Nyx Protocol v0.1 — Technical Specification (English Version)

> **"A next-generation anonymous transport protocol that unifies maximum privacy, secrecy, and performance."**

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1. Introduction

The Nyx Protocol integrates academic knowledge of high-anonymity networks with high-speed transport technologies (QUIC-compatible streams, multiplexing, 0-RTT key exchange, etc.) to provide an open protocol that enables secure and low-latency communication across environments from mobile to data centers.

This specification document describes the details at a fully implementable level for the v0.1 reference implementation (written in Rust, unsafe-free).

2. Terminology

Term	Description
Node	An endpoint that speaks the Nyx protocol, including sending, receiving, and relaying.
Client / Server	Logical roles at the application layer. Nyx treats them as peers (P2P).
Stream	A logical data channel within Nyx Secure Stream, equivalent to QUIC Stream.
Session	State between two nodes sharing key material after handshake completion.
Hop	One relay node in the Mix Routing Layer.
CID	Connection ID. A 96-bit random value identifying a stream bundle.
Frame	The smallest unit of structured data carried by Nyx Secure Stream.

3. Goals & Threat Model

3.1 Security Goals

- **Anonymity**: Hide sender, receiver, and path from observers.
- **Confidentiality**: Cryptographically conceal payload, packet length, and timing.
- **Integrity**: Detect transparent modifications.
- **Forward Secrecy**: Derive new keys for each stream, localizing impact of old key compromise.
- **Post-Quantum Ready**: Protocol allows switching to Post-Quantum KEM.

3.2 Threat Model

Adversary	Capability
Global Passive	Monitor all traffic, cannot modify.
Local Active	Partially modify/inject packets (e.g., Tor dropping attack equivalent).
Node Takeover	Control arbitrary relay nodes without key material.
Endpoint Compromise	Complete compromise of one endpoint. Prevent manual propagation to other nodes.

4. Architecture Overview

```
flowchart TD
    A[Application Layer]
    B[Nyx Secure Stream \n (QUIC-like, 0-RTT)]
    C[Mix Routing Layer \n (3-5 hops, cover traffic)]
    D[Obfuscation + FEC Layer \n (fixed 1280B, RS-FEC)]
    E[Raw UDP / Custom UDP \n (NAT traversal)]
    A --> B --> C --> D --> E
```

Each layer has an independent state machine and is pipeline-processed using Rust's `async/await`.

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5. Layer-by-Layer Specification

5.1 Nyx Secure Stream Layer

- **Frame Types**

ID	Name	Purpose
0x00	PADDING	Bandwidth adjustment, pre-encryption insertion.
0x01	STREAM	Application data.
0x02	ACK	Acknowledgment, delayed ACK aggregation possible.
0x10	CRYPTO	Handshake/key update.

- **Connection ID**: 96-bit random, independent encryption state per CID.
- **0-RTT Key Exchange**: Modified Noise_IK (see §7). Early transmission with replay defense by response.
- **Flow Control**: BBRv2-derived delay-based control, avoiding DoS.

5.2 Mix Routing Layer

- **Route Length**: Minimum 3, standard 5 hops. Paths probabilistically selected from Kademlia DHT.
- **Batching**: Fixed delay $\Delta \leq 50$ ms intervals with equal-sized packet mixing.
- **Cover Traffic**: Poisson(λ) dummy generation for pseudo-constant transmission volume.

5.3 Obfuscation + FEC Layer

- **Fixed-Length Packets**: Default 1280 B (IPv6 minimum MTU).
- **FEC**: Reed-Solomon (255,223) over GF(2^8). Target 30% redundancy rate.
- **Timing Concealment**: Async send/receive queues + $\pm\sigma$ random delay for smoothing.

5.4 Transport Interface Layer

- **Basic Transport**: Single UDP socket. Ports 43300–43399 recommended.
- **NAT Traversal**: UDP Hole Punching + ICE Lite implementation. Specific procedure:
    1. Registration to Rendezvous server (report public, private EP).
    2. Endpoint exchange to both parties → parallel STUN Ping.
    3. Adopt first responding path, close other paths. Detailed algorithm references [Bryan Ford et al.].
- **Keep-Alive**: 12-byte PADDING frame transmission every 15 s. Assumes NAT idle ≥30 s.
- **Hairpin**: Direct local connection preferred on compatible NAPT.

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6. Addressing & Node Identity

- **Node ID**: 256-bit. Uses first 256 bits of `BLAKE3(public_key)`.
- **Addressing**: DHT resolves NodeID → (IP, Port, CID List).

- **Version Negotiation**: `proto_version` (uint16) in first CRYPTO frame.

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7. Handshake & Cryptography

Item	Default Algorithm	Alternative (PQ)
DH	X25519	Kyber1024
AEAD	ChaCha20-Poly1305	Ascon128a
Hash/KDF	SHA-256 + HKDF	BLAKE3

7.1 Noise_Nyx Pattern (Modified)

```
<- s
-> e, es, s, ss  (0-RTT possible)
<- e, ee, se, es
```

- **0-RTT Data**: Encrypted in STREAM Frame with `anti_replay_nonce` for replay prevention.

7.2 Key Rotation

- **Trigger**: 1 GiB transmission OR 10 min elapsed.
- **Method**: HKDF-Expand(label="Nyx-rekey", ck) → new AEAD key.

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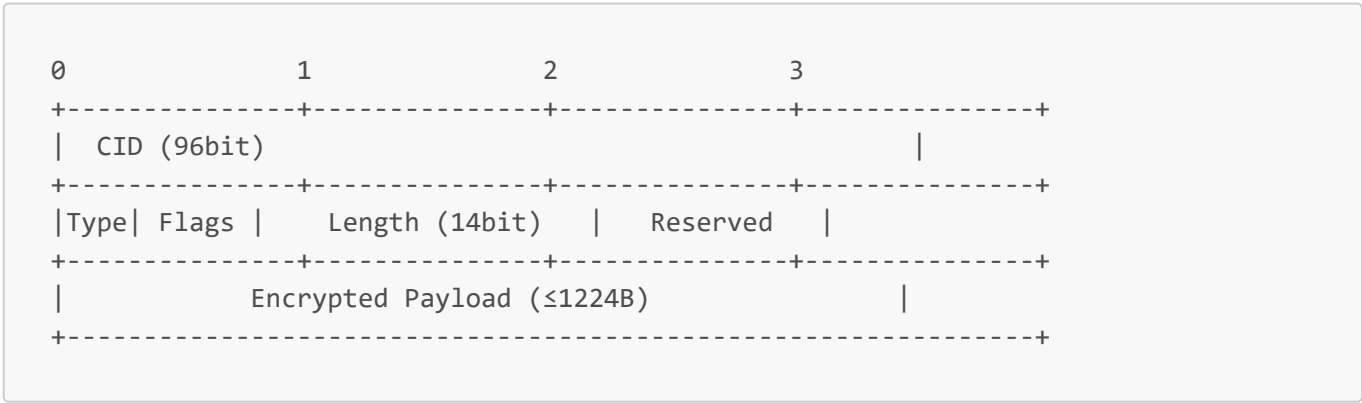
8. Packet Format



- `Type` (2bit): 0=Data,1=Control,2=Crypto,3=Reserved
- `Flags`: END_STREAM etc.
- `Length`: Payload size; padded to 1280B by Obfuscation layer.

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9. Error Handling

Code	Description	Sender Action
0x00	NO_ERROR	Graceful close

Code	Description	Sender Action
0x01	PROTOCOL_VIOLATION	Immediate session disconnect, reconnection allowed
0x02	FLOW_CONTROL_ERROR	Stop transfer, 30s back-off
0x10	CRYPTO_FAIL	Blacklist node (1h)

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10. Formal Verification

- **State Machine**: TLA+ description of Nyx Secure Stream handshake.
- **Safety Properties**: Confidentiality, key uniqueness, no recursive connections.
- **Model Checking**: TLC exhaustive check for 3-node topology, up to 5 hops.

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11. Implementation Guidelines (Rust)

1. `#![forbid(unsafe_code)]` mandatory.
2. Base on `tokio` runtime + `quinn` reference implementation.
3. Send queue uses MPSC channel for back-pressure.
4. Fuzz: `cargo-fuzz`, Coverage >90%.
5. Integrate Miri undefined behavior verification into CI pipeline.

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12. Internationalization

- **Character Encoding**: UTF-8 only permitted.
- **Message Localization**: STREAM Frame Type=0x20 `LOCALIZED_STRING` can include `lang_tag` (BCP-47).
- **Error Encoding**: Combined code + I18N string TLV.

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13. Extensibility & Compatibility

- **Configuration Negotiation**: Feature advertisement via CRYPTO extension TLV.
- **Future Versions**: Return `VERSION_MISMATCH` (0x03) and close on unsupported `proto_version`.
- **Extension Frames**: Reserve `Type=3` area, identify with `Experiment ID` (16bit).

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14. Performance Targets

Metric	Target
Handshake Roundtrips	≤ 1 RTT
Throughput (1 hop)	≥ 90% of UDP raw
Additional Latency (5 hops)	< 50 ms
Bandwidth Overhead	≤ 40%

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15. License

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16. Management Frames

Type (hex)	Name	Fields	Description
0x30	SETTINGS	list	Bulk configuration advertisement at protocol startup.
0x31	PING	nonce (64bit)	RTT measurement/keep-alive. Reply with PONG.
0x32	PONG	nonce (64bit)	PING response.
0x33	PATH_CHALLENGE	token (128bit)	New path availability confirmation.
0x34	PATH_RESPONSE	token (128bit)	CHALLENGE response.
0x3F	CLOSE	code (16bit), reason_len (8), reason	Connection termination notification.

`Setting` is (id:uint16, value:uint32) TLV. Default IDs: 0x0001=MAX_STREAMS, 0x0002=MAX_DATA, 0x0003=IDLE_TIMEOUT.

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17. Handshake Sequence Diagram

```
sequenceDiagram
    participant A as Initiator
    participant R1 as Relay (Hop1)
    participant R2 as Relay (Hop2)
    participant B as Responder
    A->>R1: Initial( e,0-RTT )
    R1-->>R2: MixForward( wrapped )
    R2-->>B: MixForward( wrapped )
    B-->>R2: Response( e,s )
    R2-->>R1: Response( wrapped )
    R1-->>A: Response( wrapped )
    Note over A,B: 0-RTT data replay prevention occurs here
```

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18. Test Vectors

18.1 Noise_Nyx Handshake (X25519 + ChaCha20-Poly1305)

Field	Hex Value
prologue	4e 79 78 30 2e 31

Field	Hex Value
s (B)	11..22 (32B)
e (A)	aa..bb (32B)

...

Complete capture reference: `tests/handshake_vec1.pcapng`.

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19. Congestion Control Parameters

- RTT sample window: 8
- BBRv2 pacing_gain cycle: `[1.25, 0.75]`
- CWND minimum: 4 * 1280B
- ECN CE flag threshold: 5%

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20. Extended Error Codes

Code	Description
0x04	VERSION_MISMATCH
0x05	PATH_VALIDATION_FAILED
0x06	INTERNAL_ERROR

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21. Security Considerations

- **Traffic Correlation**: In addition to fixed-length + Cover Traffic, use independent random sequences per link to make Padding Bytes invisible.
- **Replay Protection**: CRYPTO frame sequence (64-bit) and anti_replay_nonce (96-bit) maintain window 2^20.
- **Key Compromise**: For perfect forward secrecy, generate individual keys per stream using `HKDF-Expand(ck,stream_id)`.
- **Quantum Readiness**: Rollover to Kyber series after advertising `PQ_SUPPORTED=1` in SETTINGS, followed by re-handshake.

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22. Conformance Test Suite

- `cargo test --features conformance` for 120 cases.
- Categories: Handshake, Frame Parsing, Error Propagation, Congestion Control, FEC Recovery, NAT Traversal.
- CI requires WebAssembly implementation to pass same tests using `wasmtime`.

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23. Future Extension Registry

Range	Usage
Frame Type 0x40–0x4F	Internal experiments (unpublished)
Error Code 0x40–0x4F	Research-stage extensions
Setting ID 0x8000–0xFFFF	Private Use

This completes the full specification of Nyx Protocol v0.1. Future changes must update `proto_version` to 0x0002 or later while maintaining backward compatibility mode.