

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.

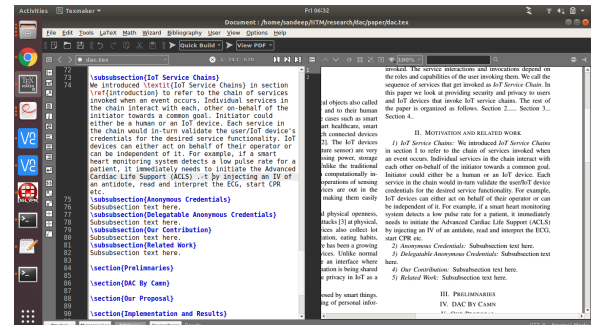


Fig. 1. IoT Service Chain

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.

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 and authorize 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 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.

To elaborate more on the technical details, when a User/IoT device detects an event, it informs the Controller of the event. As part of the signalling mechanism, the IoT device delegates its credentials to the Controller. The device delegates all its attributes to the Controller. See section V-3. On receiving the delegated credential and the event, the Controller first verifies the delegated credential using the Root Issuer's public key *ipk*. It also checks if the user's credentials are black listed or not. If the delegated credential is fine, it would then retrieve the list of services that need to be invoked for the event. For each such service, the Controller generates an anonymous credential based on the attributes that were delegated to the Controller by the user/device. The Controller selectively reveals only those

attributes that are required for the service to process the request and hides the remaining attributes. The generated attribute token as mentioned in section IV-1 will then be presented to the service for verification.

Here we have certain design options on the Controller based on whether the invoked service is constrained or not. A very constrained service, for example a Temperature Sensor would not have the processing capability to verify the attribute token generated by the Controller. Where as a Smart TV or a Smart Fridge may be able to verify the attribute token. In addition to the token verification, the service may choose to implement a policy evaluation based on the user/device attributes received in the token. See section V-4. Even here, constrained services may not be able to evaluate any policies based on the attributes in the token. the following are the design options.

- a) The Controller identifies the service as not a constrained one and would let the service perform the attribute token verification and policy evaluation.
- b) The Controller identifies the service as constrained and would in turn evaluate if the user/device delegated credential has the required attributes to fulfil the service request. Here it skips the token generation. The Controller also evaluates the policies, if any, defined for the service. The result of policy evaluation could in turn invoke the next set of services. See section. V-4. If so, the controller directly invokes the next service in the chain.

We evaluate the performance of the above options in section. VII.

The Controller generates a unique SessionID for every event generated by the system. The SessionID remains the same for all services in the chain. As mentioned above, after the Service performs the token verification and policy evaluation, it signals the next service in the chain. It passes the SessionID as part of the signalling mechanism. The next service will then reach out to the Controller for the anonymous credential using the SessionID. The Controller will then look for the desired attributes of the new service and generates an anonymous credential and passes it over to the service. This process continues till all the services in the chain are invoked.

So far we talked about each service in the chain requesting the Controller for the anonymous credential using the sessionID. Instead, the Controller can also push the anonymous credential to each service before the chain starts. This way, each service would have the credential that it has to verify and evaluate the policies. It need not wait for the chain propagation to reach it. All the services therefore can process the token in parallel thereby saving time. The number of messages that fly around are also reduced as now the service does not have to make an explicit request for anonymous credential. The drawback of such an approach is that the Controller would have to know the complete chain of services that need to be invoked for the event. For this, it needs to evaluate the policies at each and every service in the chain to know what the next service would be. Once it forms the complete chain, it starts distributing the anonymous credentials for each service using the SessionID.

- 3) *The User/IoT device*:
- 4) *The Service*:

VI. SECURITY EVALUATION

VII. IMPLEMENTATION AND RESULTS

VIII. CONCLUSION

The conclusion goes here.

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