

Delegated Anonymous Credentials with Revocation Capability for IoT Service Chains

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Abstract—The abstract goes here.

Index Terms—

I. INTRODUCTION

Internet of Things (IoT) enables physical objects also called *Things* to communicate with each other and to their human operators. This opens up a myriad of use cases such as smart homes, smart factories, smart cities, smart healthcare, smart grids etc [1]. It is also expected that such connected devices could reach upto 50 billion by 2020 [2]. The IoT devices (for example, a smart bulb or a temperature sensor) are very constrained in terms of memory, processing power, storage and most often are battery powered. Unlike the traditional computers these devices cannot perform computationally intensive tasks and are intended for minor operations of sensing and actuation. Also most of these devices are out in the open without any physical supervision making them easily susceptible to physical attacks.

Owing to the resource constraints and physical openness, IoT devices have been targets of various attacks [3] at physical, network and application layer. IoT devices also collect lot of personal information like user's location, eating habits, medical history etc because of which there has been a growing concern among consumers of such services. Unlike normal computers, these devices cannot provide an interface where the user can look up what personal information is being shared and with whom. In [4] the authors define privacy in IoT as a guarantee for the subject

- To be aware of the privacy risks imposed by smart things.
- Control over collection and processing of personal information
- Control over subject's personal information being disseminated outside of his control sphere.

They then categorize privacy threats and challenges of IoT into a) Identification b) Localization and tracking c) Profiling d) Privacy-violating interaction and presentation e) Inventory and life cycle tracking and f) linkage.

IoT services do not act in silos. They interact with each other and with external entities to provide a complete package of services to the user. For example, in Home Automation, based on the user who is entering the house (say Owner

vs Guest), a completely different set of services may get invoked. The service interactions and invocations depend on the roles and capabilities of the user invoking them. We call the sequence of services that get invoked as *IoT Service Chain*. In this paper we look at providing security and privacy to users and IoT devices that invoke IoT service chains. The rest of the paper is organized as follows. Section 2..... Section 3... Section 4..

II. MOTIVATION AND RELATED WORK

1) *IoT Service Chains*: We introduced *IoT Service Chains* in section I to refer to the chain of services invoked when an event occurs. Individual services in the chain interact with each other, on-behalf of the initiator towards a common goal. Initiator could either be a human or an IoT device. Each service in the chain would in-turn validate the user/IoT device's credentials for the desired service functionality. IoT devices can either act on behalf of their operator or can be independent of it. For example, if a smart Heart Monitoring System (HMS) detects a low pulse rate for a patient, it immediately needs to initiate the Advanced Cardiac Life Support (ACLS) by injecting an IV of an antidote, reading and interpreting the ECG, starting CPR, inform the doctor etc. The HMS in this case acts as an independent device and does not impersonate the patient. But in case of a smart fridge, which keeps track of the stock of milk, it automatically places an order for replenishment by using the owners credit card details. In this case, the smart fridge acts on behalf of the owner.

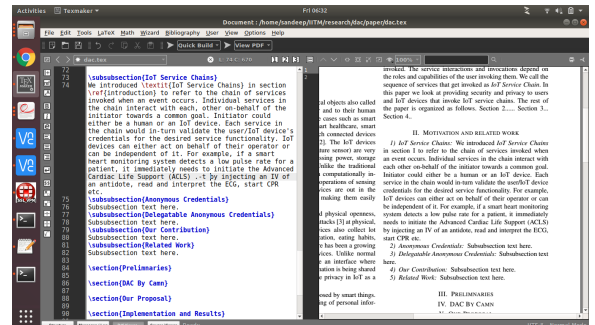


Fig. 1. IoT Service Chain

As can be seen in Fig. 1 there are 5 services in the IoT service chain. xxx explanation of HMS, ACLS etc interactions among services, authentication etc

One thing to notice from the above figure is that while the service chain is being invoked, the user/IoT device has to be online so that it supplies the necessary credentials for authentication and authorization. This isn't a huge problem if the initiating entity is a user (having a smart phone or a tablet). But for a constrained IoT device generating authentication and authorization information for each service in the chain would result in draining of its resources very quickly. Also, most of the IoT devices are duty cycled and may not remain active till the chain completes. This again results in loss of packets or in retransmission. It will be even more challenging if the user/device's privacy needs to be protected through out the chain. In this paper we focus on some of the options on how device privacy can be ensured when invoking the service chain without pushing the device to its resource limits.

2) *Attribute Based Anonymous Credentials*: In traditional credential based system, a central authority grants credentials to users and systems. These credentials can be password or token (certificate) based. When the user wants to access a resource he presents the credential to it which inturn validates the credential. The resource (also called service) trusts the central authority and thereby the credentials issued by it. Once the credential verification is done, the service checks whether the user has got the right access level to access the resource. One of the primary concern with such a system is that the service gets to know the complete details of the user presenting the credential. for example, in public key certificates issued to users, the service will know how long the credential (certificate in this case) is valid, the country, state, organization, email address etc of the user, who are all the intermediate chain of issuers etc. The only information that matters to the service is whether the certificate is valid and is issued by the central authority and whether the user possesses the required access right. But in this case lot more user details are available to it. With so much personal information available to the service, there is always a chance of misuse of data if it falls in wrong hands. According to European Union General Data Protection Regulation (GDPR) Data Minimization principle, entities should only process adequate, relevent and limited personal data that is necessary in relation to the purposes for thish they are processed. As mentioned in [4], the privacy problem becomes manifold in IoT world. One, because there are huge number of constrained IoT devices without proper security measures in place. And two, there is very little control over what personal information is disseminated from these devices to the outside world.

Anonymous Credentials introduced in [5] provide a way in which the user can prove that he holds a credential without revealing any information about the user. The verifier cannot also forge the user's credential. In Attribute Based Anonymous Credentials, the user can selectively prove that he holds the set of attributes needed by the verifier and not reveal all of his attributes, thereby maintaining privacy. The prover creates a zero-knowledge proof of possession of the credential which the verifier verifies using the public key of the central authority.

Some of the most popular Anonymous Credential Systems (ACS) are [6] and [7].

A Delegatable Anonymus Credential (DAC) System, introduced in [8] not only allows the users to generate anonymous credentials, but also allows them to anonymously delegate their credentials to other entities. For example, in a hierarchical setup, the root issuer may delegate its issuing authority to region wise issuers who in turn may delegate to division wise issuers and so on. Although there can be multiple levels of delegation, the anonymous credential generated by the prover at any level can only be verified by the public key of the root issuer. One of the primary advantages of DAC is that it alleviates the burden on the root issuer to issue credentials but still maintains anonymity of all the issuers in the chain.

3) *Our Contribution*: In section II-1 we talked about IoT service chains and the difficulty of ensuring user/IoT device's privacy during the chain propagation. We address this problem with our proposal on *Delegated Anonymous Credentials in IoT Service Chains*. We describe a mechanism in which the IoT device can delegate its credentials to a controller which in turn generates an anonymous credential based on the attributes needed by the service. Our scheme is based on the DAC system developed by Camenisch *et al.* [9]. The authors developed a scheme where credentials are not delegated anonymously but the prover anonymously proves that the entire chain of delegation is valid. The verifier verifies the anonymous credential just with the root issuer's public key.

The following are major contributions in this work.

- a) Discuss in detail the problem of ensuring privacy to users and IoT devices in IoT service chains.
- b) Implementation of the DAC scheme outlined in [9]. We used the Pairing Based Cryptography Library from [10] for the implementation. We implemented the full L-level credential Delegation, Presentation and Verification.
- c) Credential revocation has been mentioned as "future work" in [9]. We implemented revocation of credentials in our scheme.
- d) Once the verifier verifies the anonymous credential token, the next logical step would be to communicate with the prover to exchange data. In order to do that securely, a common session key needs to be established between the two parties. We demonstrate how the session key can be established.
- e) We then used the above DAC implementation to realize Delegated Anonymous Credentials in IoT service chains. We outline the framework consisting of Root issuer, Controller, User/IoT device and Service as the principal components. We describe the messages exchanged between these components and outline how privacy of users can be ensured.
- f) We implemented the above scheme and discuss the various possibilities on how token verification and policy implementation can be placed across constrained IoT services. Various metrics like time taken, number and size of messages exchanged, memory, CPU etc are evaluated for the various models that we discuss.

4) *Related Work*: Subsubsection text here.

III. PRELIMINARIES

In this section we introduce some of the concepts related to DAC building blocks.

1) *Bilinear map*: A Bilinear map is a Pairing-Based Cryptography construct that allows us to build and analyze cryptographic systems. Let G_1 , G_2 and G_T be multiplicative groups of order q , then a bilinear map $e : G_1 \times G_2 \rightarrow G_T$ satisfies the following properties

Bilinearity

$$\forall P \in G_1, \forall Q \in G_2 : e(P^a, Q^b) = e(P, Q)^{ab}$$

Non-Degeneracy

$$A \neq 0 \Rightarrow e(A, A) \neq 1$$

Computability

e is efficiently computable

2) *Zero Knowledge Proofs*: Zero knowledge Proofs (ZKP), introduced in [11] allow the prover to prove that he knows certain information without revealing the information (or anything related to it) to the verifier. A ZKP should be complete, sound and should not reveal any information from the proof. A zero-knowledge proof of knowledge is a special case where the prover possesses a secret information and not just the knowledge of it. Interactive ZKP require interaction between the prover and the verifier to prove that the prover has the secret information. For example, the Schnorr ZKP is outlined in [12]. The Non-Interactive ZKP (NIZKP) proofs do not require any kind of interaction for the proof to proceed. The Schnorr NIZKP proof is obtained through the Fiat-Shamir transformation [13].

3) *Signature Schemes*: A signature scheme consists of the following algorithms.

- Setup : Given the security parameter, the algorithm outputs public parameters.
- Key Generation : This algorithm generates a public key and the corresponding private key based on the public parameters.
- Signature Generation : This algorithm takes the private key and the message and outputs the signature. The generated signature should not be forge-able.
- Signature Verification : This algorithm takes the signature, public key and the message and output whether the verification is successful or not.

[9] uses Groth's structure preserving signature scheme [14] where the public keys, messages to be signed and the signatures are all elements of group G_1 or G_2 .

IV. DAC BY CAMENISCH *et al.* [9] AND OUR EXTENSIONS

The authors in [9] built a practical attribute based DAC system of L-level hierarchy where the delegation is not anonymous. The delegator reveals its identity and the identity of the entire chain to the delegatee during the delegation process. It is only during the presentation of the anonymous credential, the prover hides the identity of all the intermediate delegators. The prover also selectively reveals attributes at each level of delegation. The verifier in turn uses the root

issuer's public key to verify the anonymous credential token. The authors also describe the instantiation of their DAC system based on Groth [14] and Schnorr [12] schemes. The authors introduce a new signature scheme called *sibling signatures* which allows a users with a single key pair with two different signature schemes. This single key pair can be used both during delegation and token presentation.

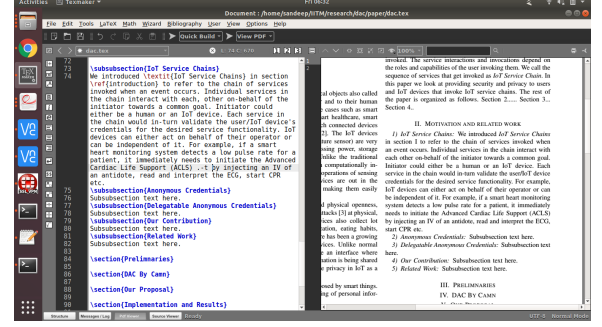


Fig. 2. Generic Construction of Camenisch *et al.* [9]

The author's generic construction scheme is depicted in Fig. 2. At Level-0 is the root issuer with public, private key pair as (ipk, isk) . The root issuer delegates certain attributes \vec{a}_1 to say *user1* at Level-1 with key pair as (cpk_1, csk_1) . It generates a signature (σ_1) on the combination of (cpk_1, \vec{a}_1) using isk . It passes on the signature and attributes to *user1*. Similarly, if *user1* at Level-1 wants to delegate certain attributes \vec{a}_2 to *user2* with key pair (cpk_2, csk_2) , it generates a signature (σ_2) using csk_1 over (cpk_2, \vec{a}_2) . *user2* then forwards the (σ_1) , \vec{a}_1 and cpk_1 generated at Level-1 as well as (σ_2) , \vec{a}_2 generated at Level-2 to *user2*. This goes on till any Level- l credential. So a Level- l credential is a combination of all signatures, attributes and public keys of all $l-1$ levels and Level- l private key.

In order to anonymously present a credential at any level, the prover generates a NIZKP proof proving that he holds the entire credential chain (signatures, attributes and public keys at each level). He can selectively reveal attributes at each level. The public keys (and thereby the identity of users) at each level will remain hidden. The verifier verifies the token using just the root issuer's public key. The authors provided an instantiation of their construction scheme using Bilinear Pairings and Groth-Schnorr sibling signatures. They used Groth1 to denote Groth signatures on messages in G_1 with public key in G_2 (called SibGS1) and Groth2 to denote Groth signatures on messages in G_2 with public key in G_1 (called SibGS2). The final attribute token would then look like

$$at \leftarrow NIZK\{\}\}$$

In order to prove that the prover holds the private key corresponding to the public key at Level- L (cpk_L), the NIZKP proof also includes the proof for a message m signed with the private key at Level- L (csk_L). In the concrete instantiation, this proof of private key possession is later turned into Schnorr signature proof of knowledge using Fiat-Shamir heuristic.

2) *The Controller*: The Controller forms the core of the system. One of the primary reasons for choosing a centralized controller based approach is to allow the flexibility for both constrained devices as well as resourceful endpoints to anonymously authenticate against services. Even on the services end, constrained IoT services, for example a smart bulb do not have the resources to validate an anonymous credential. With our approach, we allow both less constrained and very constrained endpoints to participate in the system. Some of the core functionalities of the Controller are

- a) Accepts Delegated Credentials from Users/IoT devices and generates Anonymous Credentials to be presented to services in the IoT service chain.
- b) Maintains the list of system generated events and the corresponding services to be invoked.
- c) Maintains session information like services that were invoked, what attributes are needed for each service and so on for the entire service chain.
- d) Validates the User/Device credential against BlackListed credentials.

On startup, the Controller loads the system parameters, generates public and private keys if this is the first time it is starting or loads the stored public and private keys. The Controller maintains a list of all the attributes required by each service in the system. This allows the Controller to generate anonymous credentials on behalf of the user/device by selectively revealing only the attributes required by the service and hiding the remaining ones.

IoT devices/Users generate events when there is a change in normal behaviour. For example, the HMS detecting a low pulse rate for the patient, an intruder trying to enter the house, component breakdown in a shop floor etc. All these activities generate system events which are processed by the Controller. The Controller maintains a broad list of the services that need to be invoked for each event. For example, if a Guest enters the Smart Home, access to only the Guest room needs to be allowed, the Guest preferred lighting and temperature needs to be set and so on. Once an event is detected, the Controller invokes the corresponding services maintained in its list. Each service may in turn invoke other services in a chained manner. Each service in the chain validates if the user/device that generated the event has the required attributes to fulfil the service request. This continues till all the services in the chain are invoked.

VI. IMPLEMENTATION AND RESULTS

VII. CONCLUSION

The conclusion goes here.

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