RIS-Enhanced Private 5G Network Planning in Smart Warehouses

From Digital Twin Simulation to Multipath Insights

Dr. Kan Lin
Ranplan Wireless Network Design Ltd

Abstract

The continuous deployment of 5G networks is extending into various industries—including factories, warehouses, and manufacturing areas—to enable efficient production and automation through highly reliable, low-latency wireless connectivity.

Despite this progress, several challenges remain, such as insufficient coverage in complex industrial layouts, high capital expenditure (CAPEX) for equipment, and installation difficulties within dense and reflective environments. These issues hinder widespread adoption of private 5G networks in real-world scenarios. Reconfigurable Intelligent Surfaces (RIS), as an emerging technology, naturally possess the capabilities to address these challenges.

Ranplan, a developer of wireless network planning software, provides professional tools that support network design, deployment, and testing in digital twin environments. This white paper presents a warehouse use case demonstrating how in-depth analysis of RIS deployment, combined with digital twin modelling in Ranplan Professional, can serve as a cost-effective solution to ensure that the majority of the warehouse area achieves sub-2 ms latency and 99.999% reliability, enabling safe and efficient automated warehouse machine operations.

In addition, an optional multipath analysis module within Ranplan Professional enables detailed extraction and evaluation of propagation paths in a digital twin environment. While not required for standard deployment planning, this capability is particularly valuable for researchers investigating channel behaviour, RIS-assisted propagation mechanisms, and advanced wireless system design for future network evolution. Furthermore, the extracted multipath data can support sensing of moving objects, helping machines avoid collisions and enabling more efficient route planning within environments such as warehouses.

Market Drivers and Challenges

Market Drivers

The trend toward high automation and reduced labour costs in industry is reshaping the requirements and expectations for 5G networks in warehouse environments. A fully covered 5G network can enable both manual and automated control of robots throughout the warehouse with minimal human intervention. However, these functionalities are entirely dependent on a highly reliable, low-latency wireless network.

Within a warehouse, a 5G network can support the following key functionalities:

- Remote and real-time manual robot control in emergency situations.
- Cost-efficient coverage enhancement with reduced carbon emissions.
- Autonomous robots for delivery with minimal human oversight.
- High-speed information and location exchange among robots to prevent collisions.
- Flexible network modification and rapid adaptation to meet evolving operational requirements.

5G Network and RIS Deployment Challenges

5G networks provide large-scale wireless access to multiple devices while delivering high reliability to improve the efficiency of material transportation within warehouse environments. Ranplan supports the design, optimization, and pre-evaluation of 5G private networks.

RIS are engineered structures designed to dynamically control radio propagation by reflecting and shaping wireless signals within an environment. By redirecting signals around obstacles, RIS can enhance coverage without the need for additional active base stations. Their deployment is particularly beneficial in locations where it is difficult to install cabling for additional base stations.

However, integrating RIS into private 5G networks introduces new complexities. Performance behaviour under realistic deployment conditions remains insufficiently understood, particularly in dense indoor environments with complex multipath propagation. As a result, accurate modelling and simulation are essential to ensure reliable and cost-efficient deployment.

Despite recent advancements, key challenges remain:

- Complex environments requiring extensive cabling, infrastructure investments, and continuous power supply, constraining scalability and sustainability.
- Insufficient tools and practical expertise for accurate RIS modelling and simulation under realistic 5G network conditions.
- Uncertainty in RIS performance evaluation, particularly in dynamically changing environments with multipath propagation.
- Lack of detailed insight into multipath propagation, restricting deeper analysis and algorithm optimization for RIS-assisted networks.
- Time-consuming processes for network modifications and retesting.

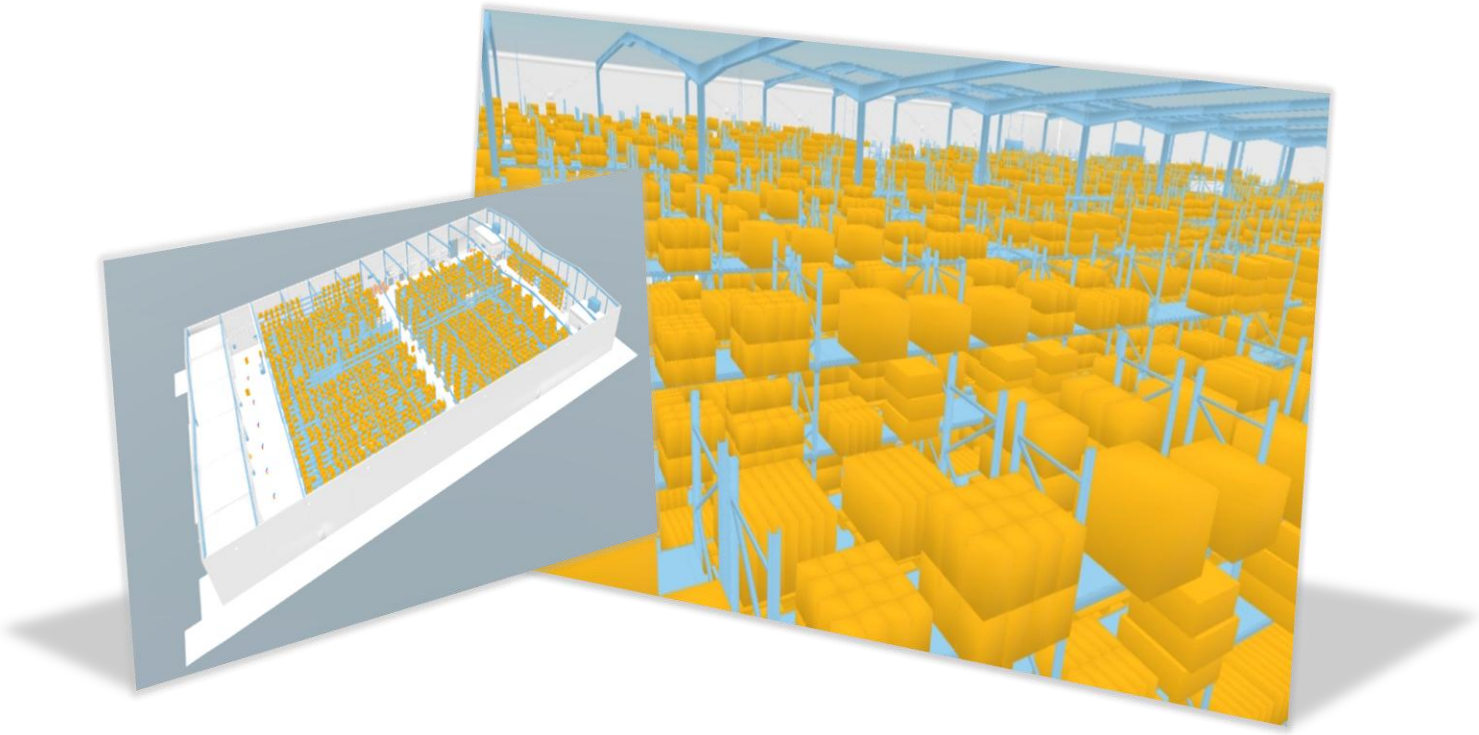
Use Case Summary: Warehouse Deployment

5G networks provide high-speed, high-reliability, and low-latency connectivity to support diverse industrial use cases. In warehouse environments, 5G enables seamless wireless communication for automated operations. However, the physical complexity of warehouse environments—characterized by dense shelving, moving objects, and varied construction materials—often leads to unsatisfactory network performance.

To address these challenges, RIS can be deployed to enhance coverage and performance while minimizing deployment costs. With RIS integration, the Key Performance Indicators (KPIs) required for autonomous warehouse operations—including uninterrupted robot coordination, rapid emergency response, and efficient material handling—can be achieved more effectively in complex environments.

Best Practices via Ranplan Professional

The warehouse network is designed to provide comprehensive wireless control and monitoring with minimal human intervention. In this scenario, autonomous robots can receive instructions from either the system or human operators, enabling them to travel to any location for retrieving and depositing goods. During task execution, the robots must continuously exchange information and location data to ensure smooth coordination and to avoid potential collisions.



Achieving this level of operational reliability in a dense and cluttered warehouse environment requires precise modelling of radio propagation, careful device placement, and iterative performance evaluation—tasks that are difficult to accomplish through manual testing alone.

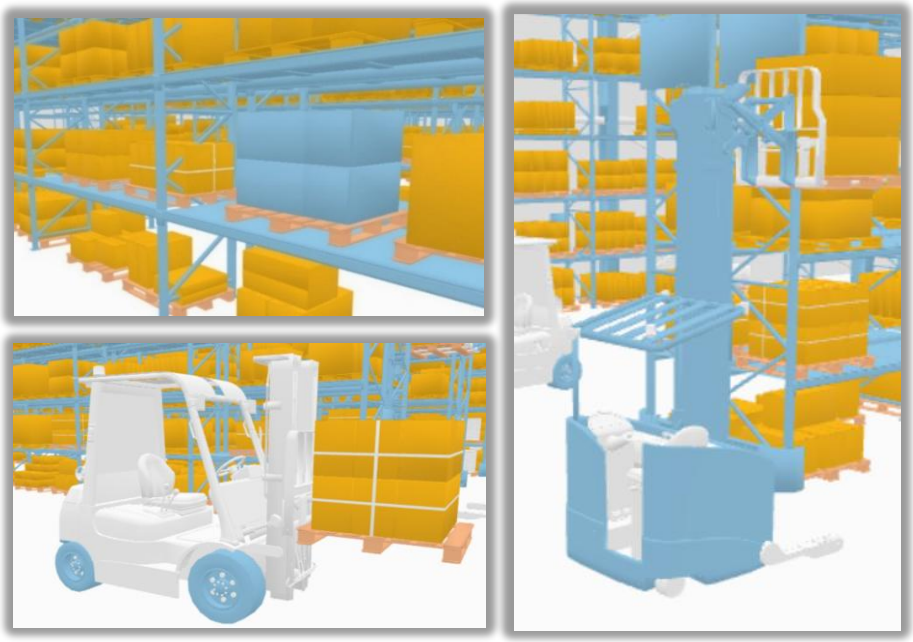
The complicated warehouse environment introduces several challenges for network designers:

- Difficult channel estimation due to the lack of detailed object modelling and environmental complexity.
- Identifying optimal RIS placement while minimizing the number of deployed devices.
- Manual and repetitive testing required to optimize the network performance.

Ranplan Professional addresses these challenges through a comprehensive, simulation-driven approach. Its digital twin-based scenario modelling enables accurate replication of warehouse environments, supporting high accuracy, ensuring precise and efficient network design. The software's fast deployment and KPI simulation tools enable users to virtually deploy devices, evaluate network performance, and refine configurations before physical installation, reducing both cost and deployment time.

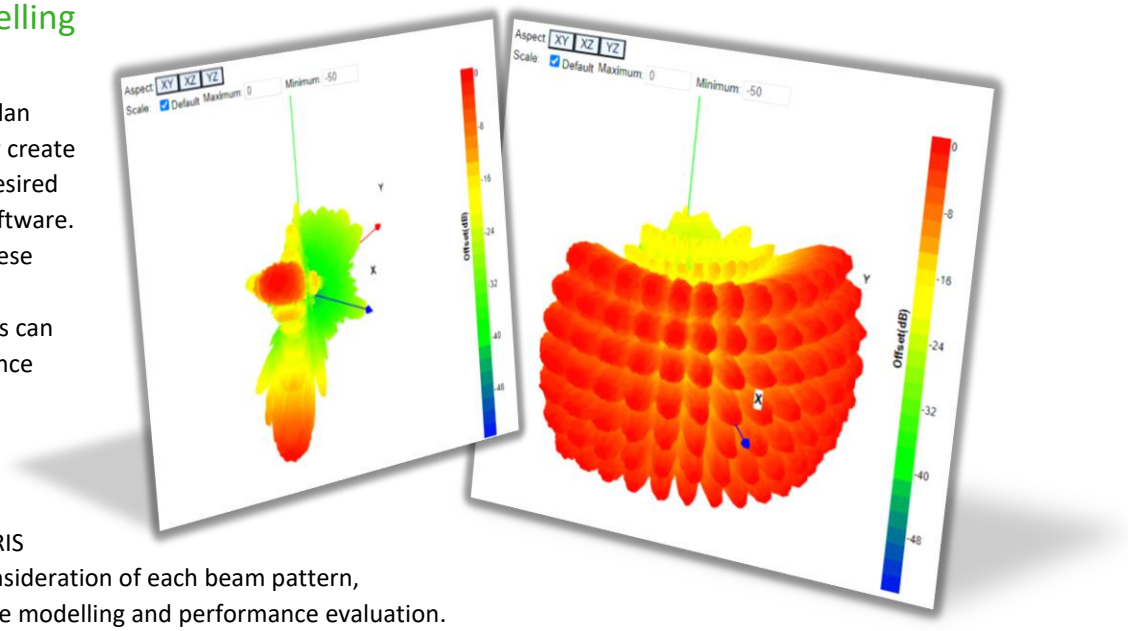
Most importantly, Ranplan Professional integrates RIS modelling and performance simulation within existing 5G systems, helping users quickly identify the best RIS locations and quantify their impact on network coverage, latency, and reliability, taking into account multipath propagation and dynamic signal interactions in complex environments. This solution-driven approach empowers warehouse operators to achieve robust, cost-effective, and future-ready 5G private networks.

Scenario Modelling



In real-world scenarios, warehouses typically contain a wide variety of materials, such as steel, concrete, glass, metal, and wood. Among these, materials like concrete, steel, and metal can cause signal propagation losses of up to 90dB, severely degrading network performance if not properly accounted for. Therefore, it is essential to model and consider these materials at the initial design stage. Ranplan Professional enables precise modelling of common warehouse objects—such as wooden boxes, forklift trucks, and elevator cars—using realistic multi-material properties. This capability allows network designers to accurately predict and optimize 5G performance in complex warehouse environments.

Network Device Modelling



Equipped with the advanced modelling capabilities of Ranplan Professional, users can quickly create accurate representations of desired network devices within the software. By designing and deploying these devices in a digital twin of the warehouse environment, users can pre-evaluate device performance under specific conditions before real-world deployment. The figures on the right illustrate how Ranplan Professional models RIS devices, including detailed consideration of each beam pattern, enabling highly accurate device modelling and performance evaluation.

Multipath Information

In complex indoor environments such as warehouses, radio signals rarely travel along a single line-of-sight path. Instead, signals reflect, diffract, and scatter off walls, shelves, machinery, and other objects, creating multiple propagation paths—commonly referred to as multipath propagation. These multipath effects strongly influence coverage, latency, reliability, and positioning accuracy, making them a critical factor in both network planning and advanced wireless research.

In addition to supporting network design, deployment, and optimization, Ranplan Professional provides advanced multipath generation and analysis capabilities that enable detailed investigation of radio propagation phenomena. These capabilities directly support a wide range of emerging research areas, including high-resolution channel modelling for 6G and THz communications, massive MIMO and extremely large aperture arrays, integrated sensing and communication, localization, positioning and mapping, and machine learning for wireless systems.

Research Area	How Multipath Information Contributes
THz / 6G Channels	Sparse but high-impact propagation paths
MIMO Communications	Degree of freedom and spatial multiplexing
ISAC	Environment sensing and awareness
Localization	Geometry inference
Reconfigurable Intelligent Surfaces (RIS)	Path and reflection analysis
Machine Learning	Feature extraction and interpretability
Digital Twin	Real-time environment replication
High-Mobility Scenarios	Dynamic propagation characterization

Multipath information is fundamentally linked to all these areas, as it captures the underlying propagation geometry and environmental interactions that govern wireless performance.

To support flexible and fine-grained multipath analysis, Ranplan Professional allows users to generate multipath information at arbitrary locations within a simulated scenario. Users can select both the multipath source and the extraction method, enabling multipath acquisition by region, individual ray tracing paths, or specific spatial points. This flexibility allows researchers and engineers to tailor the multipath data to their specific use cases. Leveraging the built-in propagation engine, multipath information can be generated efficiently with a single operation, producing detailed multipath data files containing key parameters, including:

- Path loss
- Traversal time (delay)
- Angle of Arrival (AoA)
- Angle of Departure (AoD)
- Zenith Angle of Arrival (ZoA)
- Zenith Angle of Departure (ZoD)
- Overall behavior of each propagation path

Use Case Benefits: Warehouse Deployment

Ranplan Professional supports comprehensive 5G KPI simulations, providing a clear overview of the designed network's performance. The detailed network system for the warehouse is summarized in the table on the right. These KPI simulation results also help users identify potential issues within the network design, enabling timely adjustments before actual deployment.

Parameters	Value
System	5G NR
Carrier Frequency	3600 MHz
Bandwidth	20 MHz
Transmission Power	36 dBm
Propagation Engine	Maxwell
Antenna Resolution	0.5 Meters
Antenna Coverage Radius	100 Meters