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A Framework for Blockchain-Verified Ground Infrastructure

Enabling Open Source CubeSat Communications Through Decentralized Networks

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Overview

Satellite missions face significant challenges in ground station coordination, security, and access.

Decentralized protocols offer novel solutions through cryptographic verification and trustless consensus.

Key Opportunity

Apply proven decentralized mechanisms to satellite ground station networks.

Key Challenges

Compliance

Complex legal frameworks

Security

Verification of ground station performance and data integrity

Automation

Coordination across federated operators without centralized control

Access

High costs and limitations to accessing ground stations

Protocol Applications

Ground Station Networking & Validation

Cryptographic verification of performance

Trustless scheduling and resource allocation

Performance Attestation & Proof Systems

Reputation & Stake-Based QoS

Interoperability & Standards Compliance

Compliance Through Activity Validation

Immutable records complement/ enhance contracts

Regulatory Compliance Oracles

Audit Trail & Provenance

Safety & Security Frameworks

Insurance & Liability

Spectrum Management

Dynamic Spectrum Access

Dynamic Licensing & Coordination

Coordinated Frequency Assignment

Interference Mitigation & Attribution

Spectrum Marketplace Mechanisms

Cross-Border Coordination

What is Consensus?

Consensus mechanisms are protocols that enable nodes in a distributed peer-to-peer network to agree on a single source of truth without centralized authority.

How They Generate Truth

- **Cryptographic signatures** validate attestations of physical events (location, bandwidth, coverage) through distributed witness networks
- **Byzantine fault tolerance** ensures reliability despite malicious nodes
- **Distributed verification** prevents single points of failure or manipulation

The Need for Truth

Why Decentralized Networks Need Proof Mechanisms

- **Establish Trust:** Create trust between unknown, distributed peers.
- **Robustness:** Reliable despite misbehaving nodes
- **Verifies Reality:** Multiple witnesses to cryptographically prove a physical event
- **Prevent Manipulation:** Avoid single points of failure

How Centralized Networks Handle These Challenges

- **Trusted Authority:** Central operator manages scheduling, coordination, and validation.
- **Legal Contract:** SLA's and other frameworks used to hold accountability
- **Auditing:** Reporting and 3rd Party Audits establish compliance
- **System Security:** Single point of failure but hope for best security practices of provider

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When to Use Each Model

Constraint	Single Provider	Multiprovider	Federated
Mission criticality	High ✓	Medium	Variable
Geographic diversity	Variable	Good	Excellent ✓
Capital availability	High	Medium-High	Low Required ✓
Operational Complexity	Moderate ✓	High	Variable
Regulatory Certainty	High ✓	High ✓	Limited*
Time To Deploy	Long	Medium	Fast ✓
Censorship Resistance	Low	Medium	High ✓

Different provider models enable different operational paradigms

* Refers to regulatory uncertainty around blockchain verification layers, not ground station licensing

Proof of Coverage helium

Purpose: Verify wireless network coverage via RF propagation physics

Mechanism:

- Hotspots beacon every 6 hours with randomized parameters
- Witnessing nodes record signal strength, arrival time, and distance
- Physics validation: speed-of-light constraints + inverse-square law

Innovation: First useful Proof-of-Physical-Work using real-world RF physics instead of wasted computation

Application: Prove coverage without trusted coordinator

Proof of Location/Accuracy

GEODNET

Purpose: Verify GNSS station location with <20ms latency

Mechanism:

- Validators send pseudorandom codes from GNSS Constelations
- Miners must respond within 20ms (real-time simulators cannot)
- Differential analysis from nearby stations prevents replay attacks
- Base stations are scored on their Field of View (Fov), the best FoV (100%) is the most useful and thus earns the max rewards

Innovation: Latency-based anti-spoofing combined with multi-GNSS validation for trustless positioning

Application: Validate ground station geographical claims for coverage and planning

Proof of Location/Velocity

SPACECOIN

Purpose: Validate node location and movement using RF signals

Mechanism:

- PING-PONG round trip signal propagation time determines maximum distances
- Computational techniques validate geospatial locations between nodes
- Time history enables velocity measurement for moving platforms

Innovation: Novel consensus mechanism approach to verify both position and velocity

Application: Track mobile ground terminals, validate orbital parameters

Proof of Backhaul

WITNESS CHAIN

Purpose: Trustfree bandwidth measurement resistant to collusion

Mechanism:

- Multiple distributed challengers send signed packets simultaneously
- Prover aggregates traffic and provides Merkle proofs
- Byzantine fault tolerant to $f < n/3$ corrupted challengers

Performance: 100ms verification, <10% error, 100x less data than Speedtest

Application: Verify ground station uplink/downlink capacity for SLA compliance

Proof of Compliance

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Proposed System - Under Development

Purpose: Automated regulatory reporting for Regulatory bodies/ITU compliance, instant SLA breach detection, sub-minute payment settlement

Mechanism:

- Location: Multi-GNSS cross-validation
- Frequency & Timing: Spectrum compliance + temporal proof prevents fraud and licensing violations
- Bandwidth & Quality: Statistical sampling with BFT ensures honest performance reporting

Innovation: Automate compliances

Application: Verify ground station performance for Legal and SLA compliance

Path Forward

Current State

Mechanisms are operational in terrestrial networks with satellite adaptations in progress.

Critical Research Needs

- **Validate utility layers -** Prove mechanisms work within space system constraints
- **Large-scale implementations -**Move from theoretical to production deployments
- **Regulatory compliance -** Align with spectrum regulations, CCSDS Standards and other international frameworks

Most Importantly: We need the open source community to test, validate, and scale these mechanisms

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Thank you!

Sources

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tristan@decenspace.com
t.hundley@tu-berlin.de