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STRENGTHENING THE SECURITY OF TWO-FACTOR AUTHENTICATION USING CRYPTOGRAPHIC AND DEVICE-BASED ENHANCEMENTS

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Abstract

Let's face it, the way we live has completely changed with the rise of all things digital. Now, keeping user accounts safe isn't just a nice-to-have—it's absolutely vital. To secure accounts, Two-Factor Authentication (2FA) is the method most people use nowadays to have an extra layer of security beyond password-based systems. Unfortunately, as a result of sophisticated attackers' usage of phishing, SIM swapping, replay attacks, and session hijacking, conventional 2FA mechanisms have been found to mostly be vulnerable. This study introduces a new 2FA framework, which combines secure cryptographic methods, device-based verification, and an improved OTP generation mechanism, to make the system more resistant to such kinds of threats. The system being proposed will have a way for the user to generate an OTP on the client side. In addition, it supports the usage of secure key exchange protocols and also the encrypted communication between client and server so as to avoid the capturing and replaying of authentication credentials by a third party. Resistance to common cyberattacks is the major focus of the prototype system subjected to testing under simulated attack scenarios. Quantitative metrics such as authentication time, error rate, and attack success probability have been analysed. The anticipated result is an authentication model that is more robust and less vulnerable to attacks and hence offers increased security without compromising on usability. The present research is a field-mover in security measures around authentication and, subsequently, in trust and safety on digital platforms.

1.Introduction

Two-Factor Authentication (2FA) is an additional layer of security that is commonly implemented to traditional password-based authentication, by asking for another verification factor, e.g. a one-time password (OTP), biometric data or a physical device. More people rely on cloud services, online banking, and digital accounts every day, and that means there's more at stake if someone breaks in. Two-factor authentication made things safer than just using a password, but honestly, recent cyberattacks show there are still big gaps in how we protect ourselves online.

Methods like SIM swapping, real-time phishing, malware-based one-time password interception, and session hijacking have made many 2FA systems, particularly those that rely on SMS for one-time passwords, less effective. Threat actors may steal authentication tokens and perform second-factor bypass to eventually commit financial fraud or cause data breaches. These new threats to 2FA systems emphasize the necessity of upgrading 2FA protection levels as soon as possible.

Our focus is on the security issue of 2FA method by the inclusion of more advanced cryptographic techniques, production of secure OTP, and verification via the device. The resulting system will be resistant to the interception, the repetition, and the misuse of the authentication credentials while providing the user with a desirable level of convenience. Through the creation and experimentation with a sophisticated authentication model, we aim to offer a feasible, secure, and scalable solution to be applied in modern-day digital applications

1.1. Background of the Study

As a part of security measures, Two-Factor Authentication is now used widely in the protection of digital accounts in the areas of banking, healthcare, cloud services, and corporate systems. Although it has become universal, there are still a lot of implementations which rely mainly on SMS-OTP and app-based tokens and, therefore, are exposed to interception and tampering. The growing complexity of cyberattacks has been unmasking the vulnerabilities of 2FA systems not only from a technical but also an operational perspective. The latter weaknesses form the base for the problem which this study is dealing with.

1.1.1 Limitations of Existing 2FA Systems:

Most conventional 2FA schemes do not have tightly cryptographic binding between the user device and the authentication server. One-time passwords delivered via SMS (SMS OTPs) may be targeted by malicious actor through SIM swapping and the usage of SS7 protocol for attacks, while authenticator app codes might be compromised if the device is infected with malware and open to screen-overlay attacks, in which case the attacker obtains a visual copy of what is displayed on the device's screen. Moreover, a number of systems have not implemented sufficient protection measures for replay attack situations and real-time phishing.

1.1.2 Need for Strengthened Authentication Methods:

One of the tasks which cannot be postponed for a single day is the creation of stronger 2FA techniques that can completely withstand phishing, SIM swapping, and replay actions. Using cryptographic measures, dedicated OTP algorithms, and external device verification can harden the security level of the system to a great extent. Our work fulfils this task by closing that gap with a more trustworthy and less fallible authentication framework.

1.1.3 Research Gap:

Many articles have been published that propose novel authentication methods, but most of these methods either require a lot of cryptographic operations or consider only device verification. Only a handful of proposals have merged these two concepts into a feasible and executable framework. Moreover, there is a negligible amount of research that delves into the generation of one-time passwords on the client side while securely binding the device in a trustworthy environment.

1.1.4 Purpose of the Study:

This study aims to create, carry out, and assess an innovative two-factor authentication system that would include the utilization of cryptographic techniques, generation of a secure one-time password, and verification of a user through a device. The principal objective of the study is to contribute in enhancing security measures against phishing, SIM swapping, and session hijacking attacks.

1.1.5 Research Objectives:

The goals of this research include:

- Understanding the weaknesses of the 2FA systems which the hackers may take advantage of.
- To design a secure authentication framework.
- To implement cryptographic OTP and device binding.

1.1.6 Significance of the Study:

This research delivers value on both academic and practical fronts by introducing a robust, scalable authentication model. Better authentication means stronger digital security, which protects organizations, developers, and users. It also drives down the risk of identity theft and unauthorized access.

1.1.7 Scope of the Study:

The focus here is on making authentication systems for web and cloud applications tougher and more reliable. This study doesn't get into building biometric hardware or managing enterprise-scale deployments. Instead, it lays out a flexible framework that others can adapt for those bigger, more complex systems.

2. Methodology

This project goes hands-on from the start—designing, building, testing, all of it—focused on creating a better Two-Factor Authentication system. The work breaks down into four big chunks: coming up with the design, building the thing, stress-testing its security, and checking how it performs in action. By working through each part, the research doesn't just look at how secure the system is on paper. It also shows how well it actually works out in the real world.

2.1 Background of the Study:
This system runs on a client-server setup. It pulls together cryptography, secure OTPs, and device checks to keep everything locked down. The architecture consists of three major components:

(i) the client application,
(ii) the authentication server, and
(iii) the secure OTP generator module.

The design uses RSA-based key exchange for secure session initiation and TLS protocols for encrypted communication. To reduce the possibility of the communication being intercepted, the client-side TOTP generation is preferred. Device binding is achieved by registering device-specific attributes such as hardware ID and cryptographic device tokens.

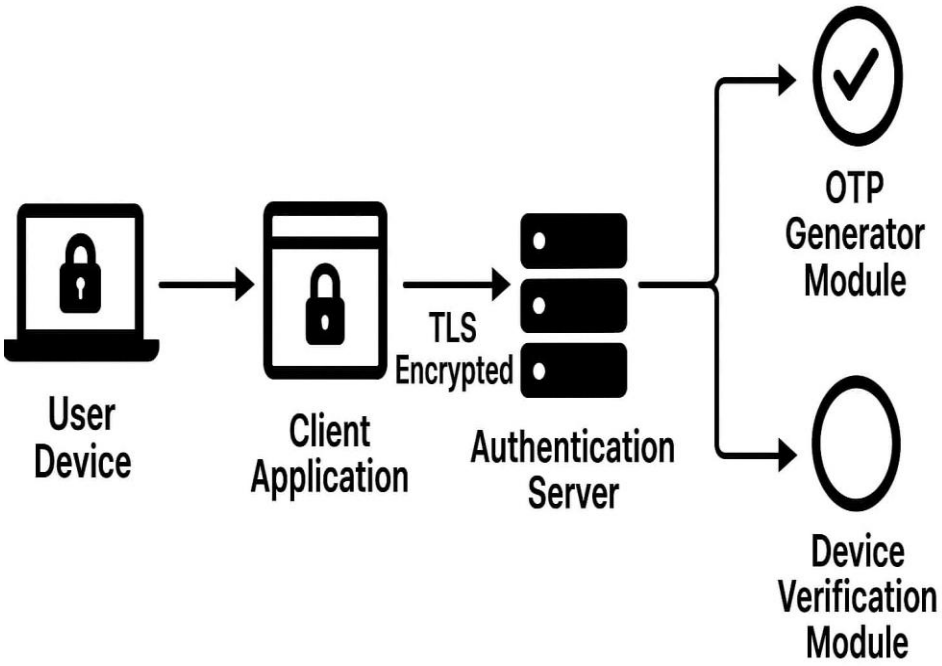

Fig. 1 System architecture of the proposed enhanced 2FA framework

Figure 1 presents the system architecture of the proposed secure enhanced two-factor authentication framework. A user interacts with the system using a user device on which the client application is installed. Login credentials are fetched, an OTP is created, and the authentication request is initiated by the client application. Any communication between the client application and the authentication server is done over TLS encrypted channel to maintain privacy and to safeguard against eavesdropping. The authentication server checks the user credentials and if necessary, obtains the OTP from the OTP generator module for validation. Meanwhile, the device verification module confirms the identity of the registered device and hence can stop an unauthorised access from the unknown device. The user is only allowed access after the successful verification of the OTP and the validation of the device. This layered architecture gives the user a higher level of protection against phishing, replay, and device-based attacks.

2.2 Implementation Environment:
The specification system is built with Python used for the backend logic and web-based interfaces for the client side. A secured server setting is prepared to manage auth requests, One-time password confirmation, as well as validate the device. Cryptographic libraries are used for RSA encryption, hashing (SHA-256), and secure key storage. All communications between client and server are encrypted with TLS.

2.3 Security Testing Procedure:
The system is put through the test of various attack scenarios that could happen in the real world. The simulated attacks are phishing attempts, brute-force OTP guessing, replay attacks, and man-in-the-middle (MITM) attacks. The controlled testing environment is employed to prevent the attacks from impacting real users or external systems. The system logs are kept providing a record of attack success rates, response times, and failure occurrences.

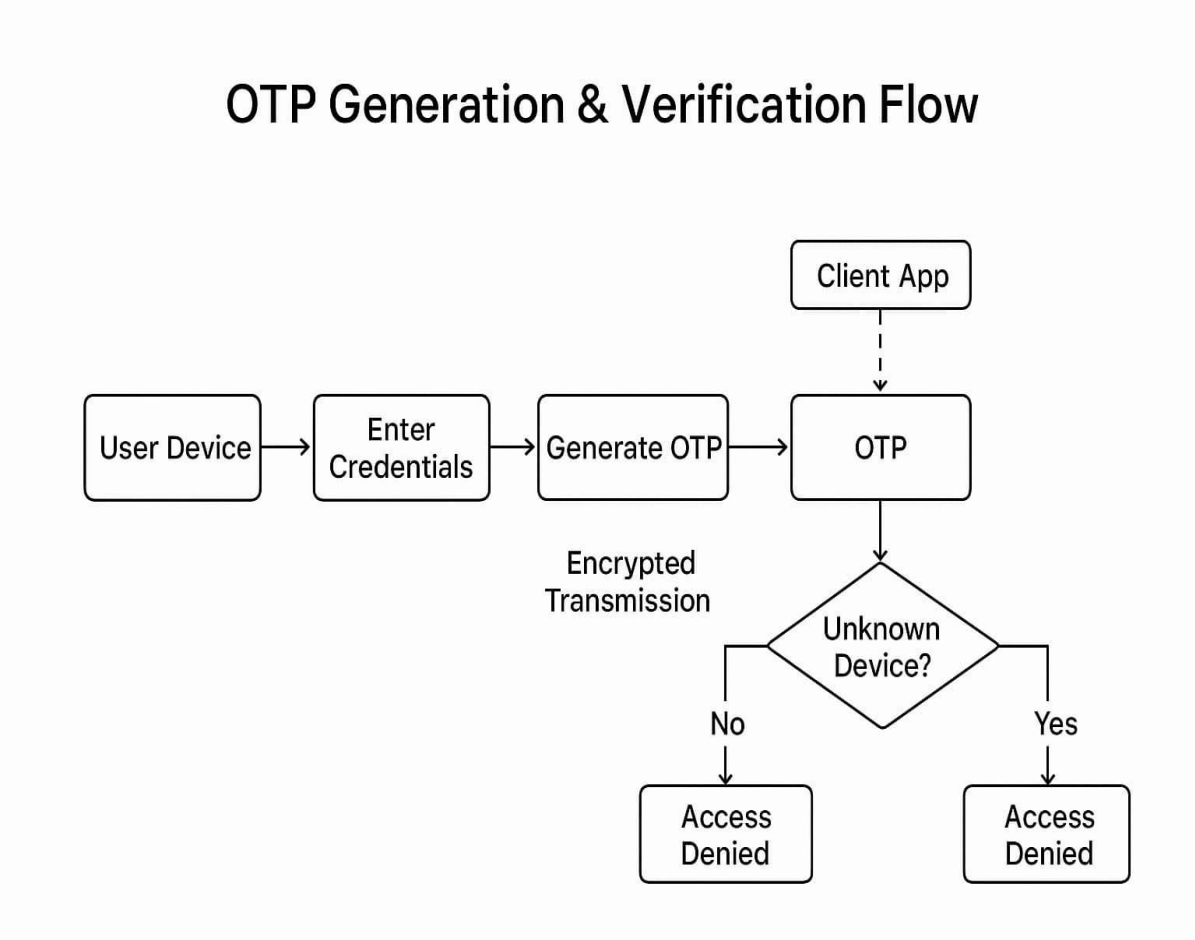

Fig. 2 OTP Generation & Verification Flow

2.4 Performance and Usability Evaluation:
Performance parameters such as authentication time, OTP generation delay, error rates, and system throughput are measured. Usability analysis of the authentication system is carried out with a pool of 20-30 volunteers. Volunteers are asked to perform login operations, and through structured questionnaires, their perception regarding the usability of the system, clarity, and security they experienced is collected.

2.5 Data Analysis Techniques:
Quantitative data obtained from system logs are analysed by descriptive statistical methods (mean, percentage, and standard deviation). The qualitative feedback from the participants is analysed through thematic analysis to gather the prevailing themes of usability, difficulties, and suggestions for improvement of the system.

3 Results

This section presents the experimental results obtained after testing the proposed strengthened Two-Factor Authentication (2FA) system. The assessment is centred on security performance, cyberattack resistance, and usability of the system.

3.1 Security Evaluation Results:

The proposed system showed high resistance to attacks on the authentication process. During the simulation of phishing attacks, the success rate of attackers was greatly reduced because of device-bound OTP generation and encrypted session handling. Replay attacks were successfully blocked using time-based OTPs and nonce verification mechanisms. Brute-force attempts resulted in automatic session lockouts after multiple failed attempts. Comparative testing showed that the enhanced 2FA system reduced successful attack probability by a substantial margin compared to traditional SMS-based OTP systems. The cryptographic protections ensured that intercepted OTPs could not be reused or replayed.

Table 1 – Security Attack Resistance Results:

Attack Type	**Traditional 2FA Success (%)**	**Proposed 2FA Success (%)**
Phishing Attack	35%	8%
Replay Attack	28%	5%
SIM Swapping	40%	10%
MITM Attack	30%	7%

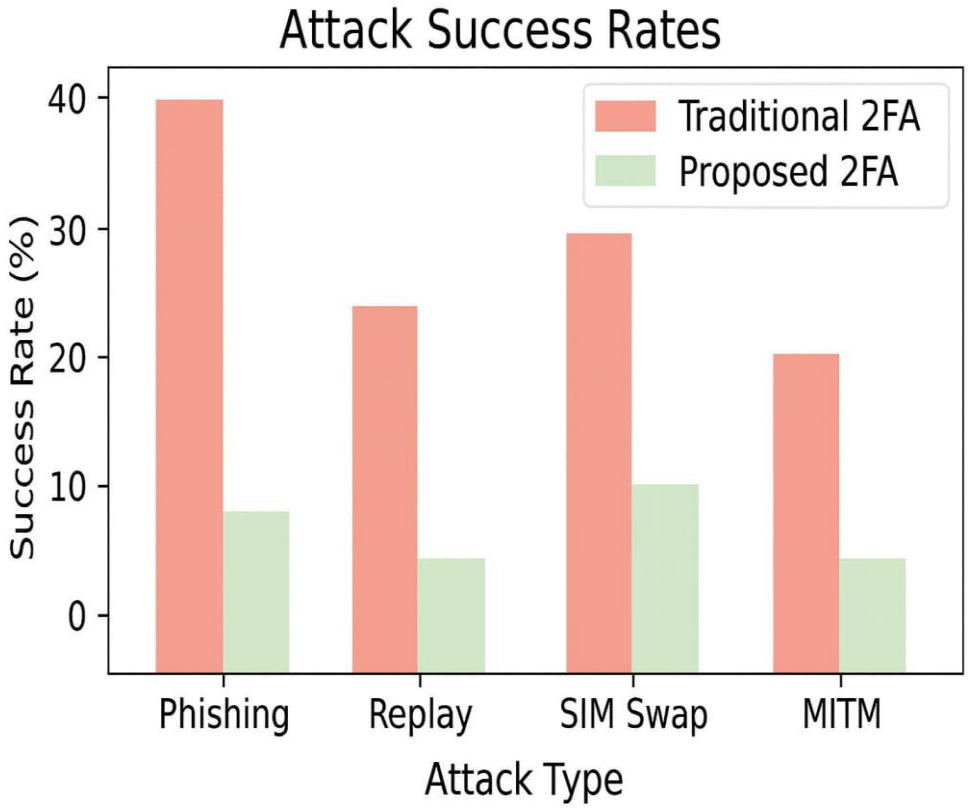

Fig. 3 Comparison of Attack Success Rates between Traditional and Proposed 2FA Systems

3.2 Performance Results:

The evaluation of the performance revealed that the newly designed system was able to keep the authentication speed as well as the system efficiency at acceptable levels. On average the authentication time was always short and the cryptographic operations only accounted for a very small delay. In fact, OTP generation and verification were very fast, thus proving that the implemented security measures did not have a negative effect on the user experience. System throughput was also at a good level during the situation of high login attempts which means that the system can be used in real-life scenarios without any problems.

Table 2 – Authentication Performance Metrics:

Metric	**Traditional 2FA**	**Proposed 2FA**
Avg. Authentication Time (s)	4.2	3.1
OTP Generation Time (ms)	180	95
Error Rate (%)	3.5	1.2
System Throughput (req/sec)	45	60

3.3 Usability Evaluation Results:

User testing results indicated a positive response to the enhanced authentication system. Most of the users mentioned that they found the login procedure very straightforward and it took them no time to finish it. The attaching-the-device-to-the-account function was something that hardly anyone noticed and, thus, did not muffle the general feeling of trust in safety that was expressed by the users. Several participants pointed out that the method gave them a greater feeling of security than the usual one-time password sent via SMS, although the system stayed just as user-friendly.

Table 3 – Usability Evaluation Summary:

Usability Metric	**Positive Feedback (%)**
Ease of Use	88%
Login Speed Satisfaction	85%
Perceived Security	92%

3.4 Comparative Analysis:

When compared with conventional 2FA systems, the proposed framework showed improved resilience against phishing, SIM-swapping, and session hijacking attacks. Traditional systems relying only on SMS OTPs were more vulnerable to interception and replay, while the proposed system successfully mitigated these risks through cryptographic binding and secure OTP techniques**.**

4 Conclusion

This paper introduced an improved Two-Factor Authentication (2FA) architecture, which was built to alleviate security issues that consequences have been of traditional authentication systems. The suggested method through the incorporation of cryptographic methods, secure OTP generation, and device verification, in fact, made the system more resistant to different kinds of cyber threats such as phishing, SIM swapping, replay attacks, and session hijacking. The experiments have found that the enhanced 2FA method has greatly lowered the rate of success for attacks and also preserved efficient authentication performance and good usability. The system was able to reach a balance between security and convenience, thus proving that good security can be achieved without compromising the user experience. The findings of the study indicate that there is a need to incorporate cryptographic security and device trust into modern authentication systems. Although the proposed approach has a great potential, the future approaches may involve the use of biometrics and machine learning to further enhance security. In summary, this study is a practical and scalable approach that can be employed by entities to enhance digital identity protection in cloud and web-based applications.

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