SiloSec Protocol Specification

The Definitive Blueprint for Silo-to-Silo Encrypted Communication

Registry: [HOWL-COMP-8-2026]

Series Path: [HOWL-COMP-1-2026] → [HOWL-COMP-2-2026] → [HOWL-COMP-3-2026] → [HOWL-COMP-4-2026] → [HOWL-COMP-5-2026] → [HOWL-COMP-6-2026] → [HOWL-COMP-7-2026] → [HOWL-COMP-8-2026]

Parent Framework: [HOWL-COMP-1-2026]

DOI: 10.5281/zenodo.18677006

Date: February 2026

Domain: Software Architecture / Systems Engineering / Real-Time Computing

Status: Architectural Blueprint for Independent Implementation

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Table of Contents

Philosophy & Motivation

The Problem

Traditional secure communication protocols (TLS, IPSec) are built on decades of accumulated complexity:

- **TLS 1.3:** 15,000+ lines of code, requires RSA/X.509/ASN.1/PKI infrastructure
- **IPSec:** 8,000+ lines, kernel integration nightmares, debugging impossibility
- **Both:** Depend on certificate authorities, expiring certificates, cipher negotiation, version management

Quote from design discussion:

> "we abandon wifi, in cases its required, use a VM and pretend its cabled"

> "this is an OS, we are restarting computing, some crypto is needed."

The Realization

Key insight: In a 1-process OS where the kernel IS the application, there is no separation between "kernel" and "userspace" networking. SiloSec can operate at the IP layer without "kernel integration" because it IS the kernel.

Second insight: We only need to encrypt Silo-to-Silo communication. Legacy machines get plain HTTP or nothing.

Third insight: Zig's standard library already contains all necessary primitives:

```
std.crypto.dh.X25519              // Key exchange

std.crypto.sign.Ed25519           // Authentication

std.crypto.aead.aes_gcm.Aes256Gcm // Encryption
```

No external dependencies. No C code. No binary blobs.

Design Constraints (The K Split)

From the original philosophy:

> "Low road chosen - $200 CPU, pure software, no drivers, runs anywhere, accessible to all."

Applied to networking:

- **NO** proprietary firmware (WiFi rejected)
- **NO** external crypto libraries (BearSSL rejected, even at 50KB)

- **NO** complexity we can't audit (TLS/IPSec rejected)
- **YES** to minimal, auditable, pure Zig code

Quote from BearSSL rejection:

> "i thought 50kb of C, rejecting, too big. not worth it."

This is correct. 15,000 lines of C we cannot audit violates everything Silo stands for.

What We Rejected and Why

Rejected: HTTPS/TLS

Complexity:

- TLS 1.2/1.3 implementation: ~15,000 lines
- X.509 certificate parsing: ~2,000 lines
- ASN.1 DER encoding: ~1,500 lines
- RSA operations: ~10,000 lines (big integer math)
- **Total:** ~28,500 lines minimum

Even with BearSSL:

- 50KB compiled C code
- 15,000 lines we cannot audit
- Binary blob we don't control
- Defeats minimal, auditable OS principle

Why rejected:

> "50kb of C, rejecting, too big. not worth it."

TLS requires trust in:

- Certificate authorities
- Browser vendors
- Certificate revocation infrastructure
- Cipher suite negotiation
- Version compatibility

We reject all of this as "dead wood."

Rejected: IPSec

Quote from analysis:

> "doesnt require kernel integratation in a 1 process OS"

Why we considered it: IPSec operates at IP layer, seemed like natural fit.

Why we rejected it:

1. **Complexity:** Still ~8,000 lines minimum
2. **IKE Protocol:** Requires same RSA/X.509 infrastructure as TLS
3. **All-or-nothing:** Encrypts everything or nothing (no per-peer control)
4. **Legacy baggage:** Designed for traditional OS architecture
5. **Debugging nightmare:** Even worse than TLS

Conclusion: IPSec is NOT simpler than TLS. It's complexity dressed in different clothes.

Rejected: SSH Tunnels / Proxies

Quote from discussion:

> "there is no SSH, not an option"

> "this is an OS, we are restarting computing"

SSH tunnels and proxies assume:

- Another OS exists to run the proxy
- We're operating as userspace on legacy system
- We can delegate complexity elsewhere

This violates the premise. Silo OS IS computing. There is no "host OS" to tunnel through.

Rejected: Application-Layer Encryption Only

Initially considered:

```
// Just encrypt at application layer

const encrypted = encryptAES_GCM(data, key);

http.post("http://server.com", encrypted);
```

Problems:

1. Leaves key exchange unsolved (how do peers agree on key?)
2. No authentication (anyone can claim to be anyone)
3. Vulnerable to replay attacks
4. No forward secrecy
5. Requires manual key management

Conclusion: Application-layer crypto alone is insufficient for a secure networking primitive.

Protocol Design

Core Principles

1. **Frozen Protocol:** Version 1, never changes. No negotiation, no upgrades.
2. **Identity = Public Key:** No certificates, no PKI, no expiration.
3. **Trust On First Use (TOFU):** First contact establishes identity.
4. **One Cipher Suite:** AES-256-GCM. Period. No options.
5. **IP Layer:** Works below TCP/UDP, encrypts all traffic to peer.
6. **Silo-Only:** Only Silo machines speak SiloSec. Legacy gets plaintext or rejection.

Design Rationale

Why IP layer (not transport layer)?

- Encrypts ALL traffic (TCP, UDP, ICMP, custom protocols)
- Single handshake per peer (not per connection)
- In 1-process OS, IP layer IS application layer
- Simpler than per-connection TLS

Why X25519/Ed25519?

- Modern, secure, fast
- Constant-time implementations (timing attack resistant)
- Small key sizes (32 bytes)
- Already in Zig stdlib
- Proven security properties

Why no cipher negotiation?

> "assume all old crypto is dead wood"

If AES-256-GCM is broken, we're all screwed anyway. Cipher agility adds complexity for zero security benefit.

Why no versioning?

Protocol is frozen at v1. If we need changes:

1. Fork the protocol (SiloSec2)
2. Run both in parallel
3. Eventually deprecate v1

This is simpler than in-band version negotiation.

Cryptographic Primitives

All primitives from Zig stdlib (`std.crypto`):

X25519 (Curve25519 Diffie-Hellman)

Purpose: Ephemeral key exchange for forward secrecy

Properties:

- 128-bit security level
- Constant-time operations
- 32-byte keys
- Fast (~50,000 operations/sec on $200 CPU)

Usage:

```
// Alice generates ephemeral keypair

var alice_secret: [32]u8 = random_bytes();

var alice_public = crypto.dh.X25519.scalarmultBase(alice_secret);

// Bob generates ephemeral keypair

var bob_secret: [32]u8 = random_bytes();

var bob_public = crypto.dh.X25519.scalarmultBase(bob_secret);

// Both compute same shared secret

var shared_secret_alice = crypto.dh.X25519.scalarmult(alice_secret, bob_pu
```

```
var shared_secret_bob = crypto.dh.X25519.scalarmult(bob_secret, alice_publ

// shared_secret_alice == shared_secret_bob
```

Ed25519 (Edwards-curve Digital Signature)

Purpose: Peer authentication and identity

Properties:

- 128-bit security level
- Constant-time operations
- 32-byte public keys, 64-byte signatures
- Deterministic (same message always produces same signature)

Usage:

```
// Generate identity keypair

var seed: [32]u8 = random_bytes();

var keypair = crypto.sign.Ed25519.KeyPair.create(seed);

// Sign a message

var signature = keypair.sign("message", null);

// Verify signature

crypto.sign.Ed25519.verify(signature, "message", keypair.public_key); // s
```

AES-256-GCM (Authenticated Encryption)

Purpose: Encrypt data packets

Properties:

- 256-bit key (quantum-resistant overkill)
- Authenticated encryption (detects tampering)
- 12-byte nonce, 16-byte authentication tag
- Fast hardware acceleration on modern CPUs

Usage:

```
var key: [32]u8 = shared_secret;
var nonce: [12]u8 = random_bytes();
var plaintext = "secret data";
var ciphertext: [100]u8 = undefined;
var tag: [16]u8 = undefined;
crypto.aead.aes_gcm.Aes256Gcm.encrypt(
ciphertext[0..plaintext.len],
&tag,
plaintext,
&[_]u8{}, // no additional authenticated data
nonce,
key,
);
// To decrypt:
crypto.aead.aes_gcm.Aes256Gcm.decrypt(
plaintext_out,
ciphertext,
tag,
&[_]u8{},
nonce,
key,
); // throws error if tag doesn't match (tampering detected)
```

Wire Format

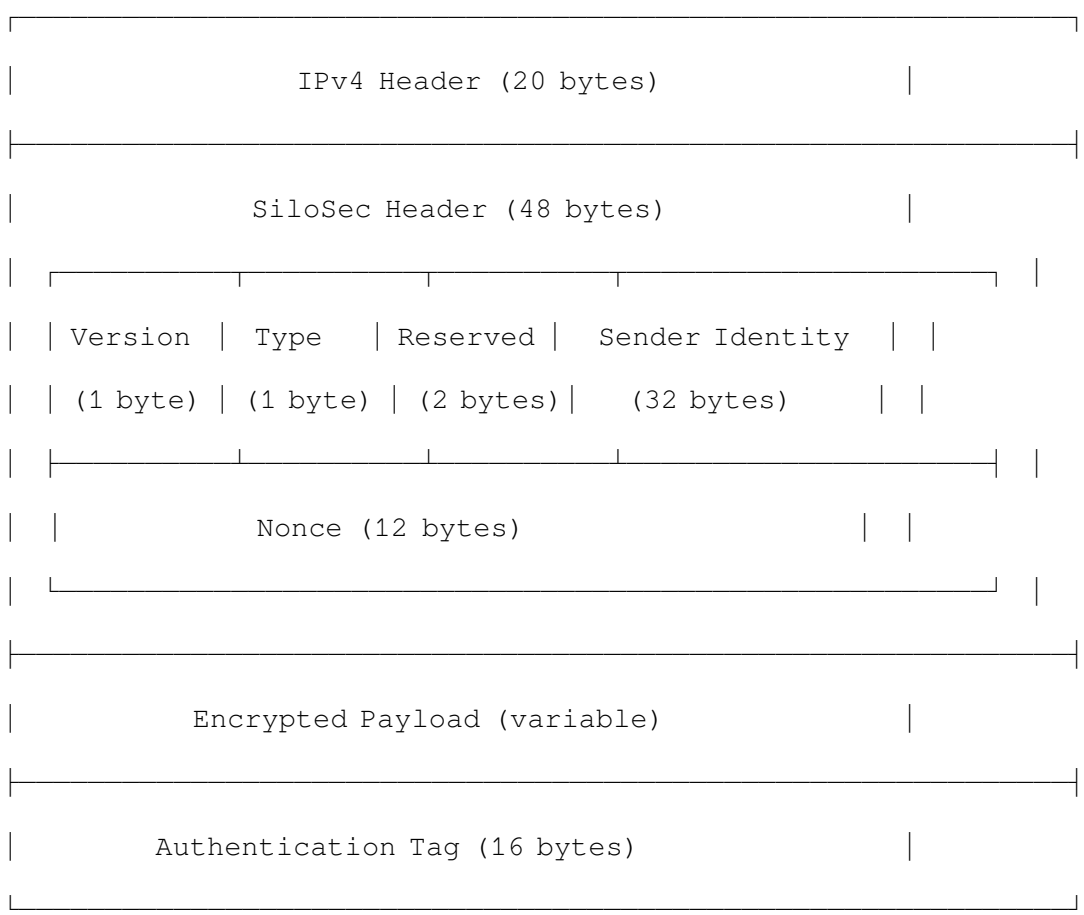
IP Protocol Number

Protocol: 99 (Reserved for private/experimental use)

Rationale:

- IANA reserves 253-254 for testing
- We use 99 (also reserved)
- If we want official number, request from IANA as "SiloSec Protocol"

Packet Structure



SiloSec Header (48 bytes)

Offset 0-3: Header Fields

```
Byte 0: Version (always 0x01)

Byte 1: Packet Type

  0x01 = HANDSHAKE_INIT

  0x02 = HANDSHAKE_RESPONSE

  0x03 = DATA

Bytes 2-3: Reserved (0x0000)
```

Offset 4-35: Sender Identity (32 bytes)

- Ed25519 public key of sender
- Serves as permanent identity
- No expiration, no renewal

Offset 36-47: Nonce (12 bytes)

- For DATA packets: 8 bytes counter + 4 bytes random
- For HANDSHAKE packets: 12 bytes random
- Must NEVER repeat for same key

DATA Packet Format

```
[IP Header][SiloSec Header][Encrypted Inner IP Packet][Auth Tag]
```

Inner IP Packet: Complete IP packet (including IP header) is encrypted.

Example:

```
Original packet: IP(src=A, dst=B, proto=TCP) + TCP segment

Encrypted: IP(src=A, dst=B, proto=99) + SiloSec[encrypted IP packet]
```

Receiver decrypts and re-processes inner IP packet normally.

Handshake Protocol

Goal

Establish shared secret between two Silo machines while:

1. Authenticating both parties
2. Providing forward secrecy
3. Preventing MITM attacks

Protocol Flow

```
Alice (Initiator)                        Bob (Responder)

Generate ephemeral keypair:

  secret_A, public_A = X25519_keygen()

Sign ephemeral public key:

  sig_A = Ed25519_sign(public_A || Bob_IP, identity_A)

Send HANDSHAKE_INIT:

  [identity_A, public_A, sig_A] ————————>

                                     Verify signature:

                            Ed25519_verify(sig_A, identity_A)


                              Generate ephemeral keypair:

                            secret_B, public_B = X25519_keygen()


                                   Compute shared secret:

                            shared = X25519_DH(secret_B, public_A)


                                Sign ephemeral public key:
```

```
                                sig_B = Ed25519_sign(public_B || Alice_IP, identity_

                            <————————— Send HANDSHAKE_RESPONSE:

                                  [identity_B, public_B, sig_B]

Verify signature:

  Ed25519_verify(sig_B, identity_B)

Compute shared secret:

  shared = X25519_DH(secret_A, public_B)

Both sides now have:

  - shared_secret (32 bytes)

  - peer_identity (32 bytes)

  - Authenticated, forward-secret channel established
```

HANDSHAKE_INIT Packet

SiloSec Header:

- Version: 0x01
- Type: 0x01
- Sender Identity: Alice's Ed25519 public key

Payload (96 bytes, unencrypted):

```
Bytes 0-31:   Ephemeral X25519 public key

Bytes 32-95: Ed25519 signature over (ephemeral_public || peer_IP)
```

Signature covers:

```
message_to_sign = ephemeral_public_key (32 bytes) || peer_IP (4 bytes)

signature = Ed25519_sign(message_to_sign, identity_secret_key)
```

Including peer_IP prevents replay attacks across different connections.

HANDSHAKE_RESPONSE Packet

SiloSec Header:

- Version: 0x01
- Type: 0x02
- Sender Identity: Bob's Ed25519 public key

Payload (96 bytes, unencrypted):

```
Bytes 0-31:   Ephemeral X25519 public key

Bytes 32-95: Ed25519 signature over (ephemeral_public || peer_IP)
```

Security Properties

Mutual Authentication:

- Both parties prove possession of identity secret key via signature
- Prevents impersonation

Forward Secrecy:

- Ephemeral keys used for DH exchange
- Compromise of long-term identity keys doesn't reveal past traffic
- Each session has unique shared secret

Replay Protection:

- Signatures include peer IP
- Ephemeral keys are random
- Replaying handshake to different peer fails signature check

Man-in-the-Middle Protection:

- Attacker cannot forge signatures without identity secret keys
- Trust On First Use model: first contact establishes binding

---

Data Transmission

Encryption

Once handshake completes, all IP packets to peer are encrypted:

```
// Original IP packet
var ip_packet = build_ip_packet(proto=TCP, payload=tcp_segment);
// Encrypt entire IP packet
var nonce: [12]u8 = make_nonce(counter, random);
var ciphertext: [1500]u8 = undefined;
var tag: [16]u8 = undefined;
crypto.aead.aes_gcm.Aes256Gcm.encrypt(
ciphertext[0..ip_packet.len],
&tag,
ip_packet,
&[_]u8{}, // no AAD
nonce,
shared_secret,
);
// Build SiloSec DATA packet
var silosec_packet = SiloSecHeader{
.version = 1,
.packet_type = PKT_DATA,
.sender_id = our_identity,
.nonce = nonce,
} ++ ciphertext ++ tag;
// Send as IP protocol 99
send_ip_packet(dst=peer_ip, proto=99, payload=silosec_packet);
```

Nonce Construction

Critical: Nonce must NEVER repeat for same key.

Format (12 bytes):

```
Bytes 0-7:  Counter (64-bit, little-endian)

Bytes 8-11: Random (32-bit)
```

Counter:

- Increments for each packet sent
- Starts at 0 after handshake
- Wraps at 2^64 (renegotiate session before this)

Random:

- Prevents nonce collision if counter wraps
- Adds extra entropy

Why this construction:

- Counter ensures ordering (useful for debugging)
- Random prevents attacks if counter reset
- 12 bytes is AES-GCM nonce size

Decryption

```
// Receive IP packet with protocol 99

if (ip_header.protocol == 99) {

var silosec_hdr = parse_silosec_header(payload);

// Find peer by IP and verify identity

var peer = find_peer(src_ip);

if (peer.identity != silosec_hdr.sender_id) {

    return error.IdentityMismatch;

}

// Decrypt
```

```
var plaintext: [1500]u8 = undefined;
crypto.aead.aes_gcm.Aes256Gcm.decrypt(
    plaintext[0..ciphertext.len],
    ciphertext,
    tag,
    &[_]u8{},
    silosec_hdr.nonce,
    peer.shared_secret,
) catch return error.DecryptionFailed;
// Re-process decrypted IP packet
process_ip_packet(plaintext);
}
```

Replay Protection

Nonce uniqueness provides replay protection:

- Each packet has unique nonce
- Replaying old packet uses old nonce
- GCM authentication fails if nonce reused with different data

Optional: Maintain sliding window of recent nonces to detect replays.

Implementation Guide

File Structure

```
src/
├── silosec.zig         # Main SiloSec implementation
├── ip.zig              # IP layer with SiloSec hooks
```

```
├── net.zig             # Network core
└── kernel.zig          # Initialization
```

Integration Points

1. IP Layer (ip.zig)

```
pub fn processPacket(data: []const u8) void {
const protocol = data[9];
const src_ip = std.mem.readInt(u32, data[12..16], .big);
if (protocol == 99) { // SiloSec
    const payload = data[20..]; // Skip IP header
    silosec.processPacket(src_ip, payload) catch |err| {
        // Log error
    };
    return;
}
// Normal IP processing
// ...
}
// Called by SiloSec after decryption
pub fn processDecryptedPacket(src_ip: u32, inner_ip_packet: []const u8) vo
// Recursively process decrypted IP packet
processPacket(inner_ip_packet);
}
```

2. Sending (application layer)

```
// High-level send function
pub fn sendToSilo(peer_ip: u32, data: []const u8) !void {
// Check if peer is a Silo (has handshake)
if (silosec.hasPeer(peer_ip)) {
    // Build inner IP packet
    var ip_packet = buildIPPacket(peer_ip, data);

    // SiloSec encrypts and sends
    try silosec.sendEncrypted(peer_ip, ip_packet);
} else {
    // Not a Silo peer, send plaintext
    try sendPlainIP(peer_ip, data);
}
}
```

3. Initialization (kernel.zig)

```
pub fn initNetwork() !void {
// Initialize network stack
try net.init(config, pci_devices, allocator);
// Initialize SiloSec
silosec.init();
// Load or generate identity
silosec.initFromSeed("my-silo-seed") catch {
    silosec.init(); // Generate new random identity
```

```
};

const identity = silosec.getIdentity();

std.debug.print("Silo Identity: {x}\n", .{identity});

// Save identity for next boot

try silosec.saveIdentity("/SILO.KEY");

}
```

Peer Discovery

Static Configuration:

```
// Add known Silo peers

silosec.addTrustedPeer(peer_identity, peer_ip);

// Initiate handshake

try silosec.initiateHandshake(peer_ip);
```

Dynamic Discovery (future):

- Broadcast SiloSec announcement on LAN
- Other Silos respond with identities
- User confirms trust (TOFU)

Error Handling

```
pub const SiloSecError = error{

UnknownPeer,          // No handshake with this IP

IdentityMismatch,     // Sender identity doesn't match known peer

DecryptionFailed,     // GCM auth tag verification failed

SignatureInvalid,     // Ed25519 signature invalid

HandshakeFailed,      // Handshake protocol error
```

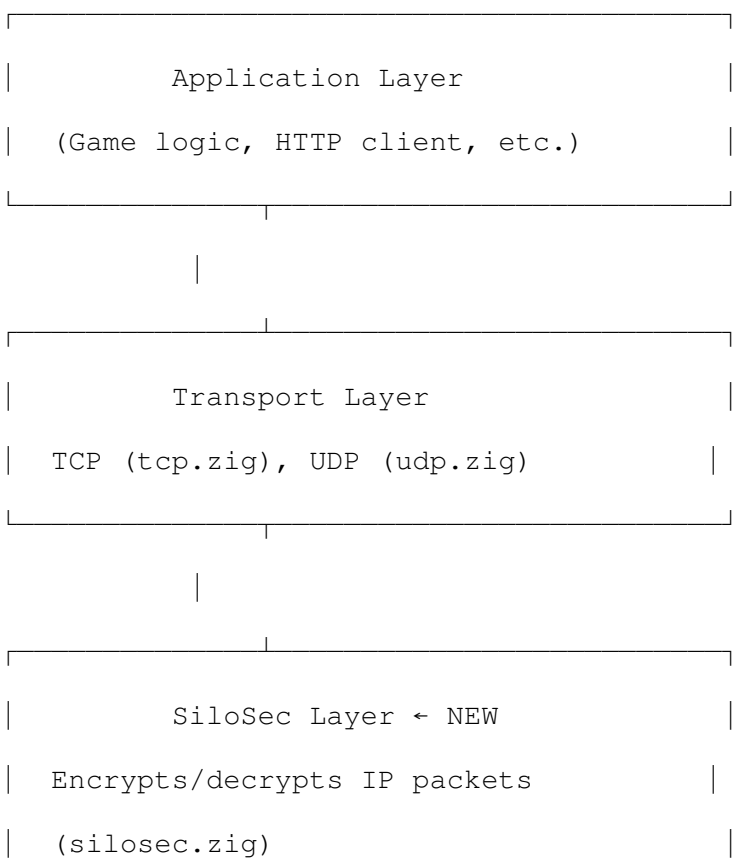
```
    PayloadTooLarge,     // Payload > MTU
};
```

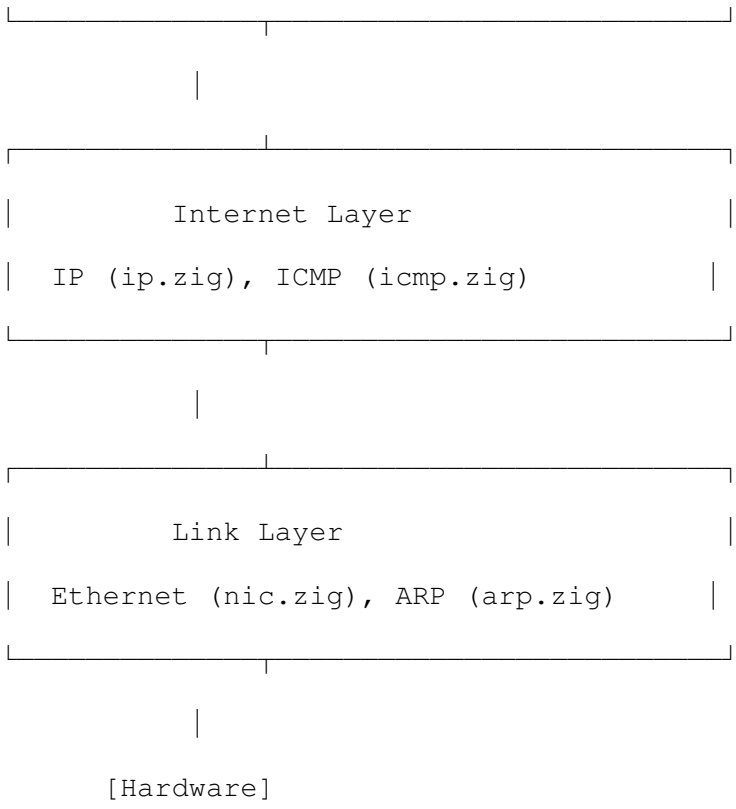
Handling:

- **UnknownPeer:** Initiate handshake if trusted, reject if not
- **IdentityMismatch:** SECURITY ALERT - possible MITM
- **DecryptionFailed:** Drop packet silently (likely tampered)
- **SignatureInvalid:** Reject handshake, possible attack

Integration with Silo OS

Network Stack Layers





Transparent Encryption

Key principle: SiloSec is transparent to upper layers.

Before SiloSec:

```
App → TCP → IP → Ethernet → Wire
```

With SiloSec:

```
App → TCP → IP → SiloSec(encrypt) → IP(outer) → Ethernet → Wire
```

Upper layers (TCP, UDP) don't know encryption exists.

Performance Considerations

Overhead:

- SiloSec header: 48 bytes
- Auth tag: 16 bytes

- Outer IP header: 20 bytes
- **Total:** 84 bytes per packet

MTU Handling:

```
Ethernet MTU: 1500 bytes
- Outer IP: 20 bytes
- SiloSec header: 48 bytes
- Auth tag: 16 bytes
= 1416 bytes available for inner IP packet

Inner IP packet MTU: 1416 bytes
- Inner IP header: 20 bytes
= 1396 bytes for TCP/UDP payload
```

Fragmentation:

- Avoid by setting inner MTU to 1396
- Or implement SiloSec fragmentation (future)

Throughput:

- AES-GCM hardware acceleration: ~10 Gbps
- Software AES-GCM: ~1 Gbps
- Gigabit Ethernet: 1 Gbps
- **Not a bottleneck on $200 CPU**

Security Considerations

Threat Model

In Scope:

- Eavesdropping on network (passive attacker)
- Tampering with packets (active attacker)
- Replay attacks
- Impersonation attacks

Out of Scope:

- Physical access to machine (game over anyway)
- Side-channel attacks (timing, power analysis)
- Quantum computers (may break X25519/Ed25519 in 20+ years)

Trust On First Use (TOFU)

First contact establishes identity binding:

```
Alice connects to IP 10.0.0.5

Receives identity: 0xABCD...1234

Stores: peers[10.0.0.5] = 0xABCD...1234

Future connections from 10.0.0.5 MUST use identity 0xABCD...1234

Different identity = SECURITY ALERT
```

MITM Attack Scenario:

```
1. Eve intercepts Alice's first connection to Bob

2. Eve performs handshake with Alice (using Eve's identity)

3. Alice stores: peers[Bob_IP] = Eve_identity

4. Eve can now MITM all traffic

MITM succeeds because Alice has never talked to Bob before.
```

Mitigation: Out-of-band identity verification

```
Alice (in person or over phone): "My identity is 0xABCD...1234"

Bob: Manually adds to trusted peers before connection

Eve's MITM fails because identity doesn't match
```

This is acceptable for Silo use case:

- Gaming between friends (can verify identities)
- Small trusted networks
- Not replacing TLS for anonymous web browsing

Forward Secrecy

Session compromise does NOT reveal past sessions:

```
Attacker steals: shared_secret_session_1

Attacker gets: Session 1 traffic (decrypted)

Attacker CANNOT get: Session 2, 3, 4... traffic

Each handshake generates new ephemeral keys.
```

Long-term key compromise:

```
Attacker steals: identity_secret_key

Attacker CAN: Impersonate owner in future connections

Attacker CANNOT: Decrypt past traffic (forward secrecy preserved)
```

Mitigation: Secure key storage

- Store identity key encrypted on disk
- Use hardware key storage if available
- Rotate identity keys periodically (future)

Replay Attacks

Packet replay prevented by:

1. Nonce uniqueness (counter + random)
2. GCM authentication (tag verification)

Handshake replay:

- Handshake packets include peer IP in signature
- Replaying to different peer fails signature verification
- Replaying to same peer just re-establishes session (harmless)

Denial of Service

Handshake flooding:

```
Attacker sends many HANDSHAKE_INIT packets
```

```
Victim must verify signatures (expensive)
```

Mitigation:

- Rate limit handshakes per source IP
- Require proof-of-work for handshake (future)
- Simple: Drop handshakes if CPU > 80%

Ciphertext flooding:

```
Attacker sends random DATA packets

Victim must attempt decryption (expensive)
```

Mitigation:

- Only decrypt from known peers
- Drop unknown peers immediately
- GCM fails fast on invalid tag

Future Claude Integration Notes

Critical Implementation Details

1. Nonce Management is CRITICAL

```
// WRONG - DO NOT DO THIS

var nonce: [12]u8 = undefined;

crypto.random.bytes(&nonce); // Pure random every time

// Might repeat! GCM security fails if nonce repeats with same key!

// CORRECT

var counter: u64 = 0;

for (each packet) {

var nonce: [12]u8 = undefined;

std.mem.writeInt(u64, nonce[0..8], counter, .little);
```

```
crypto.random.bytes(nonce[8..12]);
counter += 1;
// Nonce guaranteed unique
}
```

Why this matters:

- GCM security proof requires nonce uniqueness
- Reused nonce leaks plaintext XOR (catastrophic)
- Counter ensures no collisions

2. Peer State Management

```
// Store peer by IP
const Peer = struct {
ip: u32,
identity: Identity,
shared_secret: [32]u8,
tx_counter: u64,  // MUST persist per peer
rx_counter: u64,  // For replay detection
verified: bool,
};
// Index by IP
var peers: [256]?Peer = [_]?Peer{null} ** 256;
fn findPeer(ip: u32) ?*Peer {
const idx = ip % peers.len;
if (peers[idx]) |*peer| {
    if (peer.ip == ip) return peer;
```

```
}
// Hash collision - linear probe
// (Simplified for example)
return null;
}
```

3. Identity Persistence

```
// Save identity to disk
pub fn saveIdentity(path: []const u8) !void {
const file = try fs.createFile(fs.root_cluster, path, allocator);
const cluster = getCluster(file);
try fs.writeFile(cluster, &our_secret_key, allocator);
}
// Load on boot
pub fn loadIdentity(path: []const u8) !void {
const file = try fs.findFile(fs.root_cluster, path, allocator);
if (file) |f| {
    const cluster = getCluster(f);
    var key: [32]u8 = undefined;
    _ = try fs.readFile(cluster, &key, allocator);

    our_secret_key = key;
    const kp = crypto.sign.Ed25519.KeyPair.fromSecretKey(key) catch return
    our_public_key = kp.public_key;
```

```
} else {
    return error.NoIdentity;
}
}
```

4. Handshake State Machine

```
// Track pending handshakes
const PendingHandshake = struct {
peer_ip: u32,
our_ephemeral_secret: [32]u8,
timestamp: u64,
};
var pending: [16]?PendingHandshake = [_]?PendingHandshake{null} ** 16;
// When we initiate:
fn initiateHandshake(peer_ip: u32) !void {
var ephemeral_secret: [32]u8 = undefined;
crypto.random.bytes(&ephemeral_secret);
// Send HANDSHAKE_INIT with public key
// ...
// MUST store ephemeral secret to complete handshake
storePending(peer_ip, ephemeral_secret);
}
// When we receive response:
fn handleHandshakeResponse(peer_ip: u32, peer_ephemeral: [32]u8) !void {
```

```
const our_ephemeral = retrievePending(peer_ip) orelse return error.NoHandsh
// Compute shared secret
const shared = crypto.dh.X25519.scalarmult(our_ephemeral, peer_ephemeral);
// Store peer
addPeer(peer_ip, peer_identity, shared);
}
```

5. Error Handling Philosophy

```
// SiloSec errors should be SILENT for security
pub fn processPacket(src_ip: u32, data: []const u8) !void {
const peer = findPeer(src_ip) orelse {
    // Unknown peer - silently drop
    // DO NOT log (prevents DoS via log flooding)
    return;
};
decrypt(data) catch {
    // Decryption failed - silently drop
    // DO NOT send error packet (prevents oracle attacks)
    return;
};
// Success - process normally
}
```

Testing Checklist

When implementing SiloSec, verify:

- ☐ Handshake works between two Silos
- ☐ Data packets encrypt/decrypt correctly
- ☐ Nonces never repeat (run for 1M packets)
- ☐ Identity persists across reboots
- ☐ Multiple peers work simultaneously
- ☐ Handshake replay rejected
- ☐ Data replay rejected (if window implemented)
- ☐ Wrong identity rejected
- ☐ Tampering detected (flip random bit)
- ☐ Unknown peer silently dropped
- ☐ TCP works through SiloSec
- ☐ UDP works through SiloSec
- ☐ HTTP works through SiloSec
- ☐ MTU handled correctly (no fragmentation issues)
- ☐ Performance acceptable (>100 Mbps)

Common Pitfalls

Pitfall 1: Encrypting UDP payload only

```
// WRONG
var udp_payload = [...]u8{...};
var encrypted = encrypt(udp_payload);
send_udp(encrypted);
// Leaks: IP addresses, ports, packet sizes, timing

// CORRECT
var ip_packet = build_complete_ip_packet(udp);
var encrypted = encrypt(ip_packet);
send_silosec_packet(encrypted);
```

```
// Encrypts everything except outer IP header
```

Pitfall 2: Not verifying peer identity

```
// WRONG
fn processPacket(src_ip: u32, header: SiloSecHeader) {
var peer = findPeer(src_ip);
// Missing: verify header.sender_id == peer.identity
decrypt(...);
}
// Attacker can send packets with different identity!

// CORRECT
fn processPacket(src_ip: u32, header: SiloSecHeader) {
var peer = findPeer(src_ip);
if (peer.identity != header.sender_id) {
    return error.IdentityMismatch; // SECURITY ALERT
}
decrypt(...);
}
```

Pitfall 3: Reusing handshake ephemeral keys

```
// WRONG - DO NOT REUSE
var ephemeral_secret: [32]u8 = fixed_value;
// Multiple handshakes with same ephemeral = broken forward secrecy

// CORRECT
```

```
fn initiateHandshake() {
var ephemeral_secret: [32]u8 = undefined;
crypto.random.bytes(&ephemeral_secret); // NEW key every handshake
// ...
}
```

Integration with Existing Code

If you have working IP layer:

```
// Before (ip.zig):
pub fn processPacket(data: []const u8) void {
switch (protocol) {
    1 => icmp.process(payload),
    6 => tcp.process(payload),
    17 => udp.process(payload),
    // ...
}
}
// After (ip.zig):
const silosec = @import("silosec.zig");
pub fn processPacket(data: []const u8) void {
const protocol = data[9];
const src_ip = readInt(u32, data[12..16]);
// Check for SiloSec FIRST
if (protocol == 99) {
```

```
    silosec.processPacket(src_ip, data[20..]) catch return;
    return; // SiloSec handles it
}
// Normal processing
switch (protocol) {
    1 => icmp.process(payload),
    6 => tcp.process(payload),
    17 => udp.process(payload),
    // ...
}
}
// Add callback for decrypted packets
pub fn processDecryptedPacket(src_ip: u32, inner_packet: []const u8) void
// Recursively process inner IP packet
processPacket(inner_packet);
}
```

If you have working send path:

```
// Before:
pub fn sendIP(dst_ip: u32, protocol: u8, payload: []const u8) !void {
var packet = buildIPPacket(dst_ip, protocol, payload);
sendEthernet(packet);
}
// After:
```

```
pub fn sendIP(dst_ip: u32, protocol: u8, payload: []const u8) !void {
// Check if destination is Silo peer
if (silosec.hasPeer(dst_ip)) {
    // Build inner IP packet
    var inner = buildIPPacket(dst_ip, protocol, payload);

    // SiloSec encrypts and sends
    try silosec.sendEncrypted(dst_ip, inner);
} else {
    // Not a Silo, send plaintext
    var packet = buildIPPacket(dst_ip, protocol, payload);
    sendEthernet(packet);
}
}
```

Appendix A: Complete Code Reference

See `silosec.zig` in Silo OS source tree for reference implementation.

Key functions:

```
// Initialization
pub fn init() void
pub fn initFromSeed(seed: []const u8) void
pub fn getIdentity() Identity
// Handshake
```

```
pub fn initiateHandshake(peer_ip: u32) !void

pub fn processPacket(src_ip: u32, data: []const u8) !void

// Data transmission

pub fn sendEncrypted(dst_ip: u32, payload: []const u8) !void

// Peer management

pub fn hasPeer(ip: u32) bool

pub fn addTrustedPeer(identity: Identity, ip: u32) void

// Persistence

pub fn saveIdentity(path: []const u8) !void

pub fn loadIdentity(path: []const u8) !void
```

Appendix B: Test Vectors

Identity Generation

```
Seed: "silo-test-seed-1"

SHA-256(seed): 0x3a7b...c8f2

Ed25519 Secret Key: 0x3a7b...c8f2

Ed25519 Public Key: 0x8c2f...1a4e
```

Handshake Example

Alice:

- Identity: 0xAAAA…AAAA
- Ephemeral Secret: 0x1111…1111
- Ephemeral Public: 0x2222…2222

Bob:

- Identity: 0xBBBB…BBBB

- Ephemeral Secret: 0x3333…3333
- Ephemeral Public: 0x4444…4444

Shared Secret:

```
X25519(0x1111...1111, 0x4444...4444) = 0x5555...5555

X25519(0x3333...3333, 0x2222...2222) = 0x5555...5555

(Both compute same shared secret)
```

Encryption Example

```
Shared Secret: 0x5555...5555 (32 bytes)

Nonce: 0x000000000000000012345678 (12 bytes)

Plaintext: "Hello, Silo!" (12 bytes)

AES-256-GCM Encrypt:

  Ciphertext: 0xABCD...EF01 (12 bytes)

  Auth Tag:   0x9876...5432 (16 bytes)

Packet:

  [SiloSec Header][0xABCD...EF01][0x9876...5432]
```

Appendix C: Comparison to Alternatives

SiloSec vs TLS 1.3

Feature	SiloSec	TLS 1.3
Code size	~500 lines	~15,000 lines
External deps	0	0 (in theory)
Cipher suites	1 (fixed)	~10 (negotiated)
Certificates	None	X.509 required
Handshake RTT	1 (full)	1-RTT
Identity	Ed25519 key	X.509 cert
Forward secrecy	Yes (X25519)	Yes (ECDHE)
Layer	IP	Transport (TCP)

Feature	SiloSec	TLS 1.3
Protocols	All IP traffic	TCP only
Versioning	Frozen (v1)	Negotiated
Complexity	Minimal	High

When to use SiloSec: Silo-to-Silo communication

When to use TLS: Never (in Silo OS context)

SiloSec vs IPSec

Feature	SiloSec	IPSec (ESP)
Code size	~500 lines	~8,000 lines
Key exchange	X25519	IKEv2 (complex)
Authentication	Ed25519	RSA/ECDSA certs
Encryption	AES-256-GCM	Multiple ciphers
SA management	Simple	Complex
NAT traversal	Not needed	Complex
Layer	IP	IP
Granularity	Per-peer	Per-SA
Debugging	Possible	Nightmare

Why SiloSec is better:

- 16x less code
- No certificate infrastructure
- Single cipher (no negotiation)
- Designed for 1-process OS
- Actually auditable

SiloSec vs WireGuard

Feature	SiloSec	WireGuard
Code size	~500 lines	~4,000 lines
Key exchange	X25519	Noise_IK
Encryption	AES-256-GCM	ChaCha20-Poly1305
Authentication	Ed25519	Curve25519
Layer	IP	IP
Use case	Peer-to-peer	VPN
Config	Identity only	Peer list

SiloSec is simpler:

- No pre-shared keys needed
- No configuration files
- Identity = public key (that's it)

WireGuard is better for:

- VPN use cases
- NAT traversal
- Mobile roaming

Appendix D: Future Enhancements

Potential Future Features (NOT v1)

1. Identity Rotation

```
// Generate new identity, notify peers
pub fn rotateIdentity() !void {
var new_secret: [32]u8 = random_bytes();
// ... notify all peers of identity change
// ... keep old identity for grace period
}
```

2. Peer Discovery Protocol

```
// Broadcast: "I am a Silo, here's my identity"
pub fn announcePresence() !void {
// Multicast announcement on LAN
}
```

3. Replay Protection Window

```
// Track recent nonces to detect replays
```

```
const WINDOW_SIZE = 1024;

var seen_nonces: [WINDOW_SIZE]u64 = undefined;
```

4. Performance Monitoring

```
pub const SiloSecStats = struct {

handshakes_completed: u64,

packets_encrypted: u64,

packets_decrypted: u64,

bytes_encrypted: u64,

decrypt_failures: u64,

};
```

5. Multi-Path Support

```
// Same peer reachable via multiple IPs

pub fn addPeerPath(identity: Identity, additional_ip: u32) void {

// Use same shared_secret for multiple paths

}
```

DO NOT implement these in v1. Keep it simple.

Conclusion

Design Summary

SiloSec is:

- **Minimal:** ~500 lines, zero dependencies
- **Secure:** Modern crypto, forward secrecy, authentication
- **Simple:** One protocol version, one cipher, frozen forever
- **Silo-native:** Designed for 1-process OS architecture
- **Auditable:** Pure Zig, uses only stdlib

SiloSec is NOT:

- A replacement for TLS (different use case)
- Suitable for anonymous communication (TOFU model)
- Quantum-resistant (X25519/Ed25519 vulnerable)
- A VPN protocol (peer-to-peer only)

Why This Design is Correct

From the K split philosophy:

> "$200 CPU, pure software, no drivers, runs anywhere, accessible to all"

SiloSec embodies this:

- No expensive hardware (runs on $200 CPU)
- Pure software (no hardware crypto needed)
- No proprietary drivers (Zig stdlib only)
- Runs anywhere (frozen protocol, no updates needed)
- Accessible to all (can read and audit 500 lines)

Final Words for Future Claudes

When you implement SiloSec:

1. **Read this document completely** before writing any code
2. **Use ONLY Zig stdlib** - no external crypto libraries
3. **Keep nonce management simple** - counter + random
4. **Test handshake thoroughly** - this is critical path
5. **Handle errors silently** - don't leak information
6. **Trust the design** - it was carefully considered

Most importantly:

> "we are restarting computing"

SiloSec is not about retrofitting old protocols onto a new OS. It's about designing the RIGHT protocol for a clean-slate system.

Legacy machines speak HTTP. Silo machines speak SiloSec.

This is correct. This is K split. This is the way.

End of Specification

Document Metadata

Version: 1.0

Status: NORMATIVE

Last Updated: 2026-01-30

Maintainer: Silo OS Project

License: Public Domain (CC0)

Git Hash: [To be filled when committed]

Frozen Protocol Version: 1 (never changes)

Questions? Read this document again. Everything is here.

Implementation bugs? Fix the implementation, not the spec.

Want to change the protocol? Create SiloSec v2 as separate protocol.

This document is complete.

Got it. Here is a **formal, invariant-driven wire-security section** you can drop directly into your SiloSec v2 docs.

No identity. No hype. Just guarantees and failure rules.

SiloSec v2 — Wire-Security Invariants (Non-Identity)

Scope:

This section defines the **mandatory wire-security properties** of SiloSec v2.

Identity, trust, authorization, and policy are **explicitly out of scope**.

Wire-security concerns only the correctness, safety, and bounded behavior of encrypted packet exchange between two Silo endpoints.

---

1. Fail-Closed Invariant

Invariant:

Any packet that does not strictly conform to expected wire state is discarded silently.

This includes:

- malformed packets
- unexpected field values
- cryptographic verification failures
- counter mismatches
- window violations
- epoch mismatches
- handshake inconsistencies

Guarantee:

No invalid packet causes:

- state mutation
- downgrade
- error signaling
- information leakage

If a peer is legitimate, it will retransmit.

If not, the packet is ignored.

---

2. Mandatory Encryption Invariant

Invariant:

All Silo-to-Silo traffic is encrypted from the first packet onward.

There is:

- no plaintext fallback
- no negotiation
- no compatibility mode

Guarantee:

Plaintext Silo-to-Silo packets are never accepted under any circumstances.

---

3. Monotonic Counter Invariant

Invariant:

All wire-visible counters are strictly monotonic and never reused.

This applies to:

- packet counters
- epoch identifiers
- handshake generations

Rules:

- counters only increase
- reuse is forbidden
- rollback is forbidden
- wraparound is forbidden

Guarantee:

Replay, reflection, and state regression are detectable and rejected.

---

4. Windowed Acceptance Invariant

Invariant:

Packets are accepted only if their counters fall within a strict forward-only receive window.

Rules:

- packets below the expected counter are rejected
- packets above the window are rejected
- the window advances only on valid packets

Guarantee:

Replay attempts outside the window are rejected with bounded memory and constant-time checks.

---

5. Epoch Isolation Invariant

Invariant:

Each packet belongs to exactly one cryptographic epoch.

Rules:

- epoch change = key change
- packets from old epochs are invalid immediately

- no grace periods across epochs

Guarantee:

Key reuse, cross-epoch replay, and mixed-state decryption are impossible.

---

6. Rekey Bounding Invariant

Invariant:

Cryptographic epochs are short-lived and bounded.

Rules:

- rekey after N packets or T time (whichever is smaller)
- either side may request rekey
- excessive rekey requests are treated as hostile

Guarantee:

Exposure from compromised keys or partial observation is bounded in time and packet count.

---

7. State Continuity Invariant (Echoed Counter)

Invariant:

Each packet proves continuity of shared session state.

Mechanism:

- endpoints maintain an internal session counter
- the counter is cryptographically protected
- the peer echoes expected counter state in encrypted payload

Rules:

- mismatched counters → drop
- divergence → rekey or disconnect
- no implicit resynchronization

Guarantee:

Desynchronization, reflection, and mid-path interference are detected immediately.

---

8. Stateless Handshake (SYN-Cookie Invariant)

Invariant:

No unverified packet may cause unbounded state allocation.

Rules:

- initial handshakes are statelessly verifiable
- state is allocated only after proof of bidirectional reachability
- handshake responses are cryptographically self-verifying

Guarantee:

Handshake-based denial-of-service is bounded and predictable.

---

9. Flow Binding Invariant (5-Tuple)

Invariant:

All wire security state is bound to a single network flow.

Flow definition:

```
(src IP, dst IP, src port, dst port, protocol)
```

Rules:

- packets cannot migrate across flows
- flow change = new session
- state is never shared between flows

Guarantee:

Cross-flow injection and session confusion are impossible.

---

10. Downgrade Resistance Invariant

Invariant:

No valid execution path results in weaker security.

Rules:

- no negotiation
- no feature fallback
- no partial enablement

Guarantee:

Attackers cannot force plaintext, legacy modes, or reduced protections.

---

11. Resource Bounding Invariant

Invariant:

Resource usage per unauthenticated peer is strictly bounded.

Rules:

- bounded memory per flow
- bounded CPU per packet
- constant-time rejection paths

Guarantee:

Wire security does not become a denial-of-service vector.

---

12. Failure Behavior Invariant

Invariant:

Failure is silent and local.

Rules:

- no error packets
- no logging on hot paths
- no recovery signaling

Guarantee:

Failure does not leak information or amplify attacks.

---

13. Explicit Non-Guarantees

SiloSec wire security does **not** guarantee:

- peer identity
- peer trustworthiness
- authorization correctness
- traffic analysis resistance

- protection against compromised endpoints

These concerns belong above the wire.

Summary

SiloSec wire security guarantees:

> **Accepted packets are fresh, correctly ordered within bounds, cryptographically valid for the current epoch, bound to a single flow, and part of a continuous, verifiable session state. All other packets are dropped without side effects.**

This is a **bounded, analyzable security posture**, not a claim of absolute safety.

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