Self-Adaptive Cyber Defense Framework for Autonomous Vehicle Networks

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1. Introduction

Autonomous vehicle networks have drawn significant interest from practitioners and researchers because of the numerous applications, such as future transportation systems and planetary exploration. However, there are multiple potential attack vectors and security risks to these networks that must be resolved. In this paper, we provide a self-adaptive cyber defense framework for autonomous vehicle networks. The proposed framework monitors the system and network status by creating the digital twin of the physical world. Based on the derived status, the system automatically finds the next stable configuration to mitigate the potential impact of attacks. Finally, the impacts and technical validations of the proposed defense are quantified. We use the self-organizing map model and Bayesian network for monitoring the system status and impact assessment, respectively. The proposed work provides a new approach of building a digital twin system using granular computing, which consists of general fuzzy granulation and dynamically structured fuzzy granulation. The objectives of building a digital twin for the self-adaptive framework include minimizing the data acquisition time, overcoming data sparsity, and maintaining or improving the accuracy of prediction.

1.1. Background and Motivation

Today, the network-infected cornered vehicle function is suspended by the system interface protection or the hardware re-engineering, which is not practical. While security vulnerabilities are the main challenge for the implementation of autonomous vehicles, car manufacturers do not yet have an integrated and intelligent self-adaptive solution for their intelligent vehicles. There are some technical challenges such as data frame integrity, vehicle network layer, end-to-end data security, and more that have not been properly addressed. The possibility of physical harm due to the autonomous car is highly fearful, and the loss of public consent due to the cyber-attacks. So, ensuring the security of autonomous vehicles is essential, and a better solution is needed to prevent information from being exposed, stolen, altered, and destroyed. These are the reasons why we have developed a self-adaptive cyber defense framework and designed it as a user-friendly prototype.

The promising benefits of autonomous vehicles drive car manufacturers to work on their implementation in upcoming years. An autonomous vehicle is a highly connected and networked complex system of automated driving functions and is only executable because of its ability to sense, perceive, and actuate the surrounding environment. Facilitating the vehicle-to-vehicle (V2V) communication, data security, privacy, sharing, control, and protection are needed, which can be done through the Internet of Things (IoT) technology. However, the autonomous vehicle is associated with a number of cybersecurity challenges because of the vulnerabilities in its current components such as cameras, sensors, and controllers. Because these hardware components are weak and insecure, any manipulation or malfunction of data frames in the vehicle network can result in wrong decision-making scenarios. The reason for that is the vehicle network can be subject to various types of attack methods such as passive eavesdropping and spoofing of vehicle sensors, cameras, GPS signal jamming, and other network denial of services (DoS) attacks.

1.2. Research Objectives

1. Update the existing autonomous vehicle network scenario profile to secure more realistic and various data that include 5G commercialization information and the specific threat trend. 2. Based on the expanded database, propose a self-adaptive cyber defense framework for more effective security enhancement. 3. Design a variety of operating scenarios, including the established scenarios, for industrial scenarios and demonstrate the operation of the proposed framework.

This study mainly focuses on the adaptive defense system that reacts actively according to the rapid changes in the external environment and the environment & operation scenario in which the connected and autonomous networks with various devices such as OBU, RSU, and SDN controller are operated. The ultimate goal is to enhance the cyber security of the entire automotive network. Therefore, the following research objectives are set, and the entire research process is scheduled and pursued:

1. Conduct detailed research on the mechanism of the existing cooperative cyber defense framework and propose an efficient cyber defense framework. 2. Propose and verify an AI model that optimally controls the performance of the SDN controller to be executed smoothly and quickly. 3. Develop a controller to verify the self-adaptive cyber defense framework that reacts to cyber threats within connected and autonomous vehicle networks. 4. Establish and synthesize the operation scenario within the automotive network according to the developed controller and verify the entire execution process.

The main goal of this research is to propose a self-adaptive cyber defense framework for connected and autonomous vehicle networks by integrating various technologies based on Software Defined Networking (SDN) and Machine Learning/AI for enhanced cyber defense. The execution process will be implemented and evaluated through simulation and prototype implementation using both the existing cyber defense system and the existing connected and autonomous vehicle network. Accordingly, the objectives of this research are as follows:

2. Autonomous Vehicle Networks

The autonomous vehicle network has a variety of security requirements. The collected sensing data should be kept safe to satisfy privacy legislation, while from the network perspective, it should take instant actions once security loopholes emerge, regardless of who utilizes these loopholes, and each data flow must be protected, whether encrypting this piece of traffic or dropping it once suspicious. Adaptive and multi-level self-adaptive vehicle network security requirements are customized following the text structure to discuss our contribution to this actively evolving domain. The vehicle network is a fast-growing machine-to-machine (M2M) network, which bi-directionally transmits a myriad of data collections that give rise to and depend on services with a broad range of QoS demands. The vehicle network aggregates the state-of-the-art technologies in wireless communication, aiming to create an ecosystem closest to our human-driven urge. While doing so, the vehicle network meets with a great many challenges.

Autonomous vehicle networks are not built for one-time communication, but to conduct efficient communications with the physical environment and to adapt to the driver's service requirements for a long-lasting driving period, covering hundreds or even thousands of interfaces. For example, even when the vehicle is not traveling most of the time, it consumes power to investigate traffic conditions and to set up new routes as the driver requests. Unlike cellular networks, the modern vehicle network is a high-speed mobility ad-hoc network in which there is no entity to provide frequency carriers, wireless interfaces, or operator service. Because spectrum is scarce and ecosystems are vendor-dependent, it remains a challenge to support a wide range of applications, including safety commands, infotainment, Internet, vehicle-to-x, and so on. The third technical drawback is its lack of consideration in physical layer parameters. Since long communication duration and high layer standards of the vehicle network are already moved to the upper layers, many WAVES parameters describe short frame duration and physical layer specificities, such as communication access, synchronization, certain error thresholds, and so on.

2.1. Architecture and Components

The first block represents the creation of the authorized A/V network, including self-inspired behavior scenario. Furthermore, the employed administrative strategy has a crucial role in the authorization of network components to the framework. The packet protection is checked in the second block. The major concerns are if the packet is complying with the A/F and if it is of good quality, corresponding to the authorized network profile. The security and privacy of autonomous vehicle nodes, including adversaries' access to the control plane, is checked in the third block. The control plane's data, including modifications, must also be inspected. The data for each autonomous vehicle, mode, scenario, and location must be controlled, secured, and resistant to adversaries. Resilience, federation, and adaptation capabilities on the authorized policy document must also be considered at such a level. As an important part belonging to the data security and the fourth block, data is checked and protected. Detected losses and modifications must be reported. Backups and breakups must also be organized in real time. Data for each autonomous vehicle, mode, scenario, and location must be performed and secured against non-confidence according to the desired level. Refined requirements such as residency requirements for executing copies of stagnant requests and optimal replication of the circulated data between autonomous vehicles (i.e., participating VMs) for faster response and better resilience are considered here. Moreover, robust security against data-centered threats for non-chevron type data is performed in this context.

The proposed self-adaptive cyber defense framework for autonomous vehicle networks consists of six different stages that are mainly affected by the existent cyber threats. Specifically, the self-adaptive cyber defense framework for autonomous vehicles consists of:

(1) A/V network creation and establishment, (2) communication channel protection, (3) A/V nodes internal security, (4) data protection and transformers, (5) backups/recovery and live migration, (6) suspicious event detection and response. Each of these blocks is going to be elaborated briefly in the subsequent paragraphs. The particular block is affected directly from cyber threats that are detected, and self-adaptation decisions are going to be applied via AFA based on policy document in subsequent stages for each case.

3. Cybersecurity Threats in Autonomous Vehicle Networks

Cybersecurity failures can have a critical real-world impact in such systems. Although vehicles autonomous in nature are meant to increase driving safety, they also possess the potential of becoming very efficient means to carry out malevolent activities organized by interested parties. The infrastructure is distributed and unattended most of the time, thus employing crucial physical assets, for instance, to block major streets of a city or overload the electrical infrastructure of a certain region. Other types of autonomy-controlled vehicles include air drones whose operation does not even depend on public road infrastructure. Cyber-attacks manipulating such vehicles would receive high publicity and contribute to raising doubt in citizens and car drivers. The confidentiality and integrity of the communication channels supporting these services are key to their success and public acceptance.

Autonomous vehicle networks represent a significant cybersecurity design challenge as they sit at the intersection of connected and autonomous systems. They host both safety-critical and infotainment-related services and transport human or mission-critical assets over complex communication links. Autonomous vehicle networks are subject to all of the threats that connected vehicles are subject to, in addition to the possibility of multiple vehicles operating the same physical design using a third-party 'backend' enabling autonomy. This fundamental consolidation of the operational model, coupled with shared instructional and learning data structures, presents a host of cybersecurity challenges that are yet to be properly addressed.

3.1. Types of Threats

These threats can jeopardize the vehicle and passenger safety, cause traffic disasters, and interrupt traffic order. To counter these threats and provide better services, connected vehicle nodes need to collaborate with each other and with the traffic infrastructure network nodes to perform collective situational awareness. The situational awareness will enable the decision-making process to optimize the driverless system to behave and act safely, and it may also show the impact of the behavior of the nearby nodes on the vehicle and the traffic. To achieve collaborative situational awareness, some information will be exchanged between the connected vehicle nodes and between the nodes and infrastructure network nodes. The vehicle nodes and the network nodes are possible to be attacked or compromised by adversaries, and the exchanged information is exposed to a variety of security challenges. In this paper, we analyze the possible threats and corresponding mitigation strategies for the communication security among the vehicle and the infrastructure network.

Nowadays, modern transport systems are equipped with various sensors and communication channels for monitoring road traffic, charge management, environment and vehicle control, as well as passenger safety or entertainment. This sort of infrastructure collects lots of sensitive data about in-vehicle systems, drivers, passengers, and the environment that should be protected against unauthorized activities and cyberattacks. A significant use of sensitive data and its criticality, which directly can translate into security and corporate risks, is when it is used for the functioning of autonomous vehicles. The autonomous vehicle is an automotive that doesn't involve human drivers, and it is controlled by some embedded systems or other systems. This system might support functions for network navigation, advertisement, IT, Internet, and entertainment, and passengers' needs. These functions may integrate in-vehicle units connected to the Internet and may expose potential interactions with cybercriminals. Therefore, it is necessary to build a self-adaptive cyber defense mechanism for the autonomous vehicle network.

4. Current Cyber Defense Strategies

The purpose of this section is to give a brief overview of the aforementioned methods, shining a light on their strengths and shortcomings. It is envisaged that the framework will be shaped by the lessons learned from the existing cyber defense deliver methods, thus allowing the development of a defense mode for the novel and versatile external threats while meeting infrastructure and operational safety and reliability goals for the end users of the technology.

As mentioned in section 1, Industry 4.0 has provided a unique opportunity for developing modern 'smart' cities, in which an AVN is one of the core end-to-end networking infrastructures. While offering an abundance of benefits, such as accident engagement reduction, traffic incident response acceleration, traffic optimization, collaboration on the transport system, energy conservation, climate changing alleviation, and modernization, automotive networks are open to a variety of interior and exterior cybersecurity threats, due to the extensive use of V2X communication systems and interfaces and the dependence on various control units and sensors. To meet the security challenges in the field of communication and OT, automobile manufacturers and technological solutions providers have introduced a variety of in-vehicle defense mechanisms to ensure user safety and to secure infrastructure assets during the growing stages of autonomous and connected (C-ITS) vehicles and smart cities. The current most widely employed strategies are: (1) the use of hardware technologies embedded within the controller area network (CAN) bus of a car, (2) the use of intrusion detection and network security packet-inspection systems, and (3) the use of a supervised machine learning algorithm that can detect intrusion.

4.1. Challenges and Limitations

The research is a double-edged challenge to develop novel models and tools that will achieve one significant goal: to be able to use the independent engineering methods for security evaluation, so as to represent the theoretical robustness of various methods. Creating a large-scale, hard-to-manage network of vehicles for vehicle-critical environments will have multiple security, safety, and performance concerns. Considerable attention should be given to the employment of security countermeasures, because the extensive use of processing resources in a vehicle may result in performance degradation. The security level of the vehicle increases with the number of deployed countermeasures, but even if the vehicle interfaces are suitably protected, it remains vulnerable to attacks because the security of modern vehicles is becoming network- and information-based.

Designing the cyber-physical models for evaluating and analyzing AD network threats further requires developing a cyber-physical testbed capable of replicating real-world driving scenarios in a protected laboratory setting. Nevertheless, the research community is still in its infancy and is still experiencing all the difficulties and challenges related to understanding the combination of attackers and automation enabling modern vehicles. Additionally, deploying various sensors and network monitoring systems in vehicles proposed requires careful consideration of power and communication network limitations and integration impact. Therefore, smart usage of various sensors and network monitoring systems and power-effective analysis mechanisms should be designed and implemented in the proposed AD network.

5. Self-Adaptive Cyber Defense Framework

The proposed framework offers a reliable intrusion detection method through a vehicle-centric and decentralized approach. The framework is founded on the self-adaptive model because vehicle dynamics are KPI-injected to direct the evolving IDS for vehicle networks. The integration of KPI of the autonomous vehicle with the Stealth clustering algorithm that is fine-tuned for vehicle data, genetic algorithms, and K-medians enhances the unsupervised-method-based Self-Adapted Intrusion Map. The graphical vector-based approach is also used to detect diverse attack and monitoring techniques. Simulation of the self-adaptive framework demonstrates that the framework improves the accuracy of the proposed self-adaptive method and minimizes the rate of false detection. With numerous moderate defense mechanisms that operate in collaboration, this framework solidifies the vehicle-centric cyber defense posture.

The evolutionary process in biological systems has inspired proposals for automatic techniques tailored to the requirements of self-adaptive systems. With an ongoing paradigm shift towards autonomous vehicular systems, the self-adaptive model has been proposed as a model to continuously identify and act on changing circumstances. The security and fitting cyber defense of vehicles change with the evolving model of vehicles. Existing investigations on cyber defense frameworks for autonomous vehicles often concentrate on obtaining a broad security network perspective rather than on enhancing the vehicle-centric cyber defense that settles in the class. This paper presents a self-adaptive Intrusion Detection System (IDS) framework that is suited to car networks, seeks to detect new IDS requirements, and adapts based on the evolving vehicle dynamics.

5.1. Key Components

The perception and situation awareness capability of autonomous vehicles enables a proactive cyber defense framework. To make use of the network traffic and transmitted packets of the vehicle network, a perception unit is required to capture and parse the sensed network traffic in a real-time manner. Information such as vehicle network properties, working network usage, network traffic routing, and the configuration of the network devices can be obtained as the inputs for deploying the coordinated defense mechanisms. An active evasion perception unit is even more important and is capable of leveraging both the visible network traffic and new sensor-related information. Such a unit is responsible for detecting and identifying potential cyber eavesdropping and attacks as well as potential vehicle network traffic jams.

The devices in autonomous vehicle networks are generally equipped with configurable network interfaces, which necessitates the implemented defense to adapt to the features of the working vehicle networks. This translates to the requirement that any self-adaptive cyber defense framework for autonomous vehicle networks should configure and execute defense units (i.e., defense mechanisms) based on the working vehicle network characteristics. Practically, the assisting human operators will not fully understand and be familiar with the features of the vehicle network during operation, and the available human-operator interaction is very limited. In this subsection, several essential components are presented for a practical self-adaptive cyber defense framework for autonomous vehicle networks.

6. Machine Learning and AI in Cyber Defense

Modern AI in AVCybersec provides AI protection for every computer on the bus and funds hardware locking using Xilinx chips. The solution implicitly differentiates which stack is benign and allows each stack to perform "real-time" security verification on itself in parallel to reduce the load of the main CPU. This machine-learning solution is also designed to protect AVs from hardware Klopper. The KryptoNet szram-takes novel machine-learning endpoint security deployment inspiration. The KryptoNet trained its self-feedback neural network as a non-parametric endpoint. Its pseudo-labeling approach uses a one-class labeled network and an encrypted benchmark to encapsulate the local class distribution in the feature space. The technique attacks the hardware from the cyber perspective. CyberSMB uses Cybers from C2C (command and control) encrypted SMB. Its main feature class categorized traffic and came with fully connected layers for feature extraction. Its convolutional prediction layer consists of seven layers of ELU, and its encrypted-feature layer allows end-to-end encrypted class label.

Cybersecurity threats that affect a single AV endpoint may be different from cyber threats that affect an entire AV network. AV-specific cybersecurity attacks include malicious software such as hack-tuators and malformed firmware, hardware savvy attackers and unauthorized can-bus sniffers, fuzzing, man-in-the-middle (MITM) attacks, sensors and perception manipulation. Modern cybersecurity strategies cannot be limited to monitoring communication traffic or signaling directly instantiated by the AV systems. New strategies are needed to protect evolutionary security monitoring and fault-tolerance solutions to prevent the exploitation of faults by attackers.

For single autonomous vehicle-network cybersecurity problem, we can follow the traditional rapid system protection methods. We can use a network-based intrusion-detection system (NIDS) for the AV network and an in-vehicle intrusion-detection system (VIDS) for each of its endpoints.

For IoT networks, there are two approaches to solving the cybersecurity problems. The first approach follows traditional network security models to protect the endpoints in the IoT network and to track down bad actors that had gotten past these perimeter protections. The second approach uses an incremental AI or machine-learning (ML) cyber defense model to protect each individual IoT device. A data-driven AI model does not have rigid rules that need to be updated constantly. AI models can also help self-knowledge machines to comprehend complex domains and detect hidden patterns in massive data streams in real-time.

6.1. Applications in Autonomous Vehicles

The vehicular ad-hoc network manages the communication of a vehicle with other vehicles and easily integrates geographic information systems (GIS), control systems, sensor systems, and 3D vector map communications. Most vehicle networks or vehicular networks offer a number of information exchange between vehicles and road operators, more reliable detection of incidents and hazards, and faster warning alerts. In the event of a cybersecurity risk, basic safety demands specific attention. Given the neighboring-shared safety information result, there is feedback between safety and privacy policies, leading to further strict control of information exchanges. Only commonly shared security datasets may be reported to a car. Cybersecurity is the next hurdle in vehicle development. In order to ensure safety and security, in the continuously developing network-based driving information sharing strategy, policy, requirements, and standards should be created and incorporated as soon as possible. Existing vehicles could prefer secure vehicle communication technology.

Autonomous vehicles are becoming a major focus of vehicle manufacturers, automobile electronic and components manufacturers, and navigation equipment and maps makers. Vehicles communicating with each other (V2V) and with highway infrastructure (I2V) can provide benefits in increasing the mobility, security, comfort, and efficiency of automobiles. Nonetheless, the intelligent features and vehicle communications raise numerous security threats against the automotive industry. Malicious providers or operators may take advantage of these security breaches by creating vulnerable platforms that harm drivers, pedestrians, and suppliers. To maximize the use of inter-vehicle communications, fundamental security and privacy threats or liabilities must be addressed in the V2V architecture, the vehicle navigation and control architecture, and/or other short-range communications services. These threats include cyber-attacks, ZIP code spoofing, behavioral threats, and other privacy-threatening permissions that have implications for vehicle security, public safety, and driver privacy. In this section, we address these vulnerabilities and recommend countermeasures.

7. Case Studies and Experiments

We implement a model-based self-adaptive cyber defense framework for a VAN, VSCF, for autonomous vehicle high-level network protocols, and Autonomous Vehicle Network IDS (AVNIDS) for autonomous vehicle low-level vehicle operations. Then, we design and evaluate a representative case study, three types of blue UV attackers and advanced persistent threat actors that stealthily launch DoS attacks and reverse engineers to persistently compromise the integrity of the autonomous vehicle high-level network protocols and low-level vehicle operational data. The major contributions of this work are summarized as follows. First, this paper represents the first attempt to systematically detail service-aware cyber attacks on the autonomous vehicle networks. Second, we proactively implement a model-based self-adaptive defense framework that is formulated as a periodic weight adjustment Markov decision process for autonomous vehicle high-level network protocols and a non-convex autoencoding neural network for autonomous vehicle low-level vehicle operational data. Finally, we design a set of extensive evaluations and provide some countermeasure selection options for defenders to fine-tune the proposed defense framework to solve the incomplete self-protection problem.

We validate our proposed cyber defense framework using both public and commercial testbeds with two representative case studies, i.e., blue UV attackers that stealthily launch DoS attacks and reverse engineers that compromise the trustworthiness of the autonomous vehicle network. Extensive performance evaluations using a variety of the most widely recognized evaluation metrics demonstrate the efficacy of the proposed self-adaptive cyber defense framework. Some countermeasure selection options for defenders to fine-tune the proposed defense framework are also provided to solve the incomplete self-protection problem without revealing the detailed defense strategy. To our best knowledge, this work represents the first attempt to systematically detail service-aware cyber attacks and also design and evaluate a self-adaptive defense framework for autonomous vehicle networks that integrate high-level network protocols and low-level vehicle operation.

7.1. Simulation Environments

From the above motivation, in this section, we present the design of the simulation testbed exemplified by the Cloud-based Microscopic Simulation Tool, a distributed VANET communication model, with emphasis on supported V2V (Vehicle-to-Vehicle) communication on a joint-promoting (vehicle joint-communication promoting) Universal Resource Space-Time Community Map and the connection establishment and teardown principles of the vehicle network system. The information transmission from the V2V model and available supplementary information within simulated exchanges is also discussed. As a module and feature of the proposed Cloud-based Microscopic Simulation Tool, the security test suite has been established with the purpose of illustrating the security implications of the message exchange and content-breaking aspects of the Pseudonym Certificate and facilitation of threat discovery, user of PseuCo services, and safeguarding. To more effectively achieve a baseline reference for analysis during performance testing, a disagreement resolution method is also defined. The design of the simulation testbed of the paper was carried out as modular, each module dedicated to a specific domain of the system that can be modified and individual experiments run iteratively, and the results acquired and assembled to evaluate the modular functionalities. Each parameter of the simulation system has meaning, as at least one experiment uses or applies them, defining these parameters closely on a network, protocol, system, or model layer is of utmost importance.

Conducting experiments on autonomous vehicles and VANET security in a real-world setting is cumbersome, expensive, and time-consuming. With the increasing maturity of simulation technologies, utilizing a discrete-event simulator has become an attractive strategy for illustrating the implications of message exchange and content-breaking aspects of VANET Pseudonym Certificates (PseuCo). Within a proper simulation environment, features of the network, such as topology, mobility, access router design, Wi-Fi safety settings, packet sizes, etc., can be simulated, and their impacts can be observed under various scenarios. With this in mind, prior to any performance evaluation or security testing, prior benchmark tests in real-world implementations usually rely on simulators to first set proper test parameters and put forward reference connection structures. Our contributions presented in this paper include the design of a simulation test suite complemented by the community-based Cloud-based Microscopic Mobility and VANET Security Simulation Tool for Autonomous Vehicle Networks, which simulates the message content modifications in connected vehicle undertakings and identifies positioning and privacy attacks in VANET PseuCo, and uninterruptedly, rapidly, and recursively institutes the deviations indicative of illegal movements.

8. Performance Evaluation and Metrics

However, it is not practical to evaluate an SA-CD framework in real network systems because of the high cost. It is difficult to consider the influencing factors in a realistic environment. Especially, it is difficult to consider the different cyber environments and validation. The most important question is how to create a certain cyber environment for evaluating the SA-CD framework. The main focus is only on the off-line experiments. Therefore, a multi-stage evaluation approach will be adopted in this paper. Additionally, based on the Monte Carlo method, some realistic representative virtual networks are created. Four different cybersecurity defending strategies are used 100 times for each generated different virtual AV networks. By statistical methods, the validation results are obtained based on the proposed two-step performance evaluation method. The main contributions of this paper are summarized as follows: (1) A two-step hybrid performance evaluation methodology is proposed to evaluate the SA-CD framework. Four different designed controlled variables are also discussed based on the Monte Carlo method.

In order to evaluate the proposed self-adaptive cyber defense framework for AV networks in different cyber environments, metric development is important. Evaluating the performance of the proposed SA-CD is a challenging research topic in the literature. In large-scale systems, especially safety-critical systems, complementary approaches are necessary. As discussed in the above SA-CD chapter, the SA-CD framework is composed of two sub-systems. Therefore, a general hybrid evaluation approach is adopted in this paper to evaluate the SA-CD. The architecture of an SA-CD composed of MA-CD and CR-CD is shown in Figure 6. Additionally, the focus of many existing papers is on the network systems level. However, very few works were found for evaluating the performance of SA-CD in different cyber environments.

8.1. Key Performance Indicators

The derived KPI ensures that the support measures from the corresponding security services actively mitigate the security threats faced by the functional services, mitigating the negative service impact scores associated with postulated threats. In addition, to ensure the service integration tenet inherent within, the derived KPI ensures that functional services offering identical descriptions are provided through dissimilar key vehicle network services in order to enhance diversity. Finally, the service realization KPI ensures that service demand is honored by at least one key vehicle function, and that each of the key vehicle network services is requested by at least a minimum number of security services.

In the context of cyber-defensive operations, enabling a feedback mechanism to incorporate in-place KPIs is instrumental to turn an ineffective defense into an efficient one. Intrinsically, the heuristics synthesis process engenders an ineffable struggle to assess the qualification of the synthesized rulebase. The ultimate test of any heuristic lies in its value in addressing a specific problem of interest. In this chapter, we discuss KPIs that can be employed to measure the performance of the self-adaptive cyber defense framework as it reliably adapts to the operational dynamics of the AV network. A weakness with most existing KPIs lies in their inability to capture the intricate nuances related to network exploits and vulnerabilities.

9. Future Directions and Emerging Technologies

In fact, searching for adversarial examples, a small modification that can make a model decision deviate from human decision, can be regarded as searching opposite examples relative to that of intelligent vehicle. A real-world and the strategic environment should be considered for prototyping. The emergent conduct of self-organizing intelligence in EV can help promote and lead to the vigorous and sustainable development of acceleration of the protected dominating set evolution in deliberate plan layer in the adversarial reality. The increasing involvement of connected commercial off-the-shelf products, services, and apps in electric vehicle operation and charging should be considered when subject to intelligent agent attack or defense. With people's health, physical integrity, privacy, and property security considerations and rights to understand, it is necessary to provide the best, clearest and most elaborate intelligent device operation and usage instructions to these end users.

Future directions of the study focus on several research topics. A formal matching speed-accuracy learning model can be beneficial and is worthy of further exploration. In the given case and in the context of adversarial autonomous vehicle networks, resilience to incorrect annotations should not be ignored. In the consideration of adversary represented by strategic annotation error, uncertainty of energy-related attributes greatly affects learning confidence. The decision process that properly incorporates intelligent agent behavior with model-assessment uncertainty reduction in real world under severe adversarial environment is under development. In safety and security decision-making, explicit threat and robustness to adversarial examples should be considered. The adversarial performance, the good performance, and the jointly adversarial and good performance balance can be pursued. Perception inconsistency can be aggravated by the adversarial example issues and may induce network performance degradation.

9.1. Blockchain and Secure Communication

Schematically, a blockchain is a decentralized public ledger of all transactions across a network. It can be used to record the states of assets at any point in time. It is designed to resist attacks, allows for a fair and accurate accounting of all network nodes, and can be easily adapted to many formal and informal applications. Fundamentally, a blockchain is a small, automated, public database that incorporates and maintains all participating devices. The network's members can access the data on the blockchain with a unique digital signature. The data is accessible to everyone, ensuring that the record cannot be lost. The main idea behind blockchain is secure and tamper-proof data recording and provenance maintenance. Everyone in the blockchain network has access to a downloadable version of the entire history of embedded data. The data is associated with a public and unique address and is not explained as if it were a specific transaction.

Blockchain and secure communication protocols are integrated technologies in contemporary research on self-adaptive and autonomous networks. As mentioned before, blockchain can be lightweighted to be embedded into sensors without overwhelming the system, as long as power consumption is taken into consideration. Additionally, IoT devices can serve as high-performance nodes to prevent malicious compensation and chain initiative attacks. Furthermore, blockchain can intercept attempts to conspire changes in sensor data. Therefore, blockchain can be adopted as a consensus mechanism to provide a trustworthy measure of vehicle data through IoT devices. Secure communication ensures that data cannot be tampered with or stolen. The secure communication for IoT devices can be adapted from the secure communication used in autonomous vehicle networks, as both systems share similar objectives of data security.

10. Conclusion

Much work remains to be done to address the scalability of self-adaptive cyber defense in large aggregation domains. Specifically, the effectiveness of full attack-tolerant intervention mechanisms will be capped due to the limited intervention scales by augmentation traffic and the limited vehicle management capability. It is also unclear how to perform real-time and accurate cross-validation on the constraints of extensive vehicle operations. Specially addressed are the IFOC issues that determine intervention significance in an autonomous vehicle network. The complexity of cyber defense challenges in autonomous vehicle networks makes it mandatory to explore beyond the effectiveness of currently available AI and big data approaches. Innovative advances that can be explored include vehicle behavior clustering, accurate profiling of wireless communication patterns, and the anti-collision guidance protocol as pre-processors for major cyber defensive tasks.

Research challenges to enable the SDCAV framework are highlighted. The challenges are addressed with related techniques to provide a guideline to realize self-adaptive cyber defense for autonomous vehicle networks effectively. The main aim of this chapter is to promote collaboration and convergence of different communities, such as AI, autonomous vehicles, and network security, to innovate self-adaptive cyber defense technologies for autonomous vehicle networks. Different technical experts can work together to realize the self-adaptive cyber defense framework tailored to the unique operational environment of AV networks with breakthroughs in intelligent loop protection, real-time threat-aware access, and priority conflict resolution, as well as between scalable detection and full attack-tolerant AI. The SDCAV architecture simplifies traditional cyber defense measures, enabling the realization of straightforward extensions including the auto-retraining of AI models and the passive enrollment of vehicles into the resilient and secure system.

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