RFC-016: Lazy Clustering

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Abstract

This RFC specifies Lazy Clustering for Cyberspace federation: a relaxed synchronization model where nodes sync when convenient, not continuously. Optimized for the "loose confederacy of friends" model.

Motivation

Not every deployment needs Byzantine consensus:

- **Friends trust friends:** No active adversary
- **Bandwidth costs:** Continuous sync is expensive
- **Offline operation:** Internet isn't always available
- **Simplicity:** Complex protocols have complex bugs

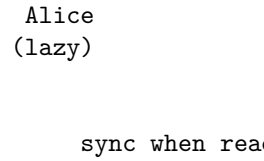
Lazy Clustering provides:

1. **Sync when ready:** Push/pull at human pace
2. **Offline-first:** Work without network
3. **Conflict detection:** Know when divergence happens
4. **Manual resolution:** Humans resolve, not algorithms
5. **Audit everything:** Full history preserved

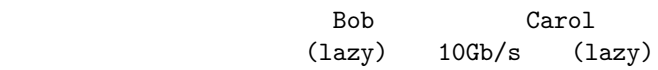
> *The best protocol is the one you don't run.*

Specification

Cluster Model



sync when ready @ 10Gb/s



No heartbeats. No leader election. No quorum.
Just friends sharing when they're ready.
At line speed when they do.

Performance Model

Lazy semantics, line speed execution.

```
Line speed (10 Gb/s):
  Typical release: 10 MB archive
  Transfer time:   8 ms
  Effective rate:  ~1000 releases/second

Starlink (100-200 Mb/s, 20-40ms latency):
  Typical release: 10 MB archive
  Transfer time:   400-800 ms
  Effective rate:  ~1-2 releases/second
  Optimized for:   Bursty, high-latency satellite links

Minimum bandwidth:
  Floor:           128 Kb/s (dual-ISDN)
  Target:          1 Mb/s (T1)
  Typical release: 10 MB archive
  Transfer time:   ~80 sec (T1), ~10 min (dual-ISDN)
  Strategy:        Delta sync, compressed archives
```

Crypto overhead (constant):

```
Signature verify: ~10  s (Ed25519)
Hash verify:      ~1 ms (SHA-512, 10MB)
Total overhead:   ~1 ms (negligible vs transfer)
```

"Lazy" means *when*, not *how fast*. When you sync, it saturates the pipe.

Design priorities: 1. Optimized for Starlink and satellite links 2. Tolerant of high latency (no chatty protocols) 3. Graceful degradation to minimum bandwidth 4. Bursty transfer patterns (sync then idle)

Heartbeat and Timekeeping

No mandatory heartbeat. That's the design.

```
Traditional cluster:  ping → pong → ping → pong → ...
Lazy cluster:         ... silence ... (sync) ... silence ...
```

Timekeeping: Lamport clocks (RFC-012), not wall clocks. - Causality without synchronization - No NTP dependency - No GPS required - Works across time zones, planets

When you need consensus: Byzantine consensus (RFC-011) + Lamport clocks. - Lazy clustering for everyday sync - Byzantine consensus for critical decisions - Same Lamport clock across both modes

Optional presence beacon:

```
(cluster-beacon
  (peer "alice")
  (lamport-time 4271)
  (last-release "2.1.0")
  (status available)
  (next-expected "when ready"))
```

Beacons are: - Pull-based (query, don't push) - Cached (no flood) - Stale-tolerant (hours/days old is fine) - Unsigned (advisory only)

Sync Modes

Push (I have something)

```
(lazy-push peer)
;; Sends my new releases to peer
;; Non-blocking, fire-and-forget
```

Pull (What do you have?)

```
(lazy-pull peer)
;; Fetches peer's new releases
;; Verifies signatures, stores locally
```

Sync (Bidirectional)

```
(lazy-sync peer)
;; Push then pull
;; Returns conflict report if any
```

Lazy Semantics

No continuous connection. Nodes are offline by default.

No consistency guarantees. Nodes may diverge.

No automatic resolution. Conflicts flagged for humans.

No urgency. Sync happens when convenient.

State Tracking

Version Vector

Each node tracks what it knows about others:

```
(define-record-type <version-vector>
  (make-version-vector entries)
  version-vector?
  (entries vv-entries))  ; Hash: node-id → latest-sequence

;; Alice's view:
;; { alice: 42, bob: 37, carol: 29 }
```

Sync Calculation

```
(define (compute-sync-set local-vv remote-vv)
  "What to send/receive"
  (let ((to-send '())
        (to-receive '()))
    (for-each
      (lambda (node)
        (let ((local-seq (vv-get local-vv node))
              (remote-seq (vv-get remote-vv node)))
          (cond
            ((> local-seq remote-seq)
             (push! to-send (releases-between node remote-seq local-seq)))
            ((< local-seq remote-seq)
             (push! to-receive (list node remote-seq local-seq))))))
      (all-nodes local-vv remote-vv))
    (values to-send to-receive)))
```

Conflict Detection

Divergence

Same version, different content:

```
(lazy-sync "bob")
;; =>
;;   Conflict detected:
;;    Version 2.1.0
;;    Local:  sha512:abc123...
;;    Remote: sha512:def456...
;;
;;    Both modified since common ancestor 2.0.0
```

Conflict Record

```
(conflict
  (version "2.1.0")
  (local-hash "sha512:abc123...")
  (remote-hash "sha512:def456...")
  (common-ancestor "2.0.0")
  (detected "2026-01-06T15:30:00Z")
  (status pending))  ; pending, resolved-local, resolved-remote, merged
```

Resolution

Manual resolution required:

```
(lazy-resolve "2.1.0" prefer: 'local)
;; or
(lazy-resolve "2.1.0" prefer: 'remote)
;; or
(lazy-resolve "2.1.0" merged: "2.1.0-merged")
```

Offline Operation

Work Offline

```
(seal-commit "Add feature")
(seal-release "2.2.0")
;; All local, no network required
```

Queue for Sync

```
(lazy-queue)
;; =>
;; Pending sync:
;;   2.1.1  (local, not pushed)
;;   2.2.0  (local, not pushed)
```

```
;;
;; To sync: (lazy-push "bob")
```

Reconnect and Sync

```
(lazy-sync "bob")
;; Sends 2.1.1, 2.2.0
;; Receives bob's changes
;; Reports any conflicts
```

Cluster Operations

Join Cluster

```
(lazy-join "bob"
  uri: "git@github.com:bob/vault.git"
  key: bob-public-key)
;; Registers peer, doesn't sync yet
```

Initial Sync

```
(lazy-pull "bob")
;; Gets bob's full history
;; Verifies all signatures
```

Leave Cluster

```
(lazy-leave "bob")
;; Removes peer from sync list
;; Keeps local copies of bob's releases
```

Cluster Status

```
(lazy-status)
;; =>
;; Cluster peers:
;;   bob    last-sync: 2026-01-05  versions: 1.0.0-2.1.0
;;   carol  last-sync: 2026-01-03  versions: 1.0.0-2.0.0  (2 behind)
;;   dave   last-sync: never       versions: none         (not synced)
;;
;; Local: 2.2.0 (2 ahead of cluster)
```

Sync Strategies

Manual (Default)

```
(vault-config 'sync-strategy 'manual)
;; User explicitly calls lazy-sync
```

Periodic

```
(vault-config 'sync-strategy 'periodic)
(vault-config 'sync-interval 3600)  ; hourly
;; Background sync when network available
```

On-Commit

```
(vault-config 'sync-strategy 'on-commit)
;; Push after each seal-commit
;; Still lazy (non-blocking, best-effort)
```

On-Release

```
(vault-config 'sync-strategy 'on-release)
;; Push only after seal-release
;; Most conservative
```

Consistency Guarantees

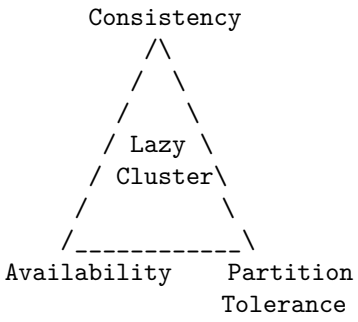
What We Guarantee

- **Signature integrity:** All releases verified
- **Causal ordering:** Within single node
- **Conflict detection:** Divergence detected
- **Audit preservation:** Full history kept

What We Don't Guarantee

- **Global ordering:** Nodes may see different orders
- **Consistency:** Nodes may have different content
- **Availability:** Offline nodes are offline
- **Automatic resolution:** Humans must resolve

CAP Theorem Position



We choose AP: Available and Partition-tolerant, eventually consistent.

Comparison with Other Modes

Aspect	Lazy Cluster	Federation (RFC-010)	Byzantine (RFC-011)
Trust	Friends	Verified peers	Adversarial
Sync	Manual/periodic	Announcement-based	Consensus
Conflicts	Manual resolve	Detect + flag	Prevented
Offline	Full support	Partial	Requires quorum
Complexity	Minimal	Medium	High
Use case	Small groups	Organizations	Critical systems

Example Session

```
;; Morning: Alice works offline
(seal-commit "Add authentication")
(seal-commit "Add authorization")
(seal-release "2.3.0")

;; Lunch: Alice syncs with Bob
(lazy-sync "bob")
;; => Pushed 2.3.0 to bob
;; => Pulled 2.2.1 from bob
;; => No conflicts

;; Evening: Alice syncs with Carol
(lazy-sync "carol")
```

```
;; => Pushed 2.2.1, 2.3.0 to carol
;; => Pulled nothing (carol hasn't released)
;; =>   Carol has unsynced commits (not our concern)
```

Security Considerations

Trust Model

Lazy clustering assumes good-faith peers:

- Peers won't inject malicious releases
- Peers won't withhold releases maliciously
- Peers will eventually sync

Not suitable for: Adversarial environments, high-value targets.

Suitable for: Research groups, open source projects, friend networks.

Signature Verification

All releases still verified:

```
(lazy-pull "bob")
;; Each release:
;;   1. Verify Ed25519 signature
;;   2. Verify hash matches content
;;   3. Check against known bob public key
;;   4. Store only if valid
```

Conflict Attacks

Malicious peer creates conflicting release.

Mitigation: - Conflicts flagged, not auto-resolved - Full audit trail of conflict - Peer reputation tracking

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Implementation Notes

Dependencies

- `crypto-ffi` - Signature verification
- `audit` - Sync logging
- Transport (git/HTTP/filesystem)

Storage

```
.vault/
  lazy/
    peers.sexp        # Registered peers
    vectors.sexp      # Version vectors
    conflicts/        # Unresolved conflicts
    queue/            # Pending pushes
```

References

1. Saito, Y., & Shapiro, M. (2005). Optimistic Replication.
2. Terry, D., et al. (1995). Managing Update Conflicts in Bayou.
3. DeCandia, G., et al. (2007). Dynamo: Amazon's Key-Value Store.
4. RFC-010: Federation Protocol
5. RFC-012: Lamport Logical Clocks

Changelog

- **2026-01-06** – Set minimum bandwidth: 128 Kb/s floor (dual-ISDN), 1 Mb/s target (T1)
- **2026-01-06** – Initial specification

Implementation Status: Proposed **Consistency Model:** Eventual (AP) **Sync Model:** Manual/periodic, offline-first **Trust Model:** Friends (non-adversarial)