KEYSIGHT

A Testbed for 6G Non-Terrestrial Networks

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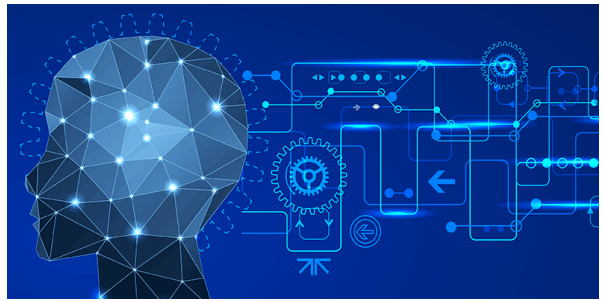
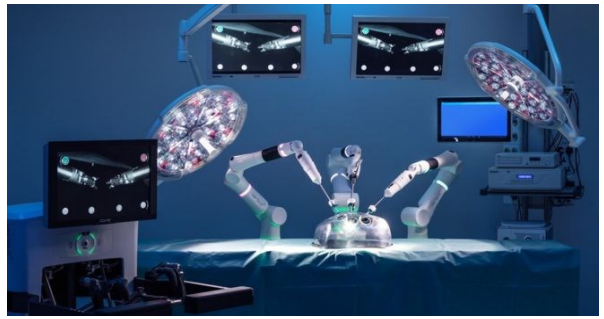
6G – Ubiquitous Wireless Intelligence

6G will enable new Use Models:

- Holographic and Multi-Sensory Communications
- All-inclusive Social Internet Of Things (SIoT)
- AI-powered H2H, H2M and M2M networks
- Widespread use of Digital Twins
- Advanced Industrial, Transportation and Cloud-Native IoT
- New communication environments: land, sea, air and space
- Emergency and Disaster management supported by critical infrastructure

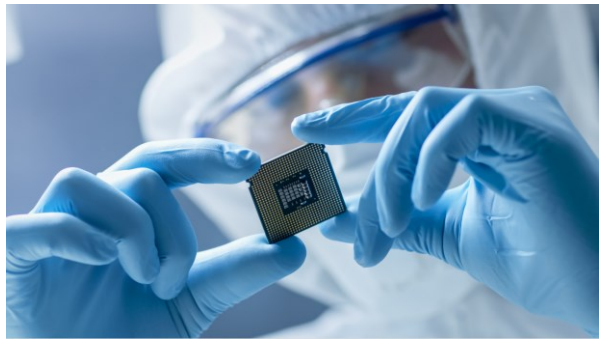




The Vision for 6G supports the United Nations Sustainable Development Goals

- 6G will be integral to the quality and opportunities of human society

Today’s 6G Research Challenges



- Sub THz research – semiconductors, components, transmitters, receivers, antennas to 350GHz
- Channel modeling and characterization at Sub-THz frequencies
- Ultra-low latency and time-deterministic processes
- Non-terrestrial network design
- Computing, semiconductor and optical architectures required for Tb/s data transfer
- Energy efficiency, energy harvesting, battery-less techniques
- Edge intelligence modeling and AI
- Modeling Network Security requirements, encryption and recovery techniques

Keysight Solutions Span the Wireless Ecosystem

Parametric Measurement Fundamentals
Digital + RF/mmWave/Sub-THz signal measurement + generation, network analysis, time-domain measurement, metrology

Wireless Device Test
Protocol development, Conformance, OTA Test, Drive Test, Network Emulation, UE Emulation, Channel Emulation

Internet of Things
Solutions for Healthcare, Industrial, Smart City, Smart Home, Wearables

Data Center Infrastructure
Component + Transceiver Test, Signal Integrity Solutions, Network + Data Visibility

High Speed Digital Systems
Solutions for DDR5, PCIe 5.0, PAM4, HDMI, MIPI, USB

Cloud
Visibility, Security, Monitoring + Performance

Design + Automation
PathWave Design Software, Data Analytics, Test Automation

Multi-technology Platforms
Satellite; Connected Car, C-V2X + DSRC

Manufacturing Test
In-Circuit Test, Industry 4.0 solutions, 5G & Automotive, Cloud-Based Data Analytics

Network Security
Solutions to Evaluate, Test, Protect and Strengthen Networks

Network Test
Chip verification, Virtual Test, Active Network Assessment

Network Visibility
Inline security + Network Monitoring

SDN, NFV, Virtualization
Software-Defined Network Solutions, Network Slicing

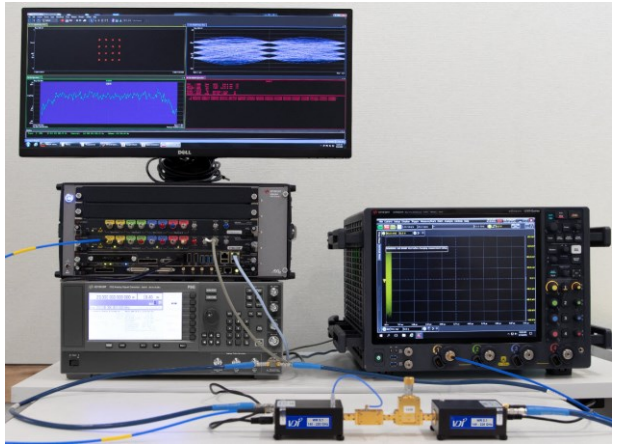
Energy Solutions
Cell + Battery Performance Test

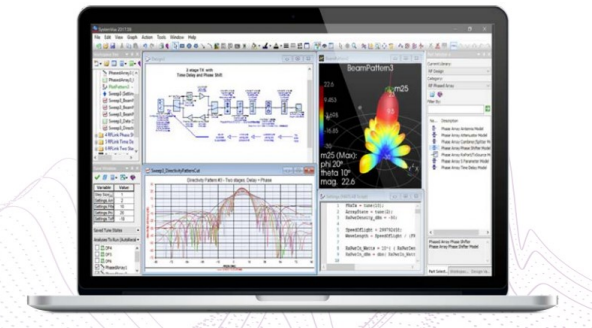
Keysight Solutions for Early 6G Research

Keysight Platforms and Testbeds allow customers to realize the potential of 6G technology

Sub-Terahertz Testbed for 6G Research

- 30 GHz of signal bandwidth up to 310 GHz, 100Gbps
- State of the art signal generation and measurement hardware
- Fully-featured Vector Signal Analysis Software platform
- 6G PHY design, waveform creation and beamforming





Outline

NR-NTN Basics

NR-NTN Prototyping

- Software Simulation
- Hardware Emulation

5G/6G Non-Terrestrial Networks

- Ubiquitous coverage
  - Mountains, rugged terrain, oceans, planes

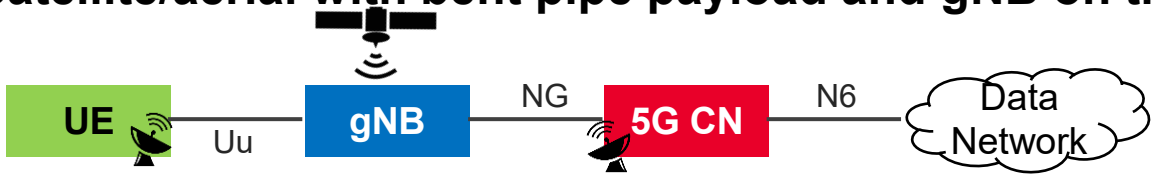
Northern Sky Research (NSR) indicates that close to 10 million active revenue sources will help provide $32.5 billion of extra revenue by 2029

NR-NTN Potential Architectures

(1)

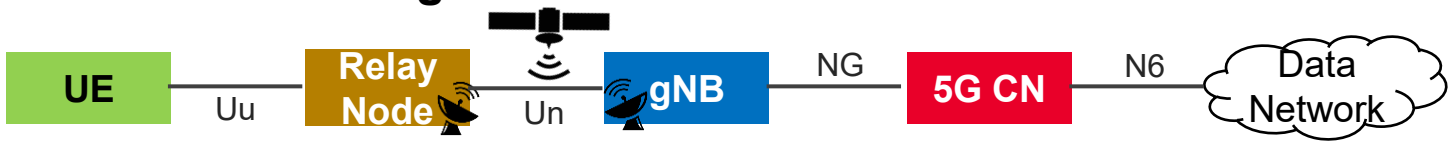
Satellite/aerial with bent pipe payload and gNB on the ground

(2)



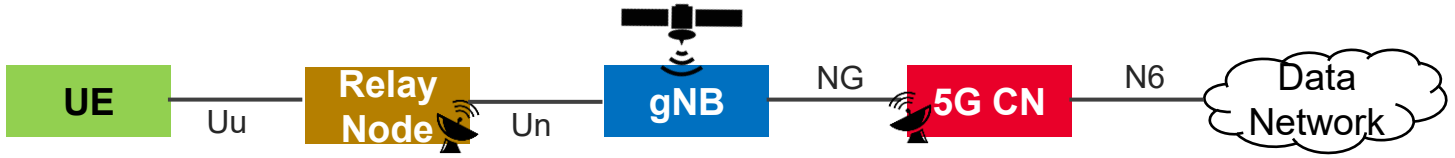
Satellite/aerial with gNB on board

(3)



Relay Nodes, satellite/aerial with bent pipe payload

(4)



Relay Nodes, satellite/aerial with gNB

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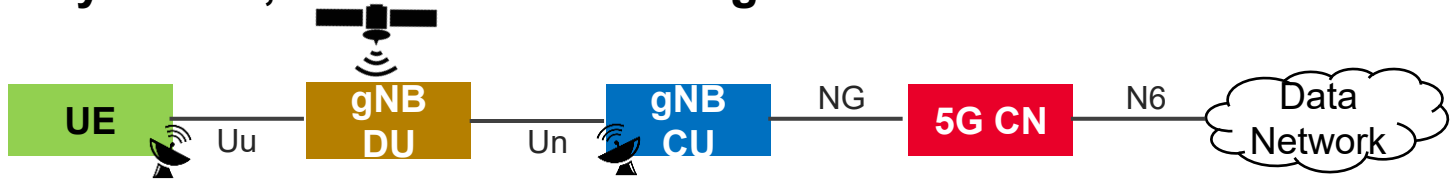
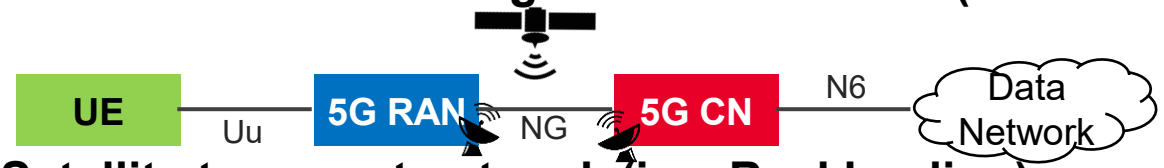


Satellite access with regenerative satellite (DU-CU split)

(6)

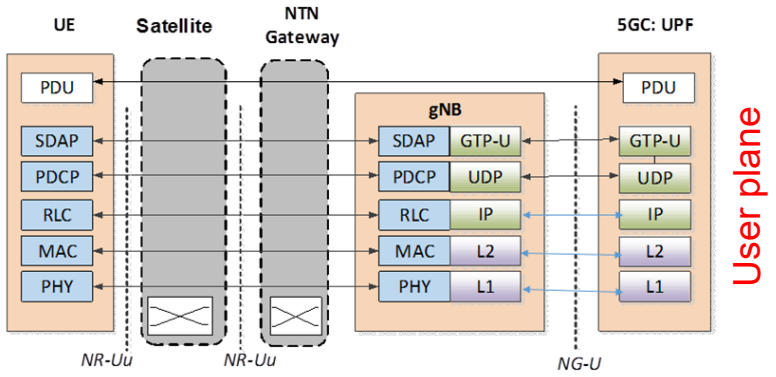


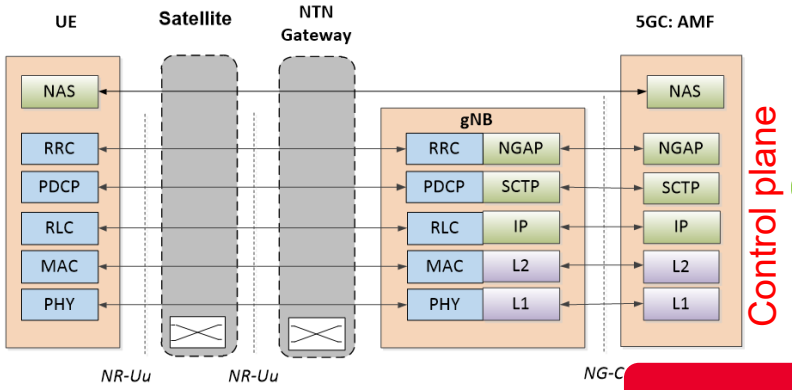
Satellite transport network (i.e.. Backhauling)

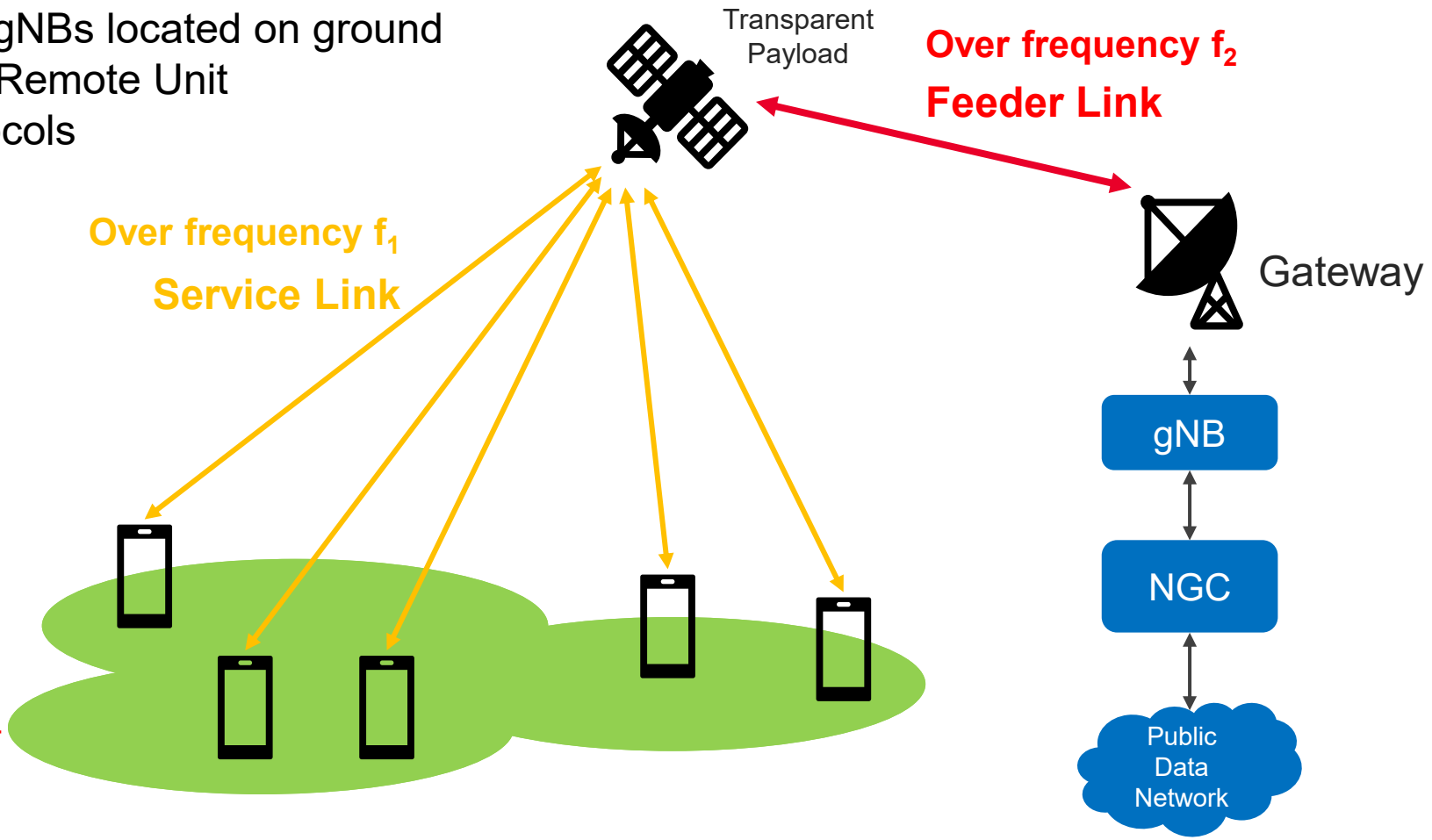
Rel-17 NR NTN Network Architecture

Transparent Payload

- NR signals generated from gNBs located on ground
- Satellite equivalent to a RF Remote Unit
- Transparent to the NR protocols





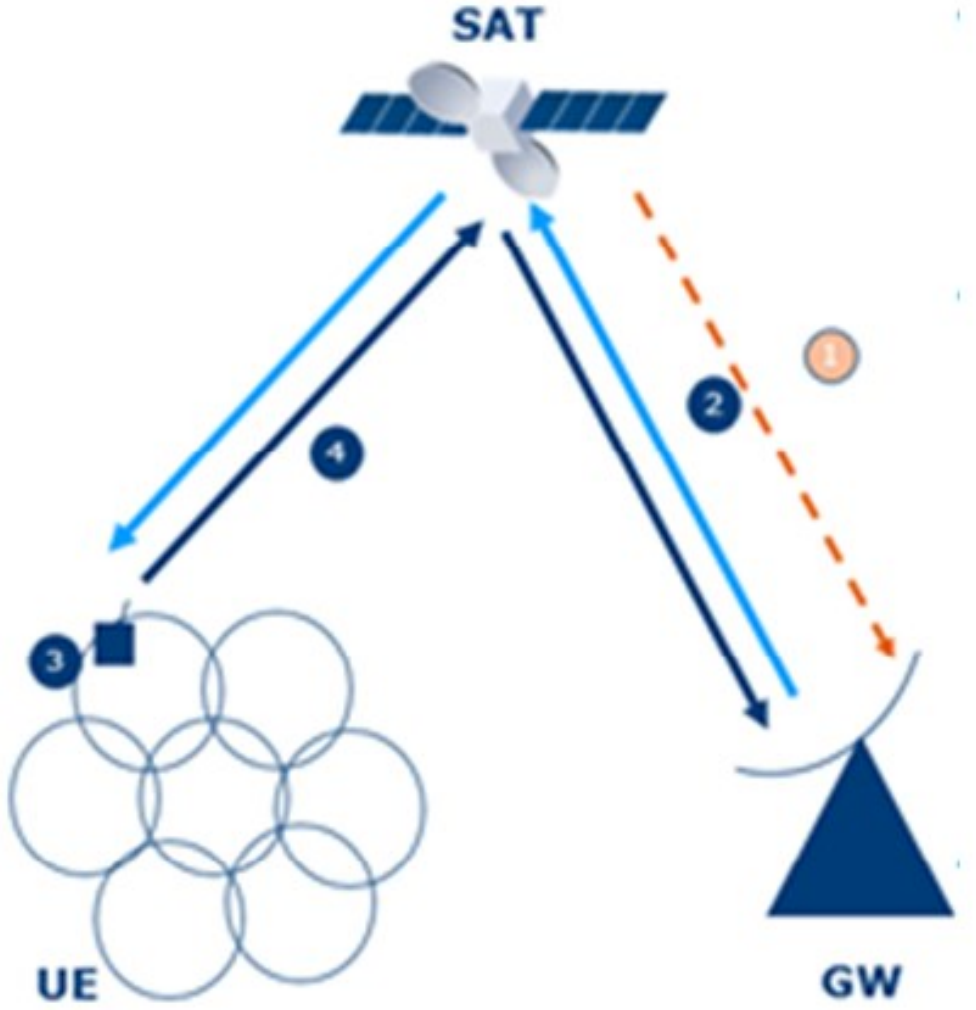


How do you account for the doppler and delay through the satellite link?

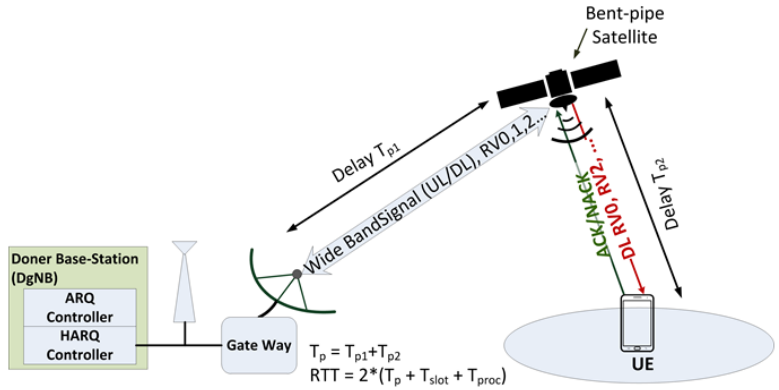
KEYSIGHT

Pre-Compensation Method (Delay and Doppler)

1. The Gateway gets from a telemetry link the position and velocity of the satellite typically using on-board GNSS, processes it and determines the satellite position and speed
2. The Gateway propagates the satellite position and velocity determined from the telemetry link to the end of the frame containing the SIB used to broadcast the current satellite position and velocity
3. The UE reads the current satellite position and velocity on the SIB and uses its GNSS-acquired position to determine the satellite delay and satellite Doppler shift
4. The UE pre-compensates the satellite delay and Doppler before transmitting on the UL
5. The gNB pre-compensates the satellite delay and doppler before transmitting on the DL



HARQ



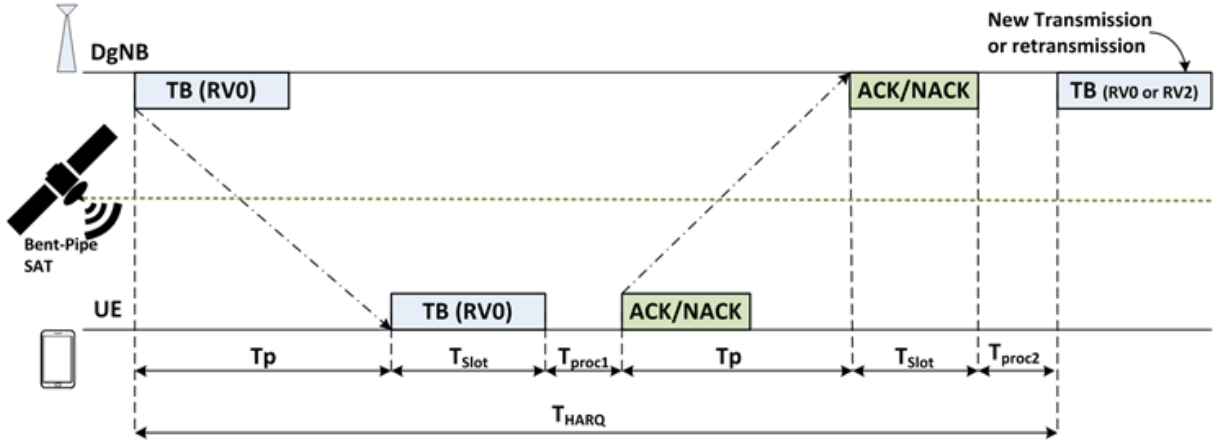
The HARQ process is a very time-critical mechanism (even more critical at extremely long RTT)

Problem

- The maximum number of HARQ processes can be very large due to the high delays
- **Cost**: UE soft-buffer needs to be increased enormously
- **Control channel reliability**: HARQ feedback field bit-size increases enormously

Solution alternatives

- Increase HARQ processes while maintain buffer size under control (32 HARQ processes)
- Disabling HARQ at L1



constellation	Max. T_{HARQ}	$N_{HARQ,min}$ processes for 1 ms slot operation	UE side feasibility
Terrestrial	16ms	16	Feasible (Rel. 15)
LEO	50ms	50	Feasible (with HARQ extension)
MEO	180ms	180	FFS (impact on TBS/MCS)
GEO/HEO	600ms	600	FFS (impact on TBS/MCS)

Outline

NR-NTN Basics

NR-NTN Prototyping
- **Software Simulation**
- **Hardware Emulation**

Workflow

New NTN developments should go through the following phases to properly deploy the NTN link

Use software to model NTN link

Prototype transceivers With COTS

Develop operational hardware and integrate in lab/chamber environment

Deploy system and test

Optimization, period test, and monitoring of systems

Security

Plan/Design/Test security throughout the workflow

Digital Twin Simulation

Covering multiple domains and applications

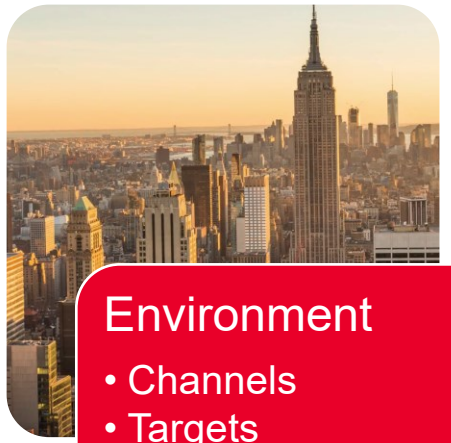
A **digital twin** is a digital representation (computer simulation) of a physical process

Protocols

- MAC/Link Layer
- Networking, incl Mesh
- Transport
- Application
- Security

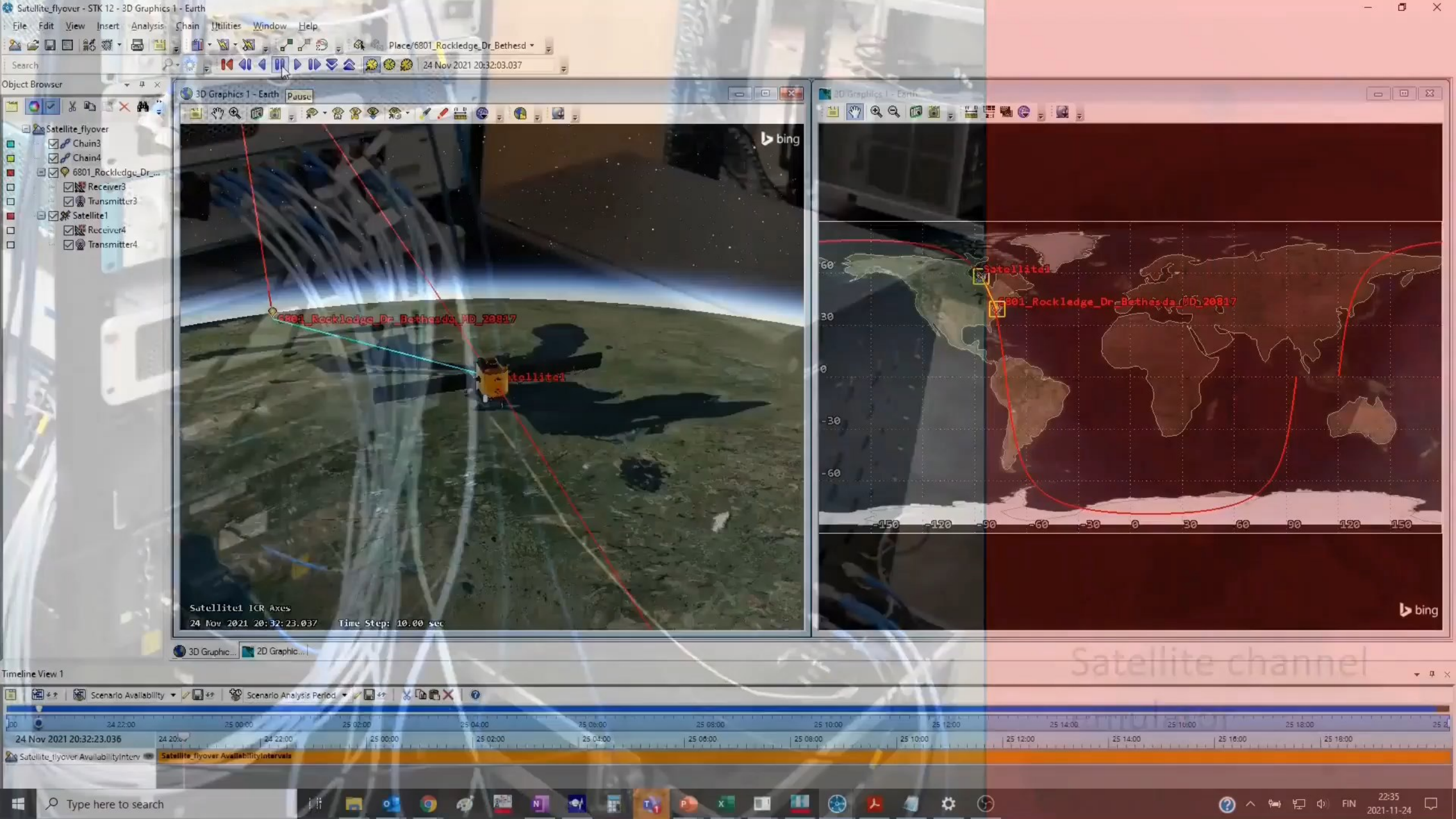
Baseband / RF

- Comms PHYs
- Algorithms
- DSP
- Custom Code
- TX/RX
- ADC/DAC
- Antenna Arrays



Environment

- Channels
- Targets
- Interference, Coexistence and other Emitters
- Dynamic movement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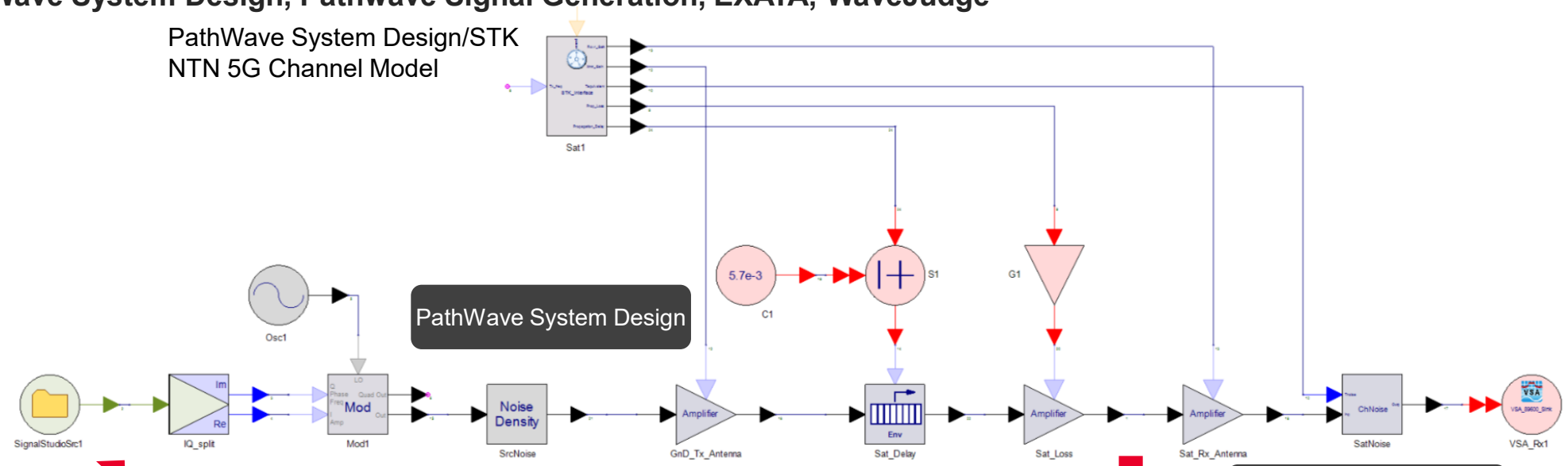
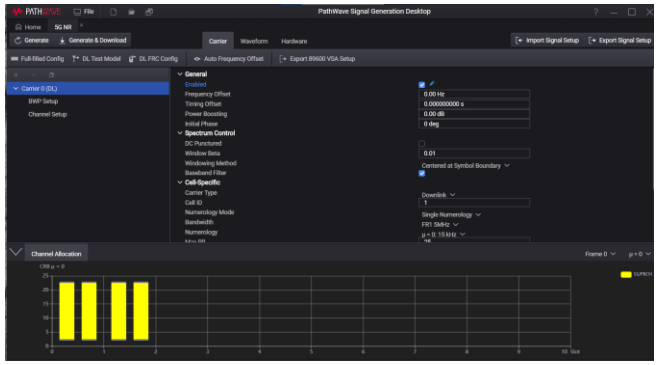
Example: NTN Simulation

PathWave System Design, Pathwave Signal Generation, EXATA, WaveJudge

PathWave System Design/STK
NTN 5G Channel Model

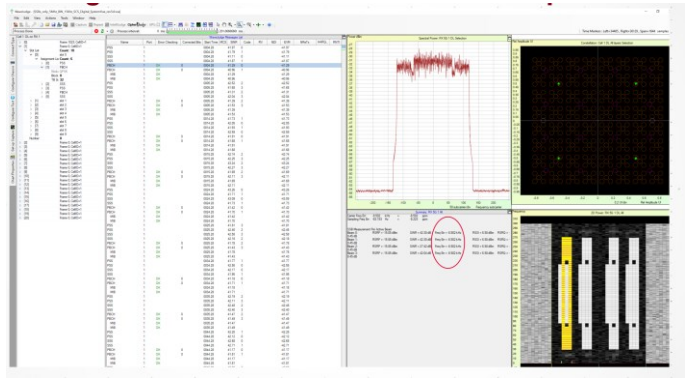


PathWave Signal Generation
5G Vector Input to PathWave System Design



PathWave Signal Generation

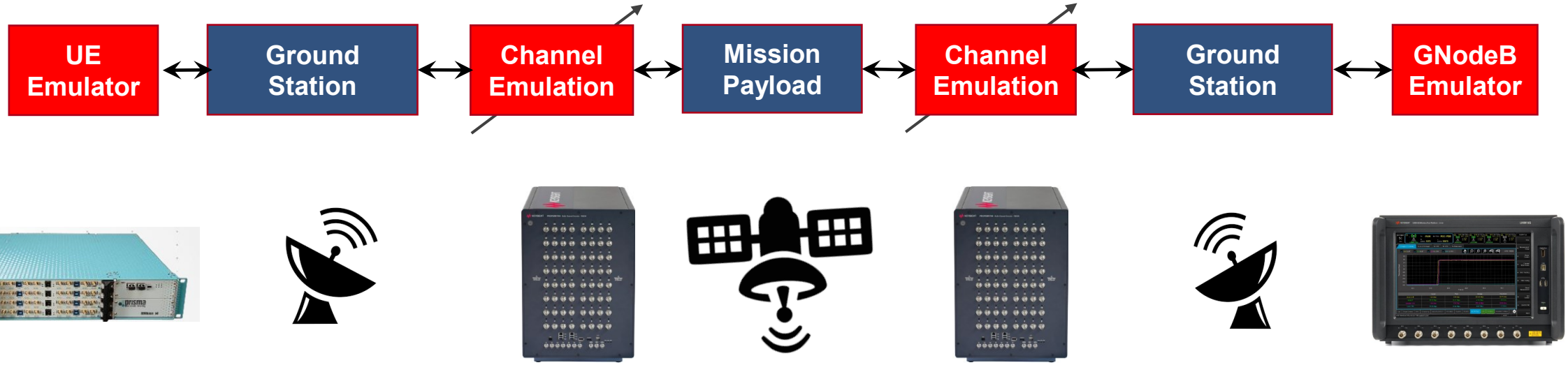
WaveJudge



Decode Showing Doppler & Other
5G Metrics & Message Content

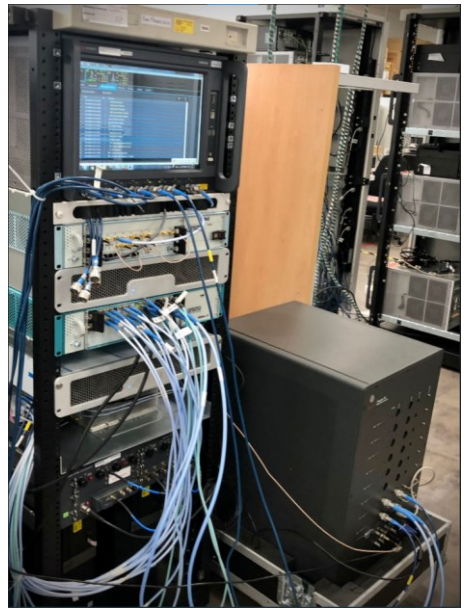
Hardware Prototyping (Scenario 1 – current 3GPP priority)

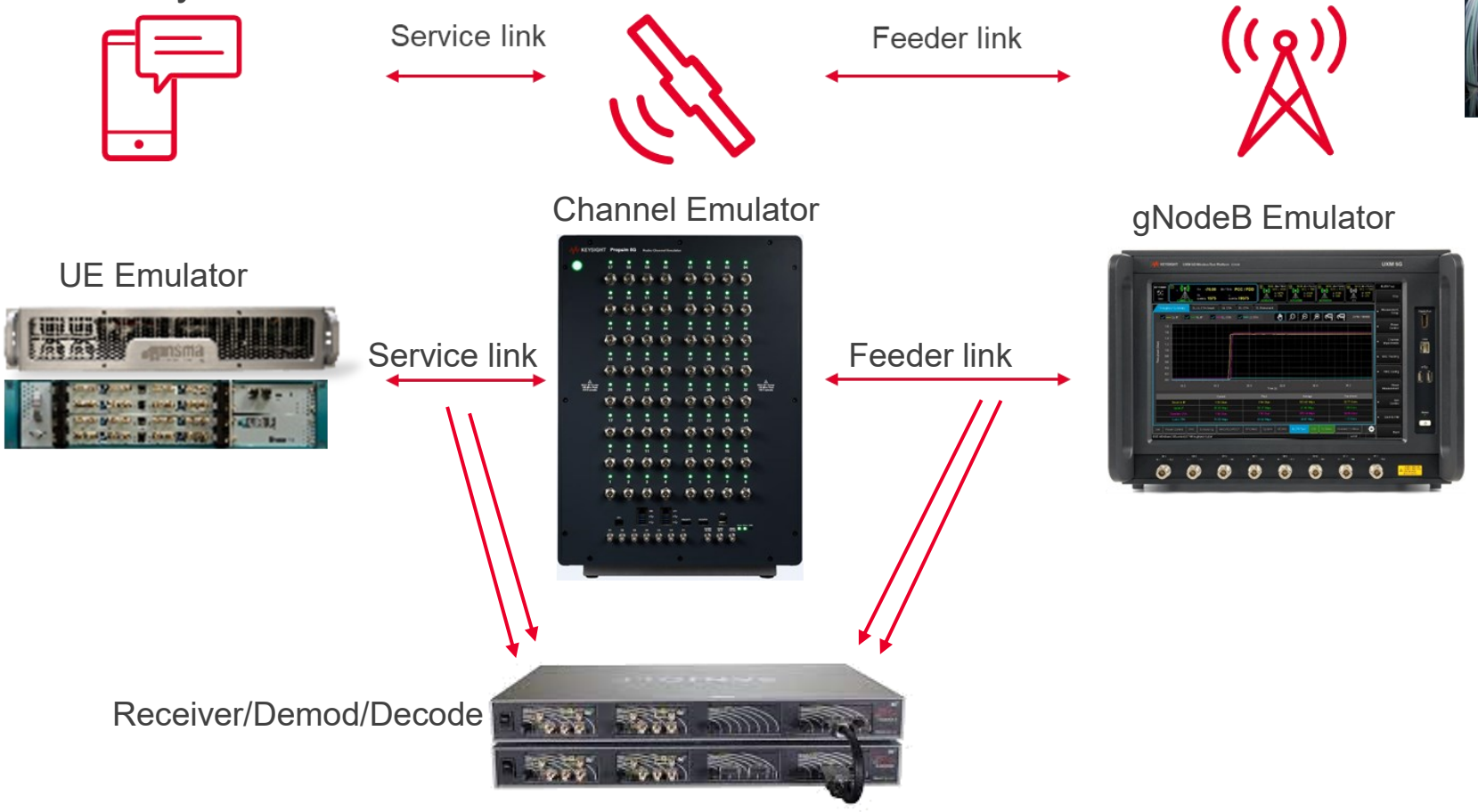
Bent pipe payload and gNB on the ground



NR-NTN End-to-End Simulation

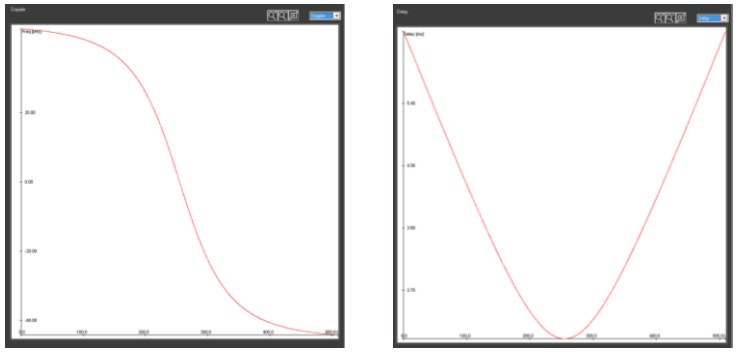
- First emulate in software to understand link and discover issues
- Use COTS test equipment modified for NTN purposes to emulate NR-NTN
- Test key PHY layer aspects of non-terrestrial communications
  - Doppler shift / Delay
  - HARQ





Configuration of Scenario

Channel Emulator

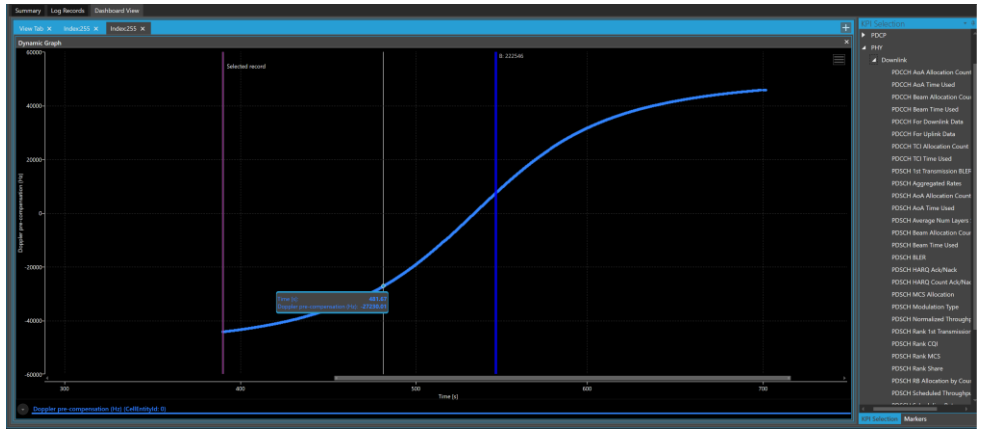


Scenario files (Doppler + delay)

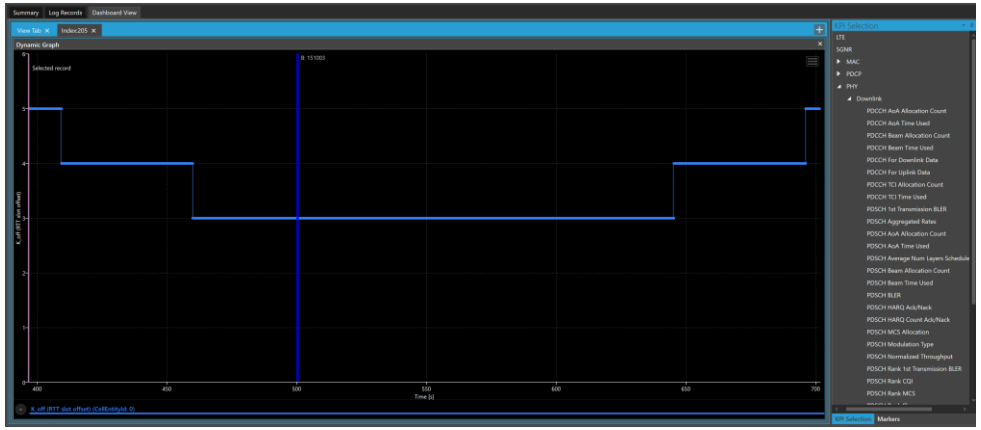
Scenario files propagated to test bed components

NTN Mode Established

Apply pre-corrections for Doppler and delay



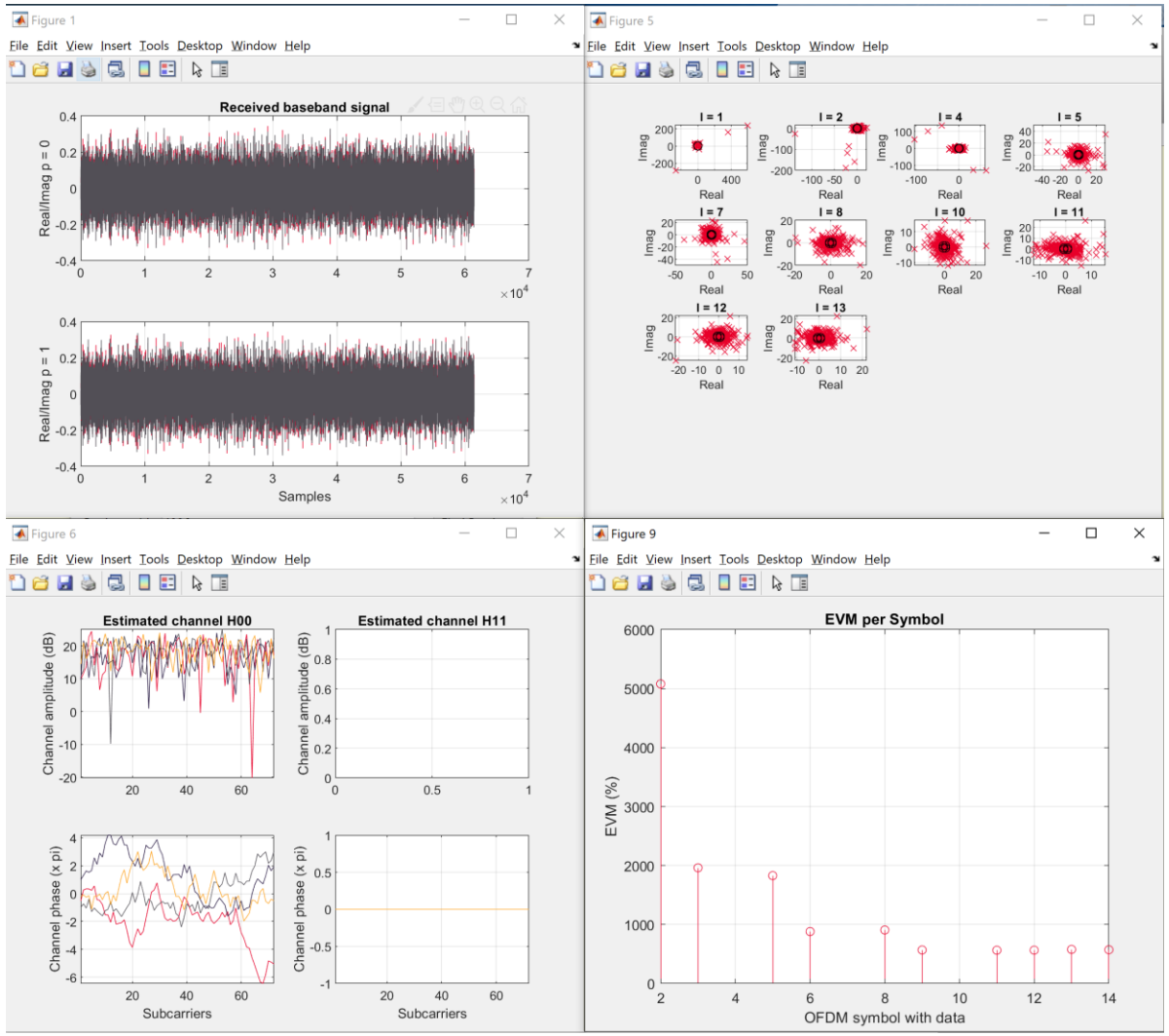
gNB Doppler shift pre-compensation in gNb for LEO 2GHz and 600 km



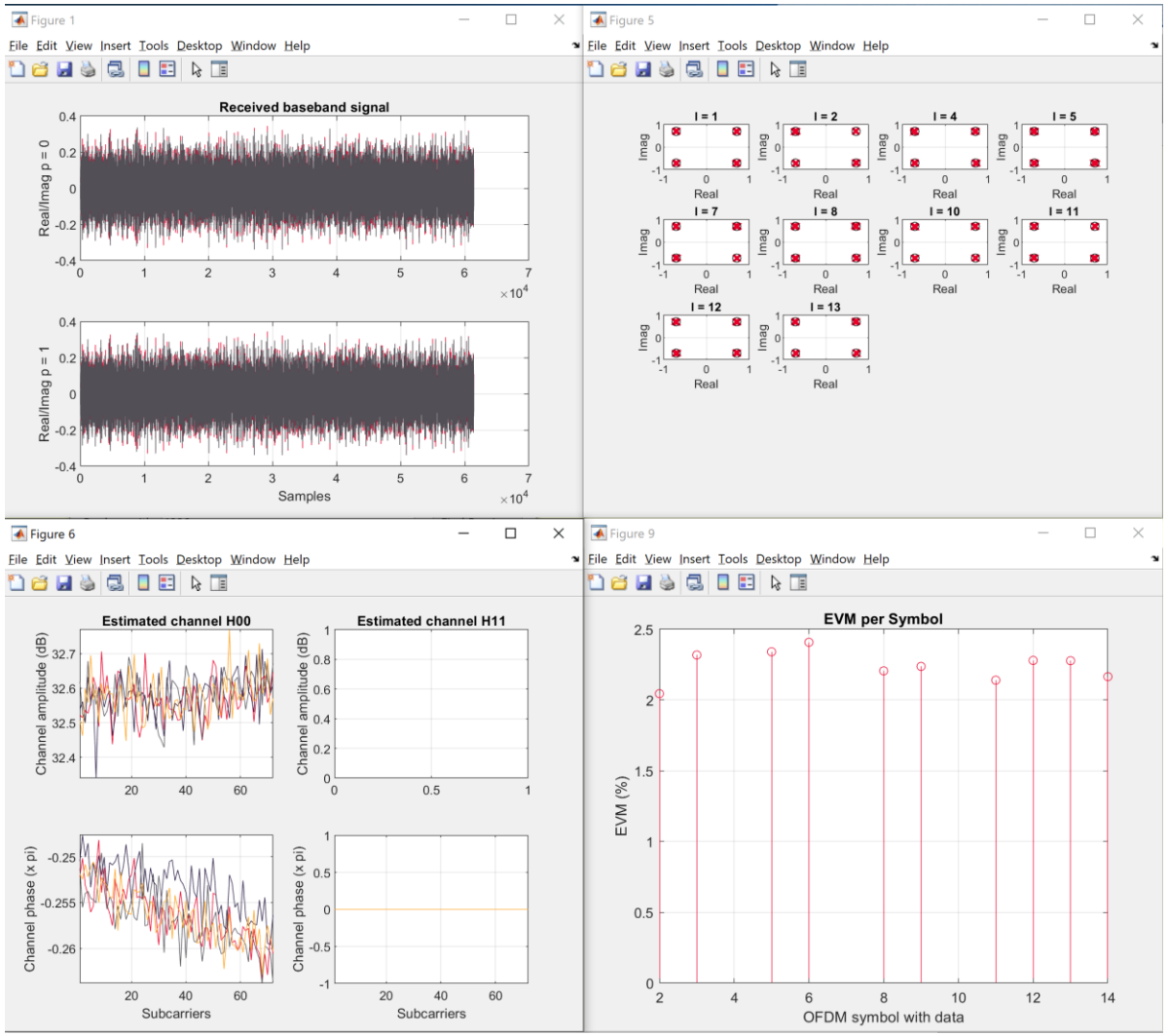
K_{offset} (RTT slot offset) applied in gNB and UE for LEO 2GHz and 600 km

NTN channel applied by Channel Emulator

Doppler Shift Pre-compensation



UE Tx Doppler pre-compensation OFF

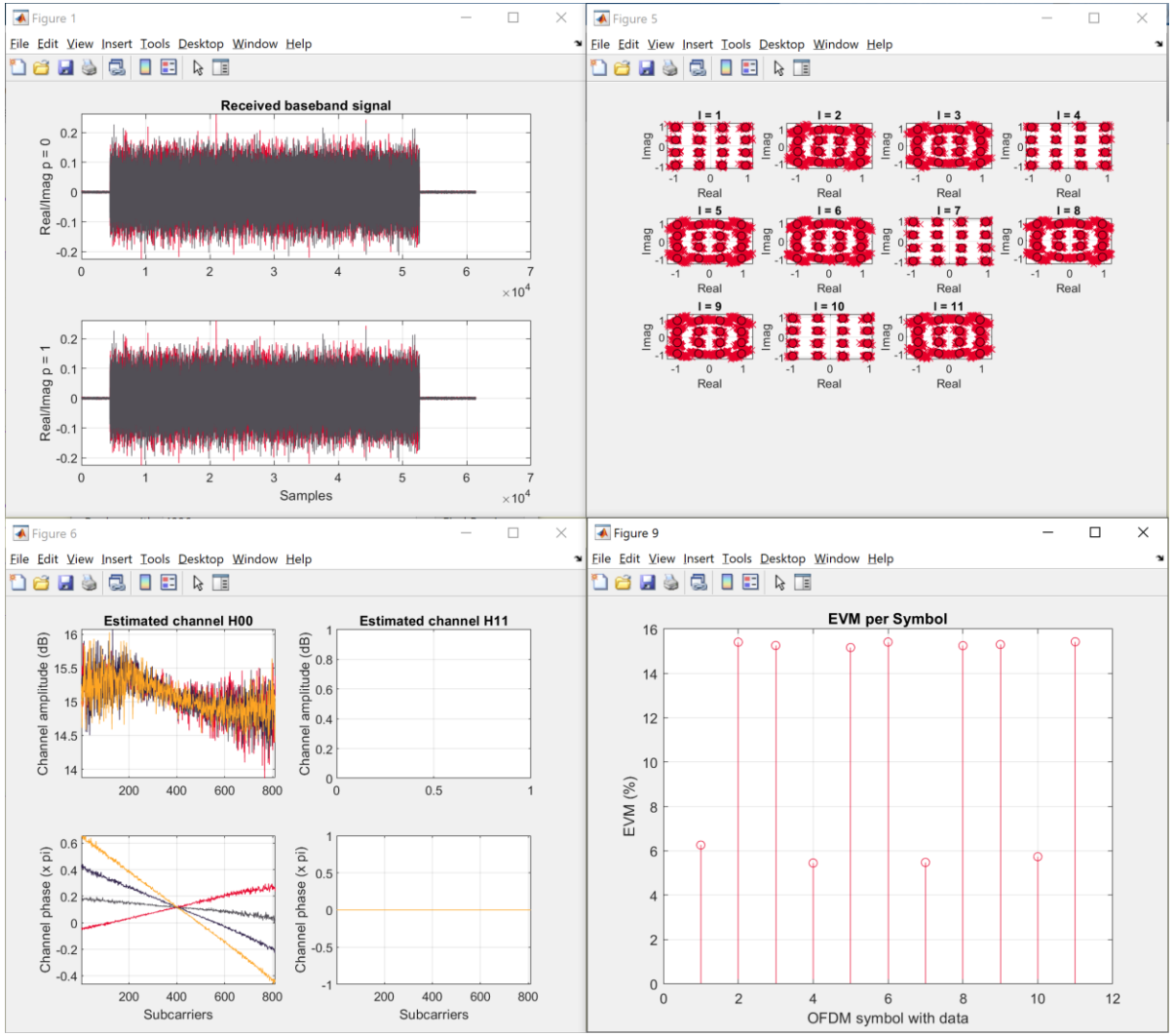


UE Tx Doppler pre-compensation ON

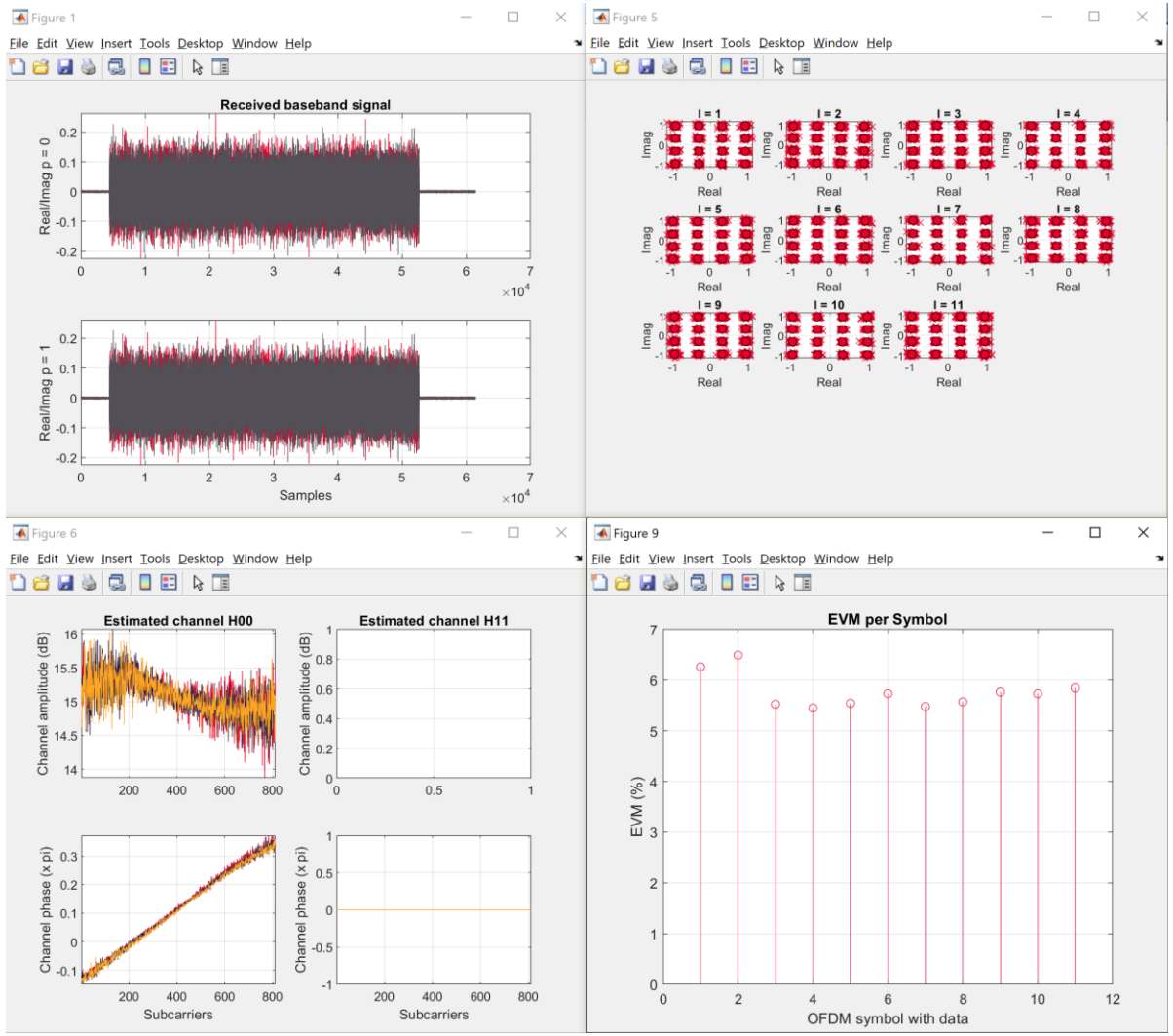
KEYSIGHT

$f_{UE\text{-}UXM}$ = 1945MHz Doppler shift = 48kHz PUSCH MCS2 PRBs(0:23)

Delay Pre-compensation



UE Tx time-varying delay pre-compensation OFF

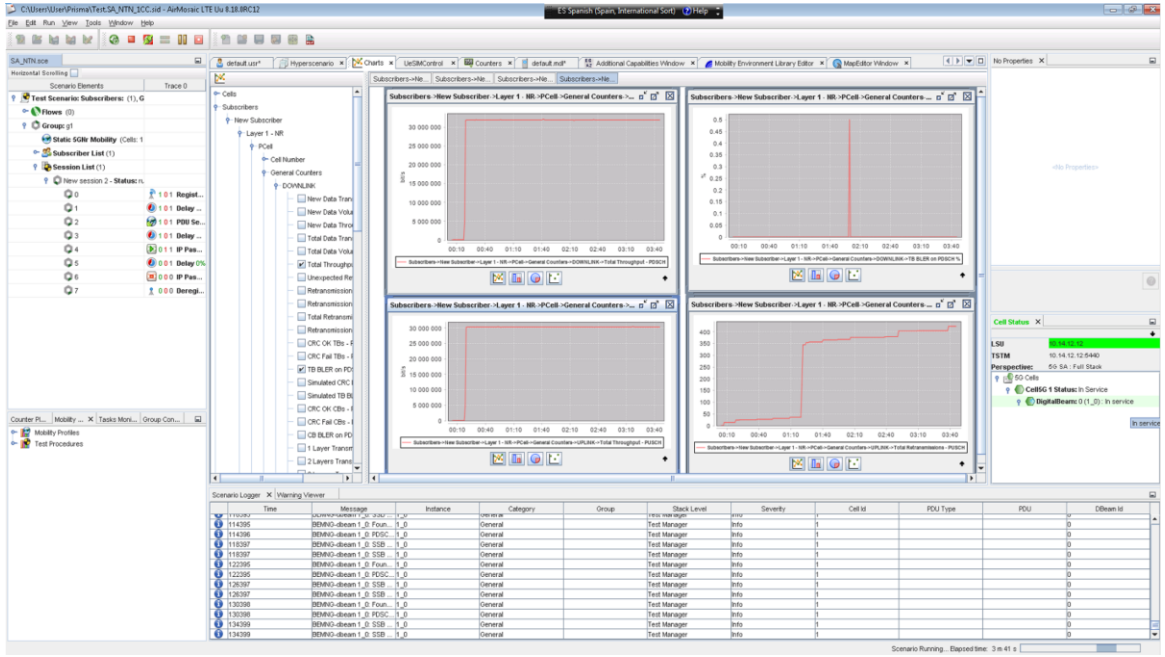


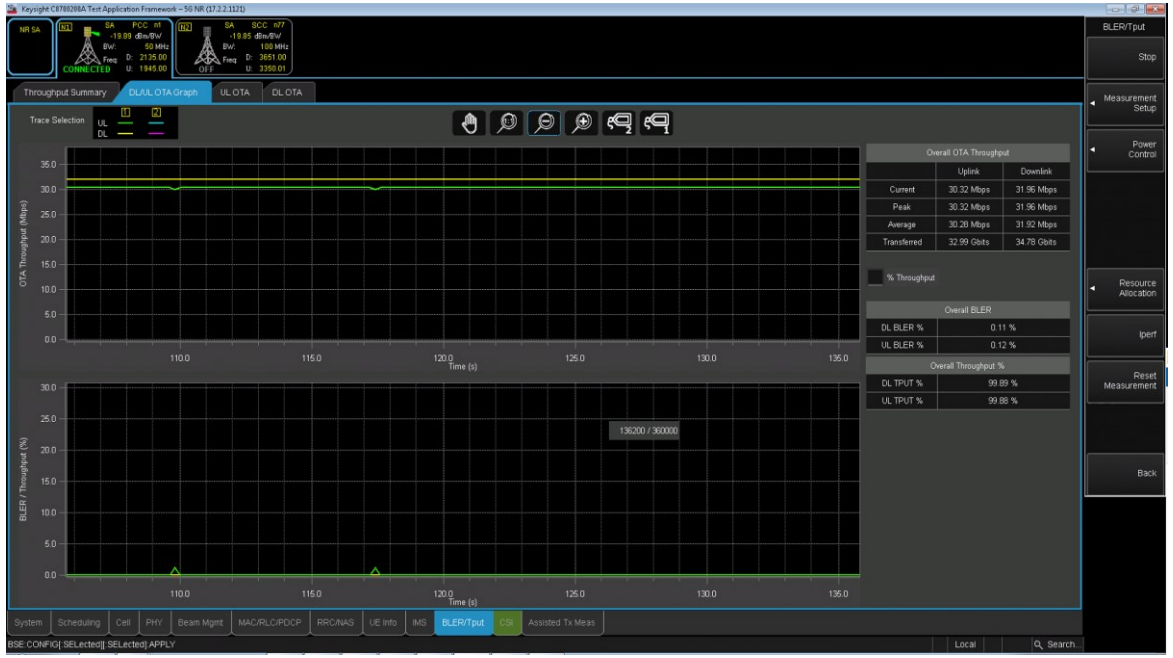
UE Tx time-varying delay pre-compensation ON

KEYSIGHT

$f_{UE\text{-}UXM}$ = 1945MHz Doppler shift = 48kHz PUSCH MCS2 PRBs(0:23)

Throughput and BLER



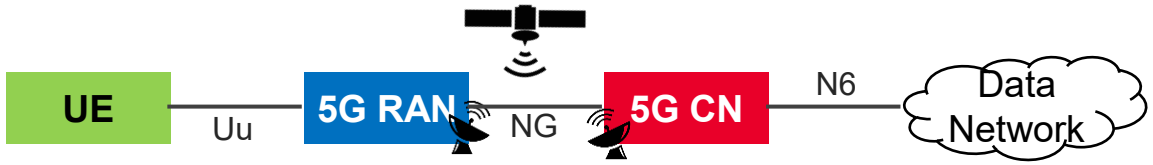


HARQ Extensions

32 HARQ Processes
63.92 Mbps DL

8 HARQ Processes
42.74 Mbps DL

Hardware Prototyping (Backhauling)



Satellite transport network (ie. Backhauling)

Conclusion

- We propose a software model and hardware testbed for NTN research
- Customize scenarios in software and hardware
- Do modeling and emulation for HAPS and other satellites easily and flexibly

- Software:
  - Physical layer design software
  - Network digital twin software
  - Satellite propagation software

- Hardware:
  - UE Emulator
  - gNodeB Emulator
  - Propagation Emulator
  - Analysis Receiver


KEYSIGHT