Mobile, Biometric Bitlocker

Project Plan

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1. Introduction

1.1 Problem Statement

Asymmetric encryption is an encryption that allows individuals to hide their data and ensure it is secure. Typically, files would be decoded using a public key and then encoded using a private key. The private key is stored in a Trusted Platform Module (TPM), which is a cryptographic module that enhances computer security and privacy. TPM chips are usually discrete chips soldered into a computer's motherboard, allowing for separation from the rest of the system. Android phones, however, lack the TPM chip; therefore, encryption keys must be stored on the device somehow. If the keys are stored on the devices, they can be found and could fall into malicious hands.

1.2 Purpose

Our solution to the problem is to dynamically generate the key using a Physical Unclonable Function (PUF). In doing so, the dynamically generated private key will not be stored anywhere on the device and will be able to authenticate against the public key. The key can only be generated at runtime, solving the issues of not having a TPM and storing the key.

1.3 Goals

Our goal is to develop an open source PUF library and integrate the library in the Android OS. The library will be used to authenticate the user by dynamically generating a private key. Encryption will occur when a user's phone is shut down. Upon successful authentication on boot, the user's data will be decrypted.

1.4 Intended Users and Uses

The integrated PUF would be used by any person who has a phone with information that they deem worthy of protecting.

According to Statista [1], 54.1% of people in the United States are using an Android. Therefore, we would want to reach the Android market with our application since most people today have

data on their phone worth encrypting. For example, any employees within a company that keep sensitive data on their phone may wish to keep their data encrypted in case their device is stolen or compromised.

1.5 Assumptions and Limitations

Assumptions:

- The PUF library is working at the beginning of the second semester.

  We have found several issues with the library received from our client. Our hope is to fix the issues we have found in the library by the beginning of next semester so we can use the working PUF to be able to develop our application.

- Android continues to support full disk encryption.

  Android currently supports full-disk encryption. However, due to the legality associated with encrypting the full-disk, Android is thinking of suspending support for it.

- Android allows developers to integrate in the boot sector.

  There is a chance that Android will not allow us to integrate our application into the boot sector. If this is the case, the application will not reach its full potential and will have to reside at the application level.

Limitations:

- Nexus 7 hardware.

  The Nexus 7 is the hardware the school provides and is the device the PUF was originally designed on. The team decided it would be best to continue implementation on this hardware. Unfortunately, this will provide some limitations. Nexus 7 is currently handles API 23, which is a much lower API than the current Android version. This prevents us from using some features that may be used in newer versions.

- Previous PUF library implementation and research.

We must use the previous implementation of the PUF. Whether we agree with the research or not, it is imperative to use it within the project.

2 Project Deliverables and Specifications

Deliverables:

- A well tested PUF Java gestures library
    - An open source library that should be released with unit tests and rewritten methods. We need to provide a valid testing framework and an appropriate architecture for the software.
    - At least 70% test coverage
- A PUF based Android application
    - The application should act as a lock screen whenever the phone is closed. It will authenticate users by asking them to draw a shape, and it should only work for the correct user. The application will also automatically start when the phone boots.
    - Authentication should happen within 5 seconds.
    - The application should work on phones with 1 GB of RAM.
    - Application size should not exceed 80 MBs.

Dates for deliverables detailed in timeline section.

3 Design

3.1 Previous Work/Literature Review

For our project, we will be working with existing software and integrating it into our project. The given implementation is named PUF. Presently, the PUF creates a unique key from data received from the user. It receives this data by displaying a pattern on the screen and forcing the user to trace the design several times. From this data, a function will find a trace range the user should always fall between. When the user attempts to draw the shape of the design

again, it will recognize the user. We received our knowledge of PUF through a paper published by our client. [2]

When considering whether similar products are in the market, no comparable implementation has been found. However, there are similar technologies available that offer different functionalities. PUF is not a new way of securing a device. In fact, the most common use of this technology for securing phones has been the fingerprint scanner, which is a property found on most mobile phones. Additionally, the idea of an Android bitlocker is not new either. Having a secure way to unlock one's data once it has been encrypted has been a problem many are trying to solve. Microsoft has a dated bitlocker that uses a key pair to encrypt and decrypt data. Their solution utilizes a USB stick, a PIN or both to be able to authenticate the user. [3]

Despite its popularity, the fingerprint scanner is not always secure. In a study conducted by Michigan State and New York University [4], researchers found there was a way to break a finger print scanner 65% of the time. In a world where we are not authorizing all sorts of payments from our phone, we think our solution would be better, for it is more unique in its generation of a key and covers more reference points than a finger scanner.

We have discussed pure authentication, but what about the other side? We need to the ability to encrypt mobile data at, ideally, a kernel level. Android already has the encryption level we are hoping to implement; that is, Android provides full-disk encryption. When the phone is turned off, all the functionality of the mobile device would be encrypted until the user is authenticated at boot. [5]

3.2 Proposed Design/System/Solutions

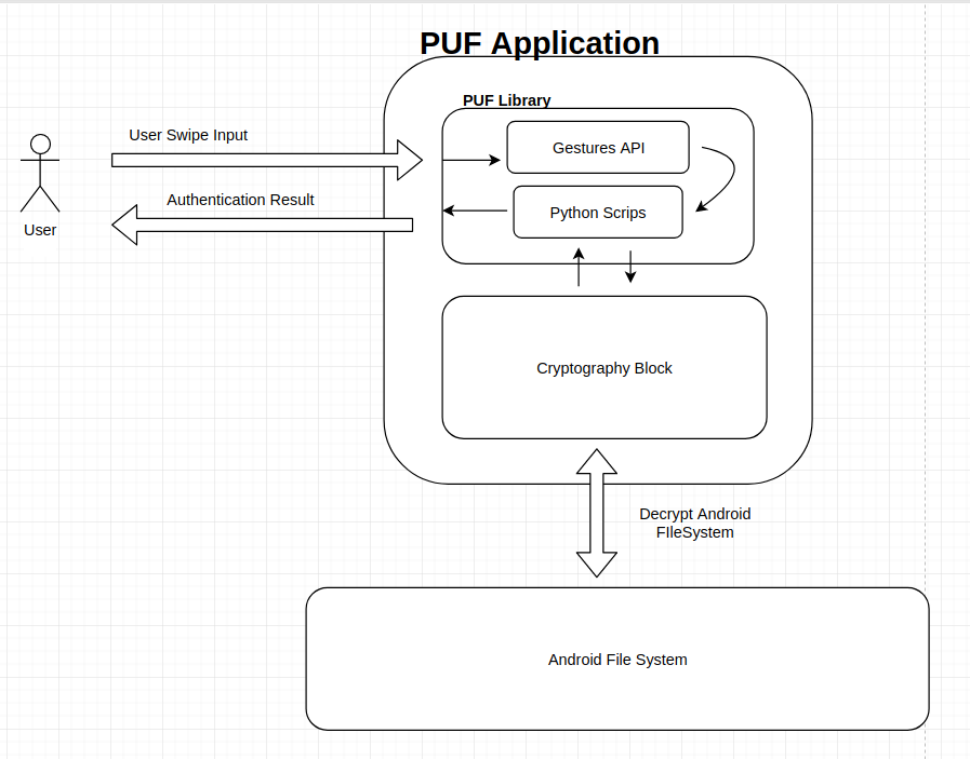


FIGURE 1 INITIAL DESIGN OVERVIEW

For our project, some of the groundwork for the solution has already been completed. The current solution is to develop an Android application using data generated from pressure readings returned by the screen when the user traces a generated shape similar to the native Android unlock pattern. The data would be generated by a Physical Unclonable Function (PUF), which has already been implemented. As stated earlier, mobile devices lack the TPM chip which can be found on most laptop computers. This enables full-disk encryption on laptop computers, where each TPM has its own unique and secret RSA key that will decrypt the disk. Since each chip has its own unique RSA key, this makes it an extremely secure method for encryption. With the lack of the TPM chip on mobile devices, there is a lack of such a secure method for encryption. Ideally, the PUF will emulate the security of the TPM chip by dynamically generating the key every time, thus eliminating the need to save it. The key generation will occur when the user traces a pattern generated by the application. When provided with the pattern, the application requires users to trace it a certain amount of times depending on the selected user

and selected strength (i.e., the higher the strength, the higher the number of traces). Doing so will develop a profile for the user based on the patterns for pressure and speed the user exhibits for that particular pattern. Furthermore, the hardware for no two devices is the same, even among devices of the same model. Therefore, the pressure readings will vary from screen to screen and, thus, importing a profile to another device should result in failure even if the same person traces the pattern on the new device. Therefore, this implementation will lead to both user authentication and device authentication, leading to maximum possible security with the given hardware.

PUF Library Block

The pattern tracing and user authentication features are all encapsulated within the "PUF Library" subblock in **Figure 1**. These features have all been implemented; however, they need to be updated, reworked and thoroughly tested before we can deem them functional or reliable. The implementation of the pattern tracing and user authentication system currently has the user trace a given pattern X amount of times when a new profile is created. This pattern is referred to as a "challenge," and it is created by referencing the Gestures API seen in **Figure 1**. As the user completes the challenges, the Gestures API will normalize the user responses and create a profile associated with that challenge. This profile will then contain the challenge along with its list of normalized responses, which can be authenticated against. The number of responses varies depending on what the user has set for their strength setting. The higher the strength, the more responses required and the more precise the authentication will be. Once the user has completed all of the required challenges and the profile has been generated, the API will be able to create a User-Device Pair, which means that the authentication system should now be able to recognize the user whenever they trace the patterns.

Once the User-Device Pair has been created and the user is now trying to authenticate by tracing the challenge, the application will use its library of Python Scripts, shown in **Figure 1**, to run some statistical analyses on the generated response. Over the course of the initial traces during profile creation, the application developed an average user pressure trace for authentication. There are scripts in the Python Scripts Library that will take this average trace and find a line that is 2 deviations above this average and 2 deviations below this average, thus

creating a zone, or distribution, of acceptance. When the user tries to trace the pattern later, the trace they generate will be evaluated by a Python script at 32, 64 or 128 points along the trace, depending on the settings and the length of the trace. From these points, a certain percentage needs to fall within the zone of acceptance for the trace to pass and user to be authenticated. This is illustrated in Fig. 4 and Fig. 6 from Dr. Akhilesh Tyagi's team's paper. [2] **Figure 2** shows a trace that passes as every point fell within the zone of acceptance whereas **Figure 3** shows a trace that failed as 22 out of the 32 points fell out of the zone and failed.

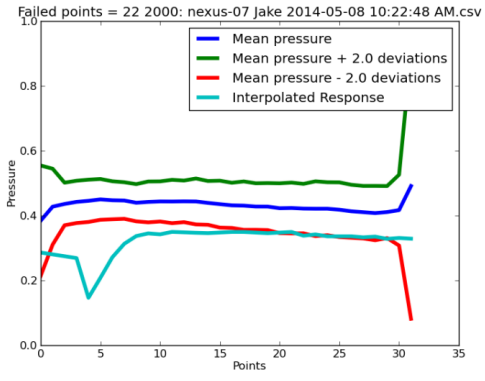


FIGURE 3 STATISTICAL CONCENTRATION/CORRECTION FOR PROFILED USER

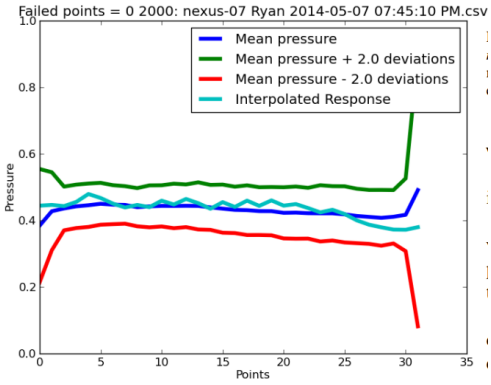


FIGURE 2 STATISTICAL CONCENTRATION/CORRECTION FOR A USER OTHER THAN PROFILED USER

Cryptographic Block

One major component of our application that has yet to be developed is the Cryptographic Block, which will be responsible for the encryption and decryption of our data. We plan to use Android's own Cryptography API to encrypt and decrypt the device's file system. As shown in the block diagram, once the user trace is authenticated through the PUF Library, the application will enter the cryptographic block and decrypt the file system. If the user is not authenticated, then the file system should remain encrypted. While we understand the high-level functionality we want, there is still more research that needs to be done in this area if we are to reach our end goal.

Currently, the goal of the solution is to integrate this application into the Android OS, so we could have application level encryption. This may look like a series of patterns that you must trace and pass when you open a certain application. If we can get this functionality in place, we

will begin to move the encryption further back into the boot up process. Our end goal is to be encrypting and requiring user authentication at the kernel level before the OS is booted, which is like BitLocker on Windows computers. However, the feasibility of this solution is currently in question, and research is being done to see whether we can implement this feature at all. We have not explored any alternatives to this solution because this project is a research project whose purpose is to examine the feasibility and security of using a PUF in Android phones to emulate the encryption behavior of TPM chips found in laptop computers.

3.3 Assessment of Proposed Solution

The proposed solution has a strength that most other encryption methods contain: PUF implementation. When functional, PUF allows some of the most effective authentication available, as only the user on their exact phone has access to their application data. Having data saved at an application level allows only specific data to be encrypted, which can be a benefit if there are certain file systems of the device that must stay unencrypted for general functionality to resume. However, this concept could also be perceived as a weakness, for the user's operating system would not be given the same protection, making the device susceptible to some attacks.

An alternative solution to consider is boot and kernel level encryption, which offers even lower-level security for the entire system. However, the trade-off with this design is that several usual background applications and general functionalities of the device would need constant authentication from the user to be allowed to operate normally, which is not very user-friendly. As ideal as this solution is from a security standpoint, it may not be feasible to make changes to the Android kernel, and it may have to be partly implemented as a surface application that starts as soon as boot sequence ends.

A weakness of tying the authentication system to the silicon level of the hardware device, which is used for advanced security, is the limited support for the models of devices supported. The usage of this application requires the user to use a specific hardware model and they are tied to that exact device to remain secure. This creates not only a higher cost for those who do not already own a supported device but costs the project more as well to add support for

multiple models, for each hardware device requires an individual design of the authentication system.

3.4 Validation and Acceptance Test

Each project requirement requires a test case for validation alongside passing the acceptance testing criteria to be considered sufficiently implemented:

Functional Requirement 1: Only a user with an authentication profile may gain access through to user data.

Test Case:

1. User A creates an authentication profile on the test device.
2. At least two different participants, including User A, attempt to access an application which requires authentication to access user data.
3. Each participant traces the authentication pattern.

Acceptance Test:

No person other than User A may unlock or decrypt user data via trace authentication through their authentication profile. Requires at least a 95% acceptance rate while maintaining less than 1% false positive results of unauthorized users gaining access.

Functional Requirement 2: Device cannot be shut down when application is encrypting.

Test Case:

1. User A has an existing profile on the test device, or otherwise creates one.
2. User A shuts down and starts up the device.
3. During startup, User A attempts to shut down the device at boot.

Acceptance Test:

User A should be prompted with a message notifying that the device cannot be shut down by normal means until the encryption steps at boot for the application complete.

Non-Functional Requirement 1: The application should be able to store multiple user profiles. (Scalability)

Test Case:

1. User A creates a user profile with the application.
2. User B creates a separate user profile with the application.
3. Both users attempt to access user data one at a time, and each trace the authentication pattern when prompted.

Acceptance Test:

Both User A and User B should be properly authenticated through their respective authentication profile and are given access to the user data. At least 95% acceptance is expected while less than 1% of the time providing access to the user via another's authentication profile.

Non-Functional Requirement 2: Response time of the authentication process should be no more than 4 seconds. (Performance)

Test Case:

1. User A has an existing profile on the test device, or otherwise creates one.
2. User A attempts to access user data and traces the authentication pattern when prompted.

Acceptance Test:

Once User A has completed tracing the given authentication pattern, the application should begin and complete the authentication process as well as notify the user of the result within 4 seconds. Requires 95% acceptance to be deemed successful, as the application or device is occasionally expected to see slowdowns.

All acceptance test cases require manual system testing utilizing the hardware device. However, validation testing when completing an issue can be enough with Java Virtual Machine unit tests, depending on the natures of the component. Unit testing follows the discretion specified in the test plan.

4 Project Timeline

The schedule for this project is based on the rolling wave planning technique, which enables the team to discuss and make decisions concerning the project as it progresses. Tasks that should be completed soon are discussed in-depth, whereas tasks scheduled for later dates are discussed in a more abstract, high-level manner. The current team is composed of individuals who have the necessary knowledge of the project parameters, hardware and software used in the project to make educated estimates for the projected times. Once the current tasks are completed and it is time to analyze the subsequent tasks, dates may be modified depending on the coming in-depth discussions and knowledge of the team.

The following diagrams present the process (**Figure 4**) and projected schedule (**Figure 5** and **Figure 6**) our team will utilize over two semesters, respectively. Regarding **Figure 5** and **6**, we decided to organize our project into five phases: research, design development, testing and delivery.

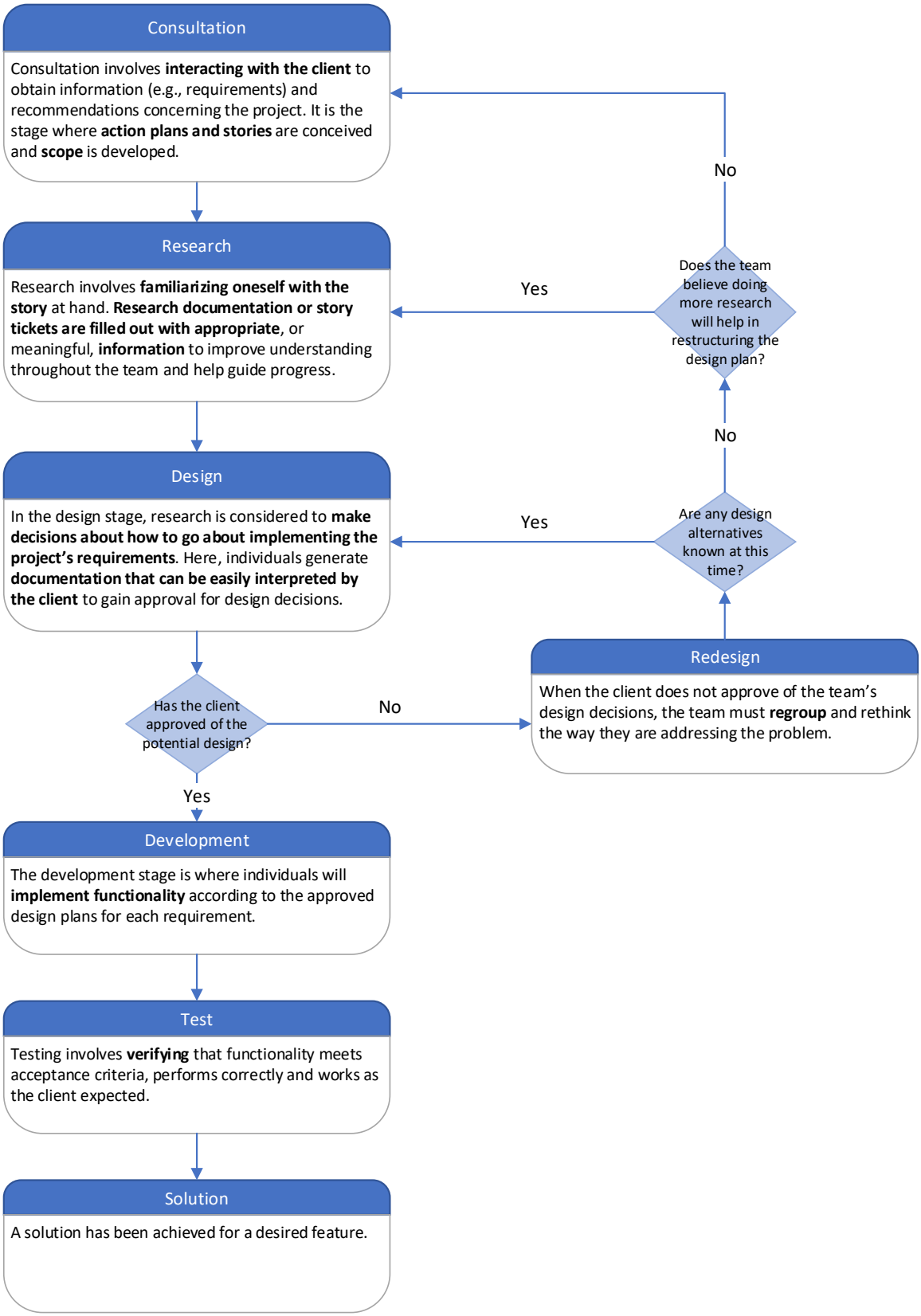
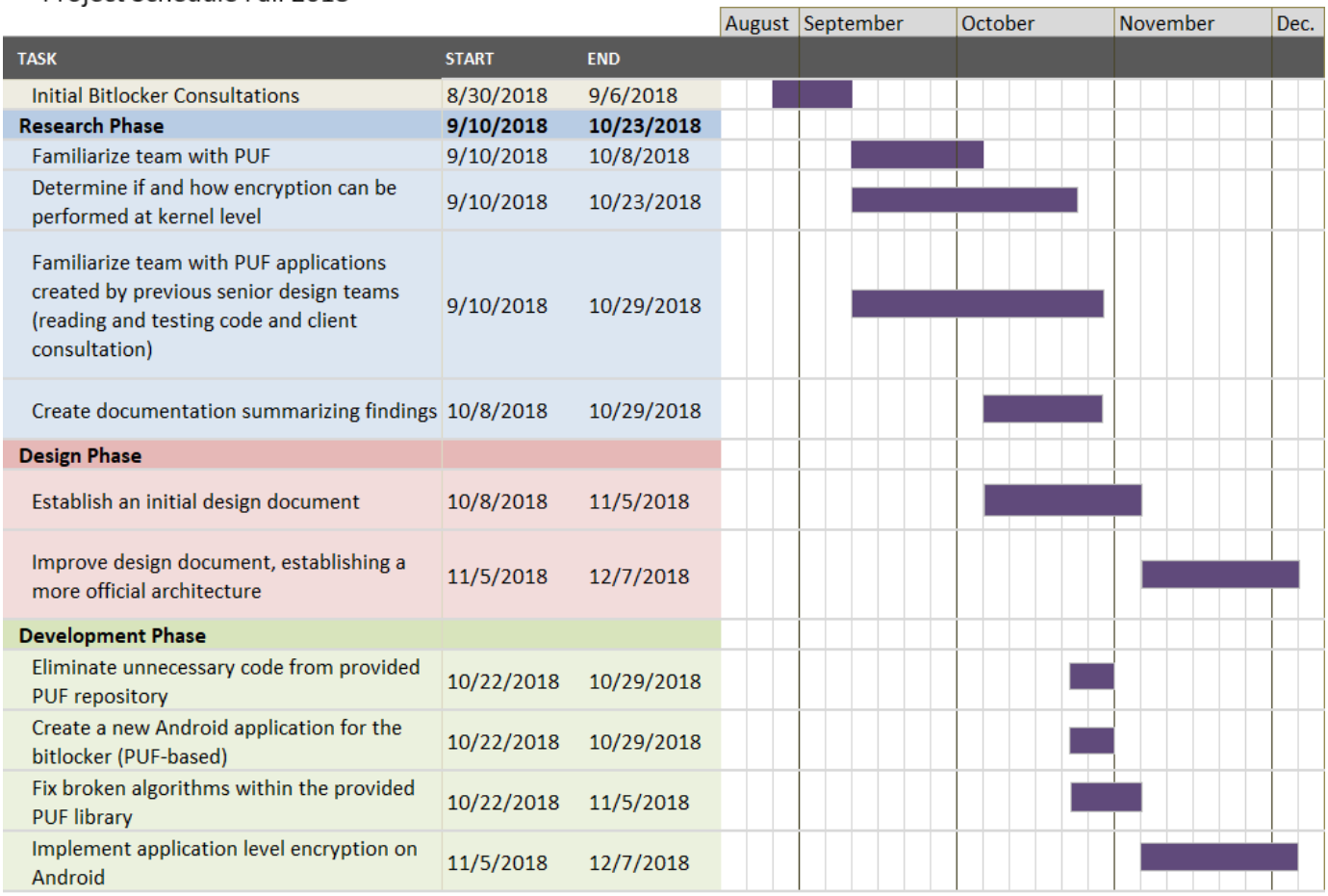


FIGURE 4 PROCESS DIAGRAM

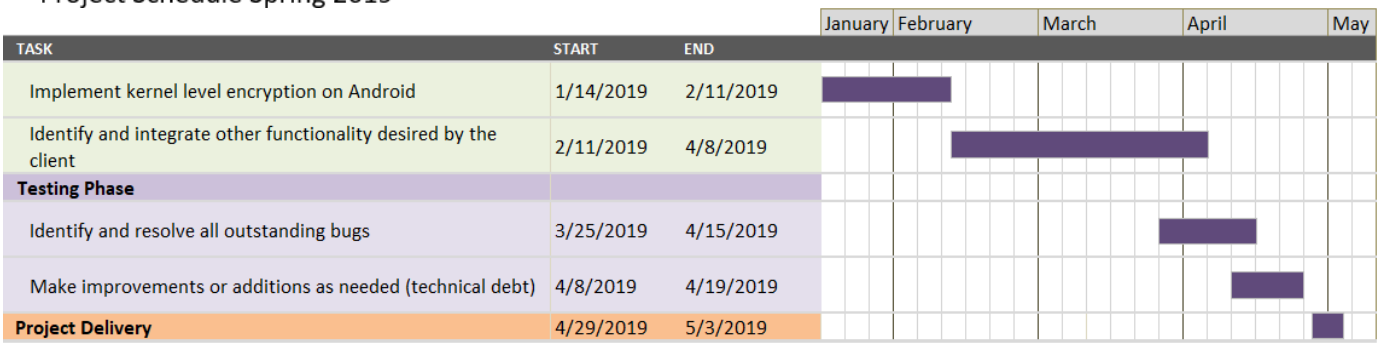
Project Schedule Fall 2018



TASK	START	END
Initial Bitlocker Consultations	8/30/2018	9/6/2018
Research Phase	**9/10/2018**	**10/23/2018**
Familiarize team with PUF	9/10/2018	10/8/2018
Determine if and how encryption can be performed at kernel level	9/10/2018	10/23/2018
Familiarize team with PUF applications created by previous senior design teams (reading and testing code and client consultation)	9/10/2018	10/29/2018
Create documentation summarizing findings	10/8/2018	10/29/2018
Design Phase		
Establish an initial design document	10/8/2018	11/5/2018
Improve design document, establishing a more official architecture	11/5/2018	12/7/2018
Development Phase		
Eliminate unnecessary code from provided PUF repository	10/22/2018	10/29/2018
Create a new Android application for the bitlocker (PUF-based)	10/22/2018	10/29/2018
Fix broken algorithms within the provided PUF library	10/22/2018	11/5/2018
Implement application level encryption on Android	11/5/2018	12/7/2018

FIGURE 5 PROJECTED FALL 2018 SCHEDULE

Project Schedule Spring 2019



TASK	START	END
Implement kernel level encryption on Android	1/14/2019	2/11/2019
Identify and integrate other functionality desired by the client	2/11/2019	4/8/2019
Testing Phase		
Identify and resolve all outstanding bugs	3/25/2019	4/15/2019
Make improvements or additions as needed (technical debt)	4/8/2019	4/19/2019
Project Delivery	4/29/2019	5/3/2019

FIGURE 6 PROJECTED SPRING 2019 SCHEDULE

A majority of our project in the fall 2018 semester (**Figure 5**) consists of researching significant concepts essential to developing our encryption application and establishing a design to guide the team in the development phase. Specifically, the team decided to spend the first two months getting familiar with the concept of a PUF, encryption techniques and the PUF applications provided by our client. Doing so ultimately assisted in creating an appropriate design plan for implementation. As the research and design phases progressed, our investigations unfortunately showed that the library used by the PUF applications contained errors. As a result, the team agreed that a few milestones hoped to be achieved within the first part of the development phase include furthering our understanding of fundamental concepts required for implementation of our client's desired application, fixing the broken algorithms within the provided PUF library and implementing a working encryption application using PUF at the application level.

In terms of the spring 2019 semester (**Figure 6**), the schedule is extremely basic. Since we are using the rolling wave planning technique, the schedule will continue to change as we learn new information about project. For this reason, the present spring schedule outlines the fundamental goals we hope to attain, including the completion of the development phase by implementing a working encryption application using PUF at the kernel level, ensuring the team finds and resolves all bugs within the application and, finally, delivering the product itself.

5 Challenges

The feasibility of our project is undetermined because it is unknown whether encryption can be performed at the kernel level. Android does not use encryption at the kernel level in its own releases, so it may be the case that it is infeasible for them to implement it. However, it is not known whether this is the case or not. It may be possible to perform this encryption, but functional reasons prevent this from being implemented, such as repetitive authentication.

There are risks involved with integrating the PUF library into a brand-new solution. No member on the team has had experience with the library or the concept of physically unclonable functions in general. We have witnessed issues with an existing application that uses the PUF library, so it has already been demonstrated to be susceptible to failure.

However, given our previous work with each other and progress already completed, we do not believe the project to be outright infeasible. Most of our project will be working with Android, which we all have experience working together on. We have created a user application, which the initial goal of this project calls for. The project also involves operating system and kernel levels of programming, and most of us have taken or are taking “Introduction to Operating Systems” or “Linux Operating Essentials,” which provide a good foundation for the programming skills and knowledge required. The project is an extension of a project that has been in progress for a few years now, so there is already lot of research and development to use as resources, and the problem space has been thoroughly explored. There are several academic articles written about PUF, justifying its practicality.

There also exist risks pertaining to authentication. Although the PUF library generates the keys used for authentication, the application that uses it must accurately authenticate a user by deciding whether a user sufficiently replicated a key. Deciding what constitutes as enough carries risk into the equation. To make the application user-friendly, it cannot produce false negatives when authenticating a user. To make the application secure, it cannot produce false positives, which will jeopardize data that is supposed to be secure. This will require thorough testing as well as statistical development to ensure accurate authentication.

5.1 Cost Considerations

Software

The project primarily utilizes open source software that incur no cost. We are using GitLab as version control, but there are free alternatives.

Hardware

To accurately test the application, the project requires physical devices that can run Android. For this reason, we have acquired two Nexus 7s from the Electronics Technology Group. The cost for a Nexus 7 is roughly $199, making the total cost of the project $398.

	Device	Cost
1	Nexus 7	$199
2	Nexus 7	$199
		Total: $398

FIGURE 7 COST TABLE

6 Process Details

Our process will consist of establishing functionality at the lowest level of security and later implementing the solution at the highest level. Our initial version will establish success at the user application level, at which point we will advance to explore a solution utilizing higher security. This may or may not be the kernel level. We will use the information learned from completing the initial version to assess what the next step should be. The goal is to encrypt a key at the kernel level.

6.1 Standards

We are not working in a traditional lab environment for this project, and most of our work is completed outside of a collaborative environment. Most of the work is going to be software development, and we have decided to follow the Agile model for development. All our standards and protocols, such as sprints, sprint planning and meeting practices are adapted from the Agile model. As a result, our standards and practices should be approved by IEEE, and none of them should be considered unethical by any organizations.

We found that the Agile model would be the best model to follow for our project because, for a project of this size, we want to make continuous incremental updates to the design rather than large infrequent changes. By making smaller, more frequent changes in the Agile model, we are able to ensure every addition to our product is thoroughly tested and working properly. Furthermore, if any change or addition is made, the Agile model provides flexibility; it is very easy to roll back to the last working state without losing a lot of work, whereas models

requiring individuals to do large chunks of work at a time do not provide this. The state and quality of the PUF Library we received at the beginning of the semester is a testament to how important it is to follow the standards of the Agile Model. Many errors exist, and the errors are interconnected and layered. In other words, solving one error often reveals another error. We can avoid issues like this in our future development and maximize our implementation quality if we simply follow Agile coding practices, such as Test-Driven Development, making incremental changes instead of large ones, having code reviews whenever code is being merged to master and having 100 percent test coverage for code.

6.2 Test Plan

As code is created, developers must create unit tests simultaneously to test their components and ensure the expected behavior is operational and the number of bugs introduced to the repository is minimal. The longer a bug or malfunction is present, the more difficult the bug is to fix since code may build on top of it. Unit tests will be in a parallel directory with similar path and test file names as the actual code. While no minimum or maximum amount of unit tests are required, all core functionality and common edge cases should be unit tests.

As core components are combined, integration tests should be designed to show the implementation of other targeted components delivers results as expected. These tests may be created by collaborating developers or by the test engineer. These tests should focus on core functionality and interactions the connecting components share. They are often still separate from fully operational actions and focus on specific functionalities.

System tests should demonstrate fully operational tests between multiple components using actual data. These should demonstrate intended functionality, and, for our purposes, some may even be end-to-end tests. These tests will be developed by either collaborating developers in need of data from a live environment or by the test engineer to show operational system behaviors.

7 Conclusion

Our goal for this project is to integrate existing software that details a PUF into an Android-based OS application. We will do this by research, design, development, testing and conferring with our client. We think this is a worthwhile project because the use of a pressure PUF as a bitlocker for a phone has not been done and will add needed security. We hope to complete the application in its entirety by the end of spring 2019.

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