SOLUTION REPORT BY CERAGON AND INTIVE

The Power of Network Digital Twins

From Concept to Implementation

Table of contents

CHAPTER 1

Introduction

Network Digital Twins (NDTs)

are dynamic, virtual representations of physical network environments that mirror real-time conditions and behaviors. They enable continuous monitoring, simulation, and impact analysis, empowering telecom operators to make faster, data-driven decisions with greater precision and confidence.

As telecommunications networks evolve, the strategic relevance of NDTs is accelerating. These digital replicas offer holistic visibility and proactive management capabilities that are essential for optimizing operations, enhancing service delivery, and mitigating risks. According to KBV Research, the global Digital Twin in Telecom market is projected to reach USD 1.6 trillion by 2031, growing at a CAGR of 22% from 2024 to 2031, underscoring their rising importance across the industry.

This Solution Report provides a practical blueprint for telecom organizations seeking to implement NDTs, helping them understand the opportunities, anticipate challenges, and make informed decisions. It explores the architectural foundations and strategic value of NDTs, while addressing key business and engineering obstacles typically encountered during deployment.

The document also examines how NDTs can strengthen network planning, performance monitoring, security, and operational agility.

CHAPTER 2

Engineering Challenges in Modern Telecommunications

Modern telecom networks are increasingly complex, distributed, and software-defined.

Operators rely on a diverse ecosystem of specialized tools for network planning, fault management, traffic analytics, cybersecurity, and cloud orchestration. However, these tools often operate in silos, leading to fragmented visibility and disjointed workflows.

This fragmentation poses significant challenges for cross-functional processes such as outage response, maintenance planning, network optimization, and security mitigation. These critical tasks still depend heavily on manual coordination across teams with disparate systems, timelines, and KPIs-resulting in reactive, risk-prone, and slow decision-making. The consequence is increased exposure to service disruptions, higher operational costs, and diminished returns on infrastructure investments.

A unified, real-time model of the network is urgently needed to bridge these gaps. NDTs offer a compelling solution by providing a synchronized, virtual representation of the network that supports integrated planning, monitoring, and automation.

Challenges and Implications in Focus

1. Data Growth and Network Scalability

Challenge

The exponential rise in data traffic driven by video streaming, cloud applications, and IoT proliferation.

Implications

- Scalable backhaul and edge computing architectures to reduce latency.
- Implementation of traffic shaping, QoS policies, and dynamic bandwidth allocation.
- Use of AI/ML for predictive traffic modeling and congestion avoidance.

2. 5G Rollout and Evolution Toward 6G

Challenge

High CAPEX and architectural complexity in deploying 5G and preparing for 6G.

Implications

- Design and deployment of dense small cell networks and massive MIMO.
- Integration of network slicing and ultra-reliable low-latency communication (URLLC).
- Advanced spectrum management, beamforming, and interference mitigation.

3. Cybersecurity and Network Hardening

Challenge

Expanded attack surface due to virtualization, remote access, and distributed architectures.

Implications

- Adoption of zero-trust security models and deep packet inspection (DPI).
- Real-time SIEM integration and automated incident response mechanisms.
- Compliance with evolving encryption and data sovereignty standards (e.g., TLS 1.3, IPSec).

4. Virtualization and Cloud-Native Transformation

Challenge

Transition from hardware-centric to software-defined, cloud-native infrastructures.

Implications

- Deployment of SDN controllers, NFV platforms, and containerized network functions (CNFs).
- Adoption of CI/CD pipelines and infrastructure-as-code (IaC) for agile network updates.
- Orchestration and lifecycle management via Kubernetes, OpenStack, or ONAP.

CHAPTER 3

Defining a Digital Network Twin

Network Digital Twin

is a dynamic, virtual representation of a physical telecommunications network. It continuously mirrors the network's architecture, components, configurations, and behaviors by integrating real-time data from live systems. This enables continuous monitoring, simulation, and analysis-supporting more intelligent decision-making, operational efficiency, and proactive network management.

Unlike static models, an NDT evolves in sync with the physical network, making it a foundational asset across the entire network lifecycle-from design and deployment to optimization and maintenance.

Core Components of a Network Digital Twin

An effective NDT architecture typically comprises five interdependent elements:

1. **Data Sources**
   a. Real-time telemetry, configuration files, event logs, and topology data.
   b. Inputs from OSS/BSS, SDN controllers, and network probes.
2. **Mapping & Modeling Engines**
   a. Logical and physical topology reconstruction.
   b. Behavioral modeling of network elements and traffic flows.
3. **Simulation & Analytics Logic**
   a. Scenario-based simulations for capacity planning, fault prediction, and impact analysis.
   b. AI/ML-driven diagnostics and performance forecasting.
4. **Interfaces & APIs**
   a. Integration with orchestration platforms, monitoring tools, and external analytics systems.
   b. Support for bidirectional control and feedback loops.
5. **Application Layer**
   a. Visualization dashboards, alerting systems, and decision-support tools.
   b. Interfaces for diagnostics, automation, and closed-loop assurance.

Figure 1. Key Elements of a Network Digital Twin

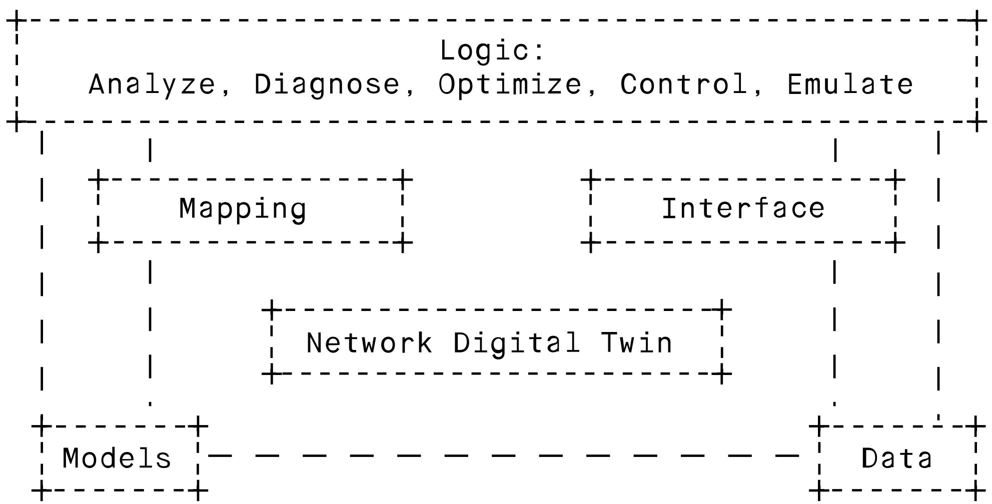
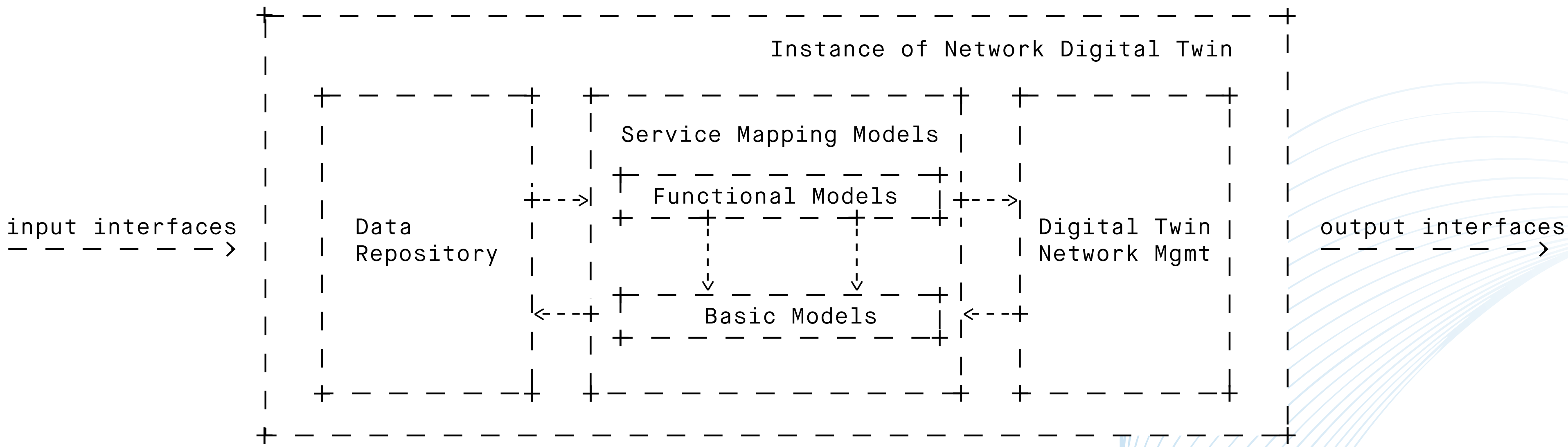


Figure 2. Example of a Reference Architecture for NDTs:



Source:IETF (https://www.ietf.org/archive/id/draft-irtf-nmrg-network-digital-twin-arch-07.html#arc Network Digital Twin IEFT)

CHAPTER 4

The Strategic Value of Network Digital Twins

Network Digital Twins

represent a transformative approach to managing modern telecom infrastructures. By creating a unified, virtual model of the network that integrates topology, telemetry, and service behavior, NDTs bridge traditional silos across planning, engineering, and operations. Rather than replacing existing tools, they orchestrate them within a dynamic environment where decisions are aligned, risks are modeled, and optimizations are continuously evaluated.

This shared, multi-layered view enables telecom teams to simulate scenarios-such as maintenance events, capacity shifts, or fault conditions-while performing predictive risk analysis and validating operational strategies. NDTs effectively close the loop between strategic planning and real-time operations: live performance data informs future design, while planning decisions are grounded in operational realities. The result is reduced friction, accelerated innovation, and improved infrastructure ROI.

CHAPTER 5

Business Impact and Value Realization

The adoption of Network Digital Twins offers transformative advantages for telecom operators seeking to enhance reliability, efficiency, and resilience. By enabling real-time simulation, predictive analysis, and scenario modeling, NDTs deliver measurable improvements across multiple business domains:

1. **Network Optimization**
   - Real-time monitoring and traffic simulation help identify inefficiencies and optimize resource allocation.
   - Supports proactive capacity planning and dynamic bandwidth management.
2. **Predictive Maintenance**
   - AI-driven trend analysis forecasts equipment failures.
   - Enables proactive interventions, reducing downtime and extending asset life.
3. **Enhanced Customer Experience**
   - Simulates end-user service levels under varying conditions.
   - Improves quality of experience and reduces churn through better service assurance.
4. **Faster Time-to-Market**
   - Virtual modeling of service rollouts allows testing and validation before deployment.
   - Reduces launch risks and accelerates delivery of new services.
5. **Cost Efficiency**
   - Simulation-driven planning avoids overprovisioning and unnecessary upgrades.
   - Enhances ROI by optimizing infrastructure investments and operational expenditures.
6. **Stronger Risk Management**
   - Enables impact analysis of network changes and cyberattack simulations.
   - Validates resilience strategies and ensures compliance with regulatory standards.
7. **Dynamic Network Adaptation**
   - Real-time configuration adjustments based on traffic trends, business priorities, or fault conditions.
   - Supports agile responses to operational changes and service demands.
8. **Seamless Integration with Emerging Technologies**
   - Facilitates adoption of 5G, Open RAN, IoT, and edge computing.
   - Provides a flexible, software-defined foundation for future network evolution.

CHAPTER 6

Implementation Considerations

Deploying a Network Digital Twin in a telecommunications environment requires more than just technical tooling: it demands cross-functional alignment and architectural rigor. As networks scale in complexity and heterogeneity, several critical challenges must be addressed to ensure successful implementation and long-term value realization.

1. Data Integration

Challenge	Considerations
Aggregating and harmonizing telemetry, topology, configuration, and performance data from diverse, often siloed systems.	• Establish robust data pipelines and normalization frameworks. • Ensure compatibility with OSS/BSS, SDN controllers, and legacy infrastructure.

2. Scalability

Challenge	Considerations
Modeling large-scale, multi-vendor, and geographically distributed networks in real time.	• Architect for horizontal scalability and modularity. • Leverage cloud-native technologies and distributed processing.

3. Real-Time Responsiveness

Challenge	Considerations
Maintaining continuous synchronization between the digital twin and the physical network.	• Implement event-driven architectures and low-latency data ingestion. • Use stream processing and real-time analytics engines.

4. Model Accuracy

Challenge	Considerations
Ensuring the digital twin reliably reflects actual network behavior, performance, and service impact.	• Validate models through iterative testing and feedback loops. • Incorporate AI/ML for behavioral prediction and anomaly detection.

5. Interoperability

Challenge	Considerations
Seamless integration with existing OSS, inventory systems, orchestration platforms, and third-party tools.	• Adopt open APIs and industry-standard interfaces (e.g., TM Forum Open APIs). • Design for backward compatibility with legacy systems.

6. Security

Challenge	Considerations
Protecting sensitive network data, models, and control interfaces from unauthorized access and cyber threats.	• Enforce zero-trust principles, encryption standards (e.g., TLS 1.3, IPSec), and role-based access controls. • Integrate with SIEM platforms and implement continuous threat monitoring.

7. Change Management

Challenge	Considerations
Embedding NDT insights into operational workflows and decision-making processes.	• Align stakeholders across planning, engineering, and operations. • Use agile methodologies to iterate and adapt processes incrementally.

8. Cost and Investment Justification

Challenge	Considerations
Managing the upfront investment and ongoing operational costs of NDT platforms.	• Build a phased implementation roadmap with measurable ROI milestones. • Leverage existing infrastructure and open-source components where feasible.

The successful deployment of a Network Digital Twin hinges not only on technical capabilities but also on organizational readiness and strategic alignment.

By addressing these challenges holistically, telecom operators can unlock the full potential of NDTs-enabling predictive operations, faster innovation cycles, and more resilient network ecosystems.

CHAPTER 7

In Practice: Ceragon's Network Digital Twin Journey

Looking to enhance service delivery, operational agility, and customer responsiveness, Ceragon partnered with intive to design and implement a scalable and user-centric Network Digital Twin solution. This collaboration exemplifies how modern software engineering practices and cross-functional development can drive transformative outcomes in telecom operations.

Project Objectives:

- Integrate data across planning, operational, and monitoring systems.
- Simulate real-time scenarios for proactive maintenance and network optimization.
- Deliver actionable insights to reduce outages, improve performance, and support faster decision-making.

Key Challenges:

- Aggregating and harmonizing large volumes of data from disjointed, heterogeneous systems.
- Ensuring real-time responsiveness while maintaining enterprise-grade data security.
- Accurately simulating complex network behaviors across multi-vendor, multi-technology environments.
- Transitioning from legacy systems without disrupting ongoing service commitments.

Technical Assessment and Design Approach:

A multidisciplinary team from intive—including system architects, DevOps engineers, and UX designers—conducted a comprehensive assessment of Ceragon's existing technical stack. This evaluation focused on:

- Integration potential with current systems.
- Scalability and modularity of the architecture.
- Development velocity and maintainability.
- User experience and operational usability.

The outcome was a set of actionable recommendations that guided the design and implementation of the NDT platform.

Solution Highlights:

- User-Centric UI/UX: A redesigned interface streamlined workflows, reduced cognitive load, and minimized the number of steps required to access critical insights. For example, related data is now accessible within a single tab, eliminating the need to open multiple windows.
- Kubernetes Orchestration: Enabled modular deployment, horizontal scalability, and high availability.
- API-First Architecture: Facilitated seamless integration with existing and future systems, supporting ecosystem expansion.
- Security and Identity Management: Leveraged Keycloak for identity and access control, ensuring compliance with enterprise security standards.
- DevOps Enablement: Standardized CI/CD pipelines and implemented robust versioning and compliance checks to support agile delivery and continuous improvement.

Outcomes and Impact

The implementation delivered real-time visibility and automation that significantly improved operational responsiveness. Continuous feedback loops and agile iteration cycles ensured that the platform evolved in alignment with user needs and business goals.

CHAPTER 8

Conclusion

As telecom networks grow increasingly complex and dynamic, Network Digital Twins are becoming essential tools for operators aiming to manage change with confidence. By bridging operational silos and enabling real-time simulation and planning, NDTs support smarter decisions, faster responses, and more efficient use of infrastructure.
To realize this potential, implementation must go beyond technical feasibility.

Success depends on aligning engineering practices with operational goals. Organizations that approach NDTs as long-term, evolving assets, are better positioned to unlock continuous value.

The collaboration between Ceragon and intive demonstrates how translating NDTs from concept to implementation can drive real operational gains. Rooted in agile engineering, user-centric design, and scalable architecture, their joint effort shows that successful NDT adoption is not only achievable-it's already underway.

Looking ahead, NDTs will continue to evolve as foundational assets, enabling telecom operators to build networks that are not only efficient today but also adaptable for the challenges of tomorrow.

About CERAGON

Ceragon is a global leader in innovative end-to-end wireless connectivity solutions, specializing in transport, access, and AI-driven managed and professional services.

Its clientele encompasses service providers, utilities, public safety organizations, government agencies, energy companies, and more. These organizations rely on Ceragon's expertise and advanced solutions for 5G and 4G broadband connectivity, mission-critical services, and a variety of applications that leverage exceptional reliability and speed.

About
intive

intive is a global technology company dedicated to crafting digital experiences that blend technical excellence with customer-centricity. Its team of 2,000 professionals, based across four continents, collaborates within intive's technology hubs.

Trusted by leading brands such as Audi, BMW, Deichmann, Meta, NewsCorp, Tandem, Paramount, Vorwerk, and Warner Bros. Discovery, intive offers agile thinking combined with deep expertise across industries, including Automotive & Mobility, Commerce, Financial Services, Healthcare & Life Sciences, and Technology, Media & Communication.

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