

RFC-011: Byzantine Consensus

Status: Proposed **Date:** January 2026 **Author:** Derrell Piper
ddp@eludom.net

Abstract

This RFC specifies Byzantine fault-tolerant consensus for Cyberspace federation, enabling agreement among distributed vaults even when some participants are faulty or malicious. N nodes tolerate up to f failures where $N \geq 3f + 1$.

Motivation

Federation (RFC-010) assumes honest peers. Reality differs:

- **Crash failures:** Nodes go offline
- **Byzantine failures:** Nodes lie, equivocate, or attack
- **Network partitions:** Messages delayed or lost
- **Sybil attacks:** Fake identities flood the network

Byzantine consensus provides:

1. **Safety:** Honest nodes agree on same value
2. **Liveness:** System makes progress despite failures
3. **Fault tolerance:** Survives f failures with $3f+1$ nodes

From Lamport, Shostak, and Pease (1982):

The Byzantine Generals Problem: reaching agreement in the presence of traitors.

Specification

System Model

Nodes: $N = 3f + 1$ (tolerates f Byzantine faults)
Network: Asynchronous with eventual delivery
Cryptography: Ed25519 signatures (authenticated channels)

Consensus Properties

Agreement: If honest node i decides v, honest node j decides v.

Validity: If all honest nodes propose v, decision is v.

Termination: All honest nodes eventually decide.

Protocol: Practical Byzantine Fault Tolerance (PBFT)

Phase 1: PRE-PREPARE

Primary broadcasts PRE-PREPARE, v, n, sig

Phase 2: PREPARE

On valid PRE-PREPARE, broadcast PREPARE, v, n, sig

Collect 2f PREPARE messages

Phase 3: COMMIT

On 2f+1 PREPARE, broadcast COMMIT, v, n, sig

Collect 2f+1 COMMIT messages

Decision:

On 2f+1 COMMIT, decide v

Message Formats

```
(consensus-message
  (type pre-prepare)
  (view 0)
  (sequence 42)
  (value-hash "sha512:...")
  (from ${primary-pubkey})
  (signature ${ed25519-sig}))
```

```
(consensus-message
  (type prepare)
  (view 0)
  (sequence 42)
  (value-hash "sha512:...")
  (from ${replica-pubkey})
  (signature ${ed25519-sig}))
```

```
(consensus-message
  (type commit)
  (view 0)
  (sequence 42))
```

```
(from #${replica-pubkey})  
(signature #${ed25519-sig}))
```

View Change

When primary fails or is Byzantine:

1. Replica timeout on PRE-PREPARE
 2. Broadcast VIEW-CHANGE, v+1, prepared-proofs
 3. New primary collects 2f+1 VIEW-CHANGE
 4. New primary broadcasts NEW-VIEW, v+1, proofs
 5. Resume protocol in new view
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Application to Cyberspace

Federation Ordering

```
(consensus-propose  
  (action release-publish)  
  (version "2.0.0")  
  (proposer #${alice-key}))  
  
;; After consensus:  
(consensus-decided  
  (sequence 42)  
  (action release-publish)  
  (version "2.0.0")  
  (decided-by (quorum ...)))
```

Threshold Governance Integration

Combine with RFC-007: – Consensus on *what* to do – Threshold signatures on *authorization*

```
(governance-decision  
  (consensus-sequence 42)  
  (action deploy-production)  
  (threshold-met 3-of-5)  
  (signers (alice carol dave)))
```

Optimizations

Speculation

Execute optimistically before commit:

Tentative execution after $2f+1$ PREPARE
Rollback if COMMIT fails

Batching

Amortize consensus over multiple operations:

```
(consensus-batch
  (sequence 42)
  (operations
    (release-publish "2.0.0")
    (release-publish "2.0.1")
    (config-update ...)))
```

Fast Path

When all replicas agree initially:

Skip PREPARE phase
Direct to COMMIT with $3f+1$ matching responses

Security Considerations

Threat Model

Tolerates: – f Byzantine nodes (arbitrary behavior) – Network delays and reordering – Message loss (with retransmission)

Requires: – $N \geq 3f + 1$ total nodes – Authenticated channels (signatures) – Eventual message delivery

Attack Resistance

Attack	Mitigation
Equivocation	Signatures prove inconsistency
Replay	Sequence numbers, view numbers
Denial of service	View change, rate limiting
Sybil	SPKI admission control

Complexity

Metric	Value
Message complexity	$O(N^2)$ per decision
Communication rounds	3 (normal case)
Cryptographic operations	$O(N)$ signatures/verifies

Implementation Notes

State Machine

```
(define-record-type <pbft-state>
  (make-pbft-state view sequence log prepared committed)
  pbft-state?
  (view pbft-view)
  (sequence pbft-sequence)
  (log pbft-log)           ; sequence → messages
  (prepared pbft-prepared) ; sequence → value
  (committed pbft-committed)) ; sequence → value
```

Dependencies

- crypto-ffi – Ed25519 signatures
 - audit – Decision logging
 - Network transport (TCP, QUIC)
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References

1. Lamport, L., Shostak, R., & Pease, M. (1982). The Byzantine Generals Problem.
 2. Castro, M., & Liskov, B. (1999). Practical Byzantine Fault Tolerance.
 3. Yin, M., et al. (2019). HotStuff: BFT Consensus with Linearity and Responsiveness.
 4. RFC-007: Threshold Signature Governance
 5. RFC-010: Federation Protocol
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Changelog

- **2026-01-06** – Initial specification

Implementation Status: Proposed **Fault Tolerance:** f failures with $3f+1$ nodes **Protocol Basis:** PBFT