GTI

Ambient IoT

– Application Cases Chapter

White Paper

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Preface

In the era of deep integration of digital economy and real economy, Ambient IoT, as a key innovation direction of IoT evolution, builds a flexible communication network and ubiquitous sensing system covering wide-area environments by deeply integrating passive communication mechanisms with local and cellular network architectures, effectively solving pain point problems such as frequent maintenance and high costs caused by traditional IoT terminals' reliance on battery power, becoming a key enabling technology for building an ecosystem of intelligent connection of all things.

Ambient IoT can connect various production factors at extremely low cost and high efficiency, transforming massive physical assets into manageable and analyzable data assets, thereby achieving visualization, automation, and intelligent management of identified objects in all elements, all processes, and full life cycles. Through deep analysis and value operation of massive data, enterprises can expand the types of production factors, improve factor quality, optimize factor combinations and production processes, and finally achieve significant improvement in total factor productivity.

This white paper focuses on benchmark application cases of Ambient IoT in key industries, systematically showcasing their solutions and commercial value, aiming to provide practical reference and path guidance for innovation in Ambient IoT application solutions and large-scale implementation.

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1. Ambient IoT Overview

1.1 Development Background

In the wave of global industrial upgrading and digital transformation, IoT, as a key technology connecting the physical world with the digital world, is penetrating into various fields with unprecedented depth and breadth. With the deep advancement of industrial digitalization, various industries have increasingly urgent needs for intelligent, automated, and visualized management of the full life cycle of production factors. However, trillions of "dumb terminals" have long been excluded from the digital world due to power supply, cost, and maintenance issues, becoming a bottleneck restricting the improvement of total factor productivity.

Although traditional RFID technology has been widely applied in retail, logistics, and other fields, its "single-point reading" working mode has limitations such as short recognition distance, weak penetration capability, and poor networking capability, making it difficult to meet the needs of large-scale, high-density, and automated management in scenarios such as industrial IoT and smart cities.

Ambient IoT technology achieves a leapfrog development from "local" to "wide-area" and from "point" to "network" by deeply integrating advanced cellular communication technology with Ambient IoT and utilizing the characteristics of cellular networks such as wide coverage, massive connections, and high reliability. It not only solves problems such as limited performance of traditional RFID technology, limited scenarios, and low degree of automation, but also lays a solid foundation for building an efficient, low-cost, and intelligent IoT ecosystem by introducing new capabilities such as integrated positioning and multi-element sensing.

1.2 Ambient IoT Market Space

Ambient IoT demonstrates huge market potential in key industries such as manufacturing, warehousing, electric power, ports, and tobacco with its advantages of wide-area coverage, massive access, and low-cost deployment.

Manufacturing Industry: As of January 2025, the number of industrial enterprises above designated size in China reached 512,000. Scenarios such as material management at the production line edge, tracking and scheduling of production equipment and carriers have strong demand for low-cost, high-efficiency Ambient IoT technology. By achieving full-process digital management of production factors, production efficiency and asset utilization can be significantly improved. According to conservative estimates, the market space in this field will exceed 10 billion yuan.

Warehousing Industry: In 2025, China's smart warehousing market scale reached the hundred-billion level. Ambient IoT can achieve automated inbound and outbound of massive materials, high-precision inventory, and bin-level positioning, minimizing the error rate of manual operations. Even if only a 1% penetration rate is achieved initially, the market space is expected to reach the billion-yuan level.

Electric Power Industry: The number of power equipment is huge and widely distributed. Traditional manual inspection has low efficiency and high costs. Ambient IoT can achieve automated monitoring and predictive maintenance of power equipment, timely discover safety hazards, and ensure safe grid operation. With the advancement of smart grid construction, the application prospect in this field is broad.

Port Industry: China's port throughput is huge, and traditional operation modes have low efficiency and high labor costs. Ambient IoT can achieve real-time tracking and intelligent scheduling of port equipment, containers, and transport vehicles, improving operation efficiency and reducing error rates. With the improvement of port automation levels, the market space in this field is expected to exceed 10 billion yuan.

Tobacco Industry: The tobacco industry has strict requirements for product traceability, anti-counterfeiting, and circulation supervision. Ambient IoT can provide a unique digital identity for each tobacco product, achieving full-chain tracking from production to sales, effectively preventing counterfeit and shoddy products, improving regulatory efficiency and consumer trust.

1.3 Ambient IoT End-to-End Core Technologies

The service capability architecture of Ambient IoT proposed in the "5G-A Ambient IoT Application Cases White Paper" in 2024 starts from four dimensions of terminal, network, cloud, and application, achieving comprehensive upgrade of IoT service capabilities through technological innovation and model optimization, but still faces challenges such as long-distance communication, massive access, efficient energy utilization, and signal processing. Ambient IoT takes system enhancement, capability improvement, and function expansion as system design goals, carrying out technology system construction and core technology solution tackling from three directions of new network, new tag, and new function.

1.3.1 New Network Technologies

New network technology is the foundation for Ambient IoT to achieve reliable connection and system expansion, focusing on optimizing air interface design, improving communication distance, enhancing massive access capability, and achieving flexible networking deployment.

First, in terms of lightweight air interface design, by simplifying protocol stacks and signaling procedures, the complexity and power consumption of tags in data processing and demodulation are reduced. Low-power-friendly transmission modes are adopted so that devices can achieve downlink data reading through simple circuits such as envelope detection, thereby meeting the operating requirements of extremely low energy consumption.

Second, in terms of massive access, the adaptive optimization of inventory parameters is achieved through accurate estimation of tag quantities, and multi-tag parallel access mechanisms are introduced to improve overall system throughput capability and inventory efficiency. At the same time, combining new multiple access schemes (such as frequency domain multiplexing based on subcarrier modulation) enhances the system's support capability for large-scale terminal access.

In terms of communication distance enhancement, interference suppression is performed from spatial domain, analog domain, and digital domain to achieve echo isolation in the backscatter communication path; the long-distance communication performance is improved by adding error correction mechanisms, improving receiving sensitivity and link margin; and the energy transmission efficiency in the energy supply link is improved to achieve longer-distance coverage.

1.3.2 New Tag Technologies

As the core carrier on the terminal side of Ambient IoT, the performance of tags directly determines system coverage capability, communication efficiency, and application expansion space. New tag technologies revolve around directions of energy harvesting efficiency, extremely low power operation, enhanced communication capability, and communication-sensing integration.

In terms of energy harvesting, consideration is given to improving RF and optical energy conversion efficiency through materials science and circuit design. RF energy harvesting gradually evolves toward higher-sensitivity rectifying devices, combining new two-dimensional materials to reduce leakage and improve switching efficiency; optical energy solutions utilize new materials such as perovskite to achieve stable power supply under weak indoor light conditions.

In terms of low-power operation, through architecture-level integration, dynamic clock management, and device-level sub-threshold design synergy to reduce power consumption, tags can maintain stable operation under microwatt-level energy conditions, thereby extending working time and improving overall energy efficiency.

In terms of improving communication capability, support for uplink and downlink multi-frequency communication is achieved through high-gain, multi-frequency point antenna structures, and impedance mismatch problems are solved; fast switching and high-order modulation capabilities are enabled for tags by designing wide-band backscatter modulators and high-efficiency matching networks; for application scenarios with strong interference in outdoor environments, precise spectrum selection and interference suppression can be achieved by combining filtering structures.

1.3.3 New Function Technologies

Ambient IoT is moving from pure identification to higher-value sensing, positioning, and fusion applications.

In terms of sensing, optimization is achieved through three aspects: connecting sensors through tag external interfaces, integrating sensor circuits on-chip with SoC, or combining sensitive materials with antenna design, realizing integration of "communication + sensing."

In terms of positioning, positioning stability is improved by combining multiple features such as RSSI and reading times, and fusion positioning methods combining multiple sensing data are adopted to reduce errors caused by environmental impact of single measurement methods.

In terms of fusion applications, electronic identity provided by Ambient IoT can be further deeply integrated with AI. Based on massive data fed back by tags, information mining is performed to achieve fusion services such as preference trend prediction, production quality diagnosis, and work efficiency analysis, promoting its implementation in logistics warehousing, intelligent manufacturing, and asset management.

2. Typical Ambient IoT Application Cases

2.1 Manufacturing Industry

2.1.1 Background Introduction

The global manufacturing industry is in a critical stage of intelligent and digital transformation. With the advancement of Industry 4.0, more and more manufacturing enterprises are beginning to introduce technologies such as automation, IoT, and big data to improve production efficiency, reduce costs, and enhance market response capabilities. Intelligent production lines, smart factories, and digital management systems are becoming industry standards, promoting the development of production processes from traditional manual operations to highly automated, intelligent, and real-time monitoring. Traditional asset management modes relying on manual registration, paper documents, and regular inventory can no longer adapt to manufacturing enterprises' needs for refined, real-time, and visualized management of the full life cycle of assets. How to achieve precise tracking of equipment and assets and real-time monitoring of production processes has become an urgent problem to be solved by manufacturing enterprises.

2.1.2 Problem Challenges

Current manufacturing enterprises face the following major challenges in asset management:

(1) Low efficiency of manual inventory: The number of assets is huge and widely distributed. Traditional manual inventory requires inputting a large amount of manpower and is time-consuming and labor-intensive. A full factory inventory often takes several days, and problems such as missed inventory and wrong inventory are prone to occur, leading to discrepancies between accounts and reality.

(2) Difficulty in asset positioning and tracking: High-value equipment, molds, carriers, etc. are difficult to locate in real time during the circulation process, with high risk of loss and low search efficiency, affecting production scheduling and material set matching.

(3) Lag in data updates: Processes such as asset warehousing, requisition, transfer, and scrapping rely on manual entry, with delays in information updates, making it impossible to achieve dynamic visualized management and affecting decision-making efficiency.

(4) Insufficient security monitoring capability: Control of access permissions for critical assets is not strict, and abnormal access is difficult to alarm in real time, posing risks of asset loss or unauthorized use.

(5) Low multi-department collaboration efficiency: Assets involve multiple departments such as procurement, warehousing, production, and finance. The information silo phenomenon is serious, and process collaboration relies on manual communication with low efficiency.

2.1.3 Application Solution

Focusing on problems in asset management of manufacturing enterprises, China Mobile cooperated with the industry to build an intelligent asset management system for manufacturing enterprises based on "China Mobile Carrier Object" Ambient IoT unified platform and "China Mobile Bailing" Ambient IoT system. The specific solution is as follows:

Overall System Architecture:

(1) Terminal Layer: Customized passive tags are affixed to each type of asset, including anti-metal tags, flexible tags, etc., adapting to different materials and environments to achieve unique identity identification of assets.

(2) Network Layer: 67 Ambient IoT node devices are deployed in key areas such as office buildings, workshops, warehouses, and entrances and exits, forming a continuous network coverage of 12,000 square meters, supporting long-distance identification of tags and data transmission back.

(3) Platform Layer: Northward connects to existing ERP and MES systems of enterprises, southward connects to Ambient IoT system, realizing functions such as asset information entry, inventory task distribution, positioning data parsing, abnormal alarm, and report generation.

(4) Application Layer: Provides Web and mobile operation interfaces, supporting multi-role permission management, achieving online approval and execution of full-process operations such as asset requisition, transfer, inventory, and scrapping.

Core Function Implementation:

(1) One-click Automatic Inventory: The system supports initiating full-factory or local inventory tasks by region or type, which can complete counting of more than 10,000 assets within a few minutes and automatically generate inventory reports.

(2) Precise Positioning: Through multi-node collaborative positioning algorithms, meter-level positioning of individual assets is achieved, supporting visualized display of asset real-time positions on 2D/3D maps.

(3) Closed-loop Process Management: From asset warehousing, labeling, binding, requisition, transfer to scrapping, full-process online management is achieved, and every step of operation has records for traceability.

(4) Abnormal Behavior Alarm: Real-time monitoring and alarm are performed on behaviors such as illegal access, long-time non-movement, and unauthorized transfer, pushing to managers' mobile terminals.

2.1.4 Application Effects

Through deployment of the Ambient IoT asset management system, comprehensive digitalization, automation, and intelligent transformation of asset management have been achieved in the manufacturing pilot factory. Inventory efficiency has improved by more than 80%, manual investment has been reduced by 70%, time for a single full-factory inventory has been shortened from the original 3 days to within 2 hours, asset positioning search time has been reduced from an average of 30 minutes to less than 5 seconds, abnormal access alarm response time does not exceed 10 seconds, and annual management cost savings of about 1 million yuan can be achieved. This has significantly improved asset utilization and operational efficiency, laying a solid foundation for manufacturing enterprises to build high-standard, high-efficiency, and high-security smart factories.

2.2 Warehousing Industry

2.2.1 Background Introduction

With the rapid development of global e-commerce and supply chain, the digital transformation demand of the warehousing industry is becoming increasingly urgent. Enterprises are promoting the intelligence of warehousing and logistics management by using technologies such as big data, IoT, and artificial intelligence. Smart warehousing systems can achieve automated inventory management, cargo tracking, and real-time scheduling, thereby improving efficiency, reducing labor costs, and lowering error rates. With the continuous changes in material mobility and demand, how to improve the flexibility and response speed of warehousing operations while ensuring precise management has become a key to industry transformation. However, many current warehousing enterprises still rely on traditional manual inventory, manual management, and information-lagging operation methods, and urgently need to use new technologies to cope with challenges.

2.2.2 Problem Challenges

Current warehousing logistics industry mainly has the following problems in full life cycle management of materials:

(1) Many types of assets and huge quantities make manual inventory prone to errors: In traditional manual scanning inventory mode, warehouse personnel need to use handheld terminals to scan, verify, and enter thousands of materials one by one. This method is prone to cause mistakes due to visual fatigue, decreased attention, etc., such as missed scanning, wrong scanning, and deviations during entry. In addition, inconveniences of manual operations brought by high shelves, poor warehouse lighting affecting barcode recognition, etc., further increase error probability, easily burying hidden dangers for subsequent inventory decisions, financial accounting, and order fulfillment.

(2) Difficulties in material positioning and searching: When materials are warehoused, they are usually stored in nearby empty spaces based on operators' memory or simple classification, usually relying on manual entry. When goods need to be picked, when pickers perform positioning based on system instructions, they usually rely on experience or perform "carpet-style" searches in huge warehouse capacity by partition. Time is wasted on ineffective path walking, which greatly reduces picking and outbound efficiency, prolongs order response time, and makes inventory management and periodic inventory abnormally complex and difficult. New means are needed to improve warehousing operational efficiency.

2.2.3 Application Solution

Focusing on the needs of the warehousing logistics industry for full life cycle management of materials, China Mobile cooperated with the industry to complete end-to-end pilot verification of Ambient IoT in warehousing scenarios. The key focus was on verifying the innovative technical effects of MIMO flexible networking, multi-head-end joint power supply, distributed joint reception, and tag high-performance codec. By deploying Ambient IoT tags, Ambient IoT base stations, and Ambient IoT platforms, it helped achieve automated and intelligent management of massive materials in warehousing.

Overall System Architecture:

(1) Ambient IoT Asset Management Platform: The Ambient IoT asset management platform connects northward to existing warehousing management systems and southward to Ambient IoT base stations. Users can issue instructions such as one-click inventory and asset positioning through the platform to achieve comprehensive warehousing management.

(2) Ambient IoT Base Stations: According to the warehouse space layout, combined with the coverage range of excitation nodes and PRRU head-end nodes, the on-site transmission distance is scientifically calculated, and deployment points are planned and deployed around materials. A total of 6 PRRU node devices and 2 carrier excitation node devices were deployed.

(3) Ambient IoT Tags: Ambient IoT tags are deployed, which use environmental RF energy harvesting and have characteristics such as small size, maintenance-free, and easy deployment.

2.2.4 Application Effects

In this pilot verification, Ambient IoT was able to meet business requirements such as second-level reading of multiple tags in complex environments, accurate identification of multi-target inbound and outbound, tag positioning accuracy of 5-7 meters, and bin-level cargo inventory. In warehousing scenarios, full-process inventory and searching of materials were achieved, and warehousing management efficiency was significantly improved. This pilot achieved real-time and accurate collection of information such as the quantity and status of goods in the warehouse. Inventory accuracy was improved to 100%, and the level of real-time and visualized inventory management achieved a qualitative leap.

2.3 Electric Power Industry

2.3.1 Background Introduction

The electric power industry is accelerating the construction of smart grids to cope with challenges of diversified energy demand and sustainable development goals. Smart grids achieve refined management and intelligent scheduling of power resources by integrating modern communication, automated control, and big data analysis technologies. With the deepening of digital transformation, functions such as remote monitoring, fault warning, and intelligent scheduling of power equipment are gradually popularized, providing strong support for improving grid reliability, reducing operation and maintenance costs, and ensuring energy security. However, in complex power equipment operating environments, how to ensure real-time monitoring, abnormal prediction, and maintenance efficiency of equipment is still an important challenge facing the industry.

2.3.2 Problem Challenges

The operating environment of power equipment has very strict requirements for stability and safety. Since the operating environment of power equipment is mostly a strong electromagnetic environment, it poses severe challenges to the signal propagation and stability of wireless communication. At the same time, in the field of temperature monitoring, existing traditional temperature measurement methods rely on a large number of sensor deployments and complex electrical contact hardware, resulting in high deployment costs. The timeliness of existing equipment temperature data collection and feedback is also difficult to meet actual needs. There is an urgent need for a monitoring solution with stability and precision.

2.3.3 Application Solution

Focusing on the temperature monitoring needs of the electric power industry, China Mobile cooperated with the industry to conduct pilot testing of new passive technologies. For the first time in the power field, the joint reporting of identification and temperature and humidity information was achieved, completing the testing of the communication-sensing integrated solution for passive tags. In this pilot, the base station side adopted a new passive authorized frequency band and a new passive air interface link scheme to achieve information collection of tags with temperature sensing and photovoltaic energy harvesting. The test items such as Ambient IoT temperature sensing function, light energy harvesting efficiency, temperature deviation, and recognition success rate were completed.

2.3.4 Application Effects

Test results show that in both good weather and cloudy days, under high electromagnetic interference conditions, the tag recognition success rate reached 100%, and the detection temperature error was within ±3°C, which can meet the temperature detection and inspection scenarios of power equipment operation. This application can achieve long-distance unmanned inventory and equipment status information collection, 及时发现 and repair abnormal equipment in a timely manner, and prevent major accidents. It is estimated that hundreds of thousands of yuan in maintenance costs can be saved annually in the scenario of predictive maintenance of power equipment.

2.4 Port Industry

2.4.1 Background Introduction

With the rapid growth of global trade, the port industry is facing increasingly large capacity demand. Using digital and intelligent means to improve port operation efficiency has become a key to industry transformation. By introducing technologies such as IoT and big data, the port industry can achieve automation of equipment management, cargo scheduling, and transport routes, thereby greatly improving operation efficiency and operation safety. Smart ports need not only to monitor the status of containers and transport tools in real time, but also to optimize operation processes through data analysis.

2.4.2 Problem Challenges

In ports that store tens of thousands of containers, traditional management methods face extremely severe challenges:

(1) Inventory difficulties: Regular manual inventory of tens of thousands of containers is time-consuming and labor-intensive. Staff need to drive vehicles and use handheld devices or cameras to scan QR codes of each box body at close range. This method is greatly affected by factors such as weather (rain, snow, strong light), box cleanliness, and angle, making it difficult to guarantee a 100% recognition rate, and manual intervention and verification are still required. The entire process takes several days or

even longer, during which normal yard operations are seriously affected, and manual counting is prone to errors.

(2) Difficulties in finding containers: When it is necessary to extract a target container that is pressed under multiple containers (commonly known as "restacking" or "unstuffing"), the system cannot provide its precise stacking position. Operators can only rely on experience or perform trial lifting of surrounding multiple containers to search for it. A single container lifting operation may trigger multiple ineffective restacking operations, seriously reducing the efficiency of gantry crane operations and ship turnaround speed.

(3) Low data real-time performance: Mobile information of containers cannot be returned to the system in real time and automatically. Information updates are delayed. This "information silo" and "data lag" makes it impossible for the dispatch center to make optimal decisions in a timely manner, and also prevents customers from querying the precise location of their containers in real time.

（4） Highly automated yards prefer to minimize the number of personnel in the production area for safety reasons; Hence, the need to adopt sensing technologies. Additionally, widely accepted and uniform container tags allow tracking outside the port area which provides additional benefits

2.4.3 Application Solution

Focusing on problems in port container management, China Mobile cooperated with the industry to conduct pilot verification of Ambient IoT in port scenarios. The specific solution is as follows:

Overall System Architecture:

(1) Smart Port Management Platform: Responsible for initiating asset management tasks, issuing task instructions to "China Mobile Carrier Object" Ambient IoT unified platform, and receiving task result data and front-end display.

(2) Ambient IoT Unified Platform: Northward connects to the smart port management platform, southward connects to the Ambient IoT system. The Ambient IoT unified platform is responsible for scheduling the Ambient IoT system to execute tasks according to business instructions, analyzing business results based on inbound and

outbound algorithms, positioning algorithms, etc., and feeding them back to the smart port management platform.

(3) Ambient IoT System: Responsible for passive network coverage of the port park, ensuring that tags can receive RF energy provided by the network and feedback data at various locations in the port. At the same time, it is responsible for parsing tag data and feeding it back to the Ambient IoT unified platform.

(4) Tags: Affixed to each container, mapped one-to-one with the container.

Core Function Implementation:

(1) Container Automatic Inventory: The system can automatically execute inventory tasks, quickly and accurately completing comprehensive inventory of tens of thousands of containers in the port park, greatly improving inventory efficiency, avoiding the time and errors of manual operations, and improving inventory accuracy.

(2) Container Spatial Positioning: Cellular network positioning technologies (such as TDoA, AoA, etc.) are adopted to achieve positioning of container 3D coordinates, providing more accurate and refined data support for container search and scheduling.

(3) Container Inbound and Outbound Management: Through fixed-point coverage at entrances and exits of the port park, automatic identification of container inbound and outbound is achieved. Through the deployment of passive tags, in the upstream and downstream links of the port, businesses such as inventory and positioning of containers can be carried out through Ambient IoT technology, achieving data connectivity of upstream and downstream of domestic and international supply chains and reducing overall management consumption.

2.4.4 Application Effects

(1) Improvement of Operation Efficiency: The inventory work of tens of thousands of containers in the entire yard has been transformed from a mode that took several days and invested a lot of manpower to "second-level" or "minute-level" automated operations. Staff only need to issue instructions on the platform, and base stations can activate all tags at once and return data to complete full-yard inventory clearing, with an accuracy approaching 100%.

(2) Precise Positioning and Reduction of Restacking: The system can display the precise 3D coordinate position of any target container in real time. Dispatch instructions can be directly issued to the field, reducing the restacking rate by 95% and improving operation efficiency.

(3) Reduction of Maintenance Costs: Passive tags do not require batteries, and the design life can reach more than ten years, completely eliminating the huge manpower and material costs of regular battery replacement.

2.5 Tobacco Industry

2.5.1 Background Introduction

With the increasingly strict regulatory policies and consumers' higher requirements for product quality, the tobacco industry is accelerating its development in the direction of digitalization and intelligence, and the demand for visualized and automated management of all production factors is becoming increasingly urgent. Intelligent production lines, automated management systems, and digital supervision platforms are helping the tobacco industry improve production efficiency and product quality. Through data analysis and IoT technology, tobacco factories can achieve full-time monitoring of production and storage environments, as well as dynamic management of the entire production and transportation process, thereby improving product safety and production and transportation efficiency.

2.5.2 Problem Challenges

With the advancement of digitalization and intelligent transformation in the tobacco industry, cigarette factories face the following problems and challenges:

(1) Insufficient adaptability of tobacco leaf monitoring in aging warehouses: The aging warehouse is the core storage area for tobacco leaves and bears the important task of long-term storage management during the tobacco leaf aging period. A large number of tobacco leaf cargo boxes are stored in the warehouse, and the internal environment of the cargo boxes needs to be monitored for temperature and humidity to ensure tobacco leaf quality. Traditional temperature and humidity monitoring relies on fixed-point sensors, which have monitoring blind spots and cannot achieve full-coverage real-time perception of all tobacco leaf cargo boxes in the warehouse. If wired methods are used for dense monitoring and deployment, a large number of lines need to be laid in the warehouse, which interferes with normal warehousing operation processes such as

forklift transfer and tobacco leaf stacking adjustment. Moreover, tobacco leaves are flammable materials, and active monitoring equipment relies on battery power supply, posing safety risks.

(2) Low effectiveness of cross-regional dynamic control of forklifts: Forklifts are key carriers for tobacco leaf circulation within the factory. Forklifts undertake the transfer tasks of tobacco leaves and materials across different regions such as aging warehouses, silk making workshops, and cigarette making and packing workshops. The daily transfer frequency is high, and it is necessary to accurately record the dynamics of forklifts entering and leaving warehouses and crossing process regions to support production scheduling and asset control. Currently, forklift entry and exit require manual recording, which is time-consuming and prone to omissions. When forklifts transfer across processes, there is a lack of real-time tracking means, making it difficult to timely position and schedule idle forklifts.

2.5.3 Application Solution

Focusing on the needs of cigarette factory warehouse monitoring and carrier management, China Mobile cooperated with the industry to complete the pilot application of Ambient IoT in the tobacco industry. Ambient IoT systems were introduced in areas such as aging warehouses and forklift warehouses, and customized Ambient IoT sensing tags were deployed on forklifts and tobacco leaf cargo boxes. Combined with the Ambient IoT unified platform, an intelligent management system covering the cigarette factory's aging warehouses, forklift warehouses, and various process warehouses was built to achieve automation and precision of tobacco leaf monitoring and forklift dynamic management. The overall application solution architecture is as follows:

Overall System Architecture:

(1) Ambient IoT Unified Platform: Northward connects to the existing tobacco leaf management system and production scheduling system of the cigarette factory to achieve data interoperability and sharing. Southward connects to the Ambient IoT system and is responsible for receiving tobacco leaf monitoring data and forklift dynamic data transmitted by the Ambient IoT system. It can display in real time the temperature and humidity distribution in different areas and stacks of the aging warehouse, pest

monitoring results, as well as forklift inbound and outbound records, cross-regional circulation trajectories, and other information.

(2) Ambient IoT Equipment: According to the spatial layout of the aging warehouse and the distribution of tobacco leaf stacks, as well as the key channel locations of the forklift warehouse, Ambient IoT equipment is deployed separately to ensure that tobacco leaf tag data and forklift tag data can be activated and stably collected and transmitted. A total of 3 Ambient IoT devices and 6 antennas were deployed.

(3) Customized Ambient IoT Sensing Tags: Temperature and humidity passive tags are equipped for tobacco leaf stacks in the aging warehouse. The tags do not require an external power supply and are powered by collecting RF energy and optical energy in the warehouse environment. They can be attached to the surface of tobacco leaf packaging or embedded inside stacks to collect temperature and humidity data in real time. Anti-metal passive tags are equipped for forklifts, recording basic information such as forklift number, model, and belonging shift. The tags have long-distance recognition capabilities and can be stably read during forklift movement.

Core Function Implementation:

(1) Intelligent Monitoring of Tobacco Leaves in Aging Warehouses: Temperature and humidity passive tags collect data every 5 minutes and transmit it to the Ambient IoT unified platform through Ambient IoT equipment. The platform displays the temperature and humidity of different regions and stacks in the warehouse in real time. When the data exceeds preset thresholds (such as temperature higher than 25°C and humidity higher than 65%), the platform automatically triggers an alarm and pushes it to the warehouse administrator via SMS and system messages. The administrator can timely adjust the warehouse ventilation and dehumidification equipment to ensure the stability of the tobacco leaf aging environment.

(2) Dynamic Automated Management of Forklifts: Equipment is deployed at key channels of each process region. When a forklift passes by, the forklift tag information is automatically read, recording the entry and exit time and warehouse number, and synchronously uploading it to the platform. The platform automatically generates electronic inbound and outbound records and generates forklift cross-regional circulation trajectories based on the reading order and time of nodes. Administrators can visually

view the current position, historical driving paths, and stay duration in each region of the forklift on the platform, achieving full-process visualized tracking of forklift dynamics.

2.5.4 Application Effects

Through deployment of Ambient IoT systems in the cigarette factory in cooperation with industry, China Mobile achieved automated upgrading of tobacco leaf monitoring in aging warehouses and full-warehouse forklift dynamic management, significantly improving management precision and operational efficiency. The tobacco leaf temperature and humidity monitoring model in the aging warehouse is currently in the construction and promotion stage. After subsequent completion, it is expected to achieve all-warehouse, no-dead-angle environmental perception and intelligent early warning, effectively avoiding tobacco leaf quality problems caused by environmental fluctuations. The method of recording forklift inbound and outbound has been upgraded from manual registration to automatic identification. It is expected to shorten registration time by about 90%. In addition, through cross-regional trajectory tracking, real-time positioning of forklifts can be achieved, and scheduling of idle forklifts can be responded to in real time, strongly supporting efficient operation of production scheduling. Furthermore, the system seamlessly interfaces with existing tobacco leaf management and production scheduling systems of the factory to achieve data interoperability and sharing, promoting the transformation of warehousing and logistics management from "manual-driven" to "data-driven," providing solid support for the tobacco industry to deepen digital transformation and improve total factor productivity, and providing a replicable practical solution for intelligent upgrading of similar scenarios in the tobacco industry.

3. Summary and Outlook

As an important innovation direction of IoT, Ambient IoT has demonstrated huge value in application practices in fields such as manufacturing, warehousing, electric power, ports, and tobacco. Through the benchmark application cases presented in this white paper, it can be seen that Ambient IoT has played an important role in improving production efficiency, reducing operating costs, and enhancing safety supervision.

In the future, Ambient IoT will evolve in directions such as active-passive fusion, high-spectrum-efficiency multiple access, symbiotic communication, and passive wireless sensing, further improving communication distance, connection density, and sensing capability, achieving deep evolution from "ubiquitous connection" to "intelligent perception." At the same time, with the continuous improvement of standards and continuous maturity of the industrial ecosystem, Ambient IoT will accelerate the construction of a full-stack ecosystem system covering "chip-tag-network-platform-application," promoting the process of technology scale commercial application.

China Mobile will continue to work together with global industrial partners to continuously invest in key core technology breakthroughs, standard leadership, and creation of benchmark cases, jointly promoting the maturity and scale application of Ambient IoT technology, and opening a new chapter of intelligent connection of all things.

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