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INFO-Y115 - Secure Software Design & Web Security

Computer Project: Report

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Contents

ABSTRACT

This report details a security-focused, PKI-based dashcam system prioritizing modern TLS hardening, confidentiality & server-blind E2EE as well as low friction revocation via key wraps. To be presented in this document; a quick-start guide with screenshots showing how users navigate the application, a systematic review of all pipelines with an emphasis on the security aspect including limitations and obstacles. Finally, a practical checklist reporting the system's all-around security posture. Public `git` repository and setup process available here as a GitLab README.md.

1 Security Overview

1.1 Architecture

SecCam runs each service in a dedicated Docker container and anchors trust in a local PKI with step-ca. The PKI bootstrap script generates a root and intermediate CA, then issues 2048-bit RSA leaf certificates for the Nginx gateway, the application server and other internal helpers; it also prepares an optional PKCS#12 bundle for full mutual-TLS. Inside the cluster, every socket is negotiated with service certificates that chain to this intermediate CA, so impersonation requires the CA's signing key, not just an access to a single host key. For external clients the trust anchor is pinned: the React bundle embeds the CA-root SHA-256 fingerprint at build time, rejecting any server that does not present the expected public key.

1.2 Traffic

All traffic enters through an Nginx reverse proxy that terminates TLS 1.3 exclusively and disables session tickets to foil passive resumption correlation. HSTS, CSP, Referrer-Policy and X-Frame-Options headers are set globally. Upstream calls from the proxy to the application server reuse TLS with client authentication: Nginx presents its own X.509 and validates the server's certificate and SAN before forwarding, eliminating blind-trust hop vulnerabilities, container-level impersonation, or transparent MITM, additionally, rate-limiting and header sanitation add basic DoS and injection resistance. After TLS is established, the session identifier is carried in a signed JWT that the server sets as an encrypted, httpOnly, sameSite cookie, so its exfiltration is greatly mitigated.

1.3 Data

The browser creates its own cryptographic material before any upload: a RSA key pair for wrapping, a fresh AES-GCM (AEAD) content key, and a HMAC-SHA-256 key for explicit integrity separation. User profile fields and each video segment are encrypted with AES-GCM and tagged with the HMAC, only ciphertext and MAC leave the client. Both symmetric keys are wrapped with the user's RSA public key (RSA-OAEP) and stored alongside the ciphertext. The private key is saved only as an encrypted JWK inside the user-controlled .sec.json bundle and is decrypted into memory at login; it never appears in cleartext on disk or in server logs. Because the content key is user-specific and the server never sees it unwrapped, a breach of the database yields nothing usable without the client's private key.

1.4 Streams

Trusted users undergo a dual-CSR workflow: one certificate asserts their organizational identity, the other authorizes platform access. After the server enacts the signature of both CSRs through the intermediate CA, these certificates allow normal users to share a stream key simply by wrapping it with any Trusted User's certificate public key. Server stores only the wrapped blob and when the trusted party requests the video, the server hands over that blob and the encrypted chunks. Decryption happens exclusively at client level, leaving the server permanently blind. Revocation consists of deleting the stored wrapped key entry, after which the former recipient can no longer unwrap future AES keys. All video sharing, validation and revocation therefore occur at the cryptographic edge.

2 Quickstart Guide

2.1 Boot the Stack

1. Follow setup instructions contained in that README file.
2. After trusting Root CA, browse page `https://localhost:3443`.

2.2 API Documentation (Swagger)

1. Browse the live API at `https://localhost:3443/api-docs`. Use these references for exact request/response shapes, authentication requirements, and example payloads for every endpoint.

2.3 Register a User (Driver)

1. In the UI, go to *Register* at `https://localhost:3443/register`
2. Enter a unique username and a email, do not use special characters for username only letters and digits, for Trusted User only use letters for fullname fields.
3. In the pop-up, start by scanning the QR code using an authenticator of your choice. Afterwards, set a strong password and download your encrypted Crypto Passport (`*.sec.json bundle`).

2.4 Register a Trusted User (Company)

1. In the UI, go to *Register* at `https://localhost:3443/register`
2. Check the *Representing a Company?* option.
3. Provide all user registration fields including full name, organization name, country.
4. In the pop-up, start by scanning the QR code using an authenticator of your choice. Afterwards, set a strong password and download your encrypted Crypto Passport (`*.sec.json bundle`).

2.5 Change Crypto Bundle Password

1. In the UI, go to *Passport* at `https://localhost:3443/passport`
2. Select your access bundle (`.sec.json`) and enter its current password.
3. Choose a strong new password and confirm.
4. Your browser decrypts the bundle and re-encrypts it with the new password. Replace your obsolete `.sec.json` bundle with this one.

Note If you lose the bundle or forget its password, your account will never be recovered. They are not conveyed to the server, account registration is the only time you get a bundle handed over; treat this payload like your own secret hardware token.

2.6 Email Verification

1. In a new tab, go to *Mailpit* at `https://localhost:3443/mailpit`.
2. Click the verification link to verify your account.

2.7 Login (2FA & Key Possession)

1. Open *Login* at `https://localhost:3443/login`.
2. Transiently load any `*.sec.json` in the React state (bundle password required).
3. Enter your username as well as a valid TOTP and press Login.

2.8 Video Streaming (Driver)

1. Navigate to `https://localhost:3443/home`.
2. Allow camera/microphone permissions.
3. Hasty recording: chunks are encrypted client-side and uploaded over the TLS reverse proxy at `https://localhost:3443/api/video/streaming`.
4. Navigate to `https://localhost:3443/playback` to retrieve your streams.
5. Available options: Read, Download, Delete video.

2.9 Share Videos (Driver → Trusted User)

1. Open *Users* at `https://localhost:3443/users`.
2. Select a trusted user; the client wraps your stream keys to their step-ca-signed certificate's public key (RSA key wrapping).
3. The server stores only the wrapped keys; plaintext keys are never exposed.

2.10 View a Shared Stream (Trusted User)

1. Navigate to `https://localhost:3443/playback` to retrieve streams shared with your Trusted User account.
2. Available options: Read, Download video.

2.11 Revoke Video Access (Driver → Trusted User)

1. Open *Users* at `https://localhost:3443/users`.
2. Click *Untrust* for the target trusted user.
3. The wrapped-keys entry is deleted from database; future access is blocked at the server and decryption fails client-side.

2.12 Retrieve Logs

1. Ensure the server is running and MongoDB is accessible. The logs are stored in the `LogModel` collection with integrity hashes to detect tampering.
2. To dump the logs to a file (with integrity verification):
   - Locally: Run `node server/logging/read-log.js dump log.txt` from the project root. This fetches logs from MongoDB, verifies each line's HMAC-SHA256 hash, and writes verified logs to `log.txt`.
   - In Docker: Execute `docker compose exec server node logging/read-log.js dump /tmp/log.txt`, then copy the file with `docker compose cp server:/tmp/log.txt ./log.txt`.
3. If any log fails the hash check, it is excluded from the output, and a warning is printed if all fail.
4. To reset (clear) the log collection: Run `node server/logging/read-log.js reset` (or the Docker equivalent).

Note Logs are tamper-evident due to appended hashes computed with a secret key. Always use this script to read logs; direct database access bypasses verification. Suspicious activity (e.g., excessive errors or floods) triggers console alerts via the logger helper.

3 Pipelines

3.1 Registration

Goal Establish identity and keys without trusting the server with plaintext or private keys; deliver an encrypted, client-held bundle required for all future transmissions (device independent).

Flow

1. **Client key generation.** The browser generates a user RSA key pair (identity), a symmetric AES-GCM key (content), and an HMAC key (integrity). *Trusted User:* builds a PKCS#10 CSR with the public key and identifiers.
2. **Client-side protection.** PII is encrypted with AES-GCM; an HMAC-SHA-256 is computed over fields/records. The AES and HMAC keys are wrapped to the user's RSA public key via RSA-OAEP (the server stores only wrapped blobs).
3. **Submission over pinned TLS.** The client sends { CSRs (*Trusted User*), encrypted PII + HMACs, wrapped keys } to `/api/user/register` over TLS 1.3. The stack is provisioned with a local CA and strict TLS; mTLS support exists along the generation of one valid browser *.p12* payload during project setup (cfr. *./cmd/1-pki_setup.sh*) but the latter is not available application-side because of development impediments.[1]

[1]Client-side PKCS#12 is brittle across browsers: see node-forge's long-standing ECDSA PKCS#12 bug at cfr. issue #925, and broader ECC support gap cfr. issue #532). Step-CA defaults to ECDSA and requires a manual process to get a full RSA chain. PKIjs also has open PKCS#12 parsing/import issues. Given these unresolved interop constraints, the encrypted `.sec.json` bundle as well as optional mTLS are standard in this

4. **Trusted User: CA signing (server → CA).** The server forwards the CSR(s) to the internal *Step-CA* and receives signed X.509 leaf certificates; one for the account and for the organization, verified at login against full-chain. Private keys never leave the client.
5. **Persist minimal state.** The database stores encrypted PII + HMACs, the user's public key, and the RSA-OAEP–wrapped AES/HMAC keys. No private keys are stored server-side.
6. **2FA bootstrap.** The server creates a TOTP secret, returns a QR URI, and stores the secret encrypted; Login will require a valid TOTP code and verified email.
7. **Client export (required).** The browser assembles an encrypted cryptographic bundle (`*.sec.json`) holding the user's private key, possible X.509 certs and session keys, protected with a password-derived key. The bundle is handed over to the user and later loaded transiently to a React state during the Login pipeline §3.3; not conveyed to the server at all.

Note For academic purposes; HTML template available to inspect the content of any `*.sec.json` bundle in the browser's console logs, find it at:
./doc/annex/decrypt_ aes_ crypto_ package.html

Registration. For the complete flow, see Annex: Pipeline – Registration (p. 18).

Technology choices & justification

TLS 1.3 end-to-end; local PKI (Step-CA). The compose stack is provisioned with a self-contained CA; services terminate TLS 1.3 and bootstrap scripts verify chains and cipher strength (AES-256-GCM). This removes external CAs from the trust boundary and allows strict pinning/chain checks. mTLS is supported; it is disabled by default in development and can be enforced at Nginx when needed. *Justification:* modern cipher suites, smallest handshake surface, and a lightweight PKI under control; easy revocation/rotation via CLI and no plaintext transit.

RSA-OAEP (SHA-256) for key wrapping. Wrapping the per-user AES and HMAC keys to the user's public key keeps the server permanently blind; only the client's private key can unwrap. *Justification:* OAEP with SHA-256 is the standard, misuse-resistant KEM for RSA in browsers; interops cleanly with WebCrypto and X.509.

AES-GCM (AEAD) for PII and video chunks. GCM gives confidentiality and integrity (auth tag) per record/chunk, so any DB tampering or transit alteration fails open on the client. *Justification:* single-pass AEAD, hardware-accelerated in browsers; perfect for chunked streaming and small PII blobs.

HMAC-SHA-256 on stored records. In addition to GCM tags, the system tracks HMACs for critical fields (email/identity). *Justification:* the client can detect silent server/DB edits even when fields are re-encrypted; cheap and widely audited.

PKCS#10 CSR + Step-CA issuance. Trusted users submit CSRs from the browser; the CA signs and returns X.509 certs bound to those public keys. *Justification:* proves possession

project.

of key material at enrollment; standard path to mTLS, signing, and verifiable identity without exposing private keys.

Encrypted `.sec.json` bundle (client custody). The only copy of private keys lives in an encrypted JSON, protected with a password-derived key (WebCrypto), handed to the user and loaded in volatile memory at login. *Justification:* keeps the server out of key custody, turns login into MFA + key possession, and simplifies multi-device usage by letting users carry/identify themselves with distinct bundles.[2]

Nginx reverse proxy as choke point. Centralizes TLS policy (TLS 1.3 only, session tickets off, strong ciphers) and can enforce mTLS if needed. *Justification:* one place to harden protocol knobs, upstream headers and rate-limit; consistent policy across services.

3.2 Certificate Issuance

Goal Bind the client-generated public keys to the platform PKI with CA-signed X.509's, while keeping private keys strictly client-side.

Flow

1. **Client CSR.** The browser that just generated the key pairs in §3.1 builds PKCS#10 CSRs over the public keys; Trusted users include organization attributes in a separate CSR. The private keys remain in memory on the client only.
2. **CSR intake (server).** The server receives the CSR payload over pinned TLS (same channel and checks as registration) and validates basic claims (e.g., presence of identifiers expected for the account type). It never interacts with private key material.
3. **CA signing (step-ca).** The server invokes the internal Smallstep CA to sign the CSRs, producing leaf certificates. This is performed with the Step CLI (`step ca sign` / `step certificate sign`) against the platform's intermediate CA; validity and options are controlled by the CLI flags.
4. **Chain & policy.** Issued leafs chain to the project's own root/intermediate created by the PKI setup script, which the stack already trusts; the build/run script explicitly verifies chains and ciphering end-to-end as part of the boot checks.
5. **Delivery to client.** The signed certificates *.pem* are returned in the same registration response path and added by the client to its encrypted `.sec.json` bundle (see §3.1); no plaintext keys are transmitted.
6. **Persist public material only.** The backend may store certificates with the user's record for lookup/auditing purposes; private keys are never persisted server-side.

Certificate Issuance. For certificate details and chain handling, see Annex: Pipeline – Certificate (p. 20).

[2]To be replaced in future work with entreprise-grade *.p12* payloads generated in the browser and enabling strict mTLS enforcement.

Technology choices & justification

Smallstep step-ca (leaf signing). Using `step ca sign`/`step certificate sign` keeps issuance simple and auditable, with first-class support for PKCS#10 CSRs, explicit notBefore/notAfter, and templating. The CA runs as an intermediate under our own root; the stack's PKI scripts build and verify that trust chain locally. *Justification:* standard CSR in, leaf out; offline/controlled issuance; minimal attack surface and easy rotation.

Project-local root/intermediate. The repository's PKI setup initializes a self-contained CA, issues service leafs, and bakes the root into the stack; the run script then verifies the full chain and TLS properties during boot. *Justification:* removes external CAs from the trust boundary and enables strict pinning/chain checks across services.

Client-side CSRs. CSRs are crafted and signed, so possession is proven to the CA without exposing private keys. *Justification:* aligns with X.509 enrollment best practice and the platform's security design.

Pinned TLS on issuance path. CSR submission and cert delivery reuse the same pinned TLS channel as registration; any chain or fingerprint mismatch aborts the flow. *Justification:* prevents MITM during identity binding and cert pickup.

3.3 Login

Goal Establish an authenticated session without exposing private keys: OTP is verified server-side; cryptographic elements are unwrapped client-side once the encrypted bundle loaded in pipeline §3.1, and only held transiently in volatile memory from there.

Flow

1. **Inputs (client).** The user provides *username* and current 6-digit TOTP, then loads the encrypted crypto bundle (`*.sec.json`) and enters its password. The browser decrypts the bundle locally (PBKDF2 → AES-GCM) to recover the user's private key and certificates in memory.
2. **OTP verification (server).** Login requires 'something I have' (TOTP device) in addition to the encrypted key bundle and a verified email. Client calls `/api/user/login` with {username, TOTP}. The server rejects unverified emails, decrypts the stored TOTP seed, and verifies the code (time windowed). On failure it returns 4xx; on success it authenticates the user. *Justification:* mitigates token theft and greatly enlarges the attack surface adversary requires in order to compromise an account.
3. **Session issuance.** The server creates a short-lived JWT (username + role), signs it, encrypts the token payload, and sets it as a cookie with `HttpOnly`, `Secure`, `SameSite=strict`. No token is returned in the request body unlike with unsafe local storage-based elements.
4. **Fetch encrypted account material.** The client calls `/api/user/current`; the server validates the cookie and returns only public/opaque fields: the RSA-OAEP–wrapped symmetric key and HMAC key (from §3.1), the encrypted PII blobs, and stored HMACs.
5. **Local unwrapping and checks (client).** Using the private RSA key from the bundle, the client RSA-OAEP-decrypts the wrapped symmetric key and HMAC key, then holds them

in volatile state. It decrypts PII with AES-GCM and validates HMACs; any mismatch aborts the session. (Trusted users additionally validate their X.509 chain against the platform root from §3.2.)

6. **Established session.** Subsequent API calls use the cookie; all sensitive operations on data use the in-memory symmetric/HMAC keys. Logout clears the cookie and zeroizes client keys; token expiry enforces re-authentication.

Login. For the device login and key-unwrap process, see Annex: Pipeline – Login (p. 22).

Technology choices & justification

MFA by design. Login combines TOTP (server-verified) with *key possession*: the encrypted `.sec.json` bundle must be locally decrypted to unwrap session keys. This binds access to both a time factor and the user's client-held keys. *Justification:* mitigates token theft and greatly enlarges the attack surface adversary requires in order to compromise an account.

Client-side unwrapping (RSA-OAEP). Only the browser uses the private key to decrypt the wrapped AES/HMAC; the server never sees plaintext keys. This preserves the "server-blind" model introduced at registration. *Justification:* ensures that even if the server is fully compromised, an attacker cannot decrypt any user data without also compromising the client's private key and bundle password.

Hardened session cookie. The JWT is short-lived and stored in an `HttpOnly`, `Secure`, `SameSite=strict` cookie; the server also encrypts the cookie payload before setting it. *Justification:* resists XSS exfiltration and CSRF; the token is opaque to client JS and never appears in URLs.

Pinned TLS continuity. The login path reuses the pinned TLS channel from §3.1, so OTP and account material travel under an authenticated transport. *Justification:* prevents MITM attacks during the critical authentication phase by ensuring the client only communicates with the intended, CA-authorized server.

End-to-end integrity. AES-GCM tags protect decrypted PII; record-level HMACs detect any DB tampering before keys are accepted into the session. *Justification:* provides an additional layer of integrity verification beyond TLS, ensuring that data has not been altered at rest on the server, even by a privileged insider.

3.4 Stream Record

Goal Ingest live camera data without exposing content to the server: video is chunked and AES-GCM–encrypted in the browser with user-session keys from §3.3; the server stores ciphertext and metadata only.

Flow

1. **Capture (client).** The browser records from the webcam (MediaRecorder). Chunks are produced at short, fixed intervals.

2. **Per-chunk encryption (client).** For each Blob, the client derives a fresh 96-bit IV and encrypts with the user's AES-GCM session key (from §3.3). The result is {`iv`, `ciphertext_with_tag`}. No plaintext leaves the browser.
3. **Authenticated upload.** The client POSTs {`encryptedChunk`, `metadata(videoName, chunkIndex, ts, size)`} to `/api/video/streaming` over pinned TLS, with the HttpOnly session cookie set (§3.3).
4. **Store (server).** The API authenticates via the cookie, does not decrypt, and persists: (i) a *Video* entry (upsert by owner+name) and (ii) a *VideoChunk* document containing the encrypted payload + metadata. Each chunk is indexed for ordered retrieval.
5. **Ack + repeat.** The server returns 200; the client continues the encrypt→upload loop. If any chunk is altered at rest, client decryption fails (GCM tag) on playback.

Stream. For video encryption and streaming setup, see Annex: Pipeline – Stream (p. 25).

Technology choices & justification

AES-GCM per chunk. Authenticated encryption amortized per segment: confidentiality + integrity via tag; minimizes blast radius on loss/corruption; ideal for streaming and resumable fetch. *Justification:* AES-GCM is a NIST-approved AEAD scheme that provides both confidentiality and authentication in a single, efficient operation. Its use per chunk ensures that any corruption or tampering of individual video segments is immediately detectable upon decryption, limiting the impact of data corruption to a single chunk rather than the entire stream.

Fresh IVs. New 96-bit IV per chunk avoids nonce reuse under a fixed key; suits Web Crypto and keeps records independent. *Justification:* Nonce reuse in GCM mode completely breaks confidentiality. Generating a unique, cryptographically random IV for each chunk eliminates this risk while maintaining compatibility with WebCrypto API constraints. The 96-bit length provides sufficient entropy while aligning with GCM specs.

Pinned TLS + cookie auth. Upload rides the same pinned TLS channel and HttpOnly/SameSite cookie from §3.3; prevents token exfiltration and CSRF on the hot path. *Justification:* Certificate pinning mitigates MITM risks even if CA infrastructure is compromised, while the hardened cookie implementation resists XSS-based token theft. This dual protection ensures both transport and authentication security for continuous data uploads.

Opaque server. The server never receives keys or plaintext; it stores ciphertext + sequence metadata. Integrity is enforced client-side by GCM, not trusted storage. *Justification:* This zero-trust architecture ensures that even a fully compromised server cannot access video content. The server isn't more than a ciphertext storage system at this point, eliminating it as a valuable target for attackers seeking video content and providing true end-to-end encryption.

Small, frequent chunks. Short intervals reduce data at risk per request, improve UX under flaky links, and ease parallel retry/replay protection at the application layer. *Justification:* Smaller chunks minimize the impact of network interruptions and enable efficient bandwidth utilization. From a security perspective, they limit the amount of data exposed if an individual request is intercepted and make traffic analysis more difficult due to uniform packet sizes.

3.5 Stream Share

Goal Grant a *trusted user* access to existing encrypted streams without disclosing plaintext or keys to the server: the owner wraps their symmetric keys to the trusted user's X.509 public key; the trusted user unwraps locally and decrypts chunks fetched from the server.

Flow

1. **Select target (owner, client).** The normal user (dashcam Driver) selects a target trusted user from the list exposed by the server (trusted users carry CA-signed X.509 certs from §3.2).
2. **Recover own session keys (owner, client).** The owner requests their stored `encrypted_symmetric_key` and `encrypted_hmac_key` (cookie-authenticated). Using the private RSA key from the local `*.sec.json`, the browser RSA-OAEP–decrypts both and holds the raw AES/HMAC in memory (as in §3.3).
3. **Wrap to trusted user (owner, client).** The owner extracts the trusted user's RSA public key from the certificate and RSA-OAEP–encrypts the AES and HMAC keys, yielding `wrappedSymmetricKey` and `wrappedHmacKey`. No plaintext keys or chunks are exposed.
4. **Create/Update trust (server).** The owner POSTs {`trustedUserId`, `wrappedSymmetricKey`, `wrappedHmacKey`} to `/api/keywrap` over pinned TLS with the session cookie. The server verifies the caller is a *normal* user, the target is a registered *trusted* user with a certificate, and stores/updates the mapping in a key-wrapping record (driver → trusted).
5. **List shares (trusted, client).** A trusted user queries `/api/video/trustedList`; the server returns owners/videos that have an active wrapping toward this trusted user.
6. **Obtain wrapped keys (trusted, client).** When choosing an owner, the trusted user calls `/api/keywrap/{owner}/keys`. The server checks that a wrapping exists (owner → this trusted user) and returns the stored `wrappedSymmetricKey` and `wrappedHmacKey`.
7. **Unwrap locally (trusted, client).** Using their private RSA key from the local `*.sec.json`, the trusted user RSA-OAEP–decrypts the wrapped keys to recover the raw AES/HMAC in memory.
8. **Fetch encrypted chunks (trusted, client).** The trusted user requests chunks via `/api/video/{videoName}/{owner}/chunks`. The server authenticates (cookie), authorizes by checking the wrapping, and returns the stored ciphertext chunks + metadata (from §3.4).
9. **Client-side decryption & playback (trusted, client).** The browser AES-GCM–decrypts each chunk with the recovered AES key (GCM tag enforces integrity), reassembles, and plays. The server remains blind to both keys and content.

Share. For encrypted sharing to trusted users, see Annex: Pipeline – Share (p. 27).

Technology choices & justification

Public-key wrapping (RSA-OAEP). Owners encrypt the stream's AES/HMAC to the trusted user's certificate public key; only the corresponding private key can recover them. This preserves end-to-end confidentiality while using standard X.509 material issued in §3.2. *Justification:* RSA-OAEP provides provable security against chosen-ciphertext attacks (IND-CCA2) under the random oracle model, making it the modern standard for asymmetric key wrapping. By leveraging existing X.509 infrastructure, cryptographic consistency is preserved while ensuring that only authorized trusted users with valid certificates can access content.

Server as blind intermediary. The backend stores opaque wrapped keys and ciphertext chunks, enforcing access solely by the wrapping relation; it never holds plaintext keys or video, aligning with the "server-blind" model from §3.1–§3.4. *Justification:* This architecture minimizes the attack surface and trust requirements for the server infrastructure. Even with full server compromise, an attacker gains only encrypted blobs and wrapped keys that remain protected by the RSA-OAEP encryption to specific user public keys.

Pinned TLS & cookie auth. All share operations reuse the same pinned TLS transport and HttpOnly/SameSite cookie from §3.3, preventing token exfiltration and cross-site forgery on the key path. *Justification:* Maintaining consistent transport security ensures that encrypted wrapped keys cannot be intercepted or modified in transit. The hardened cookie implementation provides continuous authentication while resisting devastating web vulnerabilities.

GCM integrity at the edge. Decryption in the trusted user's browser validates each chunk's GCM tag; storage tampering is detected client-side without trusting server integrity. *Justification:* By pushing integrity verification to the client, we eliminate any need to trust server-side storage integrity. This approach not only detects malicious tampering but also accidental corruption, ensuring that users only view authentic content, *ad instar* a cryptographic guarantee of content authenticity.

Revocation hook Removing a wrapping entry (see §3.6) immediately blocks further key or chunk retrieval for that pair; the server denies access on subsequent requests, and only clients still holding a plaintext key in memory could decrypt already-fetched data.

3.6 Key Revocation

Goal Immediately rescind a previously granted share without touching plaintext or re-encrypting stored data: remove the owner→trusted wrapping so the server denies further key/chunk retrieval while private keys and content keys remain client-held.

Flow

1. **Untrust (owner, client).** The owner selects a previously trusted user and issues `DELETE /api/keywrap/{trustedUserId}` over pinned TLS with the session cookie (same auth path as §3.3).
2. **Verify & delete (server).** The API authenticates the request, enforces that the caller is a *normal* user, locates the key-wrapping record (owner→trusted), deletes it, and returns 200 "removed".

3. **Owner UX update (client).** The UI removes the trusted user from the share list; no content keys are uploaded or rotated automatically (the server never had them in plaintext).
4. **Effect on trusted user (server+client).** Subsequent requests from the trusted user fail:
   (a) `GET /api/keywrap/{owner}/keys` → no wrapping ⇒ 404/403.
   (b) `GET /api/video/{video}/{owner}/chunks` ⇒ authz check fails (no wrapping) ⇒ 403.

   Without wrapped keys from the server, a trusted user cannot (re)obtain the AES/HMAC; any keys left only in volatile client memory expire with the session.
5. **(Optional) key rotation (owner, client).** If the owner wants to invalidate any key material a trusted user might still hold in-memory, they can re-enroll/rotate and re-share; rotation is out-of-band of revocation and not required for the server to block access.

Revocation. For device and certificate revocation, see Annex: Pipeline – Revocation (p. 29).

Technology choices & justification

Authorization as gate. Access to both key material and ciphertext is conditioned on the existence of an owner→trusted wrapping; deleting that single record cuts off all future reads without touching stored blobs. *Justification:* This approach implements a classic capability-based security model where possession of a reference (the wrapping record) grants access. By making this reference the sole gatekeeper, revocation becomes instantaneous and deterministic. The system avoids the computational overhead and complexity of cryptographic re-encryption schemes while maintaining perfect forward secrecy for future accesses through cryptographic access control rather than cryptographic operations on the data itself.

Server-blind state. The server never stores plaintext AES/HMAC, so revocation is a cheap metadata change (delete wrapping) rather than a cryptographic re-write. *Justification:* This design exemplifies the principle of security through minimal trusted computation. By keeping the server ignorant of actual cryptographic keys, we eliminate entire classes of attack vectors related to key management on the server side. The economic efficiency of this approach scales linearly with the number of revocations rather than with the amount of data which is exponential.

Pinned TLS + cookie session. Revocation uses the same pinned transport and HttpOnly/SameSite cookie as prior pipelines, ensuring only the legitimate owner can revoke. *Justification:* Maintaining consistency prevents context-based attacks where an attacker might attempt to exploit different security postures between different operations.

Fail-closed at the edge. Even if ciphertext remains in storage, the trusted user cannot decrypt new content without fresh wrapped keys; any already-fetched chunks still require a live in-memory key on the client side. *Justification:* This defense-in-depth approach acknowledges the reality of state distribution in distributed systems. While immediate revocation prevents new access, the system design acknowledges that clients may retain cryptographic material temporarily in volatile memory.

4 Mission Checklist

1. **Do I properly ensure confidentiality?**

   All data in transit is protected by strong TLS (a Nginx front allows only TLS 1.3 with AES-256-GCM cipher suite). The system uses its own PKI: each service (client, server, mailpit) has a unique X.509 certificate, and the client enforces certificate pinning on every API call. Sensitive user data is end-to-end encrypted: for example, user fields are stored only in encrypted (except username) form (AES-256-GCM) in the database, and each has an HMAC for integrity verification. Video content is never stored in plaintext on the server, video chunks are encrypted on the client side and uploaded already encrypted. Server-side secrets are handled carefully (random CA password and encryption keys are generated at setup and not hardcoded).

2. **Did I harden my authentication scheme?**

   Authentication requires both a verified identity and possession of client-held keys. Registration ends with the client generating keys and downloading a single encrypted crypto bundle (".sec.json") that contains the user's certs/keys; that bundle is required at login and is only loaded transiently in React state, never persisted in plaintext. There are no reusable passwords; users must verify email and then present a TOTP code (speakeasy), and the TOTP secret is stored server-side only in encrypted form. Upon successful login, a short-lived JWT is issued and stored in an HTTP-only, secure, same-site AES-encrypted cookie with attributes *Secure*, *SameSite=strict*, *HttpOnly.* For completeness: the PKI script can also emit a valid browser .p12 with password *securesoftware*; mTLS is supported but disabled by default due to Javascript .p12 generation impediments during development (cfr. §3.1).

3. **Do I properly ensure integrity of stored data?**

   The system ensures that stored data cannot be modified undetected. Each user has a unique HMAC key used to protect critical fields: for example, the database stores hmac_username, hmac_email, etc., alongside the encrypted values. Whenever user data is retrieved, the client verifies these HMACs to detect any tampering before decrypting the fields. Videos are stored in chunks with their original filenames/IDs recorded, and any addition or removal of chunks would be evident to the client by missing sequence numbers or HMAC mismatches (each chunk is encrypted with an authenticated cipher, so modification is detectable). The logging subsystem also guards integrity: every log entry is appended with an HMAC computed using a server-side secret. This means if an attacker altered or forged a log record in the database there will be evidence of integrity breach.

4. **Do I properly ensure the integrity of sequences of items?**

   Partial, application tracks sequences (such as video segments and log entries) but does not fully cryptographically chain them to prevent reordering or omission. Video chunks are indexed and sorted by chunkIndex on retrieval to preserve their proper order, and the client would notice if an expected chunk were missing (gaps in the index) or altered (decryption/HMAC would fail). However, there is no hash-chaining across video chunks or across log entries that would absolutely prevent an attacker with database access from dropping the first or last item in a sequence without detection. Logs are individually integrity-protected via HMAC, but not linked to each other, so one could remove or reorder entire log records without breaking an obvious chain.

5. **Do I properly ensure non-repudiation?**

   Not strongly ensured, system does not implement features to prevent users from repudiating their actions. Although "trusted" users are issued X.509 certificates as digital identity tokens, these certificates are not used to sign user actions or requests; they are used for establishing trust relationships and optional mTLS. All authenticated API requests rely on server-issued JWTs, which prove a user session but are generated by the server, not signed by the user. There is no use of digital signatures by end-users when uploading videos or sharing keys – for instance, when a normal user shares encryption keys with a trusted user, the keys are encrypted (ensuring confidentiality) but not signed by the sharer's private key.

6. **Do my security features rely on secrecy beyond keys/codes?**

   Security does not hinge on hidden implementation details or obscurity. The design follows standard cryptographic practices and avoids any secret sauce beyond proper secret keys and credentials. All security features use well-known algorithms (TLS, RSA, AES-GCM, HMAC-SHA256, JWT) rather than proprietary or obscured mechanisms. Critical secrets like the certificate authority password, JWT signing key, TOTP encryption key, etc., are generated at deployment time or stored in environment variables and not hardcoded in the source. There is no reliance on obscurity such as hidden endpoints or constant values that must remain unknown to attackers, API routes are openly defined and documented in the Swagger docs with access control enforced via proper authentication, not by keeping them secret.

7. **Am I vulnerable to injection?**

   No, the codebase isn't vulnerable to injection attacks (NoSQL injection, command injection or XSS) given the frameworks and mitigations in use. The server uses Mongoose for all database access, passing user-supplied values as parameters to queries (not constructing queries from strings). There are also explicit sanitization measures; for instance, the logging utility escapes or removes dangerous characters from log messages (replacing newlines, %, <, > etc.) to prevent log injection or HTML injection in logs. On the client side, the UI is a Next.js React app which inherently escapes content, and a strict Content Security Policy is set to only allow scripts from self, mitigating XSS risks. There is no use of eval or unsanitized dynamic HTML in the server or client code. Also, all inbound API data is parsed as JSON and not directly concatenated into commands or queries, and the few filesystem operations like writing certificates use sanitized, controlled inputs (organization names are used in file names but are trimmed and cannot break out of the intended directory).

8. **Am I vulnerable to data remanence attacks?**

   The PKI setup script generates a CA password and shreds the temporary file containing it immediately after use, so it cannot be recovered from disk later. The teardown script (0-total_reset.sh) thoroughly wipes data: it deletes database contents for all collections (users, videos, etc.) on reset, removes Docker volumes, and cleans up all certificate and key files from the project directory (making them writable and then deleting, even using sudo if necessary to remove root-owned leftovers). Uploaded videos are stored only in DB and can be removed via the provided delete function. Encryption keys are held in the user's encrypted bundle and are not transmitted or stored on the server in plaintext. Moreover, secrets like the JWT token are kept only in an encrypted HttpOnly cookie, cleared on logout or expiry.

9. **Am I vulnerable to fraudulent request forgery?**

   CSRF is mitigated by the use of SameSite cookies and strict CORS policies. The authentication cookie is set with SameSite=strict and Secure flags, which means browsers will not include it in cross-origin requests at all. Additionally, the server's CORS configuration only allows requests from the same origin. Because of this, a malicious third-party page could not force a user's browser to perform authenticated actions on the site. The use of an encrypted, HttpOnly cookie for the JWT also means JavaScript can't be tricked into sending the token elsewhere, and there is no reliance on URL parameters or referrer headers for auth. Furthermore, all state-changing endpoints (and sensitive reads) require a valid JWT, so even if a forgery is attempted, without the token it will be rejected. On the server side, no obvious SSRF vectors exist because the server doesn't fetch external URLs based on user input (it only contacts the local CA and uses fixed internal addresses).

10. **Am I monitoring enough user activity for detection/forensics?**

    The system includes monitoring and auditing capabilities to detect malicious activity or facilitate post-attack analysis. All significant actions (registration failures, login attempts, video uploads, deletions, etc.) are logged via a central logger module to a MongoDB logs collection. Each log entry is annotated with a timestamp, severity level, and an HMAC hash of the message content. This design not only provides an audit trail of user and system events. In addition to logging, the Nginx layer has rate limiting configured for various request types. These limits can help detect or throttle malicious behaviors such as brute-force attempts or flooding, and they indicate abnormal activity if triggered (too many API calls in a short time might surface in Nginx logs or metrics). There is no real-time alerting system, but the logs and built-in limitations provide a foundation for detecting malicious intent during a review or forensic analysis.

11. **Am I using components with known vulnerabilities?**

    No, the project does not include components with known public vulnerabilities as of the latest commit. The dependency stack is modern: it runs on Node.js 20 (Alpine), uses up-to-date libraries like Express 4.x, Mongoose 7.x, Next.js 13, and well-maintained crypto libraries (jsonwebtoken, speakeasy, node-forge etc.). The Docker images chosen are current versions (MongoDB 8.0.11, Smallstep CA 0.28.4, Mailpit latest), none of which are flagged for known security issues at current time. Important server-side libraries (node-forge for certificate parsing and jsonwebtoken for JWTs) are used without usage of deprecated or unsafe functions. The project's npm ci process in Dockerfile installs exact versions from a lockfile. All javascript packages have been audited and report no known vulnerabilities.

12. **Is my system updated?**

    The development documentation specifies recent platform versions, the Docker build pulls the latest package definitions at build time. The use of Alpine-based images and explicit package installs helps minimize unused libraries and quickly integrate security fixes (20-alpine image will include recent security patches for both Node and Alpine Linux) and the Docker Compose configuration references current images. Critical services such as the certificate authority (Smallstep) and Mailpit are also at recent releases. Moreover, the project's README encourages updating system dependencies and even provides troubleshooting steps for version mismatches.

13. **Is my access control broken (OWASP 10)?**

    The application enforces authorization at two layers: API policy and cryptography. Every protected route sits behind JWT middleware and explicit role checks; trusted vs. regular users have separate privileges, and listing/reading another user's video requires a matching key-wrapping record. Possession of the user's encrypted ".sec.json" bundle (certs/keys) is required client-side to unwrap the shared AES stream key; without that bundle, ciphertext from any endpoint remains unusable. Endpoints meant for normal users explicitly reject requests if the JWT belongs to a trusted user, and vice-versa. When fetching a video, the server ensures the requester is the owner or a trusted user with a valid wrap, else returns 403. There are no unprotected direct object references; even /api-docs is served over HTTPS and respects the same cookie auth. In practice, decryption is impossible without the client-held keys, even if an API listing were exposed.

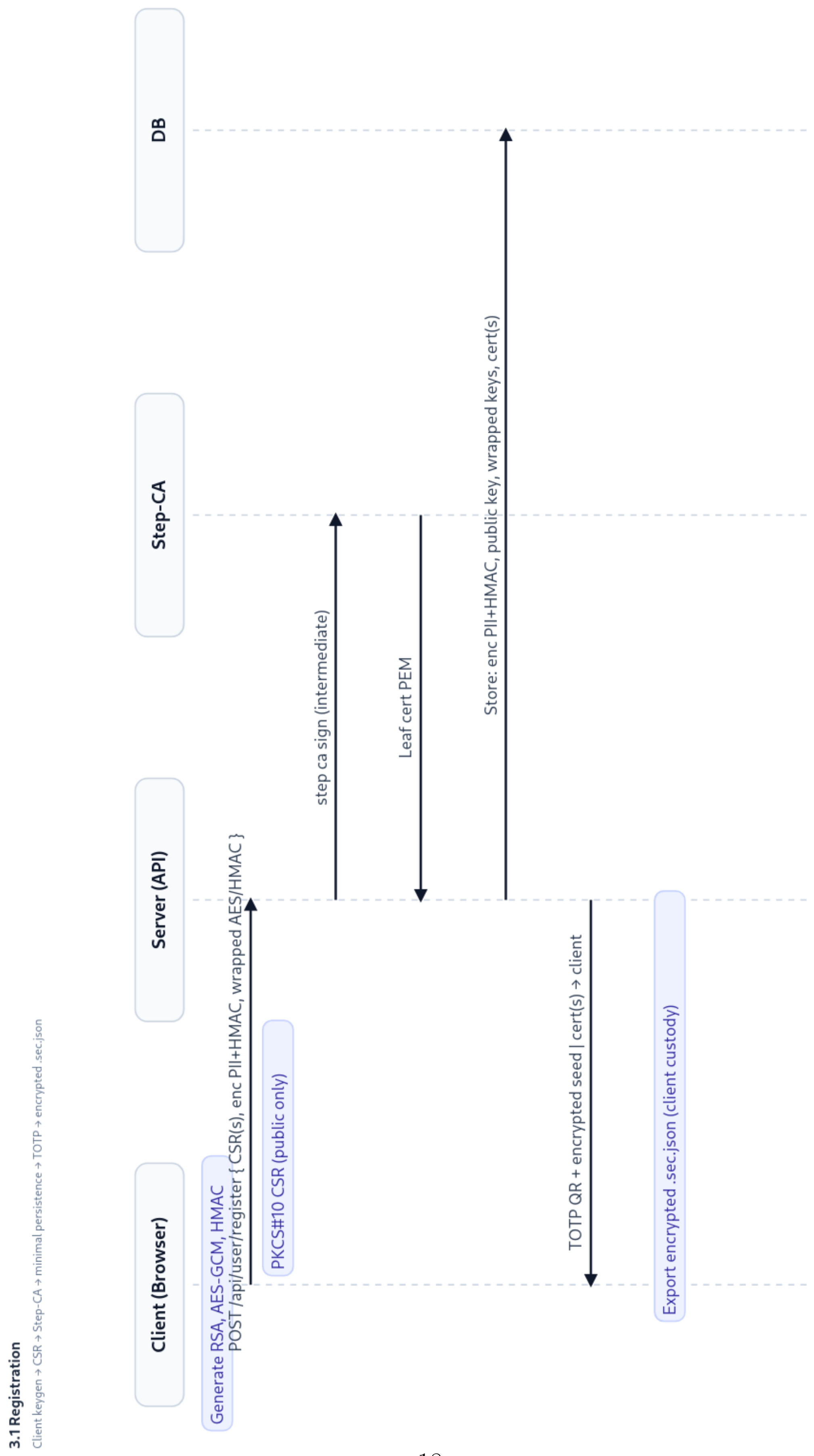
14. **Is my authentication broken (OWASP 10)?**

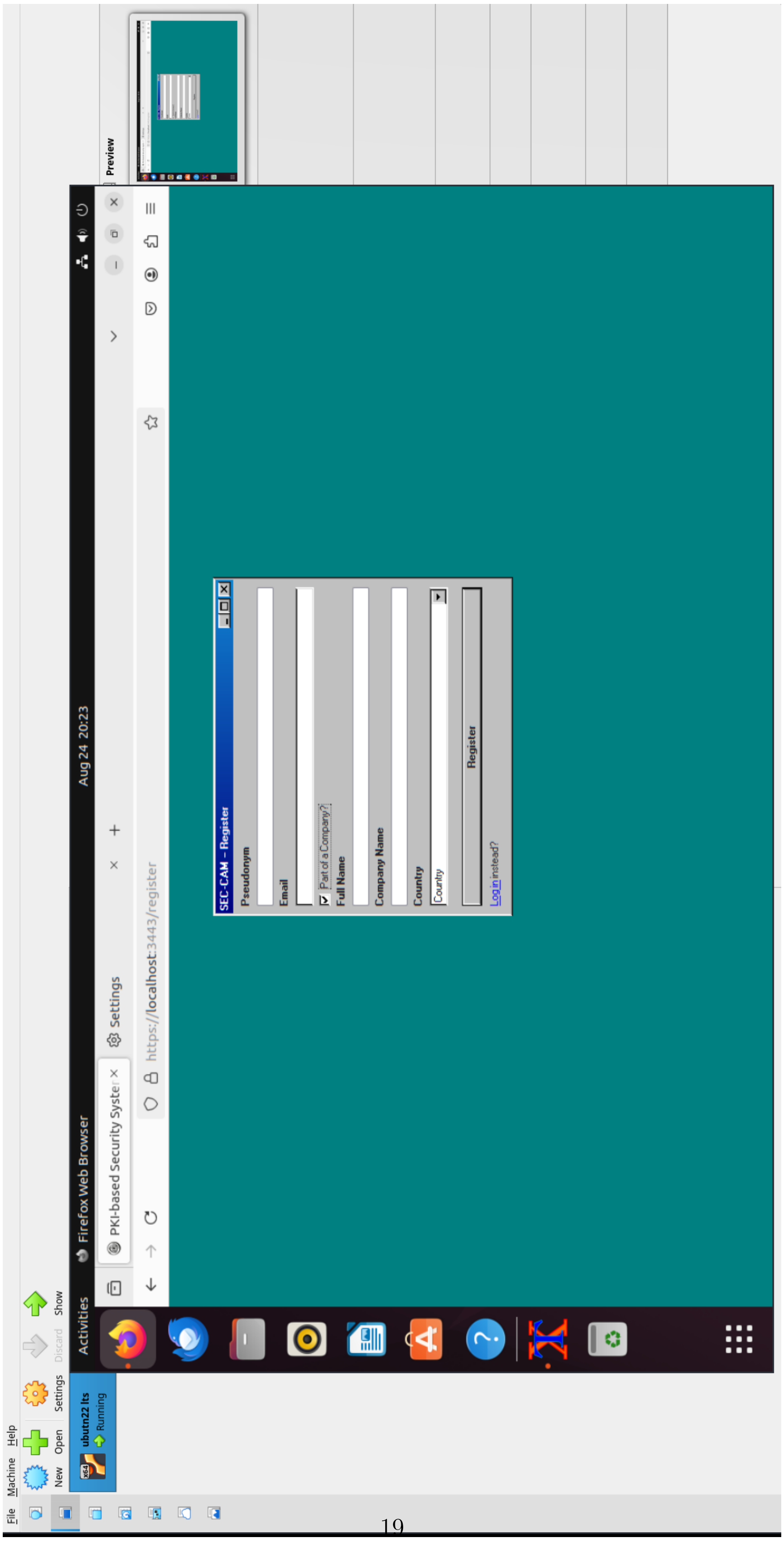
    No, authentication requires verified email, a TOTP code, and possession of the encrypted ".sec.json" bundle. Registration ends with the client generating keys and downloading that bundle; at login it must be imported and is only loaded transiently in React state (never persisted in plaintext, and the server is never shown its content). The TOTP secret is per-user and stored server-side only in encrypted form; codes are verified with speakeasy. Successful auth issues a short-lived JWT set in a hardened cookie, and the payload is additionally encrypted. This design mitigates session hijacking/fixation and CSRF. No reusable passwords are used or stored at all, removing weak-password and hashing pitfalls. One area to improve is brute-force resistance (e.g., lockout/backoff on repeated bad TOTP), though proxy rate-limits and short code windows are already mitigating that issue.

15. **Are my security features misconfigured (OWASP 10)?**

    There are a few development defaults to tighten for production (e.g., placeholder secrets in the sample env, dev CSP allowances, etc.). mTLS support exists but is disabled by default; enabling client-cert verification at the reverse proxy hardens the perimeter, and the README documents why .p12 is optional in this build. With strong secrets, strict upstream verification, mTLS on, and correct handling of the .sec.json bundle, the default setup comes strongly configured.

A Annex: Pipeline – Registration


3.1 Registration
Client keygen → CSR → Step-CA → minimal persistence → TOTP → encrypted .sec.json
Client (Browser)
Server (API)
Step-CA
DB
Generate RSA, AES-GCM, HMAC
POST /api/user/register { CSR(s), enc PII+HMAC, wrapped AES/HMAC }
PKCS#10 CSR (public only)
step ca sign (intermediate)
Leaf cert PEM
Store: enc PII+HMAC, public key, wrapped keys, cert(s)
TOTP QR + encrypted seed | cert(s) → client
Export encrypted .sec.json (client custody)



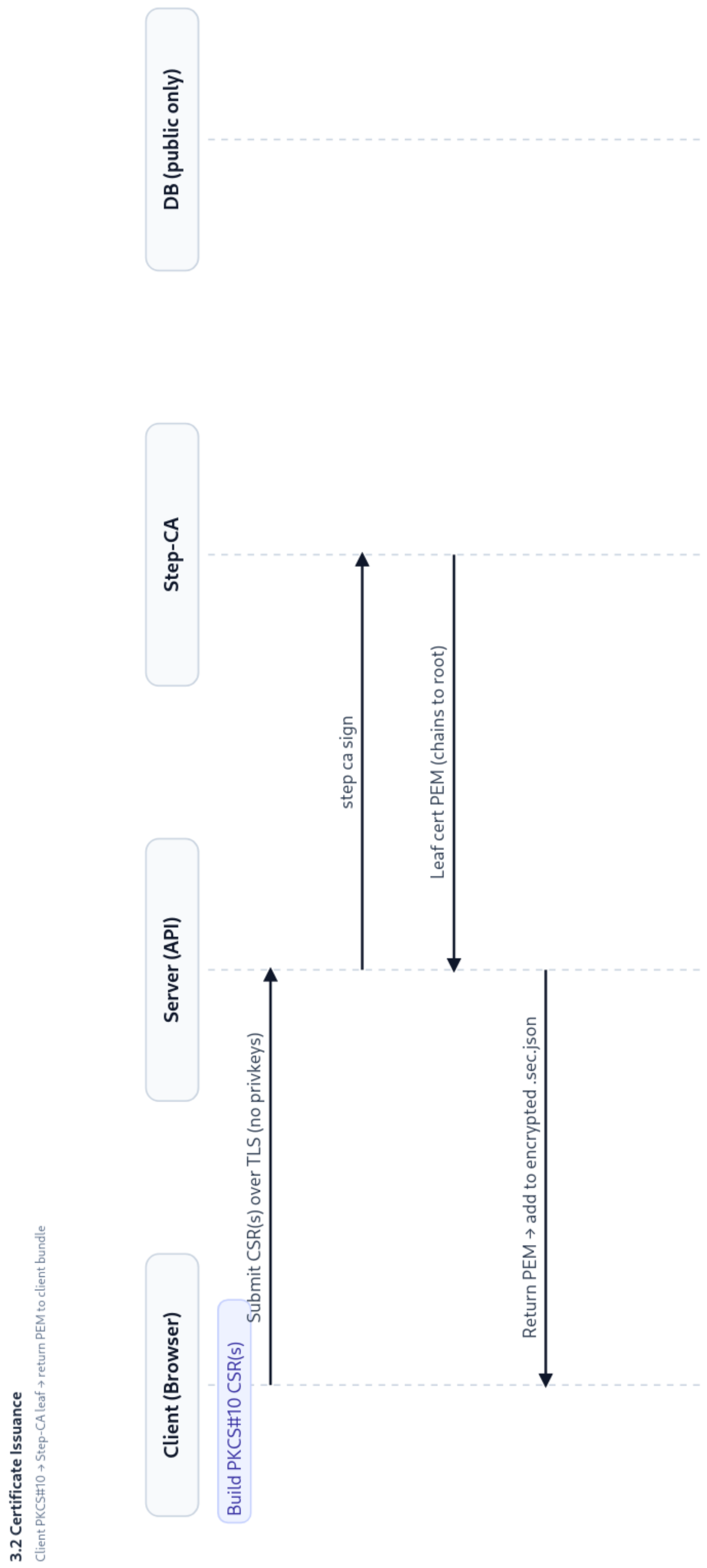
SEC-CAM – Register

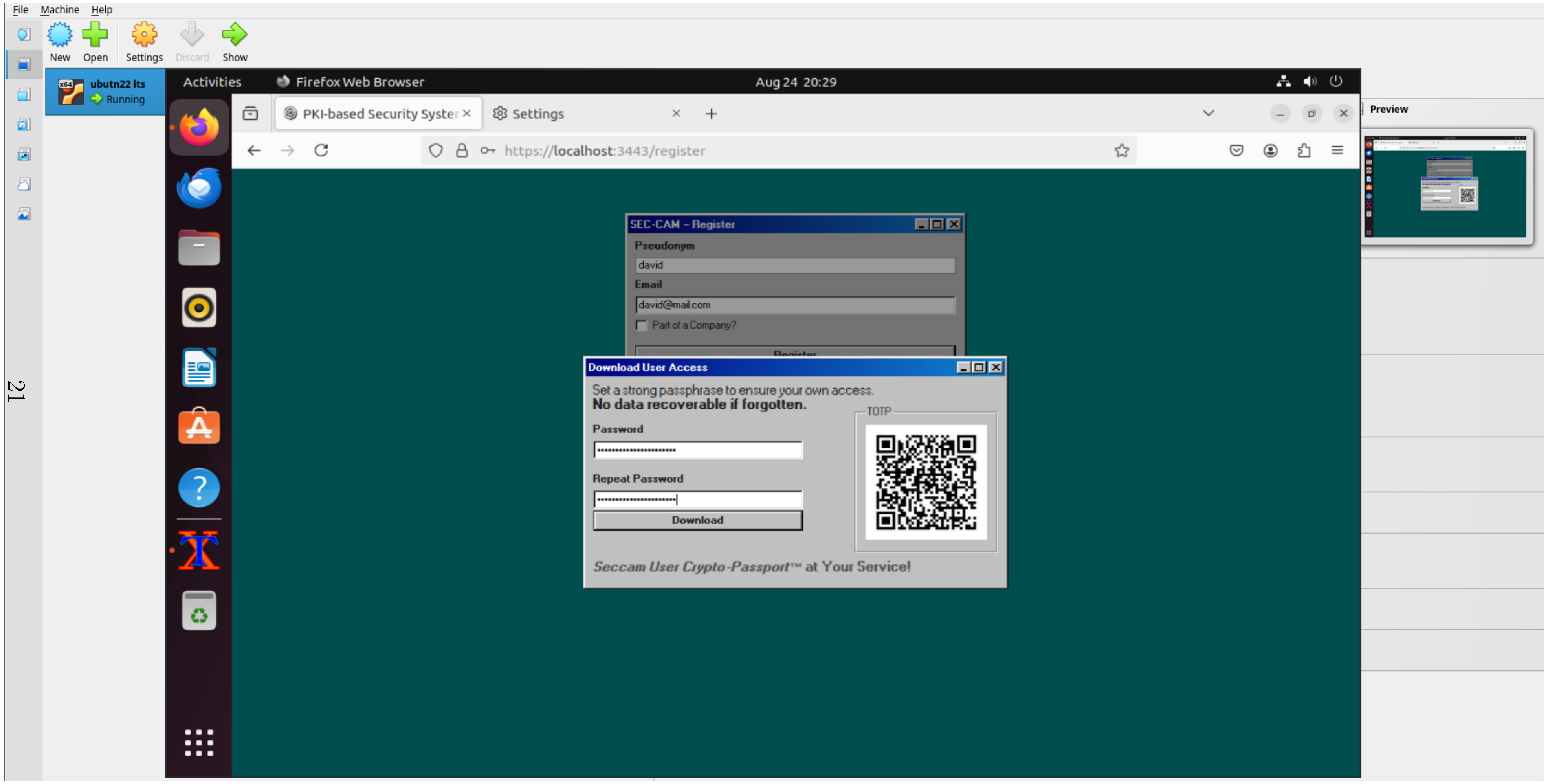
Pseudonym	
Email	
[✓] Part of a Company?	
Full Name	
Company Name	
Country	Country

Register

Log in instead?

B Annex: Pipeline – Certificate


3.2 Certificate Issuance
Client PKCS#10 → Step-CA leaf → return PEM to client bundle
Client (Browser)
Server (API)
Step-CA
DB (public only)
Build PKCS#10 CSR(s)
Submit CSR(s) over TLS (no privkeys)
step ca sign
Leaf cert PEM (chains to root)
Return PEM → add to encrypted .sec.json



https://localhost:3443/register

SEC-CAM – Register

Pseudonym: david

Email: david@mail.com

☐ Part of a Company?

Register

Download User Access

Set a strong passphrase to ensure your own access.
No data recoverable if forgotten.

Password: ••••••••••••••••••••••••

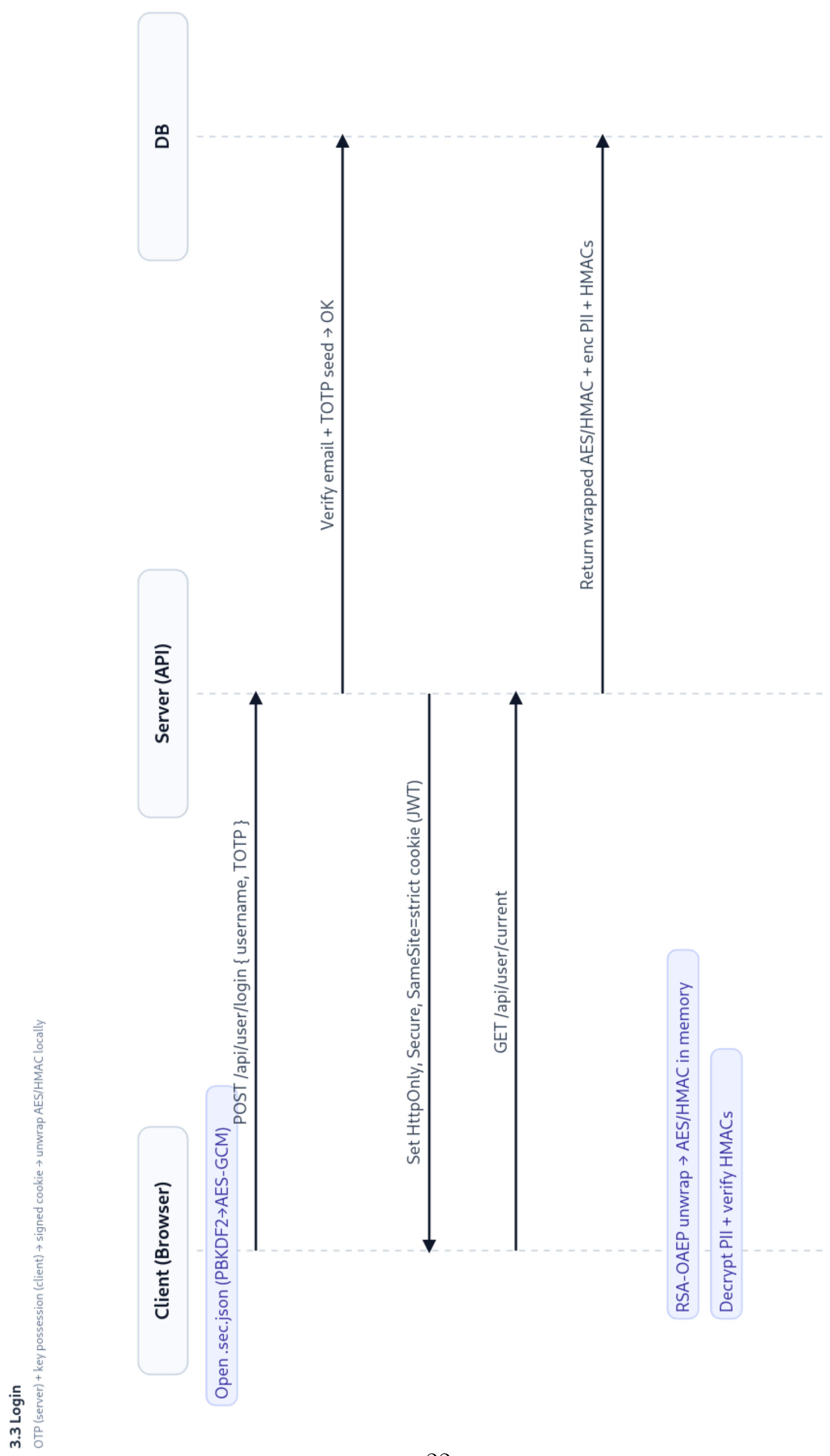
Repeat Password: ••••••••••••••••••••••••

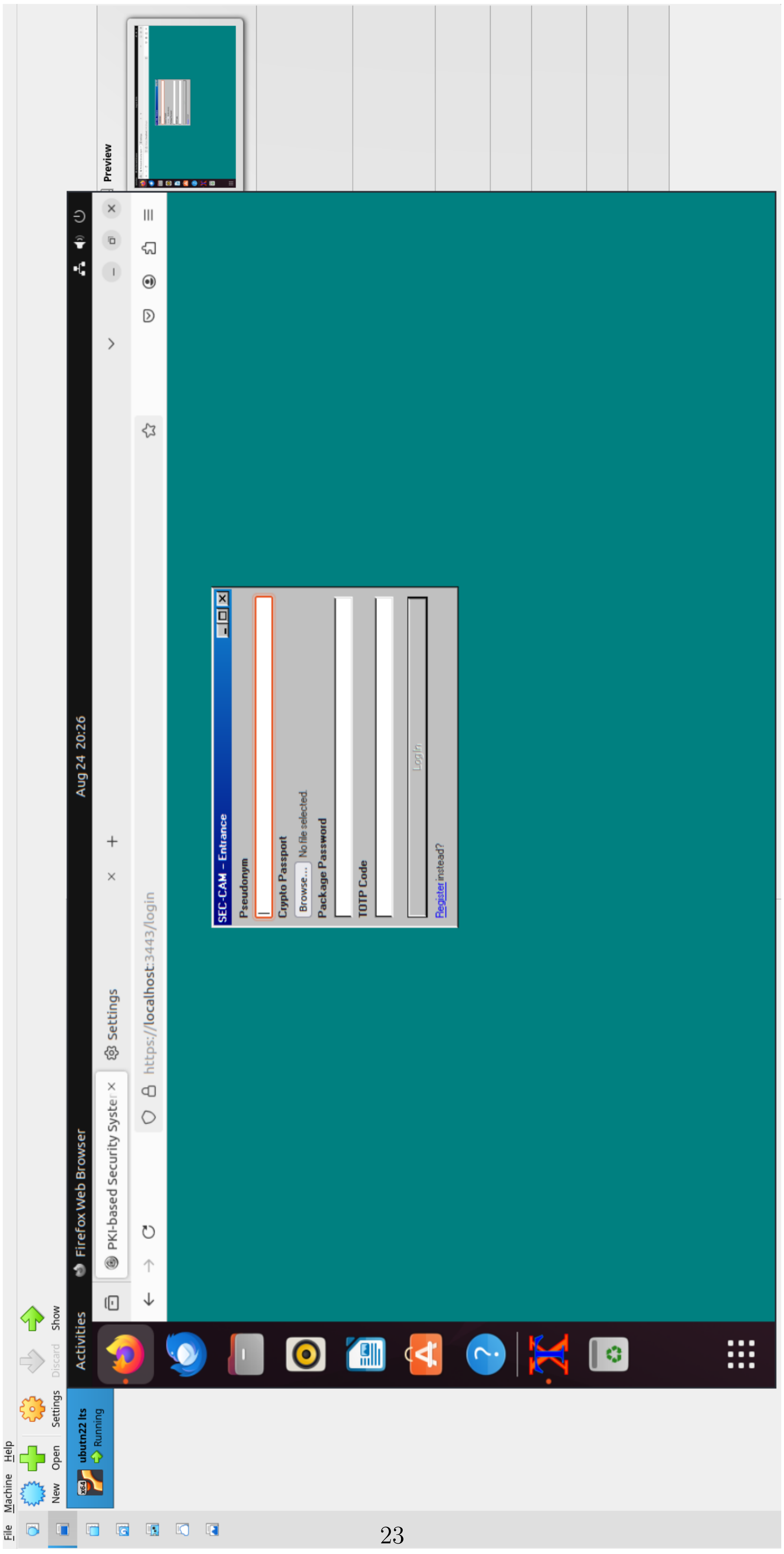
TOTP

Download

Seccam User Crypto-Passport™ at Your Service!

C Annex: Pipeline – Login


3.3 Login
OTP (server) + key possession (client) → signed cookie → unwrap AES/HMAC locally
Client (Browser)
Server (API)
DB
Open .sec.json (PBKDF2→AES-GCM)
POST /api/user/login { username, TOTP }
Verify email + TOTP seed → OK
Set HttpOnly, Secure, SameSite=strict cookie (JWT)
GET /api/user/current
Return wrapped AES/HMAC + enc PII + HMACs
RSA-OAEP unwrap → AES/HMAC in memory
Decrypt PII + verify HMACs



SEC-CAM – Entrance

Pseudonym

Crypto Passport

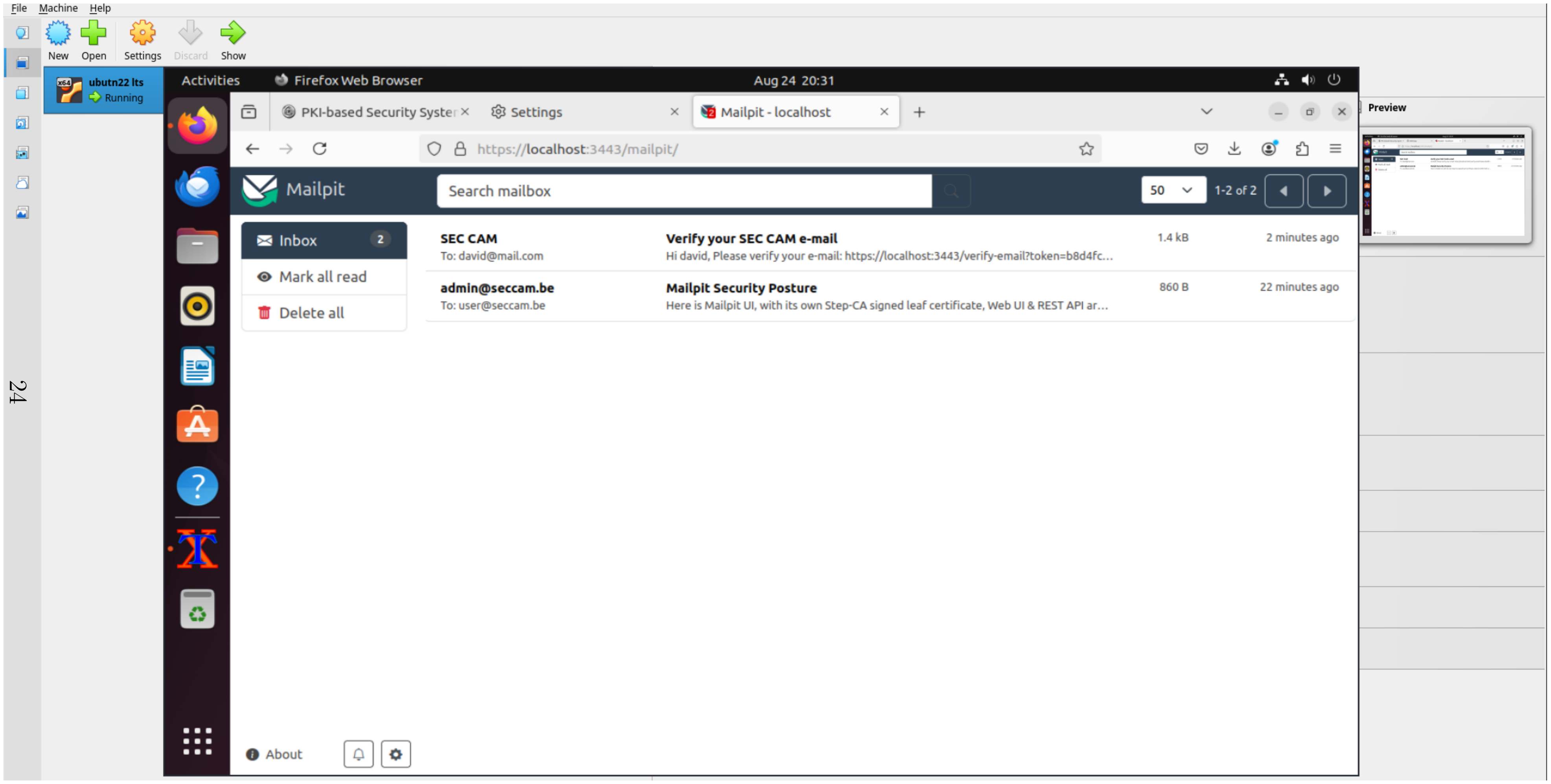
Browse... No file selected.

Package Password

TOTP Code

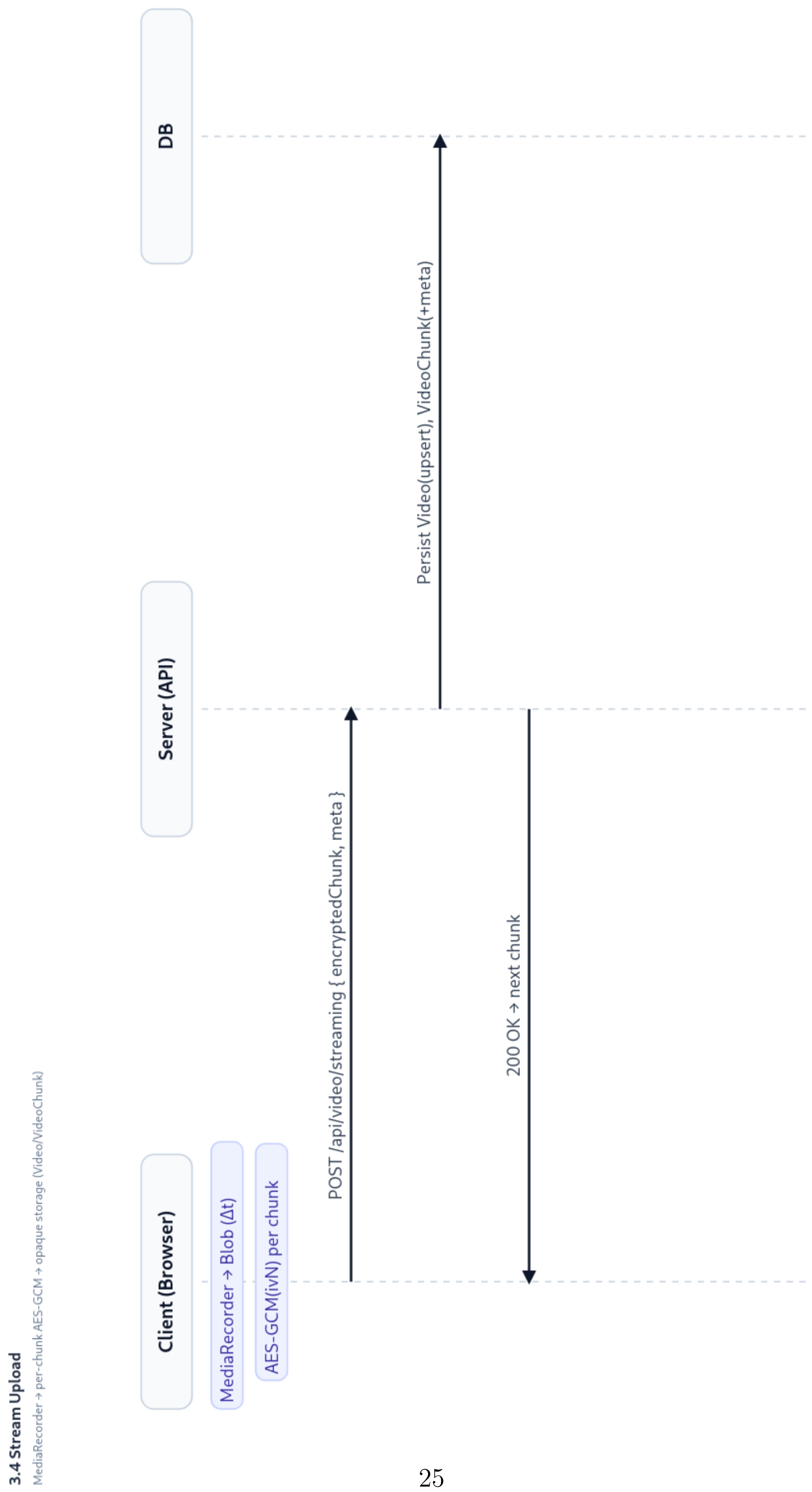
Log In

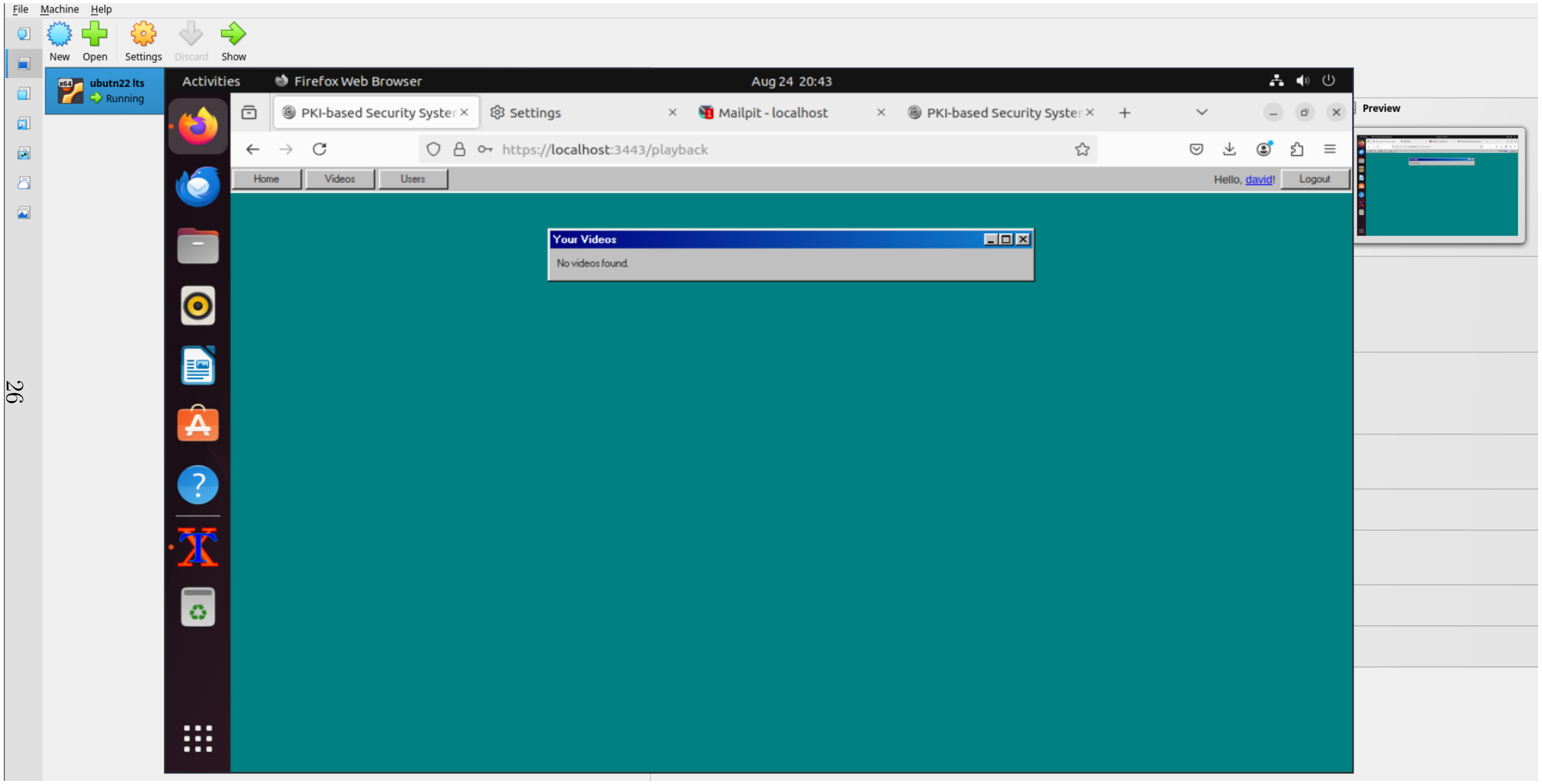
Register instead?



SEC CAM To: david@mail.com	**Verify your SEC CAM e-mail** Hi david, Please verify your e-mail: https://localhost:3443/verify-email?token=b8d4fc...	1.4 kB	2 minutes ago
admin@seccam.be To: user@seccam.be	**Mailpit Security Posture** Here is Mailpit UI, with its own Step-CA signed leaf certificate, Web UI & REST API ar...	860 B	22 minutes ago

D Annex: Pipeline – Stream

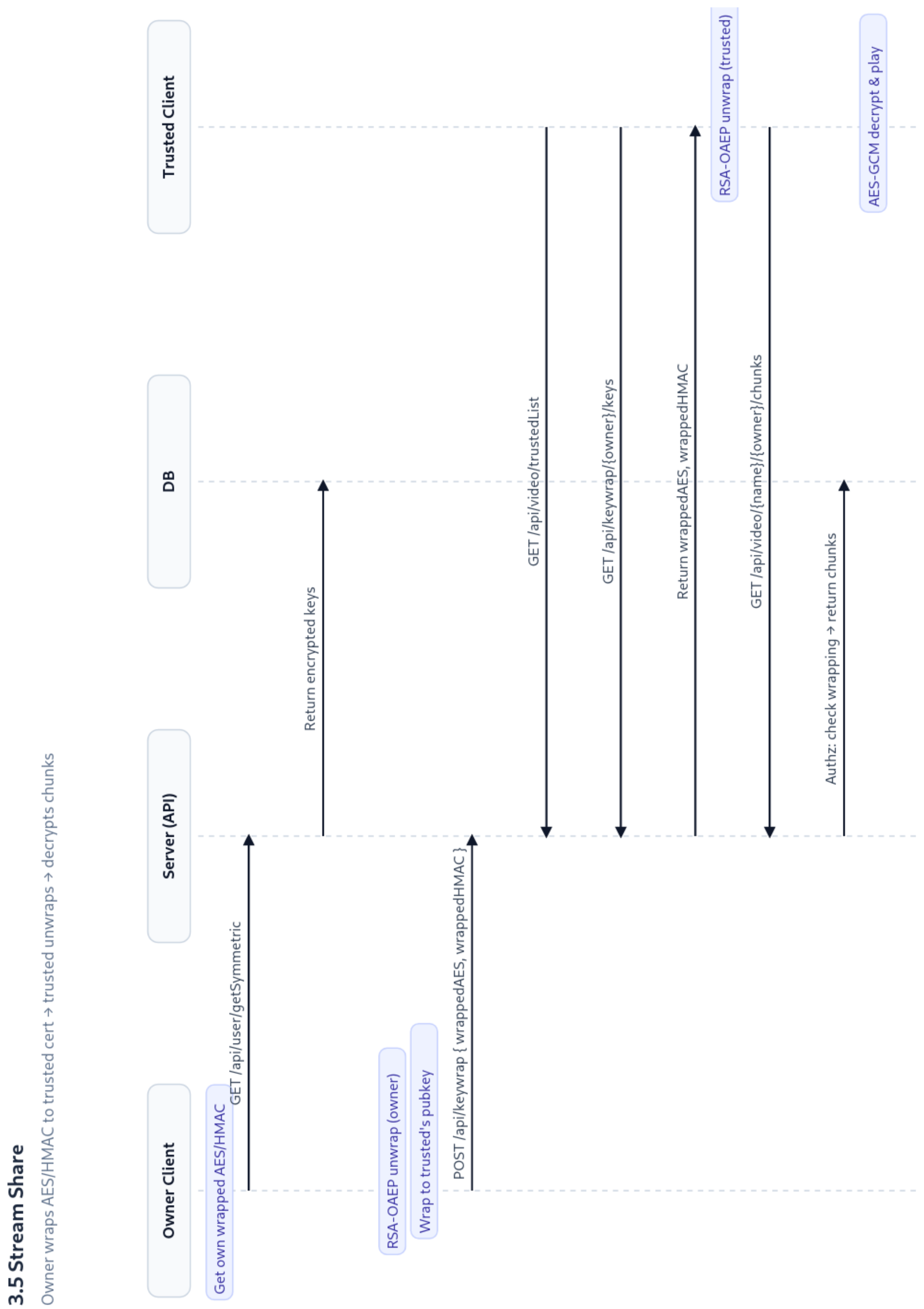

3.4 Stream Upload
MediaRecorder → per-chunk AES-GCM → opaque storage (Video/VideoChunk)
Client (Browser)
Server (API)
DB
MediaRecorder → Blob (Δt)
AES-GCM(ivN) per chunk
POST /api/video/streaming { encryptedChunk, meta }
Persist Video(upsert), VideoChunk(+meta)
200 OK → next chunk

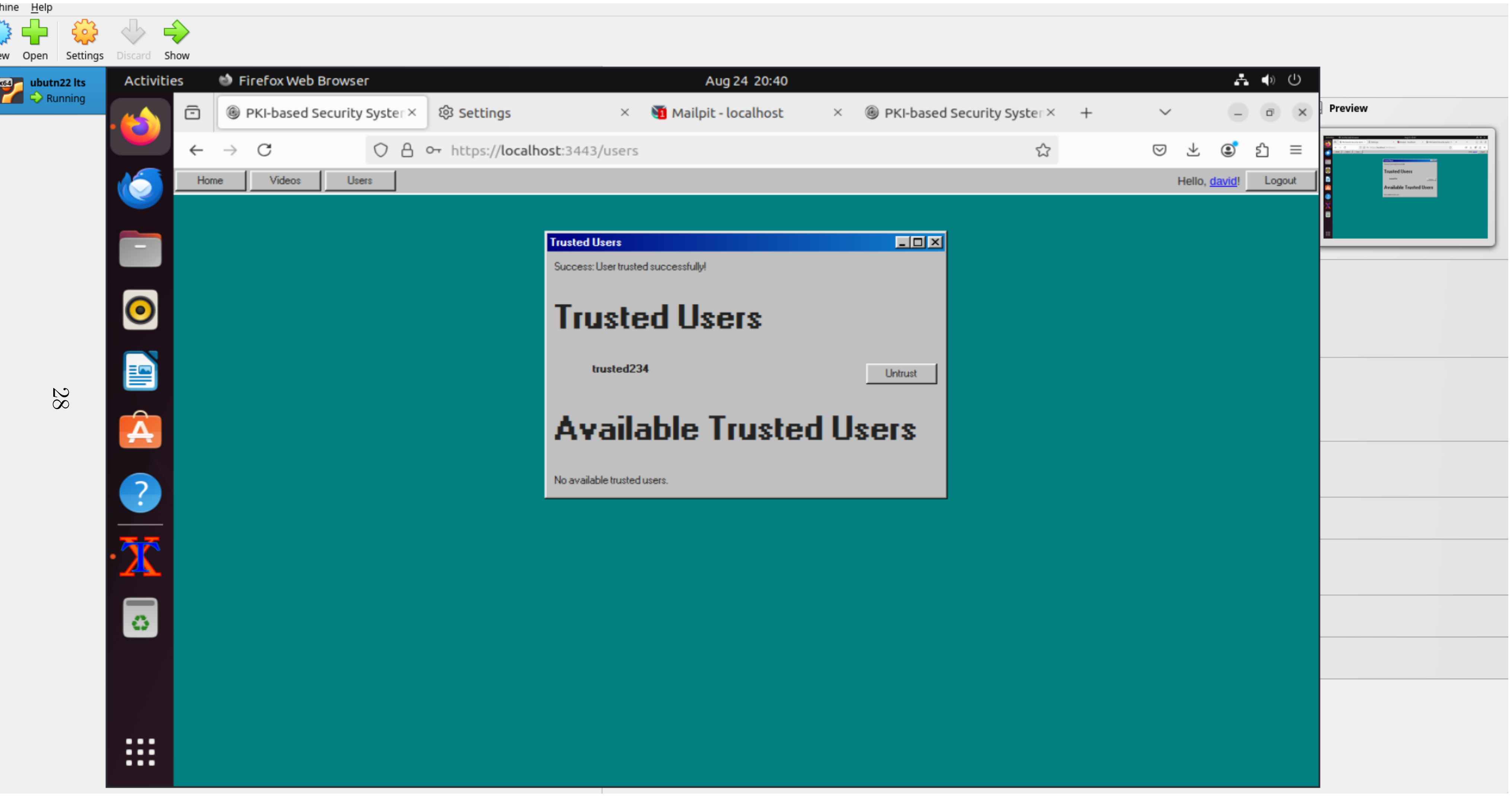


Your Videos

No videos found.

E Annex: Pipeline – Share


3.5 Stream Share
Owner wraps AES/HMAC to trusted cert → trusted unwraps → decrypts chunks
Owner Client
Server (API)
DB
Trusted Client
Get own wrapped AES/HMAC
GET /api/user/getSymmetric
Return encrypted keys
RSA-OAEP unwrap (owner)
Wrap to trusted's pubkey
POST /api/keywrap { wrappedAES, wrappedHMAC }
GET /api/video/trustedList
GET /api/keywrap/{owner}/keys
Return wrappedAES, wrappedHMAC
RSA-OAEP unwrap (trusted)
GET /api/video/{name}/{owner}/chunks
Authz: check wrapping → return chunks
AES-GCM decrypt & play



https://localhost:3443/users

Hello, david!

Trusted Users

Success: User trusted successfully!

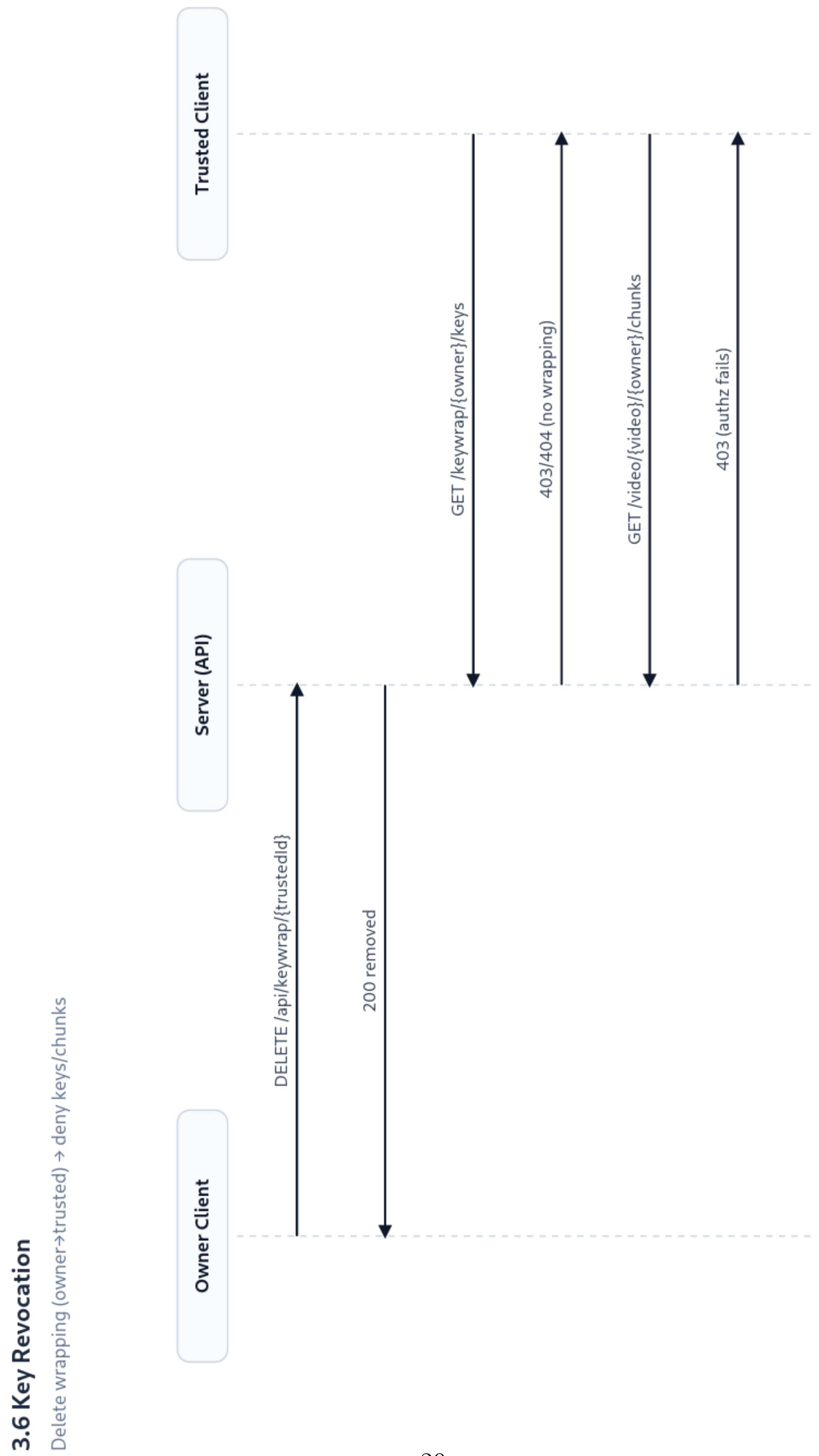
Trusted Users

trusted234 Untrust

Available Trusted Users

No available trusted users.

F Annex: Pipeline – Revocation


3.6 Key Revocation
Delete wrapping (owner→trusted) → deny keys/chunks
Owner Client
Server (API)
Trusted Client
DELETE /api/keywrap/{trustedId}
200 removed
GET /keywrap/{owner}/keys
403/404 (no wrapping)
GET /video/{video}/{owner}/chunks
403 (authz fails)