WHITE PAPER

Digitalisation of Power Grid with Private Mobile Networks

Enabling a smarter, more resilient and sustainable power grid for the future.

Reliable connectivity

Enhanced security

Operational efficiency

Sustainable transformation

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Foreword

Currently, the power grid is undergoing an unprecedented dual transformation of digitalization and new energy integration. This is not only a core requirement for achieving the Green Energy goals and building a new power system, but also a key measure for optimizing the energy structure and ensuring energy security. In this transformation, the power communication network, serving as the "nervous system" of the power grid, plays a critical role in data transmission, command delivery, and status monitoring. The quality of its construction directly determines the success of the power grid's transformation and the stable operation of the new power system.

As the "last mile" connecting the main grid to end users, the distribution network is the main battlefield for digitalization and new energy integration, and also the scenario with the most prominent and urgent communication needs. The unique characteristics of the distribution network, such as node distribution, operation and maintenance conditions, and development trends, impose extremely high and comprehensive requirements on the communication network.

The private wireless networks, with its core advantages of security, reliability, flexibility, efficiency, and cost-effectiveness, perfectly meets all communication needs in distribution network scenarios, making it one of the optimal solutions to overcome communication bottlenecks in distribution networks and support the dual transformation of the power grid.

This whitepaper reflects collective expertise. We sincerely thank all supporting organizations for their professional insights, technical recommendations, and resources throughout the research and validation process. Your industry knowledge and practical experience have been instrumental in ensuring the depth and foresight of this report.

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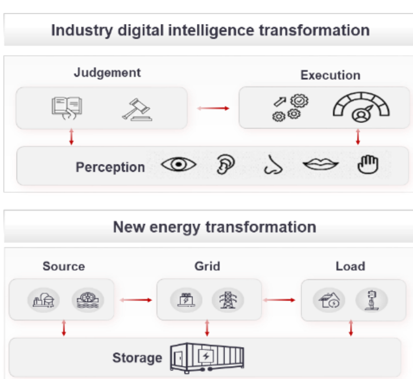
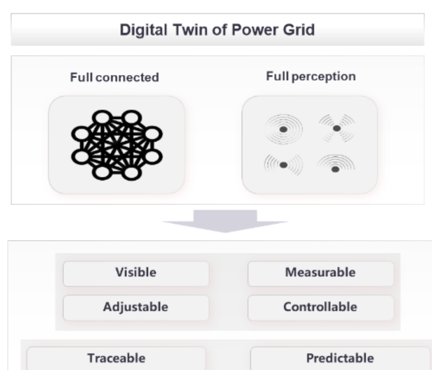
Part 1
Challenges of Power Grid Transformation

1.1 Requirements for Communication Network

With the deepening of digital transformation, distribution networks are gradually upgrading toward "comprehensive perception, refined control, and intelligent operation and maintenance." The widespread adoption of services such as distribution automation, electricity information collection, rapid fault location, and remote operation and maintenance requires the communication network to support massive terminal access, real-time data transmission, and precise command delivery. The accelerated transition to renewable energy has led to the large-scale integration of new types of terminals, such as distributed photovoltaic systems, energy storage devices, and electric vehicle charging stations, into the distribution network. This has transformed the distribution network from a traditional one-way power delivery model to a bidirectional power flow model characterized by "source-grid-load-storage" interaction, placing higher demands on the communication network's real-time performance, reliability, and flexibility.



Communication Network is Foundation for Successful Transformation



Communication Network Is Prerequisite of Digital Twin of Power Grid

As the "foundational support" for the dual transformation of the power grid, the construction level of the power communication network directly determines the pace of intelligent upgrades in the distribution network. Compared to the communication of the main high voltage power grid, medium and low voltage distribution network communication covers a broader area, involves a larger number of terminals, and operates in more complex environments, making it a key and challenging focus in power communication construction. Currently, distribution network communication still faces many bottlenecks. Traditional wired communication (such as optical fiber) is costly and time-consuming to deploy, making it difficult to cover vast areas such as remote mountainous regions and rural areas. Public wireless communication networks have issues such as security risks, insufficient reliability, very limited power backup, and significant latency fluctuations, which cannot meet the transmission requirements of critical power services. Therefore, the upgrade of distribution network communication is urgently needed.

1.2 Characteristics of Distribution Network Scenarios

As a critical link connecting the power grid with end users, the distribution network scenario defines the unique and time-critical communication requirements which become increasingly urgent needs. Its core characteristics are mainly reflected in three aspects:

First, there are a large number of nodes, a wide variety of terminal types, and significant differences in services. The distribution network covers various areas, including urban, rural, mountainous, and industrial zones, and includes a vast number of terminals such as distribution transformers, ring main units （RMU）, switchgear, smart meters, charging poles, distributed photovoltaic inverters, and energy storage controllers.

Secondly, the coverage area is extensive, the operation and maintenance costs are high, and manual inspection is difficult. Distribution network lines and terminal devices are scattered and cover a wide area, especially in rural and remote mountainous regions, where the terrain is complex and transportation is inconvenient. This makes the deployment of traditional wired communication lines difficult and costly. At the same time, the manual inspection method is inefficient, making it difficult to conduct comprehensive inspections of a large number of terminals. This often results in blind spots in inspections, making it hard to detect equipment failures and communication anomalies in a timely manner, which affects the reliability of power supply in the distribution network.

Thirdly, the trend is rapid, with new energy sources accelerating and power flows becoming bidirectional. Driven by the Green Energy goals, the integration of new energy sources is continuously accelerating, and the proportion of distributed energy access is steadily increasing. As a result, the power flow in the distribution network has shifted from traditional one-way transmission to bidirectional flow. The access and disconnection of terminal devices are random and fluctuating, and the operating state of the distribution network changes in real time. This requires the communication network to quickly adapt to the dynamic changes in terminal device access, and to transmit key data such as power flow changes and equipment operating status in real time, supporting the coordinated control of "generation-grid-load-storage" to ensure the safe and stable operation of the distribution network.

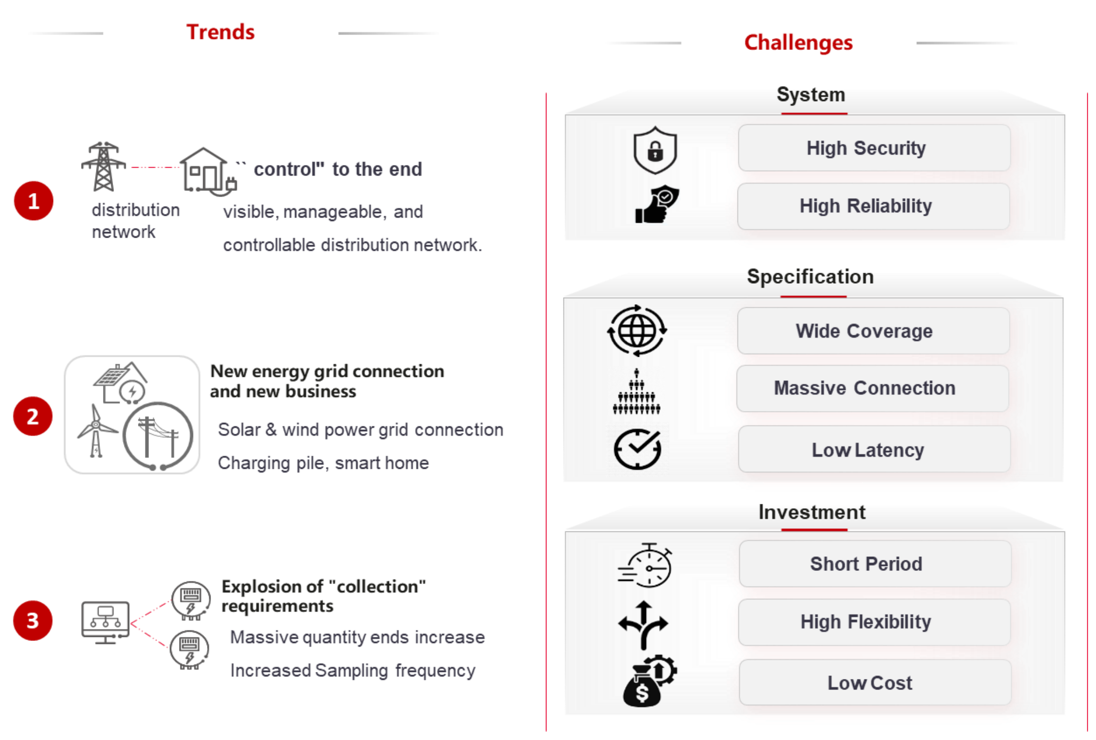
1.3 Requirements for Distribution Network Scenarios

Based on the aforementioned characteristics of distribution network scenarios and considering the rigid requirements of the dual transformation of the power grid, the core communication needs of distribution networks can be summarized into five key dimensions: "high security, high reliability, low latency, Massive connectivity, and multi-service." These five requirements are interrelated and indispensable, collectively forming the core demands for distribution network communication:

High Security: The power industry is a critical infrastructure, and distribution network data includes sensitive information such as the operational status of the power grid and user electricity consumption, which directly impacts energy security and public interest. The communication network must possess comprehensive security protection capabilities, achieving terminal identity authentication, encrypted data transmission, and network isolation to defend against security risks such as hacker attacks, data breaches, and unauthorized access, thereby ensuring the secure and controllable operation of distribution network communications.

High Reliability: Distribution network failures directly affect the power supply to end users. Communication interruptions can lead to the failure of distribution automation, inability to locate faults, and the inability to perform remote maintenance, significantly impacting power supply reliability. The communication network must exhibit extremely high stability, capable of withstanding external influences such as adverse weather conditions, electromagnetic interference, and terrain obstructions, ensuring that critical service data is not lost and that commands are not interrupted. This capability supports the fault location and self-healing isolation of distribution network faults.

Low Latency: Key services such as distribution network automation, fault isolation, and power flow control require rapid command delivery and real-time data feedback; otherwise, the impact of faults may expand and power outages may be prolonged. The communication network must possess low-latency transmission capabilities, with end-to-end latency controlled at the millisecond level, to meet the real-time requirements of these critical services.

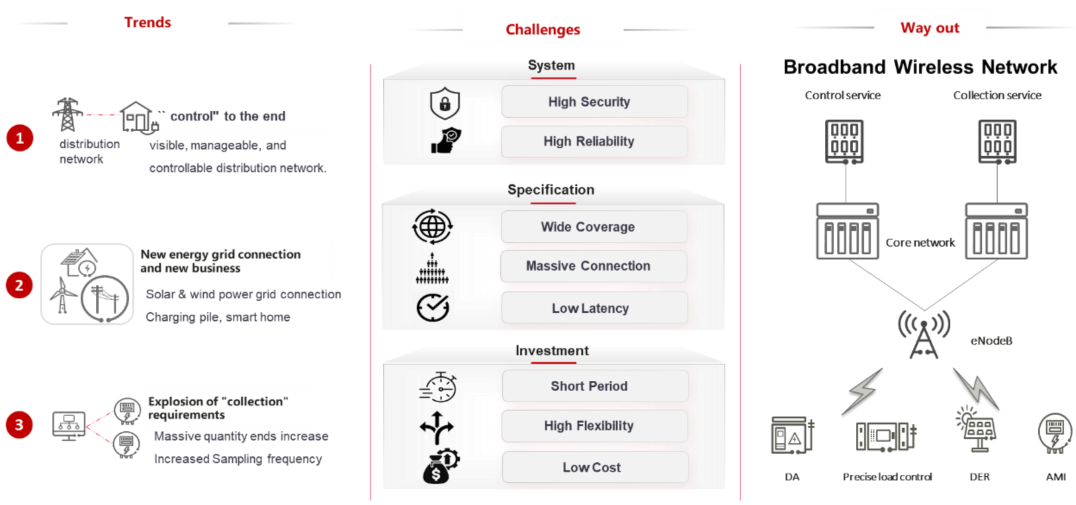


Massive Connectivity: The number of distribution network terminals is vast and continuously increasing, with tens of thousands or even hundreds of thousands of terminals potentially being connected in a single area. Terminals such as smart meters and distributed photovoltaic inverters need to be stably connected to the communication network for an extended period to enable periodic data collection and transmission. The communication network must have the capability to support large-scale terminal connections, allowing for the concurrent connection of a massive number of terminals, thus meeting the "full coverage, full access" requirements of distribution network terminals.

Multi-Service: The distribution network encompasses various services, including control, data collection, operation and maintenance, and service provisioning. These services have significantly different requirements for communication bandwidth, latency, resilience and power consumption. The communication network must possess the capability for multi-service collaborative transmission, enabling flexible allocation of network resources to meet the differentiated needs of different services. This will facilitate "one network for multiple purposes," supporting intelligent operation and maintenance of the distribution network and the improvement of high-quality services.

Part 2
Adaptability of Private Wireless Networks

Facing the core communication requirements of distribution network scenarios, among various communication technology solutions, the power wireless communication private network stands out due to its unique advantages, achieving comprehensive and high-precision alignment with the communication needs of distribution networks. It has become the optimal solution for overcoming the lack of communication in distribution networks. Its core advantages are reflected in four key aspects: security, reliability, flexibility, and efficiency, perfectly meeting the communication demands of distribution network scenarios.



2.1 High Security

The power wireless communication private network utilizes dedicated frequency bands and network architecture, completely isolated from public communication networks, effectively avoiding the security risks associated with public networks and achieving "dedicated network for dedicated use and exclusive data access." The private network is equipped with a comprehensive security protection system, supporting functions such as terminal identity authentication, encrypted data transmission, access control, and security situational awareness. This system can effectively defend against various security threats, including unauthorized access, data tampering, and hacker attacks. It meets the security protection requirements for critical infrastructure in the power industry and aligns perfectly with the "high security" core requirement of distribution network communication.

2.2 High Reliability

The private wireless networks are deployed using a dedicated frequency band, which is not affected by fluctuations in public network traffic or signal interference. This ensures stable signal transmission and strong anti-interference capabilities. Additionally, the dedicated network can optimize its architecture and transmission paths according to the needs of distribution network services, achieving redundancy and backup, including through power back-up for all active network elements. When a transmission path or power supply fails, the network can quickly switch to a backup path or installed back-up power supply, ensuring uninterrupted communication and meeting the stable transmission requirements of key services such as distribution automation and fault isolation, thus fulfilling the "high reliability" with power backup demand of distribution network communication.

2.3 Flexible Deployment

The private wireless networks do not require large-scale fiber deployments, offering flexible and convenient deployment. Based on the distribution characteristics of the terminals in the distribution network, base stations and communication terminals can be flexibly set up to quickly achieve full coverage of the distribution network, making it particularly suitable for areas such as rural and mountainous regions where wired communication is difficult to deploy. Compared to traditional fiber communication, the dedicated wireless communication network has a shorter deployment cycle and lower implementation difficulty, significantly shortening the deployment period of the distribution network communication system and reducing construction costs. Moreover, when new terminals are added, or existing ones are relocated or adjusted, the coverage of the dedicated network and the terminal access configurations can be quickly modified without the need for large-scale network overhauls. This adapts well to the "numerous and widely distributed" characteristics of distribution network terminals, meeting the flexible adaptation needs of "extensive connectivity" and "multi-service" in distribution network communication. Leveraging the advantage of flexible deployment, the dedicated network can quickly overcome the "last mile" communication chokepoint in the distribution network, enabling comprehensive access for a large number of terminals.

2.4 Efficient Transmission

Private wireless network features high transmission rates and low transmission latency, achieving millisecond-level end-to-end latency, which meets the real-time requirements of key services such as distribution automation and fault location. At the same time, the dedicated network supports concurrent access from a large number of terminals, enabling simultaneous access and data transmission for tens of thousands or even hundreds of thousands of terminals, thus meeting the "massive connectivity" needs of the distribution network. In addition, the dedicated network has the capability of multi-service collaborative transmission, allowing for flexible allocation of network resources such as bandwidth and latency according to the needs of different services. This ensures the transmission requirements of various services, including control, data collection, and operation and maintenance, achieving "one network for multiple purposes," thereby improving the efficiency and utilization of distribution network communication and aligning with the core requirements of "low latency, massive connectivity, and multi-service" in distribution network communication.

In summary, the four core advantages of the private wireless networks fully align with the core communication needs of the distribution network scenario, which include "high security, high reliability, low latency, massive connectivity, and multi-service." This effectively addresses the bottlenecks of a large number of communication nodes, wide coverage, difficult operation and maintenance, and rapid development trends in the distribution network, providing a solid communication foundation for the intelligent upgrade of the distribution network and the dual transformation of the power grid.

Part 3
Selection for Private Wireless Networks

In the selection of frequency bands for Private Wireless Networks, the core characteristics of distribution networks—"extensive coverage and complex deployment scenarios"—are taken into account. Low frequency bands, with their advantages of wide coverage, strong penetration, and low deployment costs, have become the preferred choice for distribution network scenarios. At the same time, the standardization of the frequency band and the maturity of the industry chain directly affect the deployment effectiveness and long-term development of the private network. After comprehensive comparison and evaluation, the 450MHz frequency bands, with their low frequency advantages, standardized attributes, and mature ecosystem, have become one of the optimal choices for Private Wireless Networks, perfectly meeting the deployment needs and long-term development requirements of distribution network scenarios.

3.1 Principles for Frequency Band Selection

Considering the unique characteristics and communication requirements of distribution network scenarios, the selection of frequency bands for Private Wireless Networks must adhere to three core principles to ensure frequency band suitability, deployment feasibility, and long-term stability:

The principle of prioritizing low frequency. Distribution networks cover vast areas, especially in rural and mountainous regions, where the terrain is complex and terminals are widely dispersed. These scenarios require frequency bands with wide coverage and strong building penetration capabilities also substantially to reduce the number of base stations needed and lower construction and maintenance costs which is important given the additional investments in redundancy and power back-up. Low frequency bands have longer signal wavelengths, enabling them to travel longer distances and penetrate through obstacles more effectively. This allows for efficient coverage of remote areas and regions with challenging terrain without the need for large-scale base station deployment, perfectly matching the "extensive coverage" characteristic of distribution networks. Low frequency bands minimize the number of base stations required for the network, an important element in ensuring resilience through long duration power back-up at all sites and redundant back-haul. Therefore, the principle of prioritizing low frequency is a core criterion for frequency band selection in distribution network scenarios.

The principle of standard frequency. The frequency band must comply with relevant international and domestic standards, and have standardized technical specifications and protocols to ensure compatibility and interconnectivity of equipment from different manufacturers, avoiding the "island effect," and facilitating the large-scale deployment, upgrade, and maintenance of private networks. At the same time, standard frequency bands have well-developed spectrum planning and management, effectively preventing frequency conflicts and ensuring the stability and security of private network signal transmission.

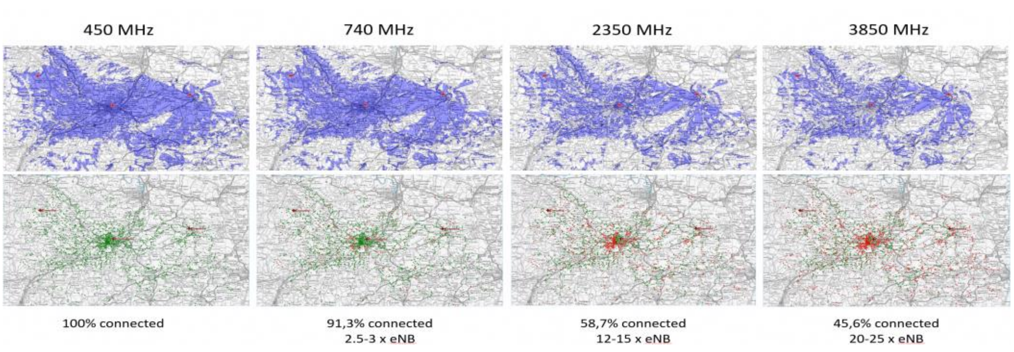
The principle of a mature ecosystem. The frequency band must be supported by a complete industrial chain, including mature supply of various devices such as chips, modules, base stations, and terminals, as well as professional technical services and operation and maintenance support, to ensure the feasibility and long-term stability of private network construction. A mature industrial chain can reduce equipment costs, improve deployment efficiency, and facilitate future network upgrades and technology iterations, thus supporting the long-term development of distribution network communication.

3.2 Advantages of the 450MHz Frequency Band

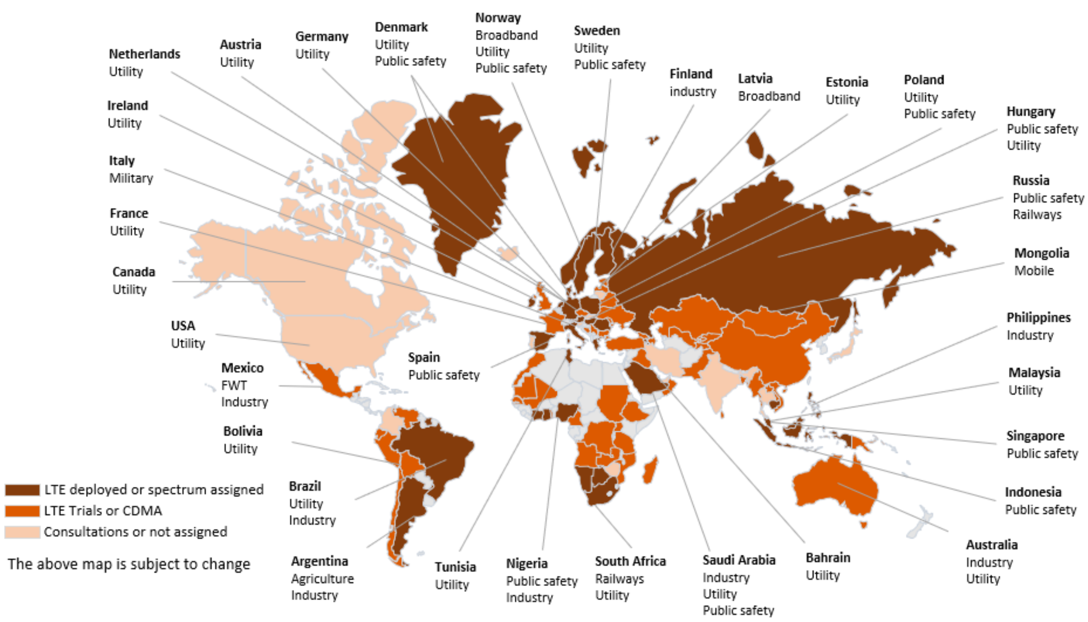
The 450 MHz frequency bands are in the lower frequency part of the radio spectrum where propagation characteristics are more significant than capacity, making them attractive for private networks but less attractive for public networks requiring higher capacity. The frequency bands are dedicated frequency bands that comply with 3GPP standards. These frequency bands have a complete industrial chain and fully meet the three core principles for frequency band selection in distribution networks.

The core advantages are mainly reflected in the following four aspects:

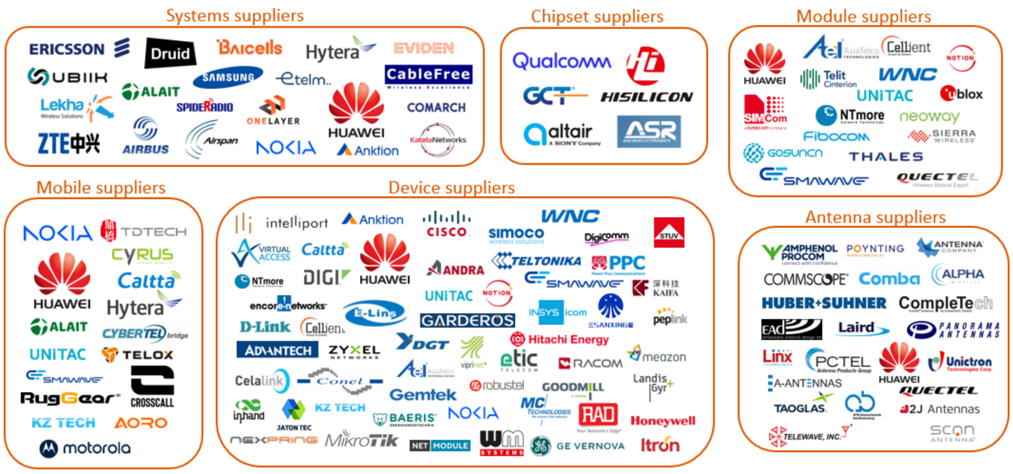
- The 450 MHz frequency bands have a significant advantage in low-frequency coverage, which is well-suited to the characteristics of wide distribution network coverage areas. The 450 MHz frequency bands have a longer wavelength, enabling longer transmission distances and stronger penetration capabilities. A single base station can cover an area of several kilometres, which is 3 to 5 times the coverage of higher frequency bands, significantly reducing the number of base stations required. This makes it particularly suitable for coverage in remote areas such as rural and mountainous regions. Compared to mid-frequency bands such as 700 MHz and 800 MHz, the 450 MHz frequency band offers broader coverage and lower deployment costs, eliminating the need for large-scale base station construction and effectively reducing the construction costs of the distribution network's wireless private network.



- Second, the 450 MHz frequency bands are standardized frequencies, with standardized 3GPP specifications and communication protocols. Mainstream equipment manufacturers both domestically and internationally support the development and production of devices for these frequency bands, enabling compatibility and interconnection among base stations, modules, and terminals from different manufacturers. This avoids issues such as device incompatibility and network incoordination. In addition, the standardized frequency bands have a well-developed spectrum planning system, effectively preventing conflicts with other frequency bands, ensuring the stability and security of signal transmission in the power wireless communication private network. This facilitates the large-scale deployment, upgrading, and maintenance of the private network, meeting the "multi-service, large-scale connectivity" requirements of distribution network communication. The long life cycles of utility telecommunications equipment will also encourage long term support for the ecosystems.



- the mature and well-developed industry chain supports the large-scale deployment of private networks. The 450 MHz frequency bands have a mature ecosystem, with professional manufacturers providing well-established products and technical services across the entire chain, from chips and modules to base stations and terminal devices. The localization rate of chips and modules from mainstream equipment manufacturers is high, ensuring an ample supply of cost-effective and high-quality equipment. This mature industry chain significantly reduces the construction costs of private wireless communication networks for the power sector, shortens the deployment cycle, and facilitates subsequent network operations, equipment upgrades, and technological iterations, providing a solid foundation for the long-term stable operation of private networks.



- it is well-suited to meet diverse service requirements and supports the intelligent upgrade of distribution networks. The 450 MHz frequency bands offer excellent transmission rates and low latency, achieving millisecond-level end-to-end latency and supporting the concurrent access of a large number of terminals. This capability not only meets the low-latency and high-reliability requirements of control-oriented services such as distribution automation and fault isolation, but also satisfies the high-connectivity and low-power needs of data collection services such as electricity information collection. Additionally, it can support the bandwidth demands of operation and maintenance services such as video inspections, enabling "one network for multiple purposes" and effectively meeting the needs of multi-service collaborative transmission in distribution networks.

Part 4
Suggestions for Private Wireless Network Deployment

4.1 For Private Network Deployment Consideration

Considering the characteristics of distribution network scenarios, communication requirements, and the advantages of the 450 MHz frequency bands, the following deployment recommendations are proposed to ensure the construction quality and operational effectiveness of Private Wireless Networks:

- Adhere to the deployment principle of "prioritizing low frequency and maintaining unified standards." The deployment of the distribution network private wireless network should prioritize the use of the standard 450 MHz frequencies, strictly following 3GPP standards and relevant regulations of the power industry, and unifying the network architecture, communication protocols, and equipment standards to ensure compatibility and interoperability of equipment from different regions and manufacturers.
- Optimize the network architecture to meet the service requirements of the distribution network. Based on the distribution of terminal devices, service types, and regional characteristics, the network architecture of the power wireless communication private network should be optimized to establish a three-layer architecture of "core network + access network + terminal." private wireless network can be deployed “tailer-made” to suit any national or regional structure and related requirements. (as opposed to the one-size-fits-all public network) The core network can adopt a centralized deployment model to allow for simpler resource scheduling and security management across the entire network. If federal/regional distribution network structures shall be taken into consideration it is, however, possible to deploy decentralized core networks which improves overall reliability/availability and security. The ability to deploy “tailer-made” networks to suit the country-specific structures and requirements of the distribution network operator(s) is a key benefit of private wireless networks.
- Strengthen security protection to ensure network and data security. Strictly follow the security protection standards of the power industry to build a comprehensive and multi-layered dedicated network security protection system. This system will implement functions such as terminal identity authentication, encrypted data transmission, access control, security situation awareness, and early warning of abnormal behaviors to defend against various security threats.
- Rely on a mature industry chain to control construction and operation and maintenance costs. Select equipment manufacturers and service providers with mature technologies and extensive experience, and prioritize the use of high quality, cost-effective chipsets, modules, base stations, and other equipment. The wide vendor ecosystem allows distribution network operators to adhere to national or geopolitical procurement preferences. By leveraging the mature 450MHz industry chain, the deployment costs of the dedicated network can be reduced, with affordable backup power solutions.

4.2 Prospects for Private Wireless Network Applications

With the continuous deepening of the power grid's digital transformation and the transition to renewable energy, the level of distribution network intelligence will also continue to improve. As the core support for distribution network communication, the application scenarios of the dedicated wireless communication network will continue to expand, and its value will become even more prominent.

In terms of distribution network operation and maintenance, the dedicated network will support the entire intelligent operation and maintenance process of the distribution network. Through functions such as remote monitoring, video inspection, automatic fault location, and remote control, the dedicated network will significantly reduce the workload of manual inspections, improve operation and maintenance efficiency, lower operation and maintenance costs, and facilitate the transition from "manual inspection" to "intelligent operation and maintenance" in distribution network management.

In terms of renewable energy integration, the dedicated power communication network will support the coordinated control of "generation-grid-load-storage," enabling real-time transmission of operational status data from new types of terminals such as distributed photovoltaics, energy storage systems, and charging piles. This will facilitate functions such as renewable energy output prediction, power flow regulation, and energy storage charge-discharge control, thereby enhancing the capacity for renewable energy integration and promoting large-scale access and efficient utilization of renewable energy.

Regarding technological evolution, with the development of 5G and 6G, Internet of Things (IoT), and artificial intelligence, the dedicated power communication network will achieve deep integration with technologies such as 5G and edge computing, further improving network speed, latency, and connectivity capabilities to meet the higher requirements of intelligent distribution network upgrades. Meanwhile, the 450MHz industry chain will continue to improve, with equipment performance being continuously optimized and costs further reduced, driving the large-scale deployment and widespread application of dedicated power communication networks, making them a core communication support for the construction of the new power system.

Part 5 Conclusion

Currently, the digital transformation of power grids and the transition to renewable energy have entered a critical phase. As the main battlefield for power grid transformation, the communication needs of distribution networks are becoming increasingly urgent and unique. The power communication network has become a core infrastructure supporting the dual transformation of the power grid. The characteristics of distribution network scenarios—such as a large number of nodes, extensive coverage, and rapid changes—determine the network's high demand for security, reliability, low latency, large connectivity, backup power, and multi-service capabilities. The dedicated power communication network, with its core advantages of security, reliability, flexibility, efficiency, and cost-effectiveness, fully meets the communication needs of distribution networks, making it the optimal solution for overcoming communication bottlenecks in distribution networks.

Considering the extensive coverage of distribution networks, communication solutions characterized by low standardized frequency bands and a mature ecosystem have become the preferred choice for deployment. The 450MHz communication solution stands out due to its significant advantage in low-frequency coverage, 3GPP standardization, a well-established industry chain, and excellent adaptability to the diverse services of distribution networks, making it one of the optimal choices for dedicated wireless communication networks in the power sector. This solution effectively supports comprehensive and highly reliable and secure coverage and efficient transmission at comparatively very low cost across the entire distribution network, providing a solid foundation for the intelligent upgrade and improvement of distribution networks communications.

The construction and application of dedicated wireless communication networks in the power sector not only address the communication bottlenecks in distribution networks, enhance the reliability of power supply and the efficiency of operation and maintenance, and reduce construction and maintenance costs, but also support the coordinated development of "generation-grid-load-storage" (GGLS), promote the integration of renewable energy, and facilitate the dual transformation of the power grid.

Part 6
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