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(54) **SYSTEMS AND METHODS FOR DETECTING VEHICLE CONTROLLER SPOOFING**

(71) Applicant: **GM GLOBAL TECHNOLOGY OPERATIONS LLC**, Detroit, MI (US)

(72) Inventors: **Ahmed Sunny**, Troy, MI (US); **Samuel B Kupfer**, Oak Park, MI (US)

(73) Assignee: **GM GLOBAL TECHNOLOGY OPERATIONS LLC**, Detroit, MI (US)

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***B60R 25/24*** (2013.01)

(52) **U.S. Cl.**
CPC ......... ***B60R 25/241*** (2013.01); ***H04W 12/121*** (2021.01)

(58) **Field of Classification Search**
CPC .................................................... B60R 25/241
USPC ............................................................ 726/22
See application file for complete search history.

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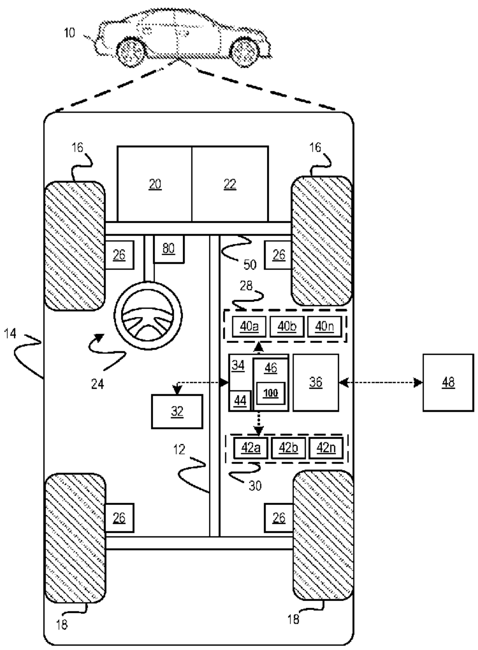
*Primary Examiner* — Michael S McNally
(74) *Attorney, Agent, or Firm* — Ingrassia Fisher & Lorenz, LLP

(57) **ABSTRACT**

Methods and systems are provided for detecting vehicle controller spoofing. The vehicle includes a plurality of vehicle controllers, a vehicle network switch, and a content addressable memory (CAM). The plurality of vehicle controllers includes first and second vehicle controllers. A first port of the vehicle network switch is designated to only receive data frames from a first vehicle controller. The first vehicle controller is associated with a first media access control (MAC) address. The CAM is configured to store an association between the first port and the first MAC address, receive a first data frame including a source MAC address at the first port, determine whether the source MAC address matches the first MAC address, and generate an anomaly event based on the determination. A generated anomaly event indicates that the first vehicle controller is masquerading as the second vehicle controller using an invalid source MAC address.

**20 Claims, 5 Drawing Sheets**



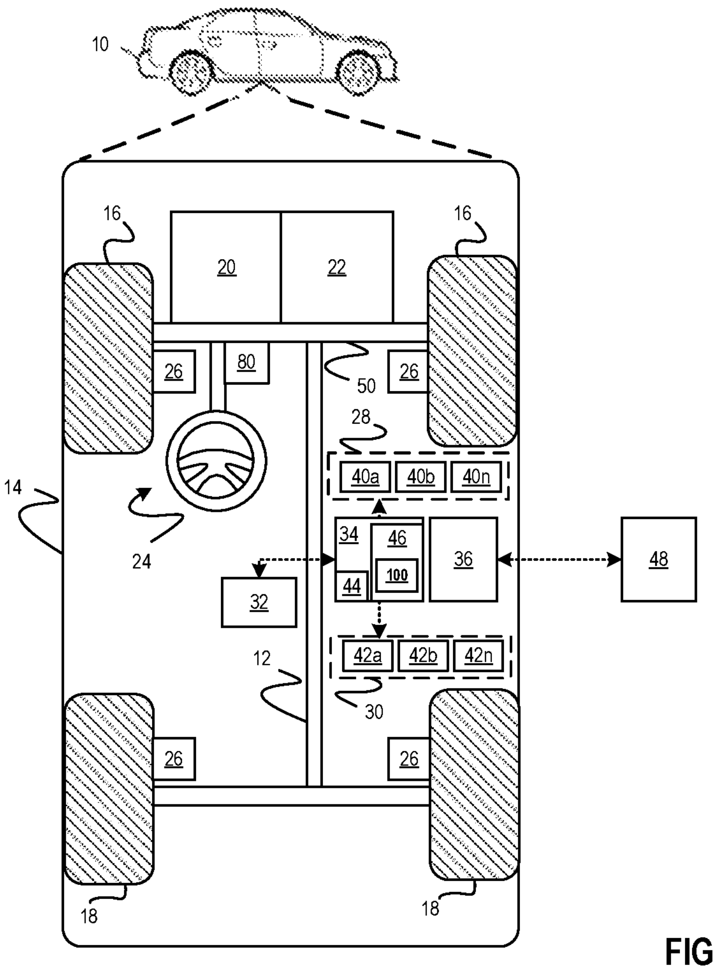

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FIG. 1

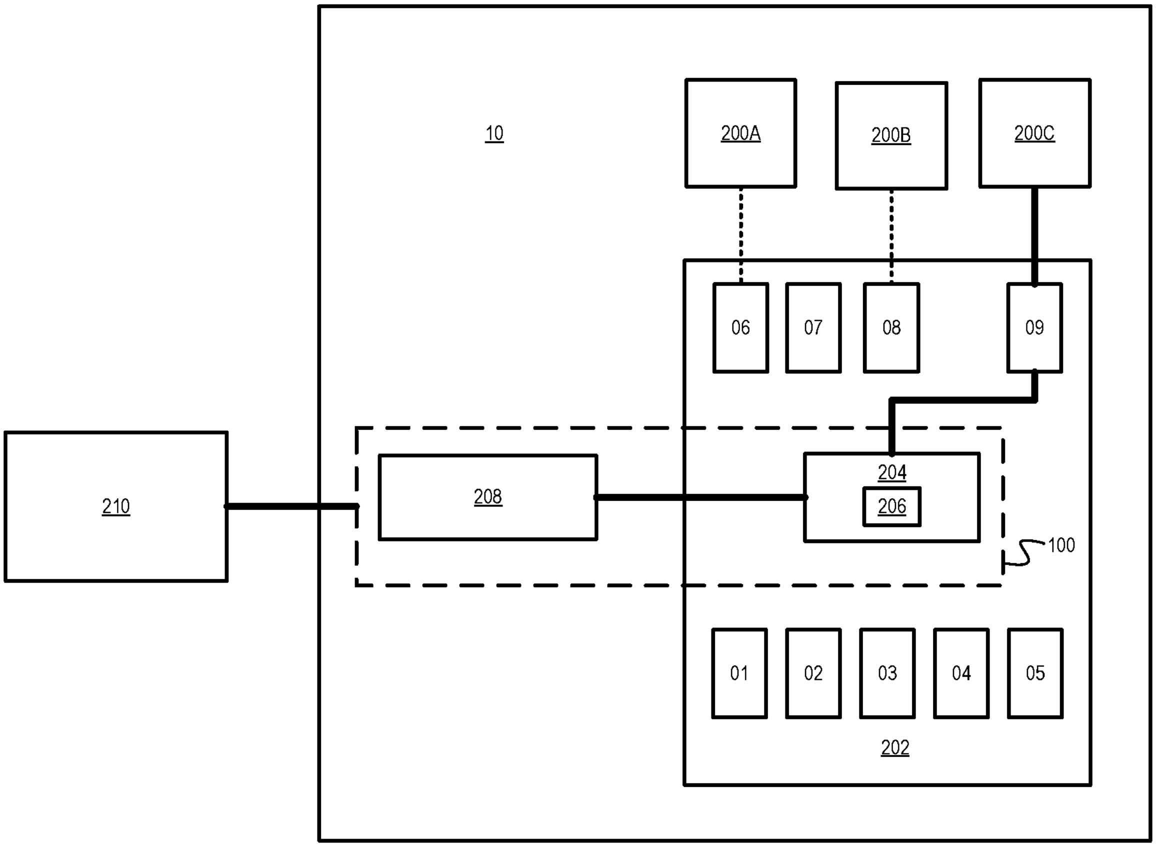
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FIG. 2

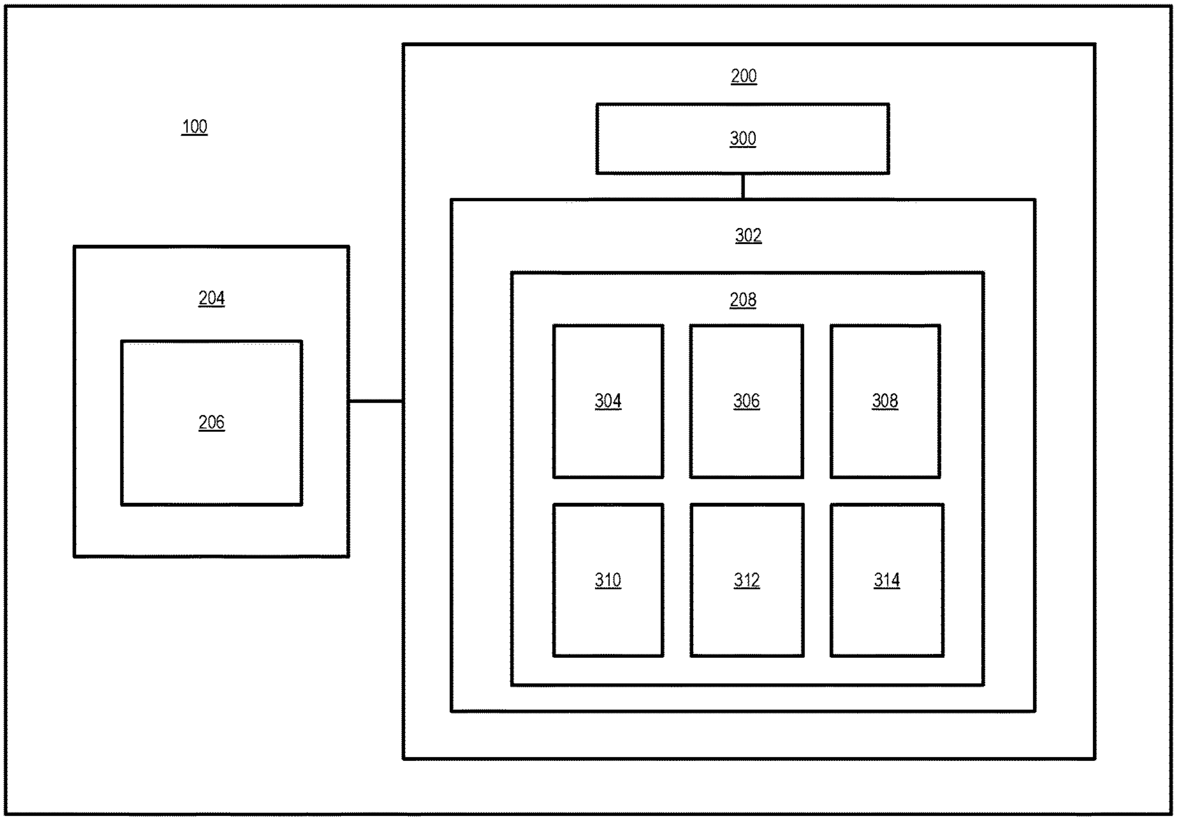

FIG. 3

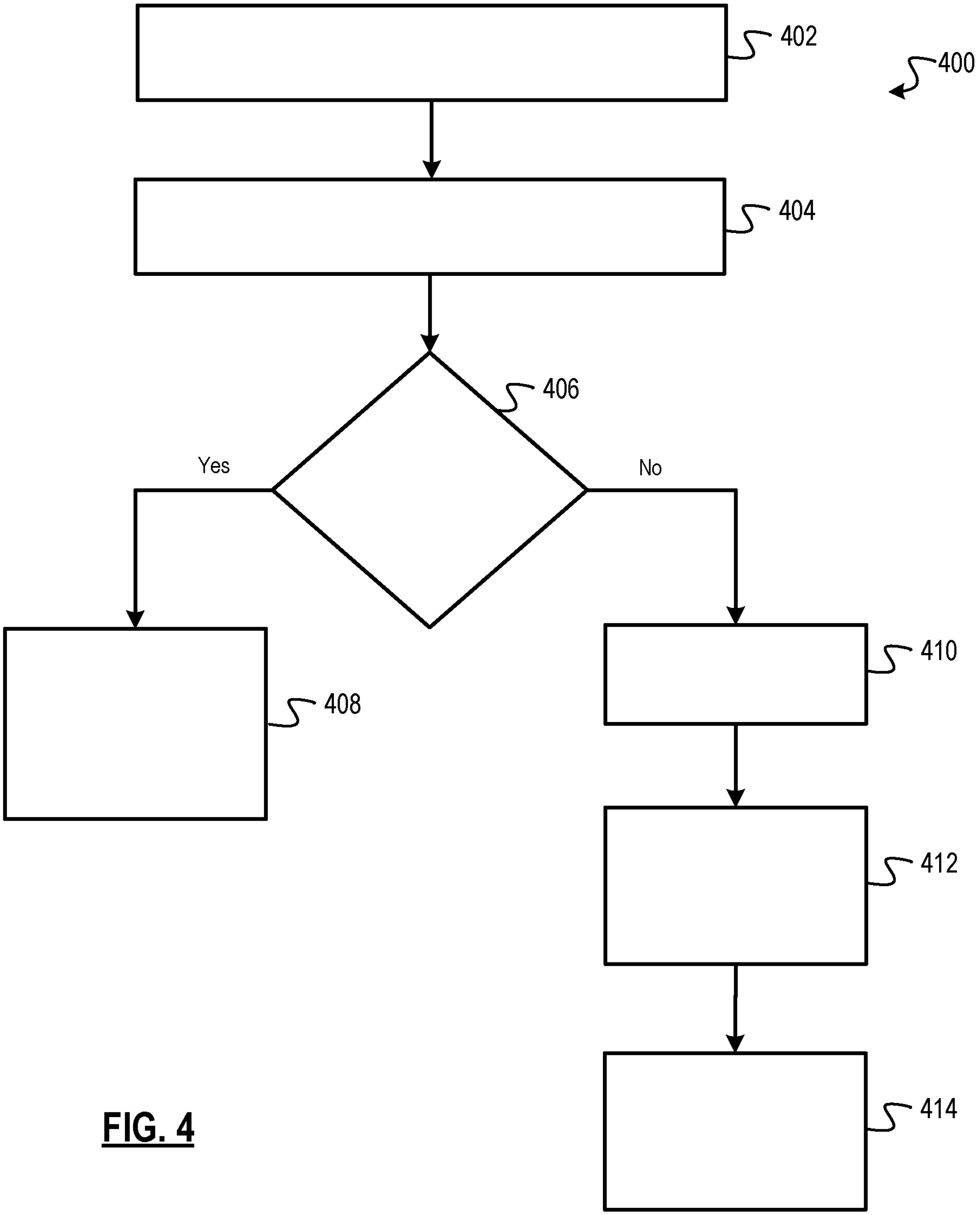

FIG. 4

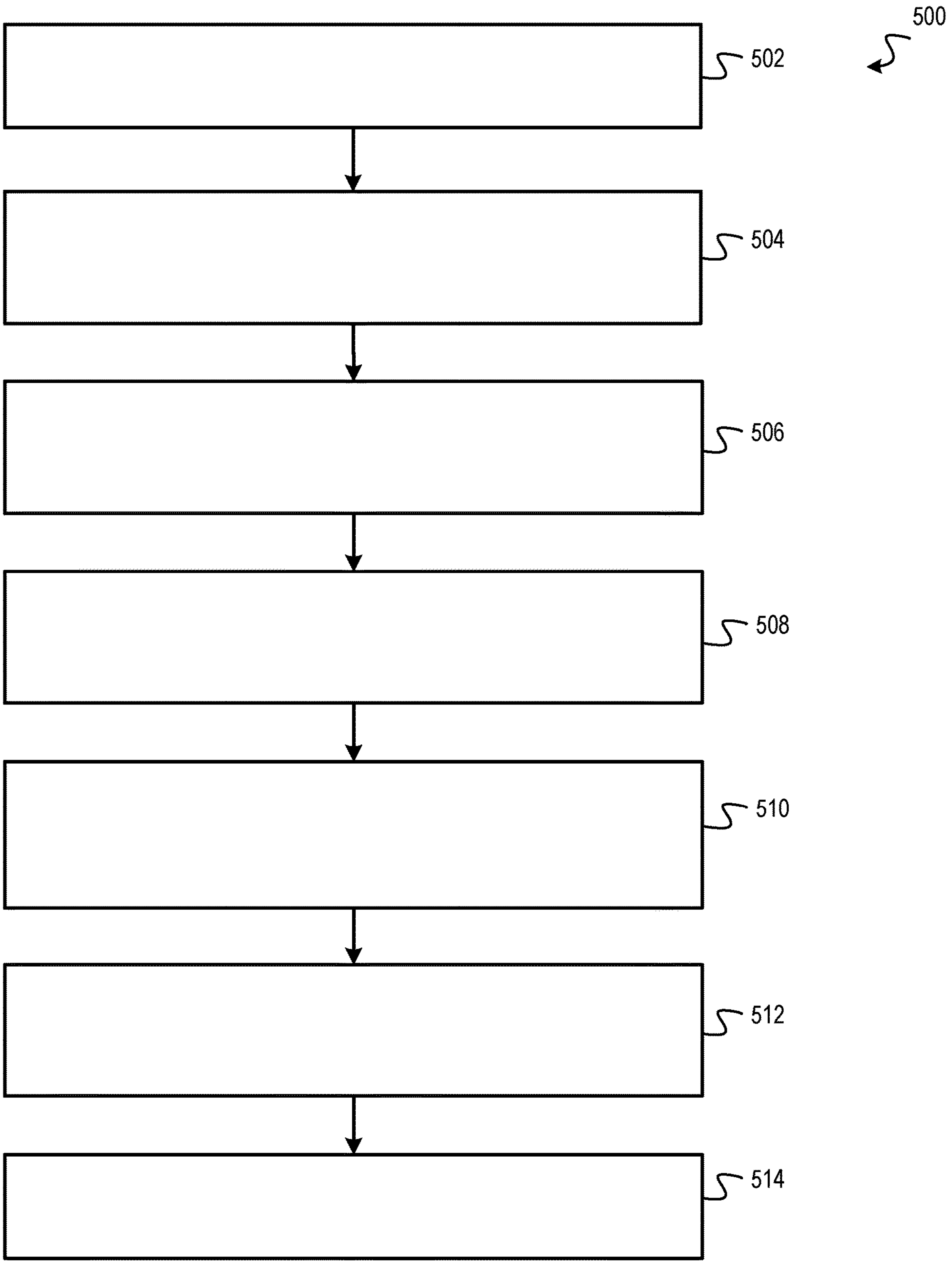

FIG. 5

# SYSTEMS AND METHODS FOR DETECTING VEHICLE CONTROLLER SPOOFING

## INTRODUCTION

The technical field generally relates to vehicles, and more particularly relates to systems and methods for detecting vehicle controller spoofing.

Software-defined vehicles (SDVs) with dynamically configurable networks introduce a revolutionary approach to automotive network topologies and communication. However, they also bring about new security challenges. One particular vulnerability involves attacks targeting a vehicle controller. In this scenario, a compromised vehicle controller falls under adversarial control, aiming to impersonate a legitimate vehicle controller in order to bypass internal access controls. Exploiting this type of control allows malicious actors to escalate their privileges and execute a wide range of attacks on an SDV, ranging from causing driver inconvenience to compromising the safety of the vehicle itself.

Accordingly, it is desirable to provide improved methods and systems to detect vehicle controller spoofing. Other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and the foregoing technical field and background.

## SUMMARY

A method for detecting vehicle controller spoofing in a vehicle includes: receiving a first data frame including a source MAC address at a first port of a plurality of ports of a vehicle network switch; retrieving a stored association between the first port and a first media access control (MAC) address from at least one memory, wherein the first port is designated to only receive data frames from a first vehicle controller of a plurality of vehicle controllers in the vehicle and the first vehicle controller is associated with the first MAC address; determining whether the source MAC address is an invalid source MAC address based on a comparison of the source MAC address with the first MAC address; and generating an anomaly event based on the determination, wherein the anomaly event is indicative of the first vehicle controller masquerading as a second vehicle controller of the plurality of vehicle controllers using a second MAC address as the source MAC address, the second MAC address being associated with the second vehicle controller.

In various embodiments, the method further includes: retrieving a stored association between the first vehicle controller and a first Internet Protocol (IP) address from the at least one memory; determining whether a source IP address received in the first data frame is an invalid source IP address based on whether the source IP address matches the first IP address; and generating a qualified security event based on the determination, wherein the qualified security event indicates that the first vehicle controller is masquerading as the second vehicle controller using a second IP address as the source IP address, the second IP address being associated with the second vehicle controller.

In various embodiments, the method further includes: retrieving a stored association between the first vehicle controller and a payload size threshold from the at least one memory, the first vehicle controller being configured to transmit payloads having a payload size that are less than or equal to the payload size threshold; determining whether a first payload size of a first payload received in the first data frame is greater than the payload size threshold; and generating a qualified security event indicating that the first vehicle controller, masquerading as the first second controller, is transmitting payloads having an invalid payload size based on the determination.

In various embodiments, the method further includes: retrieving a stored association between the first vehicle controller and a message rate threshold from the at least one memory, the first vehicle controller being configured to transmit the data frames at message rates that are less than or equal to the message rate threshold; determining whether a source message rate associated with the first data frame is greater than the message rate threshold; and generating a qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames at an invalid message rate based on the determination.

In various embodiments, the method further includes: retrieving a stored association between the first vehicle controller and at least one destination MAC address from the at least one memory, wherein the first vehicle controller is configured to transmit the data frames comprising one of the at least one destination MAC address and each of the at least one destination MAC address is associated with a destination device; determining whether a first destination MAC address received in the first data frame matches one of the at least one destination MAC addresses associated with the first vehicle controller; and generating a qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames using an invalid destination MAC address based on the determination.

In various embodiments, the method further includes: retrieving a stored association between the first vehicle controller and at least one destination IP address from the at least one memory, wherein the first vehicle controller is configured to transmit the data frames comprising one of the at least one destination IP address and each of the at least one destination IP address is associated with a destination device; determining whether a first destination IP address received in the first data frame matches one of the at least one destination IP addresses associated with the first vehicle controller; and generating a qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames using an invalid destination IP address based on the determination.

In various embodiments, the method further includes suspending routing of data frames including the source MAC address received at the first port upon the generation of the anomaly event.

In various embodiments, the method further includes: receiving the first data frame associated with the anomaly event from a content addressable memory (CAM) of the vehicle network switch; identifying at least one anomalous characteristic associated with the first vehicle controller masquerading as the second vehicle controller, based on the first data frame; transmitting a qualified security event including the at least one anomalous characteristic to a security back office for further analysis.

In various embodiments, the at least one anomalous characteristic includes the invalid source MAC address and at least one of an invalid source IP address, an invalid payload size, an invalid message rate, an invalid destination MAC address, and an invalid destination IP address.

In various embodiments, receiving the first data frame associated with the anomaly event from the CAM of the vehicle network switch includes receiving the first data frame associated with the anomaly event from a ternary content addressable memory (TCAM) of the vehicle network switch.

A vehicle configured to detect vehicle controller spoofing includes a plurality of vehicle controllers, a vehicle network switch, and a content addressable memory (CAM). The plurality of vehicle controllers includes first and second vehicle controllers. The vehicle network switch includes a plurality of ports, wherein a first port of the plurality of ports is designated to only receive data frames from the first vehicle controller and the first vehicle controller is associated with a first media access control (MAC) address. The CAM is configured to: receive a first data frame including a source MAC address at the first port; retrieve a stored association between the first port and the first MAC address; determine whether the source MAC address is an invalid source MAC address based on a comparison of the source MAC address with the first MAC address; and generate an anomaly event based on the determination, wherein the anomaly event is indicative of the first vehicle controller masquerading as the second vehicle controller using a second MAC address as the source MAC address, the second MAC address being associated with the second vehicle controller.

In various embodiments, the vehicle includes an intrusion assessment system and wherein: the first vehicle controller is associated with a first Internet Protocol (IP) address; the CAM is configured to transmit the first data frame associated with the anomaly event to the intrusion assessment system, the first data frame including a source IP address; and the intrusion assessment system is configured to: retrieve a stored association between the first vehicle controller and the first IP address from at least one memory at the intrusion assessment system; determine whether the source IP address is an invalid source IP address based on whether the source IP address matches the first IP address; and generate a qualified security event based on the determination, wherein the qualified security event indicates that the first vehicle controller is masquerading as the second vehicle controller using a second IP address, the second IP address being associated with the second vehicle controller.

In various embodiments, the vehicle includes an intrusion assessment system and wherein: the first vehicle controller is configured to transmit payloads having a payload size that are less than or equal to a payload size threshold; the CAM is configured to transmit the first data frame associated with the anomaly event to the intrusion assessment system, the first data frame including a first payload; and the intrusion assessment system is configured to: retrieve a stored association between the first vehicle controller and the payload size threshold from at least one memory at the intrusion assessment system; determine whether a first payload size of the first payload is greater than the payload size threshold; and generate a qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting payloads having an invalid payload size based on the determination.

In various embodiments, the vehicle includes an intrusion assessment system and wherein: the first vehicle controller is configured to transmit the data frames at message rates that are less than or equal to a message rate threshold; the CAM is configured to transmit the first data frame associated with the anomaly event to the intrusion assessment system; and the intrusion assessment system is configured to: retrieve a stored association between the first vehicle controller and the message rate threshold from at least one memory at the intrusion assessment system; determine whether a source message rate associated with the first data frame is greater than the message rate threshold; and generate a qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames at an invalid message rate based on the determination.

In various embodiments, the vehicle includes an intrusion assessment system and wherein: the first vehicle controller is configured to transmit the data frames comprising one of at least one destination MAC address, each of the at least one destination MAC address being associated with a destination device; the CAM is configured to transmit the first data frame associated with the anomaly event to the intrusion assessment system, the first data frame including a first destination MAC address; and the intrusion assessment system is configured to: retrieve stored associations between the first vehicle controller and the at least one destination MAC address from at least one memory at the intrusion assessment system; determine whether the first destination MAC address matches one of the at least one destination MAC addresses associated with the first vehicle controller; and generate a qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames using an invalid destination MAC address based on the determination.

In various embodiments, the vehicle includes an intrusion assessment system and wherein: the first vehicle controller is configured to transmit the data frames comprising one of at least one destination IP address, each of the at least one destination IP address being associated with a destination device; the CAM is configured to transmit the first data frame associated with the anomaly event to the intrusion assessment system, the first data frame including a first destination IP address; and the intrusion assessment system is configured to: retrieve stored associations between the first vehicle controller and the at least one destination IP address from at least one memory at the intrusion assessment system; determine whether the first destination IP address matches one of the at least one destination IP addresses associated with the first vehicle controller; and generate a qualified security event indicating that the first vehicle controller, masquerading as second first vehicle controller, is transmitting the data frames using an invalid destination IP address based on the determination.

In various embodiments, the vehicle network switch is configured to suspend routing of data frames including the source MAC address received at the first port upon the generation of the anomaly event.

In various embodiments, the vehicle includes an intrusion assessment system configured to: receive the first data frame associated with the anomaly event from the CAM; identify at least one anomalous characteristic associated with the first vehicle controller, masquerading as the second vehicle controller, based on the first data frame; and transmit a qualified security event including the at least one anomalous characteristic to a security back office for further analysis.

In various embodiments, the at least one anomalous characteristic comprises the invalid source MAC address and at least one of an invalid source IP address, an invalid payload size, an invalid message rate, an invalid destination MAC address, and an invalid destination IP address.

A system for detecting vehicle controller spoofing includes at least one processor; and at least one memory communicatively coupled to the at least one processor. The at least one memory includes instructions that upon execution by the at least one processor, cause the at least one processor to: receive a first data frame including a source MAC address at a first port of a plurality of ports of a vehicle network switch; retrieve a stored association between the first port and a first media access control (MAC) address from the at least one memory, wherein the first port is designated to only receive data frames from a first vehicle controller of a plurality of vehicle controllers in the vehicle and the first vehicle controller is associated with the first MAC address; determine whether the source MAC address is an invalid source MAC address based on a comparison of the source MAC address with the first MAC address; and generate an anomaly event based on the determination, wherein the anomaly event is indicative of the first vehicle controller masquerading as a second vehicle controller of the plurality of vehicle controllers using a second MAC address as the source MAC address, the second MAC address being associated with the second vehicle controller.

## BRIEF DESCRIPTION OF THE DRAWINGS

The exemplary embodiments will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and wherein:

FIG. **1** is a functional block diagram of a vehicle including a vehicle controller spoofing detection system in accordance with at least one embodiment;

FIG. **2** is a functional block diagram of an exemplary vehicle including a vehicle controller spoofing detection system in accordance with at least one embodiment;

FIG. **3** is a functional block diagram of a vehicle controller spoofing detection system in accordance with at least one embodiment;

FIG. **4** is a flowchart representation of an exemplary method of identifying a masquerading vehicle controller based on an invalid MAC source address in accordance with at least one embodiment; and

FIG. **5** is a flowchart representation of an exemplary method of identifying anomalous characteristics of data frames generated by a masquerading vehicle controller in accordance with at least one embodiment.

## DETAILED DESCRIPTION

The following detailed description is merely exemplary in nature and is not intended to limit the application and uses. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description. As used herein, the term module refers to an application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that executes one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality.

Embodiments of the present disclosure may be described herein in terms of functional and/or logical block components and various processing steps. It should be appreciated that such block components may be realized by any number of hardware, software, and/or firmware components configured to perform the specified functions. For example, an embodiment of the present disclosure may employ various integrated circuit components, e.g., memory elements, digital signal processing elements, logic elements, look-up tables, or the like, which may carry out a variety of functions under the control of one or more microprocessors or other control devices. In addition, those skilled in the art will appreciate that embodiments of the present disclosure may be practiced in conjunction with any number of systems, and that the systems described herein is merely exemplary embodiments of the present disclosure.

For the sake of brevity, conventional techniques related to signal processing, data transmission, signaling, control, and other functional aspects of the systems (and the individual operating components of the systems) may not be described in detail herein. Furthermore, the connecting lines shown in the various figures contained herein are intended to represent example functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections may be present in an embodiment of the present disclosure.

Referring to FIG. **1**, a functional block diagram of a vehicle **10** including a vehicle controller spoofing detection system **100** in accordance with at least one embodiment is shown. The vehicle **10** generally includes a chassis **12**, a body **14**, front wheels **16**, and rear wheels **18**. The vehicle **10** is depicted in the illustrated embodiment as a passenger car, but it should be appreciated that the vehicle controller spoofing detection system **100** may be included within any other vehicle including trucks, sport utility vehicles (SUVs), recreational vehicles (RVs), etc., can also be used.

In various embodiments, the body **14** is arranged on the chassis **12** and substantially encloses components of the vehicle **10**. The body **14** and the chassis **12** may jointly form a frame. The wheels **16-18** are each rotationally coupled to the chassis **12** near a respective corner of the body **14**.

In various embodiments, the vehicle **10** is an autonomous or semi-autonomous vehicle that is automatically controlled to carry passengers and/or cargo from one place to another. For example, in an exemplary embodiment, the vehicle **10** is a so-called Level Two, Level Three, Level Four or Level Five automation system. Level two automation means the vehicle assists the driver in various driving tasks with driver supervision. Level three automation means the vehicle can take over all driving functions under certain circumstances. All major functions are automated, including braking, steering, and acceleration. At this level, the driver can fully disengage until the vehicle tells the driver otherwise. A Level Four system indicates "high automation", referring to the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene. A Level Five system indicates "full automation", referring to the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.

As shown, the vehicle **10** generally includes a propulsion system **20** a transmission system **22**, a steering system **24**, a braking system **26**, a sensor system **28**, an actuator system **30**, at least one data storage device **32**, at least one controller **34**, and a communication system **36**. The controller **34** is configured to implement an advanced driver assistance system (ADAS). The propulsion system **20** is configured to generate power to propel the vehicle. The propulsion system **20** may, in various embodiments, include an internal combustion engine, an electric machine such as a traction motor, a fuel cell propulsion system, and/or any other type of propulsion configuration. The transmission system **22** is configured to transmit power from the propulsion system **20** to the vehicle wheels **16-18** according to selectable speed ratios. According to various embodiments, the transmission system **22** may include a step-ratio automatic transmission, a continuously-variable transmission, or other appropriate transmission. The braking system **26** is configured to provide braking torque to the vehicle wheels **16-18**. The braking system **26** may, in various embodiments, include friction brakes, brake by wire, a regenerative braking system such as an electric machine, and/or other appropriate braking systems.

The steering system **24** is configured to influence a position of the of the vehicle wheels **16**. While depicted as including a steering wheel and steering column, for illustrative purposes, in some embodiments contemplated within the scope of the present disclosure, the steering system **24** may not include a steering wheel and/or steering column. The steering system **24** includes a steering column coupled to an axle **50** associated with the front wheels **16** through, for example, a rack and pinion or other mechanism (not shown). Alternatively, the steering system **24** may include a steer by wire system that includes actuators associated with each of the front wheels **16**.

The sensor system **28** includes one or more sensing devices **40***a*-**40***n* that sense observable conditions of the exterior environment and/or the interior environment of the vehicle **10**. The sensing devices **40***a*-**40***n* can include, but are not limited to, radars, lidars, global positioning systems, optical cameras, thermal cameras, ultrasonic sensors, and/or other sensors.

The vehicle dynamics sensors provide vehicle dynamics data including longitudinal speed, yaw rate, lateral acceleration, longitudinal acceleration, etc. The vehicle dynamics sensors may include wheel sensors that measure information pertaining to one or more wheels of the vehicle **10**. In one embodiment, the wheel sensors comprise wheel speed sensors that are coupled to each of the wheels **16-18** of the vehicle **10**. Further, the vehicle dynamics sensors may include one or more accelerometers (provided as part of an Inertial Measurement Unit (IMU)) that measure information pertaining to an acceleration of the vehicle **10**. In various embodiments, the accelerometers measure one or more acceleration values for the vehicle **10**, including latitudinal and longitudinal acceleration and yaw rate.

The actuator system **30** includes one or more actuator devices **42***a*-**42***n* that control one or more vehicle features such as, but not limited to, the propulsion system **20**, the transmission system **22**, the steering system **24**, and the braking system **26**. In various embodiments, the vehicle features can further include interior and/or exterior vehicle features such as, but are not limited to, doors, a trunk, and cabin features such as air, music, lighting, etc. (not numbered).

The communication system **36** is configured to wirelessly communicate information to and from other entities **48**, such as but not limited to, other vehicles ("V2V" communication,) infrastructure ("V2I" communication), remote systems, and/or personal devices. In an exemplary embodiment, the communication system **36** is a wireless communication system configured to communicate via a wireless local area network (WLAN) using IEEE 802.11 standards or by using cellular data communication. However, additional, or alternate communication methods, such as a dedicated short-range communications (DSRC) channel, are also considered within the scope of the present disclosure. DSRC channels refer to one-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use and a corresponding set of protocols and standards.

The data storage device **32** stores data for use in the ADAS of the vehicle **10**. In various embodiments, the data storage device **32** stores defined maps of the navigable environment. In various embodiments, the defined maps may be predefined by and obtained from a remote system. For example, the defined maps may be assembled by the remote system and communicated to the vehicle **10** (wirelessly and/or in a wired manner) and stored in the data storage device **32**. As can be appreciated, the data storage device **32** may be part of the controller **34**, separate from the controller **34**, or part of the controller **34** and part of a separate system.

The controller **34** includes at least one processor **44** and a computer readable storage device or media **46**. The processor **44** can be any custom made or commercially available processor, a central processing unit (CPU), a graphics processing unit (GPU), an auxiliary processor among several processors associated with the controller **34**, a semiconductor based microprocessor (in the form of a microchip or chip set), a macroprocessor, any combination thereof, or generally any device for executing instructions. The computer readable storage device or media **46** may include volatile and nonvolatile storage in read-only memory (ROM), random-access memory (RAM), and keep-alive memory (KAM), for example. KAM is a persistent or non-volatile memory that may be used to store various operating variables while the processor **44** is powered down. The computer-readable storage device or media **46** may be implemented using any of a number of known memory devices such as PROMs (programmable read-only memory), EPROMs (electrically PROM), EEPROMs (electrically erasable PROM), flash memory, or any other electric, magnetic, optical, or combination memory devices capable of storing data, some of which represent executable instructions, used by the controller **34** in controlling the vehicle **10**.

The instructions may include one or more separate programs, each of which comprises an ordered listing of executable instructions for implementing logical functions. The instructions, when executed by the processor **44**, receive and process signals from the sensor system **28**, perform logic, calculations, methods and/or algorithms for automatically controlling the components of the vehicle **10**, and generate control signals to the actuator system **30** to automatically control the components of the vehicle **10** based on the logic, calculations, methods, and/or algorithms. Although only one controller **34** is shown in FIG. **1**, embodiments of the vehicle **10** can include any number of controllers **34** that communicate over any suitable communication medium or a combination of communication mediums and that cooperate to process the sensor signals, perform logic, calculations, methods, and/or algorithms, and generate control signals to automatically control features of the vehicle **10**. In various embodiments, the controller(s) **34** are configured to implement ADAS.

Referring to FIG. **2**, a functional block diagram of an exemplary vehicle **10** including a vehicle controller spoofing detection system **100** in accordance with at least one embodiment is shown. In various embodiments, the vehicle **10** is a software defined vehicle (SDV). The vehicle **10** includes a plurality of vehicle controllers **200**A, **200**B, **200**C. The vehicle controller **200**A, **200**B, **200**C are similar to the controller **34** described with reference to FIG. **1**. While three vehicle controllers **200**A, **200**B, **200**C are shown, a vehicle **10** typically includes more than three vehicle controllers. The vehicle controllers **200**A, **200**B, **200**C are communicatively coupled to a vehicle network switch **202**. The vehicle network switch **202** routes data frames between vehicle controllers **200**A, **200**B, **200**C. An example of a vehicle network switch **202** is an ethernet switch. While a single vehicle network switch **202** is shown, the vehicle **10** includes more than one vehicle network switch **202**.

The vehicle network switch **202** includes a plurality of ports 01, 02, 03, 04, 05, 06, 07, 08, 09. Each vehicle controller **200**A, **200**B, **200**C is configured to transmit and receive data frames via a designated port 01, 02, 03, 04, 05, 06, 07, 08, 09 of a vehicle network switch **202**. For example, port 06 is designated to only route data frames to and from the vehicle controller **200**A, port 08 is designated to only route data frames to and from the vehicle controller **200**B, and port 09 is designated to only route data frames to and from the vehicle controller **200**C. While the vehicle network switch **202** is shown as including nine ports, a vehicle network switch **202** may include a fewer or greater number of ports. While the vehicle controllers **200**A, **200**B, **200**C are illustrated as communicating via a single vehicle network switch **202**, different vehicle controllers **200**A, **200**B, **200**C may communicate via different vehicle network switches **202**.

The vehicle network switch **202** includes a content addressable memory (CAM) **204**. The CAM **204** includes routing tables that facilitate data frame forwarding operations between the vehicle controllers **200**A, **200**B, **200**C. In various embodiments, the CAM **204** is a ternary content addressable memory (TCAM). Each of the ports 01, 02, 03, 04, 05, 06, 07, 08, 09 of the vehicle network switch **202** is communicatively coupled to the CAM **204**. Each vehicle controller **200**A, **200**B, **200**C has a specific MAC address. Each of the ports 01, 02, 03, 04, 05, 06, 07, 08, 09 utilized in the vehicle network switch **202** is tied to a MAC address of a vehicle controller **200**A, **200**B, **200**C. The data packets transmitted by a vehicle controller **200**A, **200**B, **200**C are transmitted to the port 01, 02, 03, 04, 05, 06, 07, 08, 09 that is tied to the MAC address of that vehicle controller **200**A, **200**B, **200**C. The associations between the MAC addresses of the different vehicle controllers **200**A, **200**B, **200**C and the associated port 01, 02, 03, 04, 05, 06, 07, 08, 09 are stored in the CAM **204**.

The vehicle controller spoofing detection system **100** is configured to identify an attack on a vehicle controller **200**C where the vehicle controller **200**C, under adversarial control, is attempting to masquerade as another vehicle controller **200**B within the vehicle **10**. In this example, the vehicle controller **200**B is configured to transmit data frames to the vehicle controller **200**A via port 08 and the vehicle controller **200**C is configured to transmit data frames to vehicle controller **200**A via port 09. The vehicle controller **200**C has been compromised by an adversarial attack. The vehicle controller **200**C, masquerading as the vehicle controller **200**B, and is attempting to transmit data frames to vehicle controller **200**A using a source MAC address associated with the vehicle controller **200**B via the port 09.

The vehicle controller spoofing detection system **100** includes a source media control access (MAC) address validation module **206** and an intrusion assessment system **208**. The CAM **204** includes the source MAC address validation module **206**. The CAM **204** is communicatively coupled to the intrusion assessment system **208**. In at least one embodiment, a vehicle controller **200**A, **200**B, **200**C includes the intrusion assessment system **208**. In at least one embodiment, the intrusion assessment system **208** is a standalone controller **34** within the vehicle **10**. The vehicle controller spoofing detection system **100** is configured to be communicatively coupled to a security back office **210**.

The source MAC address validation module **206** is configured to determine whether a spoofing attack has occurred on a vehicle controller **200**A, **200**B, **200**C based on a data frame received from the vehicle controller **200**A, **200**B, **200**C at a specific port 01, 02, 03, 04, 05, 06, 07, 08, 09. The source MAC address validation module **206** monitors the source MAC addresses in the data frames received from the vehicle controllers **200**A, **200**B, **200**C at the different ports 01, 02, 03, 04, 05, 06, 07, 08, 09 of the vehicle network switch **202**. If the source MAC address validation module **206** determines that a source MAC address in a data frame received at a port 01, 02, 03, 04, 05, 06, 07, 08, 09 does not match the MAC address associated with the vehicle controller **200**A, **200**B, **200**C configured to transmit data frames via that port 01, 02, 03, 04, 05, 06, 07, 08, 09, the source MAC address validation module **206** generates an anomaly event. The anomaly event indicates that a spoofing attack has occurred on the vehicle controller **200**A, **200**B, **200**C associated with the port 01, 02, 03, 04, 05, 06, 07, 08, 09 that received the data frame. The source MAC address validation module **206** transmits the received data frame to the intrusion assessment system **208** to perform forensic analysis on the data frame to identify one or more anomalous characteristics. The anomalous characteristic identified by the intrusion assessment system **208** characterizes the attack. The use of the vehicle controller spoofing detection system **100** may reduce false positives associated with identifying compromised vehicle controllers within a vehicle **10**.

Referring to FIG. **3**, a functional block diagram of a vehicle controller spoofing detection system **100** in accordance with at least one embodiment is shown. The vehicle controller spoofing detection system **100** includes a source MAC address validation module **206** and an intrusion assessment system **208**. A CAM **204** at a vehicle network switch **202** includes the source MAC address validation module **206**. In at least one embodiment, the CAM **204** is a TCAM. In at least one embodiment, a vehicle controller **200** includes at least one processor **300** and at least one memory **302**. The processor(s) **300** is communicatively coupled to the at least one memory **302**. The processor(s) **300** is a programmable device that includes one or more instructions stored in or associated with the at least one memory **302**. The at least one memory **302** includes instructions that the processor(s) **300** is configured to execute. The at least one memory **302** includes the intrusion assessment system **208**. The intrusion assessment system **208** includes a source IP address module **304**, a payload size module **306**, a message rate module **308**, a destination MAC address module **310**, a destination IP address module **312**, and a qualified security event transmission module **314**. The vehicle controller spoofing detection system **100** may include additional components that facilitate operation of the vehicle controller spoofing detection system **100**. The operation of the vehicle controller spoofing detection system **100** will be described in greater detail below.

Referring to FIG. **4**, a flowchart representation of an exemplary method **400** of identifying a masquerading vehicle controller **200**C based on an invalid source MAC address in accordance with at least one embodiment is shown. The method **400** will be described with reference to an exemplary implementation of the vehicle controller spoofing detection system **100**. In various embodiments, the method **400** is implemented by a CAM **204** including a source MAC address validation module **206** As can be appreciated in light of the disclosure, the order of operation within the method **400** is not limited to the sequential execution as illustrated in FIG. **4** but may be performed in one or more varying orders as applicable and in accordance with the present disclosure. The method **400** will be described with reference to the example illustrated in FIG. **2**.

At **402**, a data frame is received from a vehicle controller **200**C at a port 09 of a vehicle network switch **202**. At the **404**, the data frame is received at a CAM **204** of the vehicle network switch **202**. The CAM **204** includes routing tables that facilitate data frame forwarding operations between the vehicle controllers **200**A, **200**B, **200**C. Each vehicle controller **200**A, **200**B, **200**C is associated with a MAC address. A MAC address is a unique identifier that is used to identify individual vehicle controllers **200**A, **200**B, **200**C within a vehicle network. Each utilized port 01, 02, 03, 04, 05, 06, 07, 08, 09 of the vehicle network switch **202** is designated to only receive data frames from a specific vehicle controller **200**A, **200**B, **200**C in the vehicle **10**. The CAM **204** stores one or more routing tables that define the associations between the individual ports 01, 02, 03, 04, 05, 06, 07, 08, 09 of the vehicle network switch **202** and the MAC addresses of the vehicle controllers **200**A, **200**B, **200**C associated with that port 01, 02, 03, 04, 05, 06, 07, 08, 09. Each data frame includes a source MAC address. A source MAC address identifies the vehicle controller **200**A, **200**B, **200**C that transmitted the data frame.

At **406**, the source MAC address validation module **206** at the CAM **204** determines whether the source MAC address in the received data frame is a valid source MAC address. When a data frame is received at a port 01, 02, 03, 04, 05, 06, 07, 08, 09 of the vehicle network switch **202**, the source MAC address validation module **206** compares the source MAC address in the received data frame with the MAC address of the vehicle controller **200**A, **200**B, **200**C associated with that port 01, 02, 03, 04, 05, 06, 07, 08, 09 as defined by the routing table(s) in the CAM **204** to make the determination.

If the source MAC address validation module **206** determines that the source MAC address in the received the data frame matches the MAC address associated with the port 01, 02, 03, 04, 05, 06, 07, 08, 09 that received the data frame as defined by the routing table(s) in the CAM **204**, the source MAC address validation module **206** determines that the source MAC address in the received data frame is a valid source MAC address. The data frame includes a destination MAC address associated with a destination device. An example of a destination device is another vehicle controller **200**A, **200**B, **200**C. At **408**, if the source MAC address in the data frame is determined to be a valid source MAC address, the CAM **204** routes the data frame to the destination device associated with the destination MAC address in the data frame via the port 01, 02, 03, 04, 05, 06, 07, 08, 09 associated with the destination MAC address as defined by the routing table(s) in the CAM **204**.

Referring back to the example in FIG. **2**, the port 09 is designated to only receive data frames from the vehicle controller **200**C. A routing table in the CAM **204** defines an association between the MAC address of the vehicle controller **200**C and the port 09. A data frame is received from the vehicle controller **200**C at the port 09. The data frame includes the source MAC address of the vehicle controller **200**C. The source MAC address validation module **206** determines that the source MAC address is valid because the source MAC address in the received the data frame matches the MAC address of the vehicle controller **200**C associated with the port 09. The data frame includes a destination MAC address associated with a destination device. The CAM **204** routes the received data frame to the destination device associated with the destination MAC address. The destination device in this example is the vehicle controller **200**A and the MAC destination address is the MAC address associated with the vehicle controller **200**A.

Referring back to FIG. **3**, if the source MAC address validation module **206** determines that the source MAC address in the received the data frame does not match the MAC address associated with the port 01, 02, 03, 04, 05, 06, 07, 08, 09 that received the data frame as defined by the routing table(s) in the CAM **204**, the source MAC address validation module **206** determines that the source MAC address in the received data frame is an invalid source MAC address at **406**.

If the source MAC address in the data frame is determined to be an invalid source MAC address, the source MAC address validation module **206** generates an anomaly event at **410**. The anomaly event indicates that the vehicle controller **200**A, **200**B, **200**C that transmitted the data frame including the invalid source MAC address is masquerading as another vehicle controller **200**A, **200**B, **200**C that has as MAC address that is the same as the invalid source MAC address in the data frame. At **412**, the source MAC address validation module **206** transmits the received data frame including the invalid MAC source address to the intrusion assessment system **208**. At **414**, the CAM **204** suspends the routing of data frames including the invalid MAC source address that are received at the port 01, 02, 03, 04, 05, 06, 07, 08, 09 that received the data frame including the invalid source MAC address.

Referring back to the example in FIG. **2**, the port 09 is designated to only receive data frames from vehicle controller **200**C. The vehicle controller **200**C has a unique MAC address. A routing table in the CAM **204** defines an association between the MAC address of the vehicle controller **200**C and the port 09. The vehicle controller **200**B has a unique MAC address. A routing table in the CAM **204** defines an association between the MAC address of the vehicle controller **200**B and the port 08.

A data frame including a source MAC address was received from the vehicle controller **200**C at the port 09. The source MAC address in the data frame transmitted by vehicle controller **200**C and received at the port 09 is associated with the vehicle controller **200**B. The source MAC address validation module **206** determined that the source MAC address in the received data frame did not match the MAC address of the vehicle controller **200**C that transmitted the data frame to port 09. The source MAC address validation module **206** determined that the source MAC address in the received data frame was invalid because the source MAC address in the received data frame did not match the MAC address of the vehicle controller **200**C associated with the port 09 in the routing table. The source MAC address validation module **206** determined that the source MAC address in the received data frame corresponded to the MAC address associated with the vehicle controller **200**B indicating that the vehicle controller **200**C was masquerading as the vehicle controller **200**B by using the MAC address associated with the vehicle controller **200**B as a source MAC address in data frames transmitted by the vehicle controller **200**C. The source MAC address validation module **206** generated an anomaly event. The anomaly event indicated that the vehicle controller **200**C that transmitted the data frame including the invalid source MAC address is masquerading as the vehicle controller **200**B having the MAC address that corresponds to the invalid source MAC address in the data frame.

The source MAC address validation module **206** transmitted the received data frame including the invalid MAC source address to the intrusion assessment system **208**. The CAM **204** suspended the routing of data frames including the invalid MAC source address associated with the vehicle controller **200**B that are received at the port 09. The anomaly event indicated that the vehicle controller **200**C may be under adversarial control and may be masquerading as a different vehicle controller **200**B in an attempt to circumvent access controls in the vehicle **10**.

Referring to FIG. **5**, a flowchart representation of an exemplary method **500** of identifying anomalous characteristics of data frames generated by a masquerading vehicle controller **200**C in accordance with at least one embodiment is shown. The method **500** will be described with reference to an exemplary implementation of the vehicle controller spoofing detection system **100**. In at least one embodiment, the method **500** is implemented by an intrusion assessment system **208**. As can be appreciated in light of the disclosure, the order of operation within the method **500** is not limited to the sequential execution as illustrated in FIG. **5** but may be performed in one or more varying orders as applicable and in accordance with the present disclosure. The method **500** will be described with reference to the example illustrated in FIG. **2**.

At **502**, the intrusion assessment system **208** receives the data frame associated with the anomaly event from the source MAC address validation module **206** at the CAM **204**. The anomaly event was generated in response to the source MAC address validation module **206** determining that the source MAC address in the data frame was an invalid source MAC address. The anomaly event indicated that the vehicle controller **200**C was compromised by an adversarial attack and was masquerading as the vehicle controller **200**B by using the MAC address associated with the vehicle controller **200**B as the source MAC address in the data frames transmitted by the vehicle controller **200**C to the port 09 of the vehicle network switch **202**. The intrusion assessment system **208** performs forensic analysis on the data frame generated by the compromised vehicle controller **200**C to identify one or more anomalous characteristics associated with the adversarial attack involving the masquerading vehicle controller **200**C.

The data frame includes a source IP address. At **504**, the source IP address module **304** generates an invalid source IP address qualified security event if the source IP address in the data frame does not match the IP address of the vehicle controller **200**C that transmitted the data frame to the port 09. Each of the vehicle controllers **200**A, **200**B, **200**C in the vehicle **10** is associated with an IP address. The associations between each of the vehicle controllers **200**A, **200**B, **200**C and the IP addresses are stored at the source IP address module **304**.

The source IP address module **304** retrieves the IP address associated with the vehicle controller **200**C that transmitted the data frame to the port 09. The source IP address module **304** determines whether the source IP address in the data frame matches the IP address associated with the vehicle controller **200**C associated with the port 09. If the source IP address module **304** determines that the source IP address in the data frame does not match the IP address associated with the vehicle controller **200**C that transmitted the data frame to the port 09, the source IP address module **304** generates the qualified security event indicating that the compromised vehicle controller **200**C is masquerading as the vehicle controller **200**B having an IP address that is the same as the IP source address in the data frame. The vehicle controller **200**C is masquerading as the vehicle controller **200**B using an invalid source IP address.

The data frame includes a payload. At **506**, the payload size module **306** generates an invalid payload size qualified security event if the payload size of the payload in the data frame is greater than a payload size threshold associated with the vehicle controller **200**C associated with the port 09 that received the data frame. Each of the vehicle controllers **200**A, **200**B, **200**C in the vehicle **10** is associated with a payload size threshold. Each vehicle controller **200**A, **200**B, **200**C is configured to transmit payloads that are less than or equal to the associated payload size threshold. The associations between each of the vehicle controllers **200**A, **200**B, **200**C and the payload size thresholds are stored at the payload size module **306**.

The payload size module **306** retrieves the stored association between the vehicle controller **200**C associated with the port 09 that received the data frame and the payload size threshold. The payload size module **306** determines whether the payload size of the payload in the data frame is greater than the payload size threshold associated with the vehicle controller **200**C that transmitted the data frame to the port 09. If the payload size module **306** determines that payload size of the payload in the data frame is greater than the payload size threshold, the payload size module **306** generates the qualified security event indicating that the compromised vehicle controller **200**C, masquerading as the vehicle controller **200**B, is transmitting payloads having an invalid payload size.

At **508**, the message rate module **308** generates an invalid message rate qualified security event if the message rate associated with the data frame is greater than a message rate threshold associated with the vehicle controller **200**C associated with the port 09 that received the data frame. Each of the vehicle controllers **200**A, **200**B, **200**C in the vehicle **10** is associated with a message rate threshold. Each vehicle controller **200**A, **200**B, **200**C is configured to transmit data frames that are less than or equal to the associated message rate threshold. The associations between each of the vehicle controllers **200**A, **200**B, **200**C and the message rate thresholds are stored at the message rate module **308**.

The message rate module **308** retrieves the stored association between the vehicle controller **200**C associated with the port 09 that received the data frame and the message rate threshold. The message rate module **308** determines whether the message rate associated with the data frame is greater than the message rate threshold associated with the vehicle controller **200**C that transmitted the data frame to the port 09. If the message rate module **308** determines that the message rate associated with the data frame is greater than the message rate threshold, the message rate module **308** generates the qualified security event indicating that the compromised vehicle controller **200**C, masquerading as the vehicle controller **200**B, is transmitting data frames at an invalid message rate.

The data frame includes a destination MAC address. At **510**, the destination MAC address module **310** generates an invalid destination MAC address qualified security event if the destination MAC address in the data frame does not match a destination MAC address associated with the vehicle controller **200**C associated with the port 09 that received the data frame. Each of the vehicle controllers **200**A, **200**B, **200**C in the vehicle **10** is configured to transmit data frames to one or more destination devices. Each destination device is associated with a MAC address. An example of a destination device is a vehicle controller **200**A, 200B, 200C. The associations between each of the vehicle controllers 200A, 200B, 200C and the one or more destination MAC addresses are stored at the destination MAC address module 310.

The destination MAC address module 310 retrieves the stored associations between the destination MAC addresses and the vehicle controller 200C that transmitted the data frame to the port 09. The destination MAC address module 310 determines whether the destination MAC address in the data frame matches a destination MAC address associated with the vehicle controller 200C that transmitted the data frame to the port 09. If the destination MAC address module 310 determines that the destination MAC address in the data frame does not match a destination MAC address associated with the vehicle controller 200C associated with the port 09 that received the data frame, the destination MAC address module 310 generates the qualified security event indicating that the compromised vehicle controller 200C is masquerading as the vehicle controller 200B using an invalid destination MAC address.

The data frame includes a destination IP address. At 512, the destination IP address module 312 generates an invalid destination IP address qualified security event if the destination IP address in the data frame does not match a destination IP address associated with the vehicle controller 200C associated with the port 09 that received the data frame. Each of the vehicle controllers 200A, 200B, 200C in the vehicle 10 is configured to transmit data frames to one or more destination devices. Each destination device is associated with an IP address. An example of a destination device is a vehicle controller 200A, 200B, 200C. The associations between each of the vehicle controllers 200A, 200B, 200C and the one or more destination IP addresses are stored at the destination IP address module 312.

The destination IP address module 312 retrieves the stored associations between the destination IP addresses and the vehicle controller 200C that transmitted the data frame to the port 09. The destination IP address module 312 determines whether the destination IP address in the data frame matches a destination IP address associated with the vehicle controller 200C associated with the port 09 that received the data frame. If the destination IP address module 312 determines that the destination IP address in the data frame does not match a destination IP address associated with the vehicle controller 200C that transmitted the data frame to the port 09, the destination IP address module 312 generates the qualified security event indicating that the compromised vehicle controller 200C is masquerading as the vehicle controller 200B using an invalid destination IP address.

At 514, the qualified security event transmission module 314 transmits the generated qualified security event(s) generated by the intrusion assessment system 208 to a security back office 210 for further analysis. The qualified security event transmission module 314 receives the qualified security events generated by one or more of the source IP address module 304, the payload size module 306, the message rate module 308, the destination MAC address module 310, and the destination IP address module 312. The qualified security event(s) define the one or more anomalous characteristics identified by the intrusion assessment system 208. The anomalous characteristics include the invalid source MAC address and one or more of an invalid source IP address, an invalid payload size, an invalid message rate, an invalid destination MAC address, and an invalid destination IP address.

While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the disclosure in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the exemplary embodiment or exemplary embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope of the disclosure as set forth in the appended claims and the legal equivalents thereof.

What is claimed is:

1. A method for detecting vehicle controller spoofing in a vehicle comprising:

receiving a first data frame including a source media access control (MAC) address at a first port of a plurality of ports of a vehicle network switch;

retrieving a stored association between the first port and a first MAC address from at least one memory, wherein the first port is designated to only receive data frames from a first vehicle controller of a plurality of vehicle controllers in the vehicle and the first vehicle controller is associated with the first MAC address;

determining whether the source MAC address is an invalid source MAC address based on a comparison of the source MAC address with the first MAC address;

generating an anomaly event based on the determination, wherein the anomaly event is indicative of the first vehicle controller masquerading as a second vehicle controller of the plurality of vehicle controllers using a second MAC address as the source MAC address, the second MAC address being associated with the second vehicle controller;

receiving the first data frame associated with the anomaly event from a ternary content addressable memory (TCAM) of the vehicle network switch;

identifying at least one anomalous characteristic associated with the first vehicle controller masquerading as the second vehicle controller, based on the first data frame; and

transmitting a qualified security event including the at least one anomalous characteristic to a security back office for further analysis.

2. The method of claim 1, further comprising:

retrieving a stored association between the first vehicle controller and a first Internet Protocol (IP) address from the at least one memory;

determining whether a source IP address received in the first data frame is an invalid source IP address based on whether the source IP address matches the first IP address; and

generating the qualified security event based on the determination, wherein the qualified security event indicates that the first vehicle controller is masquerading as the second vehicle controller using a second IP address as the source IP address, the second IP address being associated with the second vehicle controller.

3. The method of claim 1, further comprising:

retrieving a stored association between the first vehicle controller and a payload size threshold from the at least one memory, the first vehicle controller being configured to transmit payloads having a payload size that are less than or equal to the payload size threshold;

determining whether a first payload size of a first payload received in the first data frame is greater than the payload size threshold; and generating the qualified security event indicating that the first vehicle controller, masquerading as the first second controller, is transmitting payloads having an invalid payload size based on the determination.

**4**. The method of claim **1** further comprising:

retrieving a stored association between the first vehicle controller and a message rate threshold from the at least one memory, the first vehicle controller being configured to transmit the data frames at message rates that are less than or equal to the message rate threshold;

determining whether a source message rate associated with the first data frame is greater than the message rate threshold; and

generating the qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames at an invalid message rate based on the determination.

**5**. The method of claim **1** further comprising:

retrieving a stored association between the first vehicle controller and at least one destination MAC address from the at least one memory, wherein the first vehicle controller is configured to transmit the data frames comprising one of the at least one destination MAC address and each of the at least one destination MAC address is associated with a destination device;

determining whether a first destination MAC address received in the first data frame matches one of the at least one destination MAC addresses associated with the first vehicle controller; and

generating the qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames using an invalid destination MAC address based on the determination.

**6**. The method of claim **1** further comprising:

retrieving a stored association between the first vehicle controller and at least one destination IP address from the at least one memory, wherein the first vehicle controller is configured to transmit the data frames comprising one of the at least one destination IP address and each of the at least one destination IP address is associated with a destination device;

determining whether a first destination IP address received in the first data frame matches one of the at least one destination IP addresses associated with the first vehicle controller; and

generating the qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames using an invalid destination IP address based on the determination.

**7**. The method of claim **1**, further comprising suspending routing of data frames including the source MAC address received at the first port upon the generation of the anomaly event.

**8**. The method of claim **1**, wherein the at least one anomalous characteristic comprises the invalid source MAC address and at least one of an invalid source IP address, an invalid payload size, an invalid message rate, an invalid destination MAC address, and an invalid destination IP address.

**9**. A vehicle configured to detect vehicle controller spoofing comprising:

a plurality of vehicle controllers including first and second vehicle controllers;

a vehicle network switch comprising a plurality of ports, wherein a first port of the plurality of ports is designated to only receive data frames from the first vehicle controller and the first vehicle controller is associated with a first media access control (MAC) address; and

a content addressable memory (CAM) configured to:

receive a first data frame including a source MAC address at the first port;

retrieve a stored association between the first port and the first MAC address;

determine whether the source MAC address is an invalid source MAC address based on a comparison of the source MAC address with the first MAC address;

generate an anomaly event based on the determination, wherein the anomaly event is indicative of the first vehicle controller masquerading as the second vehicle controller using a second MAC address as the source MAC address, the second MAC address being associated with the second vehicle controller;

receive the first data frame associated with the anomaly event from a ternary content addressable memory (TCAM) of the vehicle network switch;

identify at least one anomalous characteristic associated with the first vehicle controller masquerading as the second vehicle controller, based on the first data frame; and

transmit a qualified security event including the at least one anomalous characteristic to a security back office for further analysis.

**10**. The vehicle of claim **9**, further comprising an intrusion assessment system and wherein:

the first vehicle controller is associated with a first Internet Protocol (IP) address;

the CAM is configured to transmit the first data frame associated with the anomaly event to the intrusion assessment system, the first data frame including a source IP address; and

the intrusion assessment system is configured to:

retrieve a stored association between the first vehicle controller and the first IP address from at least one memory at the intrusion assessment system;

determine whether the source IP address is an invalid source IP address based on whether the source IP address matches the first IP address; and

generate the qualified security event based on the determination, wherein the qualified security event indicates that the first vehicle controller is masquerading as the second vehicle controller using a second IP address, the second IP address being associated with the second vehicle controller.

**11**. The vehicle of claim **9**, further comprising an intrusion assessment system and wherein:

the first vehicle controller is configured to transmit payloads having a payload size that are less than or equal to a payload size threshold;

the CAM is configured to transmit the first data frame associated with the anomaly event to the intrusion assessment system, the first data frame including a first payload; and

the intrusion assessment system is configured to:

retrieve a stored association between the first vehicle controller and the payload size threshold from at least one memory at the intrusion assessment system;

determine whether a first payload size of the first payload is greater than the payload size threshold; and

generate the qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting payloads having an invalid payload size based on the determination.

**12**. The vehicle of claim **9**, further comprising an intrusion assessment system and wherein:

the first vehicle controller is configured to transmit the data frames at message rates that are less than or equal to a message rate threshold;

the CAM is configured to transmit the first data frame associated with the anomaly event to the intrusion assessment system; and

the intrusion assessment system is configured to:

retrieve a stored association between the first vehicle controller and the message rate threshold from at least one memory at the intrusion assessment system;

determine whether a source message rate associated with the first data frame is greater than the message rate threshold; and

generate the qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames at an invalid message rate based on the determination.

**13**. The vehicle of claim **9**, further comprising an intrusion assessment system and wherein:

the first vehicle controller is configured to transmit the data frames comprising one of at least one destination MAC address, each of the at least one destination MAC address being associated with a destination device;

the CAM is configured to transmit the first data frame associated with the anomaly event to the intrusion assessment system, the first data frame including a first destination MAC address; and

the intrusion assessment system is configured to:

retrieve stored associations between the first vehicle controller and the at least one destination MAC address from at least one memory at the intrusion assessment system;

determine whether the first destination MAC address matches one of the at least one destination MAC addresses associated with the first vehicle controller; and

generate the qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames using an invalid destination MAC address based on the determination.

**14**. The vehicle of claim **9**, further comprising an intrusion assessment system and wherein:

the first vehicle controller is configured to transmit the data frames comprising one of at least one destination IP address, each of the at least one destination IP address being associated with a destination device;

the CAM is configured to transmit the first data frame associated with the anomaly event to the intrusion assessment system, the first data frame including a first destination IP address; and

the intrusion assessment system is configured to:

retrieve stored associations between the first vehicle controller and the at least one destination IP address from at least one memory at the intrusion assessment system;

determine whether the first destination IP address matches one of the at least one destination IP addresses associated with the first vehicle controller; and

generate the qualified security event indicating that the first vehicle controller, masquerading as second first vehicle controller, is transmitting the data frames using an invalid destination IP address based on the determination.

**15**. The vehicle of claim **9**, wherein the vehicle network switch is configured to suspend routing of data frames including the source MAC address received at the first port upon the generation of the anomaly event.

**16**. The vehicle of claim **9**, wherein the at least one anomalous characteristic comprises the invalid source MAC address and at least one of an invalid source IP address, an invalid payload size, an invalid message rate, an invalid destination MAC address, and an invalid destination IP address.

**17**. A system for detecting vehicle controller spoofing comprising:

at least one processor; and

at least one memory communicatively coupled to the at least one processor, the at least one memory comprising instructions that upon execution by the at least one processor, cause the at least one processor to:

receive a first data frame including a source media access control (MAC) address at a first port of a plurality of ports of a vehicle network switch;

retrieve a stored association between the first port and a first MAC address from the at least one memory, wherein the first port is designated to only receive data frames from a first vehicle controller of a plurality of vehicle controllers in the vehicle and the first vehicle controller is associated with the first MAC address;

determine whether the source MAC address is an invalid source MAC address based on a comparison of the source MAC address with the first MAC address;

generate an anomaly event based on the determination, wherein the anomaly event is indicative of the first vehicle controller masquerading as a second vehicle controller of the plurality of vehicle controllers using a second MAC address as the source MAC address, the second MAC address being associated with the second vehicle controller

receive the first data frame associated with the anomaly event from a ternary content addressable memory (TCAM) of the vehicle network switch;

identify at least one anomalous characteristic associated with the first vehicle controller masquerading as the second vehicle controller, based on the first data frame; and

transmit a qualified security event including the at least one anomalous characteristic to a security back office for further analysis.

**18**. The system of claim **17**, wherein the at least one memory further comprises instructions that upon execution by the at least one processor, cause the at least one processor to:

retrieve a stored association between the first vehicle controller and a first Internet Protocol (IP) address from the at least one memory;

determine whether a source IP address received in the first data frame is an invalid source IP address based on whether the source IP address matches the first IP address; and

generate the qualified security event based on the determination, wherein the qualified security event indicates that the first vehicle controller is masquerading as the second vehicle controller using a second IP address as the source IP address, the second IP address being associated with the second vehicle controller.

**19**. The system of claim **17**, wherein the at least one memory further comprises instructions that upon execution by the at least one processor, cause the at least one processor to:

retrieve a stored association between the first vehicle controller and a payload size threshold from the at least one memory, the first vehicle controller being configured to transmit payloads having a payload size that are less than or equal to the payload size threshold;

determine whether a first payload size of a first payload received in the first data frame is greater than the payload size threshold; and

generate the qualified security event indicating that the first vehicle controller, masquerading as the first second controller, is transmitting payloads having an invalid payload size based on the determination.

**20**. The system of claim **17**, wherein the at least one memory further comprises instructions that upon execution by the at least one processor, cause the at least one processor to:

retrieve a stored association between the first vehicle controller and a message rate threshold from the at least one memory, the first vehicle controller being configured to transmit the data frames at message rates that are less than or equal to the message rate threshold;

determine whether a source message rate associated with the first data frame is greater than the message rate threshold; and

generate the qualified security event indicating that the first vehicle controller, masquerading as the second vehicle controller, is transmitting the data frames at an invalid message rate based on the determination.

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