APPLICATION NOTE

6G FR3 Channel Emulation and ISAC

Simulation, emulation, and testing of 6G FR3 systems and devices

KEYSIGHT

Introduction

6G aims to connect the physical, digital, and human worlds through emerging technology focusing on new spectrum utilization, artificial intelligence (AI) integration into networks and devices, digital twins, and new network architectures. These elements enhance network programmability and automation across various 6G use cases.

The wireless industry and academia are investigating new frequency ranges and technologies for wireless communications. Figure 1 illustrates the evolution of radio channel models across various generations of wireless technologies, setting up different requirements for wireless system design, development, and testing.

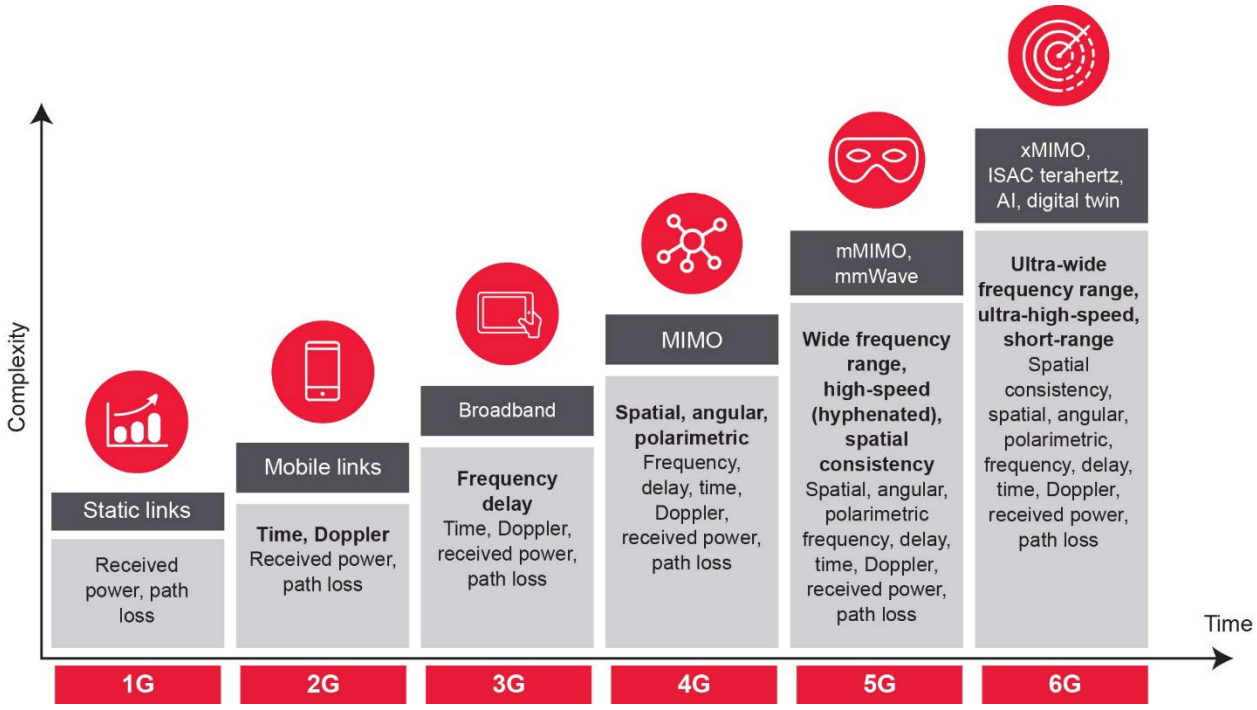


Figure 1. The evolution of wireless technologies and radio channel modeling

The wireless industry is highly interested in the FR3 7 GHz to 24 GHz upper mid-band, with a focus on the 7 GHz to 16 GHz range. The 3GPP channel modeling study item for FR3 begins in the 3GPP Release 19 cycle. The study items for Integrated Sensing and Communication (ISAC) use cases and channel modeling also begin in the 3GPP Release 19 cycle — sub-THz continues to garner significant academic research interest, with 6G pre-standardization activities in the European Telecommunications Standards Institute (ETSI).

This application note addresses the 6G channel modeling and emulation requirements for ISAC and the new FR3 frequency range planned for deployment in 6G. Learn how practical simulation and end-to-end test solutions for FR3 and ISAC can help you with your next project.

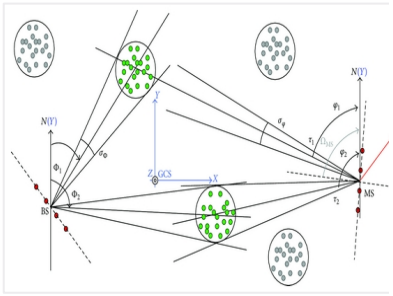
6G Requirements: A Drive Towards Deterministic Channel Models

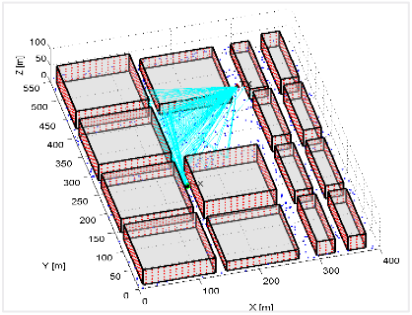
For instance, 4G and 5G addressed radio channel modeling requirements with Geometry-Based Stochastic Channel Models (GSCMs) for simulations and testing massive Multiple-Input and Multiple-Output (mMIMO). However, 6G use cases and technologies are setting new requirements for radio channel modeling. The following are the directives:

- Near-Field (NF) and short-range communications using smaller cells.
- Accurate location-based services
- Smart environments with multiple radio access (multi-RAT) technologies.
- Specular propagation at sub-terahertz (THz) frequencies.
- Flexible adaption and enhanced environment awareness.
- ISAC, and extreme MIMO (xMIMO).

The current GSCM models in TR38.901 for 4G and 5G MIMO and mMIMO beamforming have limited resolution for environmental awareness and adaptation in time, frequency, and spatial domain statistical characteristics. As a result, they cannot accurately address the requirements of 6G.

6G requires environment-aligned RF propagation models for digital twins and testing in real hardware. Environment-aligned modeling necessitates high spatial consistency across multiple user devices and base stations in the time evolution of channel characteristics, such as signal direction, delay, and phase, to properly design, test, and validate 6G wireless systems. These requirements drive the need for deterministic channel modeling. Figure 2 highlights the three main channel modeling approaches necessary in 5G-Advanced and 6G system simulations, design, and product development and testing.







Stochastic

Enhanced GSCM concept has these attributes:

- Specular path parameterization distribution of rays
- Accurate polarization model
- Location-based clusters and spatial consistency improvements

Semi-deterministic

Semi-deterministic map-based hybrid model a:

- Simplified map / layout
- Combination of stochastic and deterministic model
- Randomness to introduce random / configurable objects for blockage

Deterministic

Ray tracing modeling includes:

- Sub-wavelength sampling of deterministic path
- Accurate map / layout environment model
- Site-specific environment propagation model with AI-assisted scenario creation
- Parameterization for high-fidelity RF propagation model
- State-of-the-art visual effects in a 3D map with environment and dynamic propagation characteristics of the scenario

Figure 2. The development and use of advanced radio channel modeling across new 5G Advanced and 6G

Advanced Channel Modeling

Keysight Channel Studio is a software tool for generating radio channel models for various wireless technologies and standards. This solution provides ready-to-run simulation or emulation files compatible with multiple platforms across the Keysight product portfolio. These platforms include radio channel emulators, network emulators, signal sources, and simulation environments that support comprehensive wireless product and system design workflows from simulations to end-to-end hardware-in-a-loop testing. Figure 3 illustrates Channel Studio and the platforms using channel emulation.

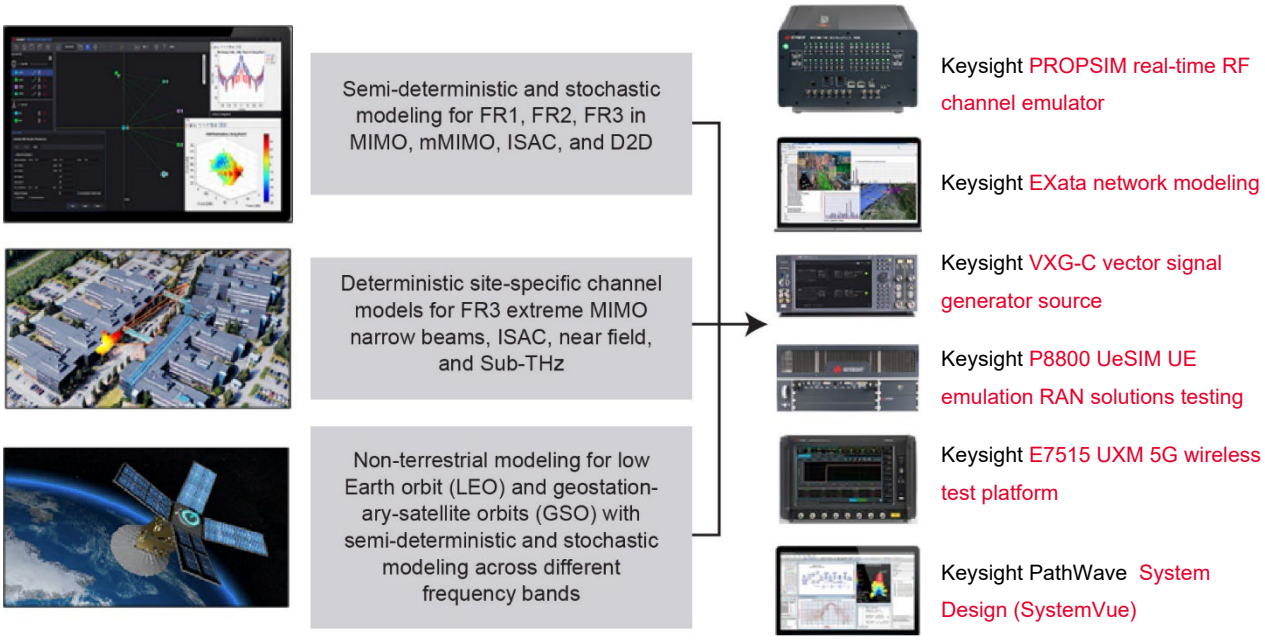


Figure 3. Applications for Channel Studio and Keysight product platforms with channel emulation capabilities

6G FR3 RF channel modeling

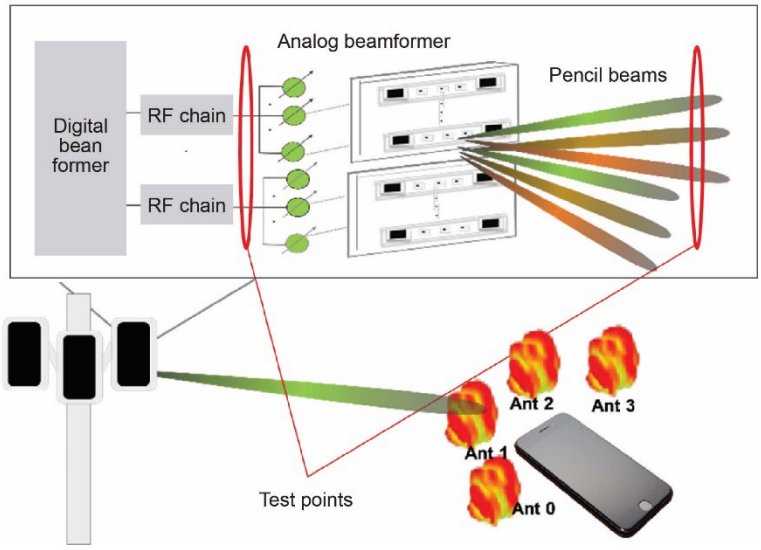
Large-aperture antenna arrays are being studied for use in xMIMO and mMIMO base stations antennas in the 6G FR3 band. xMIMO antenna arrays support narrow pencil beams and more MIMO layers than conventional mMIMO.

The design and validation of xMIMO wireless systems necessitate accurate intra- and inter-cluster angular characteristics from the channel model. This process is essential when conducting system simulations or testing the actual performance of xMIMO base stations in RAN and Open RAN (O-RAN) configurations. Dynamic channel models are necessary for evaluating beam management and precoding adaptation over user equipment movement. Dynamic channel models consider transitions between Line-of-Sight (LoS) / Non-Line-of-Sight (NLoS) and blockage conditions.

The current 3GPP GSCM channel models lack the accuracy to develop extreme beamforming algorithms with highly directive pencil beams. A new 3GPP RP-234018 Release19 technical study on channel modeling enhancements for 7 to 24 GHz for New Radio (NR) was initiated during the RAN plenary meeting in December 2023.

The following is an example of extreme hybrid beamforming, FR3 upper mid-band base station:

- MIMO layers (coexisting) — up to 64.
- Base station antennas — more than 4,000.
- Pencil beams at 3 degrees to 4 degrees.



Upper mid-band test requirements at 7 GHz to 16 GHz:

- Phase and time coherent multi-channel emulation.
- Semi-deterministic and deterministic channel models.
- Phase and amplitude with accurate calibration.
- Comprehensive measurement and analysis tools.

Employ Channel Studio software with PROPSIM FR3 multi-channel RF emulator to:

- Test platforms from four up to 64 / 256 RF channels for RF conductive / cabled and perform over-the-air testing in an anechoic chamber using a test configuration.
- Reproduce a diverse propagation environment like multipath fading, shadowing, and mobility / Doppler.
- Emulate hardware impairments like phase noise by adding noise and interference.
- Compensate for phase and amplitude error.
- Evaluate key performance metrics such as beamforming gain, beamwidth, and sidelobe levels from the physical layer (PHY) to the application layer.

Prototyping integrated sensing and communications

3GPP radio access technology supports location-based services for positioning, but the specifications do not have the built-in capability to detect objects unconnected to the radio access network.

If the system's design incorporates sensing capability, the system could provide sensing-as-a-service alongside communications. Release 19 SI considers six sensing modes: Transmission-Reception Point (TRP)-TRP bistatic, TRP monostatic,TRP-User Equipment (UE) bistatic, UE-TRP bistatic, UE to UE bistatic, and UE monostatic. Sensing aims to detect and track desired objects while distinguishing them from other objects that are not of interest.

Integrated sensing and communication means using the same devices and possibly even the same signals (waveforms) for both communication and sensing purposes. The first 3GPP-based radio access systems involved sensing activities such as localization, orientation, proximity, velocity, and potentially detecting other objects within 3GPP-defined radio access networks.

Figure 4 illustrates an object, which can be an Unmanned Aerial Vehicle (UAV), an automobile, a human, an animal, and more. Other use cases, such as environment mapping and micro-motion sensing, are identifiable. Implementing ISAC involves adding sensing functions and processing to existing communication networks. Furthermore, designing new networks and suitable waveforms for communications and sensing is critical.

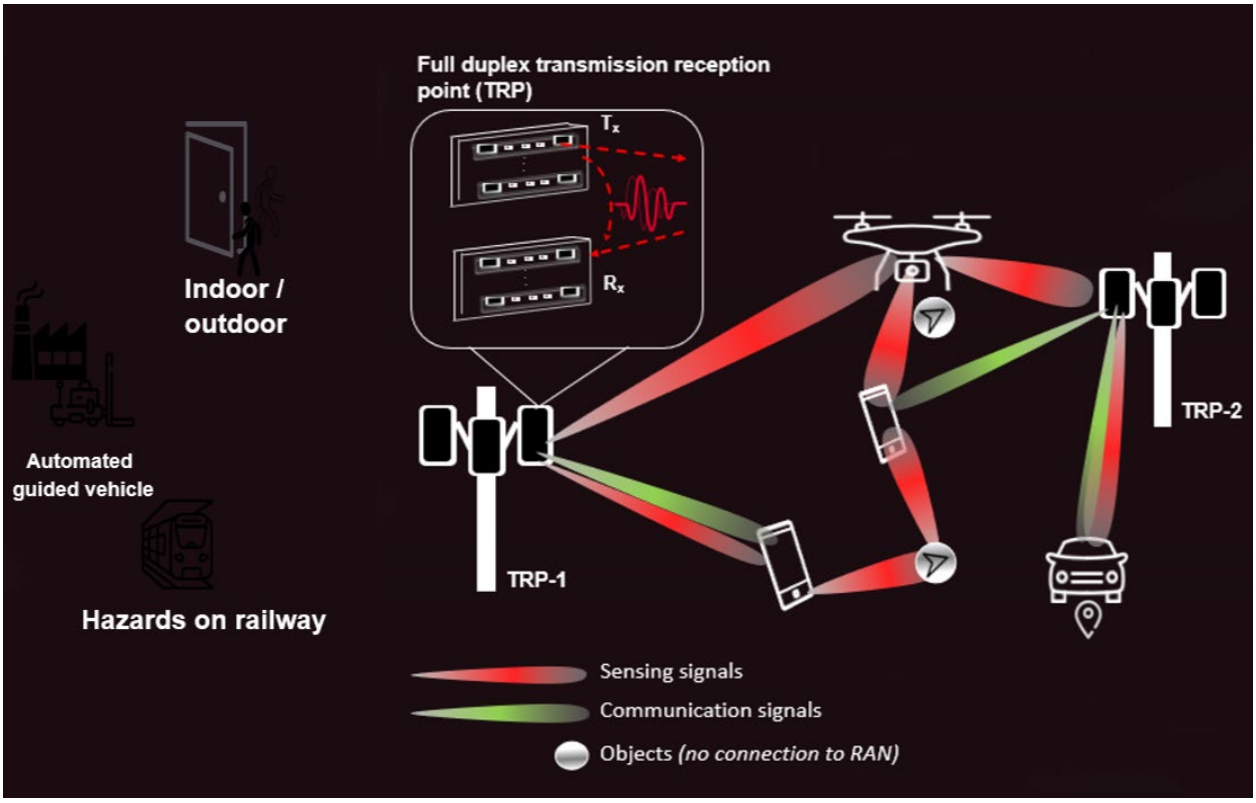


Figure 4. Example of network sensing for 3GPP Release 19 Study Item (SI) RP-233100

ISAC channel modeling

The sensing part of ISAC encompasses numerous use cases not supported by TR 38.901 channel models. These include backscattering modeling for environmental clutter or objects with specific Radar Cross Section (RCS), dynamic objects, and current channel models tailored for point-to-point communication scenarios with limited support for point-to-multipoint scenarios. Monostatic and bi / multistatic sensing simulations and testing require models with strong spatial consistency. Evaluating localization applications holds meaning only when defining the environment. For transceivers or sensing targets in motion, dynamic and spatially consistent modeling of wireless channels is necessary. This method considers time-variant absolute propagation delays, arrival / departure angles, and LoS/NLoS transitions.

The new Study Item Description (SID) for 3GPP Release 19 study on channel modeling for ISAC RP-234069 will address these gaps in radio channel modeling. Figure 5 shows the ISAC channel model for a 32T32R-capable base station system simulation, enabling real-time RF channel emulation for testing network sensing involving three moving objects.

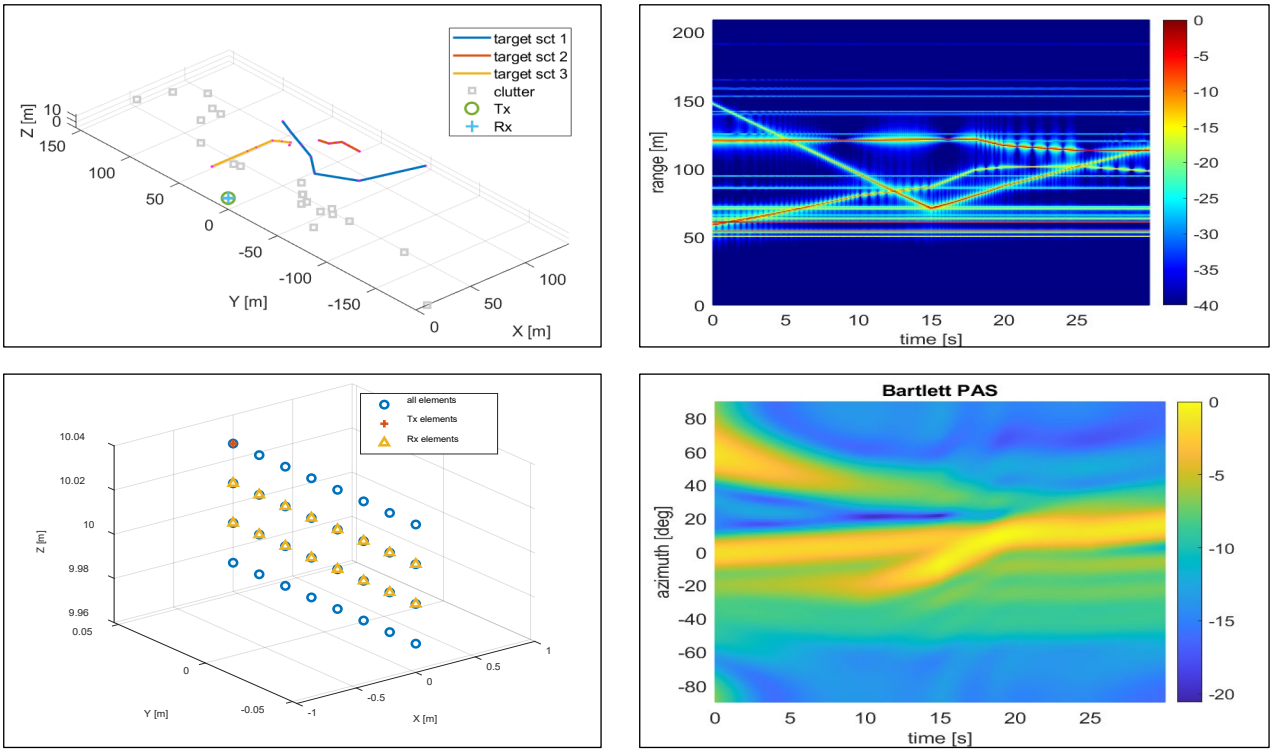


Figure 5. Semi-deterministic GSCM radio channel model for ISAC

Prototyping TRP monostatic ISAC systems

Figure 6 illustrates an ISAC use case where the transmission-reception points simultaneously transmit communication and sensing signals to the UE. Simultaneously, the transmission-reception point also receives echo signals to sense the wanted object UE inside the vehicle and reflections from other unwanted objects and backscatter.

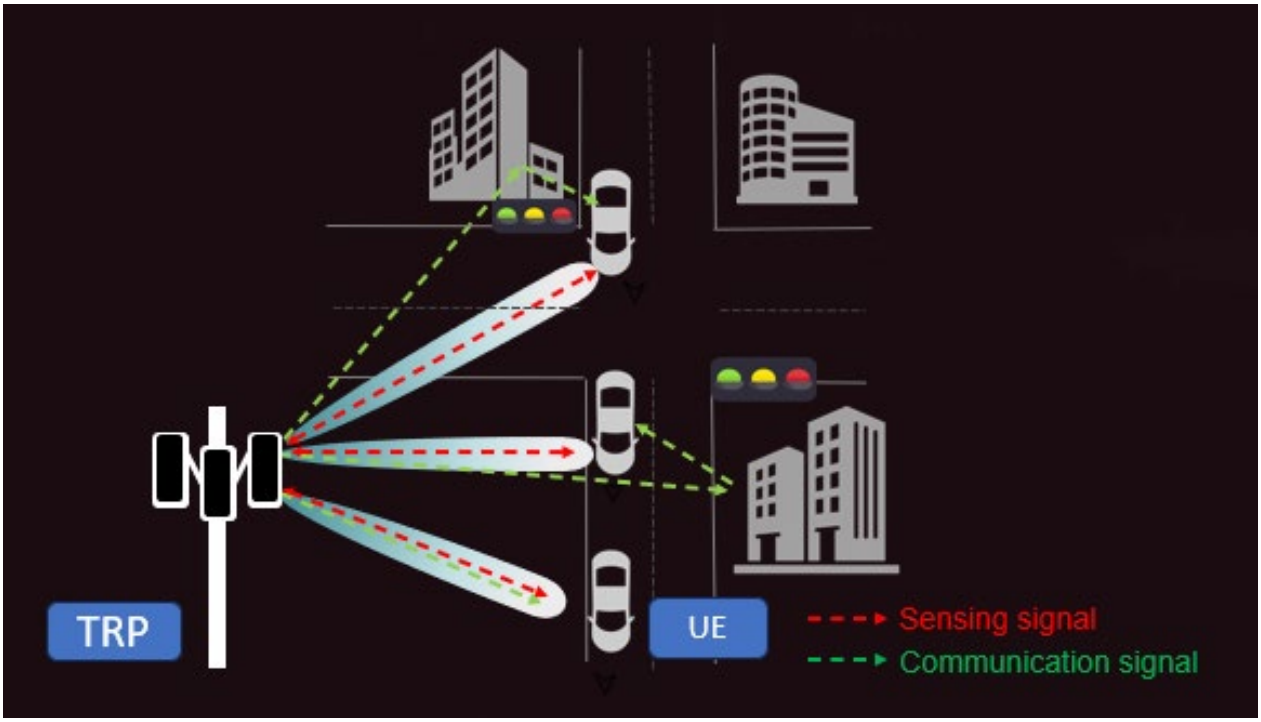


Figure 6. Example of TRP monostatic ISAC use case

The following are the test requirements for system simulation and in-lab experimentation:

- Use channel models for communication and sensing signals — echo modeling on objects and backscatters.
- Process communication and sensing signals coherently across 3GPP frequency bands and bandwidths.
- Add effects on echo and communication signals from the environment such as range (propagation delay and signal attenuation), directional characteristic, mobility (frequency Doppler), multipath propagation, and interference.

Figure 7 highlights the key features of Channel Studio and PROPSIM channel emulator for TRP monostatic ISAC testing. These solutions enable prototyping ISAC monostatic and bistatic TRP / UE scenarios, from system simulations to testing with real hardware. This product also emulates a range of factors like Doppler, multipath, channel delay, signal direction, range path loss, blocking effects, noise, and programmable interference for sensing and communication signals.

Additionally, Channel Studio and PROPSIM channel emulator solutions can replicate echo signals from objects, backscatters, and other objects from less than one meter up to several kilometers away. The solution offers an Application Programming Interface (AP)I for users to model and emulate the objects' echo / RCS in real time and trigger pre-defined object RCS waveforms from a library.

Moreover, it supports 3GPP FR1, FR2, and FR3 bands, with RF ranging from 3 MHz to 17 GHz and external Remote Radio Heads (RRHs) from 10 GHz to 32 GHz or 24 GHz to 49 GHz.

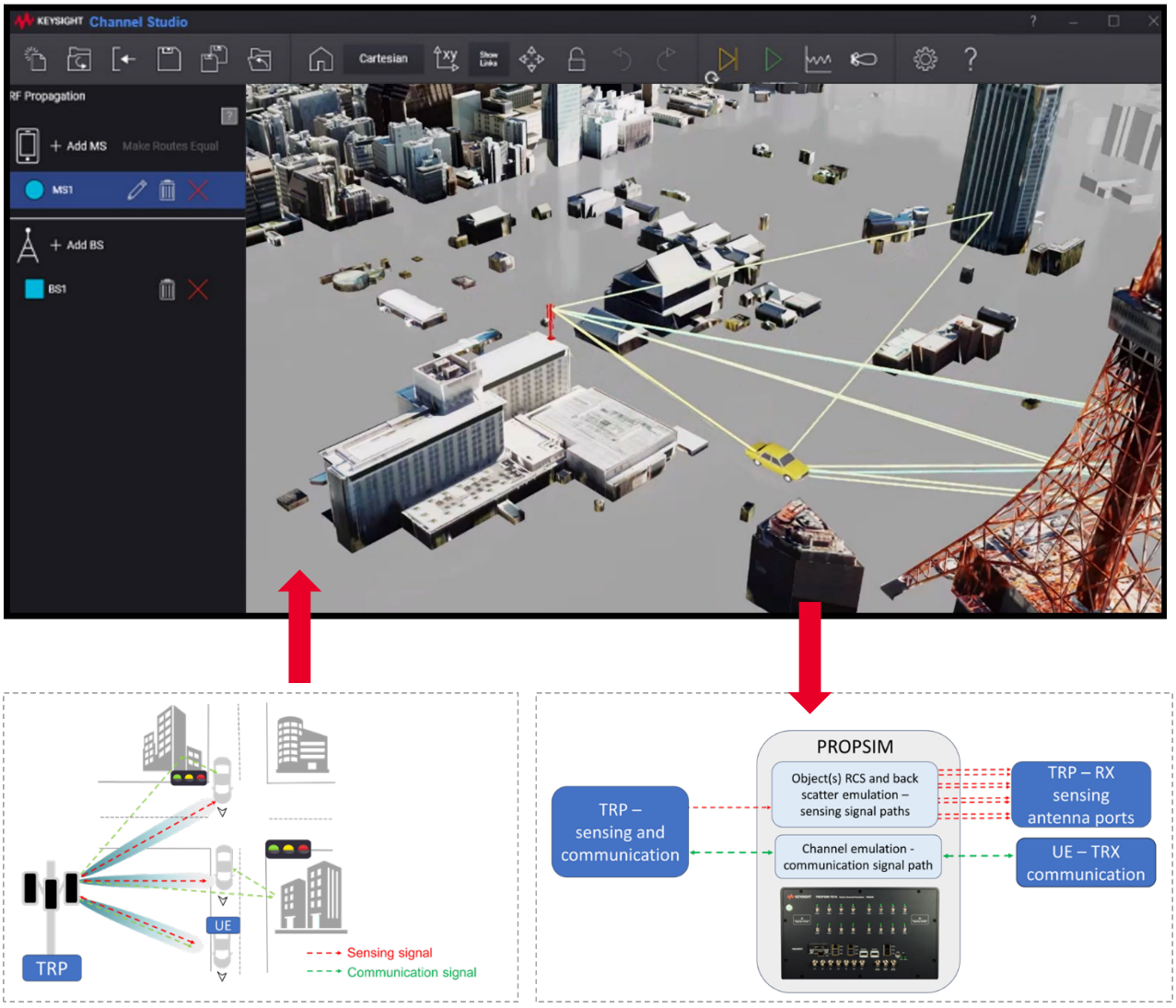


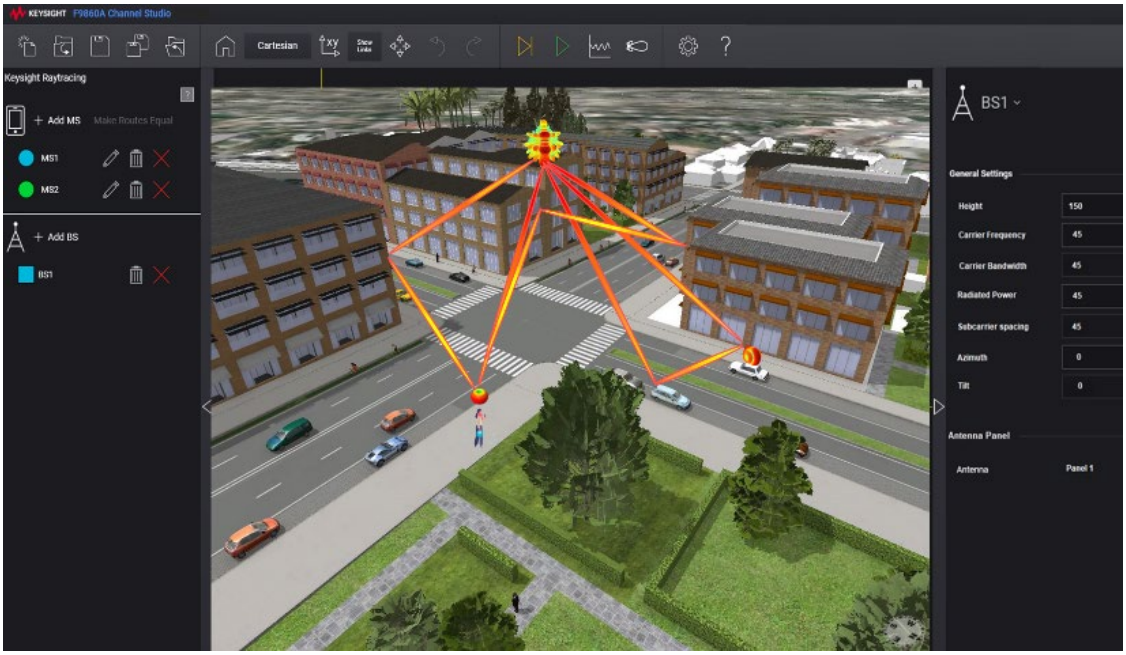
Figure 7. An example test scenario of the Keysight ISAC test solution that includes Channel Studio modeling software and a PROPSIM real-time RF channel emulator

Summary

Industry and academia are investigating new frequency ranges and technologies for 6G. Some interesting potential 6G technologies under discussion include ISAC, and FR3 frequency range for hybrid beamforming and xMIMO. These advancements necessitate more precise channel modeling and emulation tools.

You can accelerate your 6G prototyping before releasing standards using Keysight channel models and channel emulation for FR3 MIMO, mMIMO, xMIMO, and ISAC. Keysight solutions support geometry-based stochastic channel modeling and semi-deterministic and deterministic site-specific channel modeling.

Keysight provides applicable channel models to support early ISAC prototyping. We can help you meet the latest standards because we actively contribute to 6G research and standardization efforts.



For more information

Keysight PROPSIM Channel Emulation Solutions

Keysight enables innovators to push the boundaries of engineering by quickly solving design, emulation, and test challenges to create the best product experiences. Start your innovation journey at www.keysight.com.

This information is subject to change without notice. © Keysight Technologies, 2024, Published in USA, October 23, 2024, 3124-1310.EN