

# RFC-024: Network Protocol

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**Implementation:** Proposed

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## Abstract

This RFC specifies the network protocol for the Library of Cyberspace: how vaults discover each other, authenticate, exchange objects, and synchronize state. The protocol is transport-agnostic, capability-authenticated, and optimized for content-addressed data.

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## Motivation

Vaults must communicate to:

- **Replicate** - Distribute objects across vaults
- **Federate** - Link independent vaults into networks
- **Subscribe** - Receive updates from publishers
- **Query** - Search the distributed soup

The protocol must handle:

- **Intermittent connectivity** - Vaults may be offline
  - **Untrusted networks** - All communication authenticated
  - **Large objects** - Efficient chunked transfer
  - **Partial sync** - Resume interrupted transfers
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## Protocol Layers

APPLICATION LAYER (vault operations, soup queries)
MESSAGE LAYER (request/response, streaming)
SECURITY LAYER (authentication, encryption)
TRANSPORT LAYER (TCP, QUIC, Unix socket, etc.)

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## Transport Layer

### Supported Transports

```
(define transports
  '((tcp "Traditional TCP/IP")
    (quic "UDP-based, multiplexed")
    (unix "Local Unix domain socket")
    (tor "Onion-routed TCP")
    (i2p "Garlic-routed")
    (bluetooth "Local mesh")
    (sneakernet "Physical media exchange")))
```

### Connection Establishment

```
(define (connect-vault address transport)
  "Establish connection to remote vault"
  (let* ((socket (transport-connect transport address))
        (connection (make-connection socket transport)))

    ;; Perform handshake
    (connection-handshake connection)

    ;; Return authenticated connection
    connection))
```

### Multiplexing

Multiple streams over single connection:

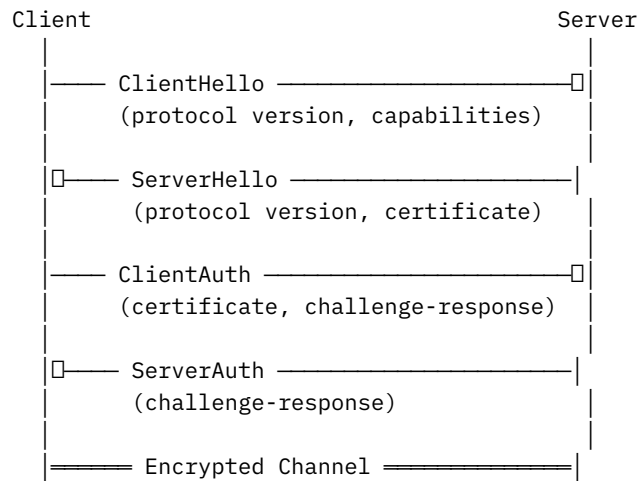
```
(define (open-stream connection stream-type)
  "Open multiplexed stream within connection"
  (let ((stream-id (allocate-stream-id connection)))
    (send-frame connection
      (frame type: 'stream-open
            stream-id: stream-id
            stream-type: stream-type))
    (make-stream connection stream-id stream-type)))
```

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## Security Layer

### Handshake Protocol

Mutual authentication using SPKI certificates:



## Handshake Implementation

```

(define (connection-handshake connection)
  "Perform mutual authentication handshake"

  ;; Send ClientHello
  (send-message connection
    `(client-hello
      (version ,protocol-version)
      (capabilities ,(local-capabilities))))

  ;; Receive ServerHello
  (let ((server-hello (receive-message connection)))
    (verify-protocol-version (server-hello-version server-hello))

    ;; Verify server certificate
    (let ((server-cert (server-hello-certificate server-hello)))
      (unless (verify-certificate server-cert)
        (error "Server certificate invalid")))

    ;; Generate session key using X25519
    (let* ((ephemeral-keypair (x25519-keypair))
           (shared-secret (x25519-shared (keypair-secret ephemeral-keypair)
                                           (cert-public-key server-cert))))

      ;; Send ClientAuth
      (send-message connection
        `(client-auth
          (certificate ,(local-certificate))
          (ephemeral-public ,(keypair-public ephemeral-keypair))
  
```

```

(signature ,(sign-challenge server-hello)))

;; Receive ServerAuth
(let ((server-auth (receive-message connection)))
  (unless (verify-server-signature server-auth server-cert)
    (error "Server authentication failed")))

;; Derive session keys
(derive-session-keys connection shared-secret))))))

```

## Session Encryption

```

(define (derive-session-keys connection shared-secret)
  "Derive symmetric keys for session"
  (let* ((key-material (hkdf shared-secret
                             info: "library-session"
                             length: 64))
         (client-key (subbytes key-material 0 32))
         (server-key (subbytes key-material 32 64)))

    (set-connection-keys! connection
      (if (connection-is-client? connection)
        (keys send: client-key receive: server-key)
        (keys send: server-key receive: client-key)))))

(define (encrypt-message connection message)
  "Encrypt message with session key"
  (let ((nonce (connection-next-nonce connection)))
    (chacha20-poly1305-encrypt
      (connection-send-key connection)
      nonce
      (serialize message))))

(define (decrypt-message connection ciphertext)
  "Decrypt message with session key"
  (let ((nonce (connection-next-nonce connection)))
    (deserialize
      (chacha20-poly1305-decrypt
        (connection-receive-key connection)
        nonce
        ciphertext))))

```

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## Message Layer

### Message Format

```
(library-message
  (version 1)
  (type request|response|stream|error)
  (id <message-id>)
  (in-reply-to <message-id>|#f)
  (capability <spki-cert>|#f)
  (body <payload>))
```

### Request Types

```
(define request-types
  '(;; Object operations
    (get-object hash)
    (put-object hash data)
    (has-object hash)

    ;; Bulk operations
    (get-objects hashes)
    (get-tree root-hash)
    (sync-objects bloom-filter)

    ;; Soup queries
    (soup-query query)
    (soup-subscribe query)

    ;; Vault operations
    (get-refs pattern)
    (get-head)
    (get-releases)

    ;; Discovery
    (get-capabilities)
    (get-peers)))
```

### Request/Response

```
(define (vault-request connection request #!key capability timeout)
  "Send request, wait for response"
  (let ((message-id (generate-message-id)))

    ;; Send request
    (send-message connection
      (library-message
```

```

    version: 1
    type: 'request
    id: message-id
    capability: capability
    body: request))

;; Wait for response
(let ((response (receive-response connection message-id timeout)))
  (if (eq? (message-type response) 'error)
      (error (message-body response))
      (message-body response))))

```

## Streaming

For large transfers:

```

(define (stream-object connection hash)
  "Stream large object in chunks"
  (let ((stream (open-stream connection 'object-transfer)))

    ;; Send chunks
    (let ((data (cas-get hash)))
      (let loop ((offset 0))
        (when (< offset (blob-length data))
          (let ((chunk (blob-copy data offset chunk-size)))
            (stream-send stream chunk)
            (loop (+ offset chunk-size)))))

      ;; End stream
      (stream-close stream))))

(define (receive-stream connection stream callback)
  "Receive streamed data"
  (let loop ((chunks '()))
    (let ((chunk (stream-receive stream)))
      (if (stream-ended? stream)
          (apply bytes-append (reverse chunks))
          (begin
             (callback chunk)
             (loop (cons chunk chunks))))))

```

---

## Object Exchange

### Get Object

```
;; Request
(get-object
 (hash "sha256:abc123..."))

;; Response (small object)
(object-data
 (hash "sha256:abc123...")
 (size 1024)
 (data #${...}))

;; Response (large object - streaming)
(object-stream
 (hash "sha256:abc123...")
 (size 10485760)
 (stream-id 42))
```

### Put Object

```
;; Request
(put-object
 (hash "sha256:abc123...")
 (data #${...}))

;; Response
(put-result
 (hash "sha256:abc123...")
 (status stored|duplicate|rejected)
 (reason #f|"quota exceeded"))
```

### Batch Operations

```
;; Request multiple objects
(get-objects
 (hashes ("sha256:aaa..." "sha256:bbb..." "sha256:ccc...")))

;; Response
(objects-batch
 (objects
 ((hash "sha256:aaa..." data #${...})
 (hash "sha256:bbb..." data #${...})
 (hash "sha256:ccc..." status: missing)))))
```

## Tree Transfer

Efficient Merkle tree sync:

```
;; Request tree
(get-tree
  (root "sha256:root...")
  (depth 3) ; How deep to fetch
  (exclude ("sha256:already-have...")))

;; Response
(tree-data
  (root "sha256:root...")
  (objects
    ((hash "sha256:root..." data #${...})
     (hash "sha256:child1..." data #${...})
     (hash "sha256:child2..." data #${...}))))
```

---

## Synchronization

### Bloom Filter Exchange

Efficient “what do you have?” queries:

```
;; Step 1: Exchange bloom filters
(define (sync-init local-vault remote-connection)
  (let ((local-bloom (vault-bloom-filter local-vault)))

    ;; Send our bloom filter
    (send-message remote-connection
      `(sync-bloom
        (filter ,local-bloom)
        (population ,(bloom-population local-bloom)))))

    ;; Receive their bloom filter
    (let ((remote-bloom (receive-bloom remote-connection)))

      ;; Compute what they might want
      (let ((to-send (filter (lambda (hash)
                              (not (bloom-contains? remote-bloom hash)))
                              (vault-all-hashes local-vault))))
        to-send))))

;; Step 2: Exchange missing objects
(define (sync-exchange to-send to-receive connection)
  (parallel
```



```

;; Send what they need
(for-each (lambda (hash)
  (stream-object connection hash))
  to-send)
;; Receive what we need
(for-each (lambda (hash)
  (receive-object connection hash))
  to-receive)))

```

## Incremental Sync

```

(define (incremental-sync local-vault remote-connection since)
  "Sync changes since timestamp or commit"

  ;; Get remote changes
  (let ((remote-changes (vault-request remote-connection
    `(changes-since ,since))))

    ;; Get local changes
    (let ((local-changes (vault-changes-since local-vault since)))

      ;; Bidirectional merge
      (sync-merge local-vault remote-connection
        local-changes remote-changes))))

```

## Conflict Resolution

```

(define (sync-merge local-vault remote changes-local changes-remote)
  "Merge changes with conflict resolution"

  (for-each
    (lambda (hash)
      (cond
        ;; Only local has it - push
        ((and (member hash changes-local)
          (not (member hash changes-remote)))
          (push-object local-vault remote hash))

        ;; Only remote has it - pull
        ((and (member hash changes-remote)
          (not (member hash changes-local)))
          (pull-object local-vault remote hash))

        ;; Both have it - verify same
        ((and (member hash changes-local)
          (member hash changes-remote))
          ))
    ))

```

```

;; Content-addressed, so same hash = same content
#t)))
(union changes-local changes-remote)))

```

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## Discovery

### Peer Discovery

```

;; Well-known peers (bootstrap)
(define (discover-bootstrap)
  (map parse-address
    (read-file "/etc/library/bootstrap-peers")))

;; mDNS/DNS-SD for local network
(define (discover-local)
  (mdns-browse "_library._tcp.local"))

;; DHT for global discovery
(define (discover-dht target-hash)
  (dht-find-providers target-hash))

;; Peer exchange
(define (discover-pex connection)
  (vault-request connection '(get-peers)))

```

### Capability Advertisement

```

;; Query vault capabilities
(get-capabilities)

;; Response
(vault-capabilities
  (protocol-version 1)
  (features (bloom-sync tree-transfer streaming soup-query))
  (max-object-size 104857600) ; 100MB
  (storage-available 10737418240) ; 10GB
  (public-key "ed25519:abc...")
  (services
    ((soup-query rate-limit: 100/minute)
     (object-transfer rate-limit: 10MB/second))))

```

---

## Soup Queries

### Remote Query

```
;; Query remote soup
(soup-query
  (type certificate)
  (issuer "vault-admin")
  (limit 100))

;; Response
(soup-results
  (count 47)
  (objects
    ((name "cert/alice" type certificate ...)
     (name "cert/bob" type certificate ...)
     ...)))
```

### Subscription

```
;; Subscribe to soup changes
(soup-subscribe
  (query (type release))
  (callback-url "library://my-vault/callbacks/releases"))

;; Subscription confirmation
(subscription
  (id "sub-123")
  (query (type release))
  (expires "2026-02-07T00:00:00Z"))

;; Push notification (when matching object appears)
(soup-notification
  (subscription-id "sub-123")
  (object (name "release/1.2.0" type release ...)))
```

---

## Error Handling

### Error Types

```
(define error-types
  '((not-found "Object not found")
    (unauthorized "Capability required")
    (forbidden "Capability insufficient")
    (quota-exceeded "Storage quota exceeded")
    (rate-limited "Too many requests"))
```

```

(timeout "Operation timed out")
(invalid-request "Malformed request")
(internal-error "Server error")
(unavailable "Service temporarily unavailable"))))

```

## Error Response

```

(library-message
  (type error)
  (id <message-id>)
  (in-reply-to <request-id>)
  (body
    (error-response
      (code not-found)
      (message "Object sha256:abc... not found")
      (retry-after #f))))))

```

## Retry Logic

```

(define (vault-request-with-retry connection request #!key max-retries)
  "Request with exponential backoff retry"
  (let loop ((attempt 0) (delay 1000))
    (let ((result (vault-request connection request)))
      (if (and (error-response? result)
                (retryable-error? result)
                (< attempt max-retries))
          (begin
            (sleep delay)
            (loop (+ attempt 1) (* delay 2)))
          result))))

```

---

## Security Considerations

### Capability Verification

```

(define (verify-request-capability request connection)
  "Verify request has sufficient capability"
  (let ((required-cap (request->capability request))
        (presented-cap (message-capability request)))

    (unless presented-cap
      (error 'unauthorized "Capability required")))

    (unless (valid-certificate? presented-cap)
      (error 'unauthorized "Invalid capability certificate"))

```

```

(unless (capability-grants? presented-cap required-cap)
  (error 'forbidden "Insufficient capability"))

;; Verify capability chain back to trusted root
(unless (verify-capability-chain presented-cap)
  (error 'forbidden "Capability chain invalid"))))

```

## Denial of Service Protection

```

(define (rate-limit connection request-type)
  "Apply rate limiting"
  (let ((limit (get-rate-limit request-type))
        (current (connection-request-count connection request-type)))
    (when (> current limit)
      (error 'rate-limited
              (format "Rate limit exceeded: ~a/~a" current limit)))))

(define (size-limit request)
  "Enforce size limits"
  (when (> (request-size request) max-request-size)
    (error 'invalid-request "Request too large")))

```

## Replay Prevention

```

(define (verify-nonce connection message)
  "Prevent replay attacks"
  (let ((nonce (message-nonce message)))
    (when (nonce-seen? connection nonce)
      (error 'invalid-request "Replay detected"))
    (record-nonce connection nonce)))

```

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## Implementation Notes

### Wire Format

Messages serialized as canonical S-expressions:

```

(define (serialize-message message)
  "Canonical S-expression serialization"
  (canonical-sexp->bytes message))

(define (deserialize-message bytes)
  "Parse S-expression"
  (bytes->canonical-sexp bytes))

```

## Compression

Optional compression for large payloads:

```
(define (maybe-compress data)
  (if (> (blob-length data) compression-threshold)
      (values (zstd-compress data) 'zstd)
      (values data 'none)))
```

## Connection Pooling

```
(define connection-pool (make-hash-table))

(define (get-connection address)
  "Get pooled connection or create new"
  (or (hash-table-ref connection-pool address #f)
      (let ((conn (connect-vault address)))
        (hash-table-set! connection-pool address conn)
        conn)))
```

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## References

1. QUIC Protocol - RFC 9000
  2. Noise Protocol Framework
  3. RFC-020: Content-Addressed Storage
  4. RFC-021: Capability Delegation
  5. IPFS Bitswap Protocol
  6. libp2p Specifications
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## Changelog

- **2026-01-07** - Initial draft
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**Implementation Status:** Draft **Dependencies:** transport, crypto, cas **Integration:** Replication, federation, distributed soup