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Delay-Tolerant and Interplanetary Networking: Resolving Names and Governing State Across Variable-Latency, Intermittently-Connected Links

Delay-tolerant and interplanetary networks break the assumptions that terrestrial naming and coordination systems depend on: round trips take minutes to hours, links go dark for scheduled and unscheduled windows, and no node can wait on a globally synchronized directory before acting. This article shows how those problems are addressed by Adaptive Indexing, the anchor-scoped naming and mutation fabric disclosed in United States Patent Application 19/326,036, which resolves names locally, reaches consensus within a partition, and reconciles on reconnection. It maps the disclosed mechanisms onto a concrete DTN deployment without inventing new transport or new physics.

What This Application Specifies

United States Patent Application 19/326,036 discloses an adaptive network framework built around an adaptive index: a set of entries organized in a parent-child hierarchy, where each entry is a semantic container identified by a structured, human-readable alias and governed by a local group of anchors. Anchors are the authoritative

governance units for their assigned entry. They resolve aliases, cache content pointers, and vote on structural changes to the containers they govern, all within a defined scope rather than across the whole network.

Three disclosed behaviors matter most for delay-tolerant environments. First, alias resolution is stepwise and anchor-local: each segment of an alias is interpreted relative to its parent scope, so a name is resolved by delegating downward through the anchors that own each level, with no global directory lookup. Second, mutation governance runs on scoped quorums: only the anchors governing an affected container participate in validating a proposed change, and the applicable policy object defines the quorum threshold. Third, and central here, the disclosure specifies asynchronous consensus and localized consensus during disconnection. Anchors may accept mutation proposals asynchronously; anchor groups can form isolated quorums under partition, validate mutations, and keep resolution responsive without full network connectivity; and upon reconnection, signed vote records and mutation lineage are reconciled against the canonical ledger for that scope using policy-defined arbitration.

The disclosure names interplanetary links explicitly as a target environment. It describes localized consensus as particularly valuable in fragmented or high-latency environments such as remote deployments or interplanetary links, and it lists asynchronous consensus, trust-weighted anchor resolution, predictive health monitoring, and location-agnostic identity abstraction as the properties that let the framework span variable-latency, intermittently-connected domains from terrestrial 5G and LPWAN to orbital and interplanetary networks.

Why It Matters

A link between Earth and Mars carries a one-way light-time delay that ranges from roughly a few minutes near opposition to more than twenty minutes near conjunction, and the link can be occulted entirely when a body sits between the endpoints. Deep-space and near-space operations live with this by treating the network as a series of

store-and-forward custody transfers rather than an end-to-end circuit, an approach standardized in the Bundle Protocol work carried out through bodies such as the Consultative Committee for Space Data Systems and the IETF DTN working group. Bundle Protocol solves reliable custody of data across delay and disruption. It does not, on its own, solve two problems that sit above the transport layer.

The first is naming. In a delay-tolerant network there is no realistic way to consult a centrally synchronized registry to turn a stable, human-meaningful name into a current endpoint, because the registry is minutes or hours away and may be unreachable. Endpoints move, get reassigned, and get replaced, and references to them must survive those changes.

The second is coordination. Nodes on a disconnected segment, an orbiter over the far side, a surface asset during a communication blackout, a relay whose window to Earth has closed, still need to make and record authoritative decisions about local state. Waiting for a globally consistent answer is not an option. The disclosed framework addresses both problems directly: it decouples names from locations through aliases bound to stable identifiers, and it lets a local anchor quorum decide and record changes now, reconciling later.

How It Composes With the Domain

Consider a deployment spanning an Earth ground segment, a set of relay orbiters, and surface assets on a remote body, connected by scheduled, occultation-limited contact windows. The adaptive index composes onto this topology as an overlay above whatever DTN transport carries the bundles.

Naming maps directly onto the disclosed alias structure. An asset such as a science instrument or a cached data product is referenced by a structured alias of the disclosed form, for example an alias scoped as a surface site under a mission domain, resolving through the anchors that own each segment. Each alias resolves to a stable unique

identifier that, per the disclosure, remains fixed even as the alias is renamed, delegated, or restructured, and even as the underlying container is split, merged, or relocated. This is the property a DTN needs: a reference to a data product or a device survives handoff between relays and reassignment of hosting nodes, because resolution follows anchor-stored lineage rather than a hardcoded location. When an alias cannot be resolved within the local scope, the disclosure describes escalation to trusted peers or delegation upward through the nesting structure, which fits store-and-forward propagation: the query travels with the data as contact windows open.

Anchor placement follows the physical partition structure. Each disconnection-prone segment, a surface site, an orbiter, the ground segment, hosts its own anchor group governing the containers relevant to that segment. Because the disclosure specifies that anchors coordinate mutation decisions only within their jurisdictional boundaries, a surface asset can register data products, update device state, and re-alias containers using only the anchors reachable on its own segment. The disclosed asynchronous acceptance of mutation proposals means proposals generated during a blackout are cached and validated when quorum is available, exactly the store-carry-forward discipline DTN transport already imposes on payloads.

Consensus under partition is the load-bearing mechanism. The disclosure describes anchor groups forming isolated quorums during disconnection, validating mutations and maintaining index responsiveness without full connectivity, then reconciling mutation lineage on reconnection through policy-defined arbitration. In the deployment, a relay that has lost its Earth window continues to govern its scope with its local quorum. Each approved mutation records its lineage: the previous anchor map, the justification, and the exact quorum configuration at ratification, all cryptographically committed. When the contact window reopens, those signed vote records reconcile against the canonical ledger for the scope. The disclosure's adjustable consensus thresholds let policy demand a light quorum for routine local updates and a

heavier, possibly unanimous, quorum for sensitive operations such as policy rekeys, which is the right knob for a mission that wants surface autonomy for telemetry but tight control over command-affecting changes.

Identity and routing compose the same way. The disclosed pseudonymous device authentication uses a dynamic hash derived from an intrinsic device identifier and a short-lived local salt, stored on a private anchor group rather than published globally, and the disclosure states this identity resolution is designed to function in delay-tolerant or high-latency environments such as interplanetary networks. Because only the location of a user's private anchor appears in the public index, a device on a remote segment can be addressed by a stable alias while its actual current handle is resolved locally by its custodial anchor. For routing, the disclosed proximity-based selection weights candidate nodes by proximity, latency, load, and a trust score, and reroutes to the next best node when one degrades; in a scheduled-contact topology this maps onto selecting among relays and rerouting around a node whose window has closed or whose link has degraded, using the anchor-maintained node index rather than a static route table.

What This Enables

Composed onto a DTN, the disclosed framework enables a mission or operator to give a data product or a device a stable, human-readable name that keeps resolving correctly after the product is relocated between relays, the hosting node is replaced, or the alias is restructured, with no coordinated global rebind. It enables a disconnected segment to keep making and recording authoritative, auditable decisions about its own state during a blackout, then merge those decisions cleanly when the link returns, because every decision carries signed lineage and a recorded quorum configuration. It enables mission-appropriate governance granularity, routine local mutations under a light local quorum and command-affecting mutations under an elevated or unanimous quorum, enforced by anchor-local policy without a controller in the loop. And because the disclosure presents the framework as a retrofittable structural overlay that adds

anchors and aliases without altering core protocols or consensus layers, it enables an operator to layer this naming and governance fabric above an existing Bundle Protocol deployment rather than replacing the transport.

Boundary Conditions

The framework is an overlay for naming, governance, and resolution. It is not a transport protocol and does not change light-time delay, contact scheduling, or link budgets; the underlying store-and-forward layer, such as a Bundle Protocol implementation, still moves the bytes, and the framework's benefits are bounded by what that layer delivers. Local autonomy has a cost the disclosure is explicit about: isolated quorums produce state that must be reconciled on reconnection, and reconciliation is resolved by policy-defined arbitration, so a mission must define arbitration policy for genuinely conflicting mutations made on segments that could not see each other. The disclosure describes reconciliation preserving coherence through lineage records but does not eliminate the need for a well-specified conflict policy. Quorum during a long blackout is only as strong as the anchors reachable on that segment; a single-node segment cannot form a meaningful multi-anchor quorum, so the security properties of scoped consensus degrade toward those of a single trusted node under deep isolation. Finally, the trust-weighting, predictive health monitoring, and forecasting behaviors described in the disclosure depend on accumulated telemetry and history, which are sparse for a newly deployed remote segment and improve only as operational data accrues.

Disclosure Scope

The technology described here, the adaptive index, anchor-scoped local consensus, asynchronous mutation acceptance and reconnection reconciliation, alias-to-identifier binding with preserved lineage, pseudonymous dynamic-hash device resolution, and proximity-and-trust-weighted routing, is disclosed in United States Patent Application

19/326,036, which names interplanetary and delay-tolerant networks among its target environments. The delay-tolerant and interplanetary networking framing in this article, including references to store-and-forward custody transfer, Earth-to-Mars light-time ranges, occultation-limited contact windows, and Bundle Protocol standardization through bodies such as the Consultative Committee for Space Data Systems and the IETF, is external domain and regulatory context provided to illustrate a faithful enabling deployment. That context is not part of the disclosure and is not claimed here; it is offered only to show how the disclosed mechanisms apply to a real-world domain.

Adaptive Indexing (/adaptive-indexing)

All 40 steps → (/inventive-steps)

Resolution without global consensus. Anchor-governed self-organization.

U.S. 19/326,036 (/patents/19-326036)

PRIMARY TECHNICAL DISCLOSURE

- The Adaptive Index: A Scalable Foundation for Decentralized Systems (/articles/the-adaptive-index-a-scalable-foundation-for-decentralized-systems)

SECONDARY TECHNICAL

- Anchor-Governed Hierarchical Nesting: Recursive Semantic Containers at Unlimited Depth (/articles/adaptive-indexing/anchor-nesting)
- Entropy-Triggered Index Splitting: Deterministic Partitioning Under Mutation Load (/articles/adaptive-indexing/entropy-splitting)
- Dormant Index Merging: Recursive Consolidation of Low-Entropy Subindices (/articles/adaptive-indexing/dormant-merging)
- Elastic Anchor Group Management: Governance That Scales With Criticality (/articles/adaptive-indexing/elastic-anchors)
- Trust-Weighted Quorum Voting: Consensus Where Weight Reflects Earned Trust (/articles/adaptive-indexing/trust-weighted-voting)
- Asynchronous Consensus Coordination: Offline Vote Completion With Reconciliation (/articles/adaptive-indexing/async-consensus)

- Best-Match Alias Querying: Longest-Match Resolution With Stepwise Delegation (/articles/adaptive-indexing/best-match-aliases)
- Action-Typed Aliases: Behavioral Intent Embedded in the Namespace (/articles/adaptive-indexing/action-typed-aliases)
- UID Persistence Through Alias Mutation: Stable Identity Across Structural Change (/articles/adaptive-indexing/uid-persistence)
- Lineage-Preserving Structural Mutation: Cryptographic History Through Every Change (/articles/adaptive-indexing/lineage-preserving-mutation)
- Proximity-Based Routing With Trust Scoring: Dynamic Path Selection in Decentralized Networks (/articles/adaptive-indexing/proximity-routing)
- Dynamic Device Hash for Pseudonymous Authentication: Volatile Identity Without Stored Credentials (/articles/adaptive-indexing/device-hash-auth)
- On-Demand Adaptive Caching: Cache Instances That Follow Usage, Not Configuration (/articles/adaptive-indexing/adaptive-caching)
- Predictive Cache Prefetching: Forecasting Models That Proactively Instantiate Caches (/articles/adaptive-indexing/predictive-prefetching)
- Contextual Access Enforcement: Policy Graphs Evaluated With Real-Time Telemetry (/articles/adaptive-indexing/contextual-access)
- Mutation Router With Contextual Signals: Policy-Aware Propagation Path Selection (/articles/adaptive-indexing/mutation-routing)
- Impact Simulation During Mutation Staging: Pre-Execution Analysis of Proposed Changes (/articles/adaptive-indexing/impact-simulation)
- DNS Bidirectional Fallback: Hybrid Resolution With Legacy DNS Compatibility (/articles/adaptive-indexing/dns-fallback)
- Asset Versioning as First-Class Metadata: Version Entries Under UIDs With Lineage Tracking (/articles/adaptive-indexing/asset-versioning)
- Telemetry-Driven Topology Mutation: Autonomous Network Reconfiguration From Operational Data (/articles/adaptive-indexing/telemetry-topology)
- The Index Is the Territory: The Navigable Substrate Beneath Both Axes (/articles/adaptive-indexing/the-index-is-the-territory)

APPLICATIONS · GENERAL

- Decentralized AI Agent and Model Federation Without a Central Registry: Adaptive Indexing for Cross-Organization Discovery and Addressing (/articles/adaptive-indexing/decentralized-ai-federation)
- Payload-Aware Edge Caching and Live Retransmission: Replacing Address-Based CDN Heuristics With Adaptive Indexing (/articles/adaptive-indexing/cdn-and-live-media)

- How to Retrofit Adaptive Indexing onto Legacy Decentralized Systems (Web3, Fediverse, DAOs) (/articles/adaptive-indexing/applying-to-legacy-systems)
- Why Edge Platforms Still Depend on a Central Authority (/articles/adaptive-indexing/why-edge-platforms-depend-on-central-authority)
- Supply Chain Tracking Through Governed Namespace Resolution (/articles/adaptive-indexing/supply-chain-provenance)
- Social Media Platforms Without Central Namespace Authority (/articles/adaptive-indexing/decentralized-social)
- Healthcare Data Federation Through Scoped Governance (/articles/adaptive-indexing/healthcare-data-federation)
- Sovereign Government Digital Identity Without a Central Registry (/articles/adaptive-indexing/government-identity-infrastructure)
- Governed Securities Identifier Resolution for Financial Market Data (/articles/adaptive-indexing/financial-market-data)
- Cross-Platform Gaming and Metaverse Namespace Governance for Portable Player Identity and Assets (/articles/adaptive-indexing/gaming-metaverse-namespace)
- IoT Device-Fleet Identity and Telemetry Without a Central Registry: Adaptive Indexing for Pseudonymous, Revocable Device Naming (/articles/adaptive-indexing/iot-device-fleet-identity)
- Coordinating Autonomous Vehicles at the Edge Without a Central Server: Adaptive Indexing for V2V and V2I (/articles/adaptive-indexing/autonomous-vehicle-edge-coordination)
- Coordinating Smart Grids and Islanding Microgrids Without a Central Controller Using Adaptive Indexing (/articles/adaptive-indexing/smart-grid-microgrid-coordination)
- **Delay-Tolerant and Interplanetary Networking: Resolving Names and Governing State Across Variable-Latency, Intermittently-Connected Links (/articles/adaptive-indexing/delay-tolerant-interplanetary-networking)**

APPLICATIONS · SPECIFIC

- Cloudflare Workers Alternative: Governed Namespace Beyond the Central Control Plane (/articles/adaptive-indexing/cloudflare)
- DNS vs. Adaptive Indexing: which holds namespace authority locally? (/articles/adaptive-indexing/dns)
- ENS vs. anchor-governed adaptive indexing: who governs namespace mutation? (/articles/adaptive-indexing/ens)
- Handshake vs Governed Namespace: Who Governs Below the Root? (/articles/adaptive-indexing/handshake)
- IPFS vs Adaptive Indexing: Content Addressing Without Governed, Mutable Naming (/articles/adaptive-indexing/ipfs)

- Fastly Alternative for Governed Edge Caching: Distributed Purge Speed vs Distributed Cache Authority (/articles/adaptive-indexing/fastly)
- Akamai Property Manager vs Anchor-Governed Edge Namespaces: Where Should Configuration Authority Live? (/articles/adaptive-indexing/akamai)
- Bluesky PLC directory vs. adaptive indexing: how do you decentralize did:plc resolution? (/articles/adaptive-indexing/bluesky)
- HashiCorp Consul vs. Adaptive Indexing: Does a Raft-Backed Service Catalog Govern Namespace Structure? (/articles/adaptive-indexing/consul)
- Istio Solved Programmable Traffic Policy. The Namespace That Routes Traffic Is Still Central. (/articles/adaptive-indexing/istio)
- Unstoppable Domains Alternative for Governed Namespace Mutation: Adaptive Indexing (/articles/adaptive-indexing/unstoppable-domains)
- The Graph vs Governed Indexing: Who Holds Authority Over the Index Structure Itself (/articles/adaptive-indexing/the-graph)
- Filecoin Proved Verifiable Storage. Discovery and Namespace Governance Are Still Unsolved. (/articles/adaptive-indexing/filecoin)
- Arweave Made Data Permanent. It Has No Governance Model for How the Namespace of Permanent Data Evolves. (/articles/adaptive-indexing/arweave)
- Ceramic vs Adaptive Indexing: Mutable Data Streams Without Governed Namespace Authority (/articles/adaptive-indexing/ceramic)
- Does Kubernetes Govern Cross-Cluster Namespaces Without a Central Control Plane? (/articles/adaptive-indexing/kubernetes)
- Amazon Route 53 vs. Anchor-Governed Namespace Authority: Reliability or Governance? (/articles/adaptive-indexing/amazon-route53)
- HashiCorp Nomad Alternative for Governed Namespaces: Distributed Scheduling, Central Namespace (/articles/adaptive-indexing/hashicorp-nomad)
- ZooKeeper Coordinates Distributed Systems. The Coordinator Is a Single Point of Authority. (/articles/adaptive-indexing/zookeeper)
- etcd Stores the State of Kubernetes. The State Store Has No Scoped Governance. (/articles/adaptive-indexing/etcd)
- Consul KV Distributes Configuration. The Distribution Authority Is Still Central. (/articles/adaptive-indexing/consul-kv)
- Raft vs Scope-Governed Consensus: A Governed Alternative to Single-Log Replication (/articles/adaptive-indexing/raft-protocol)
- Paxos vs Scope-Governed Adaptive Indexing: Consensus Without Namespace Governance (/articles/adaptive-indexing/paxos)

- Cosmos and Tendermint Alternative for Cross-Chain Namespace: Governed Adaptive Indexing (/articles/adaptive-indexing/cosmos-tendermint)
- AWS Cloud Map vs. Adaptive Indexing: Who Governs the Namespace? (/articles/adaptive-indexing/aws-service-discovery)
- Azure Traffic Manager Routes Globally. The Routing Authority Is Centrally Defined. (/articles/adaptive-indexing/azure-traffic-manager)
- GCP Service Directory Centralizes Service Registration. Registration Is Not Governance. (/articles/adaptive-indexing/gcp-service-directory)
- Netlify DNS Simplifies Deployment Routing. The Namespace Authority Is Still Netlify's. (/articles/adaptive-indexing/netlify-dns)
- Vercel Edge Alternative: Distributed Execution vs Deployer-Governed Routing Authority (/articles/adaptive-indexing/vercel-edge)
- Bunny CDN Alternative: Adaptive Indexing and Governed Edge Cache Resolution (/articles/adaptive-indexing/bunny-cdn)
- KeyCDN Optimized Content Delivery. The Delivery Namespace Is Centrally Controlled. (/articles/adaptive-indexing/keycdn)
- Limelight Networks Built Private Infrastructure for Delivery. The Namespace Governance Is Still Central. (/articles/adaptive-indexing/limelight)
- StackPath Alternative for Governed Edge: Unified Edge Services vs Distributed Namespace Authority (/articles/adaptive-indexing/stackpath)
- Envoy Proxy Made Service Mesh Data Planes Programmable. The Control Plane Still Governs. (/articles/adaptive-indexing/envoy-proxy)
- NGINX Powers the Web's Reverse Proxy Layer. Its Configuration Is Statically Defined. (/articles/adaptive-indexing/nginx)
- Traefik Alternative for Governed Routing: Beyond Provider-Derived Service Discovery (/articles/adaptive-indexing/traefik)
- Linkerd Alternative for Governed Namespaces: Service Mesh Beyond the Kubernetes Registry (/articles/adaptive-indexing/linkerd)
- Namecheap Made Domain Registration Accessible. Domain Governance Remains the Registrar Model. (/articles/adaptive-indexing/namecheap)
- GoDaddy Registered More Domains Than Anyone. The Namespace Model Has Not Changed. (/articles/adaptive-indexing/godaddy)
- DNSimple Made DNS Management Developer-Friendly. The Governance Model Is Still DNS. (/articles/adaptive-indexing/dnsimple)
- Datadog Alternative for Governed Namespaces: Observability vs Adaptive Indexing (/articles/adaptive-indexing/datadog)

- Grafana Alternative for Governed Observability: The Data Namespace It Queries Has No Governed Structure (/articles/adaptive-indexing/grafana)
- Prometheus vs Governed Namespace Indexing: The Metric Namespace Has No Adjudication Layer (/articles/adaptive-indexing/prometheus)
- New Relic Alternative: Governed Telemetry Namespace Beyond Centralized Indexing (/articles/adaptive-indexing/new-relic)
- Splunk Alternative for Governed Namespaces: Machine-Data Indexing vs Adaptive Indexing (/articles/adaptive-indexing/splunk)
- GitHub Copilot Workspace vs Governed Cross-Repository Resolution (/articles/adaptive-indexing/github-copilot-workspace)
- Tableau Pulse alternative for cross-authority analytics: governed adaptive indexing (/articles/adaptive-indexing/tableau-pulse)
- Notion AI vs Federated Anchor-Governed Retrieval (/articles/adaptive-indexing/notion-ai)
- Matrix (matrix.org / Element) alternative: adaptive semantic naming for federated identity and resolution (/articles/adaptive-indexing/matrix-protocol)
- BitTorrent Mainline DHT (Kademlia) vs adaptive indexing: semantic aliases and scoped governance over a content-hash lookup (/articles/adaptive-indexing/bittorrent-dht)
- Tailscale alternative: naming and resolution when the coordination plane is offline (/articles/adaptive-indexing/tailscale)

Adaptive Indexing overview → (/adaptive-indexing)