Validating Tomorrow's Networks Today

A Technical Overview of Digital Twin Solutions for ISAC, NTN, and End-to-End Network & Device Validation.

Channel Studio GCM, Raysim, GCM ISAC, GCM NTN, EXata & AI RAN Simulation Toolset

Why Digital Twin Testing Is Required

Wireless and network products are now expected to work correctly in conditions that cannot be reproduced, safely repeated, or even physically accessed on demand: a satellite constellation, a shared sensing-and-communication radio with no field standard yet, a 64-element beamformer at FR3/THz, or an AI algorithm that must be proven across thousands of live cells before rollout. Field trials remain the ultimate proof point, but they cannot be the first test - they are too costly, too slow to iterate on, and too risky to run trial-and-error.

A digital twin closes this gap. It is a living, dynamic model - software, hardware, or a combination of both - that stays continuously linked to, and updated from, its physical counterpart, letting engineers reduce deployment cost and risk while accelerating optimization and validation before acting in the real world. Keysight tools allow to build twins from two complementary modelling methods: physics-based models (ray tracing, geometry, propagation) for deterministic "what-if" simulation, and data-driven models calibrated from real, measured data - the foundation for AI/ML.

Why Now — Three Converging Pressures that Make Lab-Based Digital Twins Non-Optional

- **Standards can't keep pace with use cases:** Current 3GPP positioning standards let a connected device report its own location, but they were not built to detect an object that has no connection to the radio access network at all - the exact capability ISAC must add. Testing unstandardized capabilities demands emulation, not field trials
- **Precision requirements have moved up-band:** 6G's FR3 spectrum (7–24 GHz) and near-field, sensing, and positioning use cases demand materially more precise channel modeling than prior generations - precision that only deterministic, site-specific models can supply.
- **The cost of getting it wrong at scale is now systemic, not local:** An AI-RAN optimization that misbehaves is not a single dropped call - it is a policy applied across a nationwide RAN. Validating it against a high-scale digital twin before deployment is the only practical way to catch that class of failure early.

KEYSIGHT

Solution Architecture: One Modeling Core, Purpose-Built Extensions

Rather than maintaining separate tools for every use case, Keysight builds outward from a common geometric channel modeling core (GCM) inside Channel Studio. RaySim adds deterministic ray tracing on top of that same modeling philosophy; the ISAC and NTN options extend GCM's antenna and propagation engine for sensing and satellite scenarios respectively. EXata extends the twin outward to the full multi-technology network; and the AI RAN Simulation Toolset consumes data from all of the above to train and benchmark AI models. Every path converges on PROPSIM / other Keysight Products in hardware-in-the-loop, so a model validated in software can be replayed as a real, repeatable RF stimulus against a real device or network element.

Layer	Tool / Option	What It Adds
Core channel model	Channel Studio GCM	3GPP geometry-based stochastic channel & antenna-array modeling
Deterministic RF twin	Channel Studio RaySim	GPU/AI-accelerated ray tracing over real 3D maps for spatial consistency
Sensing extension	ISAC Channel Emulation Toolset	Sensing-target, micro-motion, and radar-cross-section modeling on the GCM core
Satellite extension	Channel Studio Non-Terrestrial Network (NTN)	LEO/MEO/GEO orbital, delay, Doppler, and atmospheric modeling on the GCM core
Network twin	EXata Network Modeling	L1–L7, multi-domain (air/ground/sea), full protocol-stack network digital twin
AI/data layer	AI RAN Simulation Toolset	Dataset generation, curation, and benchmarking across all the above

Addressing Development Needs & Challenges

Each tool in the portfolio exists because a specific customer cannot test what they need to test today. The table below states that problem explicitly before the technical sections unpack how each tool solves it.

Tool	Current Limitations	Key Contributing Factors
GCM	Create a standards-compliant channel scenario quickly without deep RF propagation expertise.	Accurate modeling of multipath propagation and antenna correlation typically relies on expert knowledge and substantial engineering effort
RaySim	Know whether a design will perform at one specific real site (rooftop, stadium, factory floor) before installing hardware at the location.	A stochastic average model can't predict site-specific performance, and a field drive test is a single, non-repeatable, weather-dependent snapshot.
GCM - ISAC	Verify seamless coexistence of sensing and communication functions in the chipset before production	Sensing and communication now share one chip, one antenna, and one spectrum band, with no mature field standard or live network to validate against.
GCM - NTN	Validate satellite handover performance, Doppler compensation, and latency resilience prior to device deployment.	No operator can grant a device team dedicated time on a live satellite constellation. A multi-constellation, multi-operator scenarios are emerging fast.
EXata	Ensuring reliable interoperability among wireless, wired network, and other interface of network in large-scale network environments.	Assembling thousands of real, multi-vendor network (wired/wireless) nodes in a lab is cost-prohibitive and cannot be done without disrupting a live network.
AI RAN Toolset	Prove an AI/ML model's claimed improvement is real, safe, and explainable before it runs autonomously on a live network.	A model can look accurate on a training dataset yet behave unpredictably under network conditions the dataset never covered.

GCM - Geometric Channel Modeling (the Foundation)

GCM is Channel Studio's geometry-based stochastic channel and antenna-array modeling engine and PROPSIM's standard modeling front end. It lets an engineer set up a virtual environment in which every transmitter and receiver has a physical location and RF characteristics, with location, speed, and orientation that are fully dynamic - radios move along predefined paths at varying speeds and orientations, and links update live during emulation.

The GCM has a feature which allows to builds the Ant3D antenna files from real measured or theoretical element models for MIMO, beamforming, and diversity array construction - configuring per-element position, rotation, and PROPSIM port mapping, with amplitude/phase weighting to build reusable sub-arrays that scale into larger arrays.

Because the 3GPP standard defined scenarios and cluster generation are built in and GUI-driven, a test engineer without deep RF propagation modeling expertise can create a standards-compliant scenario directly, rather than deriving multipath cluster tables and correlation matrices by hand - lowering the specialist-skill barrier to getting a valid test running.

RaySim - Deterministic, Ray-Traced RF Digital Twins

Where GCM's stochastic and semi-deterministic models give a realistic and accurate average description of a channel, RaySim adds the deterministic end of the spectrum: full ray-traced path calculation over an accurate, site-specific 3D map. This is what earns the name “digital twin” in the strict sense - full spatial consistency between the model and a specific physical location.

RaySim is an advanced RF ray-tracing and digital-twin creation tool that combines high-fidelity 3D environmental modeling with GPU-accelerated and AI-enhanced computation, bridging the gap between simulation and real-world emulation for 5G-Advanced and 6G development.

RaySim can be used to build a photorealistic RF digital twin of massive-MIMO network for verifying site-specific propagation effects against lab-based testbed measurements. A digital twin of a large private network covering a city can be built from ray-tracing models, LIDAR, telco configuration data, open-source data, lab measurements, and live telemetry combined.

RaySim scenario is tied to an actual imported 3D map rather than a one-time field measurement, the same site can be re-simulated with antenna placement, tilt, or frequency plan changes - turning a site survey from a single field event into a reusable, on-demand design tool that supports iterative what-if comparisons.

GCM for ISAC - Sensing-Target Channel Modeling

Integrated Sensing and Communication (ISAC) ask's one chip, one antenna, and one shared spectrum band to do two jobs with independent - sometimes conflicting - KPIs. Current 3GPP standards support positioning for devices that are already connected to the network, but they do not have the built-in capability to detect an object that has no connection to the radio access network at all. Closing that capability gap is the point of ISAC, and it is exactly the kind of capability that cannot be validated against an existing field standard, because no mature field standard for it exists yet.

The Wireless Sensing Modeling Tool is built directly on the Channel Studio GCM core and extends it for wireless sensing and ISAC. It follows the 3GPP TR 38.901 Rel-19 modeling approach while adding capabilities to the base communication-only model doesn't need: Sensing-target modeling, Micro-Doppler and micro-motion modeling, Background channel modeling for the communication path with beamforming, and TRP monostatic ISAC testing.

Sensing-relevant channel effects modeled include Doppler, multipath, channel delay, signal direction, range path loss, blocking effects, noise, and programmable interference - the same effect set a physical sensing environment would present, reproduced deterministically and repeatably in the lab.

GCM allows Sensing only, Sensing + MIMO communication and Sensing + massive-MIMO communication. Because all three types have the same 3GPP-aligned framework, a team can validate sensing-only R&D today and grow into full ISAC validation later without replacing the underlying tool chain.

Sensing and communication sharing one chip and antenna introduces a failure mode traditional single-function radio test never exercises - full-duplex self-interference between the outgoing sensing waveform and the simultaneously received communication signal. GCM's combined sensing-plus-background-channel modeling is what allows this specific interaction to be characterized before tape-out, rather than discovered afterward.

GCM for NTN - Satellite Channel & Orbit Modeling

No operator launches a satellite to certify a single device, yet a device must still perform correctly against orbital delay, Doppler shift, and shadowing that only exist above the atmosphere. The Channel Studio NTN option extends the same GCM core with flexible propagation-channel modeling between ground stations and LEO, MEO, and GEO satellites.

- Dynamic, phase-coherent delay and Doppler modeling, tracking the geometry of a moving satellite against a ground station or UE in real time.

- Atmospheric path loss including rain attenuation per ITU-R P.618, and 3GPP TR 38.811-aligned TDL and CDL multipath fading channel models for NTN - a standards-referenced atmospheric model that goes beyond generic terrestrial fading.
- NTN channel modeling for 2x2 and 2x4 MIMO multi-element antennas, extending single-link NTN testing to multi-antenna satellite links.
- Orbit data import via satellite ephemeris and Two-Line Element (TLE) files, the standard format for describing a satellite's orbital parameters at a given time - letting a test scenario be built directly from real published orbital data rather than a hand-built trajectory.
- OpenStreetMap and GPS-coordinate definition for ground-station and UE placement.
- Transparent (bent-pipe) and regenerative (on-board gNB) link and multi-link scenario support, covering both classic relay satellites and next-generation satellites that process the signal on board.
- Mixed terrestrial/non-terrestrial handover and multi-satellite handover testing, inherited from the GCM core and specialized for satellite constellations.

Spec	Value
Satellite links / unit	16 or 64 (PROPSIM F64 / FS16 + Aerospace option)
Coverage	Seamless L/S-band
RF range	3 MHz – 7.25 GHz (up to 100 GHz with external HW)
Channel bandwidth	40 – 1600 MHz, fully cross-connected routing
Max Doppler	± 1.5 MHz
Max delay	1600 ms

As direct-to-device satellite services expand beyond a single operator, a device may need to hand- over between constellations with different orbital parameters and waveform choices. Multi-satellite handover modeling combined with TLE import lets this be rehearsed using orbital data from more than one real constellation, without requiring simultaneous lab access to more than one live operator's network.

EXata - Network Digital Twin

GCM, RaySim, and their ISAC/NTN extensions, model the RF channel between specific radios. EXata takes the twin outward to the full network: a discrete-event, multi-technology digital twin spanning Layer 1 through Layer 7, across satellite, 4G/5G, military, and IoT networks, in any environment or condition, running at real-time or faster-than-real-time speed.

- Design Mode: build the virtual network model - nodes covering routers, switches, access points, satellites, mobile phones, radios, sensors, servers, and firewalls.
- Visualize Mode: execute the scenario and observe network behavior as it unfolds.
- Analyzer: process results and generate reports characterizing network performance.
- System-in-the-Loop emulation interface: seamlessly integrate live hardware and applications into the simulated network, so real equipment and virtual nodes interoperate in the same run.

- Optional Cyber Library: adds defense and vulnerability modeling, supporting a wide range of simulated cyber-attack scenarios for resiliency assessment without exposing a live network to real attack traffic.

EXata's network-and-device validation footprint also covers cybersecurity (firewalls, DoS, intrusion, ransomware, and cyber-resiliency assessment against real attack tooling), tactical and defense networks (Link-16/JTIDS, electromagnetic spectrum operations, jamming), smart-network/IoT supply-chain monitoring (BLE, Wi-Fi, LPWAN, cellular with indoor ray tracing), and underwater acoustic/free-space-optical communications - all evaluated in the same digital twin framework before field deployment.

Because Design Mode lets any node type - router, RU, DU, CU, or firewall - be swapped independently of the others, a specific vendor's DU or RU can be substituted into an otherwise identical network twin, giving operators a direct, apples-to-apples way to compare multi-vendor components under the same traffic and mobility conditions before a procurement decision.

AI RAN Simulation Toolset - Digital Twins for AI Itself

AI models embedded in the RAN raise a validation problem the RAN itself does not have: an AI model can look correct on a benchmark dataset and still fail once it meets network conditions the dataset never covered. The AI RAN Simulation Toolset addresses three problems the industry has not solved: generating high-quality, curated datasets for AI algorithm development; performing high-volume data generation, benchmarking, and inference inside a digital twin environment; and validating that an AI algorithm's performance improvement is real rather than a lab artifact.

- Three data sources: the Network Digital Twin (high-scale, high-fidelity RF/network data), Emulated Testbeds (Keysight UE/RU/DU/O-RAN/core emulators), and Live Network data.
- Benchmarking scores: functional accuracy (precision/recall/F1, often >95% target), real-time performance (<10 ms inference), and resource efficiency (CPU/GPU/power).
- Full traceability: versioned datasets, models, and results, storable on-prem, hybrid, or in the cloud (AWS/GCP/Azure, S3-compatible).

Recent Proof Points

- A demonstrated integration with the NVIDIA Aerial Testbed, NVIDIA Aerial Omniverse Digital Twin, and commercial radio hardware including Analog Devices' Titan O-RU platform, orchestrating an end-to-end workflow that automates dataset/scenario generation, AI/ML model training, and repeatable benchmarking.
- Keysight and Qualcomm RF digital twins for massive MIMO and AI-native 6G research, and a Keysight–Samsung–NVIDIA end-to-end AI-RAN validation workflow (both announced March 2026).
- An Energy Efficiency rApp use case achieving a 17.3% energy reduction and +5% energy efficiency (Mbits/Joule), with QoS impact held under 2%.

The toolset pairs benchmarking with explainability rather than accuracy scoring alone. Operators and regulators need to know why an AI model made a given decision, not just how often it was statistically correct - explainability is what turns a benchmarking number into an auditable basis for approving autonomous network control, which matters as more optimization decisions move from human-reviewed to fully automated.

How These Tools Enhance Customer Product Testing

The technical value of the portfolio is not any single tool - it is that every model, from a single antenna element to a nationwide RAN, terminates on the same PROPSIM/Keysight tools with hardware-in-the-loop bridge. That continuum changes what a customer's test program can do at each stage of a product's life:

Customer	Testing Challenge Today	How the Digital Twin Portfolio Helps
Chipset / device makers	Must validate ISAC, NTN, and massive-MIMO designs long before a field standard or live network exists to test against.	GCM/ISAC and GCM/NTN reproduce the exact channel and orbital conditions in the lab, on repeatable, on-demand schedules instead of one-shot field trials.
Network equipment manufacturers (RAN/gNB)	Need to prove 16TR–64TR beamforming, multi-satellite handover, and O-RAN function behavior before committing to silicon or software releases.	RaySim delivers site-specific, spatially consistent RF for HiL beam testing (verified for 16 mMIMO layers on a single PROPSIM F64); Keysight's Live-to-Lab twin exercises a RIC against thousands of simulated nodes before it touches a live DU.
Mobile network operators (MNOs)	Must qualify AI-driven RAN optimization (energy, traffic steering, MU-MIMO) and multi-vendor interoperability at nationwide scale without risking live subscriber QoS.	The AI RAN Simulation Toolset's High-Scale and High-Fidelity layers benchmark candidate models against baseline KPIs pre-deployment, and EXata provides cross-vendor, multi-technology interoperability testing in one lab environment.
Researchers / academia / standards bodies	Need 3GPP-aligned reference channel models for Rel-19/Rel-20 ISAC and 6G FR3/THz study items before commercial hardware exists.	GCM and RaySim are directly aligned to various 3GPP standards, so research results carry forward into standards-track conformance and interoperability testing without re-modeling the channel.

In every case, the practical effect is the same: the cost and risk of the first real-world attempt moves earlier in the program, into a controlled lab environment, where a failed test is a configuration change rather than a field incident.

Notable Technical Details Worth Highlighting

A few capabilities are easy to miss but materially change what a test team can do — they are called out here because they go beyond the headline feature list:

- **Mixed TN/NTN and multi-satellite handover live in the base GCM engine, not just the NTN option -** meaning terrestrial-to-satellite handover behavior can be explored even before a team licenses the full NTN option, easing the transition into satellite testing.
- **The ISAC capability gap is a standards gap, not just an engineering one -** 3GPP positioning today assumes the target device is already connected; ISAC's hard problem is sensing something that isn't. That reframes ISAC lab validation as pre-standards work, not merely pre-field work.
- **NTN atmospheric modeling references ITU-R P.618 rain attenuation directly,** not just a generic fading profile - relevant for Ka/Ku-band VSAT and any NTN link operating where rain fade is a dominant impairment.
- **TLE (Two-Line Element) import means an NTN test scenario can be built from the same orbital data format used operationally for real satellites,** shortening the path from a published constellation design to a lab test case.
- **The AI RAN Toolset has been shown integrating third-party AI infrastructure (NVIDIA Aerial / Omniverse) and third-party radio hardware (Analog Devices Titan O-RU),** indicating the toolset is designed to sit inside a multi-vendor AI-RAN stack rather than requiring an all-Keysight chain.

Self-interference between simultaneous sensing and communication on one ISAC chip, and cross-vendor O-RAN node substitution in EXata or AI RAN Toolset, are two new failure classes that only exist because these tools let customers combine functions or vendors that legacy single-purpose or single-vendor test setups never had to reconcile.

Conclusion

GCM, RaySim, the GCM ISAC and NTN options, EXata, and the AI RAN Simulation Toolset are not six unrelated products - they are one modeling philosophy applied at increasing scope: from a single antenna element, to a deterministic site-specific channel, to a sensing target, to an orbiting satellite, to a full multi-technology network, to the AI models that will eventually run that network autonomously. Each tool exists because a customer has a specific, named problem they cannot currently test for - and because every layer converges on PROPSIM/UXM hardware-in-the-loop, solving that problem in software carries forward directly onto real hardware, without re-modeling the channel or replacing the toolchain. That is the practical definition of testing the untestable