

## 1 Introduction

## 2 Acronyms and abbreviations

CAN	Controller Area Network
CAR	California Air Resources Board
DLC	Data Link Connector
ECU	Electronic Control Unit
LIN	Local Interconnect Network
MOST	Media Oriented Systems Transport
TPMS	Tire Pressure Monitoring System
V2P	Vehicle-to-pedestrian
V2N	Vehicle-to-network
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle

**Motivation** A lot of things have happened to the automotive industry, ever since the introduction of the Ford Model T in 1917. Although the main purpose of these machines remains the same (e.g. getting someone from point A to B swiftly), the relative comfort, speed and efficiency at which they do so has improved dramatically. The most important contributor to this evolution is without a doubt the introduction of electronic computers into the vehicle's architecture. The modern vehicle has been appropriately called a "Computer on wheels" [2], since each one contains up to 100 millions lines of code, spread out over as much as 70 individual ECUs (Electronic Control Units) [1]. Each ECU is a small computer controlled device that is designed to perform a specific function (e.g. braking, opening the door, speed control, etc). In addition to having this wide variety of embedded devices a modern vehicle will also employ a data bus that allows all ECUs inside a vehicle to communicate with each other. There are multiple standards that are employed even within a single vehicle, but the CAN (Controller Area Network) protocol is probably the most common and will be the focus of this paper. Alongside internal communication networks, a lot of newer models will also introduce some way of performing external communications. This can range from vehicle-to-infrastructure (V2I) communications (e.g. wireless gas payment at a gas station, wireless diagnostics at a repair shop or even virtual traffic lights), vehicle-to-vehicle communications (V2V) (e.g. automatically following another vehicle), vehicle-to-network communications (V2N) (connecting your vehicle to an already existing network, like the cellular communications network for example) and vehicle-to-pedestrian

communications (V2P) [3][4][5]. All of the extended functionality introduced greatly improves the vehicle’s flexibility and comfort, but also makes them increasingly vulnerable. As with any interconnected computer system it is susceptible to attack from malicious agents if the right level of security[18] is not attained. This is made even worse by the introduction external communications (e.g. V2I, V2V, V2N and V2P) since this allows for remote attacks, eliminating the need for physical access to the internal network (which of course should be hard to obtain). A lot of the ECUs that facilitate external communications can now be seen as potential attack vectors. One of these (and also one of the most vulnerable) is the OBD-II (On board Diagnostics) interface. OBD-II systems are widely deployed in auto-mobiles as a way of getting diagnostics information from the vehicle. OBD-II introduces a physical interface into the vehicle (usually under the steering wheel) called the Data Link Connector (DLC). This physical interface allows full access to the internal network. It has been repeatedly shown [6][7][14][15] that a set of messages or signals could be injected on a car’s CAN bus to control key components (e.g. lights, locks, brakes, and engine) as well as injecting code into key ECUs. The focus of this thesis will be to try and mitigate this kind of illegal access by introducing access control to the OBD-II interface.

**Challenges** The main challenge of this research topic is to introduce a solution that ports well to the kind of hardware that is found in modern vehicles. Introducing new components into the internal vehicle network would surely simplify things (if this were the case the solution could consist of introducing a small component that acts as a firewall for the OBD-II interface). However this would imply that any potential real-world implementations by a car manufacturer would require the installation of these components in millions of existing vehicles, which (being a very costly endeavour) would deter any manufacturers from doing so. It is the opinion of the researchers of this paper to focus on designing a solution that is easy to introduce into an existing vehicle network by way of a simple software update. Because of this decision it becomes important to take existing vehicle networks and solutions (a.k.a the context) into account when designing a solution. A leading example of constraints introduced by the context are the memory limitations of ECU micro controllers. Indeed, any solution that isn’t portable to the network (because of memory limitations, limited processing power, incompatible architectures, etc) is rendered useless. Another example is the impact of the context on the threat model. It is impossible to deny the owner of the vehicle direct access to it’s internal network (In

theory the owner could bypass the OBD-II interface by gaining direct access to the wires that compromise the network, or exploiting a vulnerability of a different entry point [6]), It is easy to see that in a proposed role-based access control solution this threat is out of scope. The main challenges of this thesis paper are summarized as follows:

- **portability:** The solution should port well to existing vehicle networks.
- **Security:** The solution should be sufficiently secure according to current computer safety standards.
- **Speed:** The solution should not impede the operation of other processes running on the same network.

**Context** As mentioned before the goal of this paper is to secure the OBD-II interface in modern cars. Before we move on it is interesting to take a look at some other issues regarding internal vehicle networks, as well as some proposed solutions to these problems. Aside from the OBD-II interface there are numerous points of entry to the internal vehicle network, both physical (Breaking into the vehicle and directly connecting to the network) or wireless (Bluetooth, TPMS or Tire Pressure Monitoring System, Radio system, etc) [6]. Take Bluetooth for example: A lot of cars include Bluetooth functionality to allow users to connect their phones and play music. The Bluetooth protocol has a large protocol-stack and has been known to have problems in the past [6]. By exploiting the vulnerabilities of a car's Bluetooth interface, a malicious agent is able to interfere with the internal network remotely (using his/her mobile phone). Another problem is that it is easy for a phone to get compromised (visiting a malicious website) [7]. This problem would be solved by using a more secure version that does not contain the aforementioned vulnerabilities.

Another approach is to secure the protocol that is used for communication within the network. As mentioned before, the CAN protocol is probably the most popular one. CAN in itself is a simple bus protocol that allows nodes on a network to send and receive messages. However CAN is a low-level protocol and does not natively support any security features. A number of secure CAN variations have been proposed: Leia[33], VatiCAN[34], VulCAN[32] and CANopen[28]. In the case of CANopen their contributions were summarized as follows:

'a generic design for efficient vehicle message authentication, plus software component attestation and isolation using lightweight trusted computing technology'.

**Contributions** The contribution of this thesis can be summarized as follows:

- To mitigate the problem of unauthorised access to the vehicle CAN network via the OBD-II Data Link Connector. Since OBD-II was designed solely for diagnostic purposes (what's in a name) the goal is to limit access accordingly. 2 Basic protocol designs are proposed.
- The proposed designs have been implemented on hardware similar to the ones found in modern cars, and a small demo is used to illustrate their operation.
- These implementations are then tested to determine if they are in accordance with the challenges proposed in section 2.

## 3 Literature Review

### 3.1 Vehicle Network Infrastructure

As mentioned before Today's automobiles contain a series of different electronic components networked together to be responsible for monitoring and controlling the state of the vehicle. Each component can communicate with all other components on the same network. The safety of the vehicle (and consequently the driver) relies on near real time communication between these various ECUs. While communicating with each other, ECUs are responsible for predicting crashes, detecting skids, performing anti-lock braking (ABS), etc [7]. There are only a couple of operations that are performed without using computer control (with the parking brake and steering being the last holdouts)[16] Let's take a closer look at ABS to get a sense of how the internal vehicle network operates. ABS was designed to keep the wheels from locking up during braking. It consists of 3 main components: wheel speed sensors, a pump and a controller. Here's how it works:

- The controller monitors the wheel speed sensors constantly (So each speed sensor periodically sends a message to the Controller).
- The controller will recognize a wheel locking whenever it detects a rapid deceleration.

- Whenever it does detect a wheel locking up, it will use the pump (again by sending a message over the network) to regulate the pressure on the brake of that particular wheel, thereby keeping it from locking up.

Figure 3.1 shows the infrastructure of a typical vehicle network. As mentioned before There are multiple communication standards that are employed even within a single vehicle. In the theoretical example from figure 3.1 we have: Controller Area Network (CAN), Local Interconnect Network (LIN), Media Oriented Systems Transport (MOST) and FlexRay. Each of these protocols specifies how messages are exchanged within the appropriate sub-networks (e.g safety, infotainment, chassis, etc). A critical component in these types of networks (the presence of sub-networks with different communication protocols) is the Gateway ECU (called control gateway in figure 3.1). This component performs a frame or signal mapping function between two communication systems, thereby allowing ECU's on different sub-networks using distinct communication protocols to exchange messages nonetheless.

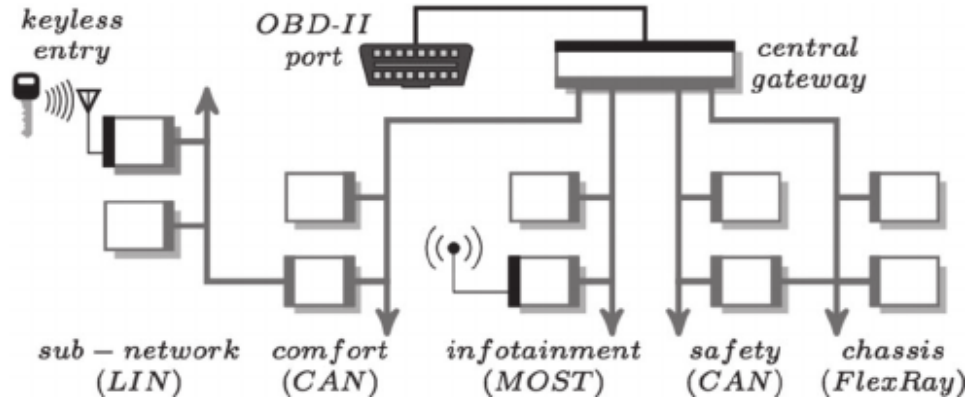


Figure 1: Typical Vehicle Network Infrastructure [8]

On top of acting as an intermediate between the different sub-networks of the vehicle, the Gateway also acts as an entry point for OBD-II messages. Any message sent via the OBD-II DLC will be translated and forwarded by the Gateway to the appropriate sub-network. It comes as no surprise that this component will have to play a crucial role when introducing access control to the OBD-II interface.

## 3.2 OBD-II

**Goal** OBD-II (On Board Diagnostics) is a specification that was introduced to allow for self diagnostic and reporting functionality for ECU's inside a vehicle, and has been mandatory in every car produced in the united states since 1996. [9]. It allows users (testers, developers, repairmen, etc) to query ECU's about diagnostics information in order to perform a detailed analysis of the vehicles internal systems. Specifically the goals of OBD-II upon introduction were:

- Standardisation: information is communicated in a standardized format to allow for 1 tool to be used on many vehicles.
- Certification: Every vehicle manufacturer required to submit certification application for review and approval, which includes a detailed description of how the OBD-II protocol was implemented.
- Help lowering emissions by identifying emission controls in need of repair.

The system can also be very useful in a number of other situations: A repairman looking for a specific component that is to be repaired, an employee at the factory testing all components before the vehicle is ready to be sold, a policeman analysing a vehicle after a crash to determine what caused the accident, a software developer testing the operation of a newly developed ECU, etc.

**Brief History** There were a lot of different proprietary diagnostics systems introduced over the years, before a standardised arrived with the introduction of OBD-II. This brief history cited from [10] does a decent job of concisely explaining how OBD-II came to be:

The origins of OBDII actually date back to 1982 in California, when the California Air Resources Board (ARB) began developing regulations that would require all vehicles sold in that state starting in 1988 to have an onboard diagnostic system to detect emission failures. The original onboard diagnostic system (which has since become known as OBDI) was relatively simple and only monitored the oxygen sensor, EGR system, fuel delivery system and engine control module.

OBDI was a step in the right direction, but lacked any requirement for standardization between different makes and models of vehicles. You still had to have different adapters to work on different vehicles, and some systems could only be accessed with costly "dealer" scan tools. So when ARB set about to develop standards for the current OBDII system, standardization was a priority: a standardized 16-pin data link connector (DLC) with specific pins assigned specific functions, standardized electronic protocols, standardized diagnostic trouble codes (DTCs), and standardized terminology.

Another limitation of OBDI was that it couldn't detect certain kinds of problems such as a dead catalytic converter or one that had been removed. Nor could it detect ignition misfires or evaporative emission problems. Furthermore, OBDI systems would only illuminate the MIL light after a failure had occurred. It had no way of monitoring progressive deterioration of emissions-related components. So it became apparent that a more sophisticated system would be required. The California Air Resources Board eventually developed standards for the next generation OBD system, which were proposed in 1989 and became known as OBDII. The new standards required a phase-in starting in 1994. The auto makers were given until the 1996 model year to complete the phase-in for their California vehicles.

Similar standards were incorporated into the federal Clean Air Act in 1990 which also required all 49-state vehicles to be OBDII equipped by 1996 – with one loophole. The OBDII systems would not have to be fully compliant until 1999. So some 1996 OBDII systems may lack one of the features normally required to meet the OBDII specs, such as the evaporative emissions purge test.

**DLC** In order to allow for a user to communicate with the vehicle's internal network, OBD-II introduces the data link connector (DLC). The DLC is a 16-pin hardware interface (although only 9 pins are enforced by the standard) that is generally found close to the steering wheel (by law it is required to be installed within 0.61 m of the steering wheel) [9]. There are 2 basic types of connectors: Type A as seen in figure 3.2 (using a 12V power supply) and Type B as seen in figure 3.2 (using a 24V power supply). the design of the two connector types prevents the insertion of a type A male

plug into a type B female socket.

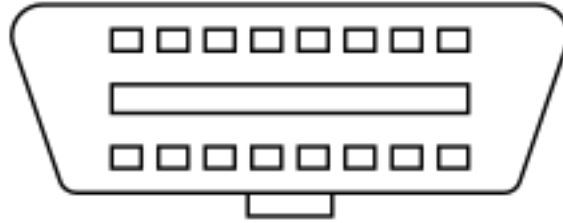


Figure 2: Type A female connector [9]

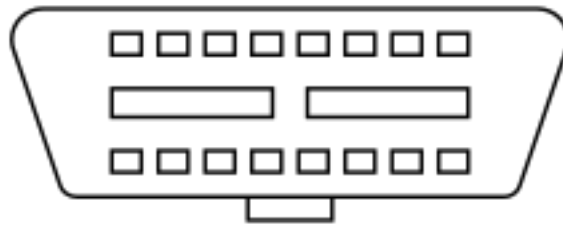


Figure 3: Type B female connector [9]

**PID's** It introduces parameter ID's which are codes used to identify and query specific data. The protocol is designed to work with multiple signalling protocols (the messaging protocol that is used to request and receive data from the network) but the CAN protocol is mostly implemented (Since 2008 all vehicles sold in the us must implement this signalling protocol).

There are multiple ways for a user to interact with this interface:

- Standard Diagnostic scanning tool is a dedicated device that consists of a small hand-held module (equipped with a small screen and some buttons) connected to a male DLC-connector (The DLC inside the vehicle is always a female).
- An advanced Diagnostic scanning tool that includes a DLC-connector with wifi/Bluetooth compatibility, allowing for remote diagnostics using a smartphone.
- A DLC-connector with a usb adapter allowing access via dedicated software on a pc.



Typically the OBD-II is used like this (CAN as signalling protocol): First the user enters the PID of the data he/she wants to query into a diagnostic tool. Secondly this data is packaged in a CAN frame and sent on the CAN-bus. Thirdly the ECU that is responsible for the data identified by the PID in the message recognizes it as it's own, and transmits a CAN frame containing the requested data. Fourthly the diagnostic tool recognizes the response and displays the data to the user. [11]

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