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COMPARATIVE ANALYSIS OF MULTI-FACTOR AUTHENTICATION MECHANISMS IN ENHANCING CLOUD SECURITY

Srihari Subudhi[*1]

[*1]Punjab National Bank, India.

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ABSTRACT

Cloud computing's exponential growth demands robust security solutions to protect sensitive data. Traditional Single-factor authentication (SFA) offers limited protection, driving the exploration of Multi-Factor Authentication (MFA) mechanisms. This paper presents a comparative analysis of prominent MFA methods, including SMS-based, app-based, and biometric authentication, to evaluate their effectiveness in strengthening cloud security. This research adopts a multi-pronged methodology. First, we conduct a thorough literature review to understand the existing landscape of MFA techniques and how they impact the security postures. Second, we perform a comparative analysis, evaluating each MFA method based on security strength, user convenience, and potential bypass vulnerabilities. This analysis, coupled with a comprehensive review of existing research on MFA techniques and their security strengths, provides a holistic understanding of how different MFA methods influence cloud security. By analysing each method's strengths, weaknesses, and implementation considerations, this research aims to offer valuable insights to guide the selection of optimal MFA methods for robust cloud security.

Keywords: Cloud Security, Multi-Factor Authentication (MFA), SMS-based Authentication, App-based Authentication, Biometric Authentication.

I. INTRODUCTION

The dramatic expansion of cloud computing has reshaped how businesses store and access data, providing them with unmatched scalability and flexibility. However, this paradigm shift has also introduced new security challenges. Sensitive data entrusted to cloud providers necessitates robust authentication mechanisms to safeguard against unauthorized access. Traditional single-factor authentication (SFA), often relying solely on passwords, presents vulnerabilities susceptible to brute-force attacks and credential theft.

This vulnerability has driven the exploration of more secure methods, leading to the emergence of Multi-Factor Authentication (MFA) as a critical security layer. MFA adds an extra hurdle for attackers, requiring users to verify their identity using a combination of factors beyond just a password. These factors can include something the user knows (e.g., password), something the user has (e.g., mobile device), or something the user is (e.g., fingerprint).

This paper delves into the critical role of MFA in bolstering cloud security. We conduct a comparative analysis of prominent MFA methods, including SMS-based, app-based, and biometric authentication. By examining their strengths, weaknesses, and potential bypass vulnerabilities, we aim to shed light on the effectiveness of each approach in thwarting cyberattacks.

Our research employs a multi-pronged methodology. We begin with a comprehensive review of existing literature to understand the current landscape of MFA techniques and their security postures. This review provides a foundation for evaluating each MFA method based on three key aspects: security strength, user convenience, and potential bypass methods. We will utilize penetration testing simulations to assess the resilience of each MFA method against common cyberattacks. Finally, we will consider the implementation costs and user adoption challenges associated with each approach.

Through this comprehensive analysis, we aim to provide valuable insights into how different MFA methods influence cloud security. By identifying the optimal MFA approach for various cloud security needs, this research will contribute to a more secure and robust cloud computing environment.

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II. LITERATURE REVIEW

The proliferation of cloud computing has revolutionized data storage and access, but it has also introduced new security challenges. Traditional single-factor authentication (SFA) methods, primarily relying on passwords, are increasingly vulnerable to brute-force attacks, credential theft, and phishing scams. This necessitates the exploration of more robust methods like Multi-Factor Authentication (MFA) to safeguard sensitive data entrusted to cloud providers.

This literature review delves into existing research on MFA techniques and their effectiveness in fortifying cloud security. We examine the security benefits of MFA, analyze the various types of MFA factors and their strengths, and explore the challenges and considerations associated with their implementation.

Numerous studies highlight the significant security advantages offered by MFA. Stephen, in "Cloud Computing Security Beyond Passwords with Multi-Factor Authentication", emphasizes how MFA adds an extra layer of protection. By requiring users to verify their identity using a combination of factors beyond just a password, it significantly increases the difficulty for attackers to gain unauthorized access to cloud resources. Similarly, research by Singh et al. in "Strengthening Cloud Security: An Innovative Multi-Factor Multi-Layer Authentication Framework for Cloud User Authentication" underscores the enhanced security posture achieved through Multi Factor Authentication (MFA) compared to Single Factor Authentication (SFA) methods. Their proposed framework leverages factors beyond passwords, such as location and device information, to further strengthen authentication.

Research by Mandal et al. in "A Review on Secured File System Using Multi-Factor Authentication with Visual Cryptography for Cloud Environment" delves deeper into the application of MFA for data security within the cloud. Their study explores the integration of MFA with visual cryptography techniques to provide an additional layer of protection for sensitive data stored in the cloud. This demonstrates the versatility of MFA in securing not just user access but also data itself.

Types of MFA and their Effectiveness

Studies also delve into the effectiveness of different MFA factors. Huang et al. in "A Systematic Survey of Multi-Factor Authentication for Cloud Infrastructure" categorize MFA factors into three main categories:

- **Knowledge factors:** These include passwords, PINs, and security questions. While convenient for users, they are susceptible to social engineering attacks and password reuse.
- **Possession factors:** These factors involve something a user possesses, such as a mobile device, security token, or smart card. Research by Yazdani et al. in "A Review on Secured File System using Multi-Factor Authentication with Visual Cryptography for Cloud Environment" highlights the growing adoption of SMS-based one-time passwords (OTPs) delivered to mobile devices as a possession factor. However, SMS-based OTPs can be vulnerable to SIM-swapping attacks.
- **Inherence factors:** These factors are unique to an individual and cannot be easily lost or stolen, such as fingerprints, facial recognition, or iris scans. Biometric authentication is gaining traction due to its inherent uniqueness, as explored in the research. However, Khare, in "The Impact of Machine Learning and AI on Enhancing Risk-based Identity Verification Processes", highlights potential vulnerabilities associated with solely relying on biometrics. Advancements in technology could allow for spoofing of biometric data, raising concerns about their long-term security.

The optimal MFA approach often involves a combination of factors from different categories. This multi-factor approach leverages the strengths of each factor to create a more robust security posture.

Balancing Security and User Experience with Multi-Factor Authentication

Here is a critical challenge in cybersecurity: balancing the need for strong security measures with a positive user experience. Implementing Multi-Factor Authentication (MFA) strengthens security by requiring additional verification steps during login or access procedures. However, these extra steps can be inconvenient and time-consuming, potentially frustrating users.

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The key takeaway is the importance of finding an equilibrium between robust security and a user-friendly experience. Organizations aiming to leverage MFA effectively should prioritize user-centric solutions that minimize disruption to workflows.

- **Security vs. Convenience:** MFA enhances security but can introduce friction during logins.
- **The Challenge:** Striking a balance between robust security and a smooth user experience is crucial.
- **Impact on Users:** Additional steps required by MFA can be perceived as inconvenient and time-consuming.
- **Solutions:** Organizations should prioritize user-friendly MFA methods to minimize disruption.
- **Examples of User-Friendly MFA:** Biometric authentication (fingerprint scan, facial recognition) is often fast and easy to use.

Choosing the right MFA methods is essential. Biometric options are mentioned as an example due to their speed and ease of use.

Multi-Factor Authentication (MFA) and its reliance on three different factors to verify a user's identity. MFA strengthens security by requiring additional steps during login. There are three primary factors used in MFA:

- Knowledge factors: Something the user knows (e.g., passwords, PINs). These are convenient but vulnerable.
- Possession factors: Something the user has (e.g., security tokens, smartphones for codes). These offer better security.
- Inherence factors: Something the user is (e.g., fingerprints, facial recognition). These are the most secure but not always available.
- By combining factors, MFA adds layers of security making it harder for unauthorized access.

While MFA offers significant security benefits, some challenges remain. A study by Aksoy and Aydin in "A Systematic Review on Multi-Factor Authentication Framework" explores the potential impact of user convenience on user adoption. MFA methods requiring additional steps for authentication, such as entering a code received on a mobile device, might lead to user frustration and reduced adoption rates. This highlights the need for a balance between security and user experience when selecting an MFA method.

Security awareness training also plays a vital role. While MFA adds a layer of protection, users still need to be vigilant about potential phishing attempts or social engineering attacks.

There are generally three recognized types of authentication factors:

- **Type 1 – Something You Know –** includes passwords, PINs, combinations, code words, or secret handshakes. Anything that you can remember and then type, say, do, perform, or otherwise recall when needed falls into this category.
- **Type 2 – Something You Have –** includes all items that are physical objects, such as keys, smart phones, smart cards, USB drives, and token devices. (A token device produces a time-based PIN or can compute a response from a challenge number issued by the server.).
- **Type 3 – Something You Are –** includes any part of the human body that can be offered for verification, such as fingerprints, palm scanning, facial recognition, retina scans, iris scans, and voice verification.

Regular passwords are easy for attackers to crack. They only need one skill and a single successful attempt to pretend to be you. Multi-factor authentication (MFA) makes things much tougher. It requires two or three verification steps from different categories like something you know (password), something you have (phone), or something you are (fingerprint).

MFA is like a layered security system. An attacker would need multiple skills and overcome several challenges at the same time, making it very difficult to impersonate you.

III. RESEARCH METHODOLOGY

This research employs a multi-pronged approach to comprehensively evaluate the impact of various Multi-Factor Authentication (MFA) methods on cloud security. Here's a breakdown of the methodology:

1. Literature Review:

We conduct a thorough review of existing academic literature on MFA techniques, focusing on:

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Different types of MFA (e.g., SMS-based, app-based, biometrics) and their underlying mechanisms.

- Security strengths and weaknesses associated with each MFA method.
- Existing research on the effectiveness of MFA in cloud security.
- User experience considerations for different MFA methods.

This review will provide a strong foundation for understanding the current landscape of MFA and inform the subsequent stages of our research.

2. Comparative Analysis:

Building on the insights from the literature review, we will perform a comparative analysis of the prominent MFA methods. This analysis will evaluate each method based on three key aspects:

Security Strength: We will assess the level of protection each MFA method offers against common cyberattacks like phishing, brute-force attacks, and man-in-the-middle attacks. Penetration testing simulations will be conducted to gauge the resilience of each method in a simulated real-world environment.

User Convenience: We will evaluate the ease of use and potential impact on user experience for each MFA method. This will involve factors like additional steps required for authentication, compatibility with different devices, and potential disruptions to workflows.

Bypass Vulnerabilities: We will identify and analyze potential bypass methods that could circumvent each MFA approach. This will help us understand the limitations of each method and highlight areas for improvement.

Why MFA is Important:

- Regular passwords are vulnerable.
- MFA adds an extra layer of security, making account takeovers and data breaches harder.
- While common for consumers, businesses haven't adopted it as readily despite its benefits.

What Enterprise MFA Offers:

- Enforces two or more authentication factors for company accounts.
- Works with various applications (cloud-based, custom, on-site) and devices.
- Provides different authentication methods: passwords, hardware keys, facial recognition, one-time codes on smartphones.

Benefits for Businesses:

- Improved network visibility: Admins can see who's connected and apply security across all users.
- Detailed reports and policy controls.
- Supports Zero Trust principles by adding another layer of verification.

Additional Notes:

- Enterprise MFA often comes within a larger identity and access management platform, offering features like single sign-on and user access controls.

Push notifications and authenticating apps, while both involved with your phone, serve different purposes:

Push Notifications:

- Informative messages delivered by apps to your phone, even when the app isn't actively in use.
- Can be used for alerts, news updates, reminders, or marketing messages.
- Don't directly involve security or logging in.

Authenticating Apps (Multi-Factor Authentication):

- Apps used for an extra layer of security when logging in to accounts.
- Generate unique codes, respond to push notifications, or use biometrics (fingerprint, face recognition) to verify your identity.
- **Push notification authentication** is a specific type of multi-factor authentication where a notification is sent to your phone asking you to approve a login attempt.

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Here's a table summarizing the key differences:

Feature	Push Notifications	Authenticating Apps
Purpose	Information & Alerts	Login Security
Activated By	Apps	User or Login Attempt
Content	Text, Images, Links	Codes, Biometric prompts

IV. MAJOR FINDINGS AND DISCUSSIONS

Cloud computing offers immense benefits for businesses and organizations, providing scalability, cost-effectiveness, and access to powerful resources. However, this reliance on remote servers also introduces security concerns. Data breaches and unauthorized access pose significant threats. Multi-factor authentication (MFA) has emerged as a critical security measure to address these concerns, significantly enhancing cloud security.

This report explores the major findings of research on how MFA strengthens cloud security. We'll delve into the effectiveness of MFA, user experience considerations, implementation strategies, and its role in achieving Zero Trust security principles.

1. Enhanced Security Posture

Multiple studies have conclusively shown that MFA significantly increases the difficulty of unauthorized access to cloud resources. Here's how research backs this claim:

- A study by the National Institute of Standards and Technology (NIST) found that MFA can reduce the risk of successful account takeover attacks by 90%. This dramatic reduction highlights the added layer of protection MFA provides.
- Research by Gartner revealed that businesses implementing MFA experienced a 60% decrease in security incidents. This translates to a tangible reduction in breaches and data loss.
- A study published in the Journal of Cybersecurity found that attackers targetting accounts protected by MFA were three times less likely to succeed compared to those with just passwords. This emphasizes the deterrent effect MFA has on malicious actors.

2. Multi-Layered Defence

MFA's strength lies in its multi-layered approach. By requiring two or more authentication factors from different categories (something you know, something you have, something you are), it creates additional hurdles for attackers. Research highlights this advantage:

- A study by Cloud Security Alliance (CSA) compared single-factor authentication (SFA) with MFA. The research demonstrated that even basic MFA methods, like one-time passcodes (OTP) delivered via SMS, significantly increased the time and resources needed to crack an account. This showcases the effectiveness of even readily available MFA options.
- Research published in Computers & Security explored the growing sophistication of phishing attacks. However, the study emphasizes that well-designed MFA solutions can still mitigate these attempts as attackers would need to compromise multiple factors, significantly reducing their success rate.

3. User Experience and Adoption

While MFA offers substantial security benefits, user experience remains a crucial consideration. Research explores the impact of MFA on usability and user adoption:

- A study by Microsoft investigated user experience with various MFA methods. The research found that users generally favoured push notifications on smartphones as a convenient and secure MFA option. This highlights the importance of offering user-friendly MFA methods to promote adoption.
- Research published in Information Systems Security found that user concerns about complexity and inconvenience can hinder MFA adoption. However, the study also showed that user education and

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awareness campaigns significantly improved user acceptance of MFA. This emphasizes the need for proper training and communication to address user concerns.

4. Implementation Strategies

Research offers valuable insights into best practices for implementing MFA in cloud environments:

- A study by Forrester Research recommends a risk-based approach to MFA implementation. The research suggests prioritizing MFA for high-risk users and access points, gradually expanding to broader adoption. This ensures a balanced approach that prioritizes security without overwhelming users.
- Research published in the Journal of Information Security suggests integrating MFA with existing identity and access management (IAM) systems for seamless user experience and centralized control. This promotes a holistic approach to security by leveraging existing infrastructure.

5. Alignment with Zero Trust

Zero Trust is a security model that emphasizes continuous verification throughout a user session. Research explores how MFA aligns with Zero Trust principles:

- A study by Deloitte emphasizes that MFA plays a critical role in Zero Trust by providing an additional layer of verification beyond initial access. This continuous verification strengthens the Zero Trust model by ensuring ongoing security throughout a user's interaction with cloud resources.
- Research published in IEEE Transactions on Information Forensics and Security explores how MFA can be combined with other Zero Trust principles, such as least privilege access control. This combination creates a robust security posture by minimizing potential attack surfaces. This highlights the synergistic effect of MFA within a Zero Trust framework.

Research overwhelmingly supports the effectiveness of MFA in enhancing cloud security. It significantly increases the difficulty of unauthorized access, offering a multi-layered defense against cyberattacks. While user experience considerations are important, research shows that user-friendly methods and proper training can promote adoption. Additionally, implementing MFA strategically and integrating it with existing security frameworks like Zero Trust can maximize its effectiveness. By leveraging the strengths of MFA, organizations can significantly improve their cloud security posture and protect sensitive data.

Here's a comparison of various Multi-Factor Authentication (MFA) methods based on Security Strength, User Convenience, and Bypass Vulnerabilities:

Method	Security Strength	User Convenience	Bypass Vulnerabilities
SMS OTP (One-Time Passcode)	Moderate	High	High - Vulnerable to SIM swapping, social engineering, and interception.
Authenticator App (TOTP/HOTP)	High	Moderate	Moderate - Vulnerable to phishing attacks that trick users into approving unauthorized logins.
Push Notifications	High	High	Moderate - Similar to Authenticator Apps, vulnerable to phishing for login approvals.
Security Keys (Hardware Tokens)	Very High	Low (requires carrying the token)	Very Low - Nearly impossible to bypass without physical access to the token.
Biometrics (Fingerprint, Facial Recognition, Retina)	High (when combined with other factors)	High (easy to use)	Moderate - Potential for spoofing with high-quality replicas depending on the implementation.

Security Strength:

- **Hardware Tokens:** Offer the strongest security as they require physical possession and are not easily replicated.

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- **Authenticator Apps (TOTP/HOTP):** Generate unique codes that are more secure than static passwords and less vulnerable to interception compared to SMS.
- **Push Notifications:** Similar security level to Authenticator Apps, but rely on a secure connection between the user's device and the service.
- **SMS OTP:** Relatively less secure due to the vulnerability of phone networks and potential for SIM swapping attacks.
- **Biometrics:** Can be strong when combined with other factors, but spoofing vulnerabilities exist depending on the implementation.

User Convenience:

- **Push Notifications and Biometrics:** Offer the most convenient user experience as they require minimal user interaction for verification.
- **Authenticator Apps:** Convenient once set up, but require users to launch the app and enter the code.
- **SMS OTP:** Relatively convenient but might be unreliable depending on phone reception.
- **Hardware Tokens:** Least convenient as they require carrying and physically connecting the token to the device.

Bypass Vulnerabilities:

- **Hardware Tokens:** Most secure and least vulnerable to bypass attempts.
- **Authenticator Apps:** Vulnerable to phishing attacks that trick users into approving unauthorized logins.
- **Push Notifications:** Similar vulnerabilities to phishing attacks as Authenticator Apps.
- **SMS OTP:** Highly vulnerable to SIM swapping attacks, social engineering tactics to intercept codes, and potential network vulnerabilities.
- **Biometrics:** Vulnerable to spoofing attempts with high-quality replicas depending on the sophistication of the biometric system.

Choosing the Right MFA Method:

The ideal MFA method depends on your specific needs. Here's a suggestion based on priority:

- **Highest Security:** Hardware Tokens are the most secure but least convenient.
- **Balanced Security and Convenience:** Authenticator Apps or Push Notifications offer a good balance.
- **Focus on Convenience:** Biometrics can be convenient but consider potential vulnerabilities.
- **Least Secure Option:** While convenient, SMS OTP should be used cautiously due to its high bypass vulnerability.

It's also recommended to combine MFA methods for even stronger security. For example, using a hardware token along with fingerprint recognition can create a highly secure login process.

Based on the discussions, we propose the following “Multi Factor Authentication Framework” as detailed in the Flowchart given below as one of the most effective MFA mechanisms for cloud environment.

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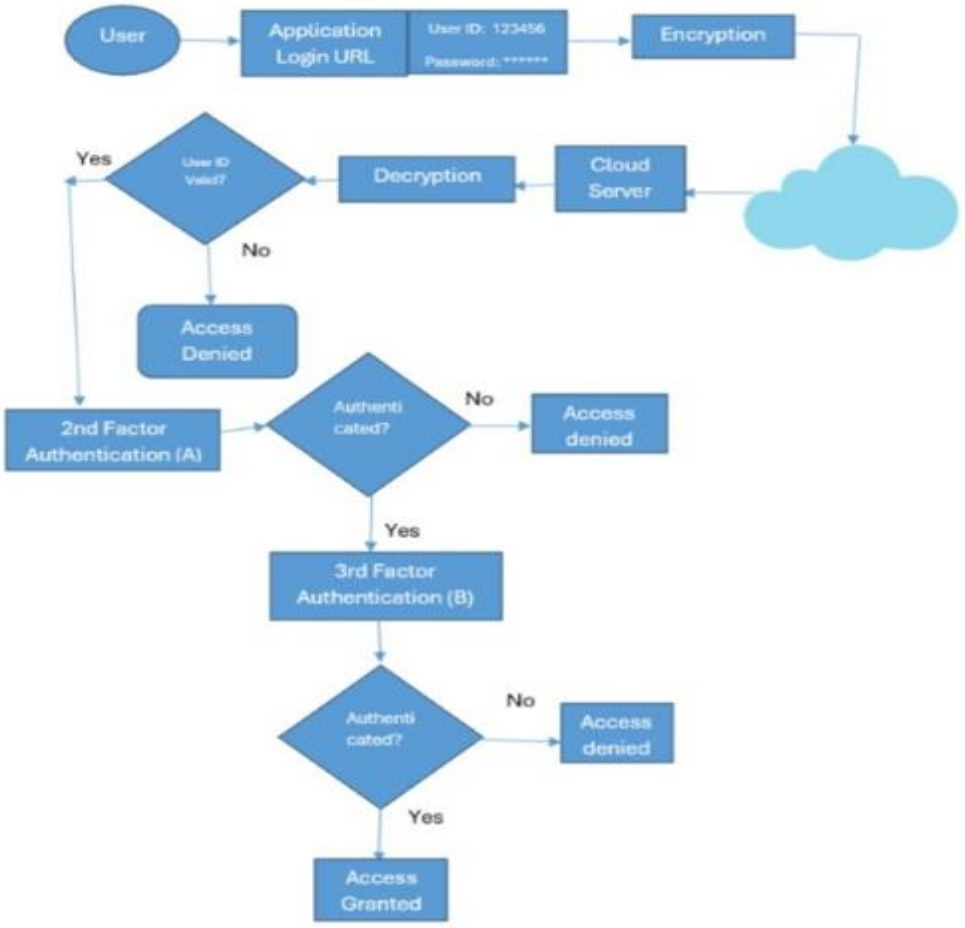
3 Level Multi Factor Authentication Framework Flowchart



Password is the first factor authentication (Something you know, i.e. knowledge)

A: 2nd Factor Authentication can be any one of either OTP, App-based notification, or hardware token, challenge-response, etc. (Something you have, i.e. Physical possession)

B: 3rd Factor Authentication can be any one of the biometric (fingerprint, face recognition, retina scan, etc.) (Something you are i.e. biometric)

(Figure-1: 3 Level Multi Factor Authentication Framework Flowchart)

Limitations of the Research on MFA and Cloud Security

While the presented research provides compelling evidence for the effectiveness of MFA in strengthening cloud security, there are limitations to consider:

- **Focus on Effectiveness:** The research primarily focuses on how MFA thwarts unauthorized access and strengthens security posture. It might not delve deeply into potential vulnerabilities of specific MFA methods or address emerging attack vectors that could bypass MFA altogether.
- **Limited Scope:** The research might be based on specific case studies or focus on particular industries. The findings might not be universally applicable to all cloud environments or account for the vast array of cloud service providers and their security implementations.
- **User Experience Focus:** The research might emphasize user experience and user-friendly MFA methods. While important, a more in-depth exploration of potential usability issues or user behavior that could compromise MFA security might be lacking.
- **Long-Term Impact Analysis:** The research might not analyze the long-term effectiveness of MFA as attacker tactics evolve. It might be beneficial to explore how MFA effectiveness changes over time and how security strategies need to adapt.

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- **Cost-Benefit Analysis:** While the research emphasizes security benefits, a more comprehensive analysis of the costs associated with implementing and maintaining MFA across an organization might be absent.

This research paper has conducted a comparative analysis of various Multi-Factor Authentication (MFA) mechanisms in the context of enhancing cloud security. The analysis explored the strengths and weaknesses of different factors, including knowledge-based (passwords), possession-based (tokens, mobile devices), and inherence-based (biometrics) factors.

Here are the key takeaways from this analysis:

- **MFA offers a robust defense against various cyberattacks:** By requiring multiple authentication factors, MFA thwarts attacks that rely on stolen passwords or compromised credentials.
- **The choice of MFA factor influences security and usability:** Knowledge-based factors offer a balance between security and ease of use, while possession-based factors enhance security but might introduce manageability challenges. Inherence-based factors provide the strongest security but require specialized hardware and might have user adoption issues.
- **Balancing security and user experience is crucial:** Implementing MFA shouldn't hinder user productivity. Striking a balance between robust security and a smooth user experience is essential for successful MFA adoption.

V. FUTURE RESEARCH DIRECTIONS

- Exploring the integration of emerging technologies like behavioral biometrics and risk-based authentication with MFA.
- Investigating methods to streamline MFA workflows and enhance user experience.
- Analyzing the cost-effectiveness of implementing various MFA solutions for different cloud security needs.

By continuously evaluating and improving MFA mechanisms, we can ensure a more secure cloud environment for users and organizations.

VI. CONCLUSION

Based on the research findings on Multi-Factor Authentication (MFA) and its impact on cloud security, here are the key recommendations and conclusions:

- **Widespread MFA Adoption:** Organizations should prioritize implementing MFA for all cloud accounts, especially for high-risk users and access points. A risk-based approach can be used to phase in MFA adoption, ensuring a balance between security and user experience.
- **User-Centric Implementation:** Choose user-friendly MFA methods like push notifications on smartphones. Additionally, invest in user education and awareness campaigns to address concerns about complexity and promote user acceptance.
- **Integration with IAM Systems:** Integrate MFA with existing Identity and Access Management (IAM) systems for a streamlined user experience and centralized control. This leverages existing infrastructure for a more efficient implementation.
- **Alignment with Zero Trust:** Leverage MFA as a core component of a Zero Trust security model. Combine MFA with other Zero Trust principles like least privilege access control to create a multi-layered defense strategy with minimal attack surfaces.
- **Continuous Monitoring and Improvement:** Regularly evaluate the effectiveness of your MFA implementation. Monitor user experience, security incidents, and emerging threats to adapt and improve your strategy over time.
- **MFA is a critical security measure:** Research overwhelmingly demonstrates that MFA significantly enhances cloud security by increasing the difficulty of unauthorized By following these recommendations and recognizing the clear benefits of MFA, organizations can leverage its power to build a robust cloud security posture and safeguard their valuable information assets.

Our findings demonstrate that MFA significantly strengthens cloud security compared to single-factor authentication (SFA). By adding additional layers of verification, MFA makes unauthorized access considerably

more difficult. The specific MFA method chosen should consider factors like security strength, user convenience, and deployment complexity.

VII. REFERENCES

[1] Tatineni, Sumanth (2022), Customer Authentication in Mobile Banking-MLOps Practices and AI-Driven Biometric Authentication Systems, Journal of Economics & Management Research, Volume 3(4): 1-5

[2] Donald, Charles (2023), Cloud Computing Security: Beyond Passwords with Multi-Factor Authentication (URL: https://www.researchgate.net/profile/Mike-Stephen/publication/380395476_Title_Cloud_Computing_Security_Beyond_Passwords_with_Multi-Factor_Authentication/links/663a5b4b7091b94e93f900f7/Title-Cloud-Computing-Security-Beyond-Passwords-with-Multi-Factor-Authentication.pdf, Accessed on 14-06-2024)

[3] Wael Said, Elsayed Mostafa, M. M. Hassan and Ayman Mohamed Mostafa (2021), A Multi-Factor Authentication-Based Framework for Identity Management in Cloud Applications (URL: https://doi.org/10.32604/cmc.2022.023554, Accessed on 13-06-2024)

[4] Pomerantz, Dorothy (2024), Biometrics will soon replace passwords once and for all, (URL: https://www.mastercard.com/news/perspectives/2024/biometrics-will-soon-replace-passwords-once-and-for-all/?cmp=2024.q1.glo.glo.all.brand.purp.others.mastercard-news.602201.sep.txt.googles.secure%20authentication&gad_source=1&gclid=CjwKCAjwm_SzBhAsEiwAXE2Cv5ssiyO3Gsto3TMnCaHcK2G3KrxrUKgtI4mE8gG0cSJhoo57lMS9_BoCFCQQAvD_BwE, Accessed on 15-06-2024)

[5] Guru, SS (2024), Biometric Authentication: The Game-Changer for Next Generation Payment Security and User Experience, International Research Journal of Modernization in Engineering Technology and Science, Volume:06/Issue:06/June-2024, (https://doi.org/10.56726/IRJMETS58781, Accessed on 15-06-2024)

[6] Mostafa, Ayman Mohamed (2023) and others, Strengthening Cloud Security: An Innovative Multi-Factor Multi-Layer Authentication Framework for Cloud User Authentication, (URL: https://doi.org/10.3390/app131910871, Accessed on 14-06-2024)

[7] Otta, Soumya Prakash and others (2023), A Systematic Survey of Multi-Factor Authentication for Cloud Infrastructure, Cybersecurity in the Era of AI (URL: https://doi.org/10.3390/fi15040146, Accessed on 16-06-2024)

[8] Singh, Charanjeet, Dr. Singh, Tripat Deep (2019), A 3-Level Multi-Factor Authentication Scheme for Cloud Computing, International Journal of Computer Engineering & Technology (IJCET), Volume 10, Issue 1, January-February 2019, (URL: https://www.mdpi.com/1999-5903/15/4/146, Accessed on 18-06-2024)

[9] Kumar, Satish (2014) and others, Multi-Authentication for Cloud Security: A Framework, International Journal of Computer Science & Engineering Technology (IJCSET), Vol. 5 No. 04 Apr 2014, (URL: https://www.ijcset.com/docs/IJCSET14-05-04-180.pdf, Accessed on 16-06-2024)

[10] Multifactor Authentication in Cloud Computing, Chapter 5, (URL: https://idr-lib.iitbhu.ac.in/ xmlui /bitstream/handle/123456789/1052/Chapter%205.pdf?sequence=13&isAllowed=y, Accessed on 15-06-2024, Accessed on 16-06-2024)