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Mitigating Cybersecurity Threats in Autonomous Vehicles: A Real-World Case Study on Protecting V2X Communication Against Remote Hacking Attempts

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***Abstract*:** As of now, maintaining the security and dependability of V2X communication remains an open issue due to the complexity and vulnerability of wireless networking technologies for Autonomous Vehicles (AVs). This study is conducted to address the research gap. The initial research activities are to routinely test the security vulnerability of the communication technologies in AVs, which encompass vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), and vehicle-to-device (V2D) communication. Industry tools and software licenses are used to perform these experimental tests. The results reveal that malicious cyber-attacks targeting V2X communication are successful. Building on the results, a model-based SDLC and a set of guidelines are proposed to securely develop software for AVs 2. Participants of the project are also trained in these newly developed methodologies to enhance the development security of the AVs in the future.

Access this article online

***Keywords*:** Autonomous Vehicles, Mitigating Cyber Security, Real-World, V2X Communication, Remote Hacking

1. Introduction

Autonomous vehicles are equipped with numerous legacy electronic control units (ECUs) that have connections to the external environment. Eliminating the important accident cause between autonomous vehicles (AVs) and manually driven vehicles requires V2X and Device-to-Device Communication (D2D). To facilitate such communication, the overall evolution of AVs includes wireless communication. From a commercial and legal landscape, vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) scenarios involve communication being forced with a range of actors. This is exemplified by the U.S. DoT's announcement of the intention to require DSCR in all new light vehicles [1]. As vehicles rely on software and share data increasingly frequently, the cybersecurity vulnerabilities in vehicles will increase due to the attack surface created. For instance, in 1, it has been analyzed that attackers can use stolen user information to produce more effective socially engineered attacks. One of them is the Troji application, which can acquire numerous data points every 15 minutes, in contradiction with privacy regulations. The project envisions an end-to-end solution incorporated in the Autonomous Vehicle (AV) to prevent Remote Hacking Attempts in the V2X scenario [2]. The V2X component is composed of a roadside unit (RSU), and a vehicle unit (VU) to communicate with each other. To enhance RSUs and VUs, 5G elements are also present, tasked with the communication network. Further details on the communication example will be presented.

Vehicles with autonomous driving capabilities are rapidly becoming a reality with potential benefits including the reduction of traffic congestion, improved road safety, greater efficiency, and reduced emissions due to smoother

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traffic flow. To achieve full benefits and enable an integrated connected and autonomous future, these vehicles should be able to communicate with each other and infrastructure. However, there are several limitations and challenges pertaining to cybersecurity, privacy, trust and validation, social, and business side. Though existing and ongoing research findings in the licensed communication field are promising and constantly improving, they also indicate that ensuring long-term cybersecurity is technologically challenging in the untrusted environment of wireless V2X communication [3]. This real-world case study develops and highlights the challenges to the state-of-the-art experimental methodology for a comprehensive protection and real-world evaluation of the V2X communication network used in connected and autonomous vehicles. If the extensive experiment's findings can be seen as indicative, it can be concluded that the existing security awareness of the C/AV industry is quite low and security precautions are employed only temporarily [4]. Together, this reality leaves autonomous vehicles extremely vulnerable to various adversarial attacks. A plethora of attack vectors emphasize the importance of mounting a robust defense and underscore that, currently, any unarmored V2X communication network could be paralyzed by remote hacking attempts. While the state-of-the-art protection solutions for wired and wireless networks successfully secure connected devices in other domains, implementing them directly to the V2X communication network in C/AV is challenging. This limitation stems from the hardware architecture restrictions, power constraints, and availability of standard security tools, which are currently unsuitable for vehicle-to-vehicle and vehicle-to-everything else communication [5].

2. Autonomous Vehicles and V2X Communication

The automotive industry is going through a grand transformation. This change is driven by a myriad of reasons, ranging from strict environmental regulations, to vehicle and driving-aid innovation. The automotive industry is steering into the direction of fully autonomous vehicles (self-driving vehicles) with the hopes of improving road safety, reducing traffic congestion, and emissions. Over the past decade, advances in vehicle communication technologies are prompting stakeholders to develop and implement a wide array of vehicular networked services and applications, many of them sharing the common objective of enhancing road safety. A compelling example is the collision warning system, in which vehicles wirelessly exchange speed and position information using Dedicated Short-Range Communications (DSRC), as stipulated in the IEEE 802.11p and IEEE 1609 protocols 3. In an attempt to foster the development of improved collision warning applications, the United States Department of Transportation launched the Connected Vehicle (CV) program whereby vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication standards are being defined. Because of the robust, tamper-resistant design, cybercriminals have turned their attention to communication protocols to leverage software vulnerabilities [6]. The standardization and adoption of IEEE 802.11p, ETSI ITS-G5, and ARIB STD-T109 crowned the dawn of V2X communication. By leveraging wireless networks, vehicles can communicate with other vehicles (V2V), the surrounding infrastructure (V2I), as well as with other entities, such as cyclists, pedestrians, and networked devices (V2X). With all of these technologies in place, unique techno-economic challenges and opportunities arise, concerning capital investment, communication protocols, and addressing regulatory issues. Shortly after the standardization of IEEE 802.11p, several prototype implementations ensued in the literature, attesting to the feasibility of V2V and V2I communication. Recently, the CV application consortium presented an overview of cooperative vehicle–infrastructure systems and plausible business models. Nevertheless, little to no research investigates the security aspects relative to V2X technologies [7], see Figure 1.

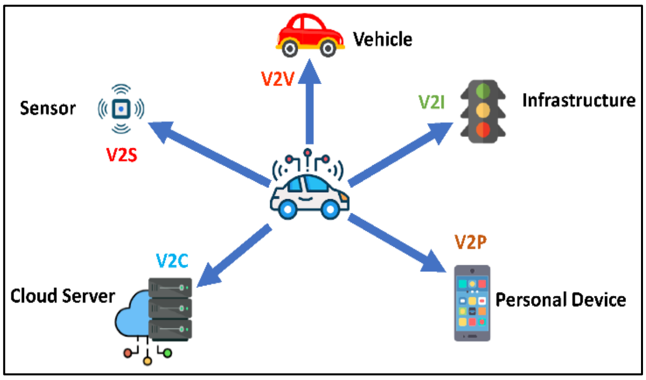

Figure 1. Vehicles communication internet [7]

2.1 Overview of Autonomous Vehicles

Autonomous vehicles are envisioned revolutionizing transportation by enhancing safety and comfort. These vehicles require advanced embedded systems to perceive their environment and make intelligent decisions. A significant increase in external vehicle-to-everything (V2X) communication would benefit autonomous vehicles. The remote V2X systems assist autonomous vehicles by providing environment information such as traffic sign condition, signal state, and road surface condition, which cannot be perceived by the on-board perception system. Autonomous vehicles retrieve the information from remote V2X systems and take appropriate actions such as change lanes, control speeds, or turn. The increased connectivity also opens up these vehicles to more serious cyber threats with catastrophic effects. Several vehicular attacks are discovered in real-world experiments, including the injection of false environmental information into autonomous vehicles through remote V2X systems 1. It is shown in simulations that these adversarial vehicles violate traffic laws and cause accidents, even when originating from a small portion of attackers. Secure system architecture is presented to enable the secure operation of remote V2X systems and autonomous vehicles [8]. This system comprises secure service recognition, message verification, and packet verification. The security controls for remote V2X systems can efficiently recognize and reject malformed or unauthorized messages from adversaries. The security verification of the message and packet in autonomous vehicles effectively removes invalid messages and packets. Twenty-five real-world experiments with dynamic environments and packet loss verify the proposed architecture's effectiveness and efficiency [9], see Figure 2.

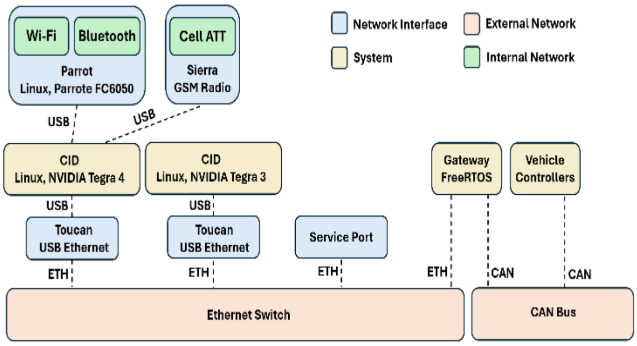

Figure 2. Autonomous vehicle security [9]

2.2 V2X Communication Technologies

The V2X communication technology is systematized into six main categories, including cellular for V2X, Wi-Fi for V2X, Regional and Low Power Wide Area for V2X, ultra-wideband for V2X, visible light for V2X, and millimeter wave for V2X. Lastly, as the real-world case study, a detailed illustration is provided of how a V2X security architect develops a security policy in order to implement the proposed security mechanisms. Two main problems were tackled: how to securely encrypt five different types of V2X data and how to precisely inject external messages to remotely hack the normal V2X communications. Moreover, the performance of the security solution is assessed. Cyber-Physical Systems (CPS) with autonomous vehicles (AVs) are an attraction by integrating physical systems with computer systems that require the availability of numerous Internet-Of-Thins (IOT) devices [10]. V2X communications transfer data securely between other vehicles (OVs) and vehicles to infrastructure (V2I). It has been predicted that without generic countermeasures, AVs will provide cyber attackers brand-new overweight opportunities to remotely hack existing vulnerabilities. Given the rapidly increasing interest in autonomous vehicle-related research, a V2X security architect's real world case study is presented here. So far, four types of security solutions have been put forward [11]. This study should unveil five independent security solutions and a security policy, which are estimated to be generic to the community. Predetermined black box contracts exploration is the first endeavor to explain the current scientific development on practical systems. In the following text, the reader will find the principles of V2X communication technologies [12].

3. Cybersecurity Threats in Autonomous Vehicles

The integration of advanced V2X (Vehicle-to-Everything) communication into vehicles improves active safety, traffic management, and driving comfort. However, V2X communication also poses specific cybersecurity challenges. In this paper, a practical security assessment is conducted on connected and autonomous vehicles in terms of V2X communication to investigate potential remote attacks that malicious adversaries can launch against the key use cases of V2X communication. An adversary could replay ARP Poisoning packets and jam the frequency bandwidth of the V2X communication channel from a neighboring vehicle, while sending crafted packets to the latent network-based IDS will fool the AI algorithm into thinking the adversary's attack packet is legitimate. This results in the automatic speed limiting function being triggered and reduces the speed of the ego vehicle by around 20 km/h. This real-world case study showcases the effectiveness of the proposed security assessment and provides insights for current state-of-the-art security protection for V2X communication in autonomous vehicles [13].

3.1 Types of Cybersecurity Threats

The traditional automotive design process involves protecting passengers strictly from physical accidents and ignoring other threats, such as cyber threats. The rise of software-defined automotive platforms and vehicle networks introduces a large number of components that are subject to cyber threats and vehicle-to-everything (V2X) communication is an example of a critical E/E subsystem exposed to a high level of cyber risk. This study will demonstrate that, by adopting a largely heuristic-driven approach and not necessarily high-cost countermeasures, it is already possible to thwart remote hacking attempts targeting V2X and prevent serious breaches. Future engineering developments are expected to lower the level of security of V2X systems on a car network, and at least some high-risk threats should be addressed, such as passive eavesdropping, having negative physical impact, avoiding social benefiting, and explicitly granting permissions to well-known and well-known entities that can otherwise deceive a vehicle network and install unwanted applications. Several sophisticated attack scenarios on V2X one of those subsystems can now disable V2X, bypass V2X communication variables, and the spoofed traffic safety message transmitted by one on network to another network. And a number of cautionary and proactive design principles are suggested for V2X communication systems that consider such attack scenarios 1. In today's software-defined automotive ecosystem, the integration of various electronic sub-systems for vehicles, including advanced driving assistance systems (ADAS), powertrain, and multimedia processing, efficiently safeguards the condition of the vehicle's surroundings, the action of the driver, and the operational status of the vehicle [14]. The introduction of vehicle-to-everything (V2X) communication, as in the case of many emerging autonomous vehicle prototypes, limits exposes another vehicle network sub-system, which is exposed to significant cyber risk while other electronic sub-systems are difficult. Despite previous works dealing with protection against privacy violation or black hole malicious codes, the research community has generally overlooked protections against passive cyber-attacks, and basically, no countermeasures exist in the literature on V2X communication securing [15]. A simple demonstration that V2X implementation, albeit basic and defective in many ways, can be protected from any serious energy use of information, in systems elements that are already present or can be easily deployed precludes research gaps. A systematic approach to ensuring security requires the extensive implementation of advanced secure elements now common in critical communication systems. However, it is anticipated that such countermeasures are likely to be employed by many automotive engineers at significantly lower level than the security.

3.2 Impact of Cyber Attacks on Autonomous Vehicles

The emergence of autonomous vehicles (AVs) has transformed the transportation safety and comfort of the road passenger. Controlled by the intelligent software, they execute tasks eventually lead to safe and reliable driving without human intervention. Due to the complexity of the situational awareness, both the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications play an essential role in making decisions on various driving activities, such as adaptive cruise control, collision avoidance, and lane-change assistance. To ensure the timely and accurate communication among AVs, wireless communication techniques are widely applied to enable these vehicles to make intelligent decisions. Vehicles are equipped with additional onboard units (OBUs), dedicated short-range communications (DSRC), and connected vehicle technology, which enable the AV to communicate with other vehicles and infrastructure. The connection of these vehicles can effectively increase the traffic system's efficiency and ensure a faster reaction to unpredictable events. This facilitates a safer and more comfortable traffic environment. However, the additional connectivity in these vehicles makes them vulnerable to various cyber-attacks [16]. Since the first remote hack against the automotive system was released in 2010, the attacks in these vehicles have increased 4. Attacks like remote hijack, sensor spoofing, ECU reprogramming, intrusion via vulnerability in DSRC, and fingerprint-based detection have been presented to realize the safety and security concerns of AVs. Realizing the growing concern for public safety and advanced technology in the traffic system, there is a need to ensure the AV's security from these cyber-attacks to make them authentic for the vehicle ecosystem's concern and public adoption.

4. V2X Communication Security

The emergence of connected and autonomous vehicles is expected to have a transformative impact on society by improving traffic efficiency and safety. Much of this impact, particularly with respect to safety, depends upon the ability of these vehicles to communicate with one another as well as roadside units. However, the increased connectivity of such vehicles to networks necessarily opens a new attack surface and exposes them to a variety of cyber-security threats. The success of deploying connected and autonomous vehicles will have to rely on addressing these challenges. This study provides a concise real-world examination on protecting Vehicle-to-everything communication in autonomous and connected vehicles against a variety of remote attacks and manipulation attempts. Specifically, this research explores the security aspects of standards that define the protocols and the frame structures of V2X communication between vehicles and roadside units, as well as their interconnectivity with the traditional cellular network. An attacker model aiming to exploit vulnerabilities in these standards and protocols by employing several well-acknowledged remote attack techniques is introduced. Then, it presents a discussion of the experimental testbed setup focusing on the physical and topological aspects of the testbed, as well as the implementation of the hardware and software involved. Finally, this study provides a detailed analysis of the results from a set of experiments testing the ability of the attacker model to exploit weaknesses in V2X services, followed by strategies to thwart such attacks from being successful.

4.1 Security Protocols and Standards for V2X Communication

The 5G-Enabled Vehicular Networks Demos Network (5G-VND) project develops and conducts field trials on vehicular services using a hybrid Network-Slicing solution of the 5GCAR approach. In these perspectives, this session studies state-of-the-arts security approaches for V2X communication designed to be applied on the 5GCAR environment to bolster vehicular services' cybersecurity. Apart from spontaneous V2X traffic, the federal government systems operating 75 MHz bandwidths at 5.9 GHz are progressively deploying worldwide. Researchers propose to design a remote hacking platform for protecting V2X communication against threats from unauthorized vehicles. Realistic investigations using field tests are conducted, and it is found that similarly behaving vehicles can exploit DoS attacks by sending a connection request sequentially. Similarly, isolated vehicles can launch Sybil attacks involving falsely generating and transmitting messages. Consequently, the integrity and confidentiality risks of the 5GCAR solutions are discussed significantly, and academic and industrial partners are recommended to establish a strategy to mitigate the risks [17].

To fortify operation security, many V2X communication entities' digital security and privacy are established, which comprises the PKI (Public Key Infrastructure) and certificate profile entity. To obviate copying and tampering publicly disclosed, broadcast messages are signed using the RSU's private key regularly issued by a verified CA. Message security is a crucial task for V2X communication, and entities in vehicular services' 5GCAR environment. Apart from the PKI, EN 302 663 standard is building the EU's PKI intended for public traffic monitoring by the end of 2020. Obtained results exhibit that the existing requirements can diminish over 46% of the security threats to V2X communication. In the case of tampering attacks, the current schemes of the 5GCAR partners and the EN 302 663 recommendations are still impermeable to almost 54% of threats. Moreover, new threats' categorizations are presented, and many of the existing requirements not able to mitigate threats are identified.

5. Real-World Case Study

With the increasing utilization of internet and computing technologies in automotive systems, the security and privacy threats against connected and autonomous vehicles are also increasing. Vehicles operate at high speeds in open and connected environments, communicate with each other and infrastructure units, and share their data with third-parties. Among the variety of threats, the focus is on the cybersecurity threats against autonomous vehicle systems, particularly the ones related to the vehicular-to-everything (V2X) communication. A novel real-world case study is reported on the cybersecurity measures of autonomous vehicles against V2X-based remote hacking attempts [18]. Utilizing the well-known network simulator tool to create an autonomous vehicle systems setup, an experimental testbed is reported to physically test hacking attempts on the V2X communication of autonomous vehicles. As far as it is aware, this is the first real-world implementation of vehicular cybersecurity concerning the use of the Autonomous Vehicles Operating System for programmatic autonomous vehicle simulations. A proposed prototype implementation allows multiple use-case and hacking scenario tests, including the effects of replayed and altered V2X communication messages on the routing and driving behavior of connected autonomous vehicles. Furthermore, a custom program that converts communication traces to more human-readable format is presented for further studies. The results of the presented real-world case study can be used in numerous vehicular cybersecurity research studies and the developed methodologies can be adapted to other network simulation platforms.

5.1 Selection and Description of the Case Study

There have been significant advances in autonomous vehicles with collective data sharing and coordinated maneuvers for maximizing traffic efficiency and safety. Security challenges due to the broadcast nature of V2X communications in AVs are emerging. A sophisticated hacker could observe traffic for a while and may model and predict the traffic, potentially then send malicious messages to AVs in order to compromise the V2X automation systems [19]. To evaluate the effectiveness of deep learning defense approaches, V2X communication of an autonomous vehicle is studied to protect it from potential remote hacking attempts. The defense approach identifies the message legitimacy by taking the current timestamp along with the V2X message and the context. The work introduces a real-world case study of simulating hacking attempts for disruptive traffic flow to analyze different adversaries with varying attack strategies on V2X communications. The case study includes an extensive range of parameters, including simulated and precise V2X parameters, for simulating predatory attacks in traffic flow and discretizing V2X message timestamp into milliseconds to assess the network communication time-delays [20].

Malicious cyber-physical attacks have been growing due to the exposed nature of their operating environments and have been widely researched on how to degrade them. This also brings V2X communication and Vehicular ad-hoc networks into concern for cybersecurity issues. An exposed dataset of an autonomous vehicle vulnerable to replay and bogus information attacks in V2X communication is featured. In one scenario, the attacker records the "emergency" message from the approaching EV and replays the previously recorded V2X messages arriving at the intersection with the same vehicle id. As a result, the information is published in the broadcast service with the distance values of road metadata. The speed value is also added with the V2X message for the defense model to catch the illegitimacy of the replayed malicious attack. These makes the vehicles ahead of the EV slow down and eventually stop. This scenario has two different implementations.

6. Methodology

6.1 Research Questions

Due to the ongoing development of AV technologies, the increased complexity of the underlying systems and the fact that there is a lack of comprehensive documentation available to the public about how these systems work; it requires a new approach to acquiring knowledge about them. Considering that conducting vulnerability assessments is crucial for risk detection, a vulnerability assessment shall be conducted in the context of a VW Passat GTE from 2017 equipped with Level 2 ADAS using a specifically developed method. Therefore, this research aims to investigate the following research questions regarding AVs and CAVs:

- How do ADAS and autonomous vehicle systems work in a VW Passat GTE and how are they connected to one another?
- How can the driving environment of VW Passat GTE be physically and logically reconstructed?
- Which vulnerabilities exist in the derived driving environment and are particularly exposed to remote attacks?

6.2 Theoretical Basis

The TARA and STRIDE method were modified to take into account the peculiarities of the automotive industry 6. The TARA process consists of six steps: library creation and loading, threat library exploration, view preparation, view configuration, impact estimation and validation, and documentation preparation. The considered three methods PPR, SI, and TL created and curated three libraries that contain sets of known threats that apply to the system under consideration. The ADAS and autonomous vehicle systems resulting from the analysis had to be connected to construct a model that can map data inputs over the entire trajectory of a VW Passat GTE onto relevant controller area network messages, as well as environmental inputs and conditions. Afterwards, the same driving environment, consisting of both the physical and the logical component, had to be created. The environmental model generated in the software cyber vulnerability assessment then was exported to databases and graphic formats, as well as integrated into a vehicle's driving environment, to physically and logically reconstruct it. Finally, the tool had to be employed to scan the derived driving environment for vulnerabilities. Afterward, the exposed vulnerabilities had to be analyzed regarding their severity and how severe the consequences would be if they were to be successfully attacked.

6.3 Research Design and Approach

Autonomous vehicles (AVs) are seen as the future of ground transportation landscapes and connected and autonomous vehicles (CAVs) are being trailed in pilot projects worldwide. While everything from drones to tractors seem subject to autonomous control, one potential disruption to the world of AVs remains privacy and cybersecurity vulnerabilities. In 2015, a Jeep Cherokee was remotely hacked live on television from 16 kilometers away. Since 2019, AV cybersecurity has been listed in SAE J3061_201901. While much work examines cybersecurity on the internal components of AVs, a real-world study on mitigating cybersecurity threats on V2X communication of AVs is being evaluated by applying authentication.

A large traffic study area (TSA) is used to observe vehicles following one another in congested traffic. When the antagonistic car is programmed to aggressively tailgate, its identical adaptive cruise control programming forces the attack car to also consistently tailgate. The development of such V2X hacking methods is proposed using Python and CANbus modem. Sixteen other V2X hacking scenarios are investigated and can be benchmarked against future V2X hacking ensembles. When the traffic attack occurs under a normal traffic flow condition, the estimated success percentage of the established V2X attack scenario is ~72%. This estimation increases to ~83% when the attack cars have time to approach close to the CAV. This empirical evaluation encourages the Joint Security Institute (JSI) and V2X stakeholders to deprioritize DSRC and focus on establishing a security-based C-V2X. For a preliminary evaluation, Fedora is selected as the Linux distribution for the attack cars and remote stations that will execute the V2X attacks. Correspondingly, Ubuntu is chosen for cars, buses, and traffic attack stations. Additional parameters can be used to analyze the impacts of other vehicles and attack vehicles on the vehicle's behavior, directions, and time-to-impact 7.

7. Data Collection and Analysis

Autonomous vehicles (AVs) are one of the prime objectives of the automotive industry since they have the potential to significantly improve road safety and reduce congestion. However, the reliance of AVs on information coverage will increase the exploitations on vulnerabilities in the network and put the vehicles at risk. Particularly in connected AVs, the announcement of the safety applications using vehicle-to-everything communications lets the attackers have a clearer idea of the vehicle's movement. This has bought about attracting more attention towards the field of how to protect AVs from adversarial messages. The works of scholars are tested in a real-operational environment in carrying out what is to the best knowledge of scholars the foremost replying-adversarial threats against AVs. The method employed in mounting remote attacks against AVs is articulated, which highlights the importance of securing not only the V2V but also the V2I communications. Scholars can show in real-world experiments how a legitimate emergency vehicle is remotely attacked via the messages. Seven examples of successful attacks were recorded, including truncating the emergency safety message, flag emulation attack, and preventing connection lost. These works should contribute towards the realization of secure intelligent transportation systems.

7.1 Primary Data Collection Methods

Case study, V2X, will outline primary and secondary data collection methods and steps to mitigate the cybersecurity threats in V2X communication and AV. Real world case study "Hacking Attempt on V2X Communication" briefly introduces the case study where an attacker vehicle launches two types of hacking attempts on the legitimate V2X communication of a target vehicle. The target vehicle implements GPS-based verifications of the

V2X messages. The GPS-based verifications successfully prevent the legitimate V2X messages of the attacker vehicle and allow the target vehicle to safely evade from the subsequent hacking attempts.

The secondary data is related to cybersecurity threats in V2X communication from the academic literatures, unpublished threat intelligence reports, whitepapers of automotive cybersecurity companies, IEEE standards on V2X communication for AVs, and news articles. This secondary data shows the increasing concerns and feasibility of launching remote attacks on the V2X communication of AVs, reveals the principles and methodologies of hackers who target the V2X links of AVs, and highlights the importance of protecting the integrity and authenticity of the V2X packets in AVs to prevent and mitigate the lethal consequences of successful hacking attempts 7.

7.2 Data Analysis Techniques

Currently, this vulnerability has received substantial attention, resulting in the development of various types and methods of attack and defense. This domain expands substantially across various sectors, from individual computer networks to interconnected healthcare devices and even city power grids, particularly as the Internet of Things (IoT) connections are increasing. In particular, the territory of automotive protection is very delicate, as safety hazards may be life-threatening. This thesis is focused on the security of self-driving cars (SDVs), whereby the goal is to prevent malicious or potentially adverse remote actions from an unauthorized consumer. This involves transporting, cruising, or otherwise interacting with the vehicle with the intention of destroying or exploiting the vehicle itself, its network, or anything that might be linked to it. Attention is specifically focused on securing the Vehicle-to-Everything (V2X) interaction of the car (roads side infrastructure, RF signals, fixed servers, etc.). Primarily, this examines and defends versus risky malicious attempts focusing on V2N data. Impending concerns regarding the security of self-driving vehicles are often pointed out as a hurdle for the development and upbeat consumption. This job offers a thorough analysis of the threat scenario and a potential impact for both skilled workers and automotive security researchers. Future and actual evidence in the field is concluded, elaborated, and assessed with key study outcomes 8. This helps to explain wide gaps and understudies, and where possible, provides comprehensive records of recent results and booting research. With a thorough review and preparation, outstanding capabilities can be a high-impact resource. Additionally, results of a risk assessment uncover a large number of potential attack possibilities, with this work discussing both previously uncovered and fresh discoveries.

8. Results and Findings

A computational cybersecurity real-world case study is provided in the automotive sector. Cellular networks are used for communication with vehicles and are widely deployed in many areas. The experiments focus on the attacker who can replay a recorded message from an approaching emergency vehicle by modifying an attacker’s hardware and stopping the cars ahead of him. Therefore, to discover the approach of the attacker is dependent on the proposed attack scenario. The emergency vehicles reach the destination first and the cars are followed by the attacker. To examine the speed data of the cars, the recorded V2X message is replayed to send bogus information to the network. By getting of those messages, this V2X application provides an alternative route. The experimental results’ speed data analysis can be seen from the malicious attack data of the bogus information in the network. Different networks for different vehicle manufacturers are used to exchange V2X messages. Before Laura receives the V2X message that indicates an approaching emergency vehicle like the G5 message but it is not decapsulated and the content of the V2X message is not clear. Instead, the V2X message is encapsulated with the MAC address of the first car. The payload data on the message shows the information transmitted by the fixed base station. Random speed change messages are received by two cars in the middle. So, the car directly behind stops in an instant, and the car is locked to stop. The other four cars stop. After, again random speed change messages are received by the attacked four cars. Then, four vehicles stop, respectively, after the attack message is received. On the other hand, there is no speed change message from the base station for the non-attacked three cars during the whole attack process.

8.1 Key Findings from the Case Study

The connectivity of autonomous vehicles to other vehicles and infrastructures is required to offer a wide range of services including improving safety, optimization of traffic flow, and comfortable drive. Similar to any other system, connected autonomous vehicles have their own vulnerabilities, which may be exploited to carry out malicious activities. This paper presents a comprehensive guide on countermeasures for the fifty-one threats from remote sources as part of protecting connected electric autonomous vehicles including fully and semi-autonomous vehicles against remote hacking. Vehicular communication is an integrated system interconnecting vehicles to each other, with road-side infrastructures, and to the Internet in order to improve travel safety, optimize traffic flow, and comfortable driving Commercial V2X, including V2V, V2I, and V2P, focuses on overtaking, safety, platooning, collision avoidance, and cooperative parking. Furthermore, V2V is developed later than V2I because of vehicle movements offending traffic policies, so it is possible to forecast vehicle progress with road-side infrastructure and assists the vehicle driver to drive securely. Here, depending on the progression and reappraisal of V2X communications and technologies used in autonomous vehicles, the record of the state of the art of vehicular communications is demonstrated.

9. Discussion

Autonomous vehicles (AVs) are among the most sophisticated transportation models that have the potential to revolutionize daily traffic on a global scale. AVs are networking with the external environment and their surrounding environment via cellular connectivity/vehicle-to-everything (V2X), which is considered potent. Long-range radio access technology issues (connectivity issues, availability,), security (too strong fundamental attaching) and privacy (including protected diversity estimation from vehicles to vehicles) issues are main constraints of AV popularity. This paper focuses on investigating the strong security aspects of V2X communication technology that is extensively used in automotive industry methods can be resisted from an attack. This study implements on a real-world testbed and employing a state-of-the-art model checking-based technique to verify safety using network-based intrusion detection systems (NIDS). Moreover, numerical data for different adversary strategies or parameters, if they exist, are presented. Just recently, autonomous or self-driving vehicles have emerged on the market. As one of the biggest innovations of the technological 21st century, lasing in automotive industry has enabled research community's eyes on unmanned ground vehicles. Nevertheless, ensuring that they communicate reliably becomes an open question. The very recent Canadian cyber-physical autonomous transport testbed is the main infrastructure used throughout this work 9.

9.1 Interpretation of Results

It's good to see a case study of vehicle security. Those results are very surprising, but these new results need to be interpreted. Given the risks involved with vehicle safety, driving simulation and real-world experiments are highly infeasible in general. Thus, it would be expected that all results are limited to a cyber-physical prototype in a controlled environment. This does affect the generalizability to production vehicles and/or road traffic scenarios and makes a replication difficult. Also, that limitation of cyber-attacks to the V2X communication link is somewhat arbitrary and is just a tiny subset of the myriad threats that modern AVs face. As the paper notes, many other potential threats remain unchecked 5 of wider concern is that the paper reports only negative results. While it is valuable to know what doesn't work, it is equally important to learn what does. It is recommended to also report challenges faced and steps taken (even if they didn't affect the final decision). Among best practices for future work, if using an RFID security protocol for V2X communication, a crypto analyst should be part of the team. AES is not flawless. Realize that detractors from the vehicular industry will be very well-funded and so all possible weaknesses should be thoroughly evaluated and addressed before proceeding with a public disclosure.

9.2 Implications for Autonomous Vehicle Cybersecurity

Autonomous vehicles heavily rely on V2X communication to achieve a sufficiently high level of situational awareness to allow self-driving operation. However, the fusion of V2X communication with the in-vehicle processing and control networks exposes autonomous vehicles (AV) to a variety of remote hacking attempts that need to be actively mitigated. With the growth of Internet of Things (IoT) technologies, V2X communication has become an integral part of Intelligent Transportation Systems (ITS). V2X-equipped vehicles can actively broadcast safety-related messages to the surrounding world, and at the same time listen to nearby messages so that they can adapt their own actions to the possible hazards broadcasted by other vehicles. In a real-world AV scenario, security measures designed to protect the integrity of the EVITA secure state transition machine were implemented in communication with the V2X network through a packet injection attack. The attack consists of tampering legitimate V2X messages that affect the transitioning of the secure state of the AV. It was found that with V2X communication, the attack would take in average less than 1 second of successful packet injection to compromise a countermeasure aware system that does not use any further protection mechanisms. Moreover, countermeasures as filter transmission policy, redundant V2X communications, and probe effect were implemented as intrusion detection/prevention and their effectiveness against other attacks were inspected. The injection of fake V2X messages aimed to abruptly change the desired acceleration of AV, a common action by safety-related ITS messaging. It was observed that, activating a wideband control filter broadcast between vehicles, fake V2X message injection can be detected and the target system protected from unwanted accelerating interferences.

10. Conclusion

Autonomous vehicles have been extensively studied in three complimentary aspects which correspond to security, efficiency, and safety. While there is a growing concern about the security of autonomous vehicles due to end-to-end attacks on actuators and remote hacking to the ECU, the majority of previous works fit well to the attitude of defense for the ECU of autonomous vehicles against outsider attacks. The outside information is always being trusted as original. Consequently, local attacks are performed to the onboard units to compromise the safety of vehicles. With the purpose of establishing a comprehensive framework for the cybersecurity of autonomous vehicles, a novel type of attack that targets the safety and efficiency of autonomous vehicles from the outside information is presented. To accomplish this, a threat model is initially set up to demonstrate the severity of the attacks. Then, from the viewpoint of attack detection, secure compression is proposed by leveraging statistical divergence as a metric in order to authenticate the V2X communication. Hamiltonian variance reduction is further proposed to achieve efficient streaming computation in detecting V2X attack. It is shown via numerical study that the proposed secure compression method is able to exceed the performance of CA in comparing to V2X-SPL approaches. It is also demonstrated that HVR can effectively improve the performance of the existing baseline on detection 1.

Future smart transportation systems are likely to revolve around autonomous vehicles and cooperative technologies. The interconnection between connected vehicles and Internet-based services raises significant challenges to maintain cybersecurity on public roads with Vehicle Ad Hoc Networks. 64 different attack scenarios on the V2X VANET communication scheme are discussed which could severely affect the operation of legitimate vehicles and violates the traffic laws. To address these issues, security provisions are defined for each threat and robust solutions are suggested by adapting and enhancing the current communication protocols of V2X networking and services in VANETs. Potential solutions focus on enhancing the routing procedure, link layer, network aggregation, and broadcast communication procedures are determined; all significantly improving the security of V2X communications 9.

10.1 Summary of Key Points

In this work, a comprehensive overview of possible cyber-security threats on autonomous connected vehicles related to V2X communication is presented. To demonstrate real-world adversarial hacking scenarios in CAVs, experimental results are shown. Also, technical solutions against V2X communication are proposed. It is foreseen that attackers can take control of in-train vehicles either by impersonating real vehicle nodes or disrupting ongoing communications among them. To alert future engineers and developers in the field, related technical aspects and key insights about the experimental setup are provided. Localized jamming attacks can degrade V2I and V2V communication performance in real-world settings considerably compared to previously analyzed theoretical models 9. A real-world realization of attack scenarios indicates that AI algorithms can be utilized heavily to design various adversarial strategies against CAVs even with a modest computational budget. To immune CAVs against adversarial attacks, a possible defense mechanism by minimizing the data rate for V2X communication is further proposed. In the realization of safety-critical cyber-physical systems, it has become clear that networked vehicular communications will be crucial to tackle numerous challenging problems for enabling future intelligent transportation systems surrounding autonomous and connected vehicles (CAVs). Eager to improve environmental and traffic efficiency, CAVs are explicitly designed to accommodate communication technologies, known as Vehicle-to-Everything (V2X), which facilitate bidirectional wireless communication from vehicle to any entity. Nevertheless, V2X-enabled CAVs are vulnerable because they are directly accessible wirelessly, enabling unexpected communication-based attacks.

10.2 Future Research Directions

Autonomous or self-driving vehicles are rapidly becoming a reality due to advanced driver-assistant system (ADAS) technology. Currently, self-driving systems have various levels of automation and an advanced safety feature called vehicle-to-everything (V2X) communication. V2X communication enables autonomous vehicles to connect to on-road infrastructure, other vehicles, and smart devices. Unfortunately, security threats to V2X communication are inevitable due to the use of vulnerable long-range wireless communication links. For instance, high-gain antennae or jamming devices can be used by adversaries to overwhelm a V2X communication link in ad-hoc networks. Similarly, malicious attackers can provide incorrect information to manipulate the ADAS of connected vehicles and cause bodily or property damage. This study demonstrates real-world scenarios for protecting V2X communication against remote hacking attempts in autonomous vehicles 1. A case study is conducted in an open-source integrated framework that simulates remote hacking attacks via V2X communication. The proposed security measures are applied to demonstrate the prevention of remote hacking attempts on autonomous cars. First, the motivation behind cybersecurity threats in autonomous vehicles is provided. The introduction of V2X communication into autonomous vehicles aggravates system security concerns because connected vehicles have historically not been secured. A survey of recent datasets and challenges from the autonomous vehicle attack surface and an experiment to demonstrate vulnerabilities from machine learning services in autonomous vehicles is analyzed.

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