GUIDE TO 5G & 6G PRODUCT DESIGN

WAVE PROPAGATION MODELING AND RADIO NETWORK PLANNING

INTRODUCTION

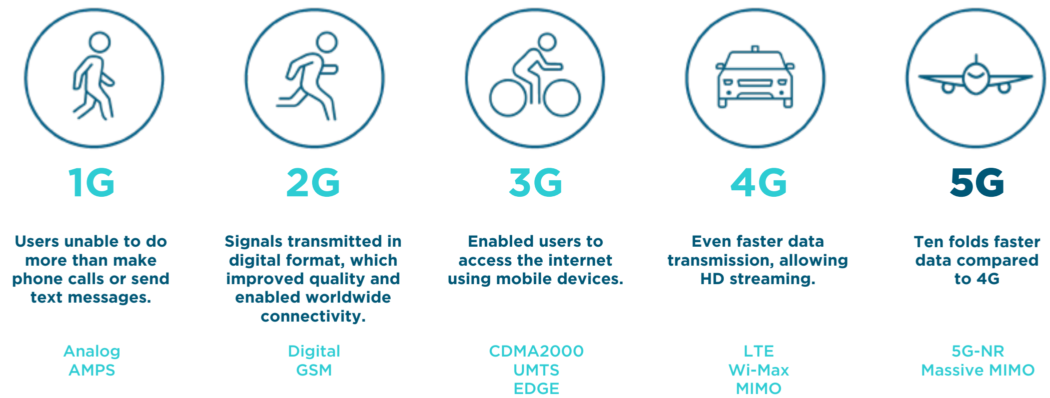
The rollout of 5G communication networks and 6G networks on the horizon promise to be a boon for telecommunications companies and the manufacturing industry globally. Faster speeds will result in higher data rates for users, perhaps as much as ten times higher than 4G capabilities, using the 3.5 GHz frequency bands for area-wide services and the 26-28 GHz bands for high data rate hotspots. Improved connectivity will enable more connections at once, as many as one million per square kilometer, according to some estimates. Improved connection speeds also open the doors for smart factory initiatives as companies evolve to Industry 4.0 practices.

How will antenna manufacturers, wireless equipment manufacturers, automobile manufacturers and suppliers, and wireless operators rise to meet these challenges? In this guide, we'll investigate the various electromagnetic and network planning simulation solutions Altair offers.

5G Product Design Guide

4G vs 5G: WHAT'S THE DIFFERENCE AND WHY IT MATTERS

The foremost distinction between 4G and 5G connectivity is the increase in reaction time, with latency reduced to no more than 1 millisecond. This opens the door for connected devices in time-critical industries, like healthcare and smart utilities.



The Evolution of Network Generations

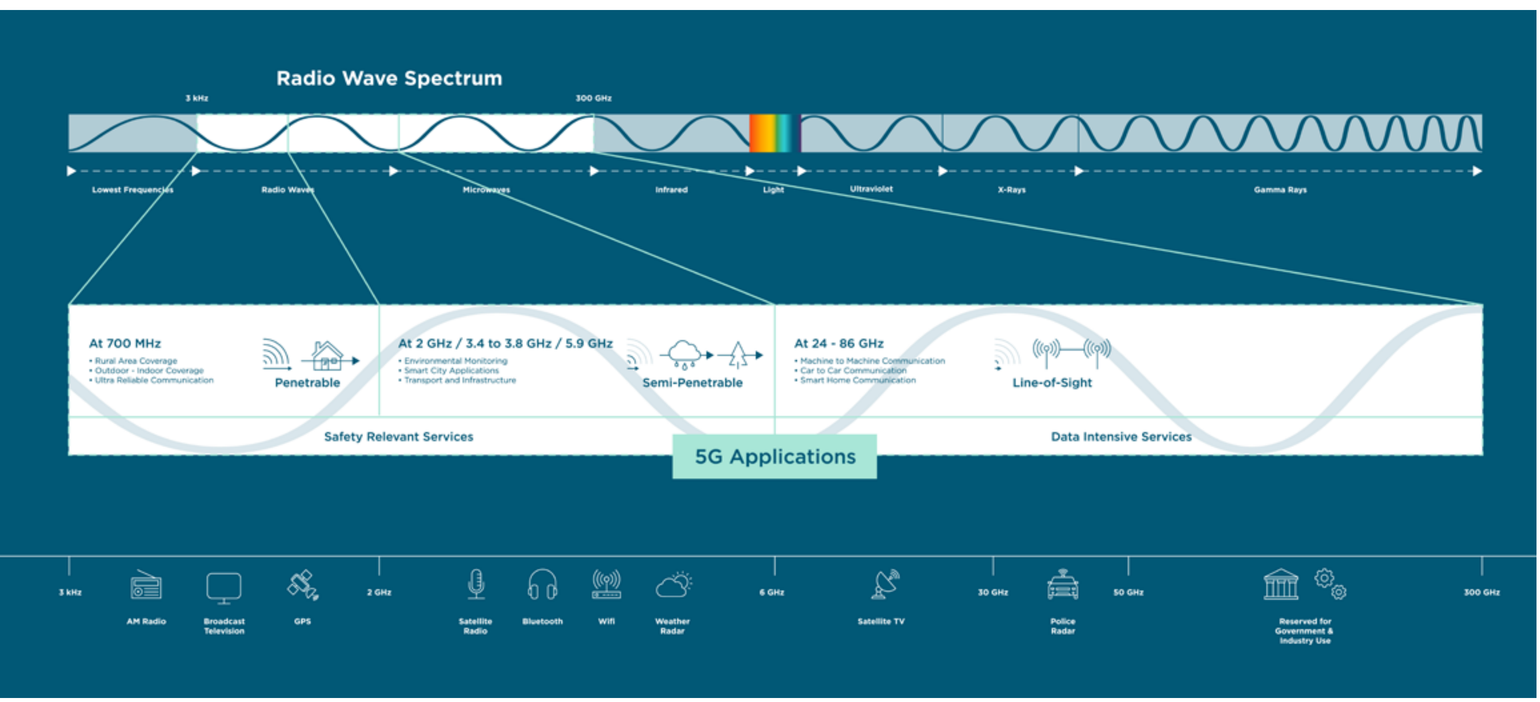
DIFFERENT APPLICATIONS REQUIRE DIFFERENT ANTENNAS

There are many applications that are addressed with the new communication standard, and multiple frequency ranges for 5G mobile communication that need to be considered. In general, 5G mobile networks can operate in various frequencies and therefore require different antennas for different frequency bands.

When looking at the multi-layer spectrum of frequencies, it's clear many applications like GPS, Wi-Fi, satellite TV, and police radar operate within this spectrum. Below 2 GHz (for example 700 MHz) is suitable for indoor and broader coverage areas as waves at this wavelength travel far and pass through objects. 2–6 GHz combines coverage, capacity, and the so-called "super data layer." Frequencies larger than 6 GHz (e.g., 24–29 GHz and 37–43 GHz) provide a high bandwidth but require a direct line of sight – even leaves on trees can block the connection.

As various frequencies are used to transport a signal for different applications, they require specialized antennas and antenna concepts. As a result, the variation of frequency bands used for the communication is one reason why we see more antennas. Additionally, the specialty of the New Radio (NR), requiring Line of Sight (LoS), accounts for another reasons why we see more antennas.

5G Frequencies, Reach, and Applications



WIRELESS COVERAGE CHALLENGES IN 5G

On the whole, as wireless technology evolved from 1G to 4G, the frequency steps were evolutionary, meaning they didn't require a large technology change.. The changes required for the antenna were evolutionary as well — antenna technology migrated from an external antenna to an internal one. 5G implementations, however, require many considerations that rely on accurate simulation models to ensure optimal performance.

1

Coverage

High-accuracy wave propagation models are required for predicting and optimizing radio coverage. This needs to be analyzed for different base station deployment scenarios, different frequencies, different environments, and along different test drives.

2

Network Performance

The new 5G cellular technologies will provide consumers with data rates of up to ten times that of previous 4G/LTE. A similar trend towards higher data rates by using higher frequencies is visible for Wi-Fi implementations exploiting the 60 GHz band with standards 802.11ad and 802.11ay. For these new technologies, achieving the desired network performance in urban and indoor environments creates new challenges. Performance will depend on the radio channel (and the associated frequencies used) which the urban and indoor building structures will impact.

3

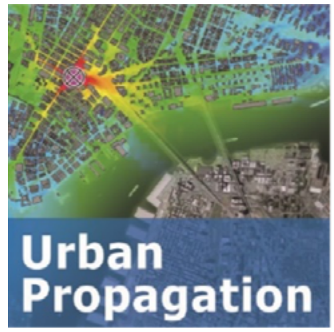
Finding the Balance Between Testing and Reducing Time to Market

This level of testing can be difficult, time-consuming, and expensive, but if not done adequately, organizations can incur even more expensive quality issues and the associated redeployment costs. Too much time spent in testing, however, can delay market entry and reduce profit. It's crucial to find the right balance.

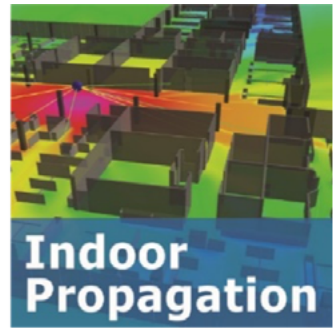
Altair's Solutions

Altair® Feko® offers a comprehensive package of solvers with true hybridization for efficient design, analysis, optimization of connected products, wave propagation modelling, and radio network planning. Feko provides various frequency and time domain techniques to compute the 3D antenna patterns of base stations, mobile stations, and other equipment like Wi-Fi routers. These 3D antenna patterns are then used in Altair® WinProp™ to evaluate the connectivity and signal propagation performance in a range of scenarios such as rural, urban, and indoor environments.

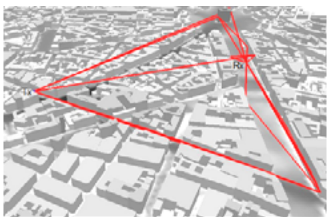
Large rural scenarios are based on the processing of topography and clutter maps in pixel formats.



WinProp offers sophisticated propagation models based on ray-optical techniques such as like ray tracing.



Indoor scenarios include 3D vectors with individual material properties to describe more complex objects like office floors.



Ray Tracing Modeling Using WinProp

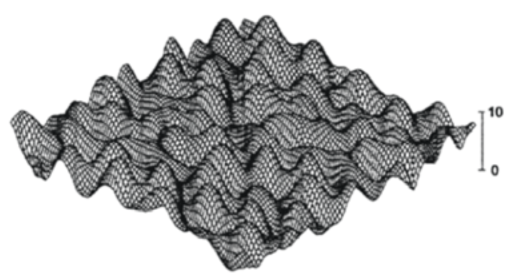
Ray Tracing

Generally speaking, radio channels are subject to multipath propagation. The figure to the right shows an urban scenario with a base station above rooftop level and a mobile station located in the street canyon, with multiple rays connecting the transmitter and receiver. Due to the environment, signal reflection from nearby buildings, diffraction around corners, and shadowing behind buildings will all affect the signaL

The superposition of multiple rays at the receiver will cause destructive and constructive interference, creating fading patterns:

Altair's Dominant Path Model offers short computation times and predicts the pathloss or signal level with high accuracy, even using default values. In a previous collaboration with a leading cellular operator, the parameters of this model were fine tuned to account for different 5G frequencies considerations of 5 cities. The high performance of this model was realized after results were produced; A mean difference of +/- 2dB for an urban environment, +/- 3dB for a suburban environment, and a standard deviation of below 6dB. Additionally, for environments where more ray bounces are necessary to simulate, Altair's Shooting and Bouncing Rays Propagation Model can be utilized.

No line of sight (Rayleigh fading)

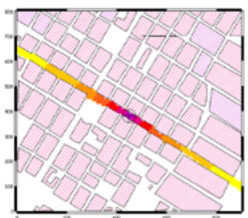


Line of sight (Rice fading)

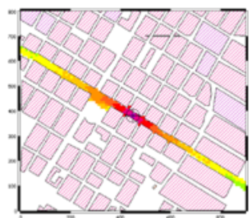
WAVE PROPAGATION FOR FREQUENCIES ABOVE 6 GHZ

Most 5G base stations in an urban environment are situated below rooftop level, at around 5 to 10 meters above street level. Almost all transmitted rays propagate through street canyons due to multiple reflection points like buildings. This effect is more pronounced in higher frequencies typically from 6GHz and above, which is incidentally the frequency range of 5G. Using Altair's electromagnetic analysis solutions, it's possible to analyze a variety of ray types.

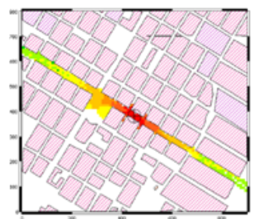
Direct, single reflection, and double reflection rays are limited to the street in which the transmitter is positioned for Line of Sight (LOS) and Obstructed Line of Sight (OLOS) regions:



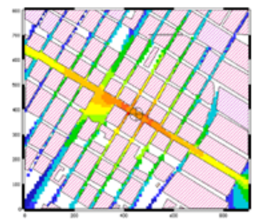
Direct



Single Reflection



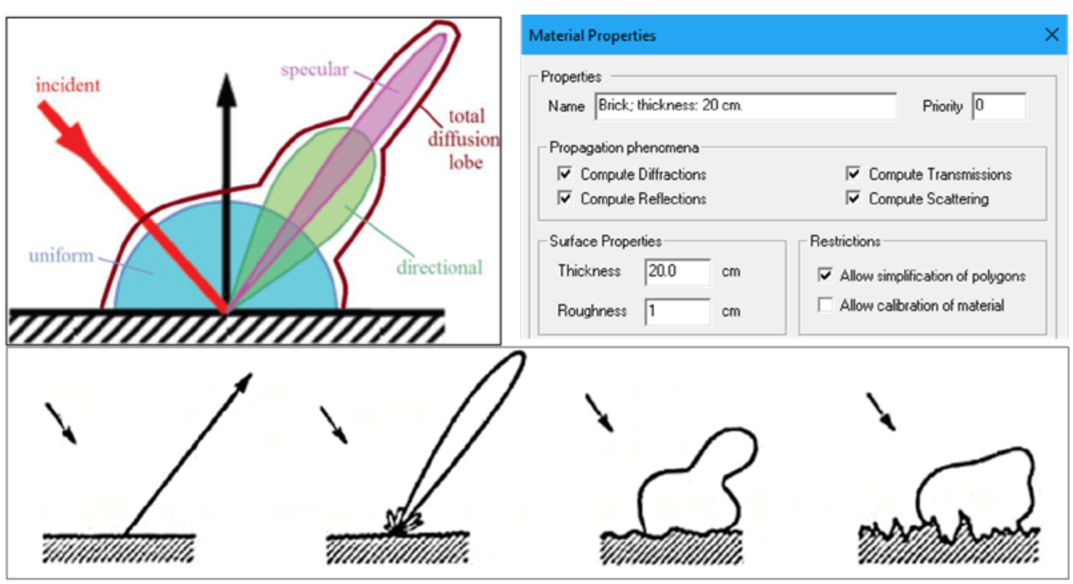
Double Reflection



Single Diffraction

Single diffracted rays have a much larger coverage range, reaching perpendicular streets. While this ray type increases the propagation area, attenuation is higher and therefore a comprehensive analysis of scatter behavior using Bidirectional Reflectance Distribution Functions is important.

Using Altair's refined scattering methodology, users can evaluate specular, directional, and uniform scattering by defining the surface roughness of considered materials.



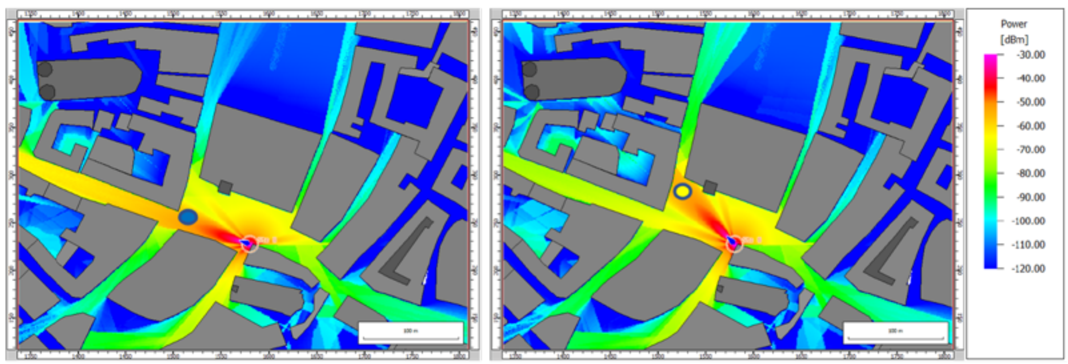
A deeper understanding of ray scattering can be achieved using Altair's refined scattering methodology.

Beamforming

The benefits of beamforming are to increase the received signal gain by making signals emitted from different antennas add up constructively, reducing the multipath fading effect. Spatial multiplexing can also be combined with beamforming when the channel is known at the transmitter.

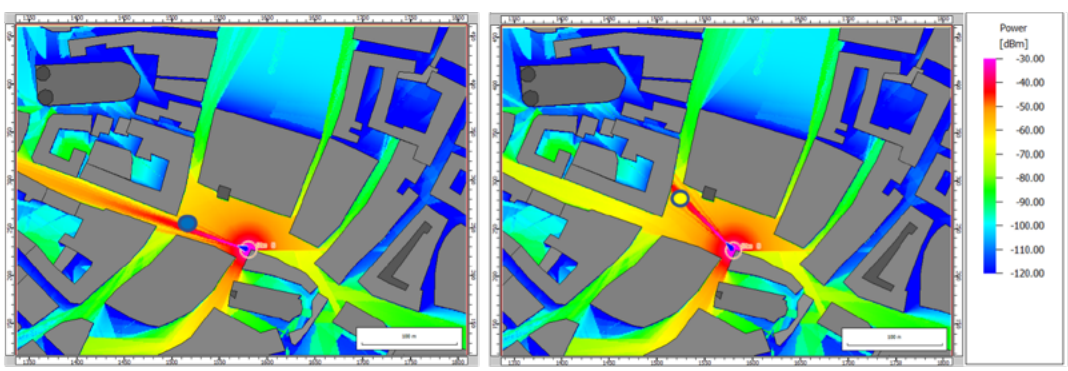
Beamforming at the transmitter can be achieved by spatial processing. In this case the same signal is emitted from each of the transmit antennas with appropriate phase weighting so the signal power is maximized at the receiver input. In the absence of scattering, beamforming results in a well-defined directional pattern, increasing the antenna gain for the desired signal and reducing the antenna gain for the interfering signal.

The images below show the signal coverage of a 4x4 antenna element configuration, with the separate users represented using blue and yellow circles:

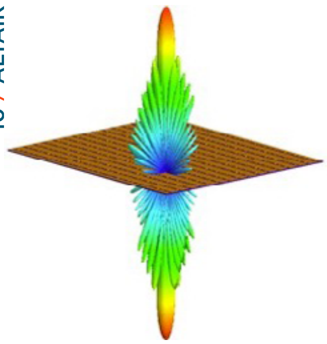


4x4 antenna element configuration

Using a 16x16 antenna element configuration a beam with higher directivity is possible, demonstrating how the width of the beam depends on the number of antenna elements used.



16x16 antenna element configuration



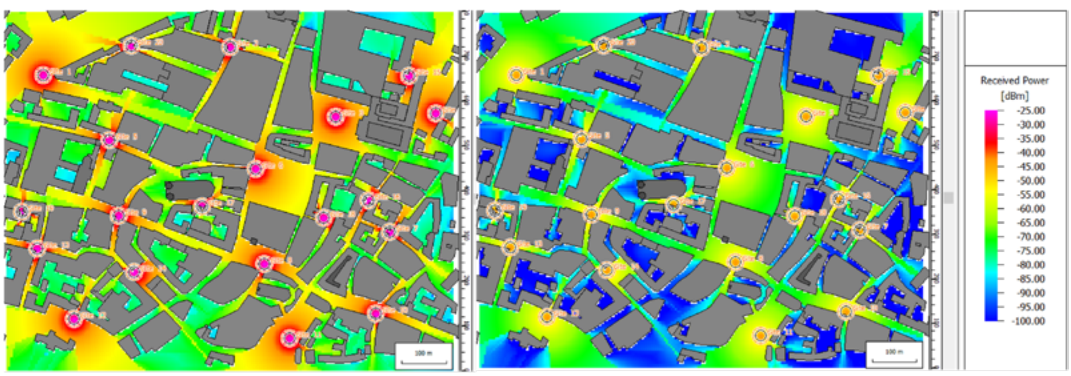
2D 16 x 16 antenna array for 5G base station working at 26 GHz designed and optimized with Altair Feko

Because of the higher antenna gain requirements in 5G, typically antenna arrays are needed on both ends, on the mobile device, and on the base station. Besides higher antenna gains, more sophisticated feeding and control circuits are needed and a good isolation between array elements must also be achieved. Feko not only includes multiple frequency and time domain methods, it also has features that quickly and accurately design and optimize antenna arrays.

Multiple antenna placement options and their interaction with the hosting board can be explored to quickly identify various trade-offs and optimization opportunities, something too expensive and time-consuming to try with physical designs. Even complex beam forming and steering capabilities and their efficiency at different frequencies can be simulated and results easily viewed in 3D models, shown in the nearby image.

Simulating and Comparing 5G Deployment Strategies

The deployment of a 5G network involves several considerations that impact the stability and function of signal strength, speed, and capacity. Ultra-dense networks require high data rate volumes to accommodate the number of devices accessing the network. Utilizing technology like beamforming makes it possible to increase the base station power levels and signal-to-noise-and-interference-ratio (SNIR) levels, while reducing interference.



3.5 GHz **26 GHz**

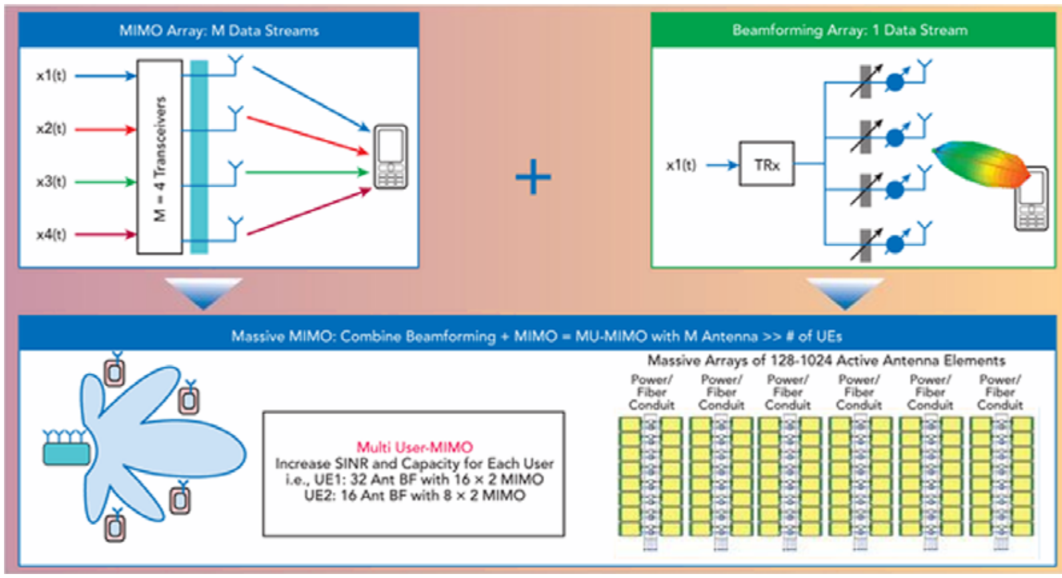
A comparison between 5G deployment strategies

Using Altair's radio planning tool, users can simulate various 5G deployment strategies at different frequency bands, including the beamforming used in 5G networks. At 3.5GHz, we can see the number of base sites showed could be sufficient for providing basic coverage. At 26GHz, the coverage map indicates areas in which the network signal is too weak, shown in blue.

Massive MIMO Antennas

A key feature of 5G is massive MIMO antennas. These systems deploy spatially separated multiple antenna elements at both ends of the transmission link which can achieve higher data rates and more reliable wireless connections than Single-Input Single Output (SISO) systems with one antenna on each end of the link. This creates localized beams towards each device.

Thanks to statistically independent propagation channels between each pair of transmit and receive antennas, different data streams can be transmitted using the same carrier, which leads to a higher total data rate. Put simply, multiple channels of data can be transmitted simultaneously. MIMO spatial coding is used to separate the channels of data to different users according to their spatial position and unique channel propagation characteristics of each Tx Rx combination. These antenna installations combine beamforming and spatial multiplexing as illustrated in the image below:



Beamforming and spatial multiplexing Microwave Journal

To develop and verify these massive MIMO antennas and its performance, the statistics of the radio channel can be simulated and analyzed using Feko. Delay spread, Azimuth angular spread, elevation angular spread, and cumulative distribution function evaluation can all be assessed, leading manufacturers to develop more accurate equipment.

The holistic representation of massive MIMO antennas within a network can optimize antenna designs and reduce development time, ensuring faster application integration and better device characteristics. Such automated design processes accelerate the path to innovation, reduce testing and measuring campaigns, cut development costs, and improve time to market speed.

Private Network Planning

The increase of bandwidth and speed that 5G delivers is also being leveraged by businesses to set up their own private networks. Industrial plans, manufacturing facilities, and logistics centers can all benefit from this technology but also need to account for signal obstructions, weather conditions, and signal frequency to ensure an efficient wireless environment. Leveraging integrated simulation of antennas and the network helps planners understand use cases, define infrastructure requirements, and create a usage plan to apply for the frequency spectrum.

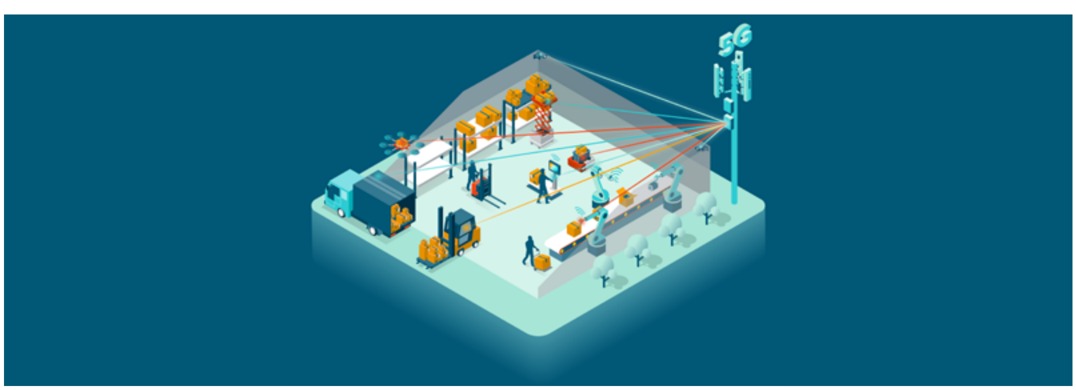
- **Improved privacy** - A 5G private network allows a dedicated local network with dedicated resources managed independently from the public network. It also offers greater privacy and security without going to the central cloud.
- **Optimized performance** - All resources are dedicated to local applications. For example, if a factory owner needs ultra-reliability and low latency, a private network can emphasize and optimize those aspects.
- **Flexibility** - As a global standard, 5G has a vast ecosystem and an extensive roadmap. This means by deploying a 5G private network, the opportunity and flexibility exist to continue integrating features that come out in future releases.

The Connected Factory Floor

Whether you call it Industry 4.0 or smart manufacturing, advances in many technologies promise a more connected factory floor in which previously "blind" equipment becomes interconnected to produce meaningful insights, predictive maintenance capabilities, and more efficient operations.

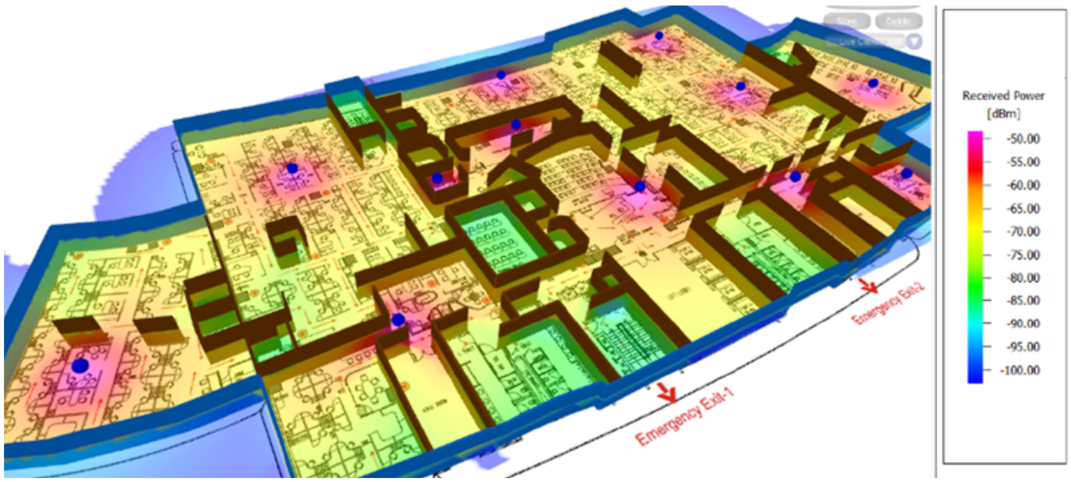
The 5G standard is the foundation for many (Industrial Internet of Things) IIoT applications. In fact, it's predicted that every €1 spent on 5G network services will enable €4 of IIoT value creation. (The private LTE opportunity for industrial and commercial IoT Habor research) Simulating the devices, 5G antennas, and the 5G networks they are operating within helps to create the desired communication performance. Having a good understanding of network performance, planning, and antenna design is therefore imperative to optimize smart factory floor capabilities. Altair's 5G network planning and wave propagation solutions give users the necessary tools to achieve a reliable private or campus network.

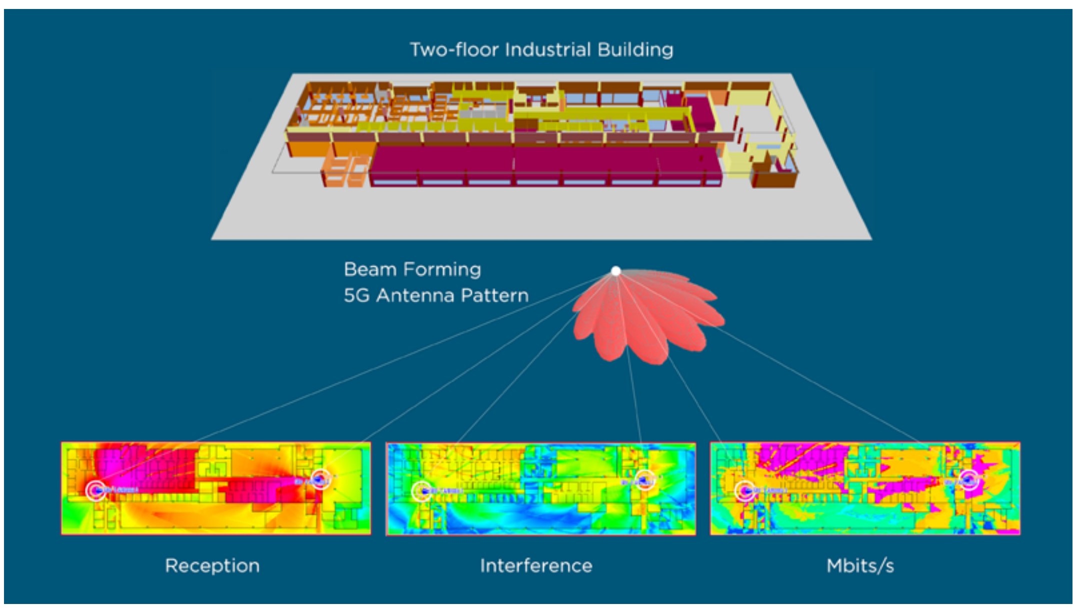
To learn more about how companies like Nokia are using Altair's 5G solutions to develop IIoT networks, watch the presentation:
Industrial IoT (IIoT) Networks Powered by 5G New Radio



Multi-floor Office Environments

Altair's 5G network planning tools can also be scaled to smaller environments such as multiple office floors with similar signal obstructions to industrial plants or manufacturing plants. Represented as 3D vectors, WinProp offers a detailed analysis of such scenarios where advanced ray tracing and dominant path models are applied. The possibility of exact representation from single antennas up to complete systems interacting with their infrastructure and environment allow a unique prediction quality and efficient network realization. The openness of Altair's 5G network simulation tools enables a smooth integration into existing planning environments.

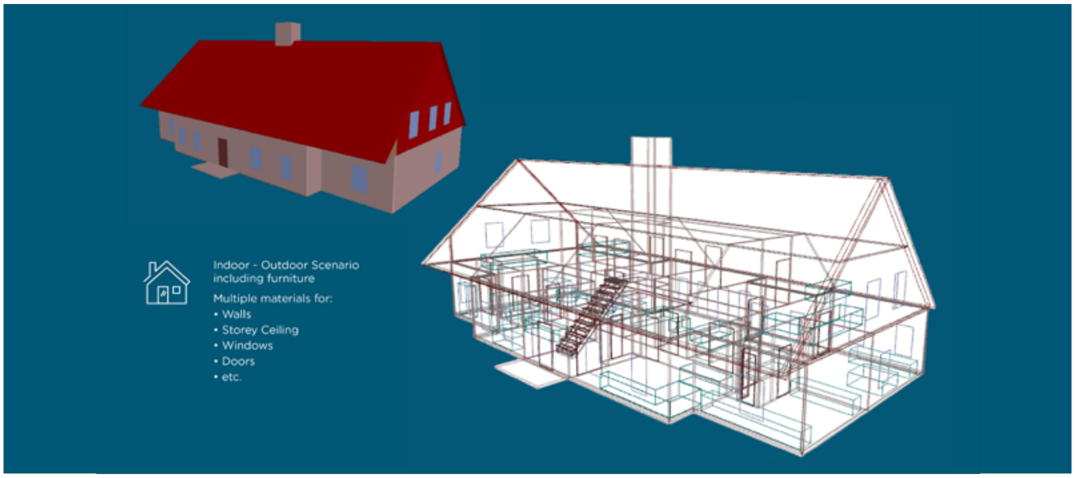




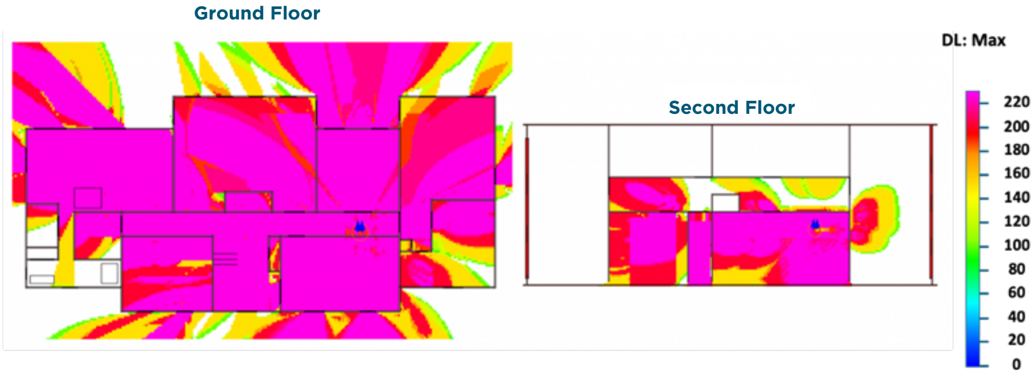
Network Planning in the Home

For home working scenarios, Altair's electromagnetic solutions can be useful to understand the performance of a Wi-Fi connection. Connection quality depends on the signal frequency, the size and layout of the house, and even what material the building is made of. Simulating and analyzing signal strength gives users a comprehensive understanding of the optimal router placement and helps them determine whether a repeater is necessary.

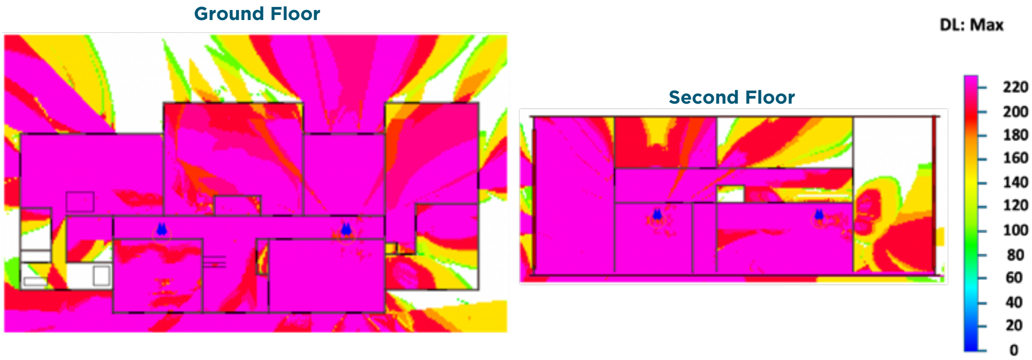
Wi-Fi and 5G networks operate at different frequencies, however this scenario illustrates the factors that affect frequency performance and demonstrates Altair's connectivity solutions.



A house model built for this study.

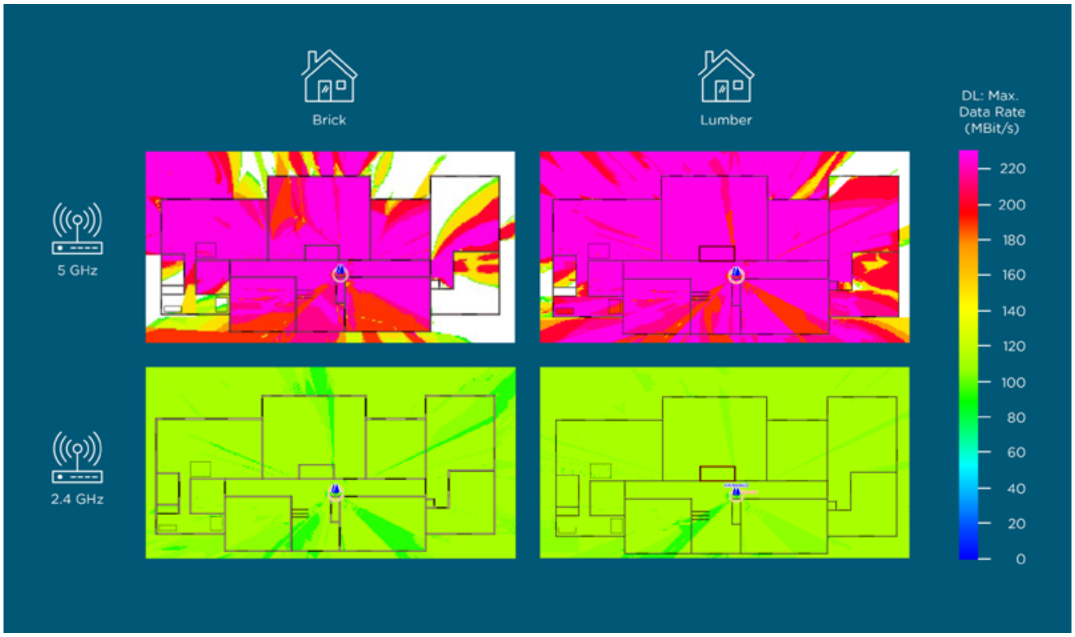


Shown above are the attainable data rates on the ground floor and second floor when the base station is moved to the right (shown in blue).



Now shown are the attainable data rates for the ground floor and second floor when the base station is moved to the right and a repeater is added.

From this analysis, we can also ascertain the performance of specific frequencies based on the material the building is made of.



Attainable data rates on the ground floor at different carrier frequencies and material variation of the building structure, considering the presence of low-level interference from routers in neighboring buildings.

2.4GHz Summary

- **Pros:** Larger coverage area, better at penetrating solid objects
- **Cons:** Lower data rate, more susceptible to interference as nearby devices are likely using the same frequency
- **2.4GHz max speed:** ~110 Mbps (in this Wi-Fi example based on the IEEE 802.11n standard)
- **2.4Ghz max distance:** Enough for a large multi-story house with terrace

5GHz Summary

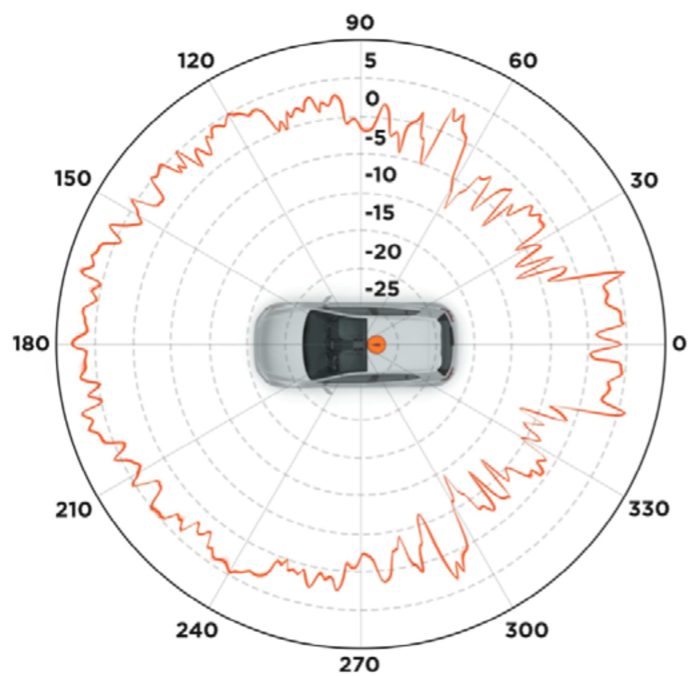
- **Pros:** Higher data rate, less susceptible to interference as there are typically fewer devices using the same frequency
- **Cons:** Smaller coverage area, less successful at penetrating solid objects
- **5Ghz max speed:** ~220 Mbps (in this Wi-Fi example)
- **5Ghz max distance:** Reasonable for a large multi-story house with terrace provided a repeater is used

INTEGRATE CAR2X COMMUNICATION

Next-generation vehicles bring increased complexity and a need for more connectivity. Altair accelerates the development and integration of vehicle-to-everything (V2X) communication, which allows better management of integration aspects, reduces complex tests, improves test runs, and lowers development costs. The possibility of exact representation from single antennas to complete systems, as they interact with the vehicle structure and environment scenarios, such as changing terrain, allows for a unique prediction quality and efficient design of wireless applications.

Altair simulation tools enable autonomous driving, assessing connectivity in real driving conditions. A holistic workflow that addresses antenna design, placement, and system performance via virtual drive tests ensures proper and optimized 5G connectivity on the vehicle.

To learn more about Altair's connectivity solutions for vehicle antenna design, [watch this video.]



Altair's connectivity solutions for vehicle antenna design.

WORKING WITH ALTAIR

By using simulation, antenna manufacturers, wireless equipment manufacturers, and wireless operators can better understand the connectivity performance of their products, opening the doors for the 5G revolution. Indoor, outdoor, and rural environments can all be considered to provide the maximum amount of coverage possible, supplying users with high-speed, low-latency, and secure networks in both personal and commercial settings.

To learn more, please visit altair.com/5g

Altair is a global technology company that provides software and cloud solutions in the areas of product development, high performance computing (HPC) and data analytics. Altair enables organizations across broad industry segments to compete more effectively in a connected world while creating a more sustainable future.

To learn more, please visit www.altair.com