White Paper

VIAVI Solutions

VIAVI Network Digital Twin

Intelligent Twin Technology for efficient, reliable, secure 5G and 6G networks

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INTRODUCTION

In recent years, I've been fascinated by the concept of digital twins and how they're transforming various industries. Digital twins are essentially virtual replicas of physical systems, allowing us to simulate, analyze, and optimize in a virtual environment. This technology is incredibly powerful for iterating in a virtual world and accelerating business outcomes and value in the real world.

At VIAVI, we've been pioneering this innovation for use in telecoms networks. Traditionally, we've focused on testing and emulation in lab environments using synthetic data and bringing our knowledge of the field into the lab. However, we're now taking it a step further by taking that knowledge and expertise to incorporate the real data from networks into our digital twin engines.

This real data is essential for building applications and leveraging AI to fill data gaps and drive automation. Our goal is to create realistic scenarios that can be tested and scaled, ensuring the data we use is as accurate as possible.

We're also working on generating realistic scenarios for various applications, such as energy saving, x/r App validation, risk prediction and Joint Communications and Sensing (JCAS). By integrating real data into these simulations, we can test and evaluate factors like scalability and latency. This approach not only enhances the testing process but also provides a framework for validating applications in a community-driven environment.

Moreover, the integration of AI into our digital twin systems allows us to create new, previously unseen scenarios, enhancing the completeness and confidence in deployment. This collaboration between digital twin operators, data providers, and AI technologies is paving the way for innovative solutions and advancements in network testing and application development. The use of digital twins, real data, and AI is revolutionizing how we test and optimize networks, leading to more efficient and reliable and secure business outcomes.

– VIAVI CTO Office

ROLE OF DIGITAL TWINS IN TELECOMS

Digital twins enable network upgrades, ensure cross-vendor compatibility, and simulate communication protocols for seamless interaction. They help model end-to-end services, identify and address potential issues, and optimize network configurations.

Network Planning and Optimization

Digital twins are transforming telecom network planning and optimization. They enable virtual-first planning by simulating and testing network configurations before physical implementation, optimizing coverage and signal strength. Digital twins help identify bottlenecks, optimize traffic flow, and enhance overall network performance. They predict potential failures for proactive maintenance, assist in resource allocation, and enable testing of new technologies like 6G. By modeling the entire network lifecycle, digital twins support long-term planning, enhance reliability, and improve connectivity while optimizing resources and reducing costs.

Energy Saving Analysis

The telecom industry faces pressures to minimize its environmental impact. With rising global data consumption and energy demands, sustainable operations are imperative. Digital twin technology optimizes energy use while maintaining performance.

Real-Time Monitoring and Optimization digital twins provide a real-time view of energy consumption, allowing operators to:

- Detect inefficiencies earl.
- Optimize energy-intensive processes
- Adjust power usage dynamically

Network Design and Simulation digital twins simulate network configurations to test energy-efficient designs and optimize infrastructure for minimal power consumption. Dynamic Energy Management digital twins manage variable demand by powering down underutilized components and redirecting traffic to energy-efficient pathways. Integration of Renewable Energy digital twins model the integration of renewable energy sources, determining the ideal mix and optimal locations for installations.

Security and Resilience

Proactively address security challenges, enhance network resilience, and ensure more reliable communications infrastructure. Digital Twins enable continuous monitoring for potential threats, allowing for prompt identification and mitigation of security risks. They incorporate vulnerability assessments, model cyber-attack scenarios, and implement early attack detection systems, enhancing overall security posture. Digital Twins also allow operators to simulate various network conditions and potential failures, identify vulnerabilities, and ensure accurate testing of security measures like firewalls systems.

Integration and Interoperability

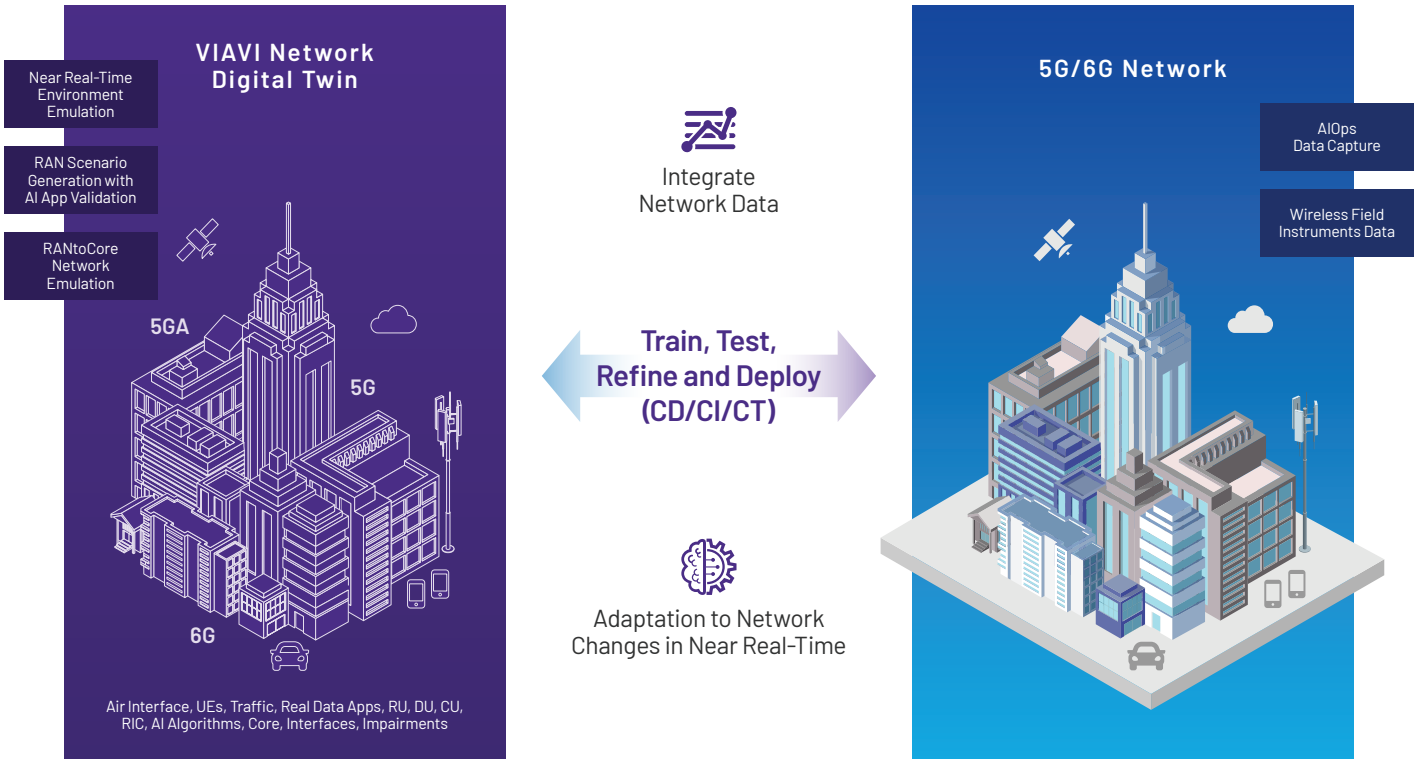
Essential for telco network integration and interoperability, digital twins provide a virtual environment for simulation, testing, and optimization. They allow telecom operators to create virtual replicas of network elements, test integration scenarios, and simulate interactions between different components and vendors' equipment.

Performance Validation

Digital Twins provide a virtual environment to simulate, test, and optimize network operations. They enable operators to replicate real-world network conditions and analyze performance metrics like scalability, reliability, and traffic flow without impacting the physical network. By syncing real-time data from the live network, digital twins allow for continuous testing of configurations, upgrades, and new technologies in a risk-free setting. This helps identify bottlenecks, predict potential failures, and validate corrective actions before deployment, ensuring seamless integration and enhanced service quality. They also facilitate automated testing workflows using continuous integration (CI) methods, improving accuracy and reducing operational costs. Through these capabilities, digital twins empower telecom operators to optimize network performance and reliability.

Automated Operations

Digital Twins validate AI/ML-driven decisions, enable proactive monitoring and management, and facilitate predictive maintenance. They enhance network performance and reliability through real-time optimization and automated responses. Digital twins also support network change management by testing new configurations before deployment, predicting degradations, and optimizing resources to reduce operational costs. These capabilities help telecom operators increase efficiency and reliability, advancing towards more autonomous network operations with minimal human intervention.



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VIAVI Network Digital Twin Solution

ENERGY SAVING ANALYSIS

Digital twins use predictive analytics to anticipate hardware failures, reducing outages and emergency repairs, and extending equipment lifespan. Network Design and Simulation digital twins simulate network configurations to test energy-efficient designs and optimize infrastructure for minimal power consumption. Dynamic Energy Management digital twins manage variable demand by powering down underutilized components and redirecting traffic to energy-efficient pathways. Integration of Renewable Energy digital twins model the integration of renewable energy sources, determining the ideal mix and optimal locations for installations.

In the 3GPP Study of management aspects of Network Digital Twin, five key use cases are defined for the role of NDT. One of the use cases, RAN Energy Saving is a focus for VIAVI.

RAN Energy Saving

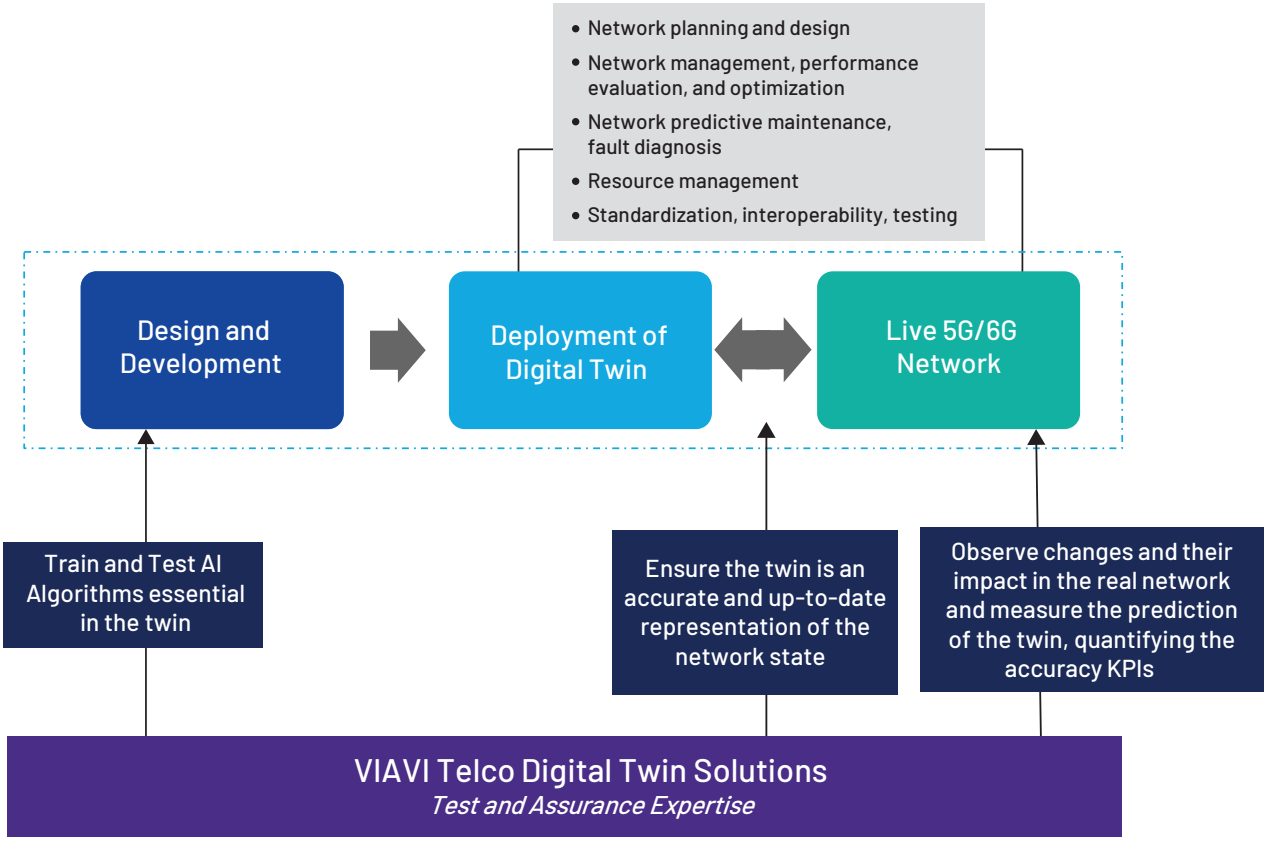
Network Digital Twin can verify the impact of energy saving policies, offering the opportunity to assess the real-time effects of these policies when applied to the network. VIAVI offers a range of digital twin technologies that significantly enhance energy efficiency in the telecom sector. Cloud-native RAN Intelligent Controllers (RICs) optimize RAN operations at scale and enable providers to onboard new applications that improve network performance and efficiency. Artificial Intelligence (AI) and Machine Learning (ML) transform the RIC into a dynamic, real-time power management tool – starting with xApp and rApp training in the lab. By emulating real-world cells, energy usage, and subscriber movements, TeraVM RIC Test trains RIC applications to operate within an optimized energy and QoE window. The effectiveness of recommended RAN optimization decisions and cell configuration algorithms are assessed and fine-tuned in the lab before deployment.

Real-Time Monitoring and Optimization	Predictive Maintenance	Network Design and Simulation	Dynamic Energy Management
VIAVI solutions provide real-time insights into network performance, enabling operators to detect inefficiencies and optimize energy use dynamically.	By using predictive analytics, VIAVI digital twins can anticipate hardware failures, reducing the need for energy-intensive emergency repairs and extending equipment lifespan.	VIAVI enables the simulation of various network configurations, helping operators design energy-efficient networks and optimize infrastructure placement. Link to Demo	VIAVI digital twins enable dynamic management of network components, powering down underutilized elements during low-demand periods and redirecting traffic to more energy-efficient pathways RAN Intelligence Solutions - VIAVI Video - English US

EVOLVING NETWORK DIGITAL TWIN SOLUTIONS

At VIAVI, our goal is to deliver solutions that understand, optimize and predict application performance without risking the live network. We offer a flexible and scalable solution that lets you choose individual components or complete RAN-to-Core digital twins. With a long history of providing solutions across Lab, Field, and Operations, and a leading R&D team, VIAVI is in the best position to demonstrate the accuracy and value of Network Digital Twin Use Case predictions.

We help customers build efficient, reliable, and secure networks, ensuring they run without energy waste or performance challenges.



Key Components of the VIAVI Network Digital Twin

Whether you're building your network replica and need support in validating its effectiveness, or you require a custom solution, the VIAVI Network Digital Twin offers the flexibility to support you in doing it your way.

Channel Modelling

VIAVI AI-powered Ray Tracing tool enables channel prediction for 3D environments, and supports planning for indoor and outdoor scenarios along with coverage and interference optimization, including for massive MIMO.

Traffic Modelling

At VIAVI, we begin by emulating thousands of mobile devices using the TM500 wireless network tester. This tool has been validated by nearly all manufacturers in the mobile network sector, ensuring a realistic digital twin. Next, we simulate system-level RAN behaviors, with the RAN twin reflecting real network conditions and system behaviors. Systems like TeraVM AI RSG (RAN Scenario Generator) can emulate a wide range of topologies, configurations, mobility patterns and traffic profiles on both real and synthetic maps. This allows us to generate large volumes of real-world traffic and comprehensively test and train AI engines and applications.

Network Synchronization Validation

By maintaining synchronization with the physical network, we ensure that validation is performed on an accurate and up-to-date representation of the network state.

Intelligent Data

NITRO Location Intelligence can be utilized to analyze every interaction between subscribers and IoT devices with the network. By providing contextual information about subscribers and devices, it allows for a precise understanding of network issues and optimization opportunities. In a digital twin scenario, NITRO Location Intelligence equips customers with the analytics needed to transform network data into actionable insights.

Live data capture solutions can enhance the network digital twin, making it a more realistic solution. Tools like the VIAVI Cloud-Native NITRO AIOps (AI for Network Operations) platform facilitate the collection and aggregation of extensive data.

Our Wireless field instruments are a key element by gathering real measurements from the network, thereby improving the accuracy of our modelling.

Security Solutions

We provide security test cases across the wireless ecosystem to ensure that network components are security compliant and do not affect network performance. Additionally, we help you understand how your network performance would fare under the weight of a cyber attack.

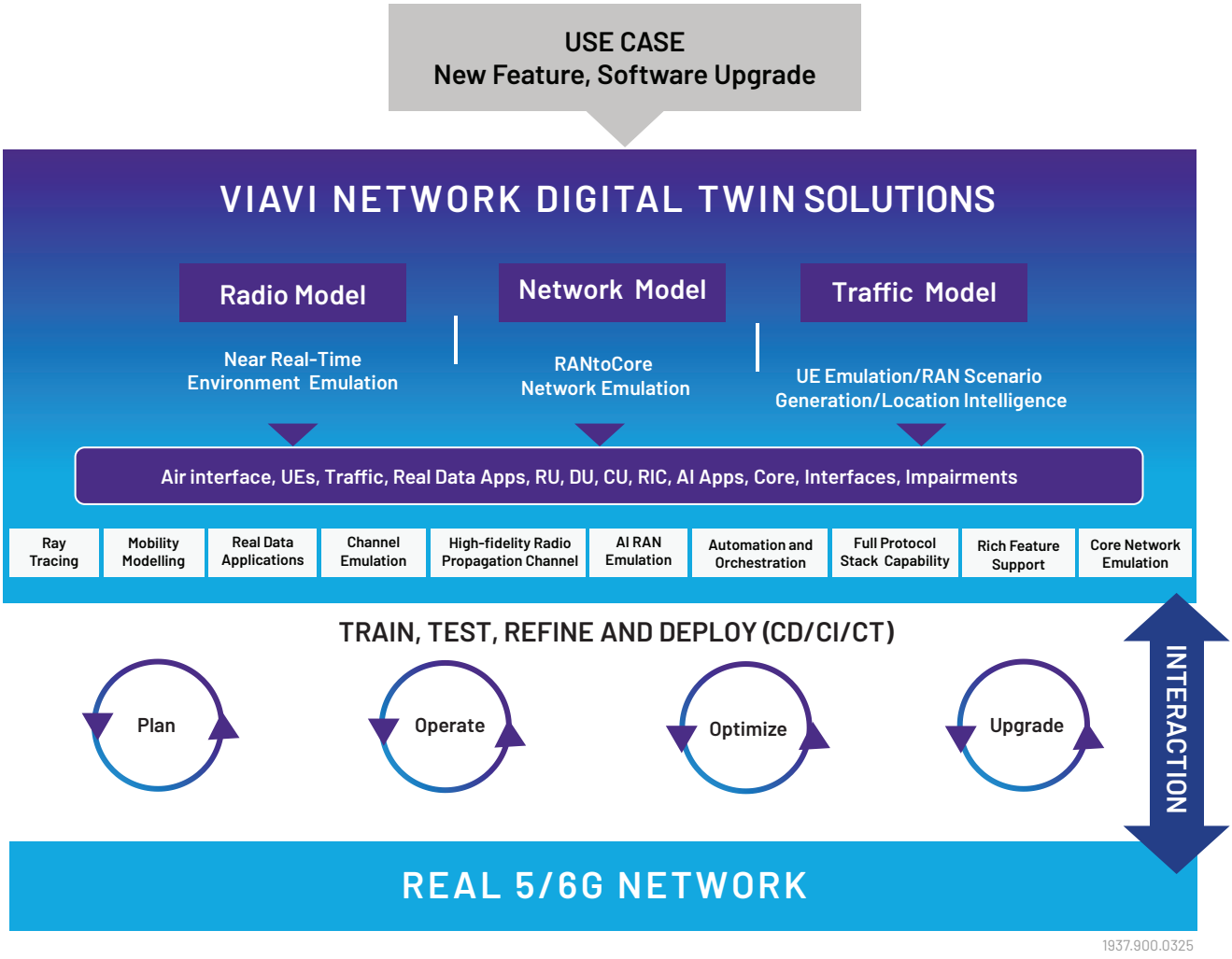
Automation

To streamline and automate the testing of campaigns, cases, and executions, and make the testing less prone to error, VIAVI offers the

VIAVI Automation Management and Orchestration System (VAMOS).

NITRO® Wireless Product and Technology Enablers

	Complete Network Digital Twin	UE Digital TWIN	RAN Digital TWIN	NTN Digital TWIN	Core Digital TWIN
TM500 UE Emulation	●	●	●	●	
TeraVM AI RAN Scenario Generator	●		●	●	
TeraVM CU, DU Emulation			●		
TeraVM App Validation Engine	●		●		
TeraVM Core Emulator	●			●	●
VAMOS Automation	●		●		●
Ray Tracing	●	●	●		
AI	●	●	●	●	●
TeraVM Security	●		●		●
NITRO Location Intelligence and AIOps	●				
Wireless Field Instruments – xEDGE, OneAdvisor 800	●	●	●	●	
Partner tools – R&S				●	



Train, Test, Refine and Deploy

NETWORK DIGITAL TWIN SOLUTIONS

BEYOND 5G USE CASES

Use Case 1

Network Equipment Manufacturers

Proving Your 6G Radio capability – In-building 6G radio performance

At the early stages of 6G radio development, proving the benefits of FR3 radio over previous generations can be challenging. For example, with only one 6G radio available on location and a single UE for calibration input, how can you demonstrate radio performance with multiple moving UEs, interactions with 5G radios, and responses to network anomalies?

Ray tracing is a powerful technique used in telecommunications for modeling and analyzing radio frequency (RF) propagation in various environments. By performing precise in-building ray tracing in a particular environment, you can simulate how wireless signals interact with features of the environment, such as walls, corners, and other obstacles.

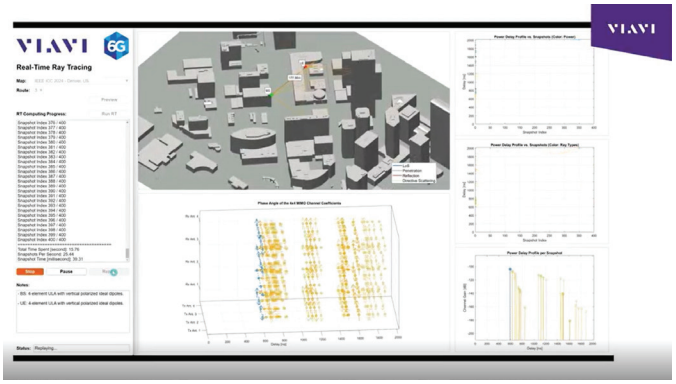
Ray Tracing with AI RAN Scenario Generation to scales up multiple simulated radios with similar characteristics. TM500 UE emulation can provide multiple UEs across the environment. It becomes easy to map both FR1 and FR3 simulations to visualize both 5G and 6G networks in sync.

The Network Digital Twin provides the ability to inject anomalies and plan various scenarios depending on thousands of variables.

Engineers now have the tools to design, analyze, and optimize communication systems, enabling them to plan better performance and coverage in different environments.

This Digital twin incorporates:

- TM500 Network Tester (UE Emulation)
- TeraVM AI RAN Scenario Generator (AI RSG)
- VIAVI Air Interface Emulation - Ray Tracing (RT)
- VAMOS (Automation and Orchestration)



Ray Tracing Capture

Use Case 2

Network Equipment Manufacturers

6G Joint Sensing and Communication (JCAS) Validation - test and verify sensing algorithms performance

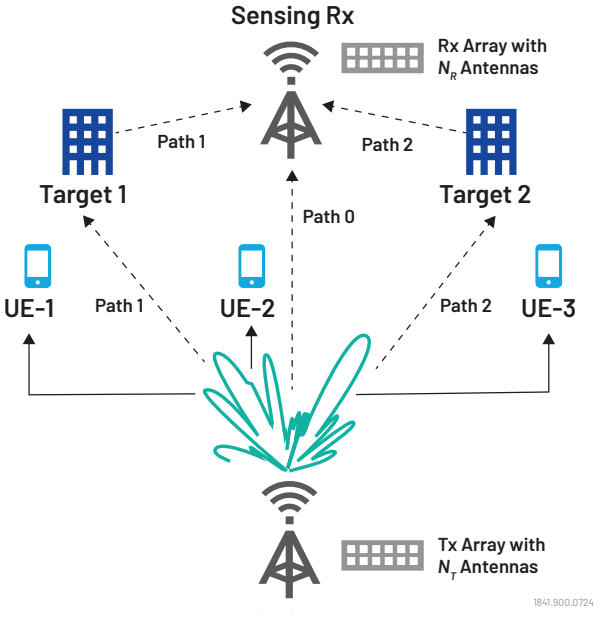
JCAS is providing new capabilities in 6G networks, such as high-accuracy localization, gesture recognition, and environmental mapping, while simultaneously enhancing communication services. JCAS integration into 6G base stations and radios is being achieved through several innovative approaches. These include unified hardware platforms that combine communication and sensing functionalities, shared spectrum usage for both tasks, and the development of dual-functional waveforms. 6G JCAS-enabled base stations are being designed to operate across multiple frequency bands, including sub-6 GHz and mmWave, to support diverse use cases.

The integration also involves coordinated multipoint JCAS, allowing multiple base stations to cooperate for improved performance. AI is being incorporated to dynamically adapt networking resources based on radio-side measurements. Advanced JCAS systems in 6G aim to utilize full-duplex technology for simultaneous transmission and reception on the same frequency resources. Additionally, 6G base stations are implementing advanced beamforming techniques to maximize both communication and sensing performance. The challenge is, how can you validate that these JCAS algorithms will work as expected?

VIAVI Network Digital Twin provides solutions for mono-static and bi-static use cases.

This Digital twin incorporates:

- Near-Real-time Raytracing Solution for JCAS RF (Environment)
- Channel Modelling:
  - UE emulation for communications
  - Ray tracing to emulate channels with targets, such as drones, cars, pedestrians, buildings, walls
  - Sensing Receiver emulation for sensing operations
  - Map-based channel emulation



Use Case 3

Network Equipment Manufacturers

RAN Digital Twin – x/rApp Security

Validate the security of APIs (Application Programming Interface) used by xApps and RIC, implementing proper input validation, rate limiting, and access controls.

- Evaluate the system of x/rApps and RIC in real scenarios
- Evaluate the impact on the real network ahead of deployment to ensure changes will be positive and not lead to performance and/or security degradations
- Traffic modeling based on real GEO Location and App utilization models

This Digital twin incorporates:

- VIAVI TeraVM AI RSG
- VIAVI Location Intelligence

Use Case 4

Mobile Network Operators

MU-MIMO Deployment Scenario

How can you test that MU-MIMO deployment performs as expected in dense, highly populated environments? How can you shift-left test correctly and capture all field corner cases in the lab to ensure the gNB coordinates multiple devices with minimal interference? Poor decisions lead to poor customer experience and can be expensive to fix in the live network.

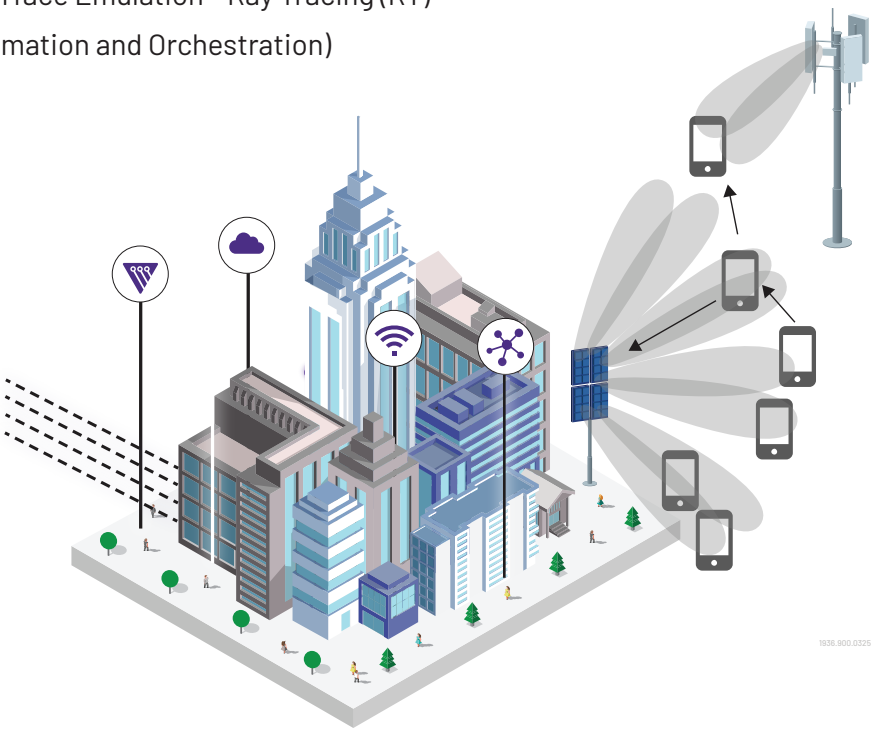
Replicate real-world Air Interface scenarios in the lab with high fidelity:

- Subscriber profiles (mobility, traffic type)
- Import real maps
- Emulate dynamic fading channel conditions with spatially distributed devices.

Connect via digital or RF interface to the network and assess performance (E2E or at component-level) in a fully automated shift-left testing approach.

This Digital twin incorporates:

- TM500 Network Tester (UE Emulation)
- TeraVM AI RAN Scenario Generator (AI RSG)
- VIAVI Air Interface Emulation - Ray Tracing (RT)
- VAMOS (Automation and Orchestration)



MU-MIMO Deployment Scenario

Use Case 5

Mobile Network Operators

Beam Management and Handover Algorithms Validation – V2X/V2N Wireless Communications

V2X/V2N wireless communications need validation for:

- AI/ML-based beamforming algorithms
- Signaling protocols
- Handover technologies

Handover Parameter Optimization: Digital twins enable the simulation and testing of different handover parameters without impacting the live network. A reinforcement learning approach using digital twins has been shown to improve handover performance.

Beam Management: Simulate and evaluate different beamforming strategies in the digital twin environment before deploying them in the physical network. You can approximate channel conditions using 3D models and ray tracing.

The digital twin allows for the simulation of interference patterns and optimization of power allocation to minimize inter-user interference. TeraVM AI RAN Scenario Generator (AI RSG) can serve as a RAN simulator, APIs for handover and beam management exposed to customers to ingest their algorithms. TeraVM AI RAN Scenario Generator generates a realistic RAN environment – moving scatterers/UEs, Ray Tracing accurately modelling blockage – key for testing beam management and handover algorithms. AI RSG KPIs, e.g., throughput and BLER, for evaluating Network Operator algorithms.

This Digital twin incorporates:

- TeraVM AI RAN Scenario Generator (AI RSG)
- VIAVI Air Interface Emulation - Ray Tracing (RT)

Use Case 6

Digital Twin for Security Breach Prevention

As mobile networks are susceptible to security breaches due to millions of end points (UE, IoT devices), network elements from different vendors, open interfaces, regular software updates, fuzzing and spoofing techniques, there are constant threats to operators, enterprises and users.

Signalling Storms

A signalling storm occurs when the number of devices attempting to connect or send signals to a network overload network resources and cause service disruptions, including major connectivity issues and service degradation.

Several high-profile network service outages worldwide in the last decade that were attributed to signalling storms, resulting in financial losses running into millions of dollars.

For IoT networks, where the number of devices that need to communicate can run into the millions, signalling storms can be disastrous for the network operator and the enterprises. The storm could result in the IoT network being taken completely offline for hours or days.

A network digital twin is the perfect sandbox to perform a 'safe attack' on a mobile network and to help understand the impact it can have on end user performance, critical infrastructure and CPU processing.

By realizing the impact, different mitigation techniques can be put in place to protect the network.

The Digital twin Incorporates:

- VIAVI TeraVM AI RSG
- VIAVI TM500 Network Tester
- VIAVI vRAN Emulation Capability

Use Case 7

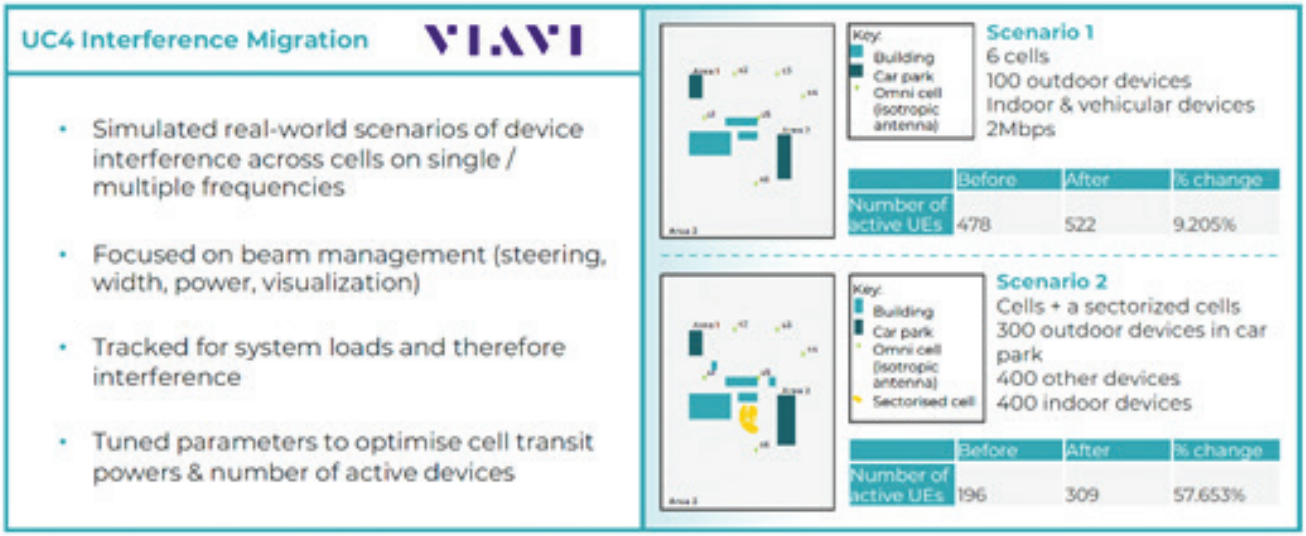
Interference Mitigation

As part of the ARI-5G project led by TIP, VIAVI contributed to interference mitigation in Open RAN by developing an Interference Mitigation xApp and providing network simulation capabilities.

- The VIAVI interference mitigation xApp was designed to address inter-cell interference, where downlink or uplink transmissions for a UE are disrupted by transmissions from other UEs served by nearby cells.
- By dynamically managing the power allocations based on data collected from the network expressing the way the UEs use the network, the solution reduced aggregate interference and improved the overall network performance.

A key enabler of this solution is VIAVI's digital twin technology, which replicates the radio network environment with a high level of fidelity and allows to predict network performance for a given configuration. The digital twin provides a controlled environment to assess the impact of different optimization changes aiming to mitigate the interference, ensuring that the optimizer selected the most effective network configuration.

Testing results demonstrated a 50% increase in the number of active UEs, highlighting the effectiveness of this approach in improving service quality. The results validated the potential of digital twin-based technology in accelerating RIC application development and deployment to support more efficient and adaptive 5G networks.



Use Case 8

Digital twin-assisted RAN Optimization for Energy Saving

VIAVI Solutions collaborated with a leading European mobile operator to optimize radio access network (RAN) energy consumption while maintaining service quality as part of a GSMA-led initiative on energy savings.

The project leveraged VIAVI's RAN optimization solution, which integrates digital twin technology to model network behavior and recommend configuration changes that balance power savings with performance requirements. The optimization process focused on identifying sectors that could be switched off while ensuring stable service levels.

- Using geolocated call trace data and advanced algorithms, the VIAVI solution provided targeted adjustments to power levels and antenna tilts across a cluster of cell sites.
- The optimization resulted in power increases, tilt adjustments and cells deactivation successfully reducing energy consumption while preserving critical performance indicators, including signal quality, call success rates, and handover efficiency.
- The digital twin environment allowed for precise accurate pre-deployment evaluation of optimization strategies prior to deployment of the changes in the live network, reducing risks associated with real-world network changes.
- By dynamically modeling the impact of adjustments, the operator was able to implement an energy-saving strategy that aligned with operational constraints and service-level targets.

It resulted in 5% of energy savings through power reduction strategies corresponding to 2.5% reduction in operational expenditure (OPEX) whilst maintaining performance KPIs.

The results of this project demonstrated how digital twin-assisted RAN optimization can reduce operational expenditures and improve network sustainability.

Use Case 9

Chipset Vendors

Ray Tracing for xURLLC Applications – Closed-loop Digital Twin

Providing near-real-time beam measurements for testing xURLLC applications. Delivering a closed-loop digital twin that adapts to the dynamic changes in the environment, especially moving objects. Some sensing algorithms can provide updated locations of moving objects and the material properties, e.g., permittivity, conductivity, reflectivity, and scattering.

VIAVI's GPU-accelerated near-real-time Ray Tracing updates the 3D model of the environment, capturing new locations of moving objects and material properties.

This closed-loop digital twin is used at the gNB for beam management:

- Sensing algorithm gives UE location
- Ray Tracing predicts path loss at UE location for all beams in the gNB's codebook
- gNB uses the predicted path loss for the selecting beam for the UE

Beam management at gNB can be carried out without RSRP reporting from UE, which is a key metric for xURLLC

This Digital twin incorporates:

- VIAVI Air Interface Emulation - Ray Tracing (RT)

DIGITAL TWIN INDUSTRY RESEARCH AND DEMONSTRATION

Country	Project Name	Description
U.S.A.	6G City-Scale Digital Twin	**Open 6G** Our collaborations with renowned research institutions such as the Institute for Wireless Internet of Things and the Open6G cooperative research center at Northeastern University have resulted in a 6G city-scale digital twin. Powered by advanced AI and machine learning (ML) technologies, it is crucial for training components like the 6G AI-Native Air Interface, advancing our understanding of network dynamics and performance. This achievement underscores the importance of AI/ML in radio propagation modeling for large-scale network digital twins, integrating insights from real-world measurements and higher-layer KPIs through cooperative efforts.
U.K.	TUDOR	VIAVI provides 6G integration and testing and will participate and co-lead 6G research and innovation work ,including: • 6G 3D channel modelling • 3D RAN digital twin • Semantic communication Awarded a £12M research grant from the UK government to advance Telecoms networks, the project involves a consortium of UK universities and international operators and vendors. It aims to tackle big challenges such as the digital divide and energy efficiency through research and innovation in open network components. Hosted by 5G/6G Innovation Centre at the University of Surrey, the project explores and expands on Open RAN principles, focusing on new open network components and their technical capabilities, as well as interoperability in the wider RAN and core. This initiative marks significant progress for the industry and society, uncovering new testing challenges and opportunities in 6G networks.

Digital Twin Industry Research and Demonstration continued

Country	Project Name	Description
Europe	6G-TWIN	**6G-TWIN** is already laying the foundation for digital twins to empower operational networks, focusing on reactive and predictive network digital twins to enable tele-operated driving and energy-saving use cases. 6G-TWIN Objective: provide the foundation for the design, implementation, and validation of an AI-native reference architecture for 6G systems. This architecture incorporates Network Digital Twins as a core mechanism for the end-to-end, real-time optimization, management, and control of highly dynamic and complex network scenarios. To achieve this, 6G-TWIN will deliver methods, modeling, and simulation solutions for the definition, creation, and management of multi-layered virtual representations of future 6G systems, where heterogeneous domains (i.e., edge, fog, and cloud) and communication technologies (e.g., cellular, optical, and Non-Terrestrial Networks (NTN)) coexist. The associated solutions will be demonstrated in two complementary use cases addressing mobility and energy-efficiency challenges, aligned with the expected use cases of 6G and the Key Performance Indicators (KPIs) defined in previously funded projects.
U.K.	Open Networks Ecosystem (ONE)	**ARIANE (Accelerating RAN Intelligence Across Network Ecosystems).** This project will simulate a real-world multi-vendor Open RAN small-cell environment with multiple RICs and xApps/rApps. The project will analyze and recommend opportunities for security hardening, measure the impact on RAN performance in various test scenarios with multiple xApps and rApps, and provide insights for standards development within the O-RAN ALLIANCE. VIAVI TeraVM RIC Test will support multiple RICs to test xApps and rApps for energy management, traffic steering, advanced traffic steering, and QoS-based dynamic resource allocation.

Digital Twin Industry Research and Demonstration continued

Country	Project Name	Description
Singapore	O-RAN ALLIANCE Global Plugfest	**Advanced Digital Twin for Network Energy Saving** - The Singapore University of Technology and Design (SUTD), in partnership with VIAVI Solutions and QCT, introduced an advanced Digital Twin (DT) solution to enhance energy savings in O-RAN based 5G networks. The team developed a synchronization rApp that keeps the virtual version of the 5G network (the DT) synchronized with the actual network in real-time. Powered by VIAVI's TeraVM AI RAN Scenario Generator (AI RSG), this DT provides a safe and efficient way to train and test AI models for energy-saving strategies without risking disruption to the live network. Using the DT, the team successfully trained and tested energy-saving strategies, which were then validated in a smaller real-world setup using QCT's O-RAN OmniRAN system. This proved that the energy-saving decisions derived from the DT could be readily applied to actual networks. Because the solution follows O-RAN's open interface standards, it is highly scalable and can easily integrate with other O-RAN systems. This innovation demonstrates how DT technology can make 5G networks greener and more efficient.

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