Antenna Digitalization White Paper

CONTENTS

01 INTRODUCTON

Antenna serves as the sole connection between networks and the physical world, playing a crucial role in wireless communications.

The beams emitted from antennas determine network performance in terms of coverage and user experience. The performance depends on how well the beams match their propagation channels and how strong they are at the points of reception. This highlights the significance of optimized antenna beams.

Creating optimal antenna beams has therefore become one of the top priorities in antenna development and an important topic of research in the field.

Fig. 1 Antenna, connecting the network and users

Since their first appearance, wireless networks have been developing following Shannon’s capacity theorem.

As networks evolve, frequency bands and channels are gradually added to enable them to provide more capacity.

Over the past few decades, antennas have evolved in a similar way, with increasing band support and array arrangements integrated into one box.

Fig. 2 Continuous evolution of antennas on bands and ports

Wireless networks are at the point where the capacity over a single channel is nearing the theoretical limit set by Shannon's Law.

To further increase network capacity, it is necessary to break the capacity limit of incumbent theories and algorithms, and this is where artificial intelligence (AI) can come into play.

AI is breathing new life into wireless networks and improving the air interface performance, network maintenance efficiency, and business operations.

AI is emerging as a new driving force that will enable wireless networks to sense their surroundings and become highly autonomous.

Fig. 3 AI, the awakening force to network

To make intelligent wireless networks a reality, both intelligent software and base station hardware digitalization are essential new capabilities required, as they are the foundation of network and site models for all network systems.

Antennas are the only way for base stations to communicate with users, and therefore digitalizing antennas is critical to the development of intelligent wireless networks..

Antenna digitalization means that, rather than continuing to exist as 'black boxes', antennas will support data driven management, providing deterministic physical information for intelligent networks. Also, they will need to be remotely adjustable to enable the full potential of intelligent wireless networks..

In the era of intelligent networks, these are new directions in antenna evolution.

The new AI era has already started, bringing with it new opportunities for the mobile industry to align antenna development with the requirements of intelligent wireless networks. This white paper will investigate the evolution path of passive antennas towards intelligence and focus on how this will help develop high performance, highly automated wireless networks.

02 Antenna Digitalization A New Trend for Intelligent Wireless

All the way from GSM, 3G, LTE and 5G to today's 5.5G era, increasing spectral efficiency has always been one of the main priorities of the communications industry as it continuously strives to achieve better user experiences.

5G networks are seeing widespread adoption and emerging technologies such as generative AI are gaining momentum.

The communications industry is ushering in a profound transformation, with wireless networks becoming increasingly intelligent and providing more automation capabilities that will further improve user experiences, as well as enable higher efficiencies for mobile network operators.

Globally, leading network operators have proposed their own vision of digital networks and working with standards organizations to define autonomous networks and their objectives for automation levels L0 to L5. Automation and intelligence are emphasized as essential characteristics of future network infrastructure and operations systems.

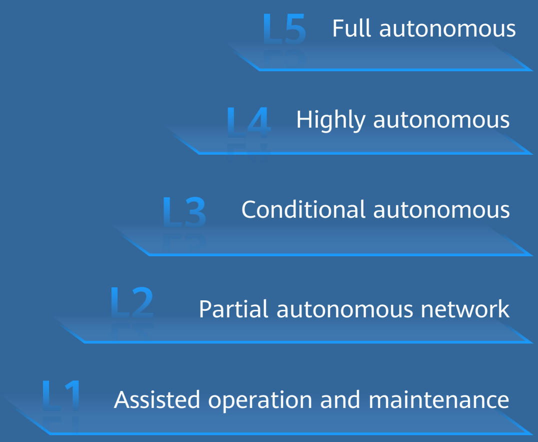


Fig. 4 Mobile networks taking steps towards full autonomy

A recent survey by TM Forum, a global industry association for service providers and their suppliers in the telecom industry, found that more than 91% of international operators are aiming to have L4 autonomous network (AN) support for their business processes by 2025 to 2027. Network autonomy is regarded as a key strategy by those operators.

To make autonomous networks a reality, the physical world has to be represented virtually through multidimensional modeling, digitalizing the physical world as a digital twin.

With digital twin models, performance parameters such as coverage, capacity and experience can be efficiently optimized. This requires using network information such as base stations, user distribution, and antenna beams as inputs for grid-based digital processing. Intelligent algorithms generate policies for synergetic optimization of network coverage, direction and power, to align quick adjustments of complex multi-layered networks with flexibly changing service requirements.

Typically in base station infrastructure equipment, most radio frequency units have initially achieved intelligence through software upgrades. Antennas are passive network components that are still considered 'dumb', in a sense that they can not provide any information about their actual location, orientation or environment. As the only media channel that facilitates information exchanges between networks and the physical world, they are now the biggest challenge for intelligent networks.

Network intelligence requires antennas to be remotely managed and adjusted in real time, and this has become one of the top research topics in the antenna industry.

2.1 Antenna Manageable

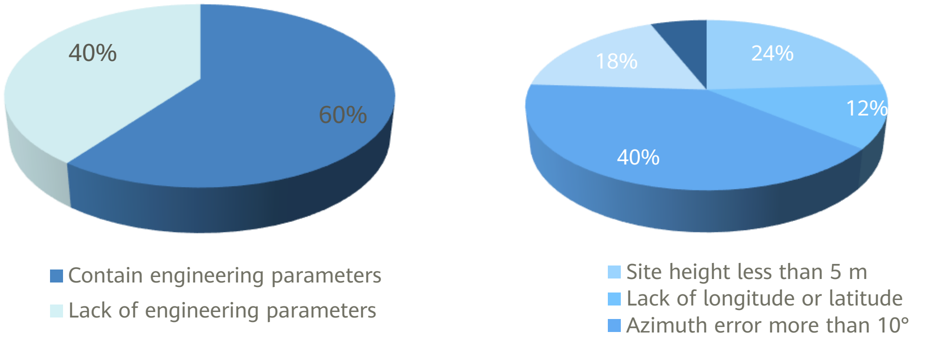
Network development goes hand in hand with site reconstruction, capacity expansion and migration to new technologies. During this process, it is common that site engineering parameters become inconsistent on different networks.

Engineering parameters (EP) are the basis of network planning and optimization. Incorrect and outdated engineering parameters will likely cause network planning and optimization to be misaligned with actual service needs and lead to subpar network performance. Ensuring engineering parameter accuracy in real time is a major industry challenge.

Fig. 5 EP gap between actual and manual

According to statistical data from real networks, completeness of site engineering parameters is below 60% in certain areas, and the real-time accuracy of these parameters cannot be ensured. In particular, up to 40% of horizontal antenna orientation angles (azimuth) have a deviation of greater than ten degrees. Such information is neither reliable nor useful for building intelligent networks.

Fig. 6 Statistics and analysis of regional engineering parameters



Antennas are the part of wireless networks that interact most closely with mobile service users, making them an ideal provider of network engineering parameters.

Key antenna-sourced engineering parameters include site longitude, latitude and elevation, as well as beam directions and shapes in 3D spaces. These parameters help building digital data model bases, and provide real-time, complete and accurate inputs for intelligent networks.

Digital antenna-sourced engineering parameters are the prerequisite for network intelligence and automation.

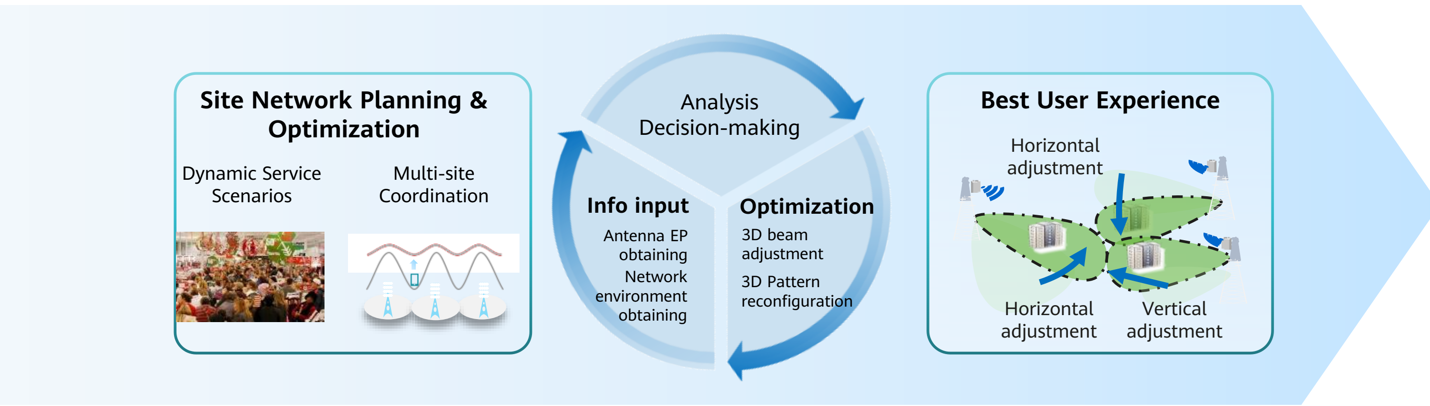
Antennas are located at the top of base stations.

This positional advantage allows them to provide more information about network environments, channels, and more, with additional capabilities evolving in the future. They will help completely virtualize the physical world and support full network autonomy.

2.2 Antenna Adjustable

Complete network data modeling enables intelligent systems to provide optimal network solutions.

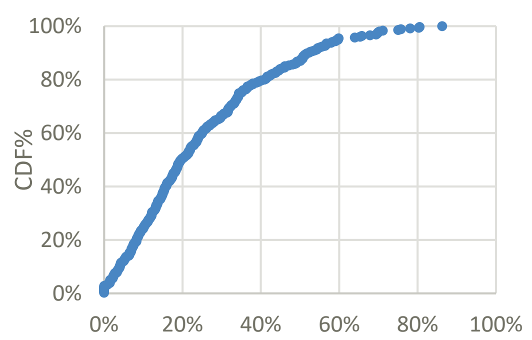
However, if antennas lack the flexibility that is needed to implement optimization solutions, network autonomy cannot be realized.



Flexible adjustment across many dimensions is necessary for antennas in intelligent networks. Only with such adjustment capabilities can optimization solutions in intelligent systems be fully implemented.

In addition, adjustments need to be made remotely in real time without manual intervention to truly implement automatic and intelligent network optimization.

Fig. 7 Inter-cell overlap analysis

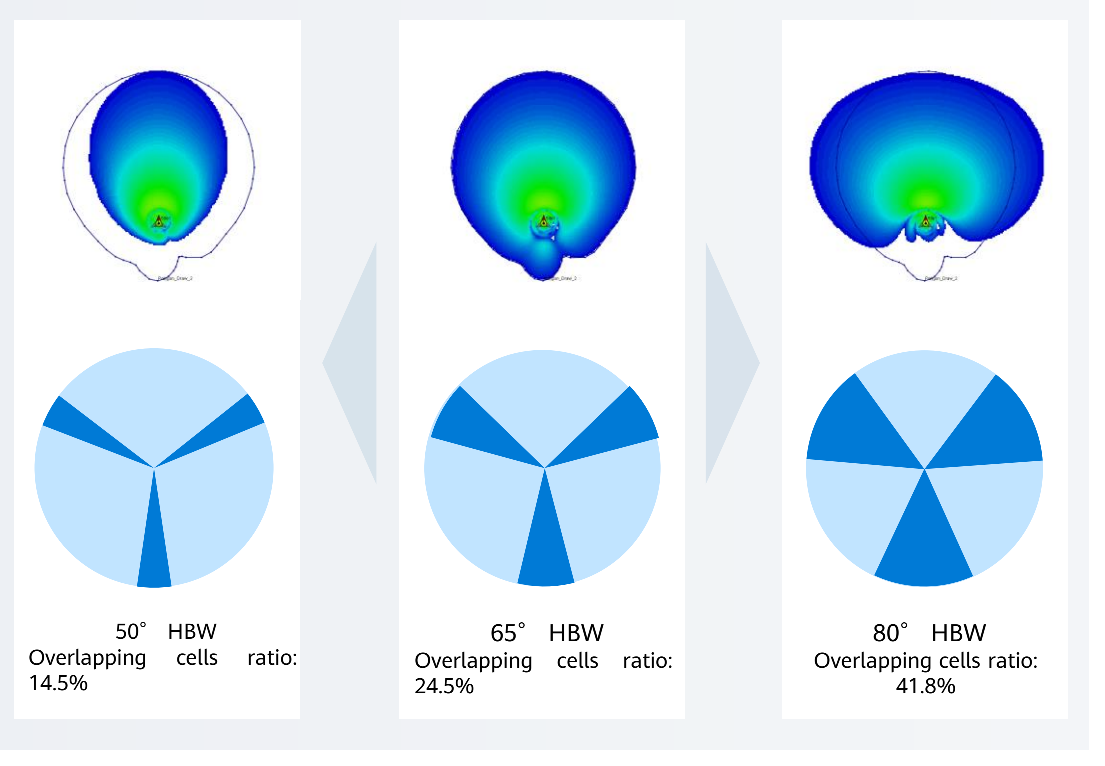


For example, more than 40% of an operators users receive services from overlapping areas in about 20% of its 300 cells.

Due to strong interference in these areas, the users get an inferior experience, with network performance overall deteriorated .

This example underscores the importance of being able to automatically adjust antenna azimuth orientation, beamwidths and downtilt angles to minimize the size of overlapping areas and ensure that most users stay within the zones which offer better coverage and better experiences.

Fig. 8 Horizontal Beamwidth (HBW) adjustment optimizes overlapping areas in cells



With coordinated multi-form site arrangements becoming mainstream, it is becoming increasingly difficult to simultaneously ensure continuous coverage and minimized interference.

This highlights the importance of being able to remotely adjust all aspects of an antenna, including downtilt, azimuth direction and beam shapes, to quickly respond to intelligent optimization decisions. This capability will be essential for autonomous networks.

03 Key Innovations for Antenna Digitalization

For antennas, network intelligence and automation require building capabilities for remote management and multidimensional adjustment.

Antenna manageability provides deterministic inputs for networks to build a complete network digital model of the real network – a digital twin. Manageability refers to capabilities of an antenna to provide the needed information support for remote control and optimization, such as real-time data about location, orientation and configuration. The data scope could additionally extend beyond the antenna itself, to include also environmental data that would be relevant and useful for achieving precise network optimization.

Multidimensional adjustment provides a higher degree of freedom and more possibilities for intelligent network optimization. Adjustment of antenna parameters such as the direction of radiation, as well as the shape of the pattern, enables precise tailoring of the radiation projection for network optimization.

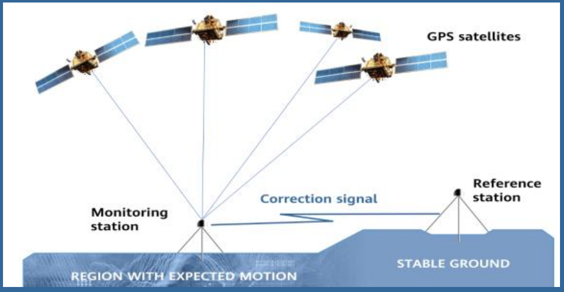
The two capabilities are complementary to each other and form the backbone of intelligent networks.

3.1 Innovations on Antenna Manageable

Cell-level network information and accurate electronic maps are important for creating digital models of networks.

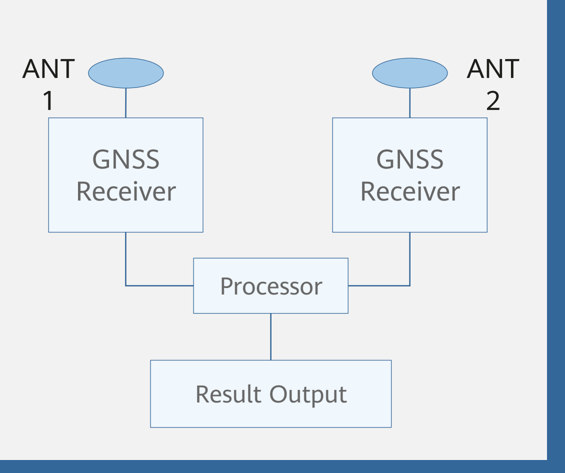
Real-time kinematic (RTK) technology enables high-precision positioning based on real-time dynamic carrier phase difference division. Antennas are located atop base station sites, providing a natural advantage for GNSS positioning.

Fig. 9 RTK positioning technology



Using RTK technology, two receivers on the top of antennas receive satellite signals. These signals are subject to further positioning processing and algorithm based optimization. This produces higher-precision site engineering parameters, including longitudes, latitudes, elevations, and azimuths. With them, accurate site model maps are constructed and updated in real time to feed intelligent networks with deterministic basic inputs.

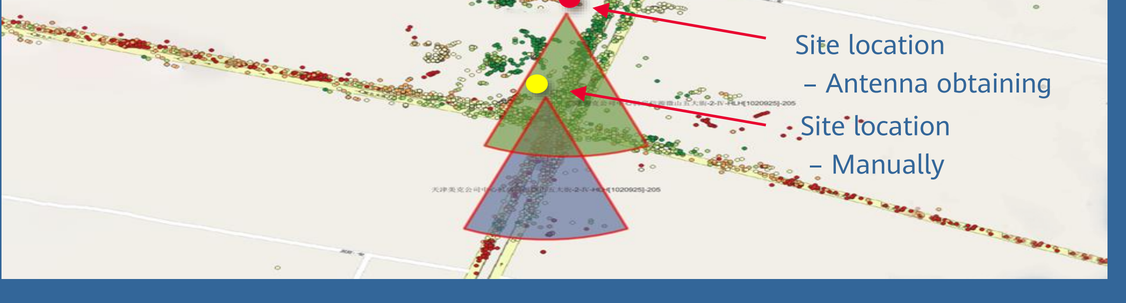
Fig. 10 Dual-antenna EP management



Field tests performed at a site show how critical accurate engineering parameters are to intelligent networks.

With manually connected longitudes and latitudes (the yellow points), the analysis detected a strong backward reference signal received power (RSRP) at an antenna, which indicated sub-optimal coverage. However, based on the longitudes and latitudes (the red points) obtained by automatic antenna sensing, the analysis found that the opposite was true: The backward signal was actually weak, indicating normal coverage.

Fig. 11 Joint analysis of network coverage and site engineering parameters



This example shows that accurate engineering parameters are vital for intelligent networks. Otherwise, false alarms may be generated, which may lead to optimizations that actually worsen network performance.

Complete calculation and information processing and transmission make expanding network capabilities more feasible. For example, with vibration, rotation, temperature, and humidity sensors in networks, the structural health, surroundings, and operating status of site infrastructure can be monitored.

This helps detect for structural site damage and avoid performance deterioration or faults caused by extreme weather. As such, it significantly improves site safety and operational efficiency. With more stable and reliable networks, it is easier to adopt and deploy new technologies.

3.2 Innovations on Antenna Adjustable

The evolution of antennas is centered on beam direction adjustment. From early mechanical downtilt adjustment to current remote electrical tilt (RET) adjustment, the most progress has been made in the vertical direction. Little progress has been made in the flexible adjustment of horizontal beam shapes.

The antenna industry now recognizes the importance of being able to flexibly adjust horizontal beam shapes, as it works towards developing solutions for intelligent networks.

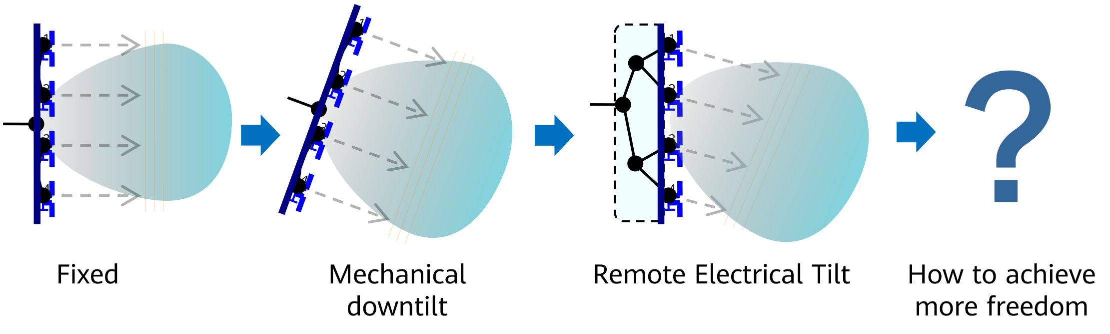


Fig. 12 The evolution of beam adjustment

Horizontal Adjustable

The horizontal direction of antenna beams are determined by the horizontal angle of the radiating antenna array. This means that adding a motor to an antenna to rotate an antenna array would make the beams horizontal adjustable..

With remote electrical downtilt adjustment already being possible, it would be reasonable to add such a motor to an antenna to make horizontal beams remotely adjustable.

3D Pattern Reconfigurable

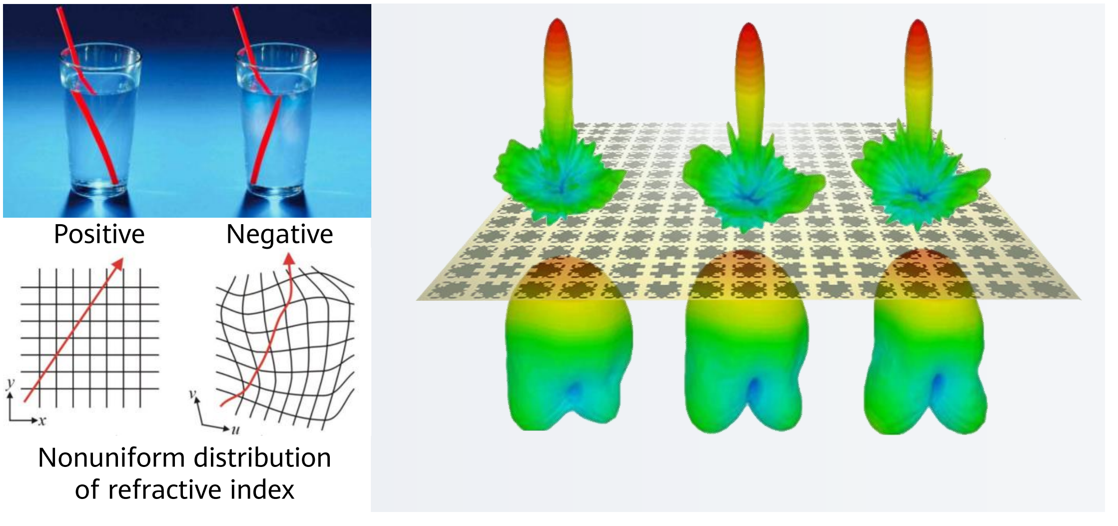
The antenna array pattern synthesis principle shows that arrays and array elements are factored into antenna beam shapes.

Given that arrays and array elements are fixed after an antenna is designed, it is impossible to reshape beams that have already been emitted by these antennas. This is the biggest technical challenge in implementing spatial beam reconstruction.

Recent research has found that metamaterials enable achieving special electromagnetic characteristics that natural materials do not have and that these materials can be used to control, focus, and redirect electromagnetic beams on their propagation paths.

Inspired by the finding, a 2D Meta surface has been constructed in front of an antenna array to reconstruct radiated waveforms and change the beam shapes, and variable devices and microcircuits have been added to control the physical characteristics of the meta surface. This shows that antenna beams can be dynamically reconfigured to meet service requirements.

Fig. 13 Pattern reconfigurable through the metasurface



04 Towards 2030 Vision of Antenna Digitalization

AI is driving a new wave of technological transformations in many sectors, including wireless networks. For networks to become intelligent, further innovation in wireless network infrastructure is needed . Antennas are a crucial element in wireless networks, and their digitalization will play an important role in the future.

Successful network evolution with digital antennas requires deep collaboration among global operators and equipment providers.
Guided by practices and driven by innovation, working together promotes a sustainable development of the digital antenna industry.

Here, we propose the vision of antenna digitalization for the future, which includes the key milestone roadmap illustrated below.

HUAWEI TECHNOLOGIES CO., LTD.
Huawei Industrial Base
Bantian Longgang
Shenzhen 518129, P. R. China
Tel: +86-755-28780808
www.huawei.com