NB-IoT Smart Gas Solution White Paper

September 2017

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CONTENT

1 PREFACE

Natural gas is the cleanest of all fossil fuels and can be used to create modern energy systems that are secure and efficient. Through the use of natural gas, the Chinese government aims to mitigate environmental pollution, improve air quality, and improve people's quality of life.

According to China's 13th Five-Year Plan (2016 to 2020), China will further advance natural gas development with the aim that by 2020, the proportion of gas used as primary energy source will rise to 9–10% from 5.9% in 2015. The pipeline network is expected to expand by 40,000 km with an annual growth rate of 10%. In addition, natural gas services will be delivered to 470 million population, 42% more than the 140 million baseline and an annual growth of 10%. To achieve these objectives, China will import more natural gas, further strengthen their peak-load regulation infrastructure, and digitalize urban natural gas services. Moreover, further market reforms will be put in place in market systems related to delivery of natural gas services to rural areas, switching from coal to natural gas, tiered natural gas pricing, and peak-load natural gas pricing. The natural gas sector will make significant progress in the years to come.

Existing smart gas meters are helping natural gas suppliers address some of the challenges they face. However, many problems remain unsolved. Data transmission is unstable, power consumption is too high, and the metering success rate is too low. Narrowband Internet of Things (NB-IoT) technology can provide security, wide coverage, massive connectivity, low power consumption, all at a low cost. It is an ideal solution to the preceding problems and is well equipped to meet natural gas customers' development requirements.

Against this backdrop, Shenzhen Gas, China Telecom, Huawei, and Goldcard jointly release NB-IoT Smart Gas Solution White Paper (September 2017). The white paper comprehensively analyzes the common disadvantages of traditional smart gas meters and the merits of NB-IoT gas meters, and describes cloud, pipe, and terminal aspects of the NB-IoT gas meter applications. This white paper also provides some predictions about the future of smart gas to promote in-depth win-win cooperation in the future.

As smart cities develop and IoT, cloud computing, big data, and other new technologies start to see widespread deployment, NB-IoT Smart Gas will become an important part of information-based smart city management. It will drive industrial innovation, improve people's livelihoods, enhance civil society, and protect the environment and the world's natural resources.

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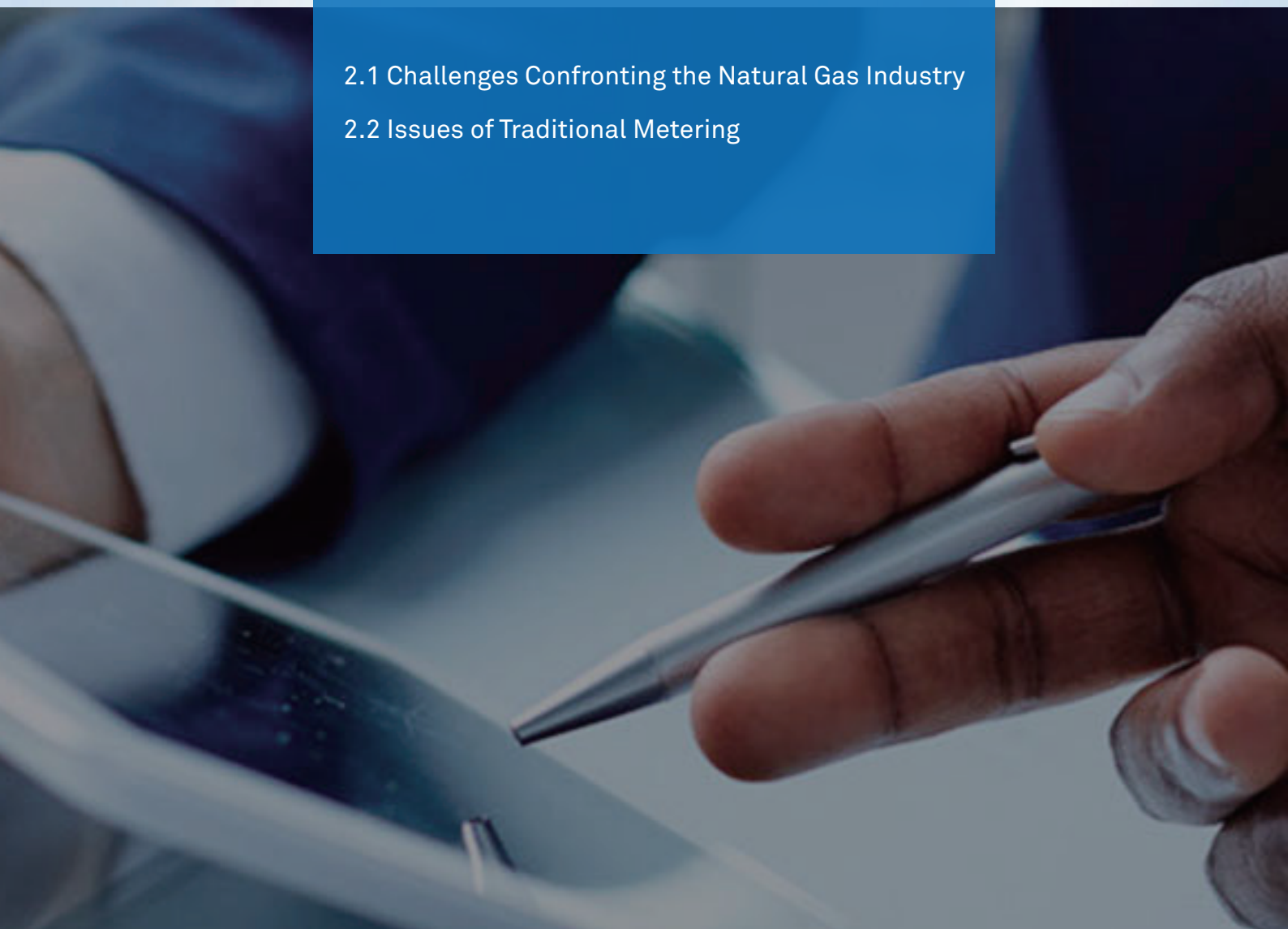
Issues and Challenges in the Natural Gas Industry



2.1 Challenges Confronting the Natural Gas Industry

Urban natural gas provisioning has made significant progress in recent years. However, natural gas utilities still face a vast array of management problems because urban natural gas services have to balance requirements from multiple concerned parties. Urban safety, consumer satisfaction, profitability of natural gas utilities, and the supply-demand balance within regions need to be taken into consideration.

2.1.1 Difficult Meter Reading, Charging, and Payment

The business model of urban natural gas utilities is delivering natural gas through pipelines, measuring natural gas consumption using meters, and charging fees based on the metering results. The precision and frequency of gas metering, as well as the promptness of payment by consumers, have a direct bearing on natural gas utilities' revenues and cash flows.

Traditional manual meter reading leads to high labor and management costs. Given that an employee can read 80 to 100 in-house gas meters per day, a small or mid-sized natural gas utility serving 300,000 residential houses must hire 150 to 200 employees to cope only with meter reading.

The billing system collects all of the data and generates bills typically at the end of each month due to inefficient meter reading. Consumers can settle their bills at specified customer service centers only after they receive the paper bills. The entire process is energy- and time-consuming. In many cities, consumers have to pay within 1–2 weeks. If they fail to pay in time, late fees are charged, which leads to decreased service satisfaction.

2.1.2 Lack of Secure Natural Gas Supply and Usage Assurance Mechanisms

For public utilities, supply and sales differences, and leakage losses during transfer and distribution are critical issues. The under-calculation of pipeline networks, measurement errors of meters, and failures to prevent and stop natural gas thefts result in considerable supply and sales differences, leading to huge losses for natural gas utilities.

Natural gas safety is crucial for natural gas pipeline networks. All issues, such as pipeline corrosion, gas leakage, high pressure and temperature, and improper use of the natural gas, require real-time remote monitoring. These potential dangers must be prevented and eliminated promptly to ensure natural gas safety.

Natural gas utilities are in urgent need of technical measures to detect real-time pipeline temperature and pressure and to monitor natural gas usage behavior. Alarms should be reported immediately after a terminal exception occurs. Alternatively, remote pipe valve control should be implemented.

2.1.3 Tiered Pricing and Energy Conservation

To promote healthy development of the natural gas industry, pricing leverage is fully utilized to reach regional supply-demand balance and steer consumers towards energy saving and emission reduction. As the natural gas price reform has deepened over the past years, the pricing regulations of non-residential natural gas usage continue to be lifted and tiered pricing effected in many regions. With the introduction of complicated pricing schemes and frequent price adjustments, traditional management methods no long apply. The natural gas industry is now calling for more precise metering.

2.1.4 Innovative Natural Gas Services with Internet Plus

IoT, mobile Internet, and big data applications provide new opportunities and challenges to management and service provisioning of energy utilities. Natural gas utilities in some cities have experimented with Internet Plus in delivering innovative natural gas services. They proactively use enterprise-level WeChat, Alipay, apps, and other new channels to expand massive consumer resources through value-added services such as natural gas insurance and natural gas stove sales. These pioneering campaigns inject vitality into the natural gas industry under the new economy.

To enable natural gas utilities to fully embrace the opportunities and challenges, the gas utilities' need for smart gas meters has been increasing in recent years.

2.2 Issues of Traditional Metering

At present, smart gas meters account for 30–40% of all existing gas meters in China. Most of them are IC card–based prepayment smart meters. Meters that support remote automatic metering constitute only a small proportion. According to their communications modes, the meters currently on the market can be divided as follows:

- Common mechanical meters. These meters are not intelligent. They require manual meter reading.
- IC card–based prepayment meters. These meters are controlled using IC cards on a per-user basis.
- Wired automatic meter reading system (AMR) meters. These meters require cable connections before being activated.
- Short-range wireless meters. Data is collected in a point-to-point or centralized manner. They can be controlled remotely.
- GPRS-based IoT meters. Scheduled data collection and remote control are made possible on GPRS cellular networks.

The wide application of smart meter reading has been hampered by data transmission instability, data security risks, high meter power consumption, weak wireless network coverage, and other problems.

2.2.1 Data Transmission

Currently, many natural gas utilities use wireless networks operating on unlicensed frequency bands for smart meter data transmission. The anti-interference and data management capabilities of such networks vary greatly. Unstable data transmission and issues in security and reliability are major concerns.

2.2.2 Power Consumption

Gas meters have strict requirements to prevent explosions. The incurring problem of high power consumption with traditional smart gas meters poses great challenges to natural gas utilities. If an external power supply is used, communications costs will increase. Built-in batteries, however, require frequent replacement due to high power consumption, which adds to maintenance costs and management difficulties. China's regulations have set the replacement interval of civil gas meters to 10 years, which is difficult for many smart natural gas utilities to achieve.

2.2.3 Network Coverage

Most gas meters in China are installed in complex environments, mainly in corridors, indoors, or underground. Therefore, they have special coverage requirements. To guarantee data transmission, signal amplifiers are typically used. However, the result is still unsatisfactory with unstable metering success rates.

2.2.4 Access of Multi-Vendor Meters

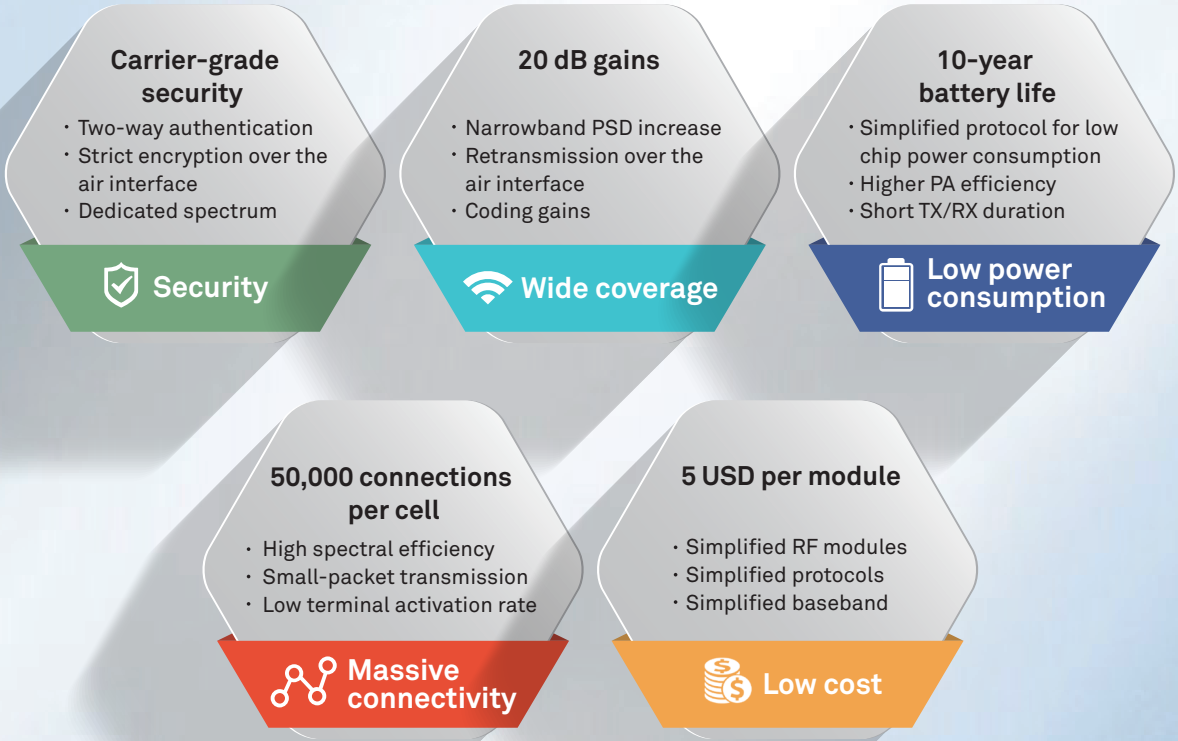
Many smart meter manufactures have emerged in response to the burgeoning smart gas metering requirements. Under fierce competition, each manufacturer uses its own communications protocols with frequent meter model and protocol updates. Each manufacturer also provides different back-end software, bringing significant risks to smart metering applications of natural gas utilities. Use of wireless networks operating on unlicensed bands for data transmission makes it difficult for natural gas utilities to set up a unified network that can serve huge numbers of smart gas meters. If gas meters are managed in many separate areas, the management difficulties and costs increase for natural gas utilities. In addition, it is costly for natural gas utilities to interconnect different meter systems supplied by different manufacturers using various communications methods during the large-scale deployment of gas meters.

3

NB-IoT for Smart Gas

3.1 NB-IoT Highlights

NB-IoT is a leading long-range wireless communication technology based on cellular networks. NB-IoT features security, wide coverage, low power consumption, massive connectivity, and low cost.



3.2 NB-IoT Advantages for Smart Gas

In the smart gas field, NB-IoT enables stable, real-time traffic data collection from gas meters, device status monitoring, command delivery, and additional remote operations. After the gas meter data and status information is collected in a secure and low-cost manner, it can be analyzed and handled promptly to implement targeted, scientific, and dynamic management. This improves the management efficiency and service satisfaction of natural gas utilities.

With these advantages, NB-IoT Smart Gas solution is ideal for addressing the common challenges that face the natural gas industry and traditional gas meters.

- In terms of **gas metering**, NB-IoT reduces metering costs and allows for real-time data analysis, scientific meter management, and prompt troubleshooting, which decreases the operation costs and improves operation efficiency.
- In terms of **data security**, E2E security management of the NB-IoT Smart Gas solution ensures data reliability. NB-IoT is used on telecommunications networks that operate on licensed spectrums. The anti-interference capacity, data security, and technical services can be assured. NB-IoT networks can be easily deployed and spread, ensuring overall data security of gas meters.
- In terms of **power consumption**, NB-IoT uses low-power signal collection units to significantly reduce energy consumption. Test results show that NB-IoT gas meters have a 10-year battery life in common application scenarios.
- In terms of **network coverage**, the Low Power Wide Area (LPWA) NB-IoT technology is advantageous in wide coverage, large capacity, and high reliability. These benefits ensure network coverage for gas meters installed in complex environments, regardless of whether they are sparsely or densely installed.
- In terms of **massive connectivity**, NB-IoT allows for a unified IoT platform to accommodate diverse IoT applications. This platform assures protocol compatibility between applications of different manufacturers and simplifies the integration. In addition, the numerous gas meters can easily access the network and interconnect with each other.

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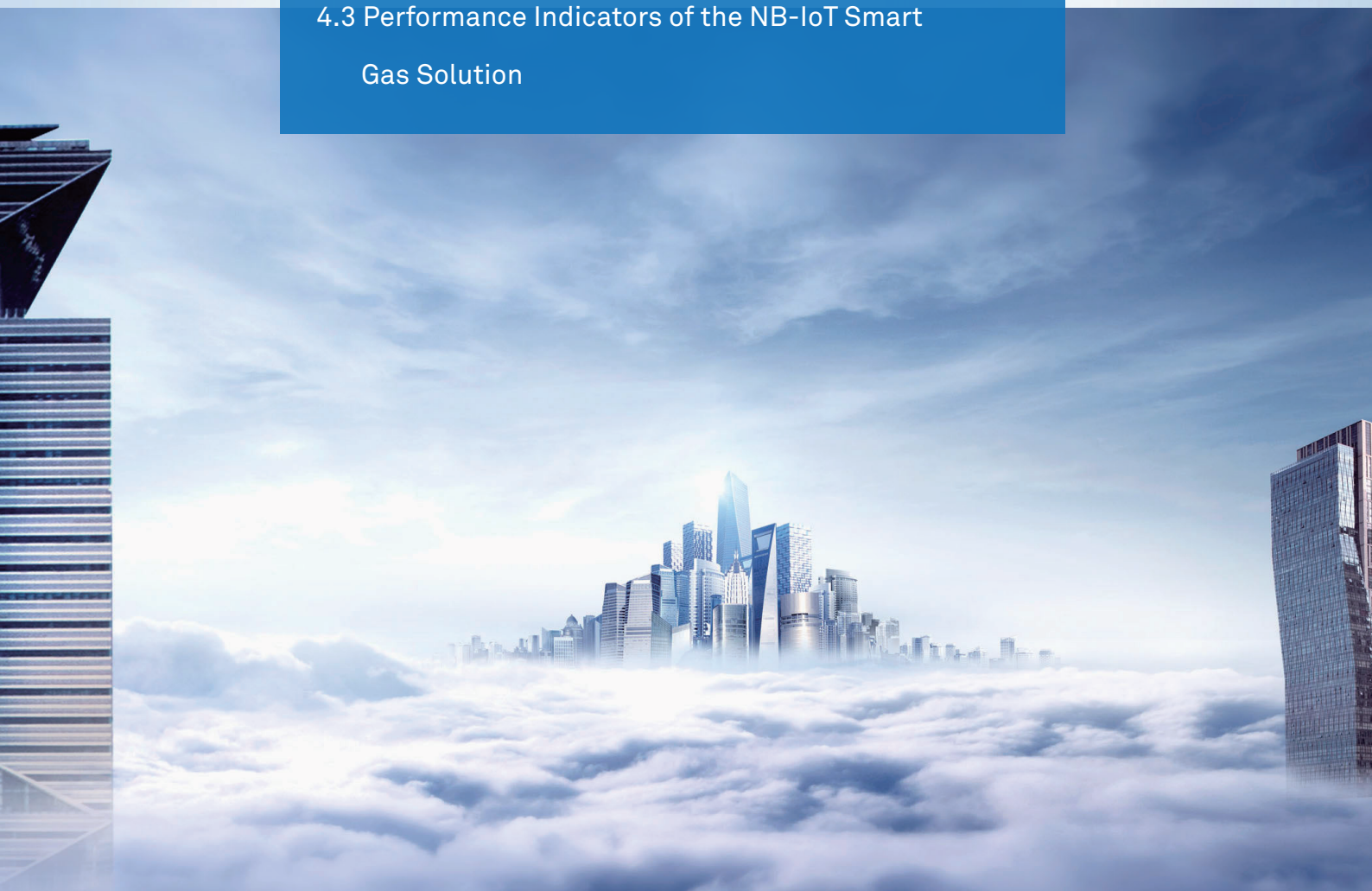
NB-IoT Smart Gas Solution



4.1 Overview

The NB-IoT Smart Gas solution fully caters to the characteristics of the natural gas industry. It focuses on smart metering and smart pipeline network construction while integrating the most recent technologies of IoT, big data storage and analysis, cloud computing, and mobile Internet. This solution disposes of the traditional service model and explores new service channels to provide a systematic energy solution. The future-oriented smart gas system framework enables natural gas utilities to provide optimal services and create more profit.

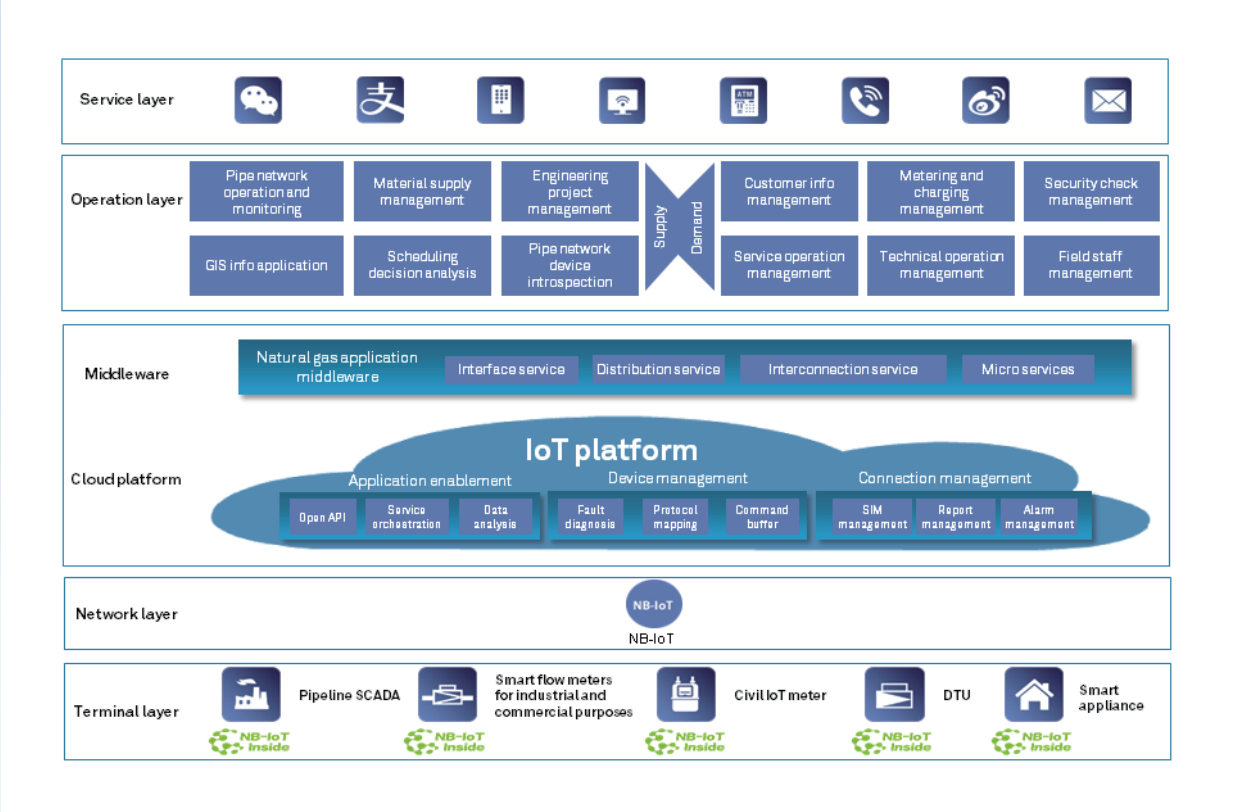


Figure 4–1 Overview of NB–IoT Smart Gas solution

The NB-IoT Smart Gas architecture integrates the cloud, pipe, and terminals to meet future ICT evolution requirements. The architecture consists of the terminal layer, network layer, cloud platform, natural gas application layer, and other related layers. These layers are integrated to an organic whole by using the IoT, cloud computing, big data, and other technologies. With this architecture, smart gas applications can be rapidly developed and rolled out.

4.1.1 Terminal Layer: Awareness Convergence of IoT

Terminals are the basic IoT bearer. As IoT develops further, smart terminals gradually replace dumb terminals. Various sensors and communications modules are integrated into terminals so that they can be controlled, managed, and communicate with each other. Smart terminals include smart civil IoT meters, smart flow meters for industrial and commercial purposes, smart pipeline networks, smart data transform units (DTUs), and multiple smart home terminals. Smart terminals with built-in NB-IoT modules can upload data to the IoT platform through NB-IoT base stations.

4.1.2 Network Layer: Simplified NB-IoT Deployment and Wide Coverage

The network is the basis for IoT communication. The network access technologies and connection modes vary depending on the IoT application scenarios and devices in use. In the smart gas scenario, the NB-IoT network operating on China Telecom's 800 MHz frequency band can fully satisfy the smart gas communications requirements. Smart metering and other related services are running on this network, which features massive connectivity, low power consumption, low cost, and wide coverage. In network deployment, NB-IoT only occupies 180 KHz bandwidth and can be deployed flexibly. Three deployment methods are available for selection: In-band, Guard-band, and Stand-alone. Only a network upgrade is required on the existing GSM, UMTS, or LTE networks before NB-IoT can be deployed nationwide. Compared with other LPWA technologies, NB-IoT is cheaper in terms of network construction costs, and can be rapidly deployed within a large scope. The 800 MHz band of China Telecom has strong signal penetration capability and deep coverage, which ensure data transmission stability and reliability in complex environments for gas metering and other services. China Telecom combines communications competence with IT operation capabilities to provide natural gas utilities and gas meter manufacturers with intelligent and controllable networks that can be perceived and diagnosed. The networks enable natural gas customers to perform in-time query and management of the terminal operating and communications status. In addition, customers have different requirements during terminal production, verification, storage, and usage. To fulfill these varied requirements, China Telecom provides lifecycle management for SIM cards in the terminals.

4.1.3 Platform Layer: Multi-Service Management on a Unified Platform

The IoT platform can be flexibly deployed. One option is to deploy the IoT platform on the eCloud cooperatively deployed by China Telecom and Huawei. Huawei provides the OceanConnect IoT platform with basic functions such as connection and device management, data analysis, and open APIs, while China Telecom handles routine operations and management.

The IoT platform provides connection perception, connection failure diagnosis, connection control, and other connection status query and management functions. The unified protocol and interface allow access of different terminals. The upper-layer industry applications realize object-based management without considering the physical connections and data transmission of terminals. Flexible and efficient data management functions are provided, including data collection, classification, structured storage, data invocation, usage analysis, and customized service reports used for analyses. Service provisioning is modular-based, and the service logic can be flexibly orchestrated for fast development of industry applications.

For the natural gas industry, Huawei and Goldcard have jointly formulated a standard natural gas packet device profile. The IoT platform provides the plug-in management function for connection with devices. This southbound interconnection service enables various smart meter manufacturers to use multiple standard protocols for fast network access and device management. In addition, the IoT platform supports integration of standard natural gas micro service suites with back-end natural gas Customer Information System (CIS). In this way, billing, customer care, and service-related operations are seamlessly associated with remote data collection, relieving natural gas utilities of considerable work in multi-device and multi-system integration.

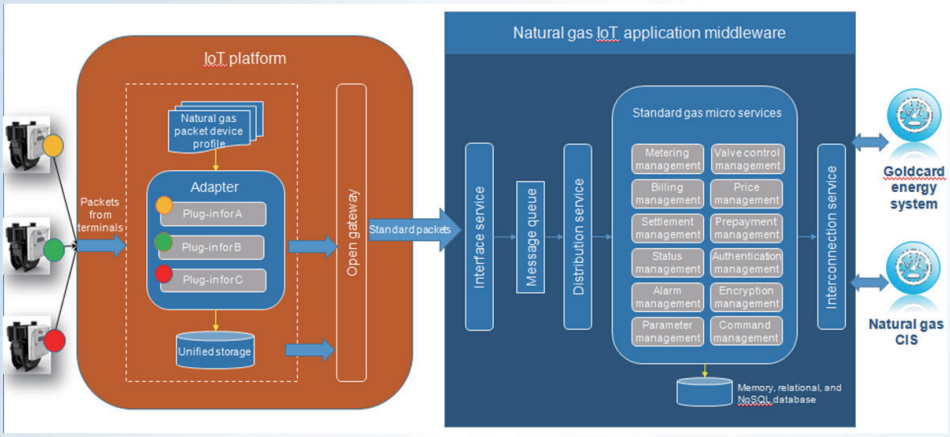


Figure 4–2 E2E integration and access solution for IoT natural gas services

In addition, the IoT platform coordinates with the NB-IoT wireless network to provide real-time command delivery, offline command delivery management, periodic and secure data reporting, and remote upgrade of devices in batches. The IoT platform only consumes half of the power consumed by traditional solutions and extends the lifecycle of devices. Economic and efficient times-based billing can be implemented to facilitate fine-grained O&M.

4.1.4 Operation Layer: Multiple smart Natural Gas Applications

Figure 4–3 Multiple smart natural gas application scenarios

IoT applications are essential for upper-layer control of IoT services. With an IoT platform, natural gas utilities can concentrate developing applications for their own industry. The smart gas application system retrieves data from the terminal layer through the IoT platform. Based on the collected data, natural gas utilities can perform customer and metering management, process billing, handle customer service, and refine management of pipeline construction, production operation, and device O&M.

4.1.5 Service Layer: Smarter, More Convenient, and More Efficient

In the IoT era, people's lives are becoming smarter, more convenient, and more efficient. The combination of IoT and smart gas changes people's experience with natural gas. With the IoT platform, users can monitor natural gas usage, review their bills, or check security data through mainstream channels such as WeChat, Alipay, Goldcard app, online customer service centers, and self-service terminals. They can also use these channels for real-time interaction with natural gas utilities, handling tasks such as rapid payment or account query.

Figure 4–4 Multi–channel support

4.2 E2E Security Defense System of NB-IoT Smart Gas

From the IoT system platform to the sensors, there are security risks everywhere. With such high expectations for the IoT market, any single risk may threaten just the core system or the entire network. Security must be taken seriously, starting with the design of the IoT architecture. An E2E security defense system must be established right at the start to ensure that the system can run reliably even when it is under attack.

4.2.1 Terminal Security: Chip, OS, and Operating Environment

Attacks on smart gas terminals may result in economic losses or even threats to personal safety. A terminal identity could be faked or the data could be tempered with. Smart gas terminals should be equipped with defenses to prevent unauthorized access. Smart gas terminal security includes chip security, operating system (OS) security, and terminal security hardening above the OS layer.

Chip security: Secure chips are preferential choices to protect gas terminal security. Chip vendors use Trusted Platform Modules (TPMs), Trusted Execution Environment (TEE), and other technologies for enhanced hardware-based encryption and isolation. These technologies provide a reliable environment and secure storage so that important keys are saved in trusted chips to prevent data leakage. Secure terminal startup is supported to protect data integrity with signature authentication before software or firmware is started or upgraded.

OS security: A secure OS is essential to the Smart Gas solution. Common lightweight IoT OS scheduling mechanisms do not differentiate between user mode and kernel mode. The same memory space is used, with all the applications and kernels running with elevated privileges, which creates various vulnerabilities for the service system. To enhance system security, a lightweight secure OS can be used. These OSs isolate the user mode from the kernel mode, and applications are isolated from each other. A lightweight secure OS can protect kernel memory and schedule kernels independently. The reliability and security of the service system are greatly improved.

Operating environment security: Lightweight, easy-to-integrate security plug-ins are used for terminal exception analysis and to encrypt communications. This protects the system from terminal intrusions and prevents attacks on key network nodes using terminals as a springboard. In addition, a secure access whitelist can be introduced to prevent unauthorized access of malicious codes.

Explosion prevention: NB-IoT-based Goldcard smart gas meters have been granted the ExibIIBT3Gb-type explosion-proof certificate by China's explosion-proof authorities. The certificate indicates terminal security during natural gas usage.

4.2.2 Network Security: Prevention of Unauthorized Access

Connecting everything means the IoT network will have to support a wide range of services and an enormous amount of traffic. The NB-IoT-based smart gas solution makes full use of NB-IoT's transmission features at the physical layer, including security features such as authentication and encryption. The solution aims to ensure the quality of the user's communications, prevent eavesdropping, and increase the difficulty of man-in-the-middle (MITM) attacks. Bidirectional authentication over the air interface, between the terminals and the network, is based on wireless standards that ensure only authorized terminals can access a given network. A secure channel is established between the terminal and the network to provide encryption and integrity protection for terminal data. This prevents data from being leaked or transmission content from being tampered with or eavesdropped on.

China Telecom's IoT services are based on dedicated IoT core network NEs. These dedicated NEs are isolated from traditional networks to prevent malicious cyberattacks. This helps enterprises not only control terminal access and network traffic but also isolate their intranet from the Internet, providing customers with a network that is reliable and stable. China Telecom also offers value-added IoT services, such as virtual private dial-up networks (VPDNs). They use Layer 2 Tunneling Protocol (L2TP) and Generic Routing Encapsulation (GRE) technologies to build virtual private networks for IoT customers. Virtual private networks are isolated from the rest of the Internet, but still allow IoT terminals to access an intranet.

4.2.3 Platform Security: Device Management Security and Data Security

The IoT platform security focuses on the following three aspects:

Management of IoT terminal access: The IoT terminals are key assets. They are the core value of the IoT platform. It is extremely important that the platform manages security for the entire lifecycle of these terminals.

IoT platform security: The IoT platform has to defend itself from attacks at both the network level and the application level. Attacks at the network level can seriously affect system availability, and the open interfaces at the application layer (such as Web, southbound and northbound, and O&M interfaces) have to prevent intrusions. The network security O&M is centrally managed for the entire platform, making threats more visible so they can be identified quickly.

IoT platform data security: A massive amount of data is collected, processed, stored, and deleted on the platform. E2E data security protection and privacy protection, and southbound and northbound interface data openness have to comply with related specifications. When managing information security, the most critical of all the different aspects is the protection of personal data. A significant amount of personal data may be transmitted from distributed terminals to an IoT platform or a processing platform. The protection of personal data must be able to comply with the privacy protection laws and regulations of the various countries and regions IoT will be deployed in.

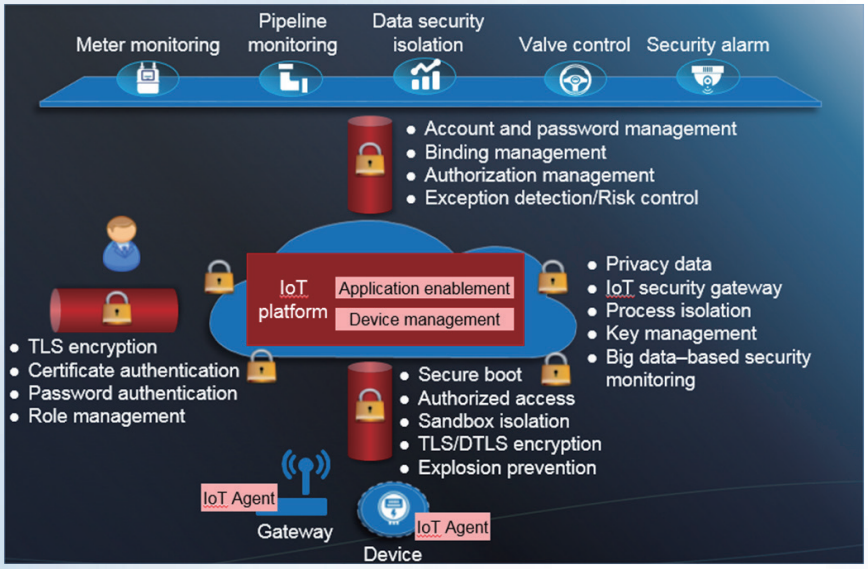


Figure 4–5 IoT platform security system

4.2.4 Application Security: Security Isolation

The IoT platform needs to be connected to different vertical applications, such as smart pipeline networks and intelligent O&M. The data security requirements for different applications differ from each other. This means that there needs to be a way to keep the different types of stored data isolated from each other. Data transmission has to be confidential and complete.

Personal data is not the only kind of data that must be isolated. The NB-IoT Smart Gas solution also provides an isolation mechanism for urban security, a very important issue for natural gas utilities. Old corroded pipelines, too much pipeline pressure or temperature, or improper use of the gas may result in tremendous physical and economic losses if there is a leak or worse, an explosion. The solution remotely monitors and collects real-time data such as the pipeline pressure and temperature, and device usage. It ensures security through valve control and by reporting alarms when there are issues.

The security of the Smart Gas solution itself is also important. Authentication and service authentication control are mandatory for cloud accesses. Otherwise, attackers can take advantage of vulnerabilities in the applications themselves to steal or otherwise tamper with the data being transmitted. Data is not just vulnerable during transmission. Data stored on your PC or mobile terminal must be isolated and encrypted too.

4.2.5 DTLS Mechanism

Smart gas meters have limited computing power, must be extremely power efficient, and must ensure metering data is secure. Therefore, in addition to E2E security, the Smart Gas solution has to consider lightweight security protocols and algorithms. The solution must carefully consider their impact on terminal power consumption.

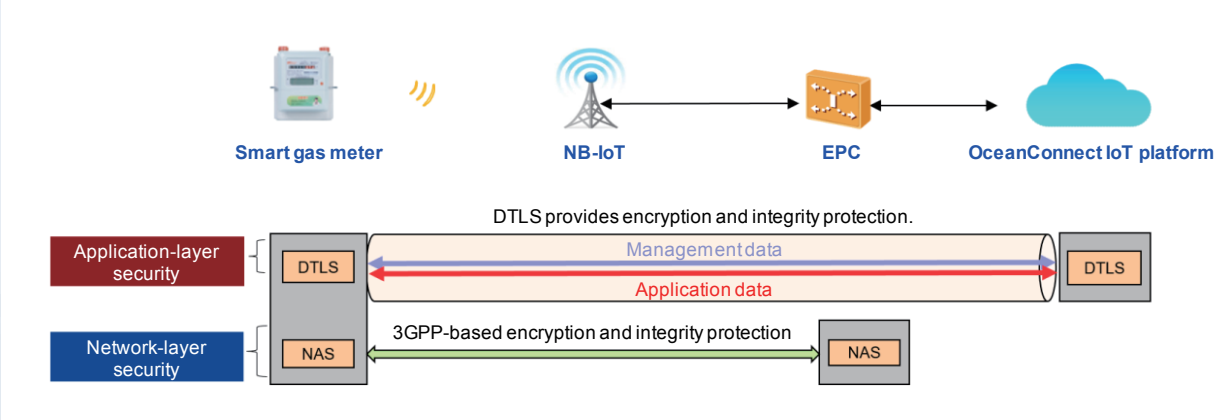


Figure 4–6 DTLS mechanism

It is recommended that the Datagram Transport Layer Security (DTLS) be used for the smart gas industry. At the network layer, all user data is transmitted on the NAS channel, and 3GPP-based encryption and integrity protection are used between smart gas meters and the EPC. At the application-layer, DTLS encryption and integrity protection are used between smart gas meters and the IoT platform or application server. A lightweight DTLS protocol has been developed for the special requirements of the smart gas industry. The power consumption and protocol processing of this lightweight protocol is better suited to the capabilities and requirements of smart gas meters. When DTLS is used:

- 3GPP-based AKA authentication is used between smart gas meters and the EPC to ensure that only authorized devices can access the network.
- 3GPP-based NAS and AS secure channels are established between smart gas meters and the EPC.
- An IPsec protected security gateway is established between the RAN and the EPC.
- DTLS/DTLS+ is used to establish secure channels between the smart gas meters and the IoT platform on the data transport layer.
- A secure transmission channel is established between the IoT platform and gas applications using the public HTTPS.

4.3 Performance Indicators of the NB-IoT Smart Gas Solution

4.3.1 Performance Model Introduction

The IoT platform and Goldcard IoT-based smart gas application middleware are integrated using application-layer APIs. Various smart devices for civil, industrial, commercial, and site use can be centrally managed and remotely controlled to meet the following management requirements:

- Multiple payment modes: Prepaid and postpaid
- Multiple settlement modes: Metered and back-end
- Multiple valve control modes: None, charge-based, and flow-based
- Multiple telecontrol methods: Concentrator, DTU, and IoT meter
- Multiple encryption methods: Integrity protection and confidentiality protection

The Smart Gas solution makes natural gas utilities more competitive by using the IoT platform, and various NB-IoT technologies, to provide the following core functions:

Flexible plug-ins: The IoT platform allows codeless device profile plug-ins to be defined. These plug-ins make development easier, shorten the time to market, and enable multiple meters from multiple vendors to reach the market more quickly. A standard packet profile is released on the IoT platform. Different vendors can each develop their own plug-ins to convert packets form terminals into packets that have been standardized for the natural gas industry. The IoT platform reports events to the middleware (IoT-based gas applications) as internal messages. The middleware then assigns the services required to invoke standard service modules, which in turn enables related functions. The middleware uses the latest distributed application system architecture and features powerful scalability.

Device management and openness: By keeping complex protocols out of sight, and simplifying upper-layer application development, the IoT platform provides standardized interconnection services through the IoT-based gas application middleware. The IoT platform can be integrated with Goldcard's gas service management system or connected to the CIS system of third-party gas services. The IoT platform can generally manage smart devices for natural gas utilities, saving them from doing complicated work of integrating these devices. The existing CIS system can easily provide telecontrol device management without major changes.

Low power consumption: The IoT platform takes advantage of NB-IoT technologies to provide E2E periodic security reports with very little power required. Far less data needs to be exchanged; power consumption is typically reduced by 50%; and device lifecycles are extended. With instant command delivery of low power consumption, the gas applications do not have to rely on high-cost VPN tunnels or power-consuming heartbeat messages.

High performance: The IoT platform can execute commands issued from industry applications offline and the applications do not need to be synchronized before the commands can take effect, which reduces system overhead for these applications.

Remote upgrade: The IoT platform also supports remote batch upgrade, and it requires very little power to do it. The gas industry can invoke and upgrade applications remotely, on demand.

4.3.2 Key Performance Indicators

Platform performance indicators: The growing number of gas meters is putting more pressure on the system. More meters means the system needs to be handle more throughput. An IoT platform can handle ten thousands of devices still able to respond in seconds. These capabilities are exactly what the natural gas industry needs for rapid growth and development. These capabilities are necessary for economic success.

Application performance indicators:

- Concurrent processing: The collection platform has an optimized system architecture, one that make use of technologies like load balancing, message queuing, caching, and NoSQL. These technologies not only increase the processing capabilities of the individual servers, they also allow for infinite, horizontal, node-based expansion, an ability to support access for a massive number of devices. The entire application system has excellent concurrent processing capabilities.

- Data collection from smart gas meters: IoT devices for civil use have to support a large number of concurrent services and a low data collection frequency. If data is collected once a day, a single device takes an average of less than 30 seconds, and never more than a minute, to process the data for the entire period.

  Industrial IoT devices report data frequently but run fewer concurrent services than devices designed for civil use. In general, if data collection is performed once every five minutes, these devices also take an average of less than 30 seconds but not more than a minute to process the data for an entire period.

- Session response: Operations during a data collection period include connection setup, authentication, data transmission, back-end service processing, transaction termination, and connection release.

  For civil and industrial meters, a single meter takes up to 60 seconds to make responses during a service session period.

Overall performance indicators of the natural gas industry

- Even a weak signal is very effective.
- The meter reading success rate is over 99%.
- One-time meter reading success rate is over 99%.

4.3.3 Performance Testing

Scenario: a single-node production environment

(1) Simulate a communications period of 200 minutes a day to tests 3 million civil meters, including connection and registration, data collection, billing and settlement, balance delivery, and charge-based valve control.

(2) Simulate a high-frequency collection scenario where data is collected from 100,000 industrial meters every five minutes. The test includes connection and registration, meter reading request reception, data collection, and alarm processing.

Results:

(1) The throughput reaches 1250 transactions per second.
(2) The average response time is 640 milliseconds.
(3) The average communication time of the devices is 30 seconds.
(4) The data can be collected from the devices in less than 60 seconds.
(5) In the trial test at Shenzhen Gas, both the success rate and the accuracy of meter reading reached 100%.

5

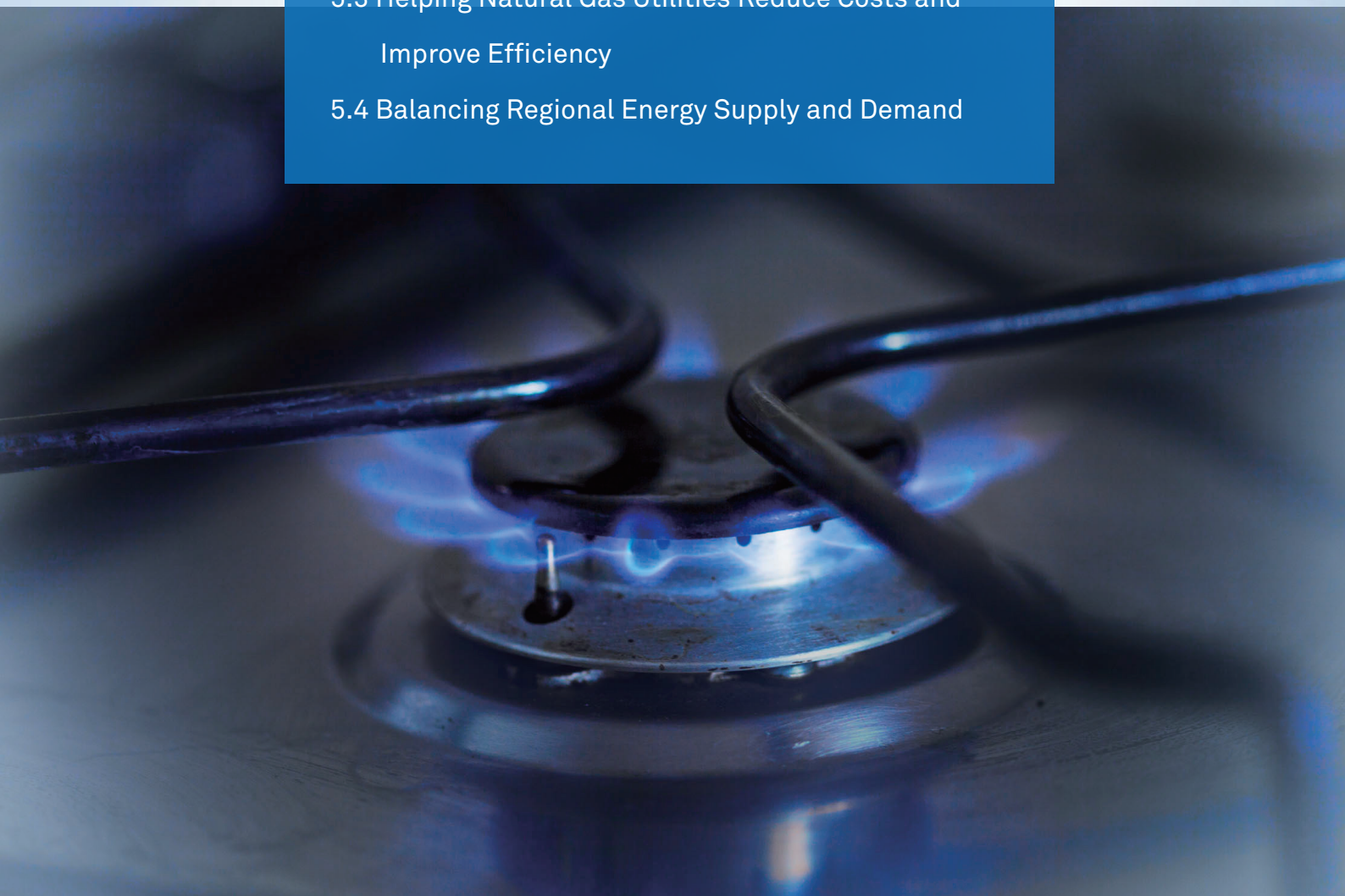
NB-IoT Smart Gas Solution Benefits

5.1 Enhancing Urban Safety

5.2 Enabling Smart Gas Services

5.3 Helping Natural Gas Utilities Reduce Costs and Improve Efficiency

5.4 Balancing Regional Energy Supply and Demand



5.1 Enhancing Urban Safety

Too much pressure in the gas lines can result in pipeline malfunctions and leakage, creating safety hazards. Inevitably, there are attempts to steal the gas, and this further increases the possibility of a disaster.

The NB-IoT-based Smart Gas solution enables over-the-air transmission and collection of data from urban gas pipelines. It ensures online monitoring of real-time pipeline data such as the pressure, flow, and temperature; and provides necessary references for production, scheduling, and management. The solution also constructs interconnected channels linking different sectors to ensure service operation in a timely manner. When a potential gas hazard is detected, the solution raises alarms, closes valves, and informs related departments when personnel need to visit a site for troubleshooting. This guarantees urban safety, reduces the cost of society management, and enhances social stability.

5.2 Enabling Smart Gas Services

The NB-IoT Smart Gas solution integrates cloud computing, big data, and the mobile Internet to provide online smart gas services. Remote meter reading allows natural gas utilities to efficiently provide precise, multi-dimensional data to residents. Residents can review billing data and make over-the-air payments at any time and from any location. Utilities can abandon traditional billing and payment methods, avoid dealing with the inconvenience of offline payment, and ultimately enhance user satisfaction and well-being. Smart gas services creates greener, smarter lives.

5.3 Helping Natural Gas Utilities Reduce Costs and Improve Efficiency

The NB-IoT Smart Gas solution enables natural gas utilities to acquire more information about the operating status of all meters. This can solve supply irregularities resulting from theft and leakage. In addition, interoperability and unified standards make maintenance and management easier. Reading the meters remotely instead of manually is more efficient, so it increases workforce productivity. Customer management, field administration, engineering management, and scheduling analysis are all improved, and customer service center and call center O&M is made easier. This solution helps natural gas utilities to reduce costs and improve efficiency, increase cash flow, and improve user interconnectivity.

Natural gas utilities can also increase enterprise profits by using value-added services and big data mining.

5.4 Balancing Regional Energy Supply and Demand

The NB-IoT-based Smart Gas solution features interoperability and precise big data analysis. By acquiring energy usage data from different regions and using intelligent scheduling, the solution can refine energy distribution, centralize the energy supply, and increase clean, low-carbon energy usage. This increases efficiency, improves coordination, and promotes sustainable development.

6

Business Model of NB-IoT Smart Gas Solution

The NB-IoT Smart Gas solution transmits data over an NB-IoT network and connects to the IoT platform where the data is transformed into a goldmine of information. It provides natural gas utilities with precise fundamental data for smart operations, helps them analyze user profiles, and produces value-added profits. This data enables users to access self-help services online, making these enterprises more interactive, which in turn improves user loyalty.

This vast sea of data considerably benefits natural gas utilities, so it has attracted their attention. However, the natural gas industry is facing new performance, security, and reliability challenges. The gas industry can use private and public clouds to meet these challenges, adapt to new market requirements, and evolve alongside the era of big data:

Private cloud: Natural gas utilities can invest in the local infrastructure and deploy an E2E solution.

Public cloud: Natural gas utilities can rent relevant services on demand to reduce one-off investment.

7

NB-IoT Smart Gas Solution Practice of Shenzhen Gas

In October 2016, Shenzhen Gas, China Telecom, Huawei, and Goldcard worked together to launch an NB-IoT-based smart gas solution pilot project.

On March 2, 2017, the world's first batch of NB-IoT gas meters manufactured by Goldcard were put into trial use. After three months of testing, the results were as follows:

- NB-IoT has obvious coverage advantages over LoRa and GPRS (5 dB and 20 dB, respectively). The power consumption of NB-IoT is almost the same as that of LoRa and much lower than that of GRPS.
- The coverage delivered in field tests was good with an average uplink rate of 13 kbps and an average downlink rate of 7.8 kbps, which is sufficient for meter reading.
- Communications services are verified on the IoT platform, including data storage, data reporting, remote valve control, remote meter reading, and remote parameter configuration, all of which meet the test case requirements.
- Service functions are verified on the gas meter reading service platform, including user registration, meter replacement, prepayment, price adjustment, communication data collection, intelligent valve control, and communication accuracy, all of which met the test case requirements.
- Other than a few exceptions such as network tuning or upgrade, the meter reading success rate was 100%. By comparing the actual readings on gas meters with the data collected by the system, the meter reading accuracy was 100%.

Building No.	Test Point	RSRP	SINR	Downlink Throughput (kbps)	Uplink Throughput (kbps)	RSRP in Metal Casing
No. 29 roof	1	−79.71	2.29	7.84	13.35	−83
	2	−76.56	5.19	8.08	13.51	−86
	3	−87.11	1.11	7.45	13.02	−90
	4	−75.18	7.47	8.23	13.66	−84
	5	−76.12	4.02	8.11	13.55	−80
	6	−76.40	4.76	8.09	13.44	−85
No. 30 roof	1	−76.30	7.35	7.27	13.87	−88
	2	−76.54	3.63	7.29	13.79	−72
	3	−72.12	9.11	8.2	11.51	−73
	4	−78.21	3.34	8.18	13.66	−82

The successful pilot project for the NB-IoT Smart Gas solution in Shenzhen was the first NB-IoT practice for the natural gas industry worldwide. NB-IoT has now been commercially deployed in the natural gas industry.

8

Trend and Prospect of Smart Gas

In the future, the Smart Gas solution will be extended to smart homes, smart communities, and smart cities. Cross-industry device management and interoperability will be based on a unified IoT platform. In addition to Smart Gas infrastructures, smart home devices of every household such as smoke detectors, audible and visual sensors, residential access control systems, and outdoor cameras; a security system for every city can all be centrally managed on the IoT platform. The IoT platform provide them with network access, interconnection, data monitoring, and lifecycle management.

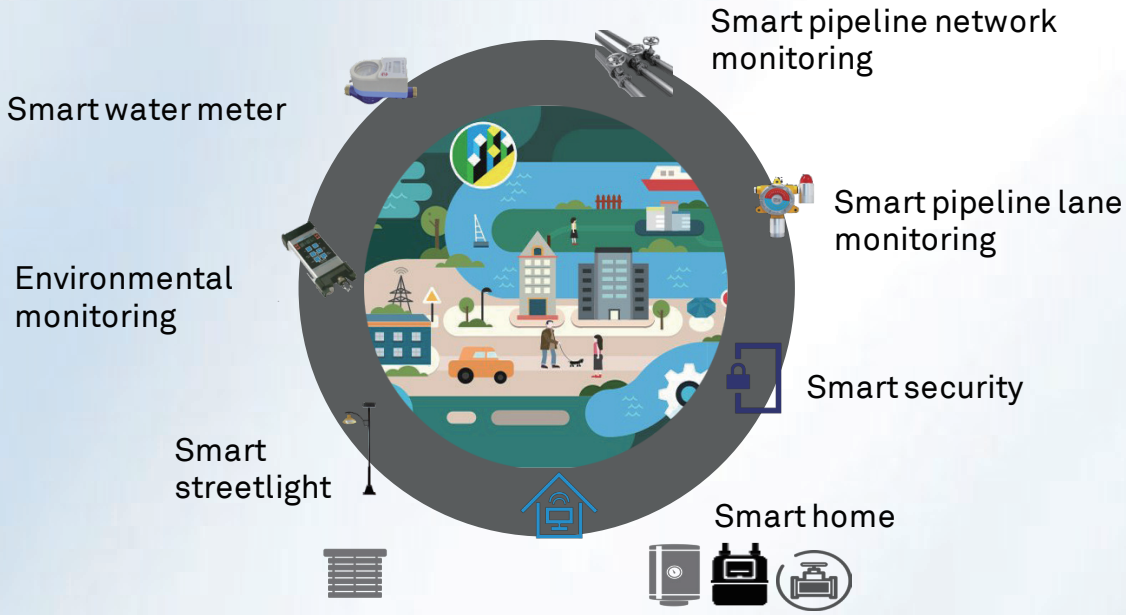


Figure 8-1 Extended ecosystem of the NB-IoT-based Smart Gas solution

9. Acronyms and Abbreviations

NB-IoT	Narrow Band Internet of Things
LPWA	Low Power Wide Area
DTU	Data Transfer Unit
SCADA	Supervisory Control And Data Acquisition
CIS	Customer Information System
OS	Operation System
TPM	Trusted Platform Module
TEE	Trusted Execution Environment
EPC	Evolved Packet Core
DTLS	Datagram Transport Layer Security
NAS	Non-access Stratum
AS	Access Stratum
IPSec	Internet Protocol Security
IaaS	Infrastructure-as-a-Service
PaaS	Platform-as-a-Service
SaaS	Software-as-a-Service
NoSQL	Not Only SQL