# CS523 Mid-Semester Report (temporary title)

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## I. Introduction

Smaller and more power efficient processors enables almost everything in our life to collect information and access internet. This gave rise to the idea of Internet of Things (IoT). As IoT devices prevail, our society faces many new challenges. How do we store the vast amount of data generated by these devices? How do we manage and secure them? And, most importantly, how can we help the data owners to protect their privacy? Many research efforts have been made to address the first two challenges. Among them, Sayed Hadi Hashemi has introduced a framework that allows scalable and secure manipulation of IoT data in his paper World of Empowered IoT Devices. However, few have been done to address the last challenge. In this paper, we further improve Sayeds framework by introducing an intuitive way, in the form of a user interface, for the user to categorize and define access-control policies to his/her data. In addition, we see the trend of processing IoT data on cloud, we add SGX support to the framework to enforce data security in cloud computing environment.

Our main contributions include:

1) While most systems tag user data from the stand point of the developers, we give users the means to tag data in a way that is intuitive to them. This, combined with an easy-to use user interface, bring the security features to an accessible level to ordinary users.
2) By adding SGX support, we made the existing framework resilient to security concerns when using an untrusted cloud service platform.

## II. Background

### A. Internet of Things

TODO (Can potentially include the paper exposing security holes in Samsung SmartThings)

### B. Security and privacy in IoT (Blockchain paper)

IoT data security is crucial in protecting user privacy. In the paper "World of Empowered IoT Devices" [2], a framework is proposed to provide secure data manipulation in a scalable way.

In the data management protocol of this framework, user data is stored in trusted third-party entities, known as data sources. IoT users are known as data owners to the data their devices collected. Entities who are trying to get access to user data are known as data requesters.

The data owner is the only party who can grant data requesters the right, called capability, to access its proprietary data. When the data requester needs data access, it contacts the data owner for the capability. After acquiring the capability, the data requester will access data at data source. Throughout the process, the data owner has the control its data.

To ensure data transparency, all data transactions are recorded using BlockChains. After a successful data transaction, the data server broadcasts the transaction and the publishers update their BlockChain Record.

### C. Intel SGX

TODO

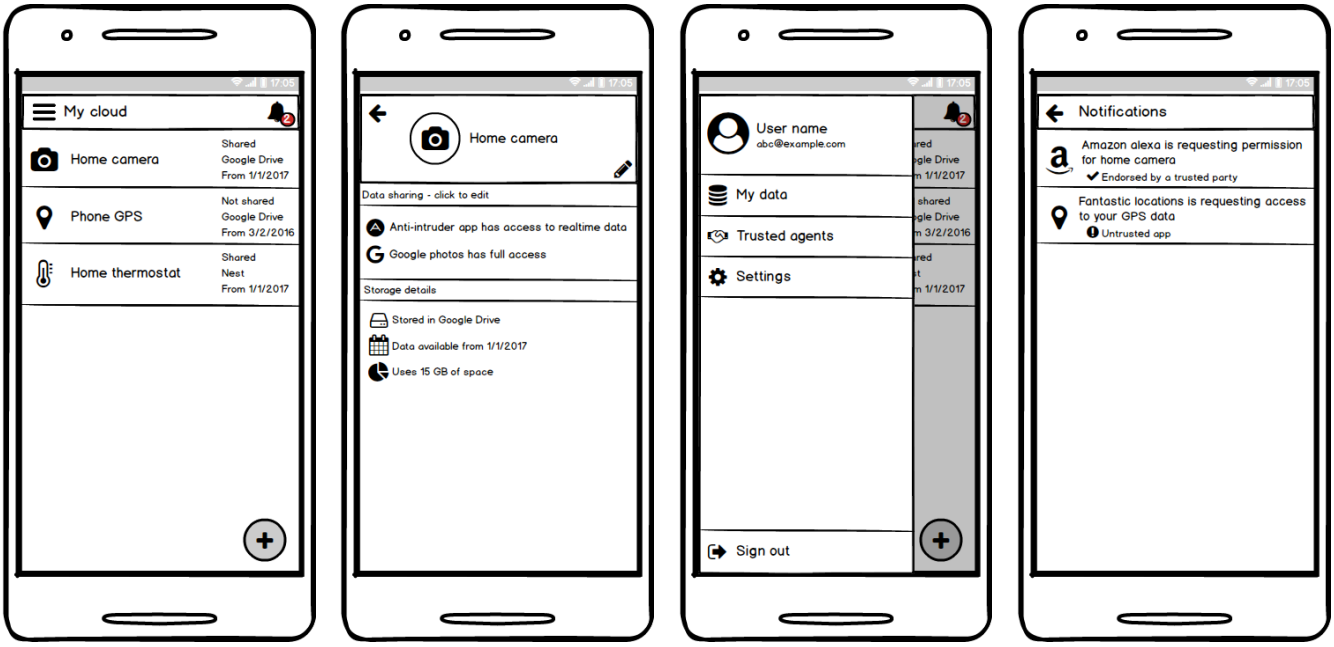
### D. Related Works

Davies et. al. points out that privacy concerns could be a major factor preventing wide-spread adoption of IoT devices [1]. Over-centralization of IoT systems is identified as a critical obstacle to eliminating concern over privacy. They propose a privacy mediator which sits in between IoT devices/data and outside world. This model includes a trusted 'cloudlet', which could be a local hub or a trusted server at the edge of the cloud. They also emphasize some important characteristics that a privacy-aware IoT system should have, like exposing summarized data, user anonymity, control over inferred sensors, and ease of use. However, the model's limitation is that data storage has to happen in the sensor or the cloudlet - this could be limiting when the number of sensors increase.

Data mining and clustering of IoT related articles expose major problem areas in IoT [3]. App over-privilege, environment mistrust, LAN mistrust and weak authentication are identified as some of the problem areas that needs work. They also conclude that permissioning needs to be more fine-grained, and recommend better standards and widely-applicable systems.

## III. Problem and solution

As evident from the previous sections, effectively addressing privacy concerns about the data generated by IoT devices is essential for the success of IoT. There are some proposed architectures which tackles this problem using user-oriented and decentralized systems. However, there's a lack of a user-facing component in such systems, which can effectively make the complex architectures usable to everyone. Our work is aimed at tackling this problem, which is "to build a user-facing component for a privacy-aware distributed user-centric IoT system (such as the blockchain based system described in




(a) Overview of user's data (b) Details of a particular device (c) Navigation drawer (d) Notifications screen

Fig. 1: UI mockup of the user facing application

[2]), which improves the user friendliness of the system while maintaining strong security and privacy guarantees."

To accomplish this, we build the user-facing component for the blockchain based IoT architecture described in "World of empowerd IoT users [2]". Since that system is still in development, we concentrate on the user facing components of the system, and simulate some of the external components.

The proposed work consists of 2 components:

1) A smartphone app to manage IoT devices and data: Smartphones are becoming the preferred devices for internet access [4]. Hence we build a smartphone app with which users can manage their IoT devices and data. The functionality provided by the app includes:
   a) A centralized view of IoT generated data owned by them.
   b) A detailed view including the data source, access permissions and other details of this data.
   c) Permission request notifications from data requesters, and a way to accept or deny them.
   d) View, add, remove trusted parties.

   This is not a comprehensive list of the functionality, as we expect to add more as the project progresses. It also hides away some complexity from the users, like managing secure connection with the server described below, and managing user's private key etc. We also focus on the user-friendliness of the app, and expect to conduct user-research to find out what capabilities do users expect to find in such an app.
2) A trusted server which manages the access control: This is the component which actually manages access control and capability issuance in accordance to the user's wishes. This is similar to cloudlets described in [1], but with some key differences. First, we intend to leverage hardware technologies like Intel SGX to ensure that the server application can run on untrusted hosts. Second, this app does not store data within it; it simply interacts with the data owner, data sources and data requesters in accordance to the protocol outlined in [2].

## IV. Threat Model

We implement our solution based on Hashemi et al.'s [2] work for sharing IoT data objects. We particularly focus on their Data Management protocol to model communication between data requesters and data owners. Meanwhile, our work is not limited to this protocol as we can extend our framework to any equivalent multi-party cryptographic communication protocol. In addition to four major parties involved in their protocol, we also add one additional party named Cloud Service Providers in our model. These providers are responsible for running our server-side implementation that enforces decisions made by users to regarding approvals/denials of data object requests.

1) **Data Owners**
   Our work primarily focuses on households with a small number of IoT devices. These individuals may interact with IoT devices using IoT applications written by IoT device manufacturers or other third-party programmers. Our framework does not trust these applications as they may leak sensitive data and violate Data Owner's privacy. Users grant or deny operations related with IoT data objects using our Android front-end application. Securing our application against Android malwares or

compromised Android OS is out of the scope of our paper, but solutions that enforce Android application security and OS security [5] can be applied as orthogonal solutions to our work.

2) **Data Source**
Although a Data Owner have a possession of data created by his Data Sources, the Data Owner may or may not manage Data Sources. We assume Data Sources are managed by trusted parties such that they honestly follow the data sharing protocol. On the other hand, enforcement of protocol on Data Sources is one of our future works.

3) **Data Requesters**
We assume data requests coming from Data Requesters to be one of the major privacy threat vectors. Data Requesters query and find data objects using the Messaging service and request those data objects to Data Owners by following the Data Management protocol. Since we assumed Data sources to be honest, Data Requesters can only obtain data objects by following the protocol. Nonetheless, Data Owners may not fully understand the risks associated with approving or denying data requests. As Hashimi et al. has mentioned, the system they have proposed is user-centric such that user has full control of access control of data. In other words, Data Owners are solely responsible for granting access to all resources. This can be a very burdensome task such that it may not be scalable as we envision IoT devices to be more ubiquitous in the future. Thus, our solution primarily focuses on providing concise and accurate information for each data request and guiding Data Owners to make autonomous decisions.

4) **Endorsers**
In our framework, trusted Endorsers are responsible for validating identity of Data Requesters and authenticity of Requesters' requests. Supplementary Information provided by Endorsers regarding the data requests may help user to make correct decisions but it may also

5) **Cloud Service Providers**
Untrusted third party Cloud Service Providers host the back-end server which processes Data Owners' actions. Note that IoT device manufacturers usually provide such service for their IoT device customers. We do not trust this computational platform and enforce security and privacy of our solution using Intel's SGX enclaves. Data Owner trusts server-side code run in the enclave, and they can validate integrity of the code using measurements provided with a cryptographic hash. While, our solution provides all security guarantees that are enforced by the enclaves, attacks that target security limitations of the Intel SGX processors are out of scope in our paper. These include Cache timing side-channel attacks [6] and Denial of Service attacks. Meanwhile, we believe orthogonal approaches [7], [8] that mitigate such threats can be applied to our solution.

We primarily focus on two attack vectors. We protect Data Owners against data requests that may violate user privacy using our user-friendly User Interface. We believe this is the most likely threat against ordinary IoT users. Our framework guides users to make intended and autonomous decisions. Meanwhile, we would also like to provide transparency and resiliency of our framework by securing the back-end with Intel's SGX.

## V. Experiment

We started out by experimenting with the UI of the application. We are currently developing an Android app, and apps for other mobile platforms like iOS is left as future work.

We made an initial version of the UI mockups, and ran a user survey to iterate over the design. The current design is shown in "Fig. 1". These images show only some of the important screens in the app, and are not exhaustive. The capabilities of the app include having an overall view of the devices and data (Fig. 1a), seeing and editing details pertaining to a particular device (Fig. 1b), receiving and acting upon data requests (Fig. 1d), and viewing and managing trusted parties.

User research shows that the following design choices enhance the experience.

- Overall view of the devices and data is very helpful.
- Notifications screen is well done because users can see whether the requester is endorsed and act on the notification from the same screen.
- Users also feel more comfortable with IoT devices when a privacy-control mechanism like this app is present.

We also identified some major areas of concern.

- Users need more control over what data is stored. In particular, they might want to delete data between certain time periods.
- Users want to minimize the data shared with third parties, and hence each device should expose various spatial and temporal summarizations.
- Guarantee of anonymity is a must when sharing sensitive data with third parties, especially for analytics purposes.

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