Bachelor's Thesis
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Performance Comparison of Lightweight Cryptography Implementations in Peer-to-Peer File Transfer for Embedded Systems

by

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ABSTRACT

This first and short section includes a summary of the work. A strong abstract highlights the research problem, which the thesis addresses, succinctly describes why the problem is worth pursuing, highlights the thesis's contributions towards addressing the problem.

For more detailed instructions on writing a good thesis at the VU, consult the VUSec thesis guide [12] or Animesh's notes [11]. There are many excellent guides on technical writing (e.g., [6, 8]); please consult them to improve your writing. We *strongly recommend* that you read, at the very least, "The Elements of Style" by William Strunk Jr. [14].

Start writing from ***day one*** *of your project and keep refining* the document until the end.

1 INTRODUCTION

Think before you write, be careful how you write, and take feedbacks seriously [7].

This section includes some motivations behind the work, explicitly or implicitly highlights the research question, provides a high-level explanation of the solution, and describes the contributions.

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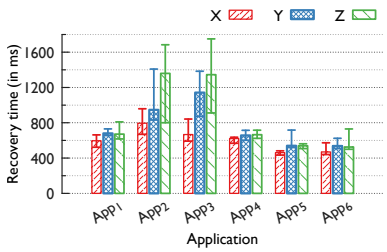

Figure 1: ***Simple one-column figure. Please include a brief explanation or takeaway.***

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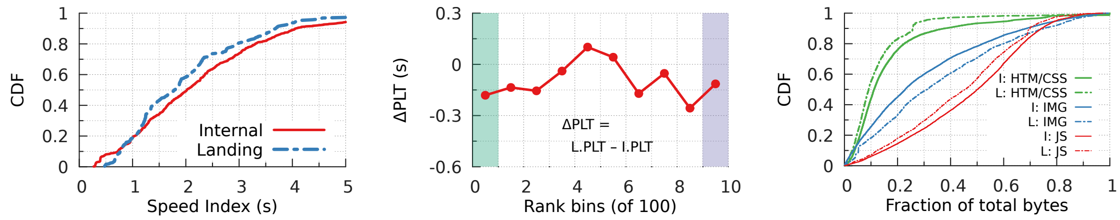

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Figure 2: ***Generate clear and beautiful figures (in PDF) that can be rendered side by side while still being easy to read and interpret. Choose colors wisely from the colorbrewer2.org website.***

Table 1: ***A simple table describing the characteristics of a data set or the results of an experiment.***

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We summarize our contributions as follows.

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2 BACKGROUND

2.1 Peer-to-Peer File Sharing

In client-server models, there is a single central server that is in charge of providing resources and services to the other clients. On the other hand, peer-to-peer networking is a distributed architecture where each peer acts as both a client and a server [13]. The main advantages of this architecture choice are the ability to communicate directly to other peers without having to hop through a central server first. It also has excellent scalability. In the context of this project, it means that we do not need another microcontroller acting as a server. This reduced costs and decreased the complexity of the implementation, as it narrowed the possible attack paths that could be used to compromise the integrity of the system. Using this P2P approach results in the file contents being sent directly to the client, which reduces the network load.

2.2 Security in Embedded Systems

Embedded systems are ubiquitous in our modern world, and some of these systems must perform important tasks securely and reliably. Due to the nature of these devices, they are not capable of handling conventional cryptography schemes, as they have limited memory and processing power. To address these challenges, lightweight cryptographic libraries have been developed to provide these devices with the tools needed to perform these tasks safely with the limited resources on which these embedded systems operate with.

2.3 Lightweight Cryptography Libraries

Lightweight cryptography libraries are implementations of cryptographic functions specifically tailored towards constrained devices such as microcontrollers. This paper focuses on three well-known cryptographic libraries:

2.3.1 Ascon. A family of lightweight cryptographic algorithms designed for use in resource-constrained environments, such as IoT devices and embedded systems [4]

2.3.2 Mbed TLS. An open-source cryptographic library primarily designed for embedded systems, offering implementations of cryptographic primitives [10].

2.3.3 Wolf SSL. A small, portable, embedded SSL/TLS library targeted for use by embedded systems developers. It is an open-source implementation of TLS written in the C programming language [15]. Similar to Mbed TLS it contains implementations for cryptographic functions.

2.4 Microcontrollers and Resource Constraints

A microcontroller (MCU) contains all the necessary components to create a complete computer system, it is often referred to as a "computer on a chip" [3]. For this project, the selected microcontroller was the ESP32 [2], more specifically the DEVKIT DOIT model, which offered the WiFi capabilities needed to communicate over a WiFi network. This MCU has a dual core CPU that operates at 240MHz and a RAM memory capacity of 512KiB, which introduced challenges when dynamically allocating memory during the program's execution. To store files, a simple 64GB microSD card was used on each MCU, which ensured sufficient capacity for most files. The microSD cards were able to be connected using the microSD card module, made possible due to the MCU being able to connect with a wide range of peripheral modules

2.5 Arduino IDE and Serial Terminal

The program was developed using Arduino IDE, which simplifies the process of compiling code and transferring the compiled binaries to the microcontroller. This is achieved using the xtensa-esp32-elf-gcc compiler and a Python script, esptool.py, which transfers the binaries to the microcontroller via a USB connection. Once the binaries are written to the flash memory of the microcontroller, they can be executed.

The serial terminal enables communication between the user and the microcontroller. Program output can be printed to the screen, allowing the user to receive information. The terminal is also used to accept user input, which can be used to execute commands or modify variables within the program's context.

2.6 Motivation for Library Comparison

As these embedded systems become more widespread in our daily lives, including in industrial applications, healthcare, and wearable devices, it is important to ensure that these devices are able to communicate with each other in a secure manner. The libraries mentioned above, while accomplishing the same goal, have different implementations.

Using a custom P2P file sharing program, these different libraries are compared and tested on different parameters, such as memory usage and time efficiency. These parameters will then be used to determine which libraries offer the best trade-off for use on embedded systems.

3 THREAT MODEL

This paper proposes a realistic threat model for a peer-to-peer file sharing program for microcontrollers connected over a WiFi network.

3.1 Attacker Goals and Capabilities

The main assumption is that the attacker seeks to compromise the confidentiality of peers on the network. To achieve this goal, the attacker may be able to perform the following attacks:

- Eavesdrop on communications to read the contents of transmitted files or messages.
- Perform a man-in-the-middle attack by intercepting and modifying messages in transit.
- Replay previously captured messages to spoof legitimate communication.
- Impersonate clients using their IP address.

It is assumed that the attacker will know the IP address of each peer, along with the port used for communication.

Furthermore, an attacker may look to compromise the availability of the network. This project considers the following attacks:

- Send a malicious payload to a peer's server that exploits a code vulnerability, such as a buffer overflow, resulting in remote code execution or a crash.

- Send continuous messages to a server that would overwhelm the system and possibly produce a crash.

3.2 Out of Scope Attacks

It is assumed that the hardware in use does not have any known vulnerabilities or exploits. The WiFi network is also assumed to be robust and has strong security, such as WPA3 [5]. Therefore, the following attacks are not considered for this project:

- Physical attacks on the hardware components that belong to the system, such as routers or microcontrollers.
- Attacks on the WiFi infrastructure, such as password spraying or other types of attacks that may affect the availability of the WiFi network.

Although the project code is open source and includes sample keys for communication between peers, it is assumed that in real-world use, these keys will be replaced and kept secret from potential attackers.

4 OVERVIEW

The system is a peer-to-peer file sharing application which was designed to run on an ESP32 microcontroller. The application, which was originally designed and tested for two peers, was also designed to be easily modifiable to handle multiple peers.

The program has three different versions, these versions are almost identical to each other; the difference lies on the cryptography libraries being used. The rest of the program structure has been kept consistent to ensure fairness when running tests.

4.1 Program Overview

The program starts its execution by first connecting to a WiFi network. After a successful connection, the microcontroller's assigned IP address will be printed to the terminal. Following this, the server will start on port 5000 and listen for any incoming connections. At this time, the user will be prompted for the IP address of the remote server that they want to connect to.

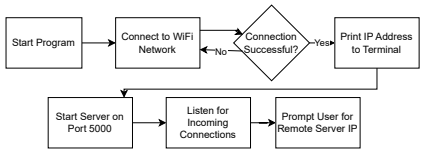

Figure 3: *Flowchart of intial program execution*

5 DESIGN

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6 EVALUATION

Discuss the design of your experiments, the results you obtained, and how they help in evaluating the claims you made in the introduction. You may also use the evaluation results in this section to justify your design choices or assess the contributions of different aspects of your design towards the overall goals.

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7 DISCUSSION

A "limitations" section, as the name implies, describes scenarios where the proposed solution may not work well. Although a "discussion" section could also highlight limitations of the proposed work, it focuses on analyzing the implications of the proposed work for current and future research.

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Cras dapibus, augue quis scelerisque ultricies, felis dolor placerat sem, id porta velit odio eu elit. Aenean interdum nibh sed wisi. Praesent sollicitudin vulputate dui. Praesent iaculis viverra augue. Quisque in libero. Aenean gravida lorem vitae sem ullamcorper cursus. Nunc adipiscing rutrum ante. Nunc ipsum massa, faucibus sit amet, viverra vel, elementum semper, orci. Cras eros sem, vulputate et, tincidunt id, ultrices eget, magna. Nulla varius ornare odio. Donec accumsan mauris sit amet augue. Sed ligula lacus, laoreet non, aliquam sit amet, iaculis tempor, lorem. Suspendisse eros. Nam porta, leo sed congue tempor, felis est ultrices eros, id mattis velit felis non metus. Curabitur vitae elit non mauris varius pretium. Aenean lacus sem, tincidunt ut, consequat quis, porta vitae, turpis. Nullam laoreet fermentum urna. Proin iaculis lectus.

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Sed consequat tellus et tortor. Ut tempor laoreet quam. Nullam id wisi a libero tristique semper. Nullam nisl massa, rutrum ut, egestas semper, mollis id, leo. Nulla ac massa eu risus blandit mattis. Mauris ut nunc. In hac habitasse platea dictumst. Aliquam eget tortor. Quisque dapibus pede in erat. Nunc enim. In dui nulla, commodo at, consectetuer nec, malesuada nec, elit. Aliquam ornare tellus eu urna. Sed nec metus. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

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8 RELATED WORK

It is quite unlikely that you were the first to address this problem. Please use this section, hence, to discuss what prior work had done and how your solution is different from or better than prior work. You may place this section immediately after the "Background" section, if necessary.

Duis aliquet dui in est. Donec eget est. Nunc lectus odio, varius at, fermentum in, accumsan non, enim. Aliquam erat volutpat. Proin sit amet nulla ut eros consectetuer cursus. Phasellus dapibus aliquam justo. Nunc laoreet. Donec consequat placerat magna. Duis pretium tincidunt justo. Sed sollicitudin vestibulum quam. Nam quis ligula. Vivamus at metus. Etiam imperdiet imperdiet pede. Aenean turpis. Fusce augue velit, scelerisque sollicitudin, dictum vitae, tempor et, pede. Donec wisi sapien, feugiat in, fermentum ut, sollicitudin adipiscing, metus.

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Srinivasan Keshav's old—but still relevant—article on how to read a paper might be quite useful for also reviewing prior work [9].

9 CONCLUSION

Briefly summarize your contributions, and share a glimpse of the implications of this work for future research.

Etiam euismod. Fusce facilisis lacinia dui. Suspendisse potenti. In mi erat, cursus id, nonummy sed, ullamcorper eget, sapien. Praesent pretium, magna in eleifend egestas, pede pede pretium lorem, quis consectetuer tortor sapien facilisis magna. Mauris quis magna varius nulla scelerisque imperdiet. Aliquam non quam. Aliquam porttitor quam a lacus. Praesent vel arcu ut tortor cursus volutpat. In vitae pede quis diam bibendum placerat. Fusce elementum convallis neque. Sed dolor orci, scelerisque ac, dapibus nec, ultricies ut, mi. Duis nec dui quis leo sagittis commodo.

Aliquam lectus. Vivamus leo. Quisque ornare tellus ullamcorper nulla. Mauris porttitor pharetra tortor. Sed fringilla justo sed mauris. Mauris tellus. Sed non leo. Nullam elementum, magna in cursus sodales, augue est scelerisque sapien, venenatis congue nulla arcu et pede. Ut suscipit enim vel sapien. Donec congue. Maecenas urna mi, suscipit in, placerat ut, vestibulum ut, massa. Fusce ultrices nulla et nisl.

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ARTIFACTS

Based on the standard Artifact Appendix template used by the USENIX Security Symposium. Please follow the self-contained instructions below and assume (i) you are compiling the final version of the Artifact Appendix (no need to cater to reviewers, but to general users of your artifact) and (ii) you are documenting everything in scope for all the artifact evaluation badges (*Artifacts Available*, *Artifacts Functional*, *Results Reproduced*). More information at [1].

A ARTIFACT APPENDIX

This artifact appendix is meant to be a self-contained document which describes a roadmap for the evaluation of your artifact. It should include a clear description of the hardware, software, and configuration requirements. In case your artifact aims to receive the functional or results reproduced badge, it should also include the major claims made by your paper and instructions on how to reproduce each claim through your artifact. Linking the claims of your paper to the artifact is a necessary step that ultimately allows artifact evaluators to reproduce your results.

Please fill all the mandatory sections, keeping their titles and organization but removing the current illustrative content, and remove the optional sections where those do not apply to your artifact.

A.1 Abstract

[Mandatory] Provide a short description of your artifact.

A.2 Description & Requirements

[Mandatory] This section should list all the information necessary to recreate the same experimental setup you have used to run your artifact. Where it applies, the minimal hardware and software requirements to run your artifact. It is also very good practice to list and describe in this section benchmarks where those are part of, or simply have been used to produce results with, your artifact.

A.2.1 Security, privacy, and ethical concerns. [Mandatory] Describe any risk for evaluators while executing your artifact to their machines security, data privacy or others ethical concerns. This is particularly important if destructive steps are taken or security mechanisms are disabled during the execution.

A.2.2 How to access. [Mandatory] Describe here how to access your artifact. If you are applying for the Artifacts Available badge, the archived copy of the artifacts must be accessible via a stable reference or DOI. For this purpose, we recommend Zenodo, but other valid hosting options include institutional and third-party digital repositories (e.g., FigShare, Dryad, Software Heritage, GitHub, or GitLab — not personal webpages). For repositories that can evolve over time (e.g., GitHub), a stable reference to the evaluated version (e.g., a URL pointing to a commit hash or tag) rather than the evolving version reference (e.g., a URL pointing to a mere repository) is required. Note that the stable reference provided at submission time is for the purpose of Artifact Evaluation. Since the artifact can potentially evolve during the evaluation to address feedback from the reviewers, another (potentially different) stable reference will be later collected for the final version of the artifact (to be included here for the camera-ready version).

A.2.3 Hardware dependencies. [Mandatory] Describe any specific hardware features required to evaluate your artifact (CPU/GPU/FPGA, vendor, number of processors/cores, microarchitecture, interconnect, memory, hardware counters, etc). If your artifact requires special hardware, please provide instructions on how to gain access to the hardware. For example, provide private SSH keys to access the machines remotely. Please keep in mind that the anonymity of the reviewers needs to be maintained and you may not collect or request personally identifying information (e.g., email, name, address). [Simply write "None." where this does not apply to your artifact.]

A.2.4 Software dependencies. [Mandatory] Describe any specific OS and software packages required to evaluate your artifact. This is particularly important if you share your source code and it must be compiled or if you rely on some proprietary software that you cannot include in your package. In such a case, you must describe how to obtain and to install all third-party software, data sets, and models. [Simply write "None." where this does not apply to your artifact.]

A.2.5 Benchmarks. [Mandatory] Describe here any data (e.g., datasets, models, workloads, etc.) required by the experiments with this artifact reported in your paper. [Simply write "None." where this does not apply to your artifact.]

A.3 Set-up

[Mandatory] This section should include all the installation and configuration steps required to prepare the environment to be used for the evaluation of your artifact.

A.3.1 Installation. [Mandatory] Instructions to download and install dependencies as well as the main artifact. After these steps the evaluator should be able to run a simple functionality test.

A.3.2 Basic Test. [Mandatory] Instructions to run a simple functionality test. Does not need to run the entire system, but should check that all required software components are used and functioning fine. Please include the expected successful output and any required input parameters.

A.4 Evaluation workflow

[Mandatory for Artifacts Functional & Results Reproduced, optional for Artifact Available] This section should include all the operational steps and experiments which must be performed to evaluate if your your artifact is functional and to validate your paper's key results and claims. For that purpose, we ask you to use the two following subsections and cross-reference the items therein as explained next.

A.4.1 Major Claims. [Mandatory for Artifacts Functional & Results Reproduced, optional for Artifact Available] Enumerate here the major claims (Cx) made in your paper. Follows an example:

(C1): *System_name achieves the same accuracy of the state-of-the-art systems for a task X while saving 2x storage resources. This is proven by the experiment (E1) described in [refer to your paper's sections] whose results are illustrated/reported in [refer to your paper's plots, tables, sections or the sort].*

(C2): *System_name has been used to uncover new bugs in the Y software. This is proven by the experiments (E2) and (E3) in [ibid].*

A.4.2 Experiments. [Mandatory for Artifacts Functional & Results Reproduced, optional for Artifact Available] Link explicitly the description of your experiments to the items you have provided in the previous subsection about Major Claims. Please provide your estimates of human- and compute-time for each of the listed experiments (using the suggested hardware/software configuration above). Follows an example:

(E1): *[Optional Name] [30 human-minutes + 1 compute-hour + 5GB disk]: provide a short explanation of the experiment and expected results.*
How to: *Describe thoroughly the steps to perform the experiment and to collect and organize the results as expected from your paper. We encourage you to use the following structure with three main blocks for the description of your experiment.*
Preparation: *Describe in this block the steps required to prepare and configure the environment for this experiment.*
Execution: *Describe in this block the steps to run this experiment.*
Results: *Describe in this block the steps required to collect and interpret the results for this experiment.*

(E2): *[Optional Name] [1 human-hour + 3 compute-hour]: ...*

(E3): *[Optional Name] [1 human-hour + 3 compute-hour]: ...*

In all of the above blocks, please provide indications about the expected outcome for each of the steps (given the suggested hardware/software configuration above).

A.5 Notes on Reusability

[Optional] This section is meant to optionally share additional information on how to use your artifact beyond the research presented in your paper. In fact, a broader objective of an artifact evaluation is to help you make your research reusable by others.

You can include in this section any sort of instruction that you believe would help others re-use your artifact, like, for example, scaling down/up certain components of your artifact, working on different kinds of input or data-set, customizing the behavior replacing a specific module/algorithm, etc.

A.6 Version

Based on the LaTeX template for Artifact Evaluation V20231005. Submission, reviewing and badging methodology followed for the evaluation of this artifact can be found at https://secartifacts.github.io/usenixsec2024/.