
vehicle communications bus 158a

FIG. 4

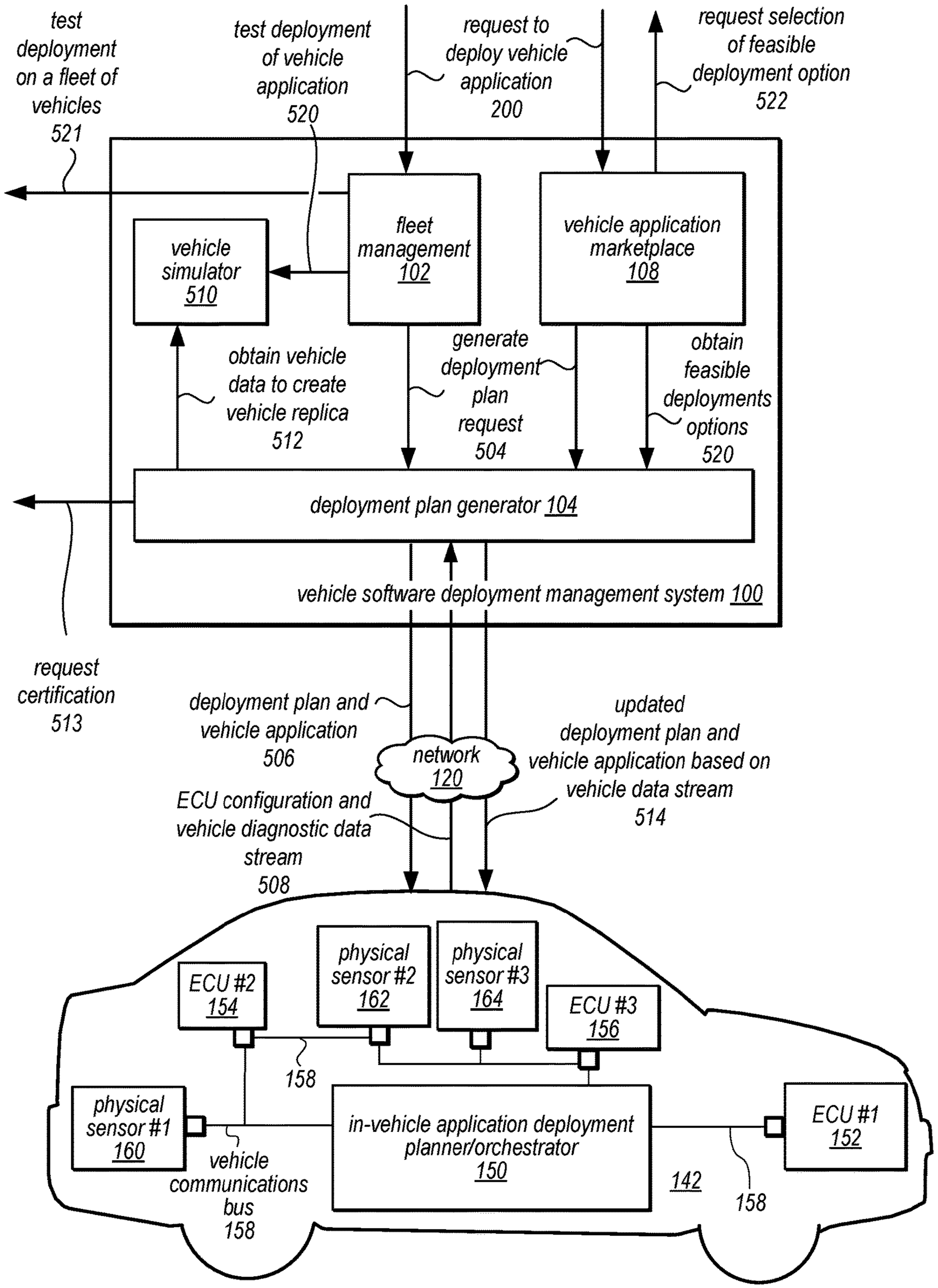

test deployment on a fleet of vehicles 521
test deployment of vehicle application 520
request to deploy vehicle application 200
request selection of feasible deployment option 522
vehicle simulator 510
fleet management 102
vehicle application marketplace 108
obtain vehicle data to create vehicle replica 512
generate deployment plan request 504
obtain feasible deployments options 520
deployment plan generator 104
vehicle software deployment management system 100
request certification 513
deployment plan and vehicle application 506
network 120
updated deployment plan and vehicle application based on vehicle data stream 514
ECU configuration and vehicle diagnostic data stream 508
physical sensor #2 162
physical sensor #3 164
ECU #2 154
ECU #3 156
158
physical sensor #1 160
vehicle communications bus 158
in-vehicle application deployment planner/orchestrator 150
142
ECU #1 152
158

FIG. 5

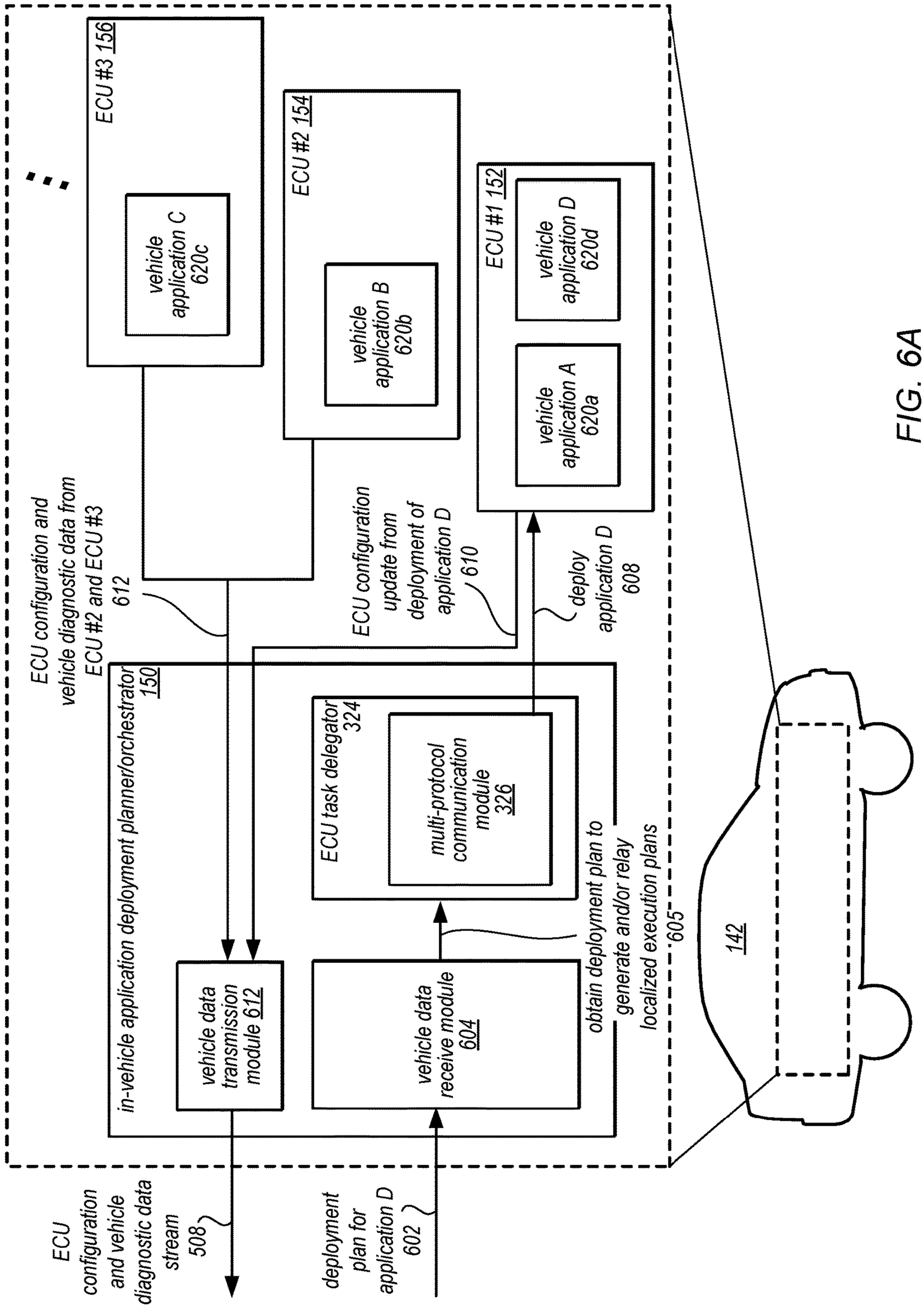

ECU #3 156
vehicle application C 620c
ECU #2 154
vehicle application B 620b
ECU #1 152
vehicle application D 620d
vehicle application A 620a
ECU configuration and vehicle diagnostic data from ECU #2 and ECU #3 612
ECU configuration update from deployment of application D 610
deploy application D 608
deployment planner/orchestrator 150
ECU task delegator 324
multi-protocol communication module 326
obtain deployment plan to generate and/or relay localized execution plans 605
in-vehicle application deployment
vehicle data transmission module 612
vehicle data receive module 604
142
ECU configuration and vehicle diagnostic data stream 508
deployment plan for application D 602

FIG. 6A

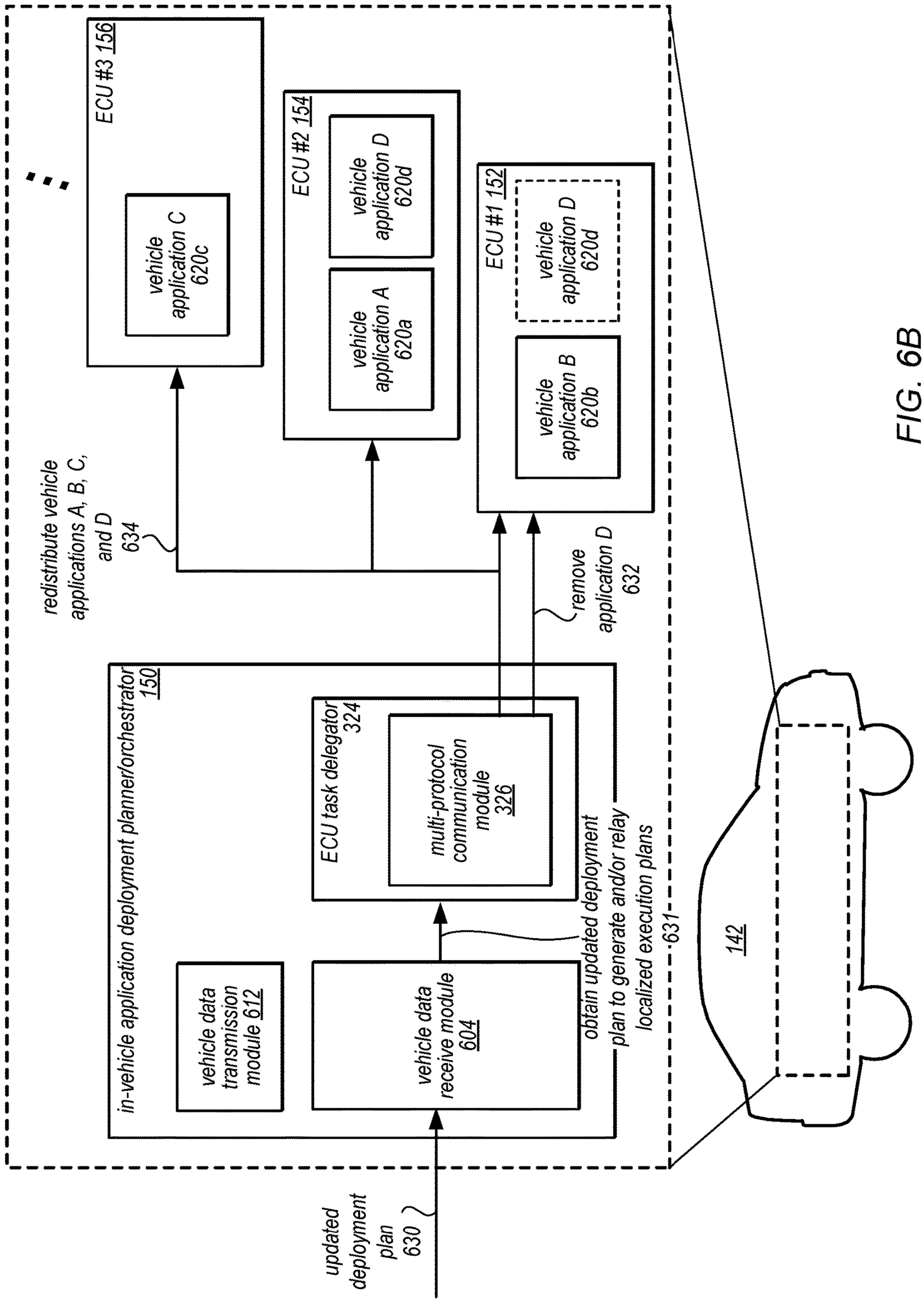

ECU #3 156
vehicle application C 620c
ECU #2 154
vehicle application D 620d
vehicle application A 620a
ECU #1 152
vehicle application D 620d
vehicle application B 620b
redistribute vehicle applications A, B, C, and D 634
remove application D 632
in-vehicle application deployment planner/orchestrator 150
ECU task delegator 324
multi-protocol communication module 326
vehicle data transmission module 612
vehicle data receive module 604
obtain updated deployment plan to generate and/or relay localized execution plans 631
updated deployment plan 630
142

FIG. 6B

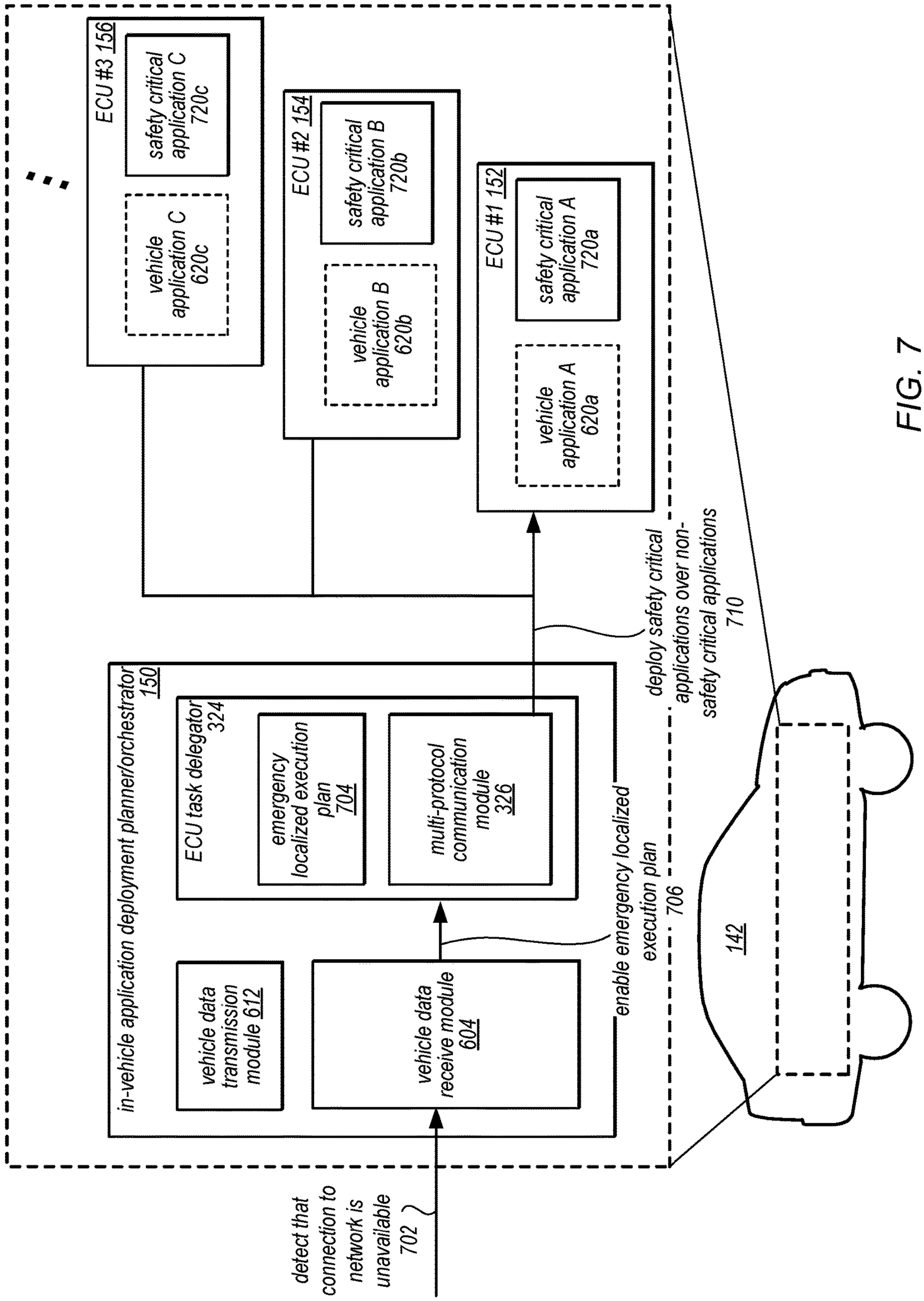

...
ECU #3 156
safety critical application C 720c
vehicle application C 620c
ECU #2 154
safety critical application B 720b
vehicle application B 620b
ECU #1 152
safety critical application A 720a
vehicle application A 620a
in-vehicle application deployment planner/orchestrator 150
ECU task delegator 324
emergency localized execution plan 704
multi-protocol communication module 326
vehicle data transmission module 612
vehicle data receive module 604
detect that connection to network is unavailable 702
enable emergency localized execution plan 706
deploy safety critical applications over non-safety critical applications 710
142

FIG. 7

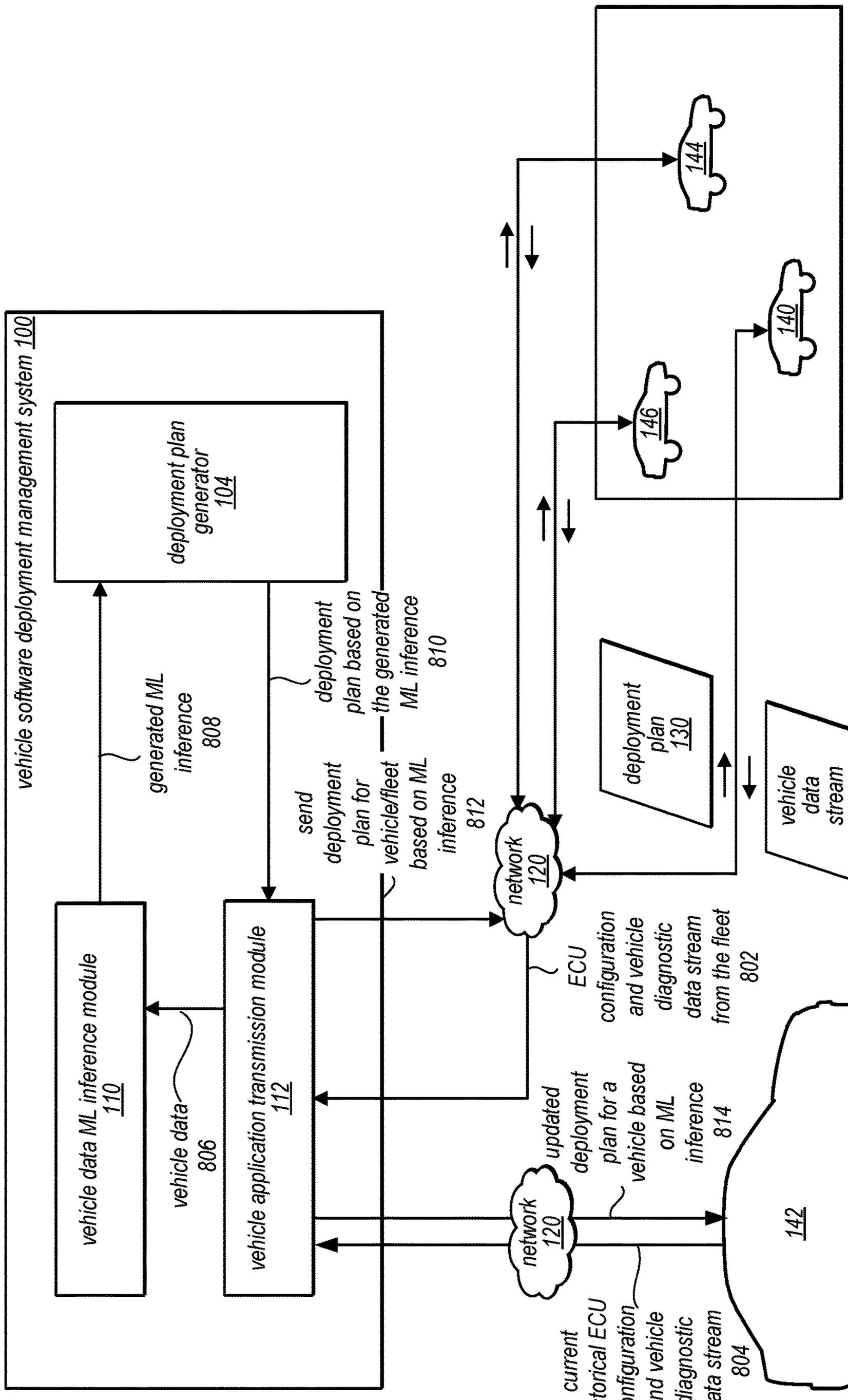

vehicle software deployment management system 100
deployment plan generator 104
generated ML inference 808
send deployment plan for vehicle/fleet based on ML inference 812
deployment plan based on the generated ML inference 810
vehicle data ML inference module 110
vehicle application transmission module 112
vehicle data 806
network 120
ECU configuration and vehicle diagnostic data stream from the fleet 802
updated deployment plan for a vehicle based on ML inference 814
current historical ECU configuration and vehicle diagnostic data stream 804
142
144
140
146
deployment plan 130
vehicle data stream 132

FIG. 8

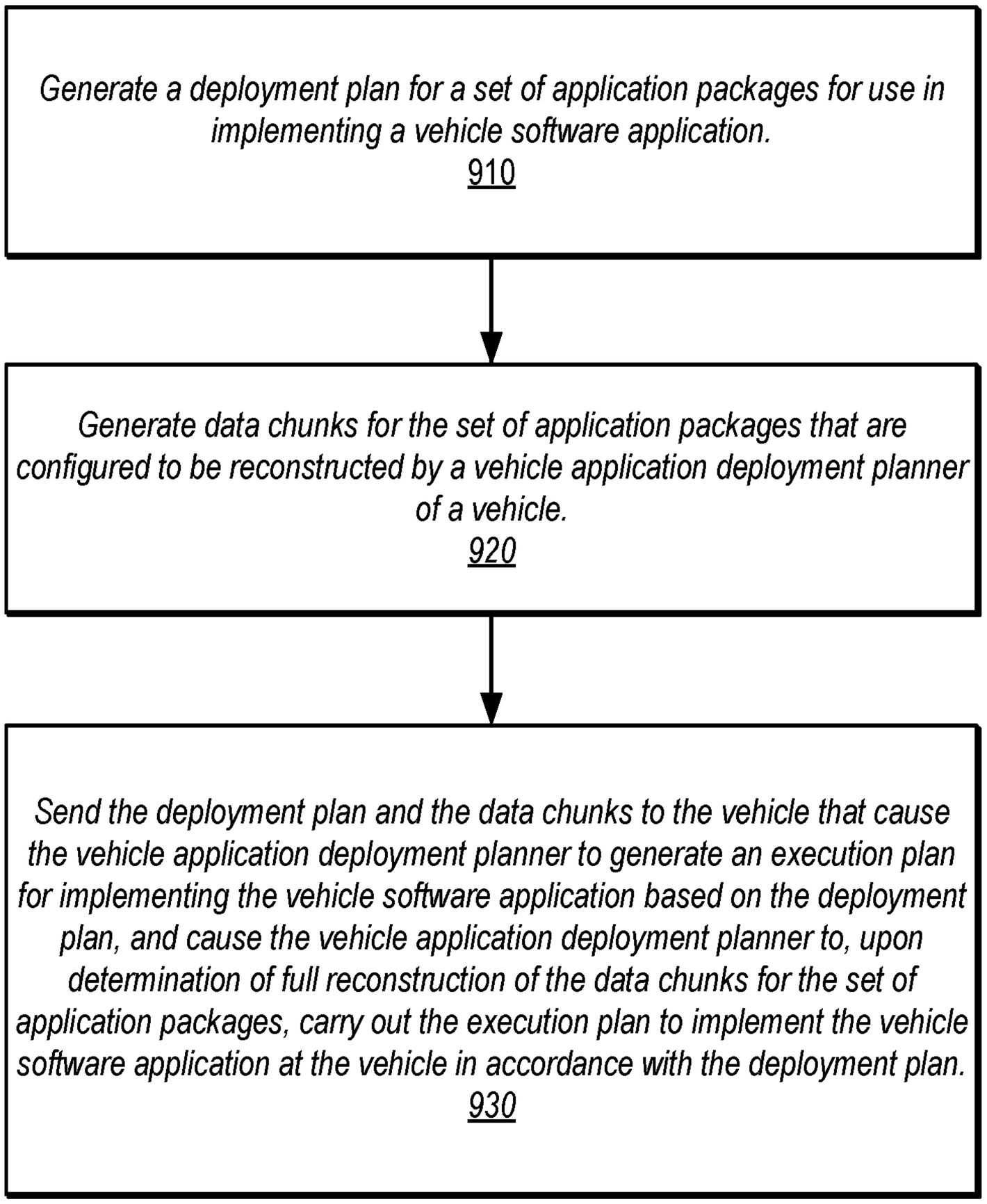

Generate a deployment plan for a set of application packages for use in implementing a vehicle software application.
910
Generate data chunks for the set of application packages that are configured to be reconstructed by a vehicle application deployment planner of a vehicle.
920
Send the deployment plan and the data chunks to the vehicle that cause the vehicle application deployment planner to generate an execution plan for implementing the vehicle software application based on the deployment plan, and cause the vehicle application deployment planner to, upon determination of full reconstruction of the data chunks for the set of application packages, carry out the execution plan to implement the vehicle software application at the vehicle in accordance with the deployment plan.
930

FIG. 9

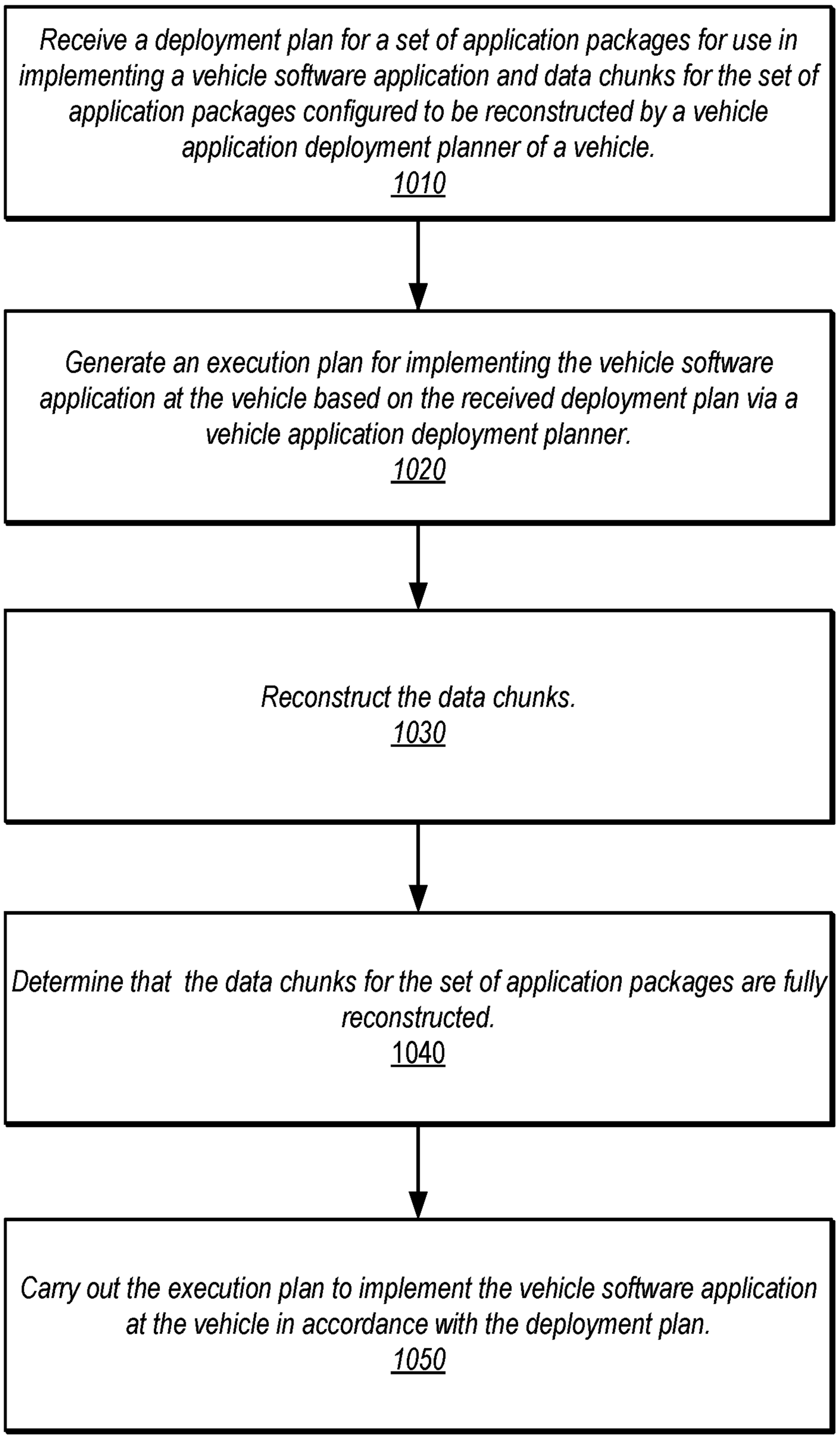

Receive a deployment plan for a set of application packages for use in implementing a vehicle software application and data chunks for the set of application packages configured to be reconstructed by a vehicle application deployment planner of a vehicle.
1010
Generate an execution plan for implementing the vehicle software application at the vehicle based on the received deployment plan via a vehicle application deployment planner.
1020
Reconstruct the data chunks.
1030
Determine that the data chunks for the set of application packages are fully reconstructed.
1040
Carry out the execution plan to implement the vehicle software application at the vehicle in accordance with the deployment plan.
1050

FIG. 10

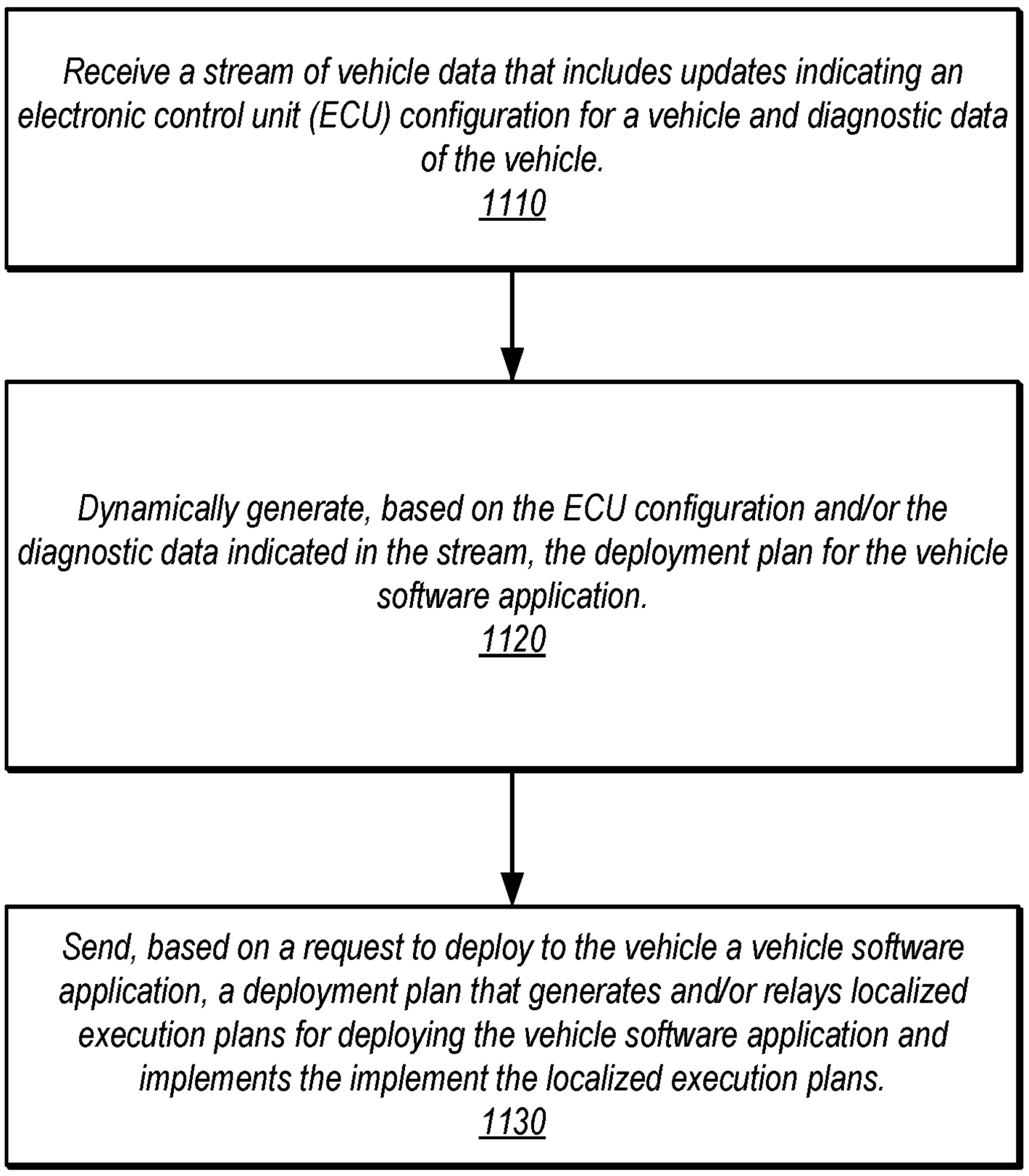

Receive a stream of vehicle data that includes updates indicating an electronic control unit (ECU) configuration for a vehicle and diagnostic data of the vehicle.
1110
Dynamically generate, based on the ECU configuration and/or the diagnostic data indicated in the stream, the deployment plan for the vehicle software application.
1120
Send, based on a request to deploy to the vehicle a vehicle software application, a deployment plan that generates and/or relays localized execution plans for deploying the vehicle software application and implements the implement the localized execution plans.
1130

FIG. 11

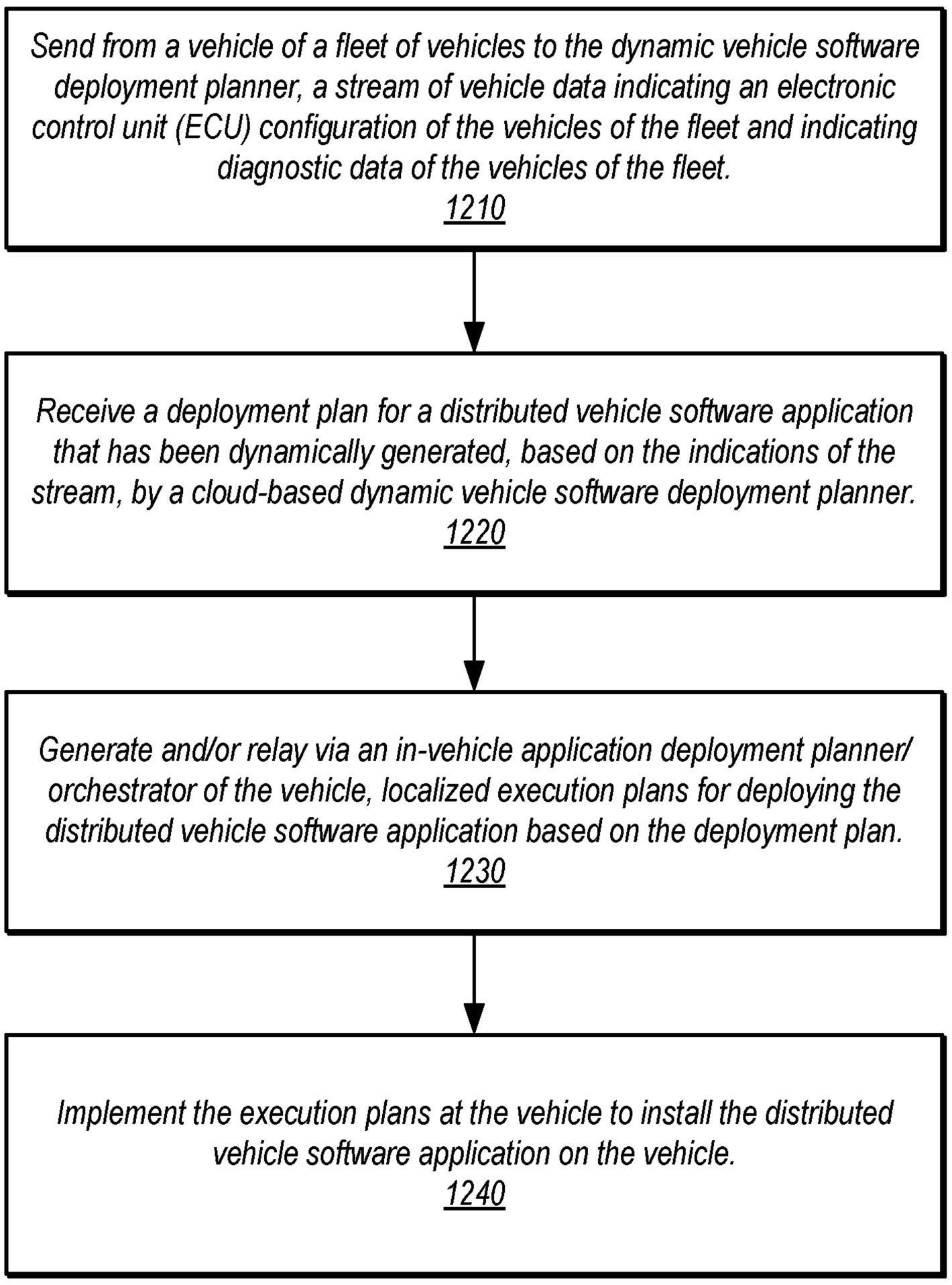

Send from a vehicle of a fleet of vehicles to the dynamic vehicle software deployment planner, a stream of vehicle data indicating an electronic control unit (ECU) configuration of the vehicles of the fleet and indicating diagnostic data of the vehicles of the fleet.
1210
Receive a deployment plan for a distributed vehicle software application that has been dynamically generated, based on the indications of the stream, by a cloud-based dynamic vehicle software deployment planner.
1220
Generate and/or relay via an in-vehicle application deployment planner/ orchestrator of the vehicle, localized execution plans for deploying the distributed vehicle software application based on the deployment plan.
1230
Implement the execution plans at the vehicle to install the distributed vehicle software application on the vehicle.
1240

FIG. 12

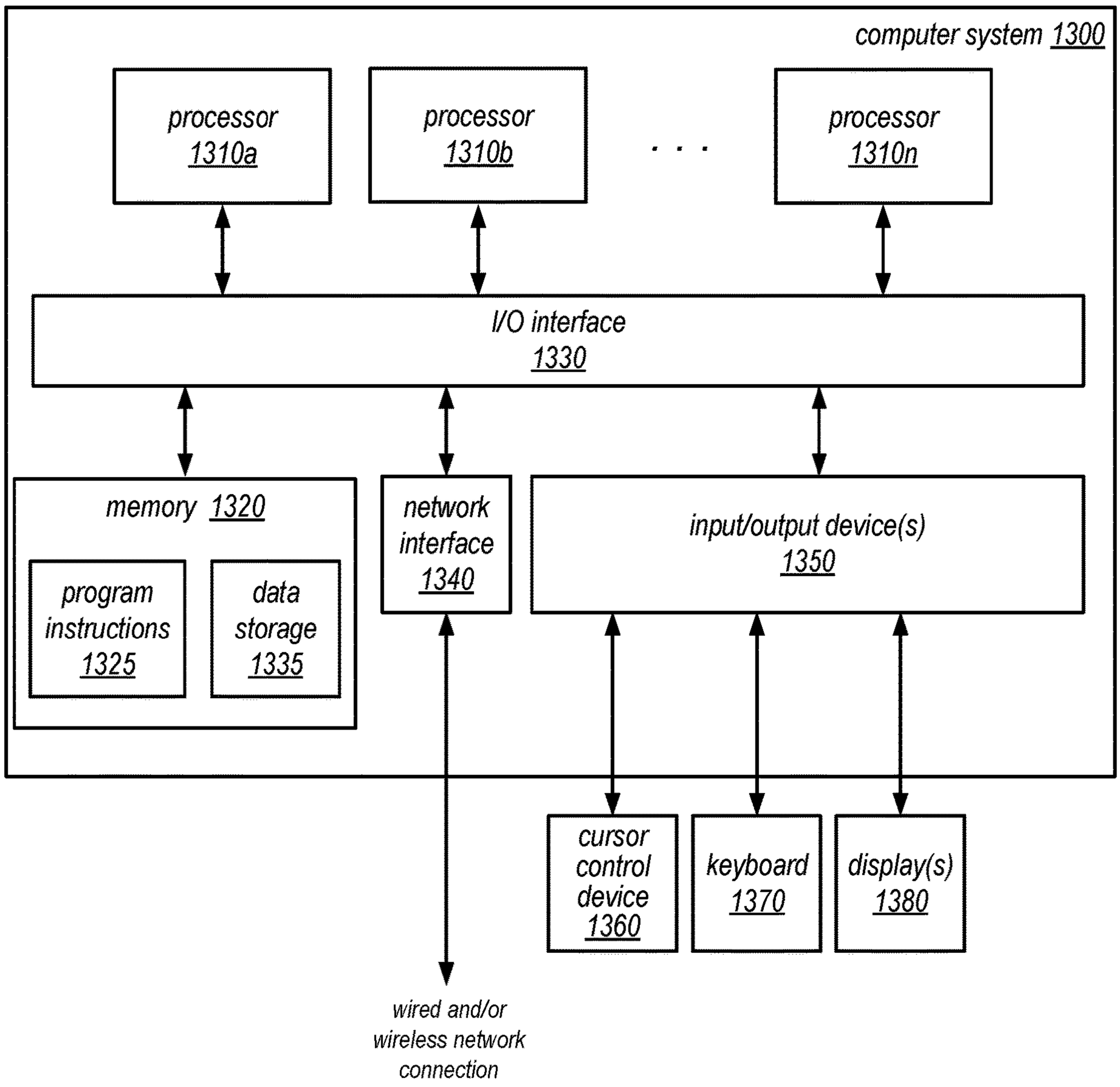

computer system 1300
processor 1310a
processor 1310b
. . .
processor 1310n
I/O interface 1330
memory 1320
program instructions 1325
data storage 1335
network interface 1340
input/output device(s) 1350
cursor control device 1360
keyboard 1370
display(s) 1380
wired and/or wireless network connection

FIG. 13

VEHICLE SOFTWARE DEPLOYMENT SERVICE

BACKGROUND

[0001] Modern vehicles, such as cars, trucks, motorcycles, etc. are often manufactured with electronic sensors and include computer systems programmed with control algorithms that take inputs from such electronic sensors to determine various control actions to be taken for the vehicle or systems implemented in the vehicles. Some vehicles may include multiple electronic control units (ECUs) and various sensor modalities. Additionally, deployment of a vehicle software application may require that the vehicle software application be compatible with an execution environment of a particular ECU that the vehicle software application will be deployed in. Moreover, a communication format a vehicle uses to receive a vehicle software application may restrict or slowdown the transfer of a software application to a vehicle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] FIG. **1** illustrates a vehicle software deployment management system that sends signed serialized data chunks of a vehicle software application and a deployment plan for the software application to vehicles using a protocol agnostic transmission format, and/or dynamically generates and sends, based on received streams of vehicle data, a deployment plan for deploying the vehicle software application, according to some embodiments.

[0003] FIG. **2** illustrates a more detailed view of a vehicle software deployment management system, its various parts, and interactions to generate signed serialized data chunks of the vehicle application and/or deployment plan and sending the signed serialized data chunks to a vehicle using a protocol agnostic transmission format, according to some embodiments.

[0004] FIG. **3** illustrates a graphical view of an example in-vehicle application deployment planner/orchestrator of a vehicle that receives a deployment from a vehicle software deployment management system and/or receives signed serialized data chunks of a vehicle application to be deployed at the vehicle, wherein the in-vehicle application deployment planner/orchestrator enables deployment of the in-vehicle application in an execution environment of the vehicle, according to some embodiments.

[0005] FIG. **4** illustrates a more detailed view of an in-vehicle application deployment planner/orchestrator for a vehicle and use of conditional rules of a deployment plan to deploy a vehicle software application, according to some embodiments.

[0006] FIG. **5** illustrates a more detailed view of a vehicle software deployment management system, its various parts, and interactions to dynamically generate and send, based on streams of vehicle data, deployment plans for deploying a vehicle software application, according to some embodiments.

[0007] FIG. **6**A illustrates a more detailed view of an in-vehicle application deployment planner/orchestrator of a vehicle that uses a deployment plan received from a vehicle software deployment management system to deploy a vehicle application, wherein the in-vehicle application deployment planner/orchestrator also sends a stream of ECU configuration and vehicle diagnostic data from ECUs of the vehicle back to the vehicle software deployment management system for use in dynamically updating a deployment plan for deploying in-vehicle applications on the vehicle, according to some embodiments.

[0008] FIG. **6**B illustrates a more detailed view of an in-vehicle application deployment planner/orchestrator of a vehicle that redeploys vehicle applications implemented using various ECUs based on an updated deployment plan from the vehicle software deployment management system, according to some embodiments.

[0009] FIG. **7** illustrates a more detailed view of an in-vehicle application deployment planner/orchestrator of a vehicle that uses an alternative localized execution plan that prioritizes availability of safety critical applications over non-safety critical applications, according to some embodiments.

[0010] FIG. **8** illustrates a vehicle software deployment management system configured to dynamically generate deployment plans for vehicle applications based on various vehicle/vehicle fleet data streams and machine learning (ML) models, according to some embodiments.

[0011] FIG. **9** illustrates a flowchart of operations performed by a vehicle software deployment management system to send signed serialized data chunks of a vehicle software application and/or a deployment plan for the software application to vehicles using a protocol agnostic transmission format, according to some embodiments.

[0012] FIG. **10** illustrates a flowchart of operations performed by an in-vehicle application deployment planner/orchestrator of a vehicle to carry out an execution plan to implement a vehicle software application, wherein the execution plan is generated by the in-vehicle application deployment planner/orchestrator based on a received deployment plan for the in-vehicle application, according to some embodiments.

[0013] FIG. **11** illustrates a flowchart of operations performed by a vehicle software deployment management system to dynamically generate and send, based on streams of vehicle data, deployment plans for deploying a vehicle software application, according to some embodiments.

[0014] FIG. **12** illustrates a flowchart of operations performed by an in-vehicle application deployment planner/orchestrator of a vehicle to carry out an execution plan to implement a vehicle software application according to a dynamically generated deployment plan received by the in-vehicle application deployment planner/orchestrator, according to some embodiments.

[0015] FIG. **13** illustrates a block diagram illustrating an example computer system that implements some or all of the techniques described herein, according to some embodiments.

[0016] While embodiments are described herein by way of example for several embodiments and illustrative drawings, those skilled in the art will recognize that embodiments are not limited to the embodiments or drawings described. It should be understood that the drawings and detailed description thereto are not intended to limit embodiments to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope as defined by the appended claims. The headings used herein are for organizational purposes only and are not meant to be used to limit the scope of the description or the claims. As used throughout this application, the word "may" is used in a permissive sense

(e.g., meaning having the potential to), rather than the mandatory sense (e.g., meaning must). Similarly, the words "include," "including," and "includes" mean including, but not limited to.

DETAILED DESCRIPTION OF EMBODIMENTS

[0017] The systems and methods described herein include techniques for implementing a vehicle software deployment management system that sends signed serialized data chunks of a vehicle software application and a deployment plan for the vehicle software application to a vehicle and/or in-vehicle application deployment planner/orchestrator of the vehicle. The in-vehicle application deployment planner/orchestrator is configured to receive both the signed serialized chunks and associated deployment plan for the vehicle software application and generate a local deployment plan for deploying components of the in-vehicle software application.

[0018] For example, modern vehicles are equipped with various electronic control units (ECUs), various types of buses that may use a plurality of in-vehicle communication protocols and that may be arranged in the vehicles in various configurations. Additionally, along with a large amount of variability with regard to vehicle environment configurations, vehicle software applications that are requested to be deployed in the vehicle may be large and complex with multiple components that are required to be deployed in a specific manner across various ones of the ECUs of the vehicles that may be arranged in different configurations that vary vehicle to vehicle. Moreover, deployment of the vehicle software may be further complicated by the software components involved in the deployment of the vehicle software having multiple dependencies. For example, a vehicle software application that is requested to be deployed may be a distributed application that requires its components to be deployed in a specific sequence due to the various components' dependencies. Note that the dependencies may include dependencies between software components, for example component A must be deployed prior to component B, as an example. Also, the dependencies may also include software/hardware dependencies or networking/software dependencies. For example, software component A may have a dependency that requires it to be deployed on an ECU with a direct bus connection to another ECU used to deploy software component B, as an example. Also, dependencies may include purely hardware dependencies, such as software component A requires installation on an ECU with a processor having X capacity, while software component B requires installation on an ECU with a processor having Y capacity, as an example.

[0019] As can be seen, the deployment of a vehicle software application, including distributed applications, in vehicle environments that encompass a wide range of combinations of vehicle hardware and software presents a non-trivial challenge.

[0020] Also, a vehicle software deployment planner of the vehicle software deployment management system (e.g., residing in the cloud, as an example) may coordinate the deployment of the vehicle software application using the deployment plan. For example, a deployment plan may instruct specific ones of the software application component to be deployed in specific ECUs based on relationship of dependencies of each of the components. In addition to determining the sequence of deployment, the vehicle software deployment planner may determine an optimal vehicle application deployment configuration based on vehicle data such as available compute resources of the ECUs, number of CPU cores, memory, cache, storage of the ECUs etc. For example, the deployment plan may instruct the vehicle software application to be deployed to an ECU with greater processing power available versus another ECU that is viable but less optimal due to a lower available processing power. The vehicle software deployment planner may be able to coordinate the deployment of the vehicle software application in an optimal configuration using the deployment plan. In some embodiments, a level of detail included in the deployment plan may vary. For example, some deployment plans may include a high-level of specificity determined by the vehicle software deployment management system (e.g., residing in the cloud), while other deployment plans may include general deployment instructions, wherein more granular determinations are made at the vehicle level, for example by an in-vehicle application deployment planner/orchestrator. As an example, a more detailed deployment plan may specify particular ECUs of a vehicle that are to be used for deployment, whereas a more general (e.g., less granular) deployment plan may specify characteristics of ECUs that are to be used for particular software components and the selection of particular ECUs based on these characteristics may be left to the in-vehicle application deployment planner/orchestrator to determine.

[0021] Moreover, in some embodiments, the vehicle software application may be large such that its size hinders the transfer of the vehicle application software and the deployment plan in a single network transmission unit, such as a payload of a data packet. In some embodiments, the vehicle software deployment management system may generate a signed serialized set of data chunks for the vehicle software application and/or deployment plan to send to the in-vehicle application deployment planner/orchestrator to be reconstructed incrementally. The use of the serialization and signatures may provide a mechanism for the in-vehicle application deployment planner/orchestrator to confirm that all relevant chunks have been received, even if sent using various different packets that may be delivered out of order, etc. Also, the use of the serialization may enable the in-vehicle application deployment planner/orchestrator to conform that packets were not lost in transmission. The chunks may be received and queued at the vehicle and assembled by the in-vehicle application deployment planner/orchestrator. The use of data chunks reduces the size of the individual data packages that must be transmitted and allows greater flexibility with regard to the types of transmission protocols and communication networks that may be used to send the vehicle application software.

[0022] In some embodiments, the deployment plan may be determined by a vehicle software deployment planner in a server (e.g., cloud server), such that a server-based vehicle software deployment planner dynamically receives vehicle information and generates the deployment plan based on the relevant vehicle information received. In embodiments where the server-based deployment planner is used, the deployment plan may contain more granular deployment details, such as the relevant instructions/execution plans for an in-vehicle deployment planner/orchestrator to orchestrate and relay to deploy the vehicle software application according to the deployment plan. In other embodiments, the in-vehicle deployment planner/orchestrator may receive a

more generalized deployment plan and may generate a more detailed deployment plan locally at the vehicle based on vehicle information available in the vehicle. In some embodiments, a partial deployment plan for a portion of the vehicle software application may be generated by the in-vehicle deployment planner/orchestrator.

[0023] FIG. **1** illustrates a vehicle software deployment management system that sends signed serialized data chunks of a vehicle software application and a deployment plan for the vehicle software application to one or more vehicles using a protocol agnostic transmission format, and/or dynamically generates and sends, based on received streams of vehicle data, a deployment plan for deploying the vehicle software application, according to some embodiments.

[0024] A vehicle system may include a vehicle software deployment management system **100** and network **120** that are connected to vehicles **140**, **142**, **143**, and **144**. Although FIG. **1** illustrates four vehicles **140**, **142**, **143**, and **144** connected to the vehicle software deployment management system **100** via the network **120**, this illustration is intended only as an example and it should be understood that any number of vehicles may form a fleet of vehicles connected to the network **120**. In some embodiments, network **120** may be connected to vehicles that contain various components configured to send and receive signals using different vehicle signal formats and/or that include various ECU environments. In some embodiments the vehicles may use a homogeneous vehicle signal format and/or a homogenous set of ECUs. Customers **122***a* through **122***n* may furthermore, be connected to vehicle software deployment management system via the network **120**. Customers **122***a* through **122***n* may be vehicle suppliers or vehicle component suppliers (e.g., vehicle original equipment manufacturers (OEMs) and/or parts suppliers). Network **120** may be a private or public network such as a direct connect connection to a service provider network hosting the vehicle software deployment management system **100**, or an Internet connection. Network **120** may furthermore be a wireless network, such as a cellular network, Wi-Fi network or other wireless network. In some embodiments the vehicles **140**, **142**, **143**, and **144** may be connected to multiple types of networks **120** and not just to one type of network **120**.

[0025] In some embodiments, the vehicle software deployment management system **100** may include a deployment plan generator **104**, a fleet management system **102**, a vehicle application storage **106**, a vehicle application marketplace **108**, a vehicle data ML inference module **110**, and a vehicle application transmission module **112**. The deployment plan generator **104** may generate a deployment plan **130** for a single vehicle, such as the vehicle **142**, or a fleet of vehicles **140**, **142**, **144**, and **146** based on the vehicle application deployment requests **124***a*-**124***n*. With regard to a vehicle software application that is to be deployed, the deployment plan generator **104** may obtain the vehicle software application that is to be deployed from a vehicle application storage **106**, external application storage **206** (shown in FIG. **2**), and/or directly from the customer **122**. In some embodiments, the vehicle software application to be deployed may be provided using Open Container Initiative (OCI) images that are compatible with ECUs in a vehicle in which the vehicle software application is to be deployed. In some embodiments, the vehicle application marketplace **108** may expose various vehicle applications allowed to be deployed to a given vehicle for the customers **122***a*-**122***n*. The customers **122***a*-**122***n* may indicate in a vehicle application deployment request a particular application to deploy to the vehicle. Although not illustrated, in some embodiments, a control plane of the vehicle software deployment management system **100** allows customers **122***a*, **122***n* to perform various actions required to deploy one or more vehicle software application as well as update the deployment plans. A control plane of the vehicle software deployment management system **100** may register vehicles, model vehicles (e.g., manage vehicle shadows), and manage data across a single vehicle or a fleet of vehicles. The deployment plan generator **104**, vehicle application storage **106**, and the vehicle application marketplace **108** will be further discussed in FIG. **2** and FIG. **5**.

[0026] In some embodiments, the deployment plan generator **104** may generate a deployment plan for a vehicle software application to be implemented using software included in containers having an Open Container Initiative (OCI) image format. The deployment plan generator **104** may generate a deployment plan **130** that may be processed by an in-vehicle application deployment planner/orchestrator **150** of the vehicle **142** to deploy the particular vehicle software application. In some embodiments, the in-vehicle application deployment planner/orchestrator **150** may include one or more subsystems that processes deployment plans sent from the vehicle software deployment management system **100**, and may create localized ECU execution plans based on metadata that are obtained from the ECUs in the vehicle through one or more ECU agents deployed at the ECUs. In some embodiments, the deployment plan **130** sent to the vehicle may create one or more localized ECU execution plans that are then transmitted by an in-vehicle application deployment planner/orchestrator **150** to respective ECUs. In some embodiments, the execution plans may be transmitted according to a specific sequence to the respective ECUs. The in-vehicle application deployment planner/orchestrator **150** and local execution plans will be further discussed in FIG. **3**.

[0027] In some embodiments, the vehicle application transmission module **112** may ingest one or more vehicle data streams **132** from the vehicles **140**, **142**, **144**, and **146**; decode the ingested one or more vehicle data streams; and transmit a deployment plan and/or vehicle applications to the respective vehicles. As further discussed herein, in some embodiments, the deployment plan may be adjusted based on the information provided in the one or more vehicle data streams **132**. The vehicle application transmission module **112** may furthermore provide a vehicle side software development kit (SDK) or other collection of software development package to interpret deployment plans (or other messages) and interpret the vehicle software application (including OCI images of the application and dependencies) to a vehicle. The vehicle application transmission module **112** may furthermore include a first-in-first-out (FIFO) type queue storing signed serialized data chunks that have been generated based on an aggregated deployment plan. The signed serialized data chunks may be formatted in a way and the vehicle application transmission module may be configured to transmit the signed serialized data chunks such that the signed serialized data chunks can be relayed using any communication protocol/mechanism a customer prefers. The vehicle application transmission module **112** may generate a set of signed serialized data chunks of only the vehicle application, only the deployment plan, or both the

deployment plan and the vehicle application. In some embodiments, the customer **122***a*-**122***n* may indicate the desired size of the data chunks for transmission to the vehicles **140**, **142**, **144**, and **146**. For example, the chunked transmission of a vehicle application and a deployment plan **170** may be determined according to the respective vehicle application deployment requests **124***a*-**124***n* of the respective customers **122***a*-**122***n*. In some embodiments, the chunks may be signed so as to enable verification by the in-vehicle application deployment planner/orchestrator **150** that the received data chunks are sent by a correct entity. In some embodiments, a third-party application may utilize a cloud-side SDK to interact with the vehicle software deployment management system **100** and transmit the signed serialized data chunks to any of the connected vehicles. Furthermore, in some embodiments, the vehicle software deployment management system **100** may communicate with the vehicles using one or more protocols including a Message Queuing Telemetry Transport (MQTT) protocol, a Constrained Application Protocol (CoAP), an Extensible Messaging and Presence Protocol (XMPP), an Advanced Message Queuing Protocol (AMQP), and/or a Data Distribution Service (DDS).

[0028] In some embodiments, in-vehicle application deployment planner/orchestrator **150** may implement a gateway for vehicle **142** to receive the chunked transmission of the vehicle application and the deployment plan **170**. Although not illustrated in detail, the in-vehicle application deployment planner/orchestrator **150** may be implemented in an ECU or other computing unit of the vehicle **142**. The in-vehicle application deployment planner/orchestrator **150** may provide an in-vehicle receive module (such as the in-vehicle receive module **314** discussed in FIG. **3**). Also, the in-vehicle deployment planner **150** may allow the vehicle to process the signed serialized data chunks transmitted through the communication protocol/mechanism utilized to transmit the signed serialized data chunks in a protocol agnostic manner. The in-vehicle application deployment planner/orchestrator **150** may incrementally reconstruct the deployment plan and application packages/container images to be used to implement the in-vehicle application based on the chunked data sent to the vehicle. Once the chunked transmission of the deployment plan and the vehicle application are received, in-vehicle application deployment planner/orchestrator **150** may incrementally reconstruct the deployment plan and the application packages/container images using the received chunks. In some embodiments, the data chunks may be verified and routed to a package manager for application reconstruction (including OCI image reconstruction) and/or an ECU task delegator for the plan execution (as discussed in FIG. **3**-**4**). In some embodiments, the deployment plans may not be processed for execution until the prerequisite OCI images are fully reconstructed in the local repository. In some embodiments, the in-vehicle application deployment planner/orchestrator **150** may use a multi-protocol communication broker to interact with ECU agents in one or more ECUs of the vehicle.

[0029] In some embodiments, a vehicle communications bus **158** of the vehicle **142** may transmit vehicle information sent from various components of a vehicle, such as electronic control unit **152** (ECU #1), electronic control unit **154** (ECU #2), and electronic control unit **156** (ECU #3). Additionally, other components, such as physical sensor #1 **160**, physical sensor #2 **162**, and physical sensor #3 **163** may be connected to one or more of the vehicle communications buses **158** and/or ECUs of the vehicle. In some embodiments the various physical sensors may include audio/visual sensors that obtain audio/visual information and may communicate such information over the vehicle communications bus **138**. In some embodiments, the various physical sensors **160**, **162**, and **164** may include a location sensor that is able to obtain the location of the vehicle. In some embodiments the location sensor may be a Global Positioning System (GPS) using cellular, wireless passive, satellite, and other types of GPS systems. The location sensor may obtain location information that is further processed by the in-vehicle application deployment planner/orchestrator **150** before being transmitted over the network to the vehicle software deployment management system **100**. In some embodiments, the various physical sensors may be connected to multiple vehicle communications buses and/or physical sensors. For example, in the vehicle **142**, physical sensor **162** (physical sensor #2) may be connected to ECU **154** (ECU #2) as well as ECU **156** (ECU #3) via the vehicle communications bus **158**. Various vehicle communications bus **158** connections may provide alternate sensor signal paths. As will be further discussed in FIG. **3** various portions of the vehicle communication buses **158** may be different types of buses and/or buses that use different types in-vehicle communication protocols. The in-vehicle communications protocols used in the vehicle **142** may include a controller area network (CAN) protocol, a remote procedure call (RPC) protocol, a controller area network flexible data-rate (CAN FD) protocol, a low-speed CAN protocol, a high-speed CAN protocol, a Society of Automotive Engineers (SAE) J1939 protocol, a CANopen protocol, and/or an on-board diagnostics (OBD) protocol.

[0030] The various vehicles **140**, **142**, **144**, and **146** may generate vehicle data stream **132** containing various pieces or types of vehicle information that are sent to the vehicle software deployment management system **100**. The in-vehicle application deployment planner/orchestrator **150** may send various diagnostic data for the vehicle **142**, including information generated by the physical sensor #1 (**160**), physical sensor #2 (**162**), and physical sensor #3 (**164**), and/or an ECU configuration of the vehicle **142** including an ECU #1 (**154**), ECU #2 (**156**), and/or ECU #3 (**158**) configuration. The vehicle application transmission module **112** may directly ingest vehicle data stream **132** and decode the information. For example, in some embodiments, the extracted vehicle data may include compressed data such as video frames, images, radar amplitude, temperature data, engine speed, driver's performance, and/or other information about the vehicle that may be decoded into usable vehicle data that may be used by the vehicle software deployment management system **100**. In some embodiments, the vehicle data may be enriched with other vehicle information. The vehicle software deployment management system **100** may utilize the received vehicle information to dynamically generate one or more updated vehicle deployment plans **130** to send to respective vehicles.

[0031] The deployment plan generator **104** of the vehicle software deployment management system **100** may dynamically generate deployment plans that allow for ongoing optimization of deployment configurations for software applications within the respective vehicles. For example, the vehicle **142** may utilize an in-vehicle application deploy-

ment planner/orchestrator **150** to carry out newly optimized deployment plans to manage the application lifecycle and deployment destinations for containers used to implement one or more in-vehicle applications, including various ECUs of the vehicle **142** used to execute code included in the containers as further discussed in FIGS. **5-6**. In some embodiments, the vehicle application deployment planner **150** may source an optimal deployment configuration from the vehicle software deployment management system **100** on an on-going basis and redeploy and/or re-allocate applications based on the dynamically updated deployment plans. One or more customers may determine and/or specify an application to deploy as well as a vehicle configuration to be used to optimize deployment of the application for using the fleet management **102** or the vehicle application marketplace **108**. The deployment plan generator **104** may use a vehicle ECU configuration and diagnostic data, as well as an ML inference generated from vehicle data and other sources to determine an optimized configuration for deployment of an application on the vehicle as further discussed in FIG. **8**. In some embodiments when the vehicle software deployment management system **100** is not able to be connected to the vehicle (e.g., situations where no internet connectivity is available for the vehicle), a localized execution plan may be utilized which prioritizes the availability of safety critical applications over non-safety critical applications.

[0032] In some embodiments, the fleet management **102** can utilize the vehicle data **132** to reconstruct a representation or state of the vehicle in a vehicle simulator, such as a virtual replica of a vehicle. The reconstructed representation may be used to test various vehicle software applications including testing the deployment of the vehicle software application as further discussed in FIG. **5**. Moreover, in-vehicle application deployment planner/orchestrator **150** may use a deployment adapter interface to communicate with the different runtime environments that can be deployed in vehicle ECU partitions such as Autosar Classic, Autosar Adaptive, Android, OCI container frameworks, and/or WASM runtimes as further discussed in FIGS. **6**A-**6**B.

[0033] Please note that the previous description of the vehicle software deployment management system and the in-vehicle application deployment planner/orchestrator is a logical description and thus is not to be construed as limiting as to the particular implementation or portions thereof. This specification continues with various examples of the vehicle software deployment management system and in-vehicle application deployment planner/orchestrator, including different components/modules, or arrangements of components/module that may be employed as part of implementing the system/planner. A number of different methods and techniques to implement protocol agnostic transmission of signed serialized transmission application packages/images and deployment plans are discussed, some of which are illustrated in accompanying flowcharts. A number of different methods and techniques to implement dynamic generation of deployment plans are also discussed, some of which are similarly illustrated in accompanying flowcharts. Finally, a description of an example computing system upon which the various components, modules, systems, devices, and/or nodes may be implemented is provided. Various examples are provided throughout the specification.

[0034] FIG. **2** illustrates a more detailed view of a vehicle software deployment management system, its various parts, and interactions to generate signed serialized data chunks of the vehicle application and/or deployment plan and sending the signed serialized data chunks to a vehicle using a protocol agnostic transmission format, according to some embodiments.

[0035] In FIG. **2**, the vehicle software deployment management system **100** may receive a request to deploy vehicle application **200**. In some embodiments, the request to deploy vehicle application **200** may be the vehicle application deployment request **124***a* from a customer **122***a* as illustrated in FIG. **1** or may be a request to deploy from another client. The request to deploy the vehicle application may indicate to the vehicle software deployment management system **100** a vehicle software application to be deployed to the vehicle **142**. In some embodiments, instead of the request to deploy vehicle application **200**, the vehicle software deployment management system **100** may receive a vehicle application **202** itself from the client/customer in addition to, or instead of, the indication of the vehicle software application to deploy. In some embodiments, the vehicle application **202** may include code included in one or more containers formatted in a OCI image format, to be deployed using a containerized computing environment. For example, the in-vehicle application deployment planner/orchestrator **150** may enable operating system (OS)-level virtualization or an OS paradigm in which a kernel allows the existence of multiple isolated software instances, called containers. The containerized environment may support various interpreted or compiled programming languages such as Ruby, Perl, Python, C, C++ and the like.

[0036] In some embodiments, the vehicle application **204** may be a custom vehicle application sent to the vehicle software deployment management system **100** together with a request to deploy the vehicle application **200**. The vehicle application **204** may be added to the vehicle application storage **106** and/or an external vehicle application storage **106**. The vehicle application storage **106** may be various kinds of object or file data stores for putting, updating, and getting data objects or files, including application packages, such as container images. For example, vehicle application storage **106** may be an object-based data store that allows for different data objects of different formats or types of data, such as vehicle software application files having an OCI format. In some embodiments, the application received may be a set of one or more custom application packages/container images that are not found in the vehicle application storage **206**. The data objects in the vehicle application storage **206** may further include related dependent software packages (dependencies) including dependent OCI images. In some embodiments, the control plane of the vehicle software deployment management system **100** may be accessed via programmatic interfaces (e.g., APIs) or graphical user interfaces to manage the applications stored in the vehicle application storage **106**.

[0037] Once the vehicle software deployment management system **100** receives a request to deploy vehicle application **200**, where the application is identified in the request **200** (or included in the request **200**), the deployment plan generator **104** may generate a deployment plan for deploying the application on the vehicle **208** and that may be used by the in-vehicle application deployment planner/orchestrator **150** to deploy the identified vehicle application as discussed in FIG. **1**. In some embodiments, the vehicle application transmission module **112** may retrieve the

vehicle application packages/container images based on indications included in deployment plan **210**. In some embodiments, the vehicle application transmission module **112** may retrieve a catalog of the vehicle applications stored in the vehicle application storage **106** and retrieve the vehicle application according to the application as described in the catalog and various dependencies further identified in the catalog. In some embodiments, the vehicle application transmission module **112** may retrieve one or more portions of the vehicle application from the external vehicle application storage **214**. Similar to retrieving the applications stored in the vehicle application storage **106**, the vehicle application transmission module **112** may retrieve the vehicle application according to how the application components are described in an external vehicle application storage **206** catalog and various dependencies further identified in the external catalog (e.g., stored in external storage **206**). In some embodiments, the vehicle application **204** may be directly provided to the vehicle application transmission module **112** from the deployment plan generator **104**.

[0038] Once the vehicle application transmission module **112** obtains all of the vehicle application components/images, the vehicle application transmission module **112** may generate data chunks of the vehicle application and/or the deployment plan. The data chunks reduce the size of the individual data packages that must be transmitted and allow greater flexibility in the types of transmission protocols and communication networks that may be used. As discussed in FIG. **1**, the data chunks may be signed and/or serialized and may be received by the in-vehicle application deployment planner/orchestrator **150** to deploy the application in the vehicle **142**. In some embodiments, a specific signature associated with the signed chunks may be recognized by the in-vehicle application deployment planner/orchestrater **150** to verify that the signed chunks are from a correct entity and/or that the signed chunks have been received by a correct vehicle. In some embodiments, the data chunks may be encrypted such that the data chunks are able to be used at a vehicle having access to a correct encryption key but otherwise unusable by non-authorized entities. For example, the in-vehicle application deployment planner/orchestrater **150** may have access to a private key in a secure store such that the vehicle **142** is able to decrypt the encrypted data chunks, whereas other vehicles that are not specifically targeted may be unable to decrypt the data chunks. In some embodiments, the vehicle application transmission module may store the data chunks in a chunked vehicle package transmission queue **212** and send the chunked vehicle application and deployment plan using one or more of the various transmission protocols described in FIG. **1**. In some embodiments, the vehicle application transmission module **112** may send the chunked vehicle application and deployment plan to the vehicle via an external data transmission service (such as a third-party over-the-air (OTA) service). In some embodiments, additional signing/encryption may be used by the external service used to transmit the data chunks. In some embodiments, a separate MQTT service **220** may be used by the vehicle application transmission module to transmit the chunked data. One or more of the data chunks may be sent using a protocol agnostic transmission format that is compatible with a plurality of different transmission protocols used for communications between the vehicle software deployment management system **100** and the vehicle **142**. In some embodiments, the protocol agnostic transmission format may be a format that is compatible with various external data transmission service/OTA services utilizing plurality of different transmission protocols.

[0039] FIG. **3** illustrates a graphical view of an example in-vehicle application deployment planner/orchestrator of a vehicle that receives a deployment from a vehicle software deployment management system and/or receives signed serialized data chunks of a vehicle application to be deployed at the vehicle, wherein the in-vehicle application deployment planner/orchestrator enables deployment of the in-vehicle application in a execution environment the vehicle, according to some embodiments.

[0040] In some embodiments, the in-vehicle application deployment planner/orchestrator **150** may include an in-vehicle receive module **312**, in-vehicle transmit module **314**, a package manager **322**, an ECU task delegator **324**, and a multi-protocol communication module **326**. As discussed in FIG. **1**, the vehicle communications buses **158** may include different types of buses and/or buses that use different types of in-vehicle communication protocols. For example, a first portion of the vehicle communication bus **158***a* may be a FlexRay bus, a second portion of the vehicle communication bus **158***b* may be an Ethernet/IP bus, and a third portion of the vehicle **142** vehicle communication bus **158***a* may be a CAN bus. In some embodiments, there may be multiple CAN buses (e.g., a CAN bus #1 and a CAN bus #2, etc.) and/or a local interconnect (LIN) bus. The vehicle communication buses may utilize the various in-vehicle communications protocols discussed in FIG. **1**. For example, the CAN bus **158***c* may utilize a high-speed CAN protocol.

[0041] As illustrated in FIG. **3**, the in-vehicle receive module **312** may receive the protocol agnostic chunked transmission **216** of the vehicle software application and the corresponding deployment plan generated by the vehicle software deployment management system **100**. The in-vehicle receive module **312** may interface with the various networks that have network connections to the vehicle and receive the chunked transmission from any one or more of the various networks according to various communication protocols. The in-vehicle receive module **312** may send a received deployment plan **330** to the ECU task delegator **324** and send application data **332** to the packager manager. The application data **332** may be organized into chunks of the application and/or chunks of one or more application packages/container images received. The package manager **322** reconstructs the application components (such as container images) using the received application data **332** in order to deploy the application in the vehicle **142**. In some embodiments, the ECU task delegator **324** may monitor the package manager **340** in order to verify the prerequisite application components, such as OCI images, are fully reconstructed before processing the deployment plans and sending one or more deployment instructions **344** to the multi-protocol communication module **326**. The one or more deployment instructions **344** may be one or more execution plans for implementing the vehicle software application at the vehicle based on the received deployment plan.

[0042] In some embodiments, an execution plan may include specific instructions regarding relevant ECUs that are to be used to deploy the application (or a specific component of an application in a case for distributed vehicle software application that is not configured using containers) on the relevant ECUs. The ECU task delegator may generate

individual localized execution plans to deploy the application (or the specific component of the application) for each of the ECUs. For example, the ECU task delegator may instruct the multi-protocol communication module **326** to get a relevant package/image **342** from the package manager **322** to deploy on ECU #1 (**152**) according to the deployment plan, and send the package/image to ECU #1 (**152**) along with ECU deployment instruction **350**. The localized ECU execution plans may be transmitted to the appropriate ECUs, for example instead of being transmitted to all ECUs of the vehicle.

[0043] In some embodiments, the multi-protocol communication module **326** may enable translation of various vehicle communication bus **158** protocols to facilitate transfer of information within the vehicle. For example, the multi-protocol communication module **326** may send the ECU deployment instructions **350** along with a given image to be deployed to ECU #1 over the CAN bus **158***c* utilizing the high-speed CAN protocol. Once sent, a multi-protocol communication module **374** of the ECU agent **370** may receive the localized ECU deployment instructions **350** using the high-speed CAN protocol and allow the deployment plan executor of the ECU agent **370** to deploy the localized ECU deployment instructions.

[0044] In some embodiments, the ECU agent **370** may interact with the underlying components of the ECU #1 provided by a real-time operating system (RTOS) vendor or other a third-party ECU vendor to manage the lifecycle of the vehicle application. Furthermore, in some embodiments, the ECU agent **370** may provision various Container Network Interfaces (CNI) plugins **372** that extend capabilities of the ECU #1, such as enabling GPU sharing extensions, shared memory extensions, zero-copy inter process communication (IPC) extensions, etc. for the ECU #1. The multi-protocol communication module **326** may inform the ECU task delegator with a status **346** sent from the ECU agent **370** as to the status of the ECU (including the deployment status of the application). The ECU task delegator **324** may send a status message **338** to be sent from the vehicle **142** to one or more recipients. A protocol agnostic transmission **360** that contains the vehicle status may be sent by the in-vehicle transmit module **314** to the vehicle software deployment management system **100** or other recipients. The in-vehicle transmit module **314** may be similar to the in-vehicle receive module **312** in supporting various transmission protocols described in FIG. **1**. In some embodiments, the separate MQTT service **220** may be used by the vehicle application transmission module to transmit the chunked data as discussed in FIG. **2**. In some embodiments, the transmission **360** may be divided into data chunks by the in-vehicle transmit module **314** and sent using a protocol agnostic transmission format that is compatible with a plurality of different transmission protocols used for communications between the vehicle **142** and the vehicle software deployment management system **100**. Although FIG. **3** illustrates the in-vehicle application deployment planner/orchestrator **150** interacting with only ECU #1 **152**, this is by way of example, and the in-vehicle application deployment planner/orchestrator **150** may be connected various other ones of the ECUs, sensors, and other vehicle components and may send respective ECU deployment instructions.

[0045] FIG. **4** illustrates a more detailed view of an in-vehicle application deployment planner/orchestrator for a vehicle and use of conditional rules of a deployment plan to deploy a vehicle software application, according to some embodiments.

[0046] In some embodiments, the localized ECU execution plans that were discussed in FIG. **3** may be generated based on ECU environment metadata obtained from the ECU agents deployed on the various ECUs. For example, the in-vehicle application deployment planner/orchestrator **150** may receive a deployment plan **400** from the vehicle software deployment management system **100**. Subsequent to generation of the localized execution plan to deploy the application to ECU #1 (**152**) as discussed in FIG. **3**, the application may fail to deploy. In some embodiments, a metadata generated by the ECU #1 (**152**) indicating a deployment failure **404** may be communicated to the in-vehicle application deployment planner/orchestrator **150**. Based on the metadata received, the ECU task delegator **324** may generate another localized execution plan to deploy the application in a contingent deployment location A (**410***a*) in ECU #2 **154**. In some embodiments, the ECU task delegator **324** may incorporate various other metadata in addition to an indication of failure to deploy an application, such as metadata indicating an ECU processing environment, including a capacity of compute resources of the ECU, types of containers the ECU supports, configurations of other applications deployed to the ECU, such as other containers implemented on the ECU, a number of CPU cores, memory, cache, storage, etc. of the ECU as well as any other performance characteristic of the ECU. For example, the ECU task delegator **324** may determine that instead of contingent deployment location A **410***a*, that the application is to be deployed to contingent deployment location B (**410***b*) in ECU #3 **156** upon determination that ECU #2 (**154**) would not provide a suitable processing environment when compared with ECU #3 (**156**). In some embodiments, other vehicle metadata may be used to determine the localized execution plan including sensor data and vehicle communications bus **158** metadata. For example, the ECU task delegator **324** may attempt to redeploy the application to ECU #1 (**152**) subsequent to receiving metadata regarding a disconnected communications bus **412** connecting ECU #3 **156** to the ECU task delegator **324**.

[0047] In some embodiments, the ECU task delegator **324** may determine the localized execution plans based on conditional rules **402** provided in the deployment plan **400**. For example, a conditional rule may state a pre-determined ECU as a contingent deployment location to be used for a given one of the container images (in instances wherein OCI container images are used) in response to a failure of deployment of that given container image. In some embodiments, the conditional rule may indicate a contingent deployment location for a given container image in response to a successful deployment of another one of the container images in the ECU of the plurality of ECUs. For example, upon a successful deployment of application to ECU #1, another application may be configured to be deployed to ECU #2. In some embodiments, the conditional rule may indicate selecting a deployment location for a given container image based on respective states, characteristics, and/or configurations of the ECUs of the vehicle. Various other conditional rules may determine how one or more application may be deployed.

[0048] FIG. **5** illustrates a more detailed view of a vehicle software deployment management system, its various parts,

and interactions to dynamically generate and send, based on streams of vehicle data, deployment plans for deploying a vehicle software application, according to some embodiments.

[0049] In some embodiments, a vehicle software deployment management system **100** may receive a request to deploy one or more vehicle applications **200**. In some embodiments, the request **200** may be received by the fleet management **102** that tracks and manages one or more vehicles of a fleet of vehicles that the given application may be deployed to. The request may indicate the vehicle(s) to deploy the one or more application to, including a virtual vehicle generated by a vehicle simulator **510** of the vehicle software deployment management system **100** or vehicles to be used as test environments. For example, the fleet management **102** of the vehicle software deployment management system **100** may test deployment of the application on a fleet of vehicles **521** that are specifically marked as test environments by sending a deployment plan and vehicle application to the test fleet. For example, based on the request **200**, the fleet management may request the deployment plan generator **104** to generate one or more deployment plans for the selected vehicles. Thus, as illustrated in FIG. **5**, the deployment plan generator **104** may transmit the deployment plan and vehicle application **506** to the vehicle **142**. In some embodiments, the deployment plan and/or the vehicle application may be transmitted as signed serialized data chunks as discussed in FIG. **2**.

[0050] The vehicle **142**, in some embodiments, may generate and send ECU configuration and vehicle diagnostic data streams to the deployment plan generator **104**. The deployment plan generator **104** may determine that a more optimal vehicle application configuration is available, and may dynamically generate, based on streams of vehicle data, deployment plans for deploying a vehicle software application, according to some embodiments. The data stream **508** may include the vehicle data as discussed in FIG. **4** and ECU status discussed in FIG. **3**. The deployment plan generator **104** may determine that a threshold level of improvement in application reliability, processing efficiency, processing speed, and/or another optimization criteria of the vehicle **142** is available. Subsequent to determination that a threshold level of improvement of the vehicle **142** is met, the deployment plan generator **104** may generate and send an updated deployment plan and vehicle application based on the vehicle data stream **514**. For example, the deployment plan generator **104** may determine that based on a vehicle diagnostic data that a portion of the vehicle communications bus is not available and send an updated deployment plan that re-deploys the vehicle application to another ECU. In some embodiments, prior to sending the updated deployment plan and vehicle application, the deployment plan generator **104** may request certification of the deployment plan **513**. For example, the deployment plan generator **104** may send a request that includes the deployment plan, vehicle application, application dependencies, vehicle metadata, and/or application test results to a certification destination, and the certification destination may initiate its own separate internal certification workflow to determine whether the deployment plan should be certified and allowed to be deployed. In some embodiments, the certification destination may reject the deployment plan and request the deployment plan generator **104** to generate another deployment plan having a different application deployment sequence or configuration, such that certification can be met.

[0051] In some embodiments, the deployment plan generator **104** may perform dependency tracking/verification in order to determine whether the deployment plan is certified to be deployed to the vehicle. For example, vehicle applications may be deployed as groups where there exists certain interdependencies between the applications (and/or components of the applications) in the group. The deployment plan generator **104** may generate one or more dependency graphs that track changes made to the applications deployed in the vehicle. The dependency graph may track the effects of various changes to the dependencies as the applications are replaced, upgraded, or removed over time. The deployment plan generator **104** may also track and/or ensure that such changes do not violate conditions upon which certification relied for already installed vehicle software applications. Also, prior to deployment of a new vehicle software application, the deployment plan generator **104** may use the dependency graph to verify that the deployment based on the deployment plan will not negatively affect the listed dependencies or otherwise violate a condition upon which certification relies. In this way, deployment of the application may be cleared with regard to certification based on a determination that the deployment will not break any of the listed dependencies from the dependency graph. A certification process that involves dependency tracking/verification may prevent potential breakage of various dependencies and prevent application deployment failure before it occurs in the vehicle.

[0052] In some embodiments, the application may be obtained from the vehicle application storage **106** and/or external vehicle application storage **206** as discussed in FIG. **2**. In some embodiments, the request to deploy vehicle application **200** may be indicated to the vehicle application marketplace **108**. The request to deploy **200** may be based on a catalog of applications that are marked available for a particular vehicle model or a particular vehicle configuration. For example, the vehicle application marketplace **108** may indicate to a client or a customer of the vehicle software deployment management system **100** a list of applications that are available to be deployed. In some embodiments, subsequent to selection of an application from the list of applications, the vehicle application marketplace may obtain feasible deployment options **520** from the deployment plan generator. For example, the deployment plan generator **104** may obtain various deployment options that meet various ones of optimization criteria (e.g., application reliability, processing efficiency, and processing speed). The vehicle application marketplace **108** may request selection of feasible deployment option **522** to the client and/or customers. In some embodiments, the request to select feasible deployment option **522** may be sent to the client that sent the request to deploy the vehicle application **200** to the vehicle software deployment management system **100**. In some embodiments, the deployment plan generator **104** may determine that no feasible vehicle software applications are able to be deployed in the vehicle. In some embodiments, the feasible deployment plan option may include the one or more feasible deployment options that includes an option to change one or more of: an arrangement of vehicle software deployed in the vehicle, a collection of vehicle software deployed in the vehicle, and/or a specification of a vehicle hardware component.

[0053] In some embodiments, a vehicle simulator **510** may create a vehicle replica **512** based on the vehicle **142** information obtained by the deployment plan generator **104**. The vehicle simulator **510** and the vehicle replica generated may be used to test deployment of vehicle application **520**. In some embodiments, the testing of deployment of the application using a deployment plan may be based on the initial request to deploy vehicle application **200**. Although FIG. **5** illustrates one updated deployment plan sent to the vehicle **142**, there may be any number of dynamic updates to the deployment plan sent to the vehicle **142** based on the ECU configuration and vehicle diagnostic data streams obtained.

[0054] FIG. **6**A illustrates a more detailed view of an in-vehicle application deployment planner/orchestrator of a vehicle that uses deployment plan received from a vehicle software deployment management system to deploy a vehicle application, wherein the in-vehicle application deployment planner/orchestrator also sends a stream of ECU configuration and vehicle diagnostic data from ECUs of the vehicle back to the vehicle software deployment management system for use in dynamically updating the deployment plan for the vehicle, according to some embodiments. In some embodiments, a deployment plan for an application, such as application D **602** may be received by a vehicle data receive module **604** that receives the deployment plan and the required application packages. In some embodiments, the application received may be application images in OCI image format and the vehicle data receive module **604** may be an over-the-air (OTA) agent that receives the deployment plan for application D wirelessly. In some embodiments, the vehicle data receive module **604** may be similar to the in-vehicle receive module **312** as discussed in FIG. **3**.

[0055] Subsequent to receiving the deployment plan for application D, the ECU task delegator may obtain the deployment plan to generate and/or relay localized execution plans **605**. In some embodiments, the deployment plan may contain all of the relevant localized instructions and/or execution plans for the in-vehicle deployment planner/orchestrator **150** to relay to relevant vehicle components (such as ECUs) in order to deploy the vehicle software application. In some embodiments, the relaying of the localized execution plans may not be restricted to unmodified transmission of the localized execution plans generated by the deployment plan generator **104**, but may also include making modifications to the localized execution plans including reassembling, decompressing, reformatting of the localized execution plans, etc. In some embodiments, the in-vehicle deployment planner/orchestrator **150** may receive a partial deployment plan containing localized execution plans for a portion of the vehicle software application and localized execution plans for a remaining portion of the vehicle software application may be generated by the in-vehicle deployment planner/orchestrator **150** as discussed in FIGS. **3-5**. The multi multi-protocol communication module **326** may deploy application D **608** to the ECU #1 (**152**) such that ECU #1 (**152**) has vehicle application A **620***a* and vehicle application D **620***d* deployed. The deployment may occur via one or more vehicle communication buses using one or more communication protocols as discussed in FIG. **3**. The various ECUs may furthermore contain various vehicle applications currently deployed, such as vehicle application B **620***b* in ECU #2 (**154**) and vehicle application C **620***c* in ECU #3 (**156**). Upon successful deployment of vehicle application D **620***d*, ECU #1 may send an ECU configuration from deployment of application D **610** to the vehicle data transmission module **612**. In some embodiments, the vehicle data transmission module **612** may be similar to the in-vehicle transmit module **314** as discussed in FIG. **3** and/or may be a transmission module able to communicate with the vehicle software deployment management system **100** via a plurality of communication protocols as discussed in FIG. **2**.

[0056] In addition to the ECU configuration from deployment of application D **610**, in some embodiments, the vehicle data transmission module **612** may receive ECU configuration and vehicle diagnostic data from ECU #2 and ECU #3 **612** and may send the data to vehicle software deployment management system **100** as data stream **508**. As discussed in FIG. **5**, based on the data stream **508** and subsequent to determination that a threshold optimization of the vehicle **142** is met, an updated deployment plan may be generated and sent to the vehicle that may further result in a redeployment of application D.

[0057] FIG. **6**B illustrates a more detailed view of an in-vehicle application deployment planner/orchestrator of a vehicle that redeploys vehicle applications in various ECUs based on an updated deployment plan from the vehicle software deployment management system, according to some embodiments. In some embodiments, the vehicle data receive module **604** may receive an updated deployment plan **630**. The vehicle software deployment management system **100** may receive the data stream **508** and dynamically generate the updated deployment plan **630**. The ECU task delegator **324** may obtain the updated deployment plan to generate and/or relay localized execution plans **631**.

[0058] In some embodiments, the localized execution plans may include one or more operations to remove application D **632** from ECU #1. The localized execution plan may furthermore include plans to redeploy not only application D **620** to ECU #2 as illustrated, but may include multiple respective localized execution plans for the respective ECUs to redistribute vehicle application A, B, C, and D **634**. For example, the updated deployment plan may redeploy previously deployed vehicle application B from ECU #2 **154** to ECU #1 **152**. In some embodiments, the various vehicle applications A **620***a*, B **620***b*, C **620***c*, and D **620***d*, may be sub-components of a distributed vehicle software application and may be redistributed according to the updated deployment plan.

[0059] FIG. **7** illustrates a more detailed view of an in-vehicle application deployment planner/orchestrator of a vehicle that uses an alternative localized execution plan that prioritizes availability of safety critical applications over non-safety critical applications, according to some embodiments. In some embodiments, the vehicle data receive module **604** may detect that connection to the network is unavailable **702**. For example, the vehicle data receive module **604** may determine that one or more of the wireless networks that the vehicle uses to receive data, such as a cellular network, Wi-Fi network or other wireless network is not available. Subsequent to the detection **702**, the ECU task delegator **324** may enable a localized execution plan **706** to be used while the network connection is unavailable. In some embodiments, instead of detecting that the connection to the network is unavailable, the vehicle data receive module **604** may detect that connection to the vehicle software deployment management system **100** is not avail-

able or that the communication quality or speed has degraded beyond a threshold level.

[0060] In some embodiments, the ECU task delegator **324** may contain emergency localized execution plan **704** and may generate an additional localized execution plan that deploys safety critical application over non-safety critical applications **710**. The emergency localized execution plan **704** may be a part of the ECU task delegator **324** or may be received from the vehicle software deployment management system **100**. For example, in the illustrated vehicle **142**, the safety critical applications A **720***a*, applications B **720***b*, and applications C **720***c* may be deployed in ECU #1 **152**, ECU #2 **154**, and ECU #3 **156** respectively over the original vehicle applications A **620***a*, B **620***d*, and C **620***c*. In some embodiments, safety-critical applications may include features that impact passenger safety (such as airbag deployment application) and/or critical vehicle performance features (such as brake control application). In some embodiments, non-safety critical applications may include various infotainment applications and/or fuel efficiency applications. The emergency localized execution plan may include prior determination as to which applications are considered safety-critical and/or non-safety critical.

[0061] FIG. **8** illustrates a vehicle software deployment management system dynamically generating deployment plan for vehicle applications based on various vehicle/vehicle fleet data streams and machine learning (ML) models, according to some embodiments. In some embodiments, ECU configuration and vehicle diagnostic data stream from the fleet of vehicles **802** may be sent over the network **120** to the vehicle application transmission module **112**. Subsequent to receiving the data stream from the fleet **802**, the vehicle application transmission module **112** may send vehicle data **806** to the vehicle data ML inference module **110** that generates ML inferences **808**. The generated ML inferences **808** may be used by the deployment plan generator **104** to determine the optimal application deployment configuration and generate deployment plans.

[0062] In some embodiments, using the vehicle data **806** from the fleet, the vehicle data ML inference module may train one or more ML models to generate one or more ML inferences. For example, based on the vehicle data **806**, the trained ML model may make an inference indicating a negative impact of deployment of a particular application to a particular ECU environment. The deployment plan generator **104** may use the ML inference to generate and send a deployment plan based, at least in part, on the generated ML inference **810**. The vehicle application transmission module **112** may send the deployment plan for the vehicle/fleet based on the ML inference **812** as discussed in FIGS. **5-6**. In some embodiments, the vehicle data ML inference module **110** may train the one or more ML models based on current and historical updates to the ECU configuration and diagnostic data of the vehicle **804** sent from the vehicle **142**. The vehicle application transmission module **112** may send an updated deployment plan for the vehicle **814** based on the ML inference obtained from the ML model using the current and historical updates to the ECU configuration and diagnostic data of the vehicle **804**.

[0063] FIG. **9** illustrates a flowchart of operations performed by a vehicle software deployment management system to send signed serialized data chunks of a vehicle software application images and/or a deployment plan for the software application to vehicles using a protocol agnostic transmission format, according to some embodiments.

[0064] At block **910**, a vehicle application deployment planner generates a deployment plan for a set of application packages for use in implementing a vehicle software application. In some embodiments, the application packages may be container images that are obtained from an external image repository as discussed in FIG. **2**. In some embodiments, the application packages may be container images according to an Open Container Image (OCI) format.

[0065] At block **920**, the vehicle application deployment planner generates data chunks for the set of application packages that are configured to be reconstructed by a vehicle application deployment planner of a vehicle. In some embodiments, the data chunks may be stored in a first in first out (FIFO) type queue in the vehicle application deployment planner as discussed in FIGS. **1** and **2**. However, in some embodiments, other queue sequencing may be used.

[0066] At block **930**, the vehicle application deployment planner sends the deployment plan and the data chunks to the vehicle. The deployment plan causes the vehicle application deployment planner to generate an execution plan for implementing the vehicle software application based on the deployment plan, and causes the vehicle application deployment planner to, upon determination of full reconstruction of the data chunks for the set of application packages, carry out the execution plan to implement the vehicle software application at the vehicle in accordance with the deployment plan.

[0067] FIG. **10** illustrates a flowchart of operations performed by an in-vehicle application deployment planner/orchestrator of a vehicle to carry out execution of a plan to implement a vehicle software application, wherein the execution plan is generated by the in-vehicle application deployment planner/orchestrator based on a received deployment plan for the in-vehicle application, according to some embodiments.

[0068] At block **1010**, an in-vehicle application deployment planner/orchestrator receives a deployment plan for a set of application packages for use in implementing a vehicle software application and also receives data chunks for the set of application packages configured to be reconstructed by a vehicle application deployment planner of a vehicle. In some embodiments, data chunks may be received in a protocol agnostic transmission format that is compatible with different transmission protocols as discussed in FIGS. **1** and **2**.

[0069] At block **1020**, the in-vehicle application deployment planner/orchestrator generates an execution plan for implementing the vehicle software application at the vehicle based on the received deployment plan via a vehicle application deployment planner.

[0070] At block **1030**, the in-vehicle application deployment planner/orchestrator reconstructs the data chunks. In some embodiments, the data chunks may be queued in a package manager **322** as discussed in FIG. **3**.

[0071] At block **1040**, the in-vehicle application deployment planner/orchestrator determines that the set of application packages are fully reconstructed from the received data chunks.

[0072] At block **1050**, the in-vehicle application deployment planner/orchestrator carries out the execution plan to implement the vehicle software application at the vehicle in accordance with the deployment plan.

[0073] FIG. **11** illustrates a flowchart of operations performed by a vehicle software deployment management system to dynamically generate and send, based on streams of vehicle data, deployment plans for deploying the vehicle software application, according to some embodiments.

[0074] At block **1110**, a vehicle application deployment planner receives a stream of vehicle data that includes updates indicating an electronic control unit (ECU) configuration for a vehicle and/or diagnostic data of the vehicle. In some embodiments, vehicle data received may include one or more of a capacity of compute resources of the ECU, types of containers the ECU supports, configurations of other applications deployed to the ECU as discussed in FIG. **4**.

[0075] At block **1120**, the vehicle application deployment planner dynamically generates, based on the ECU configuration and/or the diagnostic data indicated in the stream, the deployment plan for the vehicle software application.

[0076] At block **1130**, the vehicle application deployment planner sends, based on a request to deploy to the vehicle a vehicle software application, a deployment plan that generates and/or relays localized execution plans for deploying the vehicle software application and implements the localized execution plans. In some embodiments, the deployment plan may be sent based on receiving a certification from a certification destination that performs a certification workflow as discussed in FIG. **5**.

[0077] FIG. **12** illustrates a flowchart of operations performed by an in-vehicle application deployment planner/orchestrator of a vehicle to carry out an execution plan to implement a vehicle software application according to a dynamically generated deployment plan received by an in-vehicle application deployment planner/orchestrator, according to some embodiments.

[0078] At block **1210**, an in-vehicle application deployment planner/orchestrator sends from a vehicle of a fleet of vehicles to the dynamic vehicle software deployment planner, a stream of vehicle data indicating an electronic control unit (ECU) configuration of the vehicles of the fleet and/or indicating diagnostic data of the vehicles of the fleet.

[0079] At block **1220**, the in-vehicle application deployment planner/orchestrator receives a deployment plan for a distributed vehicle software application that has been dynamically generated, based on the indications of the stream, by a cloud-based dynamic vehicle software deployment planner. In some embodiments, the deployment plan received by the in-vehicle application deployment planner/orchestrator may be a deployment plan that was optimized for the vehicle based on historical data of the vehicle and/or a fleet of vehicles, as discussed in FIG. **5** and FIG. **8**.

[0080] At block **1230**, the in-vehicle application deployment planner/orchestrator generates and/or relays localized execution plans for deploying the distributed vehicle software application based on the deployment plan. In some embodiments, the localized execution plans may be relayed only to the appropriate ECUs instead of being transmitted to all ECUs of the vehicle as discussed in FIG. **3**.

[0081] At block **1240**, the in-vehicle application deployment planner/orchestrator implements the execution plans at the vehicle to install the distributed vehicle software application on the vehicle.

Example Computer System

[0082] Any of various computer systems may be configured to implement processes associated with a vehicle software deployment management system, in-vehicle application deployment planner/orchestrator, an operating system in a vehicle or device, or any other component of the above figures. For example, FIG. **13** illustrates a block diagram illustrating an example computer system that implements some or all of the techniques described herein, according to some embodiments. In various embodiments, the vehicle software deployment management system, the provider network that implement the vehicle software deployment management system and other cloud services, the operating system in a vehicle or device, or any other component of the above figures FIGS. **1-12** may each include one or more computer systems **1300** such as that illustrated in FIG. **13**.

[0083] In the illustrated embodiment, computer system **1300** includes one or more processors **1310** coupled to a system memory **1320** via an input/output (I/O) interface **1330**. Computer system **1300** further includes a network interface **1340** coupled to I/O interface **1330**. In some embodiments, computer system **1300** may be illustrative of servers implementing enterprise logic or that provide a downloadable application, while in other embodiments servers may include more, fewer, or different elements than computer system **1300**.

[0084] In various embodiments, computing device **1300** may be a uniprocessor system including one processor or a multiprocessor system including several processors **1310***a*-**1310***n* (e.g., two, four, eight, or another suitable number). Processors **1310***a*-**1310***n* may include any suitable processors capable of executing instructions. For example, in various embodiments, processors **1310***a*-**1310***n* may be processors implementing any of a variety of instruction set formats (ISAs), such as the x86, PowerPC, SPARC, or MIPS ISAs, or any other suitable ISA. In some embodiments, processors **1310***a*-**1310***n* may include specialized processors such as graphics processing units (GPUs), application specific integrated circuits (ASICs), etc. In multiprocessor systems, each of processors **1310***a*-**1310***n* may commonly, but not necessarily, implement the same ISA.

[0085] System memory **1320** may be configured to store program instructions and data accessible by processor(s) **1310***a*-**1310***n*. In various embodiments, system memory **1320** may be implemented using any suitable memory technology, such as static random-access memory (SRAM), synchronous dynamic RAM (SDRAM), nonvolatile/Flash-type memory, or any other type of memory. In the illustrated embodiment, program instructions and data implementing one or more desired functions, such as those methods, techniques, and data described above, are shown stored within system memory **1320** as code (e.g., program instructions) **1325** and data storage **1335**.

[0086] In one embodiment, I/O interface **1330** may be configured to coordinate I/O traffic between processors **1310***a*-**1310***n*, system memory **1320**, and any peripheral devices in the device, including network interface **1340** or other peripheral interfaces. In some embodiments, I/O interface **1330** may perform any necessary protocol, timing, or other data transformations to convert data signals from one component (e.g., system memory **1320**) into a format suitable for use by another component (e.g., processor **1310**). In some embodiments, I/O interface **1330** may include support for devices attached through various types of peripheral

buses, such as a variant of the Peripheral Component Interconnect (PCI) bus standard or the Universal Serial Bus (USB) standard, for example. In some embodiments, I/O interface **1330** may include support for devices attached via an automotive CAN bus, etc. In some embodiments, the function of I/O interface **1330** may be split into two or more separate components, such as a north bridge and a south bridge, for example. Also, in some embodiments some or all of the functionality of I/O interface **1330**, such as an interface to system memory **1320**, may be incorporated directly into processors **1310***a*-**1310***n*.

[0087] In some embodiments, the network interface **1340** may be coupled to I/O interface **1330**, and one or more input/output devices **1350**, such as cursor control device **1360**, keyboard **1370**, and display(s) **1380**. In some cases, it is contemplated that embodiments may be implemented using a single instance of computer system **1300**, while in other embodiments multiple such computer systems, or multiple nodes making up computer system **1300**, may be configured to host different portions or instances program instructions as described above for various embodiments. For example, in one embodiment some elements of the program instructions may be implemented via one or more nodes of computer system **1300** that are distinct from those nodes implementing other elements.

[0088] Network interface **1340** may be configured to allow data to be exchanged between computing device **1300** and other devices associated with a network or networks. In various embodiments, network interface **1340** may support communication via any suitable wired or wireless general data networks, such as types of Ethernet networks, cellular networks, Bluetooth networks, Wi-Fi networks, Ultra-wideband Networks, for example. Additionally, network interface **1340** may support communication via telecommunications/telephony networks such as analog voice networks or digital fiber communications networks, via storage area networks such as Fibre Channel SANs, or via any other suitable type of network and/or protocol.

[0089] In some embodiments, system memory **1320** may be one embodiment of a computer-readable (e.g., computer-accessible) medium configured to store program instructions and data as described above for implementing embodiments of the corresponding methods, systems, and apparatus. However, in other embodiments, program instructions and/or data may be received, sent, or stored upon different types of computer-readable media. Generally speaking, a computer-readable medium may include non-transitory storage media or memory media such as magnetic or optical media, e.g., disk or DVD/CD coupled to computing device **1300** via I/O interface **1330**. One or more non-transitory computer-readable storage media may also include any volatile or nonvolatile media such as RAM (e.g., SDRAM, DDR SDRAM, RDRAM, SRAM, etc.), ROM, etc., that may be included in some embodiments of computing device **1300** as system memory **1320** or another type of memory. Further, a computer-readable medium may include transmission media or signals such as electrical, electromagnetic, or digital signals, conveyed via a communication medium such as a network and/or a wireless link, such as may be implemented via network interface **1340**. Portions or all of multiple computing devices such as that illustrated in FIG. **13** may be used to implement the described functionality in various embodiments; for example, software components running on a variety of different devices and servers may collaborate to provide the functionality. In some embodiments, portions of the described functionality may be implemented using storage devices, network devices, or various types of computer systems. The term "computing device" and "ECU" as used herein, refers to at least all these types of devices, and is not limited to these types of devices.

[0090] The various methods as illustrated in the figures and described herein represent illustrative embodiments of methods. The methods may be implemented manually, in software, in hardware, or in a combination thereof. The order of any method may be changed, and various elements may be added, reordered, combined, omitted, modified, etc. For example, in one embodiment, the methods may be implemented by a computer system that includes a processor executing program instructions stored on a computer-readable storage medium coupled to the processor. The program instructions may be configured to implement the functionality described herein (e.g., the functionality of the data transfer tool, various services, databases, devices and/or other communication devices, etc.).

[0091] Various modifications and changes may be made as would be obvious to a person skilled in the art having the benefit of this disclosure. It is intended to embrace all such modifications and changes and, accordingly, the above description to be regarded in an illustrative rather than a restrictive sense.

[0092] Various embodiments may further include receiving, sending, or storing instructions and/or data implemented in accordance with the foregoing description upon a computer-accessible medium. Generally speaking, a computer-accessible medium may include storage media or memory media such as magnetic or optical media, e.g., disk or DVD/CD-ROM, volatile or nonvolatile media such as RAM (e.g., SDRAM, DDR, RDRAM, SRAM, etc.), ROM, etc., as well as transmission media or signals such as electrical, electromagnetic, or digital signals, conveyed via a communication medium such as network and/or a wireless link.

What is claimed is:

1. A system, comprising:

one or more computing devices configured to implement a vehicle software deployment management system configured to:

generate a deployment plan for a set of application packages for use in implementing a distributed vehicle software application;

generate signed serialized data chunks for the set of application packages, wherein the signed serialized data chunks are configured to be used by a vehicle application deployment planner of a vehicle to reconstruct the set of application packages; and

send the deployment plan and the signed serialized data chunks to the vehicle, wherein the deployment plan comprises instructions that, when executed, cause the vehicle application deployment planner to:

generate an execution plan for implementing the distributed vehicle software application at the vehicle based on the deployment plan; and

upon determination of full reconstruction of the application packages, carry out the execution plan to implement the distributed vehicle software application at the vehicle in accordance with the deployment plan.

2. The system of claim **1**, wherein the vehicle software deployment management system is further configured to:

receive, from a client, prior to the generating the deployment plan for the set of application packages, deployment instructions comprising one or more indications of application packages to be included in the set of application packages; and

retrieve, from one or more application package registries accessible by the vehicle software deployment management system, the set of application packages indicated to the vehicle deployment software management system by the client.

3. The system of claim **1**, wherein the deployment plan for the distributed vehicle software application comprises, for use in implementing the distributed vehicle software application at the vehicle:

one or more indications of deployment dependencies between respective ones of the set of the application packages; or

conditional rules for deployment of respective ones of the set of application packages.

4. The system of claim **1**, wherein respective ones of the application packages of the set of application packages are formatted according to an Open Container Initiative (OCI) format.

5. A method, comprising:

generating, via a vehicle software management system, a deployment plan for a set of application packages for use in implementing a vehicle software application;

generating data chunks for the set of application packages, wherein the data chunks are configured to be used by a vehicle application deployment planner of a vehicle to reconstruct the set of application packages; and

sending the deployment plan and the data chunks to the vehicle, wherein the deployment plan comprises instructions that, when executed, cause the vehicle application deployment planner to:

generate an execution plan for implementing the vehicle software application at the vehicle based on the deployment plan; and

upon determination of full reconstruction of the set of application packages, carry out the execution plan to implement the vehicle software application at the vehicle in accordance with the deployment plan.

6. The method of claim **5**, further comprising:

receiving, from a client, prior to generating the deployment plan for the set of application packages, deployment instructions comprising one or more indications of application packages to be included in the set of application packages.

7. The method of claim **6**, further comprising:

retrieving, from one or more application package storage locations accessible by the vehicle software management system, the set of application packages indicated by the client.

8. The method of claim **7**, further comprising:

receiving, from a client of the vehicle software management system, one or more client-provided custom application packages; and

storing in the one or more container storage locations the one or more client-provided custom application packages,

wherein at least a portion of the set of application packages retrieved for deployment include the one or more client-provided custom application packages.

9. The method of claim **5**, wherein the deployment plan for the vehicle software application comprises, for use in implementing the vehicle software application at the vehicle:

one or more indications of deployment dependencies between respective ones of the set of the application packages; or

conditional rules for deployment of respective ones of the set of application packages.

10. The method of claim **5**, wherein application packages of the set of application packages are formatted according to an Open Container Initiative (OCI) format.

11. The method of claim **5**, wherein the deployment plan and the data chunks sent to the vehicle are sent using a protocol agnostic transmission format that is compatible with a plurality of different transmission protocols used for communications between a given remote server and a given vehicle.

12. The method of claim **11**, wherein the plurality of different transmission protocols with which the protocol agnostic format is compatible comprises, at least:

a Message Queue Telemetry Transport (MQTT) protocol.

13. One or more non-transitory, computer-readable storage media, storing program instructions that when executed on or across one or more processors cause the one or more processors to implement:

receiving, from a vehicle software deployment management system:

a deployment plan for implementing a vehicle software application at a vehicle; and

data chunks representing a set of application packages to be used to implement the vehicle software application at the vehicle, wherein the data chunks are configured to be used at the vehicle to reconstruct the set of application packages;

generating, via a vehicle application deployment planner, an execution plan for implementing the vehicle software application at the vehicle based on the received deployment plan;

reconstructing, at the vehicle, using the data chunks, the application packages for the vehicle software application; and

upon determination of full reconstruction of the application packages for the vehicle software application, carrying out the execution plan to implement the vehicle software application at the vehicle in accordance with the deployment plan.

14. The one or more non-transitory, computer-readable storage media of claim **13**, wherein said carrying out the execution plan comprises:

determining, based on the deployment plan, respective electronic control units (ECUs) of a plurality of ECUs of the vehicle that are to be used to execute code included in the respective application packages of the set of application packages; and

transmitting the respective application packages to the corresponding respective ECUs.

15. The one or more non-transitory, computer-readable storage media of claim **14**, wherein the respective application packages are transmitted to the corresponding respective ECUs via a plurality of different in-vehicle communication protocols comprising two or more of:

a controller area network (CAN) protocol;

a remote procedure call (RPC) protocol;

a controller area network flexible data-rate (CAN FD) protocol;

a low-speed CAN protocol;

a high-speed CAN protocol;

a Society of Automotive Engineers (SAE) J1939 protocol;

a CANopen protocol; or

an on-board diagnostics (OBD) protocol.

16. The one or more non-transitory, computer-readable storage media of claim **14**, wherein said transmitting the respective application packages to the corresponding respective ECUs comprises sequentially transmitting the respective application packages to the respective ECUs according to a deployment sequence as defined in the deployment plan.

17. The one or more non-transitory, computer-readable storage media of claim **13**, wherein the program instructions that when executed cause the one or more processors to further implement:

generating, by the vehicle application deployment planner, for respective ones of the ECUs, a respective localized ECU execution plan for deploying respective ones of the application packages at the respective ones of the ECUs, wherein the localized ECU execution plans are generated based, at least in part, on metadata describing respective execution environments of the respective ones of the ECUs; and

sending the respective localized ECU execution plans to the respective ones of the ECUs.

18. The one or more non-transitory, computer-readable storage media of claim **13**, wherein the deployment plan comprises conditional rules for the deployment of the set of application packages, wherein the conditional rules comprise one or more of:

a conditional rule comprising a contingent deployment location to be used for a given one of the application packages in response to a failure of deployment of the given application package or another application package in an electronic control units (ECUs) of a plurality of ECUs of the vehicle;

a conditional rule comprising a contingent deployment location for a given application package in response to a successful deployment of another one of the application packages in the ECU of the plurality of ECUs; or

a conditional rule for selecting a deployment location for a given application package based on respective states, characteristics, and/or configurations of respective ones of the ECUs of the vehicle.

19. The one or more non-transitory, computer-readable storage media of claim **13**, wherein the received deployment plan and the received data chunks are transmitted to the vehicle application deployment planner using a protocol agnostic chunked transmission, wherein the protocol agnostic chunked transmission is compatible with a plurality of different server to vehicle transmission protocols.

20. The one or more non-transitory, computer-readable storage media of claim **19**, wherein the plurality of different transmission protocols with which the protocol agnostic format is compatible comprises, at least:

a Message Queue Telemetry Transport (MQTT) protocol.

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