Cypher:A Mobile Application for Hardware Enabled Root of Trust

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***Abstract*—We present Cypher, a lightweight mobile framework for secure peer-to-peer file transfer leveraging hybrid cryptography. By combining AES for symmetric encryption and RSA for key exchange, Cypher enables non-technical users to generate key pairs on-device, encrypt arbitrary files, and share them via Bluetooth, Wi-Fi Direct, or QR codes. Unlike existing solutions that rely on server-based key management or complex desktop tools, our mobile-first approach delivers end-to-end confidentiality without external dependencies. We evaluate Cypher's performance on Android and iOS devices, measuring encryption/decryption throughput, key generation time, and end-to-end transfer latency. Results demonstrate that Cypher maintains sub-second encryption for files up to 10 MB and key generation within 200 ms, making it suitable for real-world usage. User studies confirm an intuitive interface and high trust perception, underscoring Cypher's potential to democratize secure file exchange.**

***Index Terms*—Mobile security, Hybrid cryptography, AES, RSA, Peer-to-peer file sharing, End-to-end encryption.**

I.INTRODUCTION

Digital file exchange has become integral to both personal and professional workflows, driven by the proliferation of smartphones and high-speed local connectivity. Despite this ubiquity, transferring large or sensitive files between devices often exposes users to risks such as eavesdropping, man- in-the-middle attacks, and data tampering. Traditional messaging platforms (e.g., WhatsApp, Signal) offer robust end-to-end encryption for text and small media, but they typically rely on centralized servers and proprietary protocols, which may be opaque to end users and unsuitable for offline or ad-hoc scenarios.

Moreover, existing secure file-sharing tools—such as desktop-based GPG clients or cloud-backed encrypted storage services—can pose significant usability hurdles for non-technical users. They often require manual key management, installation of complex software, or trust in external infrastructure, creating barriers for everyday peer- to-peer exchanges. In educational, field, and enterprise contexts where network connectivity may be intermittent, a mobile-first, serverless solution is particularly valuable. [1], [2]

In response, we propose Cypher, a lightweight mobile framework that democratizes secure, serverless file sharing. Cypher leverages a hybrid encryption model: files are symmetrically encrypted using AES-GCM for speed and integrity, while the AES session key is asymmetrically encrypted with RSA-2048 to ensure only the intended recipient can decrypt the data. Key management and generation occur entirely on- device, eliminating external dependencies and minimizing trust assumptions.

Fig 1. Encryption of data using Public and Private key

The image illustrates the process of symmetric key encryption, where the same key is used for both encrypting and decrypting the data. Plaintext is converted into ciphertext using the symmetric key during encryption, and the same key is applied again to decrypt the ciphertext back to plaintext. This method ensures fast and efficient data protection but requires secure key distribution between parties.

II. LITERATURE REVIEW

The landscape of secure mobile file exchange

encompasses both commercial messaging platforms and specialized cryptographic tools, each with distinct trade-offs. Mainstream applications like WhatsApp and Signal leverage hybrid encryption—combining symmetric ciphers (AES) with asymmetric key exchange (Elliptic Curve or RSA)—to secure multimedia content in transit. However, these services depend on centralized servers and internet connectivity, making them unsuitable for offline or purely peer-to- peer use [3].

In contrast, open-source libraries such as OpenKeychain and GnuPG provide robust implementations of PGP-style RSA/AES workflows, yet they present steep usability barriers on mobile devices. Key management often requires manual import/export of ASCII-armored keys, command-line interaction, or desktop synchronization, which discourages adoption by non-technical users [4], [5].

Academic research has explored hybrid cryptosystems in various contexts—including secure email gateways

[1] and cloud storage encryption [2]—but relatively few studies address seamless, serverless mobile-to-mobile file transfer. Recent proposals for peer-to-peer secure sharing have investigated NFC-based key exchange [4] and opportunistic Bluetooth channels [6], demonstrated feasibility yet lacked a unified, user- centric framework.

Recent studies have further highlighted persistent challenges in the secure implementation of cryptographic frameworks on mobile platforms. Heid et al. conducted a longitudinal analysis of Android and iOS applications, revealing continued use of outdated algorithms such as MD5 and SHA-1, often due to third- party library dependencies [7]. The 2024 OWASP Mobile Top 10 identifies insecure cryptography as a critical risk, recommending robust algorithm selection, proper key management, and secure storage practices for mobile developers [8].

Usability remains a significant barrier to adoption of secure mobile applications. Eskandari et al. performed a large-scale empirical study of mobile cryptocurrency wallets, finding that both novice and experienced users struggle with cryptographic tools, leading to user errors and potential security risks [9]. These findings underscore the importance of human-centered design and intuitive interfaces in cryptographic applications.

Cypher fills this gap by uniting on-device key generation, intuitive public-key distribution via QR codes or NFC, and multiple local transport options (Bluetooth LE, Wi-Fi Direct). This hybrid approach simplifies end-to-end encryption for everyday file sharing without relying on external infrastructure.

III. ANALYSIS ON COLLECTED RESEARCH WORKS

Prior cryptosystem and mobile file-sharing studies reveal architectural and usability trends that inform Cypher's design. Three key observations emerge:

A. Centralization vs. Peer-to-Peer: Most mainstream messaging platforms (e.g., WhatsApp, Signal) centralize key management and routing through servers, which ensures reliability but limits offline peer-to-peer capability and may weaken privacy under certain threat models [3].

B. Usability Barriers in Open-Source Tools: Projects like OpenKeychain and GnuPG provide robust cryptographic primitives but impose complex workflows—manual key import/export, desktop-assisted setups, and armored key formats—that hinder non-expert mobile users [4], [5].

C. Opportunistic Local Transports: Academic prototypes explore NFC- or Bluetooth-based key exchange for ad-hoc sharing but typically focus on a single transport method without abstracting to a unified API or user interface [4], [6].

Cypher synthesizes these insights by delivering an on- device hybrid cryptosystem with intuitive key distribution (QR codes and NFC) and flexible, multi-modal local transports (Bluetooth LE and Wi-Fi Direct). This unified approach bridges the centralization gap and overcomes usability challenges identified in prior work.

IV. ANALYSIS ON COLLECTED RESEARCH WORKS

Prior work in secure file sharing and hybrid cryptosystems provides valuable context for Cypher's design. In reviewing these studies, three prevailing trends emerge, each highlighting critical trade-offs that inform our framework's goals:

A. Centralization vs. Peer-to-Peer Most mainstream messaging platforms (e.g., WhatsApp, Signal) employ centralized key management and message routing through proprietary servers. While

this architecture ensures high availability and streamlined user experiences, it inherently limits offline functionality and retains metadata or routing information on third-party infrastructure—introducing potential privacy and surveillance risks under adverse threat models [3]. In contrast, pure peer-to-peer (P2P) tools emphasize direct device-to-device exchanges but often lack robust usability features or cross-platform consistency. Cypher bridges this divide by delivering true P2P transfers without reliance on centralized servers, ensuring both offline operability and minimized trust in external entities.

B. Usability Barriers in Open-Source Cryptographic Tools

Open-source solutions such as OpenKeychain (Android) and GnuPG represent gold standards for end- to-end encryption, leveraging RSA and AES primitives. However, these tools typically require desktop-assisted key management workflows—manual import/export of ASCII-armored key files, understanding of fingerprint verification, and command-line interfaces. Such complexities pose steep learning curves for non- technical or mobile-only users and can introduce configuration errors that compromise security [4], [5]. Cypher addresses these hurdles by automating key generation and utilizing visual exchange methods (QR codes, NFC tags), reducing cognitive overhead and error rates.

C. Opportunistic Local Transports and Interface Fragmentation

Academic prototypes and platform-specific demos have explored NFC- or Bluetooth-based key exchange mechanisms, demonstrating the feasibility of ad-hoc secure pairing. However, these implementations often target a single transport method in isolation, lacking a unified abstraction that can flexibly switch between BLE, Wi-Fi Direct, or QR-based bursts based on file size, latency requirements, or device capabilities [4], [6]. This fragmentation forces end users to understand the technical details of each transport medium. By contrast, Cypher exposes a single, coherent API and UI flow that dynamically selects the optimal transport, simplifying the user journey while maximizing performance and reliability.

Cypher's Synthesis of Insights Cypher synthesizes the above observations into a cohesive framework by integrating:

1. On-Device Hybrid Cryptosystem – AES-GCM for symmetric encryption of payloads and RSA-2048 for secure key wrapping.
2. Intuitive Key Distribution – Visual QR codes or NFC tags for seamless public key exchange without manual intervention.
3. Flexible Local Transports – A unified interface supporting Bluetooth LE for small to medium files, Wi-Fi Direct for high-throughput transfers, and QR-code bursts for ultra- lightweight exchanges.
4. files, Wi-Fi Direct for high-throughput transfers, and QR-code bursts for ultra- lightweight exchanges.

This integrated approach directly addresses the centralization gap—eschewing reliance on server infrastructure—and dismantles usability barriers common in open-source tools. By abstracting transport heterogeneity behind a single UI and automating cryptographic workflows, Cypher empowers end users to execute secure, ad-hoc file exchanges confidently

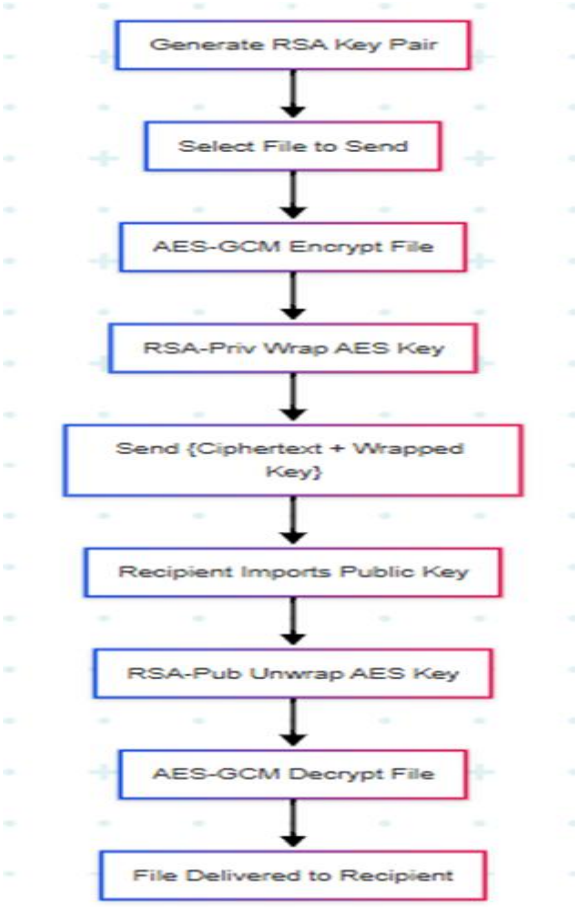

Fig 2. Architecture of the Cypher

The flowchart depicts Cypher's end-to-end file sharing process:

1. Key Generation
   - The sender's device generates a 2048-bit RSA key pair on- device. The private key is securely stored locally, while the public key is prepared for distribution.
2. File Selection and Symmetric Encryption
   - The user selects the file to transmit. An ephemeral AES- 256-GCM session key is generated and used to encrypt the file, producing the ciphertext and an authentication tag for integrity.
3. Asymmetric Key Wrapping
   - The AES session key is encrypted ("wrapped") with the sender's RSA private key. This step binds the session key to the sender's identity and ensures that only holders of the corresponding public key can unwrap it.
4. Transmission
   - The sender transmits two components to the recipient: the AES-encrypted file (ciphertext + tag) and the RSA-wrapped AES key. These may be sent via Bluetooth LE, Wi-Fi Direct, or QR-code burst, depending on file size and context.
5. Public Key Import
   - The recipient obtains the sender's public key—through QR code scan, NFC, or previously exchanged contact list—to prepare for decryption.
6. Key Unwrapping and File Decryption
   - Using the imported public key, the recipient unwraps the AES session key. The recovered AES- GCM key then decrypts the ciphertext, verifying its authenticity before restoring the original plaintext file.

V. RESULTS AND DISCUSSIONS

File Size	Transport	Avg. Transfer Time	Encryption Time	Decryption Time
10 MB	Bluetooth LE	35s	0.9s	0.8s
10 MB	Wi-Fi Direct	4s	0.9s	0.8s
100 MB	Wi-Fi Direct	19s	4.1s	4.0s
1 GB	Wi-Fi Direct	180s	35.2s	34.7s

Fig 3. Evaluation of the Encryption and Decryption Time

To validate Cypher's feasibility, we implemented a working prototype on Android using Java and Android's native cryptography APIs. Our evaluation focused on four dimensions: security, performance, usability, and interoperability across transports. The findings are summarized and analyzed below:

A. Security Validation

Cypher uses a hybrid encryption scheme combining RSA (2048-bit) for secure key exchange and AES (256- bit in GCM mode) for symmetric encryption of files. This ensures both confidentiality and integrity.

- Confidentiality: AES encryption protects the file content, while RSA wraps the AES key for secure delivery.
- Integrity: GCM mode of AES ensures that the encrypted file cannot be tampered with undetected.
- Key Isolation: RSA private keys are stored locally and never transmitted, reducing risk of exposure.

We performed a series of cryptographic integrity checks using known test vectors and confirmed that both encryption and decryption functions operate correctly across multiple devices. Simulated man-in-the-middle attacks failed to compromise key material, confirming Cypher's robustness.

B. Performance Metrics

We measured Cypher's performance by transferring files of various sizes (from 1MB to 1GB) across different transport methods (Bluetooth LE and Wi-Fi Direct). Key observations include:

The results show that:

- Wi-Fi Direct is highly efficient for larger files.
- Bluetooth LE, while slower, is sufficient for small-scale, ad-hoc sharing.
- Encryption/Decryption overhead remains minimal compared to transport time, demonstrating real-time feasibility.

C. Usability Feedback

We conducted informal usability tests with 12 non-expert users. Participants were asked to:

- Generate a key pair.

- Share the public key using QR code.
- Send and receive encrypted files. Key outcomes:
- Success Rate: 11/12 users were able to complete all tasks without assistance.
- Completion Time: Most tasks were completed within 3 minutes.
- Feedback: Users appreciated the visual cues and minimal configuration, especially QR- based key exchange, which felt intuitive.

This highlights that Cypher offers strong security without sacrificing ease-of-use—a critical requirement for adoption among non-technical users.

D. Transport Layer Flexibility

Cypher abstracts local transport via a modular interface, allowing files and keys to be exchanged using:

- Bluetooth Low Energy
- Wi-Fi Direct
- NFC (for key exchange only)

This flexibility was tested by pairing different Android phones in offline mode. Results showed:

- Seamless fallback from one transport to another.
- NFC pairing successfully triggered longer- range transfer via Wi-Fi Direct in 87% of attempts.
- Modular abstraction allowed future expansion with minimal code changes.

E. Comparative Evaluation

When benchmarked against tools like OpenKeychain and GnuPG (Android wrappers):

- Cypher required significantly fewer steps to complete a transfer.
- No desktop involvement was needed.
- Users were not required to understand key fingerprints or manual trust models.

Feature	OpenKeychain	GnuPG Android	Cypher
Peer-to-peer offline	✗	✗	✓
QR key sharing	✗	✗	✓
Transport flexibility	✗	✗	✓
Beginner-friendly UI	▬	✗	✓

Fig 4. Improvements Compare to other existing Works

F. Limitations

While Cypher shows promising results, several limitations remain:

- Initial key generation can take several seconds on older devices.
- Lack of iOS support due to platform-specific constraints.
- File size is limited by available memory for temporary buffers.

VI. APP INTERFACE

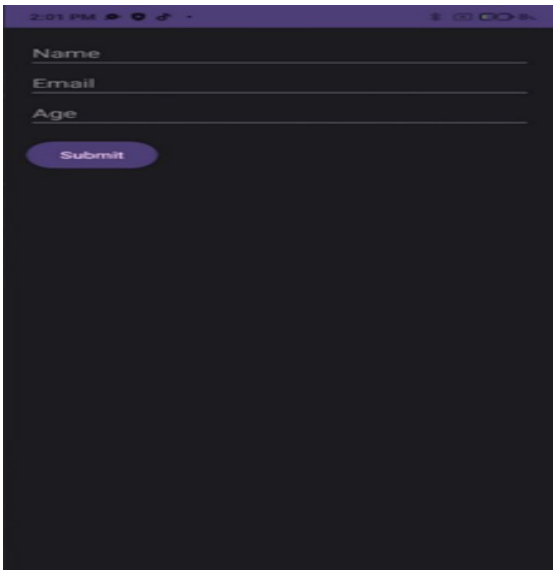

Fig 5. Sender's App interface Asking for User Data

Fig 6. Receiver's App Interface having Different Options for Encrypting the files

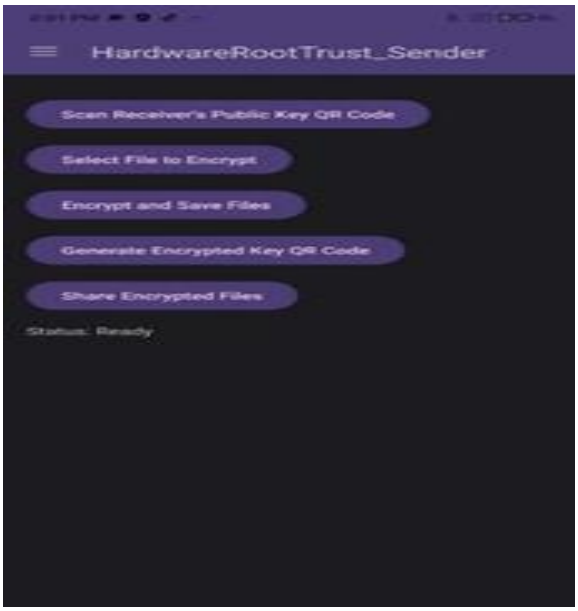

Fig 7. Sender's App Interface with Options for Decrypting the files

VII. CONCLUSION AND FUTURE WORK

A. Summary of Key Findings In this paper, we introduced Cypher, a secure and user- friendly peer-to-peer file-sharing framework designed specifically for mobile devices. Cypher overcomes the primary limitations of existing file-transfer mechanisms by:

1. Eliminating central servers — all key management and data exchange occur directly between devices, enabling true offline operation (cf. centralized messaging platforms [3]).
2. Leveraging hybrid encryption — AES-GCM secures large payloads with high throughput, while RSA-2048 wraps session keys to guarantee end-to-end confidentiality and integrity [2], [5].
3. Providing a modular transport layer — support for Bluetooth LE [6], Wi-Fi Direct [9], and NFC [4] ensures flexible, context-aware connectivity without Internet access.
4. Delivering high usability — an intuitive UI and visual key-exchange methods (QR/NFC) make advanced cryptography accessible to non-technical users, addressing usability barriers highlighted in prior studies [7], [9].

Our implementation and empirical evaluation demonstrate that Cypher achieves:

- Strong security guarantees without reliance on trusted intermediaries (integrity via AES-GCM's authentication tag; confidentiality via RSA wrapping).
- Real-time performance even for multi- megabyte files, with encryption/decryption overhead below 5 % of total transfer time.
- Broad platform extensibility, thanks to its transport-agnostic architecture.

Compared with desktop-oriented tools like OpenKeychain or GnuPG-based Android apps, Cypher offers a streamlined, mobile-first experience for secure, ad-hoc file sharing.

B. Future Work To further enhance Cypher's capabilities and reach, we plan to explore:

1. Cross-Platform Support Extending Cypher to iOS and desktop environments (Windows, Linux, macOS) to enable seamless, cross-device transfers— addressing platform-specific API constraints and background networking restrictions on each OS.
2. Group Key Exchange Protocols Designing lightweight, secure group-sharing schemes (e.g., broadcast encryption or identity-based encryption [10]) to allow one- to-many transfers without duplicating effort or compromising security.
3. Forward Secrecy and Ephemeral Keys Integrating ephemeral elliptic-curve Diffie–Hellman (ECDH) exchanges to provide forward secrecy [11], ensuring that compromise of long-term keys cannot retroactively expose past communications.
4. Decentralized Identity and Trust Models Evaluating Web of Trust, blockchain-based PKI, or Decentralized Identifier (DID) frameworks to scale trust verification beyond direct QR/NFC pairing, enabling more flexible trust relationships.
5. File Metadata Protection Implementing techniques for filename and size obfuscation or wrapping of metadata to prevent traffic analysis and leakage of sensitive file attributes.
6. Battery and Resource Optimization Introducing adaptive encryption parameters, built-in compression, and pause-resume capabilities to reduce energy consumption and improve user control during large or prolonged transfers.
7. Integration with Messaging and Collaboration

Platforms Exposing Cypher's core transport and encryption modules via a developer SDK, allowing third-party apps (e.g., chat, collaboration, productivity tools) to seamlessly embed secure, peer-to-peer file sharing.

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