



CryptoChronicles

LessPM's Quest to a Passwordless Utopian Ecosystem

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Abstract

We describe the implementation of LessPM, a passwordless password manager using Rust as a programming language. While traditional passwords have a long and respectable history, they have become increasingly vulnerable to attacks such as brute-forcing, phishing, and keylogging. LessPM seeks to address these deficiencies with a sophisticated authentication method, called Web Authentication (WebAuthn).

Through asymmetric cryptography, WebAuthn provides a secure authentication experience with the help of user-owned devices such as smartphones or hardware authenticator devices. This would eliminate the use of traditional passwords. To secure passwords stored in LessPM's, we employ AES-256 for encryption and Argon2 for hashing, WebAuthn's Credential ID serves as a key, combined with randomly generated salts and pepper.

We also use Hypertext Transfer Protocol Secure (HTTPS) to secure communication between client and server and configured Cross-Origin Request Sharing (CORS). Additionally, we used an encrypted version of JSON Web Tokens (JWT, RFC7519), inspired by JSON Web Encryption (JWE, RFC7516), to maintain user authentication between HTTPS requests.

We created a separate client as a visual proof-of-concept to adhere to a principle of least-knowledge, while the server handles requests and securely stores user data separately. Finally, we include a security analysis in LessPM's context.

The report provides valuable insights into the implementation and potential benefits of using WebAuthn and a passwordless approach, along with the security measures employed to protect user data on the server, offering promising prospects for a passwordless future in digital security.

1 Introduction

In today's digital landscape, utilizing various identifiers (such as usernames, email addresses, or phone numbers) combined with passwords has become a prevalent method for verifying an individual's identity and ensuring their authorization to access restricted materials.

This report explores the implementation of LessPM, a passwordless password manager that leverages Web Authentication (WebAuthn). LessPM aims to provide an experience free from the constraints and security implications of traditional passwords by placing a strong emphasis on security.

LessPM is designed with a multi-layer security approach to protect confidentiality and integrity of the user authentication process and passwords stored for other registered services. By leveraging WebAuthn's asymmetric cryptographic¹ nature, LessPM creates a robust user authentication mechanism for sensitive data. This is achieved by utilizing authenticators, such as smartphones or hardware authenticator devices, with biometric scanners to authenticate a user through strong means.

WebAuthn, an open standard developed collaboratively by The Fast Identity Online Alliance (FIDO) and World Wide Web Consortium (W3C), aims to provide a more secure authentication experience through biometric scanners on these devices [W3C21b].

When a user initiates the process to register in LessPM, the system issues a challenge constructed by WebAuthn from LessPM's server to the client. The user is prompted to use a biometric scanner on their device, which then constructs a keypair, signing this challenge, before sending this information back to LessPM. LessPM receives and stores the

¹Asymmetric cryptography uses a key-pair consisting of public and private keys. The public key encrypts data, while the private key decrypts it. The keys are mathematically related, but deriving one from the other is infeasible, ensuring secure communication and data exchange.

public key-part of the keypair for later authentication. This process can be seen in Figure 1.

When the user attempts to sign in, LessPM again issues a challenge, prompting the user to use their authenticator’s biometric scanner to verify their identity and presence. This time, however, the challenge is signed by the private key on the authenticator device. The device yields the signature back upon the device successfully verifying the authenticity of the user. LessPM then verifies this signature with the help of the public key stored in the previous step. This process can be seen in Figure 1.

The aforementioned described processes constructs an environment such that a malefactor is required to first access the authenticator device, and then to bypass the device’s biometric security in order to authenticate as the user in LessPM.

Passwords stored in LessPM are encrypted using AES-256, a widely recognized symmetric encryption algorithm [Sch00; DR02; ST01a]. The encryption process includes using a Credential ID (CID) that is derived from the metadata of the public key in WebAuthn, a 128-bit randomly generated salt that is unique for each password, and a 128-bit pepper. This is followed by a hash of the key using Argon2, with a separate 128-bit salt.

To maintain authentication, LessPM uses an encrypted version of JSON Web Tokens [JBS15] (JWT, RFC7519), inspired by JSON Web Encryption [IET15] (JWE, RFC7516) which are also encrypted with AES-256 and attached to HTTPS requests.

The registration, authentication, and password creation/retrieval processes all use these encrypted tokens but LessPM manages and maintains different tokens for each step, providing an extra level of security. Each token is valid for a limited amount of time before expiring. An expired token prompts LessPM to deny access to unauthorized content and forces the user to restart the process.

LessPM’s client stores the token for authentication in a cookie. This cookie is protected by various built-in functionality in browsers, using the at-

tribute `secure` to transfer the cookie over a secure connection only, such as HTTPS. Other attributes include `HttpOnly` to make sure the cookie is inaccessible to JavaScript and Cross-Site Scripting (XSS), `SameSite=Strict` to ensure the cookie is only sent to the same origin it came from, and `Expires` to limit the amount the life-time of the cookie.

LessPM uses this cookie to verify the authenticity of requests between the client and the server. All data the server provides to the client is dependent on the validity of this cookie, and no information leaves the server unless it is valid.

By examining recent advancements in authentication mechanisms and the related innovative potential of WebAuthn, we hope to illuminate the prospects of a passwordless future in digital security.

The findings in this report is not an attempt of getting rid of trivial concepts such as session hijacking, nor is it an empirical study of user’s perception of the technology seen.

2 Literature Review

The history of traditional passwords is a long and respectable one. Polybius’ *The Histories* [Pol23] contains the first documented use of passwords, describing how the Romans employed “*watchwords*” to verify identities within the military. This provided a transparent, simple way to allow or deny entry to restricted areas of authorized personnel only. The story of secret writing (in this context referenced as cryptography) goes back the past 3000 years [Doo18], where the need to protect and preserve privacy between two or more individuals blossomed.

Fernando J. Corbató is widely credited as the father of the first computer password when he was responsible for the Compatible Time-Sharing System (CTSS) in 1961 at MIT [Lev84]. The system had a “LOGIN” command, which, when the user followed it by typing “PASSWORD”, had its printing mechanism turned off to offer the applicant privacy while

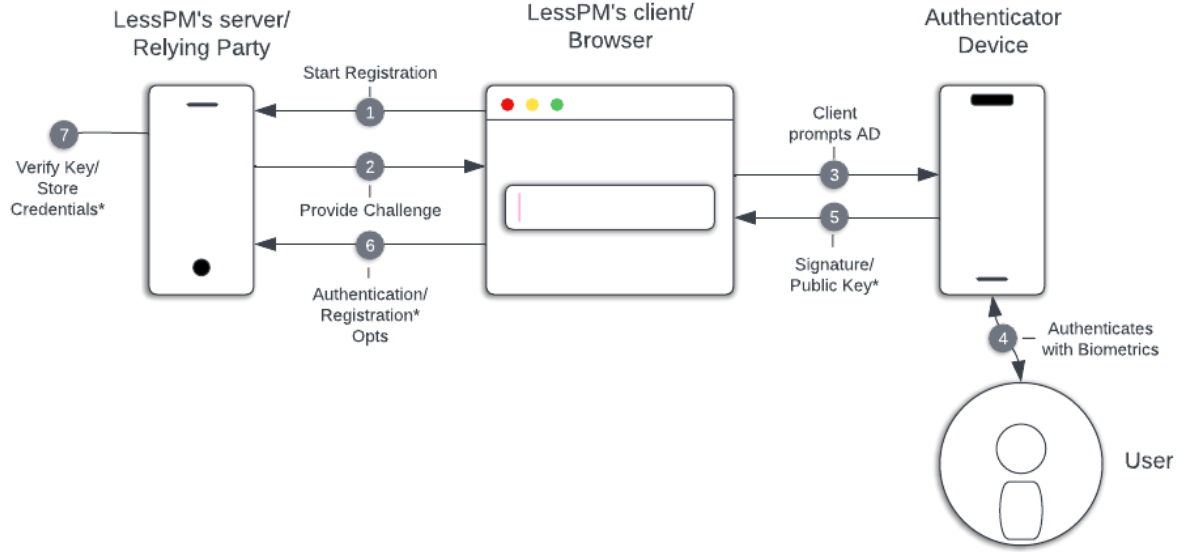


Figure 1: The process depicting the WebAuthn ceremonies in LessPM, starting with the LessPM client issuing a registration. Steps marked with Asterisk indicate the Registration Ceremony, non-Asterisk indicate Authentication Ceremony.

typing the password [65]. Given the long history of passwords and their importance, one could argue that it was a natural and judicious step in the evolution of computer systems.

The study "The Memorability and Security of Passwords", conducted in 2004, provides insights into password creation strategies, including tips on improving password entropy and methods for easy recall of passwords [Yan+00]. With an emphasis on diversity in character selection, password length, and avoiding dictionary words, the study suggests that acronym-based passwords offer a delicate balance between memorability and security [Yan+00].

However, as technology has advanced, the limitations of password-based authentication have become increasingly apparent, leading to the development of more sophisticated methods like Universal Authentication Framework (UAF) [FID17] and WebAuthn [Wor21] through the Fast Identity Online Alliance (FIDO) and The World Wide Web Consortium (W3C).

Passwordless Authentication (PA) is a growing field of study within Computer Science, as traditional authentication methods like passwords are increasingly recognized as vulnerable to attacks such as phishing² and credential stuffing.³ Passwords and sensitive information can also be a victim of successful brute-force attacks [Bon12] through data leakages by hacking or purchasing information on the dark Web.

Following NIST [Nat20; Pau17], authentication should consist of covering one of the three principles in Figure 2.

There are many approaches to passwordless authentication or a second step to authenticate

²Phishing is a form of attack where a hacker tries to leverage Social Engineering to act as a trusted entity to dupe a victim to give away credentials by opening an email, instant message, or text message, then signing into a spoofed website, seeming legitimate [OWAnd].

³Credential stuffing refers to the practice of using automated tools to inject compromised or stolen username and password combinations into web login forms to gain unauthorized access to user accounts [Mulnd].

- **Something you know:** Such as a password, an answer to a personal question, or a Personal Identification Number (PIN).
- **Something you have:** A device that contains some token or cryptographically signed keys.
- **Something you are:** Biometrics of any sort or kind. Facial recognition, retina scan, fingerprint and similar.

Figure 2: The Three Principles of Password Security [Sch00; Nat20].

with a one-time password.⁴ In 2022, Parmar et al. [Par+22] described several attractive solutions, along with their advantages and drawbacks, for performing PA using the most common methods. The study discovered that PA commonly gets accepted as the most frictionless authentication system for User Interfaces (UI) [Par+22]. Biometrics was mentioned as one of the authentication methods, concluding that it captures universal human traits, encouraging differentiation from one another [Par+22]. The same study raises the caution surrounding the loss of authentication devices and how fingerprints can be compromised [Par+22].⁵

One promising approach is using the FIDO Alliance’s collaborative work with W3C to create WebAuthn. WebAuthn permits users to authenticate through biometric information stored on a device in the user’s possession (i.e. phone, computer) or a physical security key (i.e. YubiKey, Nitrokey, Etc.) [Wor21].

In [Hus22], Huseynov utilized a Web interface with WebAuthn to create credentials that users could use for a VPN. The client required a user to authenticate through the procedure of WebAuthn. On a successful request, the Remote Authentication

Dial-In User Service (RADIUS) creates a temporary username and password, which would then be transferred as a response to the end-user, permitting them to copy and paste it into the necessary client, alternatively to construct a batch file which would establish the correct connection [Hus22]. The study suggested creating a solution for a VPN client which embedded some browser components [Hus22].

Gordin et al. [Gor21] implemented PA into an OpenStack environment using WebAuthn, which increased security and bypasses the risk of malefactors employing leaked passwords on other services [Gor21].⁶ The PA process considerably reduced the number of attacks towards a server because the server no longer has user authentication secrets [Gor21]. They, however, utilized a fingerprint as the primary biometrics, citing cost as a primary factor to discourage the use of FIDO2 [Gor21].⁷

Statista reported in 2020 that between 77–86% of smartphones now have a form of biometric scanner built into their device [Sav22]. Gorin, Et al. continue by mentioning that some individuals have trouble using their biometric scanner or getting it to work correctly on their device [Gor21], which can be a potential drawback for user adaptability.

According to a study conducted by Lyastani et al. in 2020 [Ghr+20], a significant portion of users found the usage of WebAuthn and Fido2 standard to be easy and secure, but with some concerns about losing access to their accounts or fear of others accessing their accounts [Ghr+20]. The study utilized a fingerprint Yubikey for the authentication process. Despite some reservations, the study found that overall, WebAuthn and Fido2 have good usability for passwordless authentication [Ghr+20].

The authors reported that users automatically associated the loss of the AD with losing access to the account [Ghr+20] – and vice versa – indicating

⁴Often referenced as Two-Factor Authentication or Multi-Factor Authentication.

⁵The security implication of using the core concept of FIDO2’s WebAuthn is subject to storage in the system on Apple-specific devices [App23a]. On an Android device, the implementation is up to the manufacturer of the device, where Samsung has implemented a Physically Unclonable Function [Lee+21] (PUF).

⁶See Section 3.3 for further explanation as to how this works.

⁷Authentication was provided through the Keystone environment on the OpenStack platform.

that users are slightly unwilling to replace the initial principle of "*Something you know*" with the second "*Something you have*" and third "*Something you are*" principle. Additional research is necessary to educate users, increase trust and confidence in the technology, and address concerns about the potential loss of account access.⁸

Morii et al. [Mor+17] investigated the potential of FIDO as a viable PA solution in 2017 when the FIDO2 and WebAuthn standards were yet to be widely adopted. The authors noted that, at that time, only the Edge browser had implemented proper support for FIDO2 and WebAuthn [Mor+17]. Despite the limited browser support, the study demonstrated the feasibility of integrating PA into the well-established authentication system, Shibboleth [Shi22; Mor+17].⁹

As the technology evolved from FIDO to FIDO2.0, some security concerns persisted, such as session hijacking¹⁰, which can compromise user accounts [Mor+17], highlighting the need to protect these.

Since the publication of Morii et al.'s research, browser support for FIDO2 and WebAuthn has significantly improved, with major browsers like Google Chrome, Mozilla Firefox, Apple Safari, Microsoft Edge, and Vivaldi now offering support for these standards. This broader adoption has enabled the more widespread deployment of PA solutions, providing increased security and improved user experiences across various online services.

However, the ongoing evolution of security threats and the increasing sophistication of attackers highlights the need for continuous research and development in the field of passwordless authentication, ensuring that new methods and standards

are both secure and user-friendly.

Having explored various studies and developments in the field of PA, it is evident that this area has been continuously evolving to provide secure, user-friendly solutions. However, the implementation of these solutions into stand-alone, real-world applications, such as password managers, independent of other login systems, is a critical aspect that requires thorough investigation.

In the following section, we will examine the methodology employed in this report to integrate a passwordless system into a password manager, taking into account the challenges and concerns identified in the literature. By doing so, we aim to contribute to the growing body of knowledge on passwordless authentication and its practical applications.

3 Methodology

In today's world of rapidly evolving technology, it is crucial to have a solid foundation in the underlying concepts and protocols that drive modern systems. This section aims to provide a comprehensive understanding of the key technologies and principles that are relevant to LessPM. As we explore the development and implementation of LessPM, our focus will be on the key components, technologies, principles, and steps that form LessPM's development process and encapsulation.

Our approach encompasses an explanation of the system architecture, as well as an in-depth description of the key components, technologies, tools, and steps that are involved in LessPM's encapsulation and development process to create the prototype. By thoroughly exploring these fundamental topics, we can better appreciate their significance and application in the context of the implementation, design, and architecture presented in LessPM.

One critical aspect of the development and system is its security and robustness. By providing a comprehensive account of the system development process, we aim to enable readers to understand the

⁸We believe that these concerns are mostly raised due to using a YubiKey and that using a phone-based authenticator would reveal other results.

⁹Shibboleth is a widely-used, open-source federated identity solution that enables secure single sign-on across multiple applications and organizations.

¹⁰Session hijacking refers to an attacker gaining unauthorized access to a user's authenticated session, often exploiting weaknesses in the handling of cookies, sessions, or JSON Web Tokens (JWT). See Section 3.2.

technical aspects of our work and assess the validity and relevance of our findings. To support the evidence of this report, we conclude with a security analysis to better understand the implications of a thorough implementation.

3.1 Environment

To implement LessPM, we approached the development from a type-safety environment.

3.1.1 Server

We chose Rust as the programming language for our backend, which provided significant benefits regarding the software development environment.

Rust’s emphasis on safety and performance allowed us to create a highly secure and efficient environment for LessPM without the risks typically associated with memory-related vulnerabilities [Riv19]. The built-in memory management and focus on concurrency ensures that LessPM ran smoothly, which is crucial [FLP85] when dealing with sensitive user data.

Additionally, Rust’s surrounding ecosystem is at rapid growth [Kor], containing a vast library of high-quality crates¹¹, which enables expeditious development and easy integration of various functionality. Utilizing Rust’s distinctive features, LessPM achieves enhanced security and reliability in the context of user authentication [Riv19], showcasing the benefits of utilizing a modern programming language.

LessPM ran an instance of an HTTPS server, serving as a wrapper for the sensitive data.¹² The Chromium developers mandate the constraint of a secure connection to guarantee that the pertinent Application Programming Interface (API) is invoked exclusively within a secure context [web16].

¹¹**Crate** is the Rust-specific name for a package or library.

¹²We took advantage of the Authorization header during development, as specified in RFC 7519. However, the framework we used for the server required us to expose the usage of **Authorization header** to access it in the client. See Section 3.8 for further explanation.

During development, we established a secure connection by using a self-signed certificate for the “localhost” domain.

As a deliberate decision, we opted for MongoDB due to its NoSQL architecture, which facilitated the storage of Object-like structures [Mon21] including passwords, user accounts, and other related data that LessPM stores.

3.1.2 Client

An essential part of the implementation was to create a viable client that could function as a visual entry point to LessPM and proof-of-concept. For the simplicity of the project, we chose React as a framework. React is a JavaScript library for building user interfaces, offering an efficient and flexible approach to web development. The design of LessPM was influenced by the principles of least-knowledge [LH90], which underlined by the decision to ensure that the LessPM client only retained necessary information to function properly, containing no knowledge of LessPM’s server nor its implementation.

We took advantage of React’s ability to construct a single-page application with no routing capabilities, avoiding the possibility of a malefactor utilizing URL tampering or manipulation¹³ to attempt privilege escalation or accessing restricted data.

When initiating the project’s development, we had a strong vision of creating a client that could seamlessly integrate with Chromium-based browsers as an extension.¹⁴ However, we quickly discovered that the Rust cargo used to perform WebAuthn requests did not implement this functionality. We reported this issue upstream to the authors of the cargo, and we will continue to work with the authors to ensure a proper implementation of this functionality in the future.

¹³Malefactors can perform URL Manipulation, which involves modifying a URL to request resources that would otherwise be inaccessible to a user.

¹⁴In the client’s project folder are traces of a manifest.json file and build scripts to have the client run in an extension.

LessPM's client maintains authentication and authorization through an encrypted JSON Web Token (JWT, RFC7519), inspired by JSON Web Encryption (JWE, RFC7516), passed back and forth between the server and client.

3.2 Authentication & Authorization

A system that maintains authentication and authorization through a stateless protocol such as HTTPS, requires some information to authorize a client between requested resources. LessPM took advantage of JWTs and an inspired variation of JWEs for this purpose. Although JWTs are not inherently encrypted [JBS15], combined with JWE, they serve as an essential backbone for secure data transfer in LessPM.

3.2.1 JSON Web Tokens

JWT is a compact, URL-safe string intended to transfer data between two entities, often represented as a Base64 encoding. They are often used as part of authentication and authorization scheme within a web service, application, or API, and LessPM does this as well. The data in the string is delivered as a payload and is referred to as a **claim** [JBS15].

The JWT typically consist of three parts: header, payload, and signature. The header and payload are serialized into JavaScript Object Notation (JSON) and then encoded using Base64 to ensure a URL-safe format. This permits larger bits of data to be sent in a compressed, **safe**¹⁵ format.

JWTs are widely used for scenarios such as single sign-on (SSO), user authentication, and securing API endpoints by providing an efficient and stateless mechanism for transmitting information about the user's identity and permissions [Kar18]. According to [JBS15], these should be attached to the **Authorization** part of the HTTPS header, along

with a hardcoded **Bearer** part preceding the token, as the value of the header.

In LessPM, the JWT claim contained data we could use to validate and authenticate a user between stateless HTTPS requests. LessPM utilizes two functionalities of JWTs to ensure the validity of the Base64-encoded token.

First, all tokens passed back and forth between the LessPM server and client receives an expiry time. We enforce this technique to ensure and maintain the security of accessed resources, requiring a user to reauthenticate when the expiry timestamp is passed.

Second, The tokens used in LessPM are cryptographically signed with RSA Signature Scheme with Appendix - Probabilistic Signature Scheme (RSASSA-PSS) using Secure Hashing Algorithms with 512-bit size (SHA-512), and is derived from the Rivest-Shamir-Adleman (RSA) encryption. The encryption is performed with a key-pair stored on LessPM's server to mitigate the risk of token forgery and so LessPM can maintain the validity and authenticity of the tokens created. This prevents unknown authorities from constructing or hijacking tokens belonging to LessPM.¹⁶ Other signature algorithms that can be used include Hash-Based Message Authentication (HMAC), Elliptic-Curve Digital Signature Algorithm (ECDSA), or a plaintext secret stored on the server. LessPM uses RSASSA-PSS with SHA-512 due to the asymmetric operations the algorithms perform on the encryption and decryption, whereas HMAC and ECDSA is based on symmetric- and elliptic curve cryptography.

3.2.2 JSON Web Encryption

By default, JWTs are not encrypted. It is out of the question to unnecessarily expose any sensitive details about LessPM's inner workings. This lead to

¹⁵Safe in this context should not be interchanged with secure. We reference safe as a way to transfer the data over the selected protocol, in LessPM's case this HTTPS.

¹⁶Hijacking a token could happen by a man-in-the-middle attack. This is done by a third-party individual listening and intercepting traffic in order to either read data or input their own in a client's request. This would allow an attacker to gain access to privileged information.

the decision of finding a way to encrypt the contents of the token before they are sent from LessPM’s server. Without the encryption, any malefactor could decode the Base64 encoding and gain read access to the claim that LessPM uses to authorize and authenticate.

To perform this operation, LessPM seeks inspiration from JWEs and RFC7516 [IET15].¹⁷

Before the RSASSA-PSS signed JWT is attached to the HTTPS header, LessPM encrypted the Base64-encoded data using AES-256, before turning them into a new Base64 encoded string. Encrypting the token with AES-256 elevated the overall security of the JWTs, making them more suitable for transferring sensitive data between the intercommunicating entities in LessPM.

As a final step, the ciphertext created by AES-256 is again encoded into a new Base64. When LessPM again receives this claim, we used it to gather details about the user who made the request and responded to the request accordingly. An example of this encoding can be seen in Appendix A.1.

The process functions as follows in LessPM, and can also be seen in Figure 3:

1. The client completed an authentication request.
2. A claim was constructed and created on the server. The claim could have been any data the server wished to use to authenticate the legitimacy of a future request.
3. The claim was signed with the desired algorithm. This could also have been a secret, stored on the server.
4. The claim is encoded into a Base64 string.
5. The Base64 encoded string is passed to AES-256 encryption algorithm, creating a ciphertext.

¹⁷To properly implement JWE, metadata should be encoded into the token, such as what algorithm performs the encryption [IET15]. For further explanation, see Section 5.

6. The ciphertext is created into a new Base64-encoding, which is the final token.
7. As part of the response to a request, the server appended the token.
8. The client received the token and carried it upon the next performed request.
9. When the server received the token again, it decodes the Base64-encoded ciphertext.
10. The ciphertext is decrypted, decoded and reconstructed to a claim.
11. The `exp` property of the JWT is validated and LessPM takes action accordingly.

Further, the LessPM’s server checked and verified the token before proceeding with any requests made to it. This information is updated and inspected between each re-render [Rea] of LessPM’s client.

3.3 WebAuthn

We used WebAuthn to perform passwordless authentication in LessPM. WebAuthn is a collaborative, open standard between the FIDO Alliance and W3C. The aim of the standard is to implement a secure, robust key-based authentication system for the web, to strongly authenticate users through biometrics [Wor21].

The concept relies on the use of a third-party device, called an Authenticator Device (AD), which leverages asymmetric cryptography. These devices employ biometric or hardware-based mechanism to provide secure and reliable means of authenticating a user in LessPM.

Upon registering in LessPM, the AD generated a key-pair called a Passkey. This Passkey contained a CID uniquely generated for each registered key-pair [21a; 21b], per services registered on the AD.

Further, if a malefactor gains access to an individual’s Passkey, they might compromise one specific service, whereas a traditional password could potentially compromise multiple services where password reuse occurs [Wan+18]. This suggests that

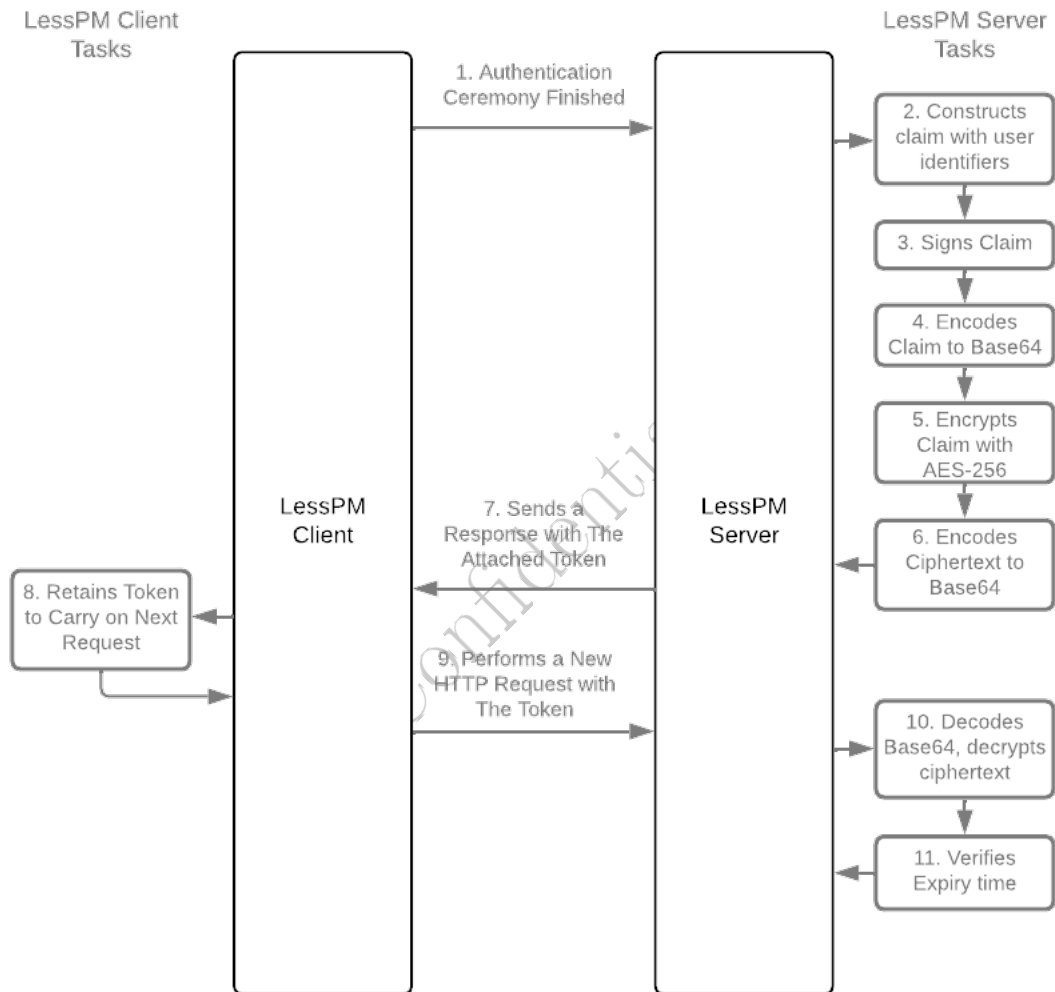


Figure 3: The Process LessPM performs each time a token is initiated. Starting with the finish of the Authentication Ceremony. The Y-axis depicts the time in which the actions are taken.

WebAuthn could create a stronger level of security, whereas a traditional password exposed in a leak might leave a user susceptible to losing access across services and devices through the reused password. Preventing the potential security threat of password reuse is a top priority for LessPM. That is why WebAuthn has been chosen as the preferred standard for passwordless user authentication in LessPM.

WebAuthn further attempts to mitigate phishing, man-in-the-middle, and brute-force attacks through its intuitive design [Wor21]. By leveraging the increasing market of smartphones with biometrics [Sav22], WebAuthn becomes a natural extension, not just for LessPM, but for general authentication.

In order to increase the security of authenticated requests, each of the steps using WebAuthn, Registration 3.3.1, Authentication 3.3.2 and Password-Creation & Retrieval 3.3.3) receives different tokens with different information and is constructed, verified, and discarded separately in LessPM.¹⁸ We made this decision to further elevate security in LessPM, so that an exposed token could not serve as more than one entry point for one of the steps.

3.3.1 Registration

When a user tried registering in LessPM, the client performs a registration request to the server, called a Relying Party (RP), carrying a relevant User Identifier (UID. i.e. username, phone number, email, Etc.). This is done to check whether a user with a similar UID existed¹⁹ in the system, and LessPM denies the registration process if it does.

If there are no users with a similar UID, LessPM responds by initiating a Registration Ceremony (RC), generated a challenge and a Unique User Identifier (UUID), which serves as the body of the

HTTPS response. LessPM also attached a JWE to the HTTPS response `Authorization` header which is sent to the client.

The `expiration` time for this claim is set to one minute to allow the user some time to authenticate.²⁰ The claim expired after this minute, and the user would then have to restart the process. This expiration timer was a decision we made to emphasize security within LessPM further.

Using the issued challenge, LessPM's client called the browser-integrated WebAuthn API²¹, prompting the user to utilize their AD to create a new Passkey credential through the Client To Authenticator Protocol (CTAP2)²² for LessPM. At this point, it is entirely up to the user to decide what device to use to authenticate. For our development, we used an iPhone 13 Pro Max, a Samsung S21, and a Samsung Galaxy A52 to test authentication.²³ We scanned the QR codes prompted through our phones, which initiated the key-pair generation on the AD after a successful biometric scan, such as facial recognition.²⁴

Finally, the AD signs the challenge using the private key stored on the device. The created public key, signed challenge, and additional metadata are combined into a public key credential object, which is forwarded to the client through CTAP2 and then sent to LessPM in a new request.

Before the new request reaches the RP/LessPM, an authentication middleware checks and validates the JWE, denying the request with an

¹⁸The token for password creation/retrieval is the same as verifying that a user is signed in and authorized to create entries on behalf of the user.

¹⁹WebAuthn does not require to check whether the CID generated by the AD exists. However, accepting users with similar identifier might leave a risk of providing unauthorized access. Hence why LessPM performs such a check.

²⁰WebAuthn describes a timeout performed within the system. In our case, this timeout is one minute. However, we chose to add this extra step to secure LessPM further, and JWEs require an expiry time (See Section 3.2).

²¹In LessPM's case, this is the `navigator.credentials` API provided by the browser.

²²The user is prompted to use their AD to prove their presence, which can involve facial recognition, providing a fingerprint, or any other modality supported by the device that the user chooses.

²³Other alternatives included a YubiKey, NitroKey, Etc.

²⁴There is a question of concern that photography can bypass facial recognition. Apple uses built-in sensors to scan depth, colours and a dot projector to create a 3D scan of a person's face. However, this approach prevents the use of photography to authenticate through their FaceID and TrueDepth technology [App23b].

Unauthorized HTTPS status code if the request is invalid.²⁵ If the RP/LessPM can validate the authenticity of the signed challenge and public key through WebAuthn, the user was stored in the database, along with the UUID generated.

Thus completing the RC. This process can be seen in Figure 1

3.3.2 Authentication

When a user wishes to perform authentication (commonly referred to as **logging in**), much of the same procedure occurs in LessPM. The user issued an authentication request in the LessPM's client, carrying the UID the user used to register. The client included this information in the body.

Upon receiving an incoming request, the RP/-LessPM checked the database for the containing UID. LessPM immediately rejected the request, should the user not exist in the database. If LessPM found an associated user with the UID in the database, the server responds by initiating and issuing an Authentication Ceremony (AC), collecting the public key associated with the user from the database and generating a new challenge. Upon validation²⁶ of the public key, LessPM creates a new JWE, which, like registration, also receives an **expiry** time of one minute for the user to authenticate, attached to the **HTTPS Authorization** header.

The challenge is issued and LessPM's client then calls the browser-integrated WebAuthn API again, prompting the use of the original AD to validate and sign the challenge through CTAP2. Unlike the registration process, the AD now yields a signed signature based on the challenge issued by the RP/LessPM, which is transferred back to LessPM's client through CTAP2 with some AD specific data [W3C21a]. A new HTTPS request is then issued with the signed challenge and the AD spe-

cific data, and the RP/LessPM then validated the signature using the stored public key. LessPM considers the user authenticated if the RP accepted and validated the signed challenge. If the AC is unsuccessful at any point in the ceremony, the ceremony is aborted and considered invalid.

Upon success a new JWE is generated. This time, the **expiry** time-to-live is set to a 15-minute²⁷ time-frame, allowing the user some time to perform necessary activities within LessPM. The WebAuthn-related process can be seen in Figure 1 and the JWE-related process can be seen in Figure 3.

3.3.3 Password Creation & Retrieval

Passwords are sensitive in nature, so it seems only natural in a security context to enforce an extra level of authentication upon retrieving and creating one unique password in LessPM.²⁸

The following options are presented to a user when they initiate a password creation process in LessPM's client:

- **User Identifier:** An identification that the user wants to associate with the password entry they are storing. Such as a username, phone number, or email.
- **Website:** A URL or similar where the password belongs.
- **Password:** The user is prompted with the input to create a strong password automatically, choosing options such as numbers, special symbols, smaller or larger characters, and the length. As an option, the user was also permitted to construct their password but warned by a warning saying that this option is less secure.

As a final step before a password is created and stored, the user is prompted to reauthenticate with

²⁵Validity in this context means not timed out, tampered with, or similar.

²⁶Validation in this context only means that the key stored in the database is valid.

²⁷The specification does not specify any upper- or lower bounds for the expiry time [JBS15]

²⁸We retrieved a complete list of the user's passwords upon successful authentication. The hashed version of the password is stripped of the returned values to protect and enforce security.

their AD. This is done in a similar manner as described for registration (See Section 3.3.1) and authentication (See Section 3.3.2).

To retrieve the plaintext version of the password, LessPM enforces a new authentication request through the AD. We made this decision to attempt to ensure the owner²⁹ of the password’s presence³⁰. In such a scenario where the owner left their computer open while logged in to LessPM, a malefactor would not be able to simply retrieve a password at will. To decrypt a password, LessPM also required the CID from the AD to perform the key-reconstruction for the encryption algorithm employed in LessPM. Further details about how encryption is achieved can be seen in Section 3.4.

3.4 Password Encryption

Due to the nature of a password manager, where a user should not know their passwords in order to keep them secure, LessPM can’t follow a typical authentication scheme.

In a typical authentication scheme, a password can be stored and hashed using multiple vectors to increase security. Such measures include using a **salt**³¹ and **pepper**³². When trying to authenticate, the user would provide their UID and password. These values are collected from the database, where a password can be stored in any form from plaintext to a hashed variation through a hashing algorithm such as PBKDF2, Argon2, or the SHA-family. After the values are collected from the database, the

²⁹In this context, we distinguish between **user** and **owner** as the person that created the password, not the person currently using LessPM.

³⁰This approach is also used in password managers on phones to avoid situations where a user might have left their computer unlocked.

³¹Salting is the process of adding a randomly generated string consisting of arbitrary characters to the password before creating a hash [See15]. This randomness of the salt makes identical passwords hash to different values, which can then be stored in the database.

³²A pepper is the process of adding a hardcoded string to the password. Unlike the salt, the pepper is often stored in the code and used as an extra measure to increase security. A sufficiently large pepper will require a malefactor to spend extra time to compute a hash.

authentication scheme checks them against the provided values from the user.

If a **salt** and **pepper** is part of the authentication scheme, they are both required to be appended (in the correct order) to the user-provided password, before the hashing and validation can take place. Upon successful validation, the user is considered authenticated and logged in.

Securing the user passwords in LessPM made this process more complicated than the one described above. Furthermore, since the passwords in a general password manager should be a randomly generated string unknown to the applicant, we cannot hash the user-provided input and compare that hashed value. This influenced the decision to introduce encryption on the passwords in LessPM.

3.4.1 Advanced Encryption Standard

We decided on the Advanced Encryption Standard (AES) with a 256-bit key-size (AES-256). AES has, since its inception in 1998, become the gold standard for encrypting various information across applications [Sch15; DR02]. In 2001, it was adopted as the successor of the leading Data Encryption standard (DES) by The National Institute of Standards and Technology (NIST) in 2001 [NIS00].

AES operates on fixed-sized units of data referred to as **blocks** [ST01b], supporting keys of sizes 128-, 192- and 256-bit [ST01c]. A Substitution-Permutation Network (SPN) structure forms the basis of the design, which achieves a high level of encryption and security in LessPM through multiple rounds of processing by combining substitution and permutation [ST01d]. AES-256 employs a 256-bit key and consist of 14 rounds of encryption, offering an advanced level of security compared to its counterparts with shorter key lengths and fewer rounds [ST01a].

In each round of encryption, AES-256 undergoes four primary transformations, operating on a 4×4 block, as described below:

1. **SubBytes** is a non-linear substitution step where each byte is replaced with another according to a predefined lookup table.
2. **ShiftRows** cyclically shifts each row of the state over a certain number of steps. of the State over varying numbers of bytes while preserving their original values.
3. **MixColumns** is a process that works on the columns of the state by combining the four bytes in each column through a mixing operation.
4. **AddRoundedKey** involves combining a sub-key with the state³³ by applying a bitwise XOR operation.

The larger key-size in AES-256 provides an exponential increase in the number of possible keys for each password encrypted in LessPM, making it significantly more resilient to brute-force attacks and further solidifying its position as a robust encryption standard for safe-guarding sensitive information.³⁴

3.4.2 AES-256 in LessPM

AES-256 requires a 256-bit key to encrypt and decrypt data. Since the CID generated by WebAuthn is unique and random for each application and device, we decided to have the CID serve as a basis for constructing the key used to encrypt passwords in LessPM.

We based the key for each password on the following premise:

1. We took advantage of the fact that each CID is unique in every application (see Section 3.3). We therefore used 192-bits of the string that is the CID, converting it to integers. Since every

CID is unique depending on the device, some CIDs are smaller than 192-bit and some are longer. To compensate for this, LessPM constructed and generated a random padding to reach the remaining difference when the CID is smaller than 192-bit.

2. We appended each key with a random 128-bit salt of integers and stored these bits with the entry in the database.
3. Then we add a 128-bit of pepper collected from an environment variable to in LessPM's code to finish the key.

We used these 448 bits as the input for the key-derivation function, Argon2 (See Section 3.5).

Upon hashing, each key is also subject to a 128-bit salt explicitly generated for the password's key in LessPM. After encryption, the password is stored in an encrypted Base64-encoded format in LessPM if the authentication process proved successful. This process happened individually for all passwords constructed and stored within LessPM.

3.5 Hashing

When we searched for a good key-derivation function, we first came across Password-Based Key Derivation Function 2 (PBKDF2). We saw PBKDF2 as a good solution for the project, but after researching the topic further, we ended up with Argon2.

Argon2 is regarded by some to be more secure than PBKDF2 due to its modern design considerations, including memory-hardness and protection against side-channel attacks, which makes it more resistant to brute-force and rainbow table attacks. PBKDF2 offers to set an amount of iterations to construct the hash and which pseudorandom function to use.

3.5.1 Argon2

Argon2 aims to provide a highly customizable function, tailored to the needs of distinct contexts [al17].

³³The term **state** refers to an intermediate result that changes as the algorithm progress through its phases.

³⁴The practical number of potential keys for an AES-256 implementation is 2^{256} possibilities. This gives us an approximation of 1.1579209×10^{77} options. The number is theoretical, as this is a worst-case scenario of options an attacker must go through to find the right key.

Additionally, the design offers resistance to both time-memory trade-off and side-channel attacks as a memory-hard function [al17].

The Key-Derivation Function (KDF) fills large memory blocks with pseudorandom data derived from the input parameters, such as password and salt.³⁵ The algorithm then proceeds to process these blocks non-linearly for a specific number of iterations [al17].

The KDF offers three configurations, depending on the environment where the function will run and what the risk and threat models are, which we take advantage of in LessPM. These can be seen in Figure 4.

- **Argon2d** is a faster configuration and uses data-depending memory access. This makes it suitable for cryptocurrencies and applications with little to no threat of side-channel timing attacks.³⁶
- **Argon2i** uses data-independent memory access. This configuration is more suitable for password hashing and key-derivation functions.³⁷ The configuration is slower due to making more passes over the memory as the hashing progresses.
- **Argon2id** is a combination of the two, beginning with data-dependent memory access before transitioning to data-independent memory access after progressing halfway through the process.

Figure 4: The three configurations offered by Argon2 [al17].

Since LessPM is required to run in as safe of an environment as possible, Argon2’s configurations offers a suitable solution.

Argon2, as a memory-intensive hashing function,

³⁵Argon2’s intension is to have a 128-bit salt for all applications but this can be sliced in half, if storage is a concern [al17].

³⁷Side-channel timing attacks analyze execution time variations in cryptographic systems to reveal confidential data, exploiting differences in time caused by varying inputs, branching conditions, or memory access patterns.

³⁷Due to the nature of prioritizing security, LessPM uses the third configuration.

demands substantial computational resources from attackers attempting dictionary-³⁸ or rainbow table attacks. This characteristic significantly hampers the feasibility of cracking passwords using such attacks, constructing an ideal scenario for LessPM’s password vault. The algorithm’s customizability allowed us to adjust its behaviour based on memory, parallelism, and iterations, catering to LessPM’s security requirements and performance needs. All of these benefits contributed to why LessPM uses Argon2 instead of PBKDF2.

3.5.2 Configuring Argon2 for LessPM

Argon2’s hashing output is dependable on configurations [al17].³⁹ Given that we emphasized security, we opted for the **Argon2id** configuration, which gave us equal protection against side-channel and brute-force attacks.

With Argon2’s customizable offer to set the option for required amount of memory, iterations, and parallelism, the memory option forces a malefactor to use a specific amount of memory for each attempt to construct the hash. The only way a malefactor can get past this requirement is to purchase more memory.⁴⁰

For LessPM, we used 128 Megabytes of memory to construct the hash.⁴¹ We went for the default suggestion of two iterations to complement the memory. To finalize the configuration, we added 8 degrees of parallelism since the system where we

³⁸A dictionary attack is an approach where an attacker tries to find a hash by searching through a dictionary of pre-computed hashes or generating hashes based on a dictionary commonly used by individuals or businesses.

³⁹Dependable in this context refers to each configuration that can possibly be constructed. An instance of Argon2 with 256 Megabytes of **memory** will not return the same hash as 255 Megabytes. The same is true for the amount of **iterations** and **parallelism**.

⁴⁰As a side note, the increase in memory usage will scale as technology evolves and more memory becomes common.

⁴¹According to [al17], the reference implementation using Argon2d with 4Gb of memory and 8-degree parallelism, the hashing process should take 0.5 seconds on a CPU with 2Gz. However, we were unsuccessful in seeing anywhere close to similar results.

developed it consists of 8 cores.⁴²

As these configurations are crucial for computing the original hash, LessPM’s key hashing provides robust resilience against brute-force and side-channel attacks [all17].

In 2015, Argon2 won the Password Hashing Competition [The].⁴³

3.6 Cors

Cross-Origin Resource Sharing (CORS) must be configured correctly when the server and client are running separately on different ports.

When a web page tries to access a resource hosted on another domain, browsers perform an additional request to the server, called a “preflight”. The preflight request determines whether the request that the web page is trying to make to the server is allowed. This request is done through the `OPTIONS` method in HTTP and contains some information about the origin, accepted Content-Type, and similar for the actual request.

LessPM responds to this with what methods and headers are allowed, denying the actual request from ever happening if the preflight is not successful.

We constructed a CORS layer⁴⁴ which contained the two domains for the server and client, permitted credentials⁴⁵ and then permitted the two HTTP methods `POST` and `GET`. We also ensured the `Content-Type`, `Authorization`, and `Cookie` headers are permitted.

Any other methods or headers should abort the request in the preflight.

⁴²The degree of parallelism is affected by how many cores a CPU contains [all17].

⁴³NIST’s competition to find an encryption algorithm inspired the Password Hashing Competition, but it took place without NIST’s endorsement.

⁴⁴In this context, we referred to a layer as a wrapper around all other requests.

⁴⁵To pass the JWT token back and forth between the server

3.7 Cookie

JavaScript can access and manipulate Cookies [HXC18]. We utilized the browser’s local cookie storage to attempt secure authentication between requests.⁴⁶ We attempted a couple of strategies listed below to fortify the cookie that LessPM set in the browser against a malefactor:

- **Strict SameSite:** This ensures that the cookie is safeguarded against Cross-Site Request Forgery (CSRF) attacks and remains restricted to its original origin domain.
- **Expires:** Once the system authenticated the user, it gave the cookie a Time-to-Live (TTL) mechanism similar to the JWE, which remained valid for only 15 minutes.
- **Secure:** We applied the `Secure` attribute to ensure that the cookie was only accessible through the HTTPS protocol. This protocol encrypts the data being sent back and forth between the client and the server, attempting to avoid eavesdroppers.
- **HttpOnly:** Setting `HttpOnly` tells the browser to make this cookie inaccessible through JavaScript. This property is important to mitigate session hijacking.

3.8 Security Analysis

The security of a passwordless password manager is of paramount importance to protect sensitive user information and prevent unauthorized access. In this subsection, we conduct a comprehensive security analysis, identifying potential attack vectors and outlining the defensive measures that have been implemented to mitigate these risks.

The defensive measures include industry-standard security protocols such as HTTPS, JWT/JWE, Argon2 hashing, salt and pepper

⁴⁶The cookie storage in a browser is subject to any vulnerabilities that can be performed on an SQLite database while having access to the computer where it is running.

techniques, CORS configuration, and secure cookie management.

Additionally, different JWTs are used for registration, authentication, and password creation/retrieval to minimize the risk of exposure. These defensive measures collectively aim to provide a robust and secure architecture for LessPM, safeguarding against various threats and ensuring the confidentiality, integrity, and availability of user data. Each element in the security analysis contains a rating, as well as a status on implemented and unimplemented.

► **HTTP** [Rating: 5 – Status: Implemented]

Weakness/Attack Vector:

Any server running HTTP (Hypertext Transfer Protocol) is passing data between a server and a connecting client. With HTTP, this data is unencrypted. A malefactor can eavesdrop this data, performing a man-in-the-middle attack, replacing information, reading tokens, perform header injections, Etc. with this unencrypted traffic.

Defensive Mechanism:

Upgrading the HTTP connection to HTTPS ensured that communication between LessPM's client and server is encrypted through Transport Layer Security (TLS). It provides confidentiality and integrity of data transmitted over the network, making it more difficult for attackers to intercept or tamper with sensitive information.

► **JSON Web Tokens (JWT)** [Rating: 5 – Status: Implemented]

Weakness/Attack Vector:

JWTs are signed with a secret specific to the server. However, if this secret is discovered or leaked, a malefactor could use this information to sign their own tokens and provide their own information. Since JWTs are signed and not encrypted, any malefactor who receives access

to a token can decode the Base64 format and read the tokens information in clear text.

Defensive Mechanism:

Properly signing the tokens with a strong algorithm prevents information from being tampered with. An attacker can still read the information in clear-text but can not forge their own tokens.

LessPM uses RSASSA-PSS with Sha-512 to sign and encode tokens, decoding them with the keypair when received. This ensures integrity and authenticity of the JWT, as the signature is verified by the server. RSASSA-PSS is a robust and secure signature algorithm that provides protection against various attacks, such as collision attacks and length extension attacks. To further impose a level of security, LessPM takes advantage of different tokens for registration, authentication, and authorization.

► **Encrypted JWT, inspired by JWE** [Rating: 3 – Status: Implemented]

Weakness/Attack Vector:

Encrypted JWTs are JWTs signed and encrypted using an algorithm for signing and encryption. However, if this encryption algorithm is not potent or weak (such as a Caesar Cipher), an attacker can break the encryption or even encrypt their own tokens. Encrypted JWTs are also subject to scenarios such as lack of key rotation, insecure length of the encryption key and improper implementation.

Defensive Mechanism:

To combat these Weakness/Attack Vectors, LessPM implements encryption partly inspired by the JWE standard. LessPM encrypts the token using AES-256, a strong encryption scheme capable of 2^{256} different keys. This ensures that the data is confidentially kept and protected from unauthorized access. While inspired, it is important to note that JWEs have

not been properly implemented in LessPM, and are subject to a hardcoded key for AES-256, that a malefactor could potentially break. Introducing some kind of key rotation or key-generation based on the user would be beneficial.

- **Hashing Keys** [Rating: 5 – Status: Implemented]

Weakness/Attack Vector:

Hashing is a one-way process to convert information (such as passwords) into a fixed-size string of characters, typically a fixed-length hash value. However, the hashing process is susceptible to a malefactor using precomputed hash-values for large number of possible passwords, stored in a lookup table called a Rainbow table attack. Hashes are also vulnerable to dictionary attacks, and not being properly implemented without using a salt, and preferably a pepper, or brute-force attacks.

Defensive Mechanism:

LessPM takes advantage of the latest within public hashing functionality, through Argon2 to hash the AES-256 key. Argon2 constructs a memory-hard and computationally expensive hash that provides protection against brute-force, rainbow table, dictionary and side-channel attacks by requiring a significant amount of computational resources and time to compute the hash.

Finally, LessPM takes advantage of using both a random salt unique for each password and a pepper (stored in the source code) of 128-bit for both. This creates a higher threshold for a malefactor by requiring access to the database and the source code to be able to quickly compute a hash. The salt and pepper are added to the key of the AES-256

- **Mitigating Password Authentication** [Rating: 5 – Status: Implemented]

Weakness/Attack Vector:

A password is a secret that a user knows. Secrets belonging to an individual will always be potentially accessible to a malefactor. There are multiple vectors that can be used, such as a user being careless and writing the password down on a piece of paper or storing the secret in an unencrypted file. Further, a password is required to be stored somewhere for a server to authenticate the user, preferably with an email for recovery. This creates two new vectors for a malefactor to exploit, the persisted storage on the server or the recovery process.

Defensive Mechanism:

LessPM takes advantage of WebAuthn to avoid the usage of passwords to authenticate the user. The user is required to have two vectors for authentication; their authenticator device and the biometrics, which is the user itself. It is, however, important to mention that any authenticator device is vulnerable to being compromised. Should a device be compromised or infected with malicious software (Malware), it could be used to intercept or manipulate authentication requests.

- **Storing passwords in plaintext** [Rating: 5 – Status: Implemented]

Weakness/Attack Vector:

Storing a password can be done in plaintext in a database protected by a password. However, should an attacker get access to the database, all passwords and their plaintext are compromised. Storing the passwords in plaintext makes the information accessible to any individual with access to the database, which causes a privacy risk.

Defensive Mechanism:

LessPM encrypt all passwords with one of the strongest public symmetric encryption processes, AES-256. Each key for each password is unique, and consists of the 192-bit CID from WebAuthn generated when the user registered

(See Section 3.4). This CID is unique to each service the user is registered with. Along the 192-bit CID, 128-bit is used from a salt and 128-bit used from a pepper. The salt is stored with the entry in the database. Using both salt and pepper enhances the security of the derived key.

- **Cross-Site Scripting, Cross-Site Request Forgery & Unauthorized Access** [Rating: 5 – Status: Implemented]

Weakness/Attack Vector:

Any HTTP server improperly configured is subject to XSS and CSRF. XSS is a process where a malefactor could inject a malicious script from a different origin, and execute said script in the context of a user's browser. This could lead to a situation where a malefactor could get access tokens or cookies, or interact with the webpage a user is viewing through the script. CSRF is a type of security vulnerability where a malefactor tricks a user to unknowingly make authorized requests to a trusted website, such as a bank or similar. This can lead to actions being performed on a user's behalf, unintentionally, without the user's consent, leading to unauthorized access.

Defensive Mechanism:

CORS is a measure that enforces a strict policy for which domains and services are permitted to access certain resources on the server. LessPM takes advantage of CORS by permitting the server itself and the client associated domain to access resources on the server. This is a preventive measure put in place to allow the communication between the client and the server, even though they are running on different ports, and potentially different domains. This ensures that only authorized clients can access the server's resources, preventing unauthorized cross-origin requests and protecting

against XSS and CSRF⁴⁷ attacks.

- **Cookies** [Rating: 5 – Status: Implemented]

Weakness/Attack Vector:

A cookie is vulnerable to many aspects of security. Improperly stored, a cookie can be accessed through JavaScript, sent to different domains, get hijacked, contain excessive expire time, or even poisoned.⁴⁸

Defensive Mechanism:

LessPM only uses one cookie, which contains the encrypted JWT. The cookie is protected through built-in browser-features such as restricted to the same origin that the cookie came from, and cannot be sent anywhere else, further preventing XSS of sensitive information. The cookie expired after 15 minutes, which is an extensive amount of time for a user to have authorized access to their passwords, before the need to reauthenticate their identity. Upon creation, LessPM makes sure that the cookie becomes set to secure. This prevents the cookie from being sent over an insecure HTTP connection, limiting it to HTTPS. Finally, the cookie is HttpOnly, so that the cookie can't be accessed through JavaScript, reducing the attack vector on LessPM even further.

- **Authorization Header** [Rating: 3 – Status: Unimplemented]

Weakness/Attack Vector:

The RFC7519 [JBS15] specifies the **Authorization** header as the appropriate place to append the token. This is of particular concern in LessPM as the HTTP framework we used requires to specify exposure of the **Authorization** header in order for

⁴⁷It would be beneficial to properly implement a CSRF token in submitted user data as well, which the server could validate when a user performs a request.

⁴⁸Cookie Poisoning is the process where an attacker modifies the content of the cookie to inject malicious data or bypass security controls.

JavaScript to read it. Exposing it to the client entails exposing it to the malefactors as well.

Defensive Mechanism:

Since exposing the `Authorization` header opens up an attack surface to malefactors, storing this value in a secured cookie similar to other cookies handled in LessPM would leave out an attack surface. This would further increase security in LessPM, as a malefactor would then not be able to read the token out of the `Authorization` header directly and act on behalf of the user.

- **Password Hashing** [Rating: 1 – Status: Unimplemented]

Weakness/Attack Vector:

An unhashed password can have severe consequences. It leaves passwords vulnerable to unauthorized access, increasing the risk of security breaches and password reuse attacks. Insiders with access to password storage may misuse or abuse plaintext passwords, violating best practices for security and compliance requirements. Proper password hashing with strong cryptographic algorithms and salt is critical to protect user passwords, prevent unauthorized access, and ensure compliance with security standards.

Defensive Mechanism:

We emphasized and recognized that only constructing a hash for the AES key leaves the stored password exposed **iff** AES gets broken or have an unknown zero-day failure. Adding some form of hashing for the password before encrypting it would serve a minor benefit, in case of encryption breakage. As of this writing, we are unsure how this hash would be properly implemented, given that we have nothing to construct the hash for the password. A potential suggestion would be to apply similar methods to how the encryption was performed.

- **Hardcoded AES for JWT** [Rating: 3 – Status: Unimplemented]

Weakness/Attack Vector:

Each JWT is encrypted with the same AES-256 key. This serves as a threat to the whole system, and was implemented this way due to the lack of time during the implementation phase. This leaves LessPM exposed in scenario that one key becomes broken and all the tokens passed between LessPM's client and server can be decrypted by a malefactor.

Defensive Mechanism:

LessPM could benefit from implementing some kind of key rotation that would construct a new key for each day or each user. In a perfect scenario, we would have applied the same techniques for the JWT token as for previously described for the password, using the CID, a salt, and a pepper constructed upon authenticating.

- **Encrypted Passkey** [Rating 1 - Status: Unimplemented]

Weakness/Attack Vector:

The public key part stored in LessPM is unencrypted and stored in plaintext. This leaves the key exposed to being read directly from a malefactor. The CID of the key is used for vital information such as serving as part of the key for the password encryption. However, seeing that this CID is useless without proper access to the code to see key-construction, and the database to get access to stored, encrypted passwords, this receives a lower rating.

Defensive Mechanism:

The Passkey could be encrypted with the same process used with passwords. This would require a user to present their AD every time the CID is necessary, which is already the case in LessPM.

- **Session Hijack Preventions** [Rating 1 - Status: Implemented]

Weakness/Attack Vector: In a stateless protocol such as HTTP, measures are needed to be taken in order to maintain authentication and authorization (See Section 3.2). These measures include a session or a token of authorization. In both cases, these tokens are needed to be stored somewhere in a client, such as a cookie or client-side variable. Protecting these storage areas is desired at the highest level, so to mitigate the risk of a session hijacking.

Defensive Mechanism: In LessPM, we implemented cookies protected by various in-browser mechanisms, such as setting the cookie's `Secure`, `HttpOnly`, `SameSite=Strict`, and `expiry` timer. All of these measure help LessPM to mitigate session hijacking through and ensuring user authenticity and authentication integrity in LessPM. As a side note, it would have been advantageous to further implement a mechanism surrounding the attachment of the connecting IP address to the JWT. This could serve as a first-line of defence in order to avoid exposure of unencrypted tokens.⁴⁹

► **Properly Implemented JWE** [Rating 1 - Status: Partially Implemented]

Weakness/Attack Vector: Incorrect implementation of JWE can lead to vulnerabilities and attack vectors. We discovered fairly late during the development of LessPM that the standard implementation of JWT does not encrypt the claims [JBS15]. In itself, a malefactor can decode the Base64-encoding of a JWT and then read the claim in plaintext. This prompted us to hastily create an inspired version of JWE [rfc7516], which could encrypt the token. This can be exploited by a malefactor, seeing that the key to encrypt the token is hardcoded⁵⁰

⁴⁹This would not work on a mobile device connected to mobile data, seeing that the IP address switches between connections.

⁵⁰It would still take 2^{256} attempts in the worst-case scenario for a malefactor to discover the key.

Defensive Mechanism:

LessPM should properly implement JWEs. Proper implementation, adherence to best practices, and staying updated with the latest standards and guidelines are crucial to mitigate the risks associated with incorrectly implemented JWE versions. Regular security audits and testing are essential for identifying and addressing vulnerabilities.

► **Multiple Authenticators** [Rating 2 - Status: Unimplemented]

Weakness/Attack Vector:

In its current implementation, LessPM supports only a single registered authenticators per username to maintain a focused security approach. During registration, LessPM checks the database for an existing username similar to the incoming one and aborts the Registration Ceremony if a match is found. However, not fully implementing support for multiple ADs in LessPM creates a case of single point of failure, where if an authenticator is lost, damaged, or compromised, a user might lose access and be locked out of their account. This also leads to reduced scalability and flexibility, where new and elaborated technologies might now be supported.

Defensive Mechanism: WebAuthn permits users to have multiple authenticators. It then follows that LessPM should also support multiple authenticators.

4 Conclusion

This report describes the details of implementing a passwordless password manager, using WebAuthn to authenticate users. The aim of the project was to create a secure and efficient solutions for managing passwords that doesn't rely on the need for a traditional password.

We came up with an intuitive way to encrypt passwords, instead of the traditional hash. To

achieve this, AES-256 was applied and Argon2 was used to construct a hash out of a key supplied through WebAuthn’s Credential ID and a randomly generated salt for both key-derivation function and the AES-256 key, combined with a pepper for the latter.

The backend where WebAuthn and the password manager was running consisted of a HTTPS server, serving content through a self-signed certificate. Because the server and client were independent of each other, we also configured CORS.

To keep a user authenticated between requests, we used an encrypted version of a JWT, inspired by the JWE [IET15]. This was achieved by storing the token in a fortified cookie in the client, being encrypted on the server before it was stored.

Despite its potential benefits, our report also highlights some limitations and challenges associated with passwordless authentication. These include the potential lack of adaptability by users and the possibility of losing the authenticator device.

Our findings suggest that future studies should explore ways to address the issue of device loss in the context of passwordless authentication. In particular, research should focus on developing methods for securely recovering access to accounts and data when a user’s primary authentication device is lost or stolen. This could include the use of backup authentication methods, such as biometric verification or recovery codes, as well as the development of secure protocols for remotely revoking access to lost devices. By addressing this challenge, we can enhance the security and reliability of passwordless authentication systems.

5 Future work

Through implementing LessPM, we aimed to create a bare-bone implementation that could serve as a reliable Minimal Viable Product (MVP). However, we recognize that more work is needed to further enhance and compliment the product. The related topics to further improve LessPM include properly

implementing JWE, supporting multiple ADs, encrypting the stored Passkey, and implement a dynamic key rotation or generation of AES-256 keys for JWT.

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ChatGPT Throughout the report, the authors utilized ChatGPT to thoroughly reiterate concepts used during development.

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A Appendix

A.1 Base64 and ciphertext

```
uAaQghfTS0jpMA1WaYozepQ4/TpN13Y6tlKSzXG0l+epVZK+
vjvD8BwMIlWVxvTaV3mcFxl665qBNsFg//81hpU8I660lq/LAXsPcdfq2vr8YRa14+GH+
Gtw6YlqLrDU3E8Rhb/
I1AvJ8u5VN8pwV1SmBZLTwL7AyEWlp4GodSrX4NS15grIFoVwRq7kXofVu1aUToD6KJcmo0X

BnwGOKWpEPUZFPd76KcA/QfXHnJHQsaR2jKWFJdRCpbtJAacAbssJk/
bJjioo3AS1caEVZbNJctp9xgqVvgQJPyhmYtMLqdjq/
SocUscTrLSPiR2X0g5sWByNim6ses2SJ3dtMYYe0r7+qtV0coX+U7w2+
uLorawsCcXCMXRunEKd5jXiydwXZjzPoKHAT8hGwDB8CNSHxg/
JXrezEJ5JKwq3Gio3xEyjD09Cfq5qLn9kENbcDZ/uRZK6+
Swxcqg1DYhGngPJbbPkb0pqcXxdLutybYgdGpFN0zCQw3/LNbxYz0BeVhVsXM+
GOVEAcKgYpnyCILwKKtFUyaRX2Q7IjdBbKP8NpG7RWZKFtRBVc4YVdWSIRpfek1/
lFkq1JrvGK/6KjyyR+
m6sb2RzUzxN01V5uTkH2m8cBUwQBUqjiNEgVQDzTeaYIZqH0j2Is4cblRcCsjoFgX3Nvh4/
0vpgpQ==
```

```
KHO
Vi3z8:Mv:RqU;

" U W y 6 '5<#{qakpj.0 U7pWTEu*
pF^ VN (&E)jD=FE=? A v % B I n *(qeIr}
?(fb*RlX"nz 'wm1: N r S 6 , tnB5f < OF0 | ^I+
*7LOB~j.-d
E,1r5
Fmljq|].rmMO-5X^Vl\ 9Qp |
* T W [(
nYUsudF _J&+,nodsS<M;Uy9oLJ U M !=:} ?:)
```

Figure 5: The Base64 encoding and relevant ciphertext after AES-256.