Research and practice on the construction of intelligent tire factories based on new-generation communication technology

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Abstract: New-generation communication technology represented by 5G, featuring low latency and high bandwidth,enables full-process,full-scenario industrial wireless interconnection. In recent years, the government has strengthened policy support for 5G fully connected factories and industrial internet, bringing significant benefits to enterprise transformation. Based on self-developed 5G industrial private network base stations and industrial internet platform technology, New Universal has deepened smart factory solutions. This paper explores the application of 5G-led new-generation communication technology in intelligent tire factories based on relevant cases and experiences.

Key words: 5G; full connectivity; tire; smart factory

Classification number: TQ330.8 **Article number:** 1009-797X(2026)03-0022-06

Document code: B **DOI:**10.13520/j.cnki.rpte.2026.03.005

1 Overview

The domestic tire market is becoming increasingly competitive. Adopting intelligent upgrades in the production process to reduce costs and increase efficiency will be an inevitable choice. The emergence of a new generation of communication technology represented by 5G, with its high-speed, low-latency, and large-capacity characteristics, provides strong technical support for the intelligent transformation of the manufacturing industry. In recent years, governments at all levels have attached great importance to the intelligent transformation of the manufacturing industry and have issued a series of policies to support and guide it, providing a favorable policy environment for the application of 5G in smart tire factories.

Relying on the factory's self-built 5G private network, it has the following characteristics:

(1) Dedicated Coverage Solution: Utilizing the operator's 4G and 5G public networks, the surrounding base stations not only cover the tire factory but also take into account the coverage of neighboring factories, residential areas, and highways, as well as routine network tests conducted by the superior operator. This requires frequent adjustments to the base station antenna down tilt, azimuth, transmit power, and algorithm parameters, making it impossible to guarantee coverage within the factory area. In contrast, 5G private network base stations are specifically designed for specific factories, and the wireless parameters related to the base station can be optimized and adjusted according to the factory's wireless environment, coverage requirements, and business characteristics.

(2) Network operation and maintenance are more closely aligned with production: When transmitting production data over the public network, it becomes challenging to assign responsibility and pinpoint issues in case of packet loss, interruptions, or delays. Depending on its business requirements, the public network often undergoes sudden

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network upgrades and maintenance, which can lead to short-term network disruptions or slowdowns, thereby affecting factory production.

(3) Complete network isolation: It boasts an independent core network, encompassing comprehensive network elements such as authentication, billing, account opening, and user plane management. This ensures that data and signaling remain within the factory, effectively addressing the cost issue of high monthly rent for public networks.

(4) Low latency and high reliability: The latency and packet loss rate are lower than those of traditional wireless solutions. Moreover, as a kind of mobile communication system, it supports a comprehensive handover process, with the handover latency across cells controlled within tens of milliseconds, making it more suitable for the operation of AGV forklifts and robots.

2 5G private network wireless coverage solution

2.1 Hardware solution

The traditional WiFi AP solution, due to its low transmission power, requires the deployment of multiple points. However, the tire production environment has its own particularities, such as high temperatures and the presence of conductive carbon black in the air. Some APs with limited protection levels are prone to malfunction after prolonged operation. The maintenance and replacement processes often involve climbing operations, which are cumbersome and increase operational and maintenance costs.

The transmission power of 5G base station equipment covers multiple levels, providing a wider range of optional solutions. For factory coverage, there are currently two base station solutions: one is the use of BBU + micro-power picoRRU, and the other is BBU + high-power RRU, as shown in figure 1.

The transmission power of micro-power picoRRU typically ranges from 500 mW to 1W, which is not significantly different from that of Wifi. Depending on the installation height and on-site obstruction conditions, the coverage radius is generally between 15 and 30 meters. With its characteristics of "multiple locations and low power", it is suitable for office buildings, factories with less severe obstruction, and coverage supplementation in individual areas. Each BBU can be externally mounted with up to 32 picoRRU. On the other hand, high-power RRU typically has a transmission power of over 40W. Depending on the antenna installation height and on-site obstruction conditions, the coverage radius can reach 100 - 300 meters. Each BBU can be externally mounted with 3 to 4 high-power RRU. These two hardware solutions have their own advantages and complement each other. Figure 2 shows a 5G project for a tire factory undertaken by Xinyuan. The outdoor high-power RRU is placed on the roof of the office building and connected to the communication equipment room via optical cables. The antenna is directly facing the factory building that needs to be covered. With fewer points, the entire production line can be covered, making daily maintenance simple and eliminating the need for climbing operations.

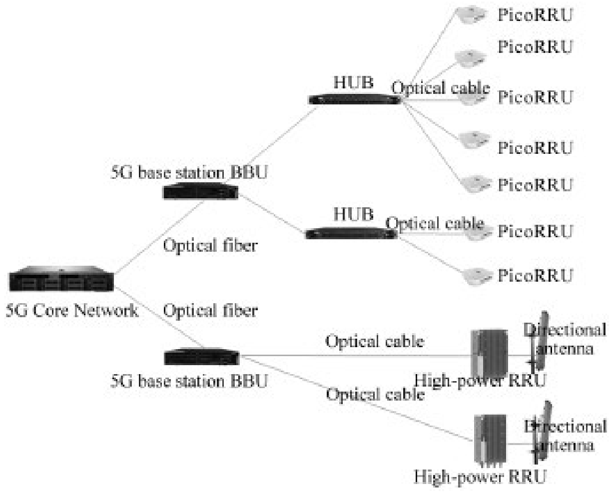

Figure 1 Typical 5G network equipment topology

Figure 2 5G high-power RRU and directional antenna deployed on the rooftop

2.2 Site selection

5G core network servers and base station BBUs are generally placed in the existing communication equipment rooms of the factory, sharing resources such as mains power and cabinets with the original equipment in the room. If a high-power RRU solution is adopted, high-power RRU and antennas are installed on the roof near the factory building, with the antennas directed towards the factory area that needs to be covered. The transmission power and antenna angle are flexibly adjusted according to actual needs.

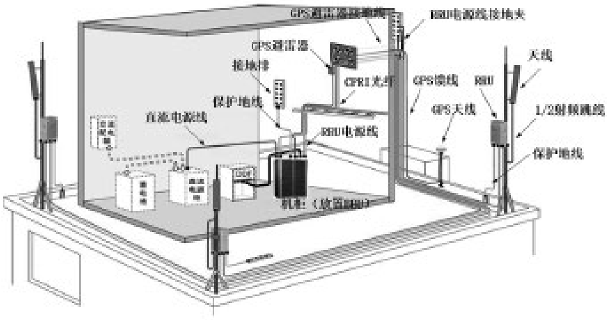

Figure 3 A typical 5G high-power base station room and rooftop

communication terminals with 5G terminals, the interference and packet loss issues inherent in traditional wireless networks are resolved. This enables AGV forklifts and stacking robots to achieve faster and more reliable responses, facilitating logistics connectivity between the three-dimensional warehouse and various processes and production lines. The 5G industrial terminals can be directly connected to, or connected via the existing on-board switches, to various subsystems of the AGV forklift, such as the PLC, control panel, power supply, and display screen. The shielding issue of the forklift housing on 5G signals is addressed through an external high-gain antenna.

Figure 4 5G industrial terminal integrated into AGV forklift

3 Typical application scenarios

The production process of tires is complex, with frequent batch switching and intricate process constraints. The production site is characterized by high temperature and humidity, and there is frequent movement of personnel and vehicles. Therefore, the intelligent transformation of tire enterprises needs to focus on three major elements: personnel flow, logistics, and production processes, to achieve unmanned, less-manned, safe, and flexible production, as well as seamless connections in production, warehousing, and logistics. As the communication backbone of the factory, the 5G private network can achieve:

(1) 5G+ Data Collection and Control: 5G industrial terminals can connect various sensors through interfaces such as Ethernet, 232, and 485, enabling the "full collection" of production data, such as particulate matter and harmful gas data collection. In situations where wiring is inconvenient, in harsh environments, and where temporary collection and monitoring are required, 5G can provide a convenient data transmission channel for various sensors.

(2) 5G+AGV: By replacing the built-in traditional communication terminals with 5G terminals, the interference and packet loss issues inherent in traditional wireless networks are resolved.

(3) 5G+MES: Leveraging 5G technology to integrate MES, PLC, and AGV forklifts, enabling the issuance of production instructions, automatic material picking, and achieving seamless integration with subsystems such as barcode scanners, APS, PLM, and ERP.

(4) 5G+ Video Surveillance: In a typical tire factory, there are hundreds or even thousands of cameras within the factory premises. Although most of the video data from these cameras can be transmitted back through wired networks, there are still certain scenarios where wireless video transmission is required as a supplement. For instance, in scenarios involving high temperatures, corrosive gases, inconvenient wiring, or temporary surveillance, using 5G as the transmission channel offers better cost-performance ratio.

(5) 5G+UWB high-precision fusion positioning: It achieves sub-meter-level positioning of personnel and assets, solving the problems of confusion and loss of personnel and assets on-site. For example, there are a large number of tire blank carts in the tire factory, filled with tire blanks of various models and batches, making positioning and management difficult. After attaching positioning tags to the tire blank

carts, the management efficiency of the carts can be greatly improved. High-precision positioning information can also be integrated and linked with subsystems such as 5G high-definition cameras, safety production systems, access control and security systems, and electronic fences. When abnormal personnel are detected in dangerous areas, an alarm will be automatically generated, and the cameras will follow the linkage to record through video. When there is a gathering of personnel in key or dangerous areas, the system will automatically trigger an alarm.

(6) 5G+ cluster scheduling: Factories are generally equipped with intercoms to facilitate intercom commanding, but traditional intercoms have poor sound quality and can only transmit voice, not video. Sometimes, complex issues encountered on-site cannot be clearly expressed through voice alone, which requires visual intercom and visual group calling. After deploying 5G within the factory, 5G intercom handsets can replace traditional intercoms, eliminating the need for dialing and enabling one-click visual single calling and group calling. The initiator of group calling can synchronously send their audio and video to each member of the group with one click, and can perform arbitrary grouping, management, and high-priority preemption through the 5G dispatch console, achieving "one call, all respond" for the production line.

4 Evolution towards 5.5G

The International Standards Organization 3GPP is also continuously promoting the smooth evolution of 5G technology towards 5.5G and 6G. With the standard freeze of 3GPP Release 18, some evolution functions oriented towards industrial scenarios, which can be regarded as 5.5G technology, have become increasingly mature. This will undoubtedly inject more vitality into 5G industrial scenarios. Among them, technologies closely related to industrial scenarios include:

4.1 Redcap (Lightweight 5G)

RedCap, whose full name is Reduced Capability, refers to lightweight 5G terminals. RedCap mainly streamlines capabilities such as 5G speed to precisely adapt to low-to-medium-speed IoT scenarios, thereby enhancing the cost-effectiveness of devices and networks. Many IoT applications do not require high throughput or strict latency, but cost and power consumption are significant considerations for these applications. In some typical data collection and control scenarios, the speed requirement for a single terminal is a few hundred Kbps, with a maximum of no more than 10 Mbps, and the latency requirement is not stringent, just a few hundred milliseconds. In these scenarios, using standard 5G industrial terminals with upload and download speeds of several hundred Mbps and latency within 20 ms results in significant performance waste and high costs. For these low-speed applications, RedCap reduces the number of antennas by lowering the data transmission rate and adopts half-duplex communication instead of full-duplex communication, thereby simplifying signal processing and saving energy. Compared to traditional 5G devices, RedCap is expected to reduce the cost of 5G industrial terminals by more than 30%. When a large number of 5G terminals are deployed in factories, RedCap will bring significant cost reductions.

4.2 Dual-path redundancy

Due to factors such as terminal handover, obstruction in the environment, electromagnetic interference, and large data volume, wireless communication can result in high packet loss rates and excessive latency. In high-real-time and control-type applications, high packet loss rates and high latency are often unacceptable. Even in 5G systems, these latency and reliability issues caused by wireless environmental problems are difficult to avoid. In the tire and chemical industries, data transmission latency and reliability are major issues related to production safety and efficiency. The concept of multi-path redundant transmission has emerged, and there are currently various technical solutions in the industry. Xinyuan has developed a 5G dual-path terminal tailored to factory needs, which greatly optimizes the latency and reliability during factory data transmission. This product reduces the packet loss rate to one-tenth of that of ordinary 5G terminals and the latency to one-third of that of ordinary 5G terminals, solving the worries of 5G in industrial control systems and making it affordable and reliable for factories to use. The terminal is equipped with two communication modules (supporting different solutions such as 5G+5G, 5G+4G, 5G+Wifi6), and during the communication process, the sender uses an FPGA (Field Programmable Gate Array) chip to achieve instant data replication, alignment, timestamp marking, and dual-path transmission with extremely low latency. The receiver uses algorithms within the programmable logic chip to achieve intelligent routing of dual-path data and discarding of redundant data packets. The CPU, baseband chip, and FPGA of this terminal are all based on domestic chip solutions.

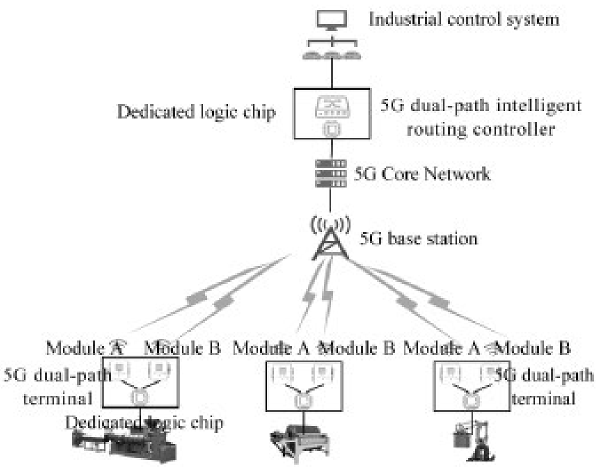

Figure 5 Schematic diagram of the dual-path terminal for the New Universal 5G network

4.3 5G Local Area Network (LAN)

Many industrial equipment communication protocols predominantly utilize the layer 2 Ethernet protocol. Compared to the layer 3 IP protocol, the advantage of the Ethernet protocol lies in its avoidance of complex routing calculations, resulting in higher communication efficiency and lower latency. Furthermore, the layer 2 protocol is also more secure, as it can achieve physical and logical isolation through VLAN technology, effectively preventing interference and attacks between different networks. Therefore, in the field of industrial Ethernet, some protocols do not define the network layer and transport layer, and these protocols are commonly referred to as "bare" Ethernet protocols, as they only define the data link layer (layer 2) and physical layer. These protocols are typically used in real-time communication and industrial control systems, as they provide lower communication latency and greater bandwidth. Some typical "bare" Ethernet protocols include Profinet, EtherCAT, and Modbus TCP. Additionally, there are many multicast/broadcast services in industrial scenarios, which can achieve distributed control and management, thereby improving production efficiency and quality.

Taking crane control as an example, originally, communication between the crane PLC and the PLC host computer control system was achieved through a layer 2 protocol, relying on the MAC address of the peer for addressing. The native 5G network, on the other hand, relies on a layer 3 protocol for IP addressing, and the address obtained by the 5G terminal is also an IP address, which does not support layer 2 data forwarding. After the introduction of the 5G network, in order to ensure normal communication between the PLC control system and the crane PLC, in addition to introducing a 5G industrial terminal for 5G wireless signal conversion, an AR router is added behind the crane PLC and in front of the PLC control system as shown in figure 6. The sending AR router is responsible for packaging the softGRE tunnel, encapsulating the industrial layer 2 protocol within the softGRE tunnel, and then communicating with the peer AR. The receiving AR router is then responsible for removing the tunnel and converting it into an industrial protocol before sending it to the crane PLC or PLC control system. At the same time, the 5G network assigns an IP address to the 5G industrial terminal. This approach is equivalent to establishing a two-layer network, with the upper layer being the enterprise private network, communicating through the softGRE tunnel, and the lower layer being the 5G network, serving as the bearer layer. This networking method is relatively complex and slightly more expensive.

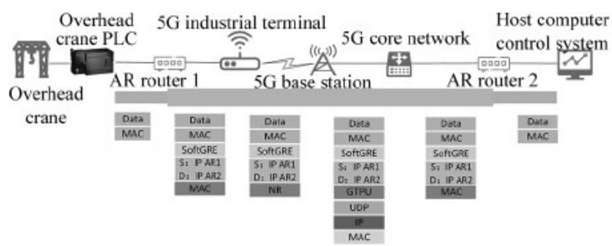

Figure 6 Traditional 5G industrial terminals require AR routers to achieve layer 2 networking

With technological advancements, once the network supports 5G LAN technology, layer 2 protocols can be directly transmitted within the 5G network, as illustrated in figure 7. There is no longer a need to insert an AR router to establish a new tunnel between the PLC control system and the crane PLC. Additionally, 5G industrial terminals no longer require IP addresses allocated by the 5G network. In this approach, the entire network constitutes a single-layer network. The 5G core network autonomously learns the MAC address list of the PLC, functioning as a virtual switch to facilitate layer 2 communication. This simplifies network configuration, reduces transformation costs, and better supports layer 2 network communication.

Another significant difference between 5G LAN and its predecessors is its ability to support broadcast and multicast. It allows terminals to dynamically join different work domains, enabling more flexible and intelligent communication between devices. For instance, joining nearby "work islands" based on location for inter-device communication can achieve more efficient and reliable logistics management and production line control. 5G LAN can support terminals to dynamically join different work domains, group devices based on location information, and enable rapid communication between devices. For example, AGV vehicles, wearable devices, inspection line marshalling, etc.

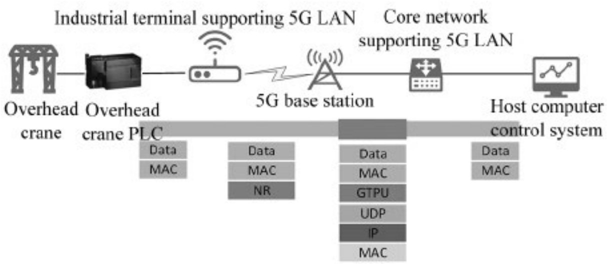

Figure 7 5G LAN technology can directly support layer 2 networking of industrial devices

Through the Layer 2 networking provided by 5G LAN, industrial users can quickly establish a Layer 2 network, enabling efficient communication and isolation between devices, meeting the special requirements of industrial communication, and enhancing the level of intelligence and automation in industrial production.

5 Conclusion

The tire smart factory is primarily an enterprise based on automation and centered around information. With 5G as its foundation, it integrates subsystems such as MES, access control, video surveillance, personnel positioning, AR inspection, cluster intercom, AGV, robotics, and energy management to achieve real-time perception of production factors such as personnel, material resources, production environment, and energy consumption. It maximizes the use of available resources and further streamlines the manufacturing process, enabling faster circulation of production factors such as information flow and logistics. Centered around the elements of "people, machines, materials, methods, environment, and testing," it helps enterprises continuously optimize resource allocation and enhance production efficiency, providing a path for high-quality innovative development and intelligent transformation of enterprises.