On the impact of lightweight ciphers in automotive networks

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Abstract—The ever more exposure of modern vehicles to computer networks has led, in recent years, to increase risks due to cyberattacks. The internal computer network of vehicles, used to connect several electronic components present on cars, is even more threatened as it is potentially exposed to external attacks. Securing the Controller Area Network (CAN) protocol, used to govern those networks, is becoming increasingly important to ensure a safe driving experience.

CAN is an ISO standard that dates back to 1983, over the years it has undergone very few changes coming to be outdated. It has been designed to minimize latency and data transmission errors through two essential features: small frames and unencrypted information transfer. The latter feature, in particular, appears to be the weak point of this protocol. Securing the communication channel is needed, but it must be done by preserving all the main features that ensure the performance of this protocol, in particular the low latency. Furthermore, the modification cannot introduce low-level alterations.

CAN security can be improved by acting at a higher level. In this work we investigate the feasibility of using symmetric encryption algorithms for securing messages exchanged on the CAN-bus. In particular, this paper evaluates the effectiveness of using lightweight ciphers, designed with the aim of introducing encryption also on devices, which have limited hardware and software resources, such as microcontrollers.

Keywords—Automotive security; Controller Area Network; Lightweight Cryptography; Cybersecurity; Encryption.

I. INTRODUCTION

We live in the Internet of Things (IoT) era, in which innumerable devices are interconnected and connected to the Internet, constantly exchanging information for several purposes [1]–[6]. In particular, IoT indicates a set of technologies that allow any type of device to be connected to the Internet and interact. The purpose of this type of solutions is varied [7]–[13] and could concern monitoring, controlling and transferring information to perform consequent actions. The automotive field, not least, has progressively invested in the IoT paradigm. In fact, modern vehicles are equipped with many sensors that enhance their features and services. It is estimated that by 2022 new vehicles will be able to communicate with each other [14]. Modern vehicles are able to exchange information over the network using wireless technologies and cloud services. However, these communication channels expose the vehicle to

potential vulnerabilities that may prejudice their functionality by attacking the internal network [15], [16].

Internet access exposes vehicles to potential attacks that can be different and varied. An attacker may be interested in spying on users to find personal information or even remotely control their vehicle. The Controller Area Network (CAN) represents the internal network of the vehicle which, in modern vehicles, consists of 70 nodes, which are the Electric Control Units (ECUs). The ECUs are responsible for controlling each component of the vehicle, from the ventilation system up to the braking system and steering [17], [18]. The communication channel, called CAN-bus, collects the exchange broadcast information between the various ECUs. Therefore, access to the CAN-bus would compromise the entire safety of the vehicle [19], [20].

The CAN-bus security issue has been addressed in the literature in several ways. One of the approaches is to redesign the CAN standard from a hardware perspective. However, this type of solution, with the exception of a substantial hardware upgrade, brings the disadvantage of not ensuring security to all vehicles already on the market [21]. Different approaches aim to equip the internal vehicle network with an Intrusion Detection System (IDS), which however, in many cases exceed the computational capacity of the microcontrollers [22], [23]. In attempt to preserve the exchange of information unchanged and considering the insufficient computational capability of microcontrollers, also possible solutions based on the Message Authentication Code (MAC) are to be excluded [24].

The aim of this work is to envision a solution for securing messages exchanged on the CAN-bus through symmetric encryption algorithms. In particular, a solution using lightweight ciphers is proposed and evaluated. Lightweight ciphers provide encryption facilities on devices which have limited hardware and software resources, such as microcontrollers.

With the aim of extending our solution to all vehicles already on the market, the selected lightweight ciphers are PRESENT [25], SIMON and SPECK [26], which should produce safety improvement with little delay in communications. With the goal of evaluating the proposed approach, a prototype using Automotive Grade Linux (AGL) [27] was developed to evaluate the impact of the proposed solution on system performance. This paper is organized as follows. In Section II we provide the background underlying the proposed approach. In Section III we provide our solutions in order to protect modern vehicles. In Section IV we describe a proof of concept of our proposed solution. In Section V we discuss a preliminary test activity.

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into two levels, that is high and low. The former deals with the logic and advanced functions that are offered to user applications, whereas the latter carries out security checks, transactions, caching, encoding and decoding of messages. The system is in fact designed to extract the various messages that can be admitted starting from a JSON file. Therefore, the applications require the transmission of a signal simply by using the name assigned to them during compilation. The lowest level of the CAN API then deals with the translation of this string into a frame of data and vice versa. The services are defined in files that are used by the `afb-daemon` binder and the latter can be queried via HTTP or WS specifying the name of the API to be used followed by the desired method. The actual writing and reading on/from the communication channel is done using the native Linux drivers.

III. PROPOSED SOLUTION

This section deals with the proposed solution, which aims to protect connected vehicles from possible attacks. In fact, an attacker, through the use of malware, could attack and control an entire fleet of vehicles. Furthermore, it is necessary to pay careful attention to make changes that do not compromise the performance of the protocol. In other words, security must be increased without compromising the efficient execution of message exchange. [32]

Four types of messages can be exchanged on the CAN bus, but the only one on which encryption could be applied is the data frame, which is involved in the exchange of information. However, the length of the data field is often of variable length and does not exploit all transmissible bytes. In this regard, to improve the resistance of the system to brute force attacks, it is necessary to use all the 64 bits available, using dummy data in order to introduce noise.

However, in the use of cryptographic algorithms, which would improve vehicle safety, there are very important limitations. Microcontrollers, i.e., hardware with limited memory capacity, the need to preserve the performance of the CAN protocol and the limited amount of data to be encrypted are the main limitations to consider when choosing ciphers. Lightweight ciphers are the best solution in the conditions described above. The main feature of lightweight encryption is to find the best compromise between security and lightness, reducing the resources needed to execute the algorithm, both in terms of space and time. In our case, due to the type of application, it is necessary to use ciphers capable of working on low performance hardware and with a particularly high encryption and decryption speed. These main features are peculiar to be implemented in the automotive sector. Some of the most well-known lightweight ciphers are PRESENT [25], SIMON and SPECK [26].

A. Protection of CAN Data Frames

The field to consider, to prevent that an attacker takes control of the vehicle, is the data frames field, which contains information exchanged to all nodes on the internal network. Therefore, encrypting this field could be crucial for security improvements. We remark that for performance reasons, the protocol tends to transmit the minimum number of bits needed for each message. In fact, most of the messages exchanged on the bus do not use all the 64 bits available. However, for

reasons related to security and correct use of ciphers, it is necessary to include dummy data to fill the entire field. It must not be forgotten that this operation could compromise the performance of the CAN protocol.

The proposed solution includes the using of a fixed key [33], [34], usable for the entire life of the vehicle or to be changed at regular intervals, to encrypt the messages exchanged on the CAN-bus. In fact, this solution does not imply hardware changes or synchronization problems between the different components responsible for communication. This key must be generated during production, remaining secret for the entire life of the vehicle.

However, if an attacker could discover the key, the safety of the entire vehicle would be compromised [35]. In this regard, the use of a fixed key is not very recommendable and this key should be changed at regular intervals.

The proposed solution involves the addition of a small operation during the production phase of the vehicle. Using a fixed key implies a little change in the production chain between the vehicle manufacturer and electronic component suppliers. More precisely, the latter will have to provide a software for flashing the firmware of the individual ECU, allowing the inclusion of the key during the assembly phase. Finally, we point out that although the key must be kept secret, however, it must be available for technical interventions such as replacing an ECU.

IV. EXPERIMENTAL PHASE

To implement the proposed solution it is necessary to modify the modules dedicated to writing and reading messages on the CAN-bus, present in Automotive Grade Linux. It was therefore necessary to modify these modules by inserting an encryption phase after writing and a decryption phase before the reading. AGL is an open source environment, so it allows us to clone the source of the modules by modifying them as necessary.

In AGL, the *low CAN service* module is responsible for communication with the CAN-bus, through which it is possible to read, write and subscribe signals via HTTP or WS interface. This module could be modified at various points, to make the safety improvements proposed. The appropriate solution concerns to intervene at the binding definition level, making changes to the functions responsible of sending and receiving a message, without changing the embedded libraries.

A. Message Encryption

The binding is defined in the file **low-can-binding/binding/low-can-cb.cpp** and is designed in such a way that the writing of messages is managed by two different functions, depending on the mode used. In particular, the function **write_signal()** is invoked when we specify only the name and value of the signal to be sent. The writing of a raw frame instead passes through the function **write_raw_frame()**. Both of the functions mentioned above invoke the function **send_frame()**, which represents an excellent point to enter and carry out the encryption before the frame is passed to the sending module [36].

Listing 1: Encryption in writing phase

```
static int send_frame(struct canfd_frame&
                    cfd, const std::string& bus_name)
```

```

{
    if (bus_name.empty()) {
        return -1;
    }

    std::map<std::string, std::shared_ptr<
        low_can_subscription_t>>& cd =
        application_t::instance().
        get_can_devices();

    if (cd.count(bus_name) == 0)
    {cd[bus_name] = std::make_shared<
        low_can_subscription_t>
        (low_can_subscription_t());}

    //Start Encryption

    encrypt(cfd);

    //End Encryption

    return cd[bus_name]->tx_send(cfd,
        bus_name);
}

```

The modification consists simply in accomplishing, before the end of the function **send_frame()**, the encryption of the field **data** and eventually the modification of the value of the field **len**, keeping it consistent with the number of bytes actually used in **data**. In fact, the structure received as a parameter by the function **send_frame()** has several fields, among which there is **data** containing the raw information of the message and **len** which indicates the length of the message. In the code shown in Listing 1, the structure is passed as a parameter to the function **encrypt()** that inside it must provide for the implementation of the chosen cipher scheme and, if necessary, for the insertion of *dummy data* and for the modification of the **len** field.

B. Message Decryption

Intervention in reading requires a modification to the class **can_message_t** in order to make the vector editable **data_**. In fact, in this field the raw information is processed at a higher level. The modification concerns both the header in which the class is defined, and the file in which the behavior of the various methods is defined. The files in question are, respectively, **low-can-binding/can/can-message.hpp** and **low-can-binding/can/can-message.cpp** [36].

Listing 2: Adding set in prototype in **can-message.hpp**

```

void set_data_vector(std::vector<uint8_t
    >&);

```

Listing 3: Implementation of the method in **can-message.cpp**

```

void can_message_t::set_data_vector(std::
    vector<uint8_t>& data)
{
    data_ = data;
}

```

Once the problem of updating the data field has been solved, it is possible to intervene again in the definition of the binding, so as to define the decryption operation. In practice, the point in which to make changes is within the function **read_message()**.

Listing 4: Decryption in reading phase

```

int read_message(sd_event_source *
    event_source, int fd, uint32_t revents
    , void *userdata)
{
    low_can_subscription_t* can_subscription
        = (low_can_subscription_t*)userdata
        ;
    if ((revents & EPOLLIN) != 0)
    {
        can_message_t cm;
        utils::socketcan_bcm_t& s =
            can_subscription->get_socket();
        s >> cm;

        // Sure we got a valid CAN message ?
        if (! cm.get_id() == 0 && ! cm.
            get_length() == 0)
        {
            //Start Encryption
            std::vector<uint8_t> data (
                CANFD_MAX_DLEN);

            data = decrypt(cm.get_data_vector
                ());

            cm.set_data_vector(data);
            //End Encryption

            push_n_notify(cm);
        }

        // check if error or hangup
        if ((revents & (EPOLLERR|EPOLLRDHUP|
            EPOLLHUP)) != 0)
        {
            sd_event_source_unref(event_source);
            can_subscription->get_socket().close();
        }

        return 0;
    }
}

```

It remains to define the encryption mode, according to those chosen for the encryption process.

V. EXPERIMENTAL RESULTS

The function **system_time_us()** is used to obtain the delay between the reading and writing phases of a message exchanged on the CAN-bus. This function is used before the encryption and after decryption phases, providing the time spent during the entire process. The time obtained represents the delay brought by the use of the proposed methodology.

The average of time obtained is between 300 μ s and 1ms and, according to [37], it is more efficient to use hardware-oriented ciphers than the software one. To give an idea of the two effects to the delay generated by our solution, we can refer to a fundamental phase of driving a vehicle, which is the braking phase. The proposed solution generates delays in communication, which we can influence the various phases of driving the vehicle. Even if these delays are very low, to appreciate their significance we consider a crucial phase, which is the braking phase, transforming the delay in communication in terms of distance accumulated. However, even if, in the worst case, 1ms represents a very low value, it causes an extra distance to travel of about 40 mm, in terms of break reaction if a driver was travelling at 150 Km/h of speed. The delays obtained in terms of distance, in the best (300 μ s) and in the worst (1 ms) case, are reported in Table I.

TABLE I: Excess distance due to the delay introduced by the encryption

Speed [Km/h]	Distance (300 μ s) [mm]	Distance (1ms) [mm]
50	4.2	13.9
100	8.3	27.8
150	12.5	41.7
200	16.7	55.5
250	20.8	69.4
300	25.0	83.3

According to the Table I, the results are encouraging. There are two main causes of the accumulated delay during the encryption and decryption phases, that are the algorithm used and the hardware on which the system is installed. The realized prototype has been installed on a Raspberry Pi 3 to simulate a generic ECU. However, on the vehicles present in today's market, microcontrollers are installed that could be even less efficient.

VI. CONCLUSIONS

The study conducted in this paper deals with a cybersecurity problem in the automotive sector. In particular, was analysed the problem of the exchange of unencrypted messages on the CAN-bus and the feasibility of encryption that at least manages to prevent attacks on vehicles. According to the literature, an attacker who remotely penetrates into a vehicle's communication channel has the same control level of the driver. In this paper was analysed how important it can be to secure the CAN-bus, by obfuscating messages without altering their structure. This choice arises from the desire to keep the proposed solutions compatible with all the devices on the market, opening, in fact, to the possibility of correcting the security problem even on vehicles that already populate our roads. It has therefore been seen how message encryption is possible for all transmitted identifiers, as well as for sections containing data. We remark that due to the application field, the choice of the cipher is rather important, ensuring the least possible delay. Therefore, the use of lightweight ciphers has been evaluated. The study also focused on the implementation of a prototype through Automotive Grade Linux operating system and the interactions between the latter and the CAN-bus, achieving reasonable results. In fact, the maximum delay,

introduced of our solution, is 1 ms and if the vehicle travels at 150 Km/h of speed, the extra distance generated by the delay is about 40 mm, which is a reasonable value. Further considerations on error handling in the decryption phase are demanded to future steps.

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