GridMesh – The Edge-Native DSO Co-Pilot

Context and Problem

Today's DSOs still run grids in a centralized, cloud-centric way, with a control room or SaaS platform orchestrating millions of field devices. That architecture fails in three critical ways. First, latency and fragility: stability issues unfold in milliseconds while cloud control loops respond in seconds and collapse when the WAN link is congested or down. Second, hub-and-spoke bottlenecks: scaling a single "brain" for millions of EVs, heat pumps and home batteries is brittle and costly. Third, traceability gaps: under new GB rules such as BSC Modification P415, Virtual Lead Parties (VLPs) can trade behind-the-meter flexibility, but traditional systems cannot reliably show which asset did what during communications blackouts, complicating settlement and compensation under P415 and P444.

Our design goal is a DSO Co-Pilot that still works when the cloud does not: delivering sub-second local reflexes at substations, with UEI/Beckn-native, P415/P444-aligned evidence for markets and regulators.

Concept and Value Proposition

GridMesh re-architects the grid as a network-of-networks. Each substation hosts a Sentinel Agent that monitors local constraints in real time, pre-arms flexibility via Unified Energy Interface (UEI) over the Beckn Protocol, executes that flexibility locally in under one second with no cloud round trip, and records P444-style traces for later audit and settlement.

A central Co-Pilot dashboard acts as the policy brain: configuring risk-aware policies (for example minimum reserve per feeder), showing which substations self-healed and which assets responded, and presenting aggregated P415/P444-aligned settlement views for VLPs and suppliers. For the DSO, GridMesh is a co-pilot, not a replacement: it owns fast local reflexes while policy, oversight and market interaction stay in the control room.

Users and Use Cases

Our primary users are DSO control-room operators, who need confidence that substations stay stable even when WAN links degrade; flexibility aggregators and VLPs, who must prove delivery to get paid under P415 and future compensation regimes; and regulators and auditors, who need machine-readable evidence consistent with BSC modifications P415 and P444.

Key use cases show how this works in practice. In U1 (voltage spike mitigation), when voltage on Feeder X exceeds 253 V, the local Sentinel fires pre-armed EV/BESS discharge in under 200 ms, restores voltage within limits, and logs a signed P444-style trace of the event. In U2 (WAN outage resilience), a regional connectivity incident isolates several substations, but their Sentinels keep managing constraints autonomously using pre-armed contracts; when WAN returns, all P444-style logs synchronise, enabling P415-compliant settlement and P444 compensation for suppliers and VLPs. In U3 (policy optimisation), the Co-Pilot analyses a week of P444 traces and proposes changes—such as raising the minimum flexible reserve on Feeder 7 to 80 kW between 18:00–21:00—which operators can approve or override.

Architecture

GridMesh uses a two-layer architecture designed for resilience and speed. The Central Policy Brain runs in the cloud with a role of strategy, policy and audit rather than fast control. It ingests P444-style event logs from all substations and hosts an AI planning layer using Sierra AI for orchestration and Claude 3.5 Sonnet for reasoning. Together they learn from disturbance history and propose risk policies such as reserve margins, acceptable cost per kW and trigger thresholds. Sierra manages the complexity of multi-party B2B negotiation lifecycles, while Claude generates post-event natural-language incident reports for DSO operators, explaining why specific assets were selected. A Co-Pilot dashboard exposes live risk posture by feeder and substation, active Armed Contracts per site and P415/P444-aligned settlement views per VLP and supplier.

At the edge, Sentinel Agents are deployed per substation with the role of execution and survival. Each Sentinel implements two loops. The Slow Loop handles negotiation and arming on the order of seconds to minutes, using UEI/Beckn flows (search, select, init, confirm) to discover nearby flexibility providers such as EV charging hubs and BESS aggregators, optimise cost versus reliability, and establish conditional Armed Contracts like "Cluster EV_A will discharge 20 kW if V exceeds 253 V with SLA under 200

ms.” The Fast Loop provides reflex execution in sub-second timeframes by subscribing to local telemetry and SCADA. On triggers such as voltage above 253 V or thermal loading above 95%, it selects relevant Armed Contracts and sends pre-signed activation packets locally, without any cloud round trip. This deterministic Python runtime bypasses LLM reasoning entirely when milliseconds matter, acting as pure reflex, and writes P444-style event records capturing time, trigger, assets, delivered kW, observed latency and hashes of UEI/Beckn messages for a complete audit trail.

Protocol and Standards Alignment

Beckn Protocol is an open, decentralised set of API and data specifications for interoperable, peer-to-peer digital networks. Unified Energy Interface (UEI) is a Beckn-based open network for energy transactions—EV charging, virtual storage and flexibility—promoted for interoperability via the UEI Alliance and related initiatives. GridMesh uses UEI descriptors to encode conditional flexibility so contracts are machine-readable and executable without human interpretation; for example, a search for “Conditional Flexibility” tagged with TRIGGER_TYPE=VOLTAGE_HIGH, TRIGGER_THRESHOLD=253V, SLA_LATENCY=200ms and MIN_POWER_KW=50 defines exactly when, how fast and how much power must be delivered.

On the market side, P415 modifies the GB Balancing and Settlement Code to create a new Trading Party category for VLPs, enabling independent aggregators to participate directly in wholesale markets, while P444 introduces compensation for VLP actions in the Balancing Mechanism so suppliers and VLPs are fairly treated when those actions change metered volumes. GridMesh’s P444-style local traces and UEI/Beckn logs give VLPs the evidence needed to benefit from P415 while supporting P444 compensation calculations, even under degraded connectivity. Every DER is assigned a DEG Universal ID (for example did:deg:uk:substation:007), preventing spoofing and enabling universal discovery across all registered VLPs simultaneously.

MVP Scope

The MVP delivers a simulated but end-to-end slice. The Edge Sentinel prototype features a rule-based Fast Loop achieving under 200 ms detection-to-activation in an Edge VM, plus a Slow Loop using UEI/Beckn-style REST calls to mock BAP/BPP endpoints. A grid and DER simulator provides a single-feeder model generating voltage and loading alongside a small fleet of EV/BESS agents with configurable capacity and price.

GridMesh BAP and Aggregator (BPP) mocks include a minimal Beckn BAP for search, select, init and confirm operations, plus one or more BPP endpoints representing EV/BESS aggregators. The Co-Pilot dashboard displays live feeder status and alarms, active Armed Contracts per substation, and an event timeline showing P444-style event records with P415-oriented settlement summaries per VLP. Evidence and metrics include measured detection-to-activation latency under 200 ms, a clear mapping from each event to responding assets and kWh delivered, and UEI/Beckn payloads with P444-style traces visible in the UI for auditors and judges. Settlement uses cryptographic receipts with SHA256 hashing and Ed25519 signatures, creating tamper-proof Local Energy Receipts that prove flexibility delivery with millisecond precision.

Economics and Future Extensions

Let C_flex represent the cost of procuring flexibility and C_violation the expected cost of equipment failure, outages and regulatory penalties. Since C_flex is much smaller than C_violation for DSOs, GridMesh’s Sentinels continuously and automatically pre-arm low-cost flexibility when local risk is high, turning resilience into a quantifiable optimization problem. DSOs see fewer overloads, fewer voltage complaints and lower non-compliance risk; VLPs and aggregators gain verifiable, P415-compatible revenue streams from behind-the-meter assets; and the system supports market-based flexibility and compensation through P415 and P444 while moving intelligence to the edge where physics demands it.

For a DSO at the scale of UK Power Networks (8.3 million customers), GridMesh can prevent on the order of tens of blackout-grade events per year, cut response times from tens of seconds to sub-second, capture several-fold more flexibility value than manual coordination and reduce P444 audit costs by orders of magnitude through automation. Scaled across all UK DNOs, the same pattern unlocks multi-GW flexibility and system-level savings measured in billions of pounds. Future work includes multi-substation coordination via edge-to-edge gossip, richer AI policy optimisation and integration with physical lab hardware, extending the vision toward a distributed “immune system” for the grid.