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J. Zhao, Ed.
R. Pang, Ed.
S. Zhang, Ed.
China Unicom
H. Shi, Ed.
C. Sun, Ed.
Purple Mountain Laboratories

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AI Agent Architecture for Network Digital Twin
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Abstract

This document proposes an AI agent architecture for Network Digital Twin (NDT) that integrates AI agents with digital twin technology.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

Digital twins have emerged as a powerful paradigm for network management, providing virtual representations of physical networks that enable simulation, analysis, and optimization. However, traditional digital twin architectures often lack the autonomous decision-making capabilities needed for modern network environments. This document proposes an architecture that combines digital twin concepts with intelligent AI agents, creating a more dynamic and responsive network management system.

The architecture is designed to be compatible with existing digital twin architectures. This approach enables distributed decision-making, adaptive behavior, and enhanced collaboration between digital twin components.

2. AI Agent Architecture for Network Digital Twin

Based on the concept of the Network Management Agent (NMA) [I-D.zhao-nmop-network-management-agent], we propose an AI Agent architecture for Network Digital Twin (NDT) [I-D.irtf-nmrg-network-digital-twin-arch]. This architecture extends the traditional network digital twin by integrating AI agents into each core component. While preserving the fundamental structure of digital twins, the architecture introduces enhanced autonomous capabilities and intelligent decision-making across the network management lifecycle.

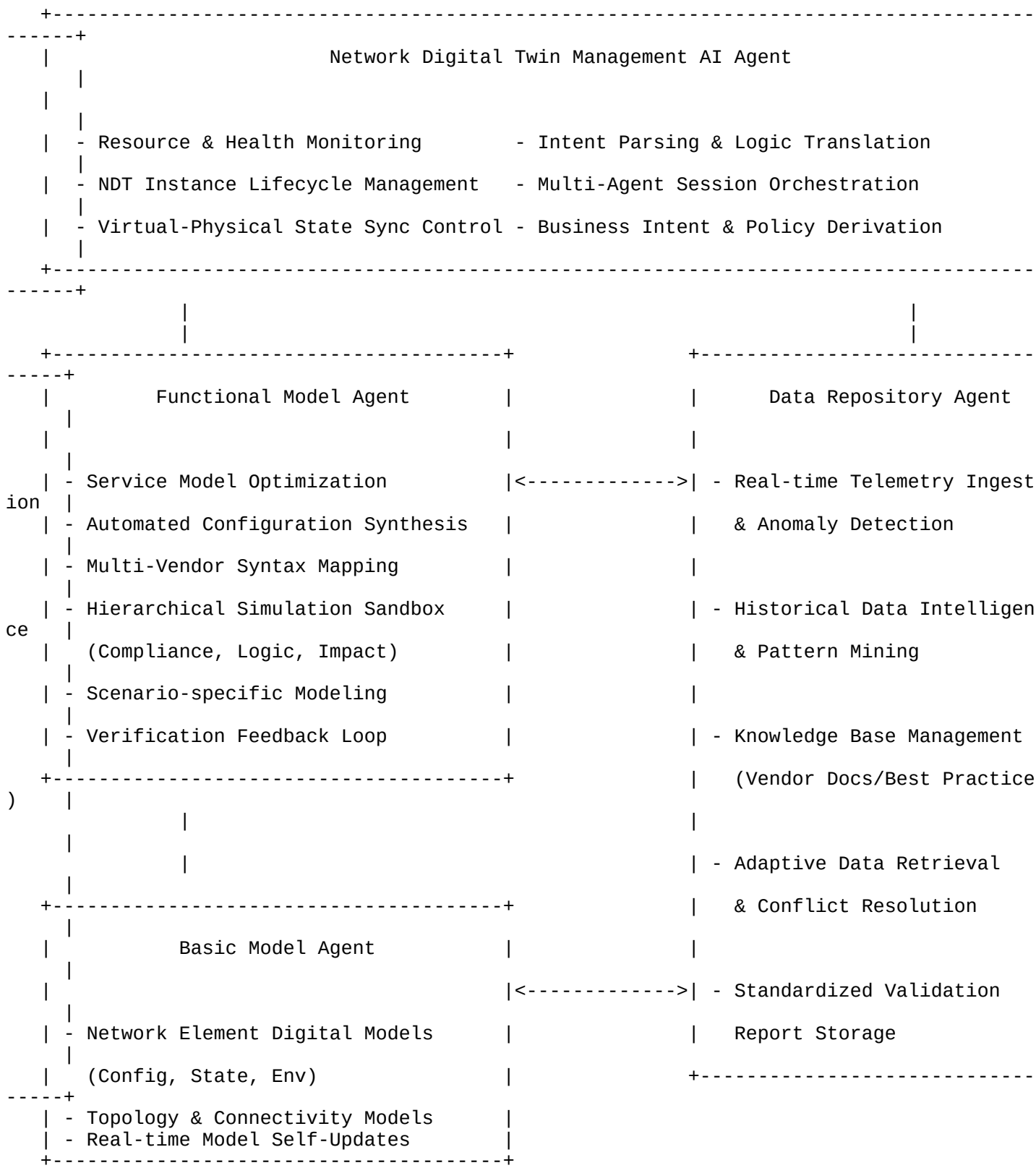

Figure 1: AI Agent Architecture for Network Digital Twin

The following figure illustrates the hierarchical interaction between the Management, Functional, Basic, and Data agents.

3. Architecture Components

3.1. Network Digital Twin Management AI Agent

The Network Digital Twin Management Agent serves as the central coordination and management component, providing the following key functionalities:

* Resource Monitoring: Continuously tracks and monitors the status, performance metrics, and operational health of all resources within the digital twin environment.

* Lifecycle Management: Governs the complete lifecycle of NDT instances, encompassing instantiation, configuration, state synchronization, maintenance, and termination.

* Session Control: Orchestrates communication sessions and interactions among various AI agents to ensure coherent operation.

* Intent Translation & Policy Derivation: Derives executable policies from high-level business intents through semantic parsing and internal logic models.

* Virtual-Physical Synchronization Control: Manages bidirectional data flow between the NDT and the physical network to ensure accurate representation.

3.2. Functional Model AI Agent

The Functional Model Agent is responsible for advanced service modeling, configuration generation, and optimization. It autonomously invokes required functional models per validation policies and refines them via historical data analysis.

* Service Model Optimization: Refines models through performance analysis and adaptive learning algorithms.

* Automated Configuration Synthesis: Generates vendor-specific configurations or intermediate policy representations based on the intent model.

* Hierarchical Simulation Sandbox: Provides a multi-stage environment to verify configurations across compliance, logic, and business impact layers.

TBD.

3.3. Basic Model AI Agent

The Basic Model Agent maintains fundamental network element and topology representations. It is capable of updating digital models in real-time based on physical network changes to ensure the accuracy of validation.

3.4. Data Repository AI Agent

The Data Repository AI Agent serves as the intelligent data governance and provisioning component. It autonomously manages the data lifecycle with the following capabilities:

* Real-time Data Collection: Implements multi-protocol ingestion for streaming telemetry while autonomously detecting data anomalies.

* Historical Data Intelligence: Curates structured data and knowledge graphs to support pattern mining, and model training.

* Adaptive Data Services: Provides context-aware data retrieval with intelligent caching and conflict resolution.

* Knowledge Base Integration: Stores network configurations, vendor documents, and best practices to support incremental model updates.

* Validation Reporting: Generates standardized, machine-readable validation reports including rule IDs, configuration items, and evidence.

4. Agent Interactions

The architecture employs bidirectional Agent-to-Agent (A2A) communication: the Functional and Basic Model Agents interact with the Data Repository Agent for data synchronization, while the Management Agent centrally orchestrates these interactions to maintain a coherent workflow.

Inter-agent interactions SHOULD support state rollback mechanisms to ensure the virtual state remains synchronized with the physical network during failed intent decompositions.

5. Intelligent Use Case Realization

5.1. Automated IP Network Configuration Generation

This use case demonstrates how the AI Agent architecture automates the end-to-end lifecycle of network configuration.

5.1.1. Intent Understanding and Policy Generation

* Intent Parsing: The Management Agent receives declarative intents, identifying network objects and resolving logic conflicts between multiple intents.

* Config Generation: The Functional Model Agent produces vendor-specific configurations. It maintains context awareness by retrieving current states from the Basic Model Agent.

* Vendor-agnostic Abstraction: The system uses an intermediate policy representation to ensure functional consistency across heterogeneous hardware.

5.1.2. Multi-Level Simulation and Verification

Before deployment, configurations MUST undergo a multi-stage verification process:

* Semantic Consistency Verification: Ensures that synthesized configurations result in deterministic network behavior, bridging the gap between probabilistic AI generation and deterministic network operations..

* Hierarchical Validation: The Functional Model Agent executes simulations in a sandbox layer-by-layer: 1. Compliance: Detecting syntax errors and policy violations. 2. Functional Correctness: Verifying reachability and protocol convergence via the Basic Model Agent. 3. Service Impact: Evaluating potential performance degradation using traffic patterns from the Data Repository Agent.

5.1.3. Model Evolution and Feedback Loop

* Closed-loop Optimization: If verification fails, the Management Agent feeds error reports back to the generation models of the Functional Model Agent for iterative optimization.

* Incremental Learning: Experts can manually correct AI outputs, which are stored in the Data Repository Agent to fine-tune future generation and verification models.

5.2. Cutover Simulation (Scenario Construction)

* Process Reproduction: The architecture simulates the complete cutover lifecycle, including device startup/shutdown, routing adjustments, and configuration delivery.

* Risk Mitigation: By monitoring link status and business capacity in the NDT, the Network Digital Twin Management AI Agent and Functional Model Agent jointly identify plan loopholes and optimize emergency response sequences before physical execution.

6. Security Considerations

AI-Generated Risks: Specific checks must be implemented to detect "hallucinated" commands or non-compliant security policies generated by large language models.

7. IANA Considerations

TBD.

8. Informative References

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Authors' Addresses

Jing Zhao (editor)
China Unicom
Beijing
China
Email: zhaoj501@chinaunicom.cn

Ran Pang (editor)
China Unicom
Beijing
China
Email: pangran@chinaunicom.cn

Shuai Zhang (editor)
China Unicom
Beijing
China
Email: zhangs366@chinaunicom.cn

Hongwei Shi (editor)
Purple Mountain Laboratories
Nanjing
China
Email: shihongwei@pmlabs.com.cn

Chen Su (editor)
Purple Mountain Laboratories
Nanjing
China
Email: suchen@pmlabs.com.cn