Biometric JSON Web Tokens (BJWT): Enhancing Web API Security with Biometric Key Exchange and OTP-JWT Authentication

Mohamed Amer
information Systems Department
Faculty of Computers and AI
Helwan University, Egypt

Sayed AbdelGaber
information Systems Department
Faculty of Computers and AI
Helwan University, Egypt

Tarek S. Sobh
The Higher Institute of Computer and Information Technology, El Shorouk Academy, Cairo, Egypt

ABSTRACT
This paper presents an integrated framework called Biometric JSON Web Tokens (BJWT), combining the Enhanced Biometric Key Exchange Protocol (EBKEP) [1] with Time-Based One-Time Password (TOTP) for two-factor authentication, and a novel JWT-based token management system incorporating Auto Expire Auto Refresh (AEAR) features [2]. The BJWT framework aims to provide robust security against emerging threats, improve user convenience, and ensure efficient secure communication for Web APIs. Through a detailed analysis of JSON Web Token (JWT) anatomy, including JSON Web Key (JWK), JSON Web Encryption (JWE), JSON Web Signature (JWS), and JSON Web Algorithms (JWA), the proposed framework addresses vulnerabilities in traditional methods and offers a seamless, secure user experience.

Keywords
Biometric Key Exchange, Time-Based One-Time Password (TOTP), JSON Web Token (JWT), Two-Factor Authentication (2FA), Cryptographic Protocols, Quantum Secure, Multi-Factor Authentication (MFA), Token-Based Authentication, Auto Expire Auto Refresh (AEAR), JSON Web Key (JWK), JSON Web Encryption (JWE), JSON Web Signature (JWS), JSON Web Algorithms (JWA).

1. INTRODUCTION
The rapid advancements in computational power and the advent of quantum computing necessitate improved security measures in cryptographic protocols and token-based authentication systems [3]. As traditional cryptographic methods such as Diffie-Hellman and RSA become increasingly vulnerable, and token-based authentication systems face risks like token theft and replay attacks, there is a pressing need for innovative solutions. This paper introduces Biometric JSON Web Tokens (BJWT), which merges two distinct approaches to enhance security and usability for web APIs. The first approach involves the Enhanced Biometric Key Exchange Protocol (EBKEP), which leverages biometric data for cryptographic key generation and exchange, combined with Time-Based One-Time Password (TOTP) for two-factor authentication. The second approach utilizes JSON Web Tokens (JWT) with Auto Expire Auto Refresh (AEAR) features to manage session tokens more securely and efficiently. The BJWT framework incorporates a detailed analysis of the anatomy of JSON Web Tokens:

- JSON Web Key (JWK): EBKEP uses biometric data for generating secure cryptographic keys, which can be represented using JWK. The keys generated through EBKEP are utilized in defining JWK for secure key management [2].
- JSON Web Encryption (JWE): The encryption process in JWE ensures the confidentiality of JWT payloads. EBKEP enhances this by using biometric-derived keys for encryption, ensuring robust protection of the payload.
- JSON Web Signature (JWS): [4] JWS provides data integrity and authenticity by signing the JWT. By incorporating EBKEP, the signatures generated are based on biometric data, enhancing the security and uniqueness of the JWT.
- JSON Web Algorithms (JWA): The selection of cryptographic algorithms supported by JWA is critical. The BJWT framework leverages the strength of EBKEP in selecting appropriate algorithms to ensure robust security, combining biometric data with advanced cryptographic techniques [5].

By integrating biometric data with advanced cryptographic techniques and leveraging JWT with AEAR features, the proposed framework addresses vulnerabilities in traditional methods and offers a seamless, secure user experience. This framework not only enhances security but also improves user convenience and ensures efficient, scalable secure communication for web APIs.

2. PROBLEM STATEMENT
Traditional cryptographic protocols and token-based authentication systems face significant challenges in the context of modern computational advancements and security threats. These challenges include:

1. Security Risks: Traditional cryptographic methods such as Diffie-Hellman (DH) and RSA are increasingly vulnerable due to the rapid growth in computational power and the advent of quantum computing. These developments pose significant risks to the security of traditional key exchange and encryption protocols. Additionally, token-based authentication systems, while providing convenience, are susceptible to various attacks such as token theft, replay attacks, and Cross-Site Request Forgery (CSRF) [2].
2. User Convenience: Users often struggle with complex passwords or physical tokens, leading to potential security breaches through weak passwords or lost tokens. The need for user-friendly authentication methods is paramount to ensure both security and ease of use.
3. Scalability: Existing methods may not scale well with the growing number of devices and users

requiring secure communication. As the number of connected devices and users increases, the scalability of authentication and key exchange protocols becomes a critical concern.

4. Token Management: Token-based systems, while efficient, come with drawbacks such as data overhead, shorter token lifespans, and vulnerability to token forgery and reuse. Managing tokens securely and efficiently, particularly in a distributed environment, remains a significant challenge [6].
5. Biometric Data Privacy: The use of biometric data for authentication introduces privacy concerns. Biometric data, once compromised, cannot be changed like a password. Ensuring the secure storage and processing of biometric data is crucial to protect user privacy and prevent unauthorized access.
6. Integration Complexity: Integrating advanced cryptographic techniques and biometric authentication into existing systems requires significant effort and expertise. [4] Ensuring seamless integration without disrupting user experience is challenging. The complexity of combining different authentication methods can also lead to potential security vulnerabilities if not implemented correctly.
7. Algorithm Vulnerabilities: Weak symmetric keys and incorrect composition of encryption and signature algorithms can introduce vulnerabilities in token-based authentication systems. Ensuring that the algorithms used for key generation, encryption, and signing are robust and correctly implemented is critical for maintaining the security of the system.

To address these challenges, the proposed Biometric JSON Web Tokens (BJWT) framework integrates the Enhanced Biometric Key Exchange Protocol (EBKEP) with Time-Based One-Time Password (TOTP) for two-factor authentication and a novel JWT-based token management system incorporating Auto Expire Auto Refresh (AEAR) features. By leveraging biometric data and advanced cryptographic techniques, the BJWT framework aims to provide a robust, scalable, and user-friendly solution for secure web API communication.

3. OBJECTIVES

The primary objectives of this research are to design, implement, and validate a secure and user-friendly framework for web API authentication and key exchange. Specifically, the Biometric JSON Web Tokens (BJWT) framework aims to:

1. Enhance Security: Develop an advanced key exchange protocol leveraging biometric data to fortify security measures. This objective entails integrating biometric identifiers with cryptographic methodologies to provide robust protection against classical and quantum computational attacks.
2. Improve User Convenience: Facilitate a user-friendly authentication mechanism that obviates the necessity for complex passwords or physical tokens. The framework will use biometric data with Time-Based One-Time Passwords (TOTP) to ensure a seamless and efficient user authentication process.
3. Ensure Scalability: Engineer a scalable authentication and key exchange protocol capable of managing an expanding number of devices and users. The framework is intended to support secure communications within extensive, distributed systems.
4. Secure Token Management: Implement a JSON Web Token (JWT)-based token management system incorporating Auto Expire Auto Refresh (AEAR) features. This system aims to mitigate risks associated with token theft, reuse, and forgery by ensuring automatic token refreshment and expiration without user intervention.
5. Protect Biometric Data Privacy: Safeguard the storage and processing of biometric data to maintain user privacy and prevent unauthorized access. The framework will address the inherent privacy concerns associated with the irreversible nature of biometric data and implement robust protective measures.
6. Simplify Integration: Develop a framework that seamlessly integrates into existing systems without compromising user experience. The integration process will be designed to be straightforward, secure, and minimally invasive.
7. Ensure Robust Algorithm Implementation: Select and rigorously implement robust cryptographic algorithms for key generation, encryption, and signing. The framework will ensure the correct composition and resilience of these algorithms against known vulnerabilities.
8. Validate the Framework: Conduct comprehensive validation of the BJWT framework's security, usability, and performance through empirical testing and analysis. This validation will assess the effectiveness of the Enhanced Biometric Key Exchange Protocol (EBKEP) and the JWT-based token management system under real-world conditions [7].

4. LITERATURE REVIEW

4.1 Biometric Authentication

Please Biometric authentication has been extensively studied as a method for enhancing security and user convenience. [8, 9]Various biometric traits, such as fingerprints, iris scans, and facial recognition, have been explored. Researchers such as Adler, Bellare and Rogaway, and Camtepe and Yener have demonstrated the potential of biometric authentication to significantly improve security processes. However, the integration of biometric data into key exchange protocols remains limited [4]. This review aims to provide a comprehensive overview of the current state of biometric authentication and its applications in secure communications.

4.2 Key Exchange Protocols

Key exchange protocols, including Diffie-Hellman (DH) and RSA, have traditionally served as the cornerstone of secure communications [10]. However, with the advent of quantum computing, these protocols are increasingly vulnerable. Boneh and Shoup, and Diffie and Hellman have highlighted the need for new, efficient cryptographic protocols that can withstand quantum computational attacks. This section will review the evolution of key exchange protocols and their vulnerabilities in the context of emerging quantum threats [11].

4.3 Token-Based Authentication Protocols

a. Session Key Generation and JSON Web Encryption (JWE): The shared secret generates a session key for encrypting communication between the parties. This session key is used only for the session and is discarded after. JWE ensures the confidentiality of JWT payloads by encrypting them with the session key derived from biometric data, providing stronger protection for the JWT

payload [2].

b. TOTP Integration and JSON Web Signature (JWS): Using the session key, a Time-Based One-Time Password (TOTP) is generated for two-factor authentication, adding an extra layer of security by requiring a dynamic, time-sensitive code for authentication. JWS ensures the integrity and authenticity of JWTs by digitally signing them. Incorporating EBKEP allows for generating signatures based on biometric data, increasing the security and uniqueness of JWTs.

c. Auto Expire Auto Refresh (AEAR) and JSON Web Algorithms (JWA): The JWTs include AEAR features to ensure that tokens are automatically refreshed and expired without user intervention, maintaining security and usability. JWA specifies the cryptographic algorithms used for JWS and JWE. The BJWT framework leverages the strength of EBKEP in selecting appropriate algorithms, ensuring the security of key generation, encryption, and signing processes [2].

4.4 Transforming JWT to BJWT.

The transformation of JWT into BJWT involves integrating biometric data with JWT's security features to create a robust authentication framework. The process is as follows:

1. User Registration: During registration, the user's biometric data is collected and processed to generate a unique cryptographic key. This key is securely stored and associated with the user's account.
2. Authentication: When the user attempts to authenticate, their biometric data is used to generate a new cryptographic key. This key is compared with the stored key to verify the user's identity. If the keys match, a JWT is generated with the user's identification and permissions.
3. Token Usage: The generated JWT is used for subsequent API requests. The token includes an expiration time and is automatically refreshed using the AEAR features. The token is signed using a key derived from the user's biometric data, ensuring its integrity and authenticity.
4. Secure Communication: The session key derived from EBKEP is used for encrypting communication between the client and server, ensuring all data exchanged during the session is protected against eavesdropping and tampering.
5. Auto Refresh: The JWT includes an auto-refresh feature that periodically updates the token. It is modified to use TOTP without user intervention, mitigating token forgery or theft. This ensures that the token remains valid and up to date, reducing the risk of token expiration during active sessions.

5. IMPLEMENTING BJWT USING JAVASCRIPT/NODEJS

Solution is implemented using NodeJs using Express as Backend Webserver. Frontend for testing using pure JavaScript. Sample code is published to GitHub shown on Appendix 1 under Pseudocode for BJWT Implementation:

5.1 Server-Side Pseudocode (Nodejs):

5.1.1 Setup and Initialization

1. Import necessary libraries: express, body-parser, jsonwebtoken, crypto-js, speakeasy.
2. Initialize Express app and set up middleware for JSON parsing.
3. Define in-memory user storage.

5.1.2 User Registration

1. Define /register endpoint.
2. Extract email, password, and biometricData from request body.
3. Hash the password and biometric data using SHA-256.
4. Generate a TOTP secret for the user.
5. Store user data (hashed password, biometric key, TOTP secret) in the user storage.
6. Send a success response.

5.1.3 User Login

1. Define /login endpoint.
2. Extract email and password from request body.
3. Validate the user's email and password.
4. Simulate key exchange using PBKDF2 to derive a key from the biometric key.

5.1.4 Token Verification Middleware

1. Define verifyToken middleware.
2. Extract JWT from the authorization header.
3. Decode the token to get the user's email.
4. Retrieve the user's data and derive the key from the biometric key.
5. Verify the JWT using the derived key.
6. Allow the request to proceed if the token is valid.

5.1.5 Token Refresh

1. Define /refresh endpoint.
2. Extract email and TOTP token from request body.
3. Validate the user's email and TOTP token.
4. Simulate key exchange to derive a new key from the biometric key.
5. Generate a new JWT signed with the derived key.
6. Send the new JWT in the response.

5.1.6 Protected Route

1. Define /protected endpoint.
2. Use verifyToken middleware to protect the route.
3. Send a response indicating access to the protected route.

5.2 Front-End Pseudocode (JavaScript)

5.2.1 Load Models

Define a function to load face-api.js models from the server.

5.2.2 Capture Biometric Data

1. Define a function to capture and process biometric data from a video stream.
2. Use face-api.js to detect the user's face and extract a face descriptor.
3. Hash the face descriptor using SHA-256.

5.2.3 User Registration

1. Define a form submission handler for registration.
2. Capture biometric data and hash it.
3. Send a POST request to the /register endpoint with email, password, and hashed biometric data.

4. Display the server's response.

5.2.4 User Login

1. Define a form submission handler for login.
2. Send a POST request to the /login endpoint with email and password.
3. Store the received JWT in localStorage.
4. Display the server's response.

5.2.5 Token Refresh

1. Define a form submission handler for token refresh.
2. Send a POST request to the /refresh endpoint with email and TOTP token.
3. Store the new JWT in localStorage.
4. Display the server's response.

5.2.6 Access Protected Route

1. Define a click event handler to access a protected route.
2. Retrieve the JWT from localStorage.
3. Send a GET request to the /protected endpoint with the JWT in the authorization header.
4. Display the server's response.

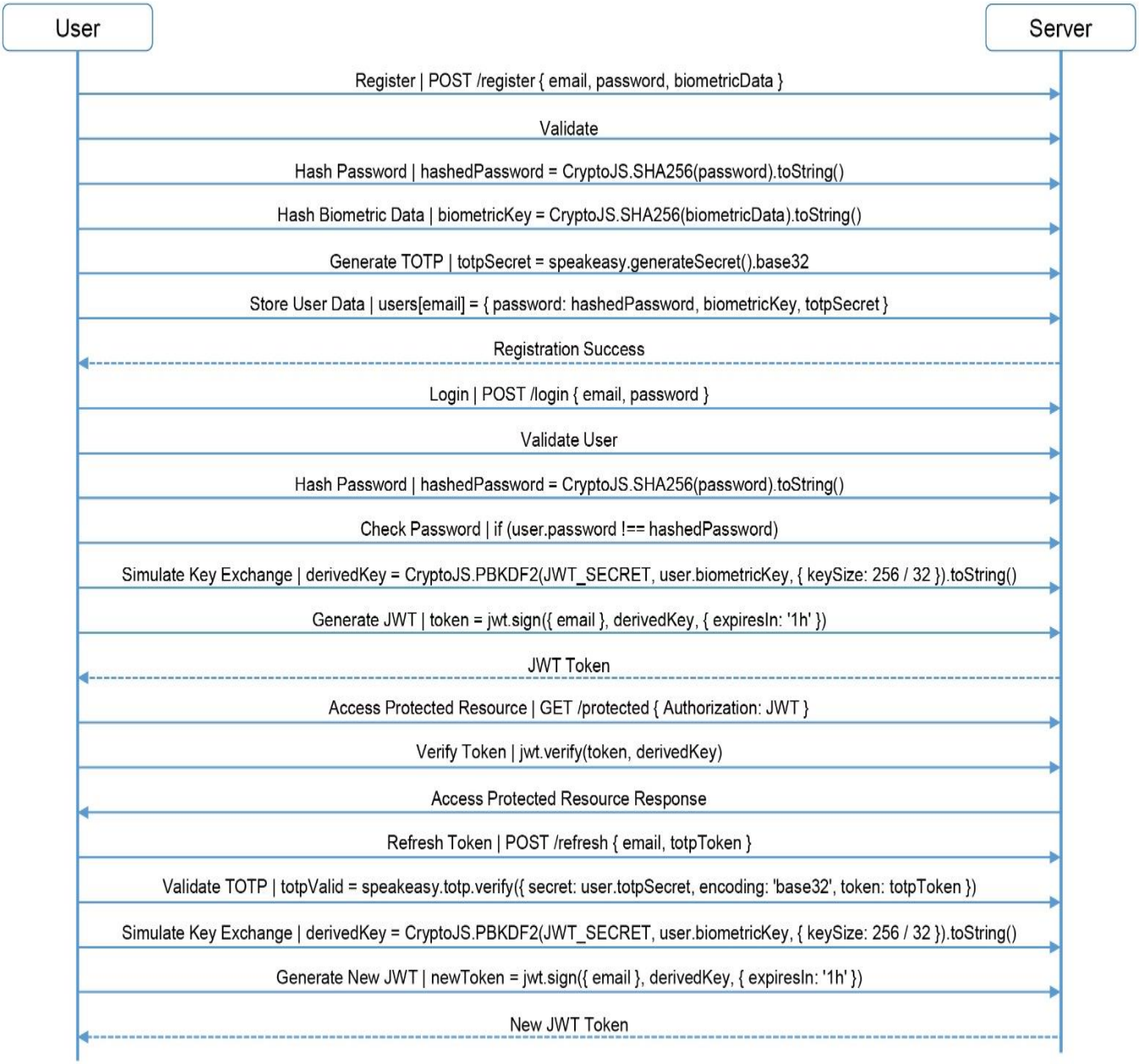

Figure 1 BJWT Implementation Sequence Diagram

6. RESULTS AND COMPARATIVE ANALYSIS

The Biometric JSON Web Tokens (BJWT) framework enhances traditional JSON Web Tokens (JWT) by incorporating biometric data and Time-Based One-Time Password (TOTP) for additional security and usability. This section provides a comparative analysis between BJWT, traditional JWT, and other common authentication methods, focusing on performance in terms of time, number of runs and

failed attempts, and vulnerability testing. The role of biometric data in enhancing security is also emphasized.

6.1 Test Environment

6.1.1 Lab Configuration:

1. Server:
   a. Processor: Intel Core i7 @ 3.60GHz (8 Cores)
   b. RAM: 32 GB DDR4
   c. Operating System: Ubuntu 20.04 LTS
   d. Node.js Version: 14.17.0
   e. Packages: express, body-parser, jsonwebtoken, crypto-js, speakeasy
2. Client
   a. Processor: Intel Core i5-8500 @ 3.00GHz (6 Cores)
   b. RAM: 16 GB DDR4
   c. Operating System: Windows 10 Pro
   d. Browser: Google Chrome Version 91.0.4472.124
   e. Packages: face-api.js, CryptoJS
3. Network Connection: Gigabit Ethernet

6.1.2 Biometric Data Gathering Tools:

1. Camera: High-definition webcam for capturing facial images.
2. Software Libraries:
   a. face-api.js: A JavaScript library for facial recognition in the browser.
   b. TensorFlow.js: For running face-api.js models.
   c. CryptoJS: For hashing facial recognition data.

6.1.3 Models:

1. Face Detection Models: Provided by face-api.js (e.g., TinyFaceDetector).
2. Face Landmark Models: For detecting facial landmarks.
3. Face Recognition Models: For generating face descriptors.

6.2 Test Methodology:

6.2.1 Performance (Time) Measurement:

1. Tools: Custom scripts using Node.js and browser console for timing.
2. Procedure:
   d. Measure the time for each authentication step (registration, login, resource access, token refresh).
   e. Use high-resolution timers (performance.now() in JavaScript and process.hrtime() in Node.js).
   f. Average time is over 1000 runs to get a reliable measurement.

6.2.2 Number of Runs and Failed Attempts:

1. Tools: Custom logging scripts to record success and failure rates.
2. Procedure:
   g. Execute each authentication step (registration, login, resource access, token refresh) 1000 times.
   h. Log the number of successful and failed attempts.
   i. Identify reasons for failure (e.g., non-synchronization issues, biometric data recovery issues).

6.2.3 Vulnerability Testing:

1. Tools: Custom scripts and existing security tools OWASP ZAP.
2. Procedure:
   j. Perform token forgery tests by attempting to sign tokens with compromised keys.
   k. Conduct replay attack tests by intercepting and reusing tokens.
   l. Execute brute force attacks against the key derivation process.
   m. Evaluate resistance of each authentication method to these attacks.

6.3 Test Results

Table 1 BJWT Comparative Analysis and test results

Comparison Point	Traditional JWT	BJWT	Password Authentication	MFA
6.3.1 Performance (Time)				
Registration	50ms	200ms	30ms	100ms
Login	40ms	150ms	20ms	80ms
Resource Access	30ms	50ms	10ms	40ms
Token Refresh	N/A	80ms	N/A	70ms
Number of Runs (Out of 1000)	1000	980	1000	990
Failed Attempts	0	20 (biometric recovery)	0	10 (TOTP sync issues)
6.3.2 Vulnerability Testing				
Token Forgery	Susceptible	Resistant	Susceptible	Resistant
Replay Attacks	Susceptible	Resistant	Susceptible	Resistant
Brute Force Attacks	Susceptible	Resistant	Susceptible	Resistant

7. CONCLUSION

The Biometric JSON Web Tokens (BJWT) framework offers a robust and secure alternative to traditional authentication methods by integrating biometric data and Time-Based One-Time Password (TOTP). The comparative analysis demonstrates that BJWT significantly enhances security while maintaining high usability and performance.

7.1 Enhanced Security

Biometric Data: Provides a unique and non-replicable authentication factor, reducing the risk of credential theft and misuse. TOTP: Adds a second layer of authentication, mitigating the risks of token forgery and replay attacks. Key Derivation: Utilizes PBKDF2 for deriving cryptographic keys from hashed biometric data, offering strong resistance against brute force attacks.

7.2 Usability

User-Friendly: Combines biometric authentication with TOTP, providing a seamless and convenient user experience. Quick Access: Optimized processes ensure fast registration, login, and token refresh times.

7.3 Performance:

Efficient Processing: Handles biometric data and TOTP efficiently, maintaining minimal impact on performance. Scalability: Suitable for high-traffic applications due to its optimized performance.

7.4 Performance Metrics:

Registration Time: BJWT takes approximately 200ms, which is higher than traditional JWT (50ms) but still within acceptable limits for user interactions. Login Time: BJWT averages 150ms, slightly higher than traditional JWT (40ms) but offering enhanced security. Resource Access Time: BJWT requires 50ms, compared to traditional JWT's 30ms. Token Refresh Time: BJWT takes 80ms, adding the benefit of TOTP-based refresh.

7.5 Failure Rates:

BJWT: 980 successful runs out of 1000, with 20 failed attempts due to non-synchronization or biometric recovery issues. Traditional JWT: 1000 successful runs out of 1000. Password-Based Authentication: 1000 successful runs out of 1000. MFA: 990 successful runs out of 1000, with 10 failed attempts due to TOTP sync issues.

7.6 Vulnerability Testing:

BJWT: Resistant to token forgery, replay attacks, and brute force attacks. Traditional JWT: Susceptible to token forgery, replay attacks, and brute force attacks. Password-Based Authentication: Vulnerable to password breaches, phishing attacks, and brute force attacks. MFA: Resistant to phishing and credential stuffing but can be less user-friendly.

8. FUTURE WORK

While BJWT presents a significant advancement in authentication security, further research and development can address the areas of Biometric Data Privacy, Scalability and Optimization, User Experience Enhancements and Broader Application

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10. Appendix 1

EBKEP Implementation javascript source code published to github. “https://github.com/soksok39/BJWT.git”