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Authenticated and Secure Automotive Service Discovery with DNSSEC and DANE

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Abstract—Automotive softwarization is progressing and future cars are expected to operate a Service-Oriented Architecture on multipurpose compute units, which are interconnected via a high-speed Ethernet backbone. The AUTOSAR architecture foresees a universal middleware called SOME/IP that provides the service primitives, interfaces, and application protocols on top of Ethernet and IP. SOME/IP lacks a robust security architecture, even though security is an essential in future Internet-connected vehicles. In this paper, we augment the SOME/IP service discovery with an authentication and certificate management scheme based on DNSSEC and DANE. We argue that the deployment of well-proven, widely tested standard protocols should serve as an appropriate basis for a robust and reliable security infrastructure in cars. Our solution enables on-demand service authentication in offline scenarios, easy online updates, and remains free of attestation collisions. We evaluate our extension of the common vsomeip stack and find performance values that fully comply with car operations.

Index Terms—Automotive security, authentication, attestation, service orientation, SOME/IP, AUTOSAR, standards

I. INTRODUCTION

Future cars will connect to the Internet as well as to other vehicles and infrastructure (Vehicle-to-X (V2X)) for improving road safety, traffic efficiency, and driver comfort. This opens a large attack surface across communication interfaces [1]–[3] and in-car software [4], [5]. Nevertheless, current automotive protocols and Electronic Control Units (ECUs) often lack security mechanisms [6] since they were designed for a closed environment. Industry standards (e.g., ISO/SAE 21434 [7]) and legislation (e.g., the European Cyber Resilience Act) demand automotive security throughout the entire supply chain for hardware and software.

Service-Oriented Architecture (SOA) for automotive software emerges as a paradigm that facilitates service provisioning by various suppliers of an Original Equipment Manufacturer (OEM). Scalable service-Oriented MiddlewarE over IP (SOME/IP) [8] – standardized by AUTOSAR – is the most widely deployed middleware tailored to the automotive environment and implements service-oriented communication via IP and Automotive Ethernet [9]. Paired with Time-Sensitive Networking (TSN) [10], Automotive Ethernet can meet real-time requirements. In this architecture, services are envisioned to be dynamically updated and orchestrated on the vehicle ECUs [11]. Therefor SOME/IP provides a complementary Service Discovery (SD) [12] that detects service availability and establishes sessions between producers and consumers.

SOME/IP, however, does not verify the authenticity of service providers.

The problem of securing SD is not unique to the automotive domain. On the Internet, the endpoints of services are determined with the help of the Domain Name System (DNS). Its Domain Name System Security Extensions (DNSSEC) [13] ensure data integrity and authenticity of the DNS records. In addition, DNS-Based Authentication of Named Entities (DANE) [14] binds public certificates to names to ensure the authenticity of the connection endpoint unambiguously and without attestation collisions. DNSSEC and DANE are well-established and widely deployed Internet standards with almost eight million DNSSEC verified zones and more than half a million DANE enabled zones on the Internet¹.

In this paper, we leverage the DNSSEC protocol and its operational ecosystem to solve the problem of service authenticity and certificate management in vehicles. We focus on SOME/IP SD for automotive service invocation, even though our approach could be transferred to other in-vehicle protocols. Unlike earlier proposals, which manually pre-provisioned certificates for adding authentication during session establishment [15], our approach manages security credentials dynamically and is capable of fully functional updates.

We model SOME/IP service descriptions as a DNS namespace and store parameters of SOME/IP service endpoints in the DNS. This allows us to bind certificates to the service names using DANE. Thereafter, DNSSEC ensures authenticity and integrity of the records following a content object security model, which allows for seamless replication of records including caching, as well as credential updates. In cars, we verify the authenticity of the publisher endpoints with the help of a lightweight challenge-response scheme anchored at the DANE certificates. We demonstrate the feasibility of our approach by extending the SOME/IP reference implementation with access to a local DNS resolver for service parameters and certificates during the SD. We compare the performance of our scheme to the reference implementation.

The remainder of this paper is structured as follows. Section II recaps the SOME/IP SD and related work on secure discovery of services. Section III presents our concept of DNSSEC-based SD for publisher authenticity. We evaluate our concept in Section IV and discuss performance results. Section V concludes with an outlook.

¹ SecSpider Global DNSSEC deployment tracking [Online]. Available: https://secspider.net/stats.html (Accessed 28.11.2022)

II. IN-CAR SERVICE SECURITY AND RELATED WORK

Modern cars have a wide range of heterogeneous services as analyzed in our previous work [16]. Among them are Advanced Driver Assistance Systems (ADAS), which improve road safety and driving experience, and multimedia applications for infotainment. Traditionally, Electrical/Electronic (E/E) architectures are rigidly integrated at design time and tightly couple software components to their ECUs. As the number of services increases, E/E architectures become more complex. Orchestrating software applications across hardware resources in a dynamic SOA allows for a more flexible software architecture [11]. This enables shorter innovation cycles, frequent updates, and on-demand installation of services.

Current vehicles are vulnerable to networked attacks via various interfaces including V2X communication [2], [3]. In an unprotected network of services, a malicious participant can compromise the communication across the entire network. This could disrupt the function of safety-related services.

Current automotive systems and protocols were often designed for closed environments [6] and lack a robust security layer. The AUTOSAR platform [17] advises two major SOA solutions for the automotive domain, SOME/IP and Data Distribution Service (DDS) [18]. DDS supports basic service authenticity [19], while SOME/IP, the most widely deployed protocol in the automotive domain, is tailored to a closely protected automotive environment. SOME/IP SD lacks security means [15] including data confidentiality, protection against replay attacks, service authorization and authentication. We focus on securing SOME/IP through service authentication using the established Internet standards DNSSEC and DANE combined with common authenticity standards.

A. Common Standards for Authentication

Service authentication mechanisms generate trust by attesting the identity of a service provider. The certificate-based X.509 Public Key Infrastructure (PKI) [20] uses asymmetric cryptography and a trust anchor. Certificates contain the public key that proves the identity of an entity, such as a service, and a signed reference to the trusted entity. A client application requests this certificate and authenticates it using the public key of the trusted instance. Subsequently, the client verifies the endpoint authenticity via a challenge-response protocol ensuring the entity possesses the private key.

The public Certification Authority (CA) model uses the X.509 PKI to attest certificate authenticity of Internet applications. The Transport Layer Security (TLS) handshake protocol, for example, verifies the endpoint authenticity of entities. The main problem with the public CA model is that any trusted CA can issue a certificate for any domain name [14]. Multiple signing CAs can generate attestation collisions.

DNSSEC [13] is a well-established infrastructure to secure the DNS against unauthorized modifications of its records. It adds signature records to the DNS that ensure integrity and authenticity of the data stored in plain text records. Asymmetric cryptography establishes a chain of trust from the root zone to any delegated zone. This chain of trust is built along the name hierarchy, though, and remains resistant against attestation collisions, which the Web PKI generates if multiple CAs sign the same resource name.

A robust and mature ecosystem developed during more than 15 years of DNSSEC deployment. This includes not only software and tooling but also a professional practice and thorough analyses of credential maintenance [21] including the roll-over of the DNSSEC root keys [22]. It is noteworthy that DNSSEC can also be deployed for private namespace management independent of the global Internet naming hierarchy.

DANE enables the binding of certificates to names in the DNS. It uses TLSA records to store certificate data tied to domain names. The certificate presented by a server must then match against the certificate associated with DNS data to determine the integrity and authenticity of the server. The security of DANE is bound to DNSSEC and thus benefits from the inherent chain of trust, which ensures the integrity and authenticity of the TLSA records.

In this work, we modify the SOME/IP SD to query DNSSEC-verified service parameters and connection information stored in the DNS. Further, we bind certificates to services using TLSA records. We sign all records to obtain signature records and achieve authenticity and integrity of the service parameters and certificates. The benefit from this approach is a collision-free publisher authenticity that is protected by the well-established DNSSEC infrastructure.

B. SOME/IP Service Discovery

SOME/IP is widely used in automotive networks and is capable of communicating via UDP and TCP transport. Its design goals include scalability and low resource consumption. SOME/IP uses a publish-subscribe model. Publishers can notify subscribers about an update or an event that has occurred. SOME/IP SD announces and discovers services via multicast. It also performs the session establishment between publishers and subscribers after a successful subscription. SOME/IP provides no means for service authenticity.

Figure 1 shows the SOME/IP SD sequence for service announcements, discovery, and subscription. The SOME/IP SD uses multicast find and offer messages to request and announce services, which are described by their ID, instance ID, major and minor version. An offer entry uses so-called endpoint options to describe how to contact a service. There are two concepts of discovering a service. (1) A publisher periodically updates an offer message, as an offer has a limited lifetime. (2) A subscriber requests a service via a find message, whereupon corresponding publisher instances announce it via an offer message. After the subscriber receives the offer message, it subscribes to the service via unicast specifying its receiving endpoint description and the desired Eventgroup. If the publisher can provide this service, it acknowledges the subscription, after which the transmission of the requested data begins.

C. In-Vehicle Service Authenticity and Confidentiality

Secure discovery mechanisms are essential to prevent attackers from infiltrating automotive networks and eaves-

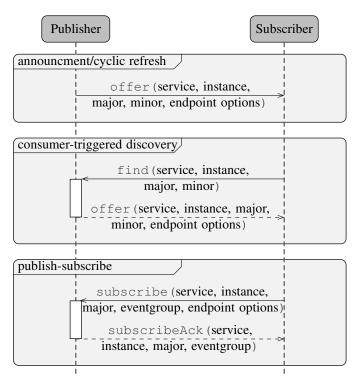


Fig. 1: Service announcement, discovery, and subscription according to the SOME/IP service discovery protocol.

dropping on in-vehicle communication. Challenge-response schemes can authenticate nodes to control service access. Message encryption keeps unauthorized participants from eavesdropping on network communication. In this work, we focus on publisher authenticity using a challenge-response scheme based on the public credentials obtained from DNSSEC.

Common standards for authentication have been applied to in-vehicle networks. Challenge-response mechanisms require cryptographic keys that are commonly pre-deployed on the vehicle ECUs and can be both symmetric secret keys [23] or asymmetric key pairs [24]. Further, a PKI uses a trust anchor to enable the authenticity and integrity of certificates with keys that can be revoked when they are no longer secure [25], [26]. In this work, we use asymmetric cryptography for a challenge-response mechanism and DNSSEC with its inherent chain of trust to ensure certificate authenticity.

Prior research proposed methods for securing SOME/IP, including message encryption and service authentication [15], [27], [28]. Iorio et al. [15] follow the public CA model and a challenge-response scheme using asymmetric cryptography. Each vehicle has a different trusted root certificate, used to sign the certificates of the ECU and the services, creating a simplified chain of trust. They also bind access control policies to the signed certificates. We use a similar challenge-response scheme based on asymmetric cryptography to authenticate publishers. Ma et al. [28] use Message Authentication Codes (MACs) against message forgery, and a key management center that derives temporary session keys from encrypted received nonces. Zelle et al. [27] propose two solutions

for SOME/IP message authentication, one that authenticates services on the ECUs themselves, and another introducing an authorization server to authenticate messages. These solutions, however, require pre-deployed keys and certificates on every ECU, which generates the challenge of credential management in practice. In contrast, we use the DNS recursive resolver infrastructure for managing certificate provisioning and DNSSEC and DANE for ensuring certificate authenticity, reducing the load on the ECU. Our approach only requires signature validation on the ECU.

III. DNSSEC IN SOME/IP SERVICE DISCOVERY

Our approach transforms SOME/IP SD to utilize the established Internet technologies DNSSEC and DANE for secure service discovery and authentication. Therefor we first map SOME/IP SD data fields to DNS names and record data. Second, we bind DANE certificates to the service names to verify the authenticity. Our prototype implementation is based on the *vsomeip* [29] reference implementation, which dictates our architecture and naming.

A. Designing a DNS Namespace for SOME/IP Services

The main challenges in designing a suitable DNS namespace for automotive services are to avoid collisions with existing query names, remain compatible with DNS naming conventions, and simultaneously preserve all SOME/IP SD query properties. Four fields specify a service: service ID, instance ID, major version, and minor version. In a find message, a subscriber must specify at least a service ID, and the other fields can be wildcarded. For example, not specifying an instance ID results in receiving all running instances of a service. In total, a service can be requested in 2^3 ways.

Table I shows DNS entries for a service based on SOME/IP find parameters, using symbolic names for simplicity. We use *service* as the parent domain, which can be customized, for example, to an OEM or tier-X supplier. More specifically, adding *tier-x.oem* as the parent domain would enable a hierarchy that passes down the rights to maintain and certify service records in each subdomain. The four data fields are prepended to the query name in the same order as in the find message service description. An unspecified field in a find message corresponds to the absence of that field in the query name. The arrangement of the four fields is arbitrary, but must be

TABLE I: SVCB records for one service with symbolic query names and concrete record data.

QNAME	RDATA (SVCB)
_someip.minor.major.instance.id.servicesomeip.major.instance.id.servicesomeip.minor.instance.id.servicesomeip.minor.major.id.servicesomeip.instance.id.servicesomeip.major.id.servicesomeip.minor.id.servicesomeip.minor.id.servicesomeip.id.service.	port=30509 ipv4hint=10.0.0.5 protocol=UDP instance=2 major=1 minor=2

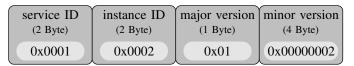


Fig. 2: Service description in find and offer messages.

IP address	L4-protocol	port number
(4 Byte)	(1 Byte)	(2 Byte)
10.0.0.5	UDP	30509

Fig. 3: Endpoint details in offer and subscribe messages.

followed consistently as they determine valid query names. We prepend *_someip* to each branch, following the semantic scope of the attribute leaf name pattern.

We consider the two gray-marked query names specifying a minor version without a major version impractical and therefore invalid. Even though the SOME/IP SD specification does not object to such queries, the number of valid query names per service is reduced to six.

To prevent ambiguity when wildcarding different fields, we include the symbolic name before the data field value making records uniquely distinguishable. As per our namespace design, a service with ID 1, instance ID 2, major version 1, and minor version 2 has this concrete query name:

_someip.minor0x00000002.major0x01.instance0x0002.id0x0001.service.

B. Choosing a Record Type for SOME/IP Endpoints

The IETF specifies various record types for storing data in the DNS. To ensure interoperability between SOME/IP SD and DNSSEC, we need a DNS record that can contain all information originally provided in offer messages. This includes the service description (Figure 2) and additional endpoint options (Figure 3), specifying how to connect to a service using an IP address, L4-protocol, and port number.

The main DNS service record candidates are SRV and SVCB. The SRV record [30] specifies a service endpoint location, including a transport port and domain name data fields. SRV record names should follow attribute leaf naming [31], using underscored names prepended to the parent domain for semantic classification of services, for example, including the transport protocol in the name (e.g., _ldap._tcp.example.com). This does not comply with SOME/IP SD as the transport protocol is not specified in find messages. Next, the SRV record does not provide a data field for the IP address of a service, but holds a domain name referencing an address record instead, which requires additional queries as a detour to obtain an address and available transport protocols. The SVCB record [32] stores general purpose service bindings and is still an active IETF Internet-Draft in the converging phase to become a standard. SVCB data includes fields for port number, IP address and 255 other fields for private use to store service parameters, making it our preferred option.

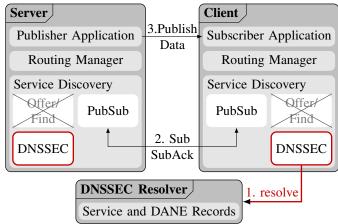


Fig. 4: SOME/IP SD modification for using DNSSEC.

Table I shows the SVCB record data uniform for all query names of a single service, with offer message fields and endpoint options mapped accordingly. The record data refers to an UDP-accessible service at port 30509 and IP address 10.0.0.5 stored as ipv4hint, with instance ID 2, major version 1, and minor version 2 specified in case wildcards were used in the query name. The instance ID, major version, minor version and layer 4 protocol are each mapped to one of the 255 fields for private use.

C. Integrating the SOME/IP SD for using DNSSEC

DNSSEC ensures records are unchanged and correct when the subscriber receives them. This is already an advantage over the SOME/IP SD, where anyone can send conflicting offers [27]. Our approach showcases the adaptation of a SOME/IP stack for DNSSEC-based service discovery using the open source reference implementation *vsomeip* [29].

Figure 4 depicts the conceptual architecture inherited from the *vsomeip* stack, comprising an application, routing manager, and service discovery used by both the client and server. The routing manager handles the local transport-specific endpoints for the applications and forwards messages between them.

Our modifications to enable DNSSEC during SOME/IP SD are also illustrated in Figure 4. Instead of the original offer/find procedure, the client retrieves the publisher endpoint description via a DNSSEC resolver. With that, publisher services no longer announce themselves, and we gain secure service discovery through the implicit trust established by DNSSEC records. Clients can subscribe to the service and receive published data after obtaining the service record.

D. Ensuring Publisher Authenticity with DANE

DNSSEC verifies subscription parameters used to access the endpoint. Nevertheless, attackers can still mimic this endpoint, for example, using IP spoofing. DANE validates publisher authenticity to ensure that the subscriber connects to the correct publisher.

Figure 5 shows our secure service discovery and invocation process. After the subscriber has resolved the service endpoint

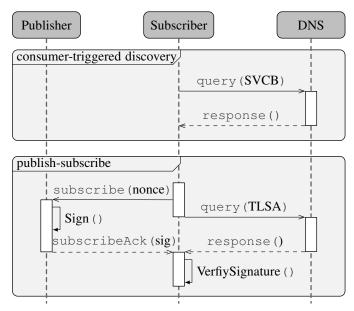


Fig. 5: Augmented SOME/IP SD with DNSSEC and DANE for secure publisher service discovery and authentication.

through a DNS query, it subscribes to the service with the information from the SVCB record. At the same time, the subscriber queries the DNS for the DANE TLSA record containing the public certificate of the service, which is again protected with DNSSEC. With this the subscriber can validate the signature of the publisher.

We employ a challenge-response scheme to ensure that the publisher endpoint is authentic and indeed the owner of the corresponding private key. With the subscribe message, the subscriber sends a random 32-bit nonce in a SOME/IP configuration option as a challenge to the publisher. The publisher signs the challenge with its private key and sends the subscription acknowledgement with the signed random nonce back to the subscriber, also utilizing a configuration option. The subscriber validates the signature with the public certificate of the publisher, providing assurance of authenticity. With a future extension, the subscriber and publisher could agree on a session key during the challenge-response process to enable message encryption for confidentiality.

E. Operating DNS-based Automotive Service Discovery

In operation, we foresee that a car has a local DNSSEC recursive resolver that caches verified records as soon as the car has Internet connectivity. Each time a record is retrieved, the DNSSEC recursive resolver ensures the chain of trust before caching it, eliminating the need for DNSSEC validation during SD. This ensures that the service discovery is still operational when the vehicle is disconnected from the Internet. Cached records are refreshed before they expire, and it shall be part of future experimentally driven research to determine appropriate cache lifetimes in real deployments. In this way, our approach exploits the benefits of a well-established standard

infrastructure for obtaining data integrity, authenticity, and a robust procedure for certificate management.

IV. DISCOVERY CAPABILITIES AND PERFORMANCE

We evaluate the performance of the proposed solution compared to the unchanged SOME/IP SD protocol. Therefore, we first compare the service discovery capabilities showing differences in communication schemes and security mechanisms. Then, we evaluate the performance of our prototype implementation in terms of discovery and subscription latency.

A. Key Features and Implications

Table II summarizes differences in key features between the proposed approach using DNSSEC and DANE, and the SOME/IP SD protocol. SOME/IP was initially released in 2016 as a module in the AUTOSAR platform and targets local in-vehicle networks. DNSSEC and DANE are defined in RFCs by the IETF. Our approach with DNSSEC and DANE leverages this technology with over 15 years of global deployment and operational experience on the Internet. With this we gain the benefits of a tried, resilient and security hardened infrastructure.

The SOME/IP SD uses group communication, whereas the DNS uses unicasts. For DNS-based discovery, this implies that multiple clients of the same server must all query the DNS resolver separately, while with SOME/IP SD, a publisher can inform subscribers with a single multicast offer, reducing the network load. An evaluation in a realistic automotive setup with a large number of services would show whether our approach introduces significant performance penalties, but we leave that open for future work.

Endpoint discovery in the SOME/IP SD uses offer messages initiated by the publisher, while with DNS, the consumer queries the resolver directly. This means that publishers can provide endpoint information during runtime with SOME/IP SD, but the DNS resolver is not aware of the service runtime location. This requires predefined IP addresses and ports for all service instances in DNS records, which should be the same for all vehicles. However, this is not a problem within a local network where the IP addresses can be freely selected. In turn, the DNS records can be verified along the DNSSEC trust chain, which is not possible for the endpoint information provided by the publisher. This prevents malicious services to offer false endpoint information, for which there is no protection with SOME/IP SD.

There are no service authentication means in SOME/IP SD by default. Previous work proposed using the public CA model [15], [27] or a custom key management center [28] to ensure the authenticity of public certificates pre-deployed on each node in an additional challenge-response handshake. Our approach exploits the DNSSEC and DANE mechanisms as an established standard to ensure implicit certificate and service information authenticity through the DNSSEC trust chain. We integrate a challenge-response mechanism similar to the TLS handshake into the SOME/IP subscription process ensuring endpoint authenticity. With this, we have to perform

TABLE II: Feature comparison between the SOME/IP SD protocol and the proposed approach based on DNSSEC and DANE.

Feature	SOME/IP SD (and related work)	SD w/ DNSSEC and DANE (our approach)
Standard commission	AUTOSAR [8], [12]	IETF [13], [14], [32]
Introduction and deployment	Basic support in AUTOSAR since Nov. 2016, deployment in production vehicles just starting	DNSSEC first standardized in 1997, over 15 years of global deployment and operational experience
Target environment	Developed for local in-vehicle network	Hardened for global Internet deployment
Service discovery scheme	Multicast find/offer messages	Unicast DNS query/response
Endpoint detail distribution	Provided initiated offer messages with the service runtime location	Consumer requested DNSSEC-signed SVCB records with pre-defined endpoint information
Authentication scheme	None by default, challenge-response [15], [27], central authorization server [27], [28]	Challenge-response during subscription
Certificate distribution	Pre-deployed public certificates on all participating nodes [15], [27], [28]	Consumer requested public certificates from DNSSEC-signed TLSA records
Certificate update procedure	No automated mechanism, requires simultaneous update of all cients and servers in workshop or OTA [15], [27]	Established mechanism for certificate management, including update and revocation

additional lookups in the DNS to retrieve the certificate and the service information from an in-vehicle DNSSEC resolver. In our benchmark, we evaluate the discovery latency showing that the certificate lookups do not introduce a significant overhead.

A vital advantage in using DNSSEC and DANE mechanisms are the well-established certificate management procedures. Easy online updates are performed by adding new records to the DNS for the new version of the app and new keys on the publisher node can be deployed with a new version of the application. This ensures that older versions can still use the old certificates while the already updated applications can use the new certificates. In contrast, pre-deployed keys must be updated on every client and server node. In case of certificate changes that also affect the private keys, the private key in question must be updated, both for pre-deployed certificates with SOME/IP and for certificates in TLSA records.

Previous work investigated attack vectors on the SOME/IP SD protocol, such as Man-In-The-Middle (MITM) attacks exploiting offer messages [27]. Our consumer-triggered discovery approach with known IP addresses from the DNS is not affected by the identified attacks, although an attacker using ARP and IP spoofing could act as a malicious proxy altering the messages when no encryption or signature is used. We assume that the local DNS resolver is only accessible from the in-vehicle network and therefore not easily manipulated, which also prevents potential Denial of Service (DoS) attacks from the outside. Even if the uplink of the DNS is jammed, the in-vehicle network communication can still operate. However, if the vehicle is operated for an extended period of time without an Internet connection, the authenticity of the service

cannot be guaranteed, as the certificates could expire or be revoked in the meantime. Single Point of Failures (SPOFs) can be faced by replicating the local DNS resolver as well as the external DNSSEC server.

B. Evaluation Setup

We measure the service discovery and subscription latency and the cost of the cryptographic operations. We do not directly compare our solutions to [15], [27], [28] since we do not have access to their implementations, but we use similar cryptographic operations for authentication. Compared to predeployed certificates (cf. [15], [27]), the DNS resolver is introduced as an additional instance (cf. [27], [28]) with DNSSEC and the data authenticity is outsourced to the DNSSEC. In doing so, we compare four different solutions, all of which are implemented based on the *vsomeip* [29] stack:

- 1) **SOME/IP SD:** An unaltered *vsomeip* implementation that we use as a baseline.
- DNSSEC: A DNSSEC augmented *vsomeip* that replaces the original offer/find procedure with our DNSSECbased consumer-triggered discovery.
- 3) DNSSEC w/ DANE An authentication approach based on the DNSSEC discovery implementation that uses DANE records to retrieve the publisher certificate, and our challenge-response mechanism during the subscription phase to authenticate the publisher.
- 4) SOME/IP SD w/ AUTH: An authenticated approach returning to the original SOME/IP SD without any DNS operations that uses pre-deployed certificates and our challenge-response mechanism to authenticate the publisher.

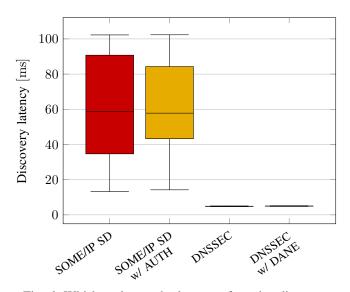


Fig. 6: Whisker plot on the latency of service discovery.

Someth SD Someth SD Someth SD Dissec Dissect D

Fig. 7: Whisker plot on the latency of service subscriptions. The small squares are outliers.

Our evaluation setup consists of three nodes for a client, a server and a DNSSEC resolver, which are arranged as shown in Figure 4. All nodes run on the same host system (CPU: AMD FX-8350 with 8 cores at 4Ghz, RAM: 16GB) in separate containers (*Docker*: 20.10.22) connected via the Docker virtual bridge network.

The server and client containers run on a Linux OS with the SOME/IP stack, and libraries for DNS lookups and cryptography (*Ubuntu*: 18.04.6 LTS, *vsomeip* [29]: 3.1.20.3, *Crypto*++ [33]: 8.7.0, *Crypto*++ *PEM Pack*: 8.2). The DNSSEC resolver runs on a Linux OS (*Ubuntu*: 22.04.1 LTS, *Unbound*: 1.17.0).

The DNS entries for the SVCB and TLSA records of the publisher service are already in the cache of the DNSSEC resolver and validated along the trust chain, as would be the case in an automotive deployment.

As SOME/IP uses group communication for service discovery, it applies common practices for scattering multicast communication to reduce the load on the network and hosts. For example, responses can be delayed collecting multiple requests and answer them in a single response, and a random initial delay prevents all ECUs from flooding the network by sending discovery messages at the same time. Since we compare it to standard DNS discovery via unicast queries, which does not include any of such delays, we turn off the request-response delay in *vsomeip* to get comparable results. Moreover, we only look at the connection of one server and client, for which these mechanisms are not needed. However, the startup phases of SOME/IP SD remain unchanged, and thus a random initial delay between 10 ms and 100 ms delays the startup of the discovery phase.

C. Discovery and Subscription Latency Benchmark

Our benchmark evaluates the latencies of the discovery, subscription, and cryptographic operations. For each of the

four compared solutions, we collect fifty samples with timestamps indicating the beginning and end of different phases to calculate the latency based on the difference between these timestamps. Figure 1 and Figure 5 show the sequences of the consumer-triggered discovery and publish-subscribe phases for the SOME/IP SD and the DNS discovery, respectively.

Figure 6 shows the consumer-triggered discovery latency of all four different solutions. Here, we measure the time that elapses from the completion of the initialization of the client until the result of the service discovery is available. Since the measured interval for the discovery does not include authentication operations, the latency of the solutions with publisher authentication are expected to be the same as without publisher authentication. The DNS discovery latencies are between 4 ms and 6 ms. Both SOME/IP SD variants have a latency between 13 ms and 103 ms due to the random initial delay between 10 ms and 100 ms. Without an initial delay, the latency of the SOME/IP SD would be similar to that of the DNS discovery.

Figure 7 shows the subscription latency of the four candidates. We measure the time that elapses between the sending of the first subscription message and the completion of the connection setup, including the verification of the publisher signature in the authenticated approaches. The solutions without publisher authentication have a latency under 1 ms. With publisher authentication the latency is between 4 ms and 9 ms. In detail, signing the nonce at the publisher takes between 3 ms and 7 ms, verifying the signature at the client side is below 2 ms. The trade-off in using our challenge-response scheme results in a maximum delay of 8 ms.

Considering the overall discovery and subscription latency the publisher authentication does not have a significant impact on the latency, for which the multicast scattering is the most notable delay. DNSSEC and DANE enable publisher authenticity without a large performance penalty even compared to authentication with pre-deployed certificates. We achieve this by querying the TLSA record at the same time as we initiate the subscription. However, the latency of the TLSA response containing the certificate depends on the link to the DNS server. This could impact the results when the DNS query takes longer than the subscription handshake. Here, an evaluation with an Ethernet-connected DNS server would be interesting to see the impact of the latency. In addition, the performance for a larger number of services should be analyzed to determine scalability with DNS discovery compared to SOME/IP SD in a realistic automotive network.

V. CONCLUSION AND OUTLOOK

In this paper, we designed and analyzed basic security elements for the rapidly evolving service-oriented software architecture in future cars. In provisioning service authentication and managing attestation credentials, we addressed the urgent demand for securing a heterogeneous, distributed, and dynamically updatable software ecosystem that will drive the connected cars of the near future.

Our work was intentionally built on well-established standards. DNSSEC and DANE enable certificate management and service authenticity while being a thoroughly validated, operationally stable Internet standard. SOME/IP is a widely accepted service-oriented middleware standardized by AUTOSAR. We demonstrated how to combine the SOME/IP SD with the Internet name system in design, implementation, and evaluation. Our findings indicated that SOME/IP SD can interact with the DNS without operational overhead, while DNSSEC with DANE contribute not only a robust, reliable security solution but also a stable infrastructure for replication, (off-line) caching, and key management.

This basic solution to automotive service security opens three future research directions. First, the remaining SOME/IP service primitives for onboard session establishment and migration need a detailed security design and assessment. Second, operational guidelines for namespace management and service updates in the automotive ecosystem shall be developed. Third, we aim at configuring a full-featured production-grade vehicle with our security solution and evaluate its properties in macroscopic benchmarks.

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