Intelligent Operation and Maintenance: Practices and Reflections

China Unicom

IETF 125

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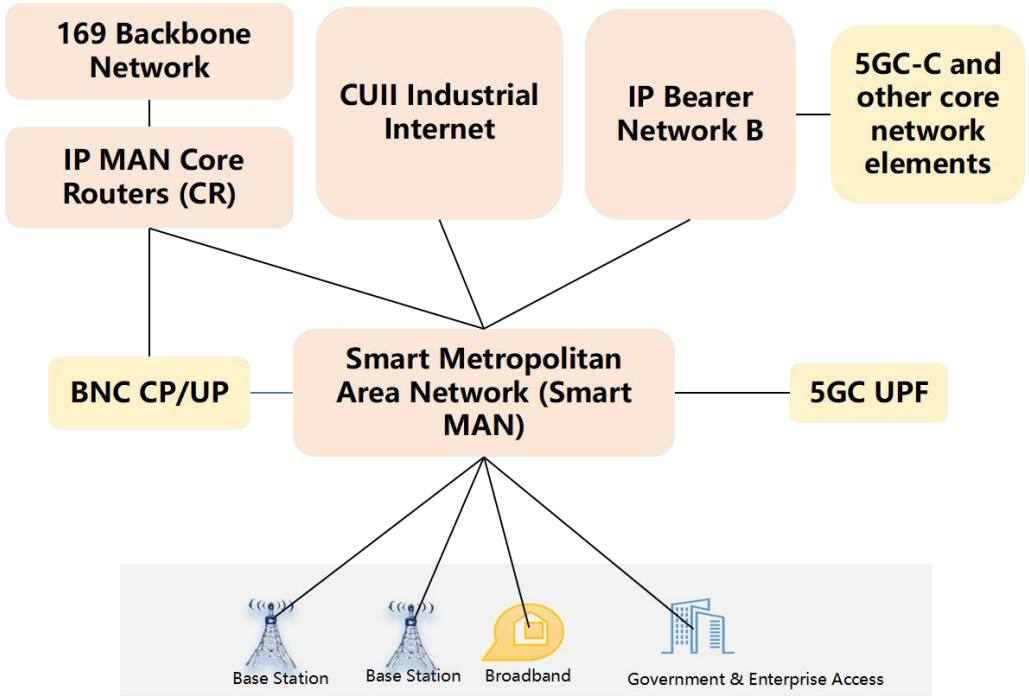
China Unicom IP Network Overview

- As a major integrated telecommunications carrier in China, we provide domestic and international communication and digital information services.

Composition of the core IP network architecture

- China 169 Backbone Network
- IP Metropolitan Area Network (MAN)
- CUII Industrial Internet
- Smart Metropolitan Area Network (Smart MAN)
- IP Bearer Network B



Our Thoughts on Intelligent Operation and Maintenance

- To manage such a large-scale and complex IP network efficiently, we aim to equip the network with resilience enhancement capabilities for more intelligent operation and maintenance.
- To build network resilience enhancement capabilities covering the full O&M lifecycle:

Pre-event	In-event	Post-event
Network Simulation	Traffic Monitoring	Real-live Network O&M Issues

Core Pain Points!

Pain Points in Network Simulation

Cross-Layer Co-simulation

- **Problem:** Difficulty in "Physical-IP-Application" collaborative simulation, making it impossible to build **full-stack twin models** for complex environments.
- **Current State:** Poor **inter-layer coordination** due to lack of unified mapping and logical alignment across protocols.

Lag in Rule Generation

- **Problem:** Cannot **rapidly and automatically** generate simulation rules for diverse scenarios and dynamic demands.
- **Current State:** Manual or semi-automated simulation configuration is slow and inflexible, unable to handle complex network elements and protocols.

Insufficient Data-Model Fusion

- **Problem:** Gap between **macro-level business forecasting** and **micro-level device validation**.
- **Current State:** Emulation focuses on device-level details while numerical simulation targets traffic and quality.

Challenges in Real-time Performance & Accuracy

- **Problem:** Cannot meet the requirements for **real-time synchronization** and "**zero-error**" validation in large-scale networks.
- **Current State:** Massive data volumes demand real-time collection, yet current model precision cannot 100% eliminate risks for **live-network operations**.

Pain Points in Traffic Monitoring

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The Connectivity Gap (Quality Dimension)

- **Problem:** Lack of deterministic **end-to-end** localization.
- **Why：** In heterogeneous networks, Current in-situ telemetry techniques such as iFIT fail cannot achieve end-to-end monitoring due to **insufficient multi-vendor support**.

RCA (Root Cause Analysis)
MTTR (Mean Time To Repair)

Single-vendor silos **VS** Cross-domain Services

Due to inconsistent telemetry metadata

The Attribution Gap (Traffic Dimension)

- **Problem:** Real-time multi-dimensional analysis of massive traffic remains unachievable.
- **Why:**

FLOW methods	**Sampling**
High-precision on-board analysis	**High resource overhead**

- **Problem:** **"Blind spots"** in traffic change detection.
- **Why:** IP-based monitoring suffers from header attribute degradation caused by cross-domain IP changes and NAT translation.

The Service Gap (Application Awareness)

- **Problem:** Mismatch between network monitoring and user experience.
- **Why:** current methods are IP-centric monitoring, not application-aware. Without identifying specific applications, the network cannot provide **differentiated services.**

Pain Points in Live Network O&M Issues

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❶ Hidden Risks

Problem: Long-tail risks exist after network cutover.	**Why:** Improper label configurations or code defects often cause periodic faults weeks or even months after deployment.

❷ Application Interaction

Problem: Abrupt changes in traffic flow direction are hard to detect.	**Why:** Configuration changes in upper-layer applications cause IP traffic surges or shifts, leaving the network layer only able to respond passively.

❸ Collaboration Efficiency

Problem: The costs of response and fault troubleshooting are excessively high.	**Why:** Complex fault troubleshooting still relies on manual cross-specialty and cross-department coordination, lacking fully-automated methods.

Related I-D: https://datatracker.ietf.org/doc/draft-zhao-opsawg-network-resilience-ps/

Next: Network Resilience Capabilities for O&M

To address traditional O&M challenges and enhance network survivability, networks must be equipped with comprehensive resilience capabilities across the full lifecycle:

Pre-Event

Deep Perception & Prediction

- From traffic visualization to intelligent risk forecasting.

Closed-Loop Simulation & Verification

- Pre-operation deduction to contain risks upfront.

Intelligent Strategy Reserve

- Pre-generate adaptive responses from historical/simulation data.

In-Event

Rapid Anomaly Perception

- Real-time monitoring to detect sub-threshold anomalies.

Precise Intent Recognition

- Pinpoint hidden configuration vulnerabilities from data.

Adaptive Control

- Shift to elastic control for auto-tuning and recovery.

Post-Event

Disposition Logic Capture

- Institutionalize best practices into a knowledge base.

End-to-End Closed-Loop Governance

- Monitor recovery to validate mitigation effectiveness.

Capability Iteration & Optimization

- Refine simulation & decision-making via case analysis.

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Some of Our Practices for Network Resilience

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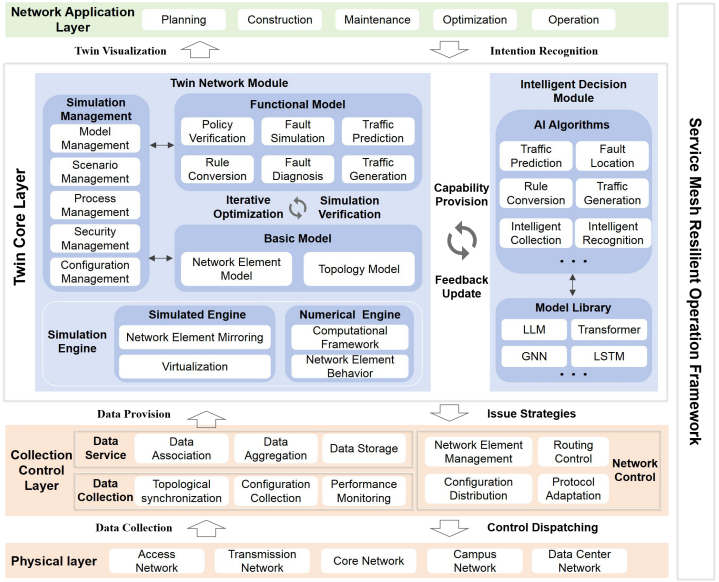
	Pre-event	In-event	Post-event
	Network Simulation	**Traffic Monitoring**	**Current Network O&M Issues**
Core Pain Points	Insufficient High-Fidelity and Dynamic Construction Capabilities	Traffic Monitoring Invisibility	Reactive Troubleshooting and Cross-domain Collaboration Difficulties
	Simulation & Verification	**Deep Perception**	**Adaptive Control**
	Post-Mortem Analysis » Proactive Prevention	Seeing » Understanding	Static Hardening » Elastic Response
			Create a self-improving cycle
Targeted Practical Solutions	**IP Network Simulation System** +	**IP Network Traffic Monitoring & Analysis Platform** =	**Intelligent Computing Center Network O&M Platform**

Notice: All cases have completed pilot verification in the live network.

Practice 1: IP Network Simulation System

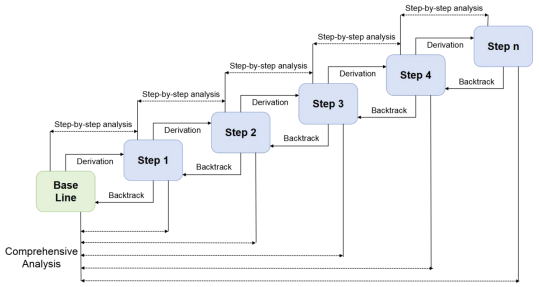
To address the core challenge of "insufficient high-fidelity & dynamic construction capabilities" in network simulation, we propose a digital twin network architecture driven by integrated numerical simulation and emulation.



Scenario Simulation, Deduction & Path Simulation Comparison

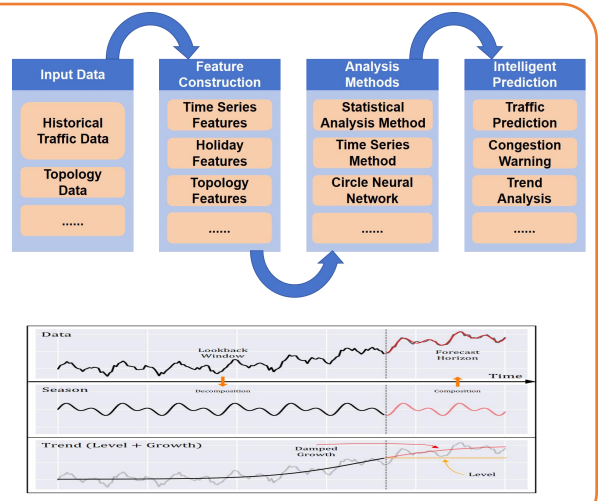
Deduction Analysis and Dynamic Rollback in Cutover Simulation

- Cutover simulation requires configuration-level simulation.
- Extract atomic operations (forward execution and stack-based rollback for executed steps) from live-network steps.
- Orchestrate on-demand operations for step-by-step impact analysis.



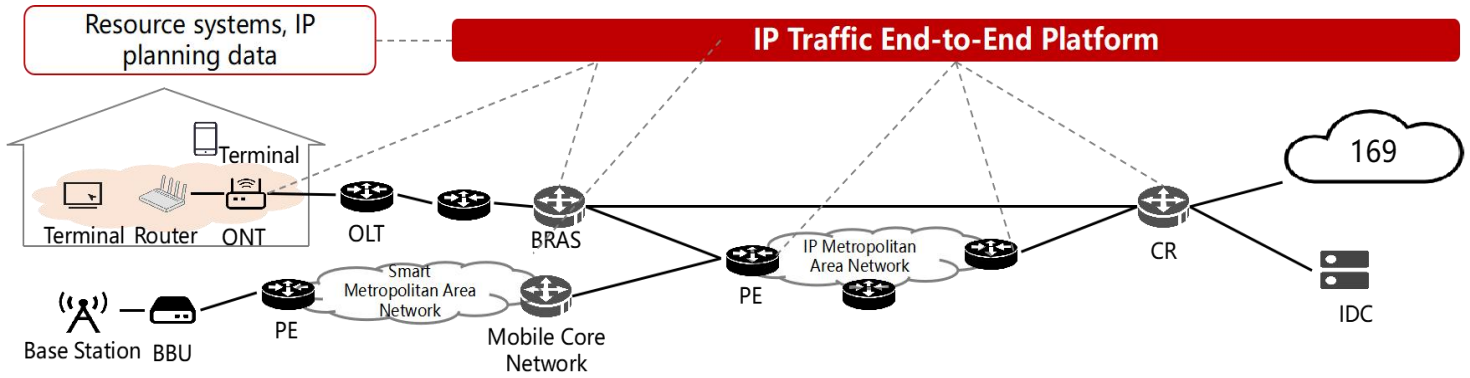
Intelligent Network Traffic Prediction

- Traffic analysis requires numerical simulation.
- Build a spatio-temporal deep neural network for end-to-end traffic analysis.
- Issue real-time alerts for traffic beyond predicted ranges to guide O&M.



Practice 2: IP Network Traffic Monitoring and Analysis Platform

- To address the core "invisibility" challenge in Internet traffic monitoring, this platform provides an **end-to-end** IP traffic monitoring and analysis system covering home broadband, mobile networks, bearer networks and applications.



Traffic Monitoring in Private Network Scenarios

Quality Anomaly Monitoring and Analysis

- **Multi-domain Full-stack Collection:** Eliminate cross-professional barriers for end-to-end multi-domain traffic & quality data collection.
- **Routine Monitoring and Analysis:** Establish routine analysis to turn invisible traffic into visible digital metrics.
- **IPv6 Capability Assessment:** Compare IPv4/IPv6 live-network performance, identify deployment bottlenecks, and support IPv6+ rollout with data.
- **Granular Traffic Flow Insight:** Refine traffic analysis to provincial levels, support inter-domain settlement, planning & service forecasting.

Related I-D: https://datatracker.ietf.org/doc/draft-pang-v6ops-ipv6-monitoring-deployment/

Practice 3: Intelligent Computing Center Network O&M Platform

This system delivers end-to-end intelligent operation, control and resource optimization for intelligent computing services via three core capabilities of the Computing-Network Convergence Layer.

Full-spectrum Perception & Multi-dimensional Monitoring

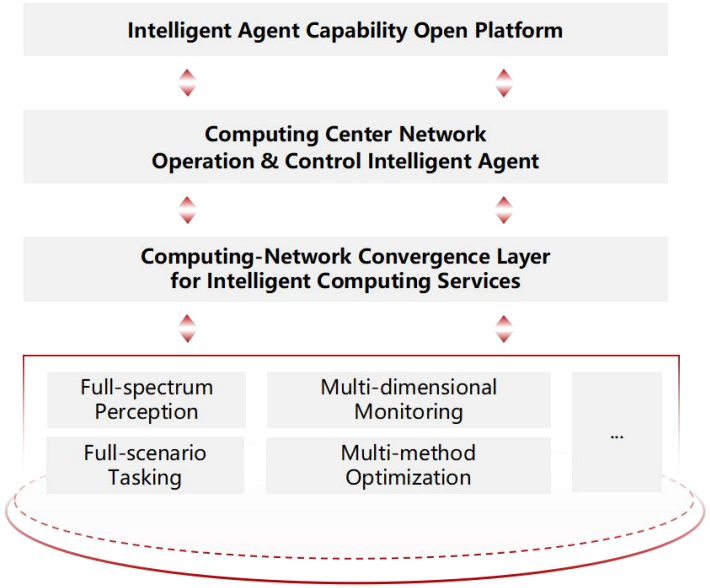
- Full-domain topology & multi-dimensional fault visibility
- Real-time millisecond-level traffic, lossless metrics (PFC/ECN/CNP) and hardware resource monitoring

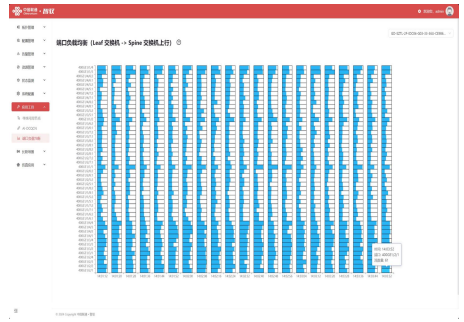
Full-scenario Tasking

- Full-scenario Business Support: Cover the entire process of task executions including large-scale training and large-model fine-tuning.
  e.g., on-demand computing resource scheduling.

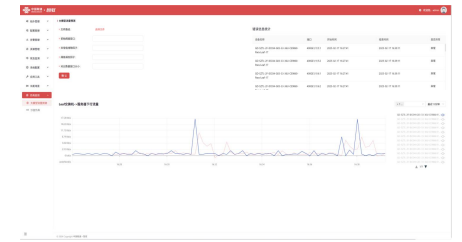
Multi-method Optimization

- Large-model traffic prediction & simulation
- AI-DCQCN-based load balancing and congestion control optimization

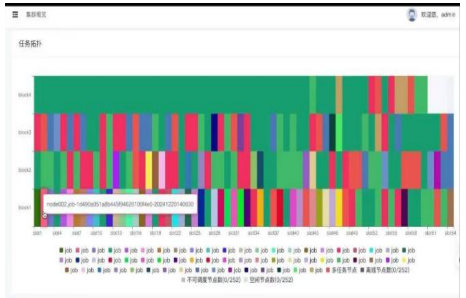




Load Balancing Optimization



Large-model Traffic Prediction

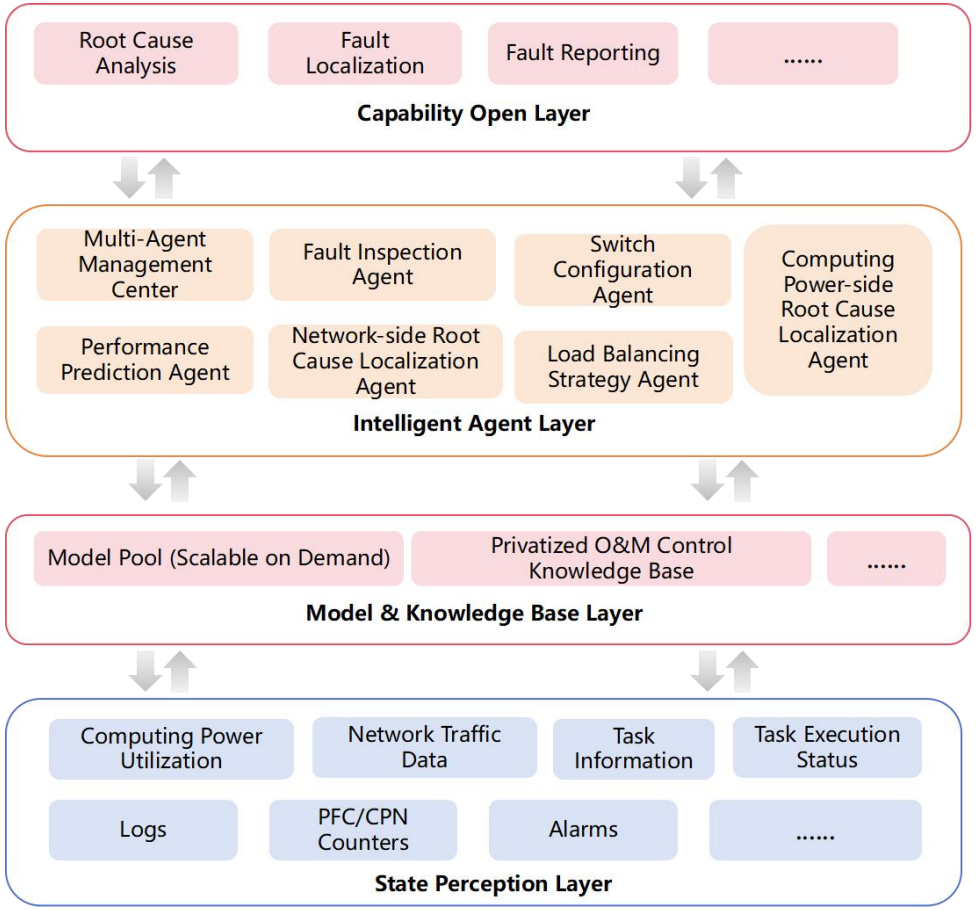


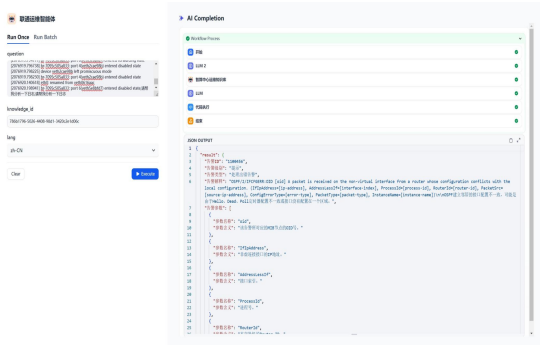
Multi-task Hybrid Scheduling

Second-level Fault Recovery

Practice 3-1: Intelligent Computing Center O&M Control Intelligent Agent System

Build an Intelligent Computing Center O&M control knowledge base, develop an in-house operation and control intelligent agent based on reinforcement learning and AI large models, and enable the implementation of customized O&M control scenarios through capability opening.





Knowledge Graph

Model Construction

Fine-tune large AI models based on the knowledge base, and leverage reinforcement learning algorithms to design reward functions for each step in the workflow, thereby achieving continuous model optimization.

Thanks for Listening!

If you are interested in our work, please reach out to us!

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