5G Model Library

5G is the latest technology standard for broadband cellular networks which employs cutting-edge technologies to deliver higher multi-Gbps peak data speeds, ultra-low latency, increased reliability, and massive network capacity.

Due to the increased bandwidth, it is expected that 5G networks will not only serve cellphones like existing cellular networks, but will also be used as general internet service providers for laptops and desktop computers, competing with existing ISPs such as cable internet, and will make possible new applications in the Internet of Things (IoT) and machine to machine (M2M) areas.

Benefits of 5G

- **Higher Speed: Up to 10 Gbps data rate (10 to 100x speed improvement over 4G and 4.5G networks)**
- **Higher Capacity: Up to 100x number of connected devices per unit area (compared with 4G LTE)**
- **Lower Latency: 1-millisecond latency**
- **Enhanced Battery life: Up to 10-year battery life for low power IoT devices**
- **Efficient Spectrum Usage**

Modeling of 5G Networks

Network deployment is challenging. It needs to consider the terrain, channel characteristics, user density, traffic profiles, existing 4G/5G network deployment, and available locations. Traditionally, gathering such information needs extensive field tests and often measurements from past deployments. Modeling and analysis of 5G networks offers a cost-effective, convenient to way to obtain metrics which can be used for network planning prior to deployment.

- Modeling and simulation can be used to determine the optimal layout of base stations (cell towers) to provide adequate coverage over a given geographical area.
- Simulation can be used to uncover any potential capacity and coverage issues and determine whether applications (voice, video, messaging, etc.) will perform satisfactorily over the mobile network.
- Simulation can shed light on how applications will perform in the presence of other types of traffic which compete for the same resources.
- Simulation can be used to assess the interference between the 5G network and other commercial and tactical wireless networks deployed in the region.
- Simulation can be used to assess the cyber resilience of 5G networks, i.e., the vulnerability of the network to cyber attacks, effectiveness of the security measures to counter and contain attacks, and the ability of the network to deliver services even when subject to cyber attacks.

SCALABLE's 5G Models

SCALABLE's 5G Model Library includes high-fidelity models to help evaluate the performance and behavior of 5G cellular networks. In particular, the 5G models implement features to support the enhanced Mobile Broadband (eMBB) functionality of the 5G standard. The underlying technologies implemented by the SCALABLE 5G models include:

- **Massive Multiple Input and Multiple Output (MIMO)**
- **Beamforming**
- **Network Slicing**
- **Edge Computing**

SCALABLE's 5G Model Library supports two modes of deployment: **non-standalone (NSA)** and **standalone (SA)**. The NSA mode uses the new 5G frequency spectrums for radio access while using the Evolved Packet Core (EPC) of existing LTE networks which are enhanced to support 5G NSA. This approach allows new 5G services to be introduced quickly while maximizing the reuse of existing 4G networks. The SA mode uses a flexible cloud-based 5G Packet Core to provide Software-Defined Networking (SDN) and Network Functions Virtualization (NFV) capabilities to unlock the full potential of 5G.

Major Features of 5G Physical (PHY) Layer Model

- Frequency Division Duplex (FDD) support in FR1 (≤ 6 GHz) band and Time Division Duplex (TDD) support in FR1 and FR2 (≥ 24 GHz) bands
  - FDD support for NSA mode
  - FDD and TDD support for SA mode
- In TDD, numerologies 0,1,2 in FR1 band
- In TDD, numerologies 2, 3 in FR2 band
- Massive Multi-Input Multi-Output (MIMO) with beamforming

Major Features of Medium Access Control (MAC) Layer Model

- Packet Data Convergence Protocol (PDCP) sublayer
- Media Access Control (MAC)
  - Buffer status report, Random access
  - Hybrid Automatic Repeat Request (HARQ)
  - Round robin and proportional fair scheduling
- Radio Link Control (RLC) sublayer
- Radio Resource Control (RRC) sublayer
- Switching between 5G and Wi-Fi Interfaces
- Carrier aggregation of up to 16 component carriers

Major Features of 5G Core Model

- Initial Registration
- Data Path Management (from DN to UE and vice versa)
- Handover Decisions
- Network Slicing

Creating 5G Scenarios

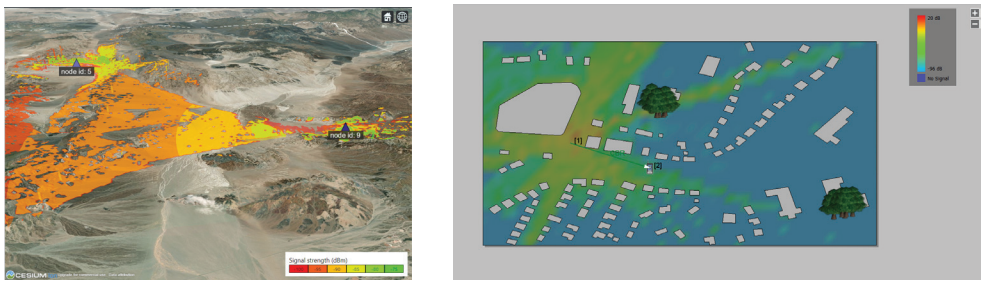
SCALABLE's EXata and QualNet network simulator and emulator platforms provide an intuitive, easy-to-use GUI for creating simulation scenarios of a variety of communication networks, including 5G.

- The GUI supports a drag-and-drop functionality to create networks using pre-configured high-fidelity models of devices and links. The models are highly parameterized and can be easily customized to accurately reflect the devices, channel frequencies, etc., expected to be used in the proposed network.
- Terrain features (hills, trees, buildings, etc.) have a significant impact on signal propagation and must be incorporated in the simulation scenario in order to accurately assess network performance. The GUI supports easily importing terrain data in several widely used formats.
- The GUI also provides models of different types of applications (voice, video streaming, email, messaging, web browsing, etc.) which can run over cellular networks. To more accurately mimic real-world mix of applications in a simulation scenario, EXata and QualNet also provide tools to capture traffic from existing cellular networks and wireless LANs which can be used in 5G network simulations.

Analysis of 5G Scenarios

SCALABLE provides several visualization and analysis tools for assessing performance of networks.

- The Statistics Database collects time-stamped statistics at different levels of granularity during a network simulation. These statistics can be analyzed and used to generate reports to understand performance issues and compare design alternatives.
- EXata and QualNet GUIs and the companion Scenario Player provide visualization of traffic flows and key metrics while a simulation is running. This provides valuable insight into network behavior, for example how different types of applications running simultaneously interact with each other, for instance how video streaming by some users affects the time to download an audio clip by other users.
- SCALABLE's Scenario Analyzer displays simulation data from the Statistics Database in the form of graphs and heat maps. A heat map displays signal coverage as a colored overlay over the scenario terrain. Different colors represent different signal strengths and each area is shown in the color associated with the strength of the received signal in that area. Heat maps provide a convenient way to identify gaps in coverage provided by a planned 5G network as well as possible interference with other wireless networks in the same region. The figure below shows heat maps in a rural and an urban region.



Heat Maps Showing Coverage of 5G Base Stations in Rural and Urban Environments