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AccessAuth: Capacity-aware Security Access Authentication in Federated-IoT-enabled V2G Networks

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Abstract

Vehicle-to-Grid (V2G) systems promoted by the federated Internet of Things (IoT) technology will be ubiquitous in the future; therefore, it is crucial to provide trusted, flexible and efficient operations for V2G services using high-quality measures for security and privacy. These can be achieved by access and authority authentication. This paper presents a lightweight protocol for capacity-based security access authentication named *AccessAuth*. Considering the overload probability and system capacity constraints of the V2G network domain, as well as the mobility of electric vehicles, the ideal number of admissible access requests is first calculated adaptively for each V2G network domain to actively achieve capacity-based access admission control. Subsequently, to provide mutual authentication and maintain the data privacy of admitted sessions, by considering whether there is prior knowledge of the trust relationship between the relevant V2G network domains, a high-level authentication model with specific authentication procedures is presented to enforce strict access authentication such that the sessions are conducted only by authorized requesters. Additionally, efficient session revocation with forward security and session recovery with no extra authentication delay are also discussed. Finally, analytical and evaluation results are presented to demonstrate the performance of *AccessAuth*.

Keywords: V2G, authentication, capacity, security.

1. Introduction

Vehicle-to-Grid (V2G) is a critical network service in the “Smart Grid” (the next-generation power grid) and is considered as one of the most powerful approaches for enabling renewable energy sources to provide ancillary electrical services and for managing and monitoring power usage [1–4]. A typical V2G network includes four main entities, electric vehicles (EVs), local aggregators (LAGs), certification authorities (CAs) and a control center (CC). Without loss of generality, EVs can be either power consumers or providers; they may belong to a specific group and have corresponding group attributes. The LAGs are the service access points for power and wireless communications for EVs. The CAs are trusted entities that belong to different independent institutions. They maintain secure databases containing detailed power and other information about various certified EVs and LAGs. Specifically, the components $Profiles$ *Repository*, *Policies Repository* and *Access List* are included in a CA. The $Profiles$ *Repository* is composed of the certified EVs and LAGs as well as their profiles (e.g., their attributes and personal information). The *Policies Repository* is a collection of various policies for available access resources. The *Access List* maintains information about authorized EVs. Finally, the CC acts as the only entity trusted by all the other entities in the entire V2G network environment.

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To implement the exchange of power and data, the V2G network employs a two-way communication infrastructure. The power links are deployed to charge the batteries of EVs by consuming power from the smart grid. They are also able to discharge stored power back to the smart grid. A variety of wireless/wired communication technologies are integrated to support communications between the entities involved in exchanging power-related data. Using this network architecture, an EV not only can replenish its power from or discharge unused stored power back to the connected LAG but also apply for data services via the LAG. Moreover, in a V2G network domain, a number of LAGs can be connected to a CA based on the capacity of the CA to handle the EVs' access requests. Due to the inherent mobility of EVs, when an EV is connected to a LAG serving as its default access point for power and wireless communication, we say that the EV is working in its "home mode." in contrast, when an EV is temporarily connected to a LAG managed by a different independent institution, we say that the EV is working in "visiting mode" [5].

Note that, given these characteristics (e.g., vehicle location and mobility, charging and discharging options, driving patterns and preferences, limited communication range, etc.), V2G networks are different from other broadly applied communications systems. Although V2G technology is considered a critical part of the future "Internet of Energy" [6, 7], to the best of our knowledge, it is still a very young research field. Fortunately, promoted by advances in emerging IoT technology, V2G systems in the smart grid that fit into the broader concept of federated IoT promise a future in which a multitude of physical objects and devices within the V2G networks will be connected to the Internet to create smart environments. These objects and devices are expected to carry embedded computer intelligence that will allow them to connect, cooperate, and communicate within social, environmental and user contexts to achieve better power-load management and improved power efficiency and reliability. Hence, V2G is also a special type of cyber-enabled application [8, 9].

Although the IoT paradigm is a valuable addition for controlling and managing energy appliances in V2G networks, the adopted network infrastructure suffers from a variety of serious security challenges [10–14], and the range of possible security attacks has still not been well investigated; consequently, security and privacy issues remain particularly problematic. Specifically, mutual authentication mechanisms between the EVs and the associated LAGs are imperative and must be provided to ensure legitimate communications. Moreover, data exchanged between the EVs and other entities involved in V2G networks must be secured, data privacy must be preserved throughout the network, and the LAGs must be prevented from recognizing and tracing the identities and behavior preferences of the EVs they serve. Therefore, to address these security and privacy concerns, this paper proposes $AccessAuth$ and offers the following main contributions.

1. On the basis of a thorough discussion of the issues of efficiently maintaining security and privacy, which must be achieved in the access authentication mechanisms used by federated-IoT-enabled V2G networks, $AccessAuth$, a lightweight protocol for capacity-based security access authentication with conditional privacy, is proposed.

2. In $AccessAuth$, by considering the overload probability and system capacity constraints of the V2G network domain as well as the mobility and session characteristics of EVs, a capacity-based active access admission control scheme is developed to reduce the session-dropping probability (SDP) and the session-blocking probability (SBP) for access requests. Concretely, the ideal number of admissible access requests is adaptively calculated for the V2G network domain using a Markov model. This ideal number can be used to determine whether the V2G network domain will admit a new access request.

3. Subsequently, when an access request is admissible for a V2G network domain, by considering whether prior knowledge of the trust relationship exists between the relevant V2G network domains, a high-level authentication model with specific authentication procedures is presented that provides mutual authentication while maintaining the data privacy of admitted sessions by ensuring that only authorized sessions can be conducted.

4. Within the framework of $AccessAuth$, efficient session revocation with forward security and session recovery that involve no extra authentication delay are also discussed.

The remainder of this paper is organized as follows. Section 2 discusses security and privacy issues and provides a review of current research achievements. Section 3 presents a concrete implementation and discussion of $AccessAuth$. Section 4 demonstrates the performance of $AccessAuth$ through both analysis and evaluation results. Finally, we summarize and conclude this paper in Section 5.

2. Security & Privacy Issues and Related Works

In V2G networks, security attacks and vulnerabilities suffered during power and data interactions can be categorized into three main types: data capture, data deception and data blocking [5]. Successful breaches will result in cascade effects with disastrous results. Therefore, designed access authentication protocols for V2G networks must address the following critical requirements to maintain security and privacy and to ensure authorized and reliable interactions among legal entities:

1) Mutual authentication, verification and their defense against attacks. Before initializing communications, EVs and LAGs should authenticate with each other to prevent *redirection*, *impersonation*, and other types of attacks. Verifying that LAGs offering access services are authorized by the CAs is critical to prevent a disguised LAG from disclosing private information acquired from carelessly connected EVs. Additionally, the designed access authentication protocols must be able to overcome various types of well-known, feasible security attacks.

2) Session key establishment. Data transmitted over V2G networks should be protected against illegal entities to ensure data confidentiality and against unauthorized manipulation and destruction to ensure data integrity. Adversaries should not be given opportunities to intrude on established communication sessions and perform a variety of malicious activities such as eavesdropping, data tampering, disseminating harmful data, and so forth.

3) Strong anonymity and untraceability of EVs. Private information concerning EVs, such as their battery status, behavior preferences, and so on, should not be disclosed during the authentication process to help protect against misuse of this information by *insider* attacks.

4) Conditional privacy preservation. As part of the strong anonymity and untraceability of EVs, their location information should not be associated with their identities as they roam between different V2G networks. However, in emergency situations, the CAs and the CC are responsible for interrogating the related private information of EVs (e.g., their identities and locations).

5) Anonymity for CAs and the CC. The identities of CAs and the CC must also be hidden from unauthorized entities; otherwise, domino effects may occur. For example, eavesdroppers or adversaries could conduct traffic analyses to reveal private information about EVs.

6) Low computational load and communication overhead. Because huge numbers of entities will participate in these future V2G networks, the overhead generated during access authentication (e.g., computation and communication) must be minimized, and the delay due to authentication should be small enough so that the system can respond quickly to EVs' access requests.

Currently, an extensive body of research exists that focuses on security and privacy issues in V2G networks. Based on discussions of V2G network architectures and the state-of-the-art security challenges faced during power and communication interactions, Zhang et al. [5] proposed a context-aware authentication solution that considers battery statuses and their roles. EV batteries may exist in different states (e.g., charging, fully charged and discharging) during communication interactions. Zhang et al. [15] proposed a battery-status-aware authentication scheme (BASA) by identifying unique security challenges relevant to an EV's various battery states and considering that an EV may have a variety of roles (e.g., energy demand, energy storage or energy supply). Zhang et al. [16] also proposed a role-dependent privacy preservation scheme (ROPS) by demonstrating that dissimilar security and privacy concerns exist. By exploiting a fuzzy identity-based encryption method with lattice-based access control and dedicated error-correction coding, Wu et al. [17] proposed a dedicated data access authentication scheme able to enforce fine-grained access authentication that resists corruption from noisy channels and environmental interference. To address the issue that most current identity authentication (IA) schemes and technologies face various kinds of attacks and large-scale certification problems, Xu et al. [18] proposed the HyCPK, which is an improved CPK algorithm based on a single-double hybrid matrix.

Because mobility is an important characteristic of V2G networks, an EV may work in different modes (e.g., home mode and visiting mode), causing security and privacy issues to become even more challenging due to the untrusted entities in visiting mode. By employing a bilinear pairing technique with an accumulator and performing batch verification, Saxena et al. [19] proposed a mutual authentication scheme to preserve the privacy of EVs working in different modes. Considering that EVs present different security challenges in different modes, Liu et al. [20] proposed an aggregated-proofs based privacy-preserving authentication scheme (AP3A) to achieve simultaneous identification and secure identification. In mobile networks that employ smart grids, it is widely accepted that Demand-Response (DR) techniques help in improving efficiency, reliability and security. However, the security requirements of different DR events (e.g., security access service, security communication service and security analysis service) are dynamic for various practical demands. To address this issue, Guo et al. [21] proposed an event-oriented dynamic security service mechanism for DR that dynamically composites the above three types of security services into fine-grained subservices. Also, considering the communications characteristics among EVs, Guo et al. [22] proposed a unique batch authentication protocol named UBAPV2G, in which, rather than verifying each message for each individual EV, the aggregator checks the responses from a batch of EVs using only one signature verification and then broadcasts a signed confirmation message to inform the batch of EVs using only one signature.

Similarly, based on previously identified emerging privacy issues in V2G networks, Yang et al. [23] considered the trade-off between the rewards obtained by the EVs and the financial benefits obtained by the power grid and proposed a privacy-preserving communication and precise reward architecture for V2G networks. In this approach, an ID-based blind signature is introduced to enhance anonymity. Wang et al. [24] enhanced Yang et al.'s framework with formal definitions of unforgeability and restrictiveness and proposed a new traceable privacy-preserving communication and precise reward scheme using available cryptographic primitives. Generally, in V2G networks, multiple levels of charging services must be provided for EVs; therefore, some private information of EVs may be disclosed to determine the charging service quality. He et al. [25] proposed a privacy-preserving multi-quality charging (PMQC) scheme, in which both authentication and an evaluation that determines the charging service level that can be offered to EVs are efficiently achieved without revealing private information. Considering several security concerns such as identity-irrelevant location privacy, frequent authentication for EVs, and the confidentiality and integrity of the exchanged electricity trade data, Abdallah et al. [26] proposed a lightweight, secure and privacy-preserving V2G connection scheme. However, the maintained traces for accountability and electricity exchange operations also result in a large risk of exposing the private information of EVs to eavesdroppers and adversaries.

To establish a session key built on an elliptic curve cryptography-based restrictive partially blind signature, a security and privacy-preserving mechanism for aggregator-based V2G networks was proposed in [27]; however, in this scheme, the EVs must open their accounts at the LAGs, which increases the risk of *insider* attacks. Additionally, by utilizing a restrictive partially blind signature to protect EV's identities and certificateless public key cryptography to simplify the certificate management required by traditional public key infrastructure (PKI) and to overcome the key escrow problem in identity-based public key cryptography, T-seng [28] proposed a secure and privacy-preserving communication protocol for V2G networks. In contrast, Vaidya et al. [29] analyzed the shortcomings of using traditional PKI for V2G networks and proposed a multi-domain PKI model built on elliptic curve cryptography along with a self-certified public key technique that uses implicit certificates.

While acknowledging the proposals in the literature that have been found to be efficient, each still has some limitations. For example, some generate additional overhead [19–22], and some present practical solutions to only some of the well-known security concerns [5, 15–18, 23–29]. To the best of our knowledge, the challenges of security and privacy in V2G networks must still be investigated to a much greater extent to achieve an optimal balance of performance and security.

3. AccessAuth: The Proposed Protocol

3.1. Capacity-based Active Access Admission Control

In a typical federated-IoT-enabled V2G network domain, the LAG needs to communicate with the external network on behalf of active sessions triggered by authorized EVs. The logical positions of LAGs will determine whether they are potential forwarding efficiency bottlenecks in network communications. Additionally, objects (e.g., EVs) served within a V2G network domain also need to communicate with each other; consequently, the scarcity of available spectrum bandwidth will be another communication bottleneck. To guarantee the Quality of Service(QoS) of active sessions and provide adequate services for new access requests—including both migrated sessions and newly initiated access requests triggered by the EVs—we propose a capacity-based active access admission control scheme in which each LAG in the V2G network domain will periodically analyze the arrival rate of new access requests, the probability of migration, and the probability of active session termination and, finally, obtain the ideal number of admissible access requests during the current period. The results of these calculations will be used to determine whether new access requests should be admitted. The pseudocode for the proposed capacity-based active access admission control scheme is shown in Algorithm 1.

Algorithm 1 Capacity-based active access admission control

Input: for the i-th V2G network domain, N_i^{new}: the number of admitted newly initiated access requests; $N_i^{accessed}$: the number of accessed sessions; $N_i^{capacity}$: the capacity limitation of served sessions; $N_i^{admissible}$: the ideal number of admissible newly initiated access requests.

Output: The admissible new access requests.

```
/* at time $t$ */
/* admission for a migrated session */
if ($N_i^{accessed} + 1 \leq N_i^{capacity}$) then
    admissible;
    $N_i^{accessed}$++;
else
    reject;
end if
/* admission for a newly initiated access request */
if (($N_i^{new} + 1 \leq N_i^{admissible}$) & ($N_i^{accessed} + 1 \leq N_i^{capacity}$)) then
    admissible;
    $N_i^{new}$++;
    $N_i^{accessed}$++;
else
    reject;
end if
```

From Algorithm 1, to enhance the systemic benefit of a V2G network domain, we assume the processing capacity of the V2G network domain as a constraint and enable as many admissible new access requests as possible to reduce the SDP for migrating sessions while maintaining a low SBP for newly initiated sessions. To this end, Algorithm 1 is intended to obtain the defined $N_i^{admissible}$ and is solved as follows. Note that the performance loss resulting from dropping an ongoing session is more serious than that from blocking an attempt to initiate a new session; therefore, we assign higher admission priorities to migrating sessions than to newly initiated sessions.

Before stating specifically how Algorithm 1 calculates $N_i^{admissible}$, we must provide some definitions. First, we assume that $\vec{S} = \{S_1(t), S_2(t), ..., S_n(t)\}$ is the systemic state vector of all V2G network domains, where $S_i(t)$ is the number of sessions being served in the i-th V2G network domain at time t, and $S_i(t) \geq 0$ ($i = 1, 2, ..., n$, n is the number of V2G network domains in a federated-IoT-enabled V2G network environment, $t = 0, 1, 2, ...$). Here, $MS = \{ms_{ij}(t)\}_{n \times n}$ is a matrix of migrated sessions, and $ms_{ij}(t)$ ($0 \leq ms_{ij}(t) \leq 1$, $i, j = 1, 2, ..., n$, $t = 0, 1, 2, ...$) is the probability of a session migrating from the i-th V2G network domain to the j-th one, which can be calculated by the ratio of the number of migrated sessions to the total number of sessions served by the i-th V2G network domain. Note that data about migrated sessions, including their mobility and session characteristics, will be periodically collected by the CA deployed in each V2G network domain and used to generate the matrix MS at the current moment. The vector of terminated sessions is $\vec{TS} = \{ts_1(t), ts_2(t), ..., ts_n(t)\}$ in all V2G network domains at time t, where $ts_i(t)$ ($0 \leq ts_i(t) \leq 1$, $i = 1, 2, ..., n$, $t = 0, 1, 2, ...$) denotes the probability of a session being terminated in the i-th V2G network domain. That value can also be calculated using the ratio of the number of terminated sessions to the total number of sessions served by the i-th V2G network domain. The vector $\vec{N}_{admissible} = \{N_1(t), N_2(t), ..., N_n(t)\}$ represents the ideal number of newly initiated access requests admissible by all the V2G network domains at time t, and $N_i(t)$ ($N_i(t) \geq 0$) is the factor that determines whether new access requests are admitted.

Based on the above definitions, at time $t+\varepsilon$, the number of sessions being served in the i-th V2G network domain can be deduced using the Markov model as shown in Eq. (1):

$$S_i(t+\varepsilon) = S_i(t) - S_i(t) \cdot ts_i(t) - \sum_{\substack{j=1 \\ j\neq i}}^{n} ms_{ij}(t) \cdot S_i(t) + N_i(t) + \sum_{\substack{j=1 \\ j\neq i}}^{n} ms_{ji}(t) \cdot S_j(t). \tag{1}$$

For convenience, we assume that $\sum\limits_{\substack{j=1 \\ j\neq i}}^{n} ms_{ij}(t) + ts_i(t) = 1$; therefore, Eq.(1) can be simplified to Eq. (2):

$$S_i(t+\varepsilon) = \sum_{\substack{j=1 \\ j\neq i}}^{n} ms_{ji}(t) \cdot S_j(t) + N_i(t). \tag{2}$$

Given the system's state $\vec{S}$ at time t, if an $\vec{N}_{admissible}$ obtained according to MS could enable the systemic state at time $t+\varepsilon$ to approach the near-ideal one represented by $\vec{S^*}$, that is the final $\vec{N}_{admissible}$ we expect. When the near-ideal state $\vec{S^*}$ is obtained, the left side of Eq. (2) can be replaced by $\vec{S^*}$, and sequentially, $\vec{N}_{admissible}$ could be obtained as in Eq. (3).

$$\vec{N}_{admissible} = \vec{S^*} - \vec{S} \cdot MS. \tag{3}$$

Because the number of served sessions has a positive impact on the overall benefit of a V2G network domain, in the near-ideal state $\vec{S^*}$, the number of admissible sessions must be maximized within the aforementioned capacity limit. Accordingly, as shown in (4), we can deduce a formula to solve $\vec{S^*}$. Where $\vec{S^*} \geq \vec{S} \cdot MS$ is configured in terms of Eq. (3) to ensure $\vec{N}_{admissible} \geq 0$ in the near-ideal system state, $0 \leq {S_i}^* \leq N_i^{capacity}$ is introduced to constrain the number of served sessions to fewer than the capacity limit, and $p({S_i}^*) \leq p_i^{overload}$ is introduced to constrain the current overload probability represented by $p({S_i}^*)$ to a value no greater than the threshold $p_i^{overload}$.

$$\begin{aligned} & max \sum_{i=1}^{n} {S_i}^* \\ & \text{s.t.} \quad 0 \leq {S_i}^* \leq N_i^{capacity} \\ & \qquad \vec{S^*} \geq \vec{S} \cdot MS \\ & \qquad p({S_i}^*) \leq p_i^{overload}. \end{aligned} \tag{4}$$

As shown in (4), to solve $\vec{S^*}$, $p({S_i}^*)$ must first be determined. Here, we partially refer to the method proposed in [30]. For the i-th V2G network domain, we assume that there are ${S_i}^*$ served sessions at time t and that the arrival rate of newly initiated access requests follows a Poisson distribution with parameter λ_i and is represented by $p(N_i^{arrival} = k) = (\lambda_i^k / k!) \cdot e^{-\lambda_i}$. Additionally, at the end of time t, for each V2G network domain, the served sessions attached to the original V2G network domain but migrating to another V2G network domain all are independent events, and their properties correspond to a binomial distribution. Therefore, we assume that, following a binomial distribution, as shown in Eq. (5), the probability of served sessions attached to the i-th V2G network domain is represented by $B(d_i, {S_i}^*, ms_{ii}(t))$, where $d_i = {S_i}^* \cdot ms_{ii}(t)$ is the number of attached served sessions. Similarly, the probability of sessions served by the i-th V2G network domain migrating to the j-th ($j \neq i$) V2G network domain is represented by $B(m_i, {S_i}^*, ms_{ij}(t))$, where $m_i = {S_i}^* \cdot ms_{ij}(t)$, and the probability of sessions served by the j-th V2G network domain migrating to the i-th V2G network domain is represented by $B(m_j, {S_j}^*, ms_{ji}(t))$, where $m_j = {S_j}^* \cdot ms_{ji}(t)$. Accordingly, at the end of time t, there will be $N_i^{served} = d_i + k + \sum_{j=1, j\neq i}^{n} m_j$ sessions served by the i-th V2G network domain, and the probability distribution of the number of served sessions, denoted as $p(N_i^{served})$, can be represented by the convolution summation of $B(d_i, {S_i}^*, ms_{ii}(t))$, $p(N_i^{arrival} = k)$ and all $B(m_j, {S_j}^*, ms_{ji}(t))$. According to the $central - limit\ theorem$, it is acceptable that $p(N_i^{served})$ can be further approximated by the normal distribution as shown in (6).

$$B(d_i, {S_i}^*, ms_{ii}(t)) = C_{{S_i}^*}^{d_i} \cdot ms_{ii}(t)^{d_i} \cdot (1 - ms_{ii}(t))^{{S_i}^* - d_i} \tag{5}$$

$$p(N_i^{served}) \sim N\left(d_i + k + \sum_{j=1, j\neq i}^{n} m_j, \sqrt{d_i \cdot (1 - ms_{ii}(t)) + k + \sum_{j=1, j\neq i}^{n} m_j \cdot (1 - ms_{ji}(t))}\right) \tag{6}$$

$$\begin{aligned} p({S_i}^*) &= \prod_{N_i^{served} = N_i^{capacity}+1}^{\infty} P(N_i^{served}) = 1 - \prod_{N_i^{served}=0}^{N_i^{capacity}} P(N_i^{served}) \\ &= 1 - \Phi\left(\frac{\left(N_i^{capacity} - (d_i + k + \sum_{j=1, j\neq i}^{n} m_j)\right)}{\sqrt{d_i \cdot (1 - ms_{ii}(t)) + k + \sum_{j=1, j\neq i}^{n} m_j \cdot (1 - ms_{ji}(t))}}\right) \end{aligned} \tag{7}$$

$$\begin{aligned} & p({S_i}^*) \leq p_i^{overload} \quad \Leftrightarrow \quad p({S_i}^*) - p_i^{overload} \leq 0 \\ \Leftrightarrow \quad & 1 - \Phi\left(\frac{\left(N_i^{capacity} - (d_i + k + \sum_{j=1, j\neq i}^{n} m_j)\right)}{\sqrt{d_i \cdot (1 - ms_{ii}(t)) + k + \sum_{j=1, j\neq i}^{n} m_j \cdot (1 - ms_{ji}(t))}}\right) - (1 - \Phi(\beta_i)) \\ \Leftrightarrow \quad & \Phi(\beta_i) - \Phi\left(\frac{\left(N_i^{capacity} - (d_i + k + \sum_{j=1, j\neq i}^{n} m_j)\right)}{\sqrt{d_i \cdot (1 - ms_{ii}(t)) + k + \sum_{j=1, j\neq i}^{n} m_j \cdot (1 - ms_{ji}(t))}}\right) \\ \Leftrightarrow \quad & \beta_i \cdot \sqrt{d_i \cdot (1 - ms_{ii}(t)) + k + \sum_{j=1, j\neq i}^{n} m_j \cdot (1 - ms_{ji}(t))} + \left(d_i + k + \sum_{j=1, j\neq i}^{n} m_j\right) - N_i^{capacity} \leq 0 \end{aligned} \tag{8}$$

Accordingly, the current overload probability of the i-th V2G network domain can be defined in Eq. (7), and it is further defined according to $Laplace's\ theorem$, where $\Phi(x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} e^{-t^2/2} dt$. Note that, without loss of generality, for the i-th V2G network domain, there will be only one given threshold $p_i^{overload}$ and $\exists \beta_i$, $p_i^{overload} = 1 - \Phi(\beta_i)$. Hence, as shown in (8), the configured constraint of $p({S_i}^*) \leq p_i^{overload}$ can be represented in another way.

Now, based on the finally defined $p({S_i}^*)$, we can further obtain $\vec{S^*}$ by solving (4) and, finally, obtain the $\vec{N}_{admissible}$ through Eq. (3). By introducing the Metropolis rule of simulated annealing algorithm into the particle swarm algorithm (SA-PSO), we can use the SA-PSO (which was developed in our previous work [31]) to solve the optimization problem defined in (4). The specific implementation of the SA-PSO is available in [31]. For each V2G network domain, the elements in $\vec{N}_{admissible}$ are used as the basis for determining whether to admit a newly initiated access request at the current moment. As a reminder, after updating the MS in the next moment, the corresponding $\vec{N}_{admissible}$ must be recalculated to satisfy the new requirements of mobility and session triggered by the EVs and to maximize the entire systemic benefit under the constraints of capacity and overload probability.

3.2. Authentication Model

Based on this developed capacity-based active access admission control scheme, to maintain access security and conditional privacy in V2G networks when a new access request is admissible, a high-level authentication model is developed as shown in Fig. 1. In practice, in a federated-IoT-enabled V2G network environment, the certified EVs may consist of multiple groups with corresponding group attributes [32]. Specifically, the number of certified EVs in each group may be different, but these grouped EVs with distinctive (or identical) session characteristics are likely to have correlated mobility. To collectively provide access authentication for EVs in the same group, the existing authentication mechanisms (e.g., one-to-one authentication) have been shown to not only fail to fully use the group characteristics but also to cause significant system overhead and large (even unacceptable) authentication delay. Therefore, a secure and efficient group-based authentication mechanism must be employed in the developed authentication model.

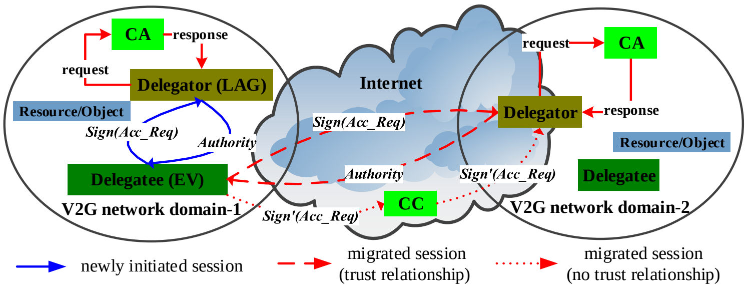


Figure 1: A high-level authentication model in a federated-IoT-enabled V2G network environment.

As shown in Fig. 1, a $Delegator(LAG)$ is a delegation decision-making entity and a $Delegatee(EV)$ is a delegation requestor entity. In the implementation of authority delegation for a newly initiated access request of EV, an access request from a $Delegatee$ located in its default V2G network domain will be signed using a specific group-based signature scheme, e.g., a forward secure revocable group signature (FSR-GS), and forwarded directly to the default $Delegator$. Upon receiving the access request, the $Delegator$ will validate the signature and evaluate the access request based on the combination of available rules and polices provided by the CA to determine whether to grant some or all of its authority to the $Delegatee$. If the verification result is positive, a corresponding response with the requested authority would be returned to the $Delegatee$; otherwise, an error message or a rejection decision would be returned.

In contrast, in the implementation of authority delegation for a migrating EV session, we will consider two different scenarios based on whether a trust relationship between the two relevant V2G network domains has been established. When a trust relationship between two V2G network domains has already been established through some mutual authentication scheme, the $Delegatee$ located in V2G network domain-1 would sign the access request using FSR-GS and forward it directly to the $Delegator$ in V2G network domain-2. Subsequently, the operations for authority delegation in this scenario would be the same as those performed for a newly initiated access request. When no prior trust relationship between the two V2G network domains exists, unlike the approach used for the first scenario, the signed access request would be forwarded to the $Delegator$ through the CC, which is the only entity trusted by all other entities. Detailed explanations for the implementations of considered authority delegation are provided below.

3.3. Authentication Procedures

As stated above, FSR-GS will be employed as an important means for signing the access request in this work; therefore, we first review the definition of FSR-GS. As described in [33, 34], an FSR-GS is composed of several important probabilistic polynomial-time algorithms and an interactive mechanism, and it can be represented by a six-tuple $(G.Kg, G.Enroll, G.Revoke, G.Sign, G.Ver, G.Open)$. The concrete definitions and implementations of these tuples can be found in [33, 34]. Additionally, the entities participating in FSR-GS include a group manager, a group member and a verifier. For the considered scenarios of authority delegation in this work, the CC acts as the global group manager, and the CA in each V2G network domain acts as a local group manager; the former has a global master key pair (mPK_{CC}, mSK_{CC}), and the latter has a local master key pair (mPK_{CA}, mSK_{CA}). The certified LAGs in each V2G network act as verifiers or $Delegators$. The two types of group mangers and each LAG have signing and verification key pairs, respectively, represented by (PK_{CC}, SK_{CC}), (PK_{CA}, SK_{CA}) and (PK_{LAG}, SK_{LAG}) and generated by a conventional digital signature scheme (e.g., the Elliptic Curve Digital Signature Algorithm (ECDSA)). Correspondingly, using $G.Kg$, the generated initial information of the group members (also called "signers") managed by the global group manager and local group manager are represented by $\Omega_{CC} = (c_g, \mu_g)$ and $\Omega_{CA} = (c_l, \mu_l)$, respectively, where c_g and c_l are initialized to 'g_1' and μ_g and μ_l are initialized to '1.'

During the setup phase of the federated-IoT-enabled V2G network environment, the CC announces its global master public key mPK_{CC} to all its group members, including the certified CAs, LAGs and EVs, and the CA in each V2G network domain announces its local master public key mPK_{CA} to all its group members, including the certified LAGs and EVs. In each V2G network domain, the ID_{CA} and PK_{CA} of the CA and the ID_{LAG} and PK_{LAG} of each LAG are publicly known to all the authorized accessors and to the EVs and CA in the other V2G network domains using an already established trust relationship. Additionally, each LAG shares a session key $Shared\_Key(sess.)$ with its managing CA.

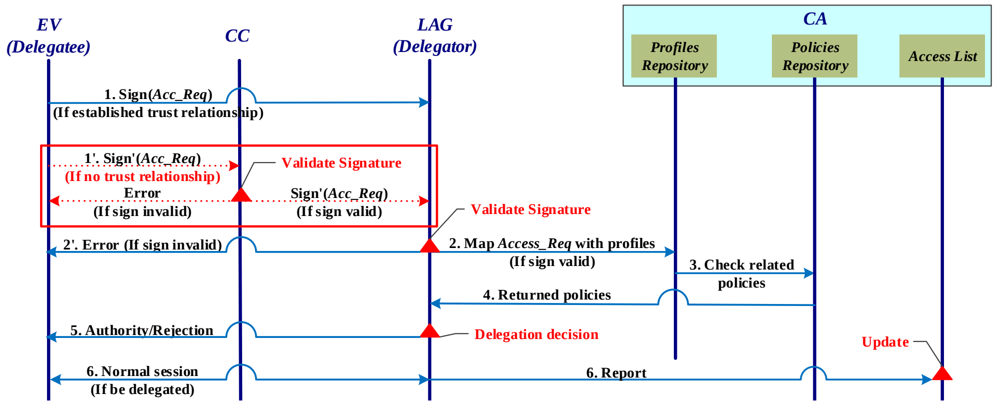


Figure 2: The overall framework for implementing considered authority authentication.

During the authentication phase of a new access request, the three scenarios, namely, i) authentication for a newly initiated access request, ii) authentication for a migrated session with established trust relationship, and iii) authentication for a migrated session without established trust relationship, will be discussed separately. The overall framework for implementing considered authority authentication is shown in Fig. 2.

i) When $Delegatee(i)$ makes a new access request, it must authenticate itself to the default CA through a direct interaction. The default CA will execute $G.Enroll$ to generate a signing key, $Key_i(sig.)$, a (public) membership key, $Key_i(mem.)$, and a revocation key, $Key_i(rev.)$, for $Delegatee(i)$. All these generated keys and PK_{CA} are sent to $Delegatee(i)$ using a secure transmission protocol. Upon receiving this required knowledge, $Delegatee(i)$ first chooses a random number ξ and a temporary identity $alias(VID)$ and then generates a group signature σ_i as shown in Eq. (9), where T is a timestamp added to defend against $replay$ attacks, VID is defined as a tetrad $(ID, Profile, Context, Policy)$, ID is the unique identifier of the $Delegatee(i)$, $Profile$ refers to the $Delegatee(i)$'s profile (e.g., attributes and personal information), $Context$ refers to the security contexts (e.g., trust level and authentication level) and other context considerations (e.g., battery status, working mode), and $Policy$ is a set of policies associated with $Delegatee(i)$'s preferences or access permissions. Subsequently, by using the public key PK_{LAG} of the default LAG, $Delegatee(i)$ encrypts the message $\{alias(VID), g^{\xi}, \sigma_i, T\}$ to produce an access request $AR_i = (alias(VID), g^{\xi}, \sigma_i, T)_{PK_{LAG}}$ and sends AR_i to the default LAG.

ii) When $Delegatee(i)$ needs to migrate a session and the trust relationship between the two relevant V2G network domains has already been established, $Delegatee(i)$ generates a group signature σ_i, as shown in Eq. (9), using the necessary knowledge provided by the target CA from the other V2G network domain, and subsequently produces an access request $AR_i = (alias(VID), g^{\xi}, \sigma_i, T)_{PK_{LAG}}$ using the target LAG's public key PK_{LAG}. Then, it sends AR_i to the target LAG.

$$\sigma_i = G.Sign(mPK_{CA}, Key_i(sig.), Key_i(mem.), Key_i(rev.), \Omega_{CA}, alias(VID) \| g^{\xi} \| T) \tag{9}$$

iii) When $Delegatee(i)$ needs to migrate a session and no trust relationship between the two relevant V2G network domains exists, $Delegatee(i)$ must authenticate itself to the CC by a direct interaction. The CC will execute $G.Enroll$ to generate $Key'_i(sig.)$, $Key'_i(mem.)$ and $Key'_i(rev.)$ for $Delegatee(i)$. All these generated keys and PK_{CC} are then sent to $Delegatee(i)$ using a secure transmission protocol. Upon receiving this required knowledge, $Delegatee(i)$ first chooses a random number ξ and a temporary identity, $alias(VID)$ and then generates a group signature, σ_i, as shown in Eq. (10). Subsequently, by using the CC's master public key, mPK_{CC}, $Delegatee(i)$ encrypts the message $\{alias(VID), g^{\xi}, \sigma_i, T\}$ to produce an access request $AR_i = (alias(VID), g^{\xi}, \sigma_i, T)_{mPK_{CC}}$ and sends AR_i to the CC. Upon receiving the request AR_i, the CC uses its master private key mSK_{CC} to decrypt the request to obtain the secret message $\{alias(VID), g^{\xi}\sigma_i, T\}$ and executes $G.Ver$ to check the validity of the group signature σ_i. If the message is invalid, the CC rejects the access request; otherwise, the CC uses the target LAG's public key PK_{LAG} to re-encrypt the message $\{alias(VID), g^{\xi}, \sigma_i, T\}$, producing a new access request $AR'_i = (alias(VID), g^{\xi}, \sigma_i, T)_{PK_{LAG}}$. Finally, it sends AR'_i to the target LAG.

$$\sigma_i = G.Sign(mPK_{CC}, Key'_i(sig.), Key'_i(mem.), Key'_i(rev.), \Omega_{CC}, alias(VID) \| g^{\xi} \| T) \tag{10}$$

Upon receiving AR_i or AR'_i, the default/target LAG first decrypts the message using its private key SK_{LAG} to obtain the secret message $\{alias(VID), g^{\xi}, \sigma_i, T\}$. Then, it checks to ensure that the time-stamp T falls within the allowable time-scope by comparing it with the current time. When T is legitimate, it executes $G.Ver$ to check the validity of the group signature σ_i. If the validation fails, the LAG replies with an error message rejecting the access request, either directly to $Delegatee(i)$ or through the CC; otherwise, upon validation success, the LAG sends the message $\{alias(VID), g^{\xi}, \sigma_i, T\}$, encrypted by the defined shared session key $Shared\_Key(sess.)$, to the managing CA. After receiving the message, the CA obtains the identity of AR_i by executing $G.Open$, which indicates that the CA can provide conditional privacy. Then, it invokes the deployed $Profiles\ Repository$ to map the profiles of $Delegatee(i)$ with VID. The mapped profiles of VID, together with the $Context$, are then sent to the $Policies\ Repository$ to obtain the relevant disclosed policies, which are, finally, sent back to the LAG. After receiving the relevant policies, the LAG will combine them and decide whether to approve the authority authentication. When the decision is positive, the LAG chooses another random number ξ', generates $\lambda' = ECDSA.Sign(SK_{LAG}, alias(VID) \| g^{\xi} \| g^{\xi'})$ and then sends a message $\{g^{\xi'}, \lambda'\}$ to $Delegatee(i)$ while, in parallel, it computes a session key, $Key(sess.) = (g^{\xi})^{\xi'}$. Subsequently, it erases ξ' from its memory; otherwise, the access request would be rejected.

Upon receiving the message $\{g^{\xi'}, \lambda'\}$, $Delegatee(i)$ will execute $ECDSA.Ver(PK_{LAG}, alias(VID) \| g^{\xi} \| g^{\xi'}, \lambda')$ to verify the validity of λ'. If the result is '1', $Delegatee(i)$ generates another session key $Key'(sess.) = (g^{\xi'})^{\xi}$

corresponding to $Key(sess.)$ and erases ξ from its memory. Subsequently, $Delegatee(i)$ will produce a session $S_i = (alias(VID)\|g^{\xi}\|g^{\xi'})_{Key'(sess.)}$ through symmetric encryption, which is then sent to the LAG. Upon receiving the message, the LAG will decrypt it using $Key(sess.)$ and check its validity. If it is valid, the LAG concludes that $Delegatee(i)$ has established a session key and proceeds with a normal session; otherwise, the access request is rejected. Finally, when the access request is accepted, a report is sent to the CA to update the *Access List*. The membership information of the CA should be updated as $\Omega_{CA} = (c_l^{Key_i(mem.)}, \mu_l \cdot Key_i(mem.))$.

$$\Omega_{CA} = \left(c_l^{\left(\prod_{j=k}^{n} Key_j(rev.)\right)/Key_i(rev.)}, \mu_l \cdot \left(\prod_{j=k}^{n} Key_j(rev.)\right)/Key_i(rev.) \right) \tag{11}$$

3.4. Discussions of Session Revocation and Recovery

In a real world application, within a period of time after the delegation, the sessions of some EVs may expire or some EVs may want to suspend their session services for some amount of time according to plans made in advance.

For the former case, because the expiration time of the session for an accessed $Delegatee(i)$ is registered in the *Access List* of the serving CA, after the registered expiration time of $Delegatee(i)$ has elapsed, the assigned signing key $Key_i(sig.)$ is invalidated from then on. The serving CA should remove $Delegatee(i)$ and execute $G.Revoke(mPK_{CA}, Key_i(rev.), \Omega_{CA})$ to update the membership information. The updated membership information is denoted as $\Omega_{CA} = (c_l^{Key_i(rev.)}, \mu_l \cdot Key_i(rev.))$. Note that in *AccessAuth*, to ensure forward security for session revocation, the anonymity of the revoked session's protocol must be executed before the revocation such that eavesdroppers or adversaries cannot correlate the revoked session and derive previous or subsequent interrogations.

For the latter case, when $Delegatee(i)$ wishes to reactivate a suspended session, the registering CA is generally required to execute $G.Enroll$ to generate new keys (e.g., $Key_i'(sig.)$, $Key_i'(mem.)$ and $Key_i'(rev.)$) for $Delegatee(i)$ and then re-invoke the authentication procedure described above. Obviously, this approach imposes additional authentication overhead and greatly increases the authentication delay. To overcome the shortcomings of this inconvenient approach, *AccessAuth* still uses the previously assigned keys. We assume that, at the time when $Delegatee(i)$ wishes to reactivate its session service, the session represented by $\{S_k, ...S_n\}$ (the session for $Delegatee(i)$, $S_i \in \{S_k, ...S_n\}$) has been revoked, and the current membership information is represented by $\Omega_{CA} = \left(c_l^{\prod_{j=k}^{n} Key_j(rev.)}, \mu_l \cdot \prod_{j=k}^{n} Key_j(rev.) \right)$. Therefore, when $Delegatee(i)$ wishes to recover its session service, we need only update the membership information as shown in Eq. (11). In this way, $Delegatee(i)$ can automatically reactivate its previous session.

4. Performance-Security Trade-off

4.1. Proofs of Security & Privacy Requirements

This section analyzes *AccessAuth* with respect to the critical security and privacy preservation requirements listed in Section 2.

1) Mutual authentication, verification and their defense against attacks. Regardless of whether a trust relationship has been established between two relevant V2G networks, the authentication procedures in *AccessAuth* allow only a legitimate EV in the networks to generate a valid group signature based on the keys generated by $G.Enroll$ and the membership information Ω. Subsequently, authentication of the target LAG is achieved by responding with the message $\{g^{\xi'}, ECDSA.Sign(SK_{LAG}, VID\|g^{\xi}\|g^{\xi'})\}$. Using that message, the EV can determine the identity of the target LAG and proceed with a normal session. Therefore, *AccessAuth* satisfies the requirement of mutual authentication.

Additionally, during the setup phase of the federated-IoT-enabled V2G network environment, only the CA can generate valid certificates—including ID_{LAG} and PK_{LAG}—for the target LAG. Consequently, other LAGs or illegal entities cannot eavesdrop using different IDs and public keys. Therefore, we can conclude that $AccessAuth$ also satisfies the verification requirement.

Moreover, $AccessAuth$ can prevent various types of well-known security attacks. For example, the temporary identity *alias* introduced for EV and the generated shared secret authentication and session keys efficiently defeat *impersonation* and *repudiation* attacks. Similarly, because adversaries cannot decrypt encrypted messages with the private key owned only by the certified entity in the communication, $Man - In - The - Middle(MITM)$ attacks can also be defeated. Because the shared secret keys for ongoing sessions are different and are regenerated for newly initiated sessions, the well-known key attacks can also be prevented. Finally, the timestamp T added to the generated group signature during the authentication procedure can defeat *replay* and *injection* attacks, and because the CA maintains conditional privacy, the identity and location of an EV can be verified to resist *redirection* attacks.

2) Session key establishment. Session keys (e.g., $Key(sess.)$ and $Key'(sess.)$) generated by challenge-response $(g^{\xi}, g^{\xi'})$ are used as shared secret keys for each authority between the EV and LAG within the whole expiry period. Thus, data confidentiality and integrity in the sessions can be ensured.

3) Strong anonymity and untraceability of EVs. In the authentication procedures described for $AccessAuth$, the EV creates a temporary identity *alias*, and the FSR-GS is used to sign the access request with the *alias*. Thus, during an ongoing authentication and session, the EVs private information is effectively protected, even for revoked sessions. Because an EV will apply for the next session using a new $alias(VID)$, eavesdroppers or adversaries will be unable to correlate the sessions and derive previous or subsequent interrogations, as described in detail for FSR-GS in [33, 34].

4) Conditional privacy preservation. In an emergency, the identities and locations of EVs must be able to be interrogated. In the authentication procedures described for $AccessAuth$, only the CA can obtain this private information by executing $G.Open$, indicating that conditional privacy can be preserved.

5) Anonymity for CAs and the CC. In the authentication procedures described for $AccessAuth$, an access request triggered by an EV is encrypted by the PK_{LAG} of the target LAG. Only the target LAG can use its SK_{LAG} to decrypt and obtain either the secret message or the identity of the registering CA or CC; consequently, the identity of the registering CA or CC is hidden from all legal and illegal entities except the visited LAG. Thus, the anonymity of both the CAs and the CC can be guaranteed.

4.2. Performance Analysis and Evaluation

To numerically analyze and evaluate the performance of $AccessAuth$, we consider a federated-IoT-enabled V2G network environment including four V2G network domains. First, to evaluate the capacity-based active access admission control scheme, we conducted a simulation using the MATLAB 2012a platform. The relevant performance characteristics of the executing host were as follows: a 64-bit Windows 7 operating system and an Intel(R) Core(TM) i5-3450 CPU running at 3.10 GHz with 4 GB of RAM. In the simulations, the initial number of served sessions in each V2G network domains was set to 100, the capacity limit of each V2G network domain was set to $N_i^{capacity} = 200$ $(i = 1, 2, 3, 4)$, the time period ε was set to $\varepsilon = 60s$, and the session migration probability matrix during the time period was assumed to consist of three cases: Case 1: $MS = \begin{bmatrix} 0.6 & 0.15 & 0.05 & 0 \\ 0.15 & 0.6 & 0.15 & 0.05 \\ 0 & 0.15 & 0.65 & 0.15 \\ 0.05 & 0.15 & 0.6 & 0.15 \end{bmatrix}$; Case 2: $MS = \begin{bmatrix} 0.8 & 0.05 & 0.1 & 0 \\ 0.05 & 0.75 & 0.05 & 0.05 \\ 0 & 0.05 & 0.8 & 0.1 \\ 0.05 & 0.05 & 0.7 & 0.1 \end{bmatrix}$; and Case 3: $MS = \begin{bmatrix} 0.6 & 0.05 & 0.1 & 0 \\ 0.05 & 0.6 & 0.05 & 0.05 \\ 0.1 & 0.05 & 0.6 & 0.05 \\ 0 & 0.7 & 0.05 & 0.05 \end{bmatrix}$. The corresponding vectors of session termination probability during the time period were $\vec{TS} = \{0.2, 0.05, 0.05, 0.05\}$, $\vec{TS} = \{0.05, 0.1, 0.05, 0.1\}$ and $\vec{TS} = \{0.25, 0.25, 0.2, 0.2\}$, respectively. Note that the configurations for the three cases were chosen randomly, but the session migration probability and the session termination probability vary considerably across the different scenarios.

Fig. 3 shows the impact of overload probability on the average ideal number of admissible sessions in the V2G network environment. We can clearly see that the ideal number of admissible sessions gradually increases as the overload probability limit increases. Nevertheless, even when using the same overload probability limit for different cases of MS, the ideal number of admissible sessions will be different. Concretely, in Case 1, the average probability of session migration is greater; therefore, the ideal number of admissible sessions must be reduced to avoid migrated and newly initiated sessions arriving in great numbers in the V2G network, causing the overload probability to increase beyond the given limit. In Case 3, the average probability of session termination is greater, which means those session durations are relatively short. Therefore, the ideal number of admissible sessions can be increased—without negatively impacting the overload probability. In Case 2, because the average probabilities of session migration and termination fall between the preceding two cases, the ideal number of admissible sessions at the same overload probability limit lies in the middle as well.

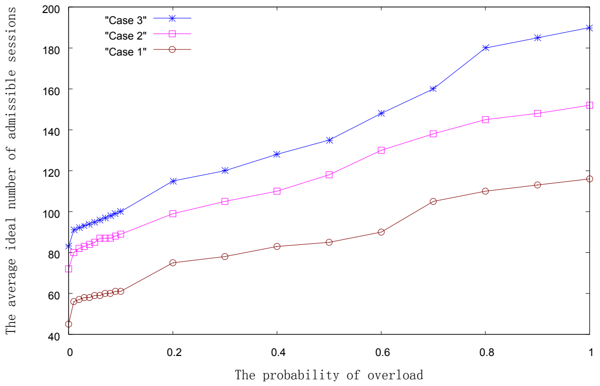
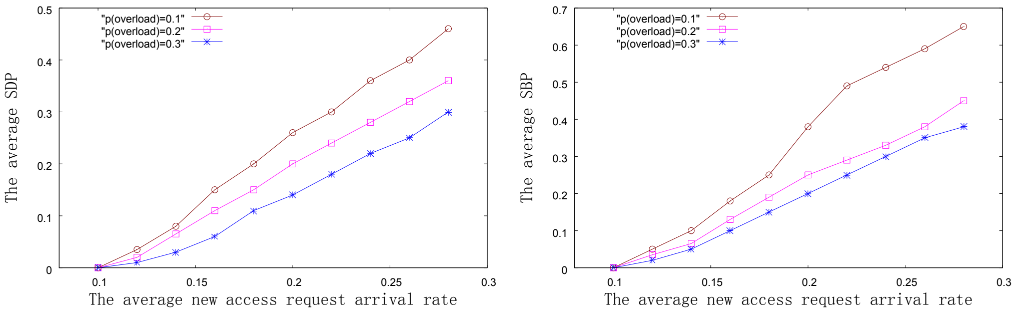


Figure 3: The impact of overload probability on the average ideal number of admissible sessions in the V2G network environment.



(a) The impact on average SDP

(b) The impact on average SBP

Figure 4: The impact of overload probability on average SDP and SBP in the V2G network environment.

Using Case 2 (the intermediate-level performance case) as an example, but with a different average new access request arrival rate, Fig. 4 shows the impact of overload probability on the average migrated session-dropping probability (SDP) and average newly initiated session-blocking probability (SBP) by the averaged results over 500 time periods of ε. When the overload probability limit is fixed, when the average new access request arrival rate increases, both the average SDP and average SBP gradually increase because of the limited number of admissible new access requests. However, as the overload probability limit increases, the ideal number of admissible newly initiated access requests, $N_i^{admissible}$, computed by Eq. (3) will also increase. Consequently, the number of admissible new access requests in the V2G network environment will increase as well. Thus, the average SDP and average SBP are gradually reduced. Note that the performance penalty for dropping an ongoing session is more serious than that for blocking a newly initiated session; therefore, higher admission priorities are assigned to migrated sessions than to newly initiated sessions, and the reduction in average SDP is greater.

Using Case 2 as an example with the same configuration as in the former experiment and a fixed overload probability $p(overload) = 0.2$, Fig. 5 shows the performance of system utilization in terms of the average number of sessions served in the created federated-IoT-enabled V2G network environment. The NOA-GM that we proposed in [35] and the method proposed in [36] were selected for comparison. The method in [36] was developed based on MIR (Mobile IP Reservation Protocol), in which, if the network load is lower than a pre-defined threshold, both migrated sessions and newly initiated access requests are admissible; otherwise, newly initiated access requests would be blocked. The NOA-GM first periodically evaluates the load status of the access networks using the proposed dynamic weighted load evaluation algorithm to identify candidate underloaded access networks. Then, it achieves the optimal results by evaluating the candidates using normalized models of objective and subjective metrics. From Fig. 5, in the proposed method, as the average new access request arrival rate increases, the average number of served sessions in the proposed work experiences a steady increase based on the previously demonstrated performance concerning the average ideal number of admissible sessions, the average SDP, and the average SBP. In the NOA-GM and the method in [36], when the average new access request arrival rate is relatively low, the average SBP and SDP in some time periods of ε may be low due to the fixed pre-defined threshold; therefore, the average number of served sessions gradually increases. However, as the average new access request arrival rate increases, the average SBP and SDP may be high due to the fixed pre-defined threshold, which adversely affects the average number of served sessions.

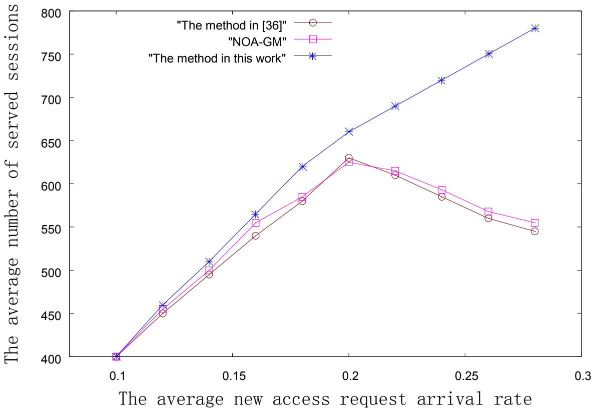


Figure 5: The performance of system utilization.

In addition, the performance of the authentication procedure of *AccessAuth* is analyzed and evaluated using two performance metrics: computational load and communication overhead. The scheme proposed in [19], the scheme named P^2 in [23], and the scheme in [28] are selected for comparisons. To achieve fair comparisons, all the compared schemes use the same experiment configuration. Concretely, the relevant performance parameters of entities involved in the V2G network environment, e.g., EV, LAG, CA and CC, are shown in Table 1, and the time costs of the primitive cryptographic operations conducted on these entities (obtained by the *OpenSSL* library) are shown in Table 2. For the sake of convenience, the time costs of highly efficient operations such as hash functions, symmetric encryption/decryption, Auth.code (HMAC), and point addition are omitted because their contributions to the overall computational load are insignificant. In this comparison, n EVs simultaneously trigger access requests (in 40% of these triggered access requests, no prior trust relationship exists between the relevant V2G network domains). Comparisons of the computational loads and the communications overhead are shown in Table 3 and Table 4, respectively.

In Table 3, T_{EV}, T_{LAG}, T_{CA} and T_{CC} represent the computational load on a EV, LAG, CA and the CC, respectively. As Table 3 shows, when using *AccessAuth*, if a trust relationship exists between the

Table 1: The relevant performance parameters of involved entities.

Entity	CPU	RAM	OS
EV	Qualcomm(R) Octa-core 1.5 GHz	2 GB	Android 4.2.2
LAG	Intel(R) Dual-core 3.1 GHz	4 GB	64-bit Win-7
CA	Intel(R) Hexa-core 1.6 GHz	16 GB	Win server 2012
CC	Intel(R) Hexa-core 1.6 GHz	16 GB	Win server 2012

Table 2: The time costs of the involved primitive cryptographic operations.

Entity	T_{SM} (ms)	T_{IO} (ms)	T_{EO} (ms)	T_{PO} (ms)
EV	0.54	0.33	0.5	16.6
LAG	0.36	0.33	0.38	11.5
CA	0.3	0.26	0.31	8.6
CC	0.3	0.26	0.31	8.6

T_{SM}: the time for a scalar multiplication operation;
T_{IO}: the time for an inverse operation;
T_{EO}: the time for a exponentiation operation;
T_{PO}: the time for a pairing operation;

relevant V2G network domains, the primitive cryptographic operations for a successful access authentication are conducted on the entities EV, LAG and CA; otherwise, a successful access authentication requires additional cryptographic operations on the CC. Overall, pairing operations are required in the compared schemes; however, $AccessAuth$ instead takes greater advantage of scalar multiplication operations, which are much more efficient than pairing operations and result in much less computational load. Therefore, $AccessAuth$ is more efficient than the compared schemes.

With respect to the communication overhead, a CA deployed in a V2G network domain is generally remotely connected with various LAGs; thus, we treat the communication overhead for transmitting an authentication message between a LAG and the CA as one unit and use it as a reference and criterion. The communication overhead between an EV and a LAG is assumed to be η $(0 < \eta < 1)$. Similarly, because the CC is often located in a remote location in a V2G network environment, the communication overhead between the CC and a EV or a LAG can also be treated as one unit. In $AccessAuth$, when no prior trust relationship exists between relevant V2G network domains, the signed access request will be forwarded through the CC, which causes the total communication overhead to be $\eta + 5$ for a successful authentication; otherwise, the authentication request will be forwarded directly to the LAG, and a successful authentication requires a total communication overhead of $2\eta + 3$. Overall, as shown in Table 4, $AccessAuth$ outperforms the compared schemes with respect to communication overhead. Because it achieves both computation and communication efficiency, $AccessAuth$ has a more acceptable authentication delay; therefore, it is more suitable for practical application requirements.

Table 3: Comparisons of computational load.

Schemes	Computational load (ms)
scheme in [19]	$n \times (T_{EV} + T_{LAG} + T_{CA})$=$n \times ((T_{PO} + 3T_{EO}) + (T_{PO} + 5T_{EO} + 6T_{SM}) + (3T_{EO} + 2T_{SM}))$=$n \times 35.19$
P^2 in [23]	$n \times (T_{EV} + T_{LAG} + T_{CA})$=$n \times ((4T_{PO} + 9T_{EO} + 10T_{SM}) + (6T_{PO} + 6T_{EO} + T_{SM}) + (4T_{EO} + 5T_{SM}))$=$n \times 183.84$
scheme in [28]	$n \times (T_{EV} + T_{LAG} + T_{CA})$=$n \times ((4T_{PO} + 9T_{EO} + 8T_{SM}) + (6T_{PO} + 2T_{EO} + T_{SM}) + (4T_{EO} + 3T_{SM}))$=$n \times 180.64$
$AccessAuth$	$0.4 \times n \times (T_{EV} + T_{CC} + T_{LAG} + T_{CA}) + 0.6 \times n \times (T_{EV} + T_{LAG} + T_{CA})$=$0.4 \times n \times ((3T_{SM} + 8T_{EO} + T_{IO})$ $+(T_{SM}) + (T_{IO} + 18T_{SM}) + (3T_{EO}))$+$0.6 \times n \times ((3T_{SM} + 8T_{EO} + T_{IO}) + (T_{IO} + 18T_{SM}) + (3T_{EO}))$=$n \times 13.81$

Table 4: Comparisons of communication overhead.

Schemes	Communication overhead
scheme in [19]	$n \times (6\eta + 4)$
P^2 in [23]	$n \times (3\eta + 4)$
scheme in [28]	$n \times (4\eta + 5)$
AccessAuth	$0.4 \times n \times (\eta + 5) + 0.6 \times n \times (2\eta + 3)$

5. Conclusion

This paper addresses the security and privacy requirements for access authentication in a federated-IoT-enabled V2G network environment and proposes *AccessAuth* as a lightweight protocol for capacity-based security access authentication. The implemented capacity-based active access admission control scheme in *AccessAuth* was demonstrated to efficiently reduce the SDP for migrated sessions while maintaining a low SBP for newly initiated access requests. Moreover, the designed authentication model, which includes specific authentication procedures that consider whether prior trust relationships exist between the relevant V2G network domains, was shown to efficiently satisfy the critical security and privacy preservation requirements. Finally, analytical and evaluation results were used to demonstrate the performance of *AccessAuth* with regard to computational load and communication overhead. The results indicate that *AccessAuth* is more suitable for practical applications requirements than are previous approaches.

In the future, we plan to implement this protocol as middleware architecture in a federated-IoT-enabled V2G network environment to enhance its operating efficiency. Additionally, continuously improving this protocol to cope with emerging security and privacy concerns and some other open issues are directions we hope to explore further in future work.

Acknowledgments

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