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An Internet of Energy Things Based on Wireless LPWAN

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ABSTRACT

Under intense environmental pressure, the global energy sector is promoting the integration of renewable energy into interconnected energy systems. The demand-side management (DSM) of energy systems has drawn considerable industrial and academic attention in attempts to form new flexibilities to respond to variations in renewable energy inputs to the system. However, many DSM concepts are still in the experimental demonstration phase. One of the obstacles to DSM usage is that the current information infrastructure was mainly designed for centralized systems, and does not meet DSM requirements. To overcome this barrier, this paper proposes a novel information infrastructure named the Internet of Energy Things (IoET) in order to make DSM practicable by basing it on the latest wireless communication technology: the low-power wide-area network (LPWAN). The primary advantage of LPWAN over general packet radio service (GPRS) and area Internet of Things (IoT) is its wide-area coverage, which comes with minimum power consumption and maintenance costs. Against this background, this paper briefly reviews the representative LPWAN technologies of narrow-band Internet of Things (NB-IoT) and Long Range (LoRa) technology, and compares them with GPRS and area IoT technology. Next, a wireless-to-cloud architecture is proposed for the IoET, based on the main technical features of LPWAN. Finally, this paper looks forward to the potential of IoET in various DSM application scenarios.

1. Introduction

Under intense environmental pressure, the global energy sector is transitioning toward clean and sustainable development. The concept of the smart grid has been widely accepted in the last decade as a means of integrating higher percentages of renewables [1,2]. In 2016, China's government announced new policies on combining the Internet with smart energy in order to demonstrate new clean energy technologies [3,4]. The government and the energy industry have recognized that the construction of an energy-Internet backbone via smart grid is the core strategy to promote a clean energy revolution for a new era.

A clean energy system requests a robust communication infrastructure that can accept greater variation from renewable energy inputs [5]. From the perspective of control theory, maximizing system observabilities enhances the system controllability. To balance a complex energy system, it is therefore necessary to obtain abundant information from both the supply and demand side. The information Internet is a reliable tool that can collect information at zero marginal cost. Nevertheless, energy systems are still restricted by closed-information environments due to management and technical issues.

Particularly on the demand side, for example, communication infrastructure is incomplete at the power distribution level [6], and even less communication infrastructure is available for utilization systems at lower voltage levels. Despite developments in the smart grid over the last decade, periphery energy networks are still out of the scope of system operators [7].

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Management is not the only problem, as technology also plays a critical role in the issue of demand-side management (DSM). The current power automation architecture was developed based on standards to satisfy the particular requirements of centralized generation and transmission systems [8]. With the rapid integration of distributed energy resources, the current design cannot meet the requirements of the fast changes that are happening on the demand side. Meanwhile, the end users do not have the expertise required to operate and maintain such complicated systems. Under these circumstances, technical complexity has become a major bottleneck restricting the acceptance of DSM applications such as demand response in the real world [9,10].

To overcome this barrier, low-power wide-area network (LPWAN) is a new solution in the context of a wireless breakthrough in the communication sector. Unlike WiFi and ZigBee, LPWAN enables massive wireless connections covering long distances with minimum power consumption and maintenance [11]. Two representative technologies of LPWAN are the narrow-band Internet of Things (NB-IoT) [12] and Long Range (LoRa) technology [13]. The NB-IoT is inherited from cellular communication, and seamlessly works on the existing global system for mobile (GSM) and long term evolution (LTE) networks in licensed frequency bands [14]. Many telecom operators have been ambitiously working on weaving together city-scale Internet of Things (IoT) networks based on NB-IoT. In contrast, LoRa technology operates in the unlicensed frequency band, so that end users are free to build up LoRa gateways that are similar to house-owned WiFi routers. Therefore, LoRa technology is perfect for outlying regions without cellular network coverage, or for establishing private networks with specific requirements for quality and security [15].

LPWAN provides a practical and economical way of establishing IoT networks. This paper presents the potential of an Internet of Energy Things (IoET) based on LPWAN as a future communication infrastructure for DSM applications. First, we briefly review the technologies of NB-IoT and LoRa as the representatives of LPWAN. Next, a new architecture is proposed for the IoET to establish wireless-to-cloud connections between end devices and the cloud computing center. Finally, this paper looks forward to the potential of the IoET in various DSM application scenarios.

2. LPWAN technologies

LPWAN represents a new trend in the evolution of IoT technologies. Unlike 3G/4G or WiFi, these systems do not focus on enabling high data rates per device or on minimizing latency. Rather, the key performance metrics defined for LPWAN are energy efficiency, scalability, and coverage. Many LPWAN players have come to the market, with the two most widely accepted players being the LoRa and NB-IoT technologies. This section briefly reviews the main features of both technologies and compares them with existing telecom and IoT technologies.

2.1. LoRa technology

LoRa technology, developed by Semtech, is the most widely used technology for LPWAN in the sub-GHz unlicensed band [16]. Due to the utilization of unlicensed bands, the LoRa network is open to customers who lack authorization from radio frequency regulators. As a result, the LoRa network is easy to deploy over a range of more than several kilometers, and serves customers with minimum investment and maintenance costs.

LoRa technology has made tremendous improvements to existing technology in order to achieve its target [17,18]. The first of these is LoRa modulation based on the chirp spread spectrum (CSS) scheme, which uses broadband linear frequency-modulated pulses whose frequency increases or decreases based on the encoded information. The Shannon-Hartley theorem indicates that an increase in transmission channel bandwidth is a way to overcome a poor signal-to-noise ratio (SNR). CSS, which has been used for radar applications since the 1940s, was chosen for its inherent robustness to channel degradation mechanisms such as multipath fading, the Doppler effect, and in-band jamming interference. As a result, the maximum coupling loss (MCL) for the LoRa modulation reaches as high as 148 dB—20 dB greater than that of existing sub-GHz communications—in order to extend the coverage distance to kilometers and increase the capacity of the network. LoRa modulation features six spreading factors that result in adaptive data rates. This feature enables multiple differently spread signals to be transmitted at the same time on the same frequency channel.

The other improvement is the optimization of the LoRa network protocol for energy-limited sensors because the uplink traffic usually exceeds the amount of downlink for IoT networks. Under this environment, the LoRa technology specification has defined three modes of different data-receiving windows for different application scenarios. In addition, data encryption is supported by LoRa technology to ensure channel security by means of AES-128 encrypted key pairs.

Thus far, LoRa technology has been tested in 56 countries in demonstrations on smart meters, traffic tracking, smart appliances, and smart healthcare [19]. In the Netherlands, the telecom operator KPN has deployed a LoRa network that covers the entire country, as has SK Telecom in Korea [20]. In addition, a LoRa Alliance with more than 300 members is collaborating to define an open global standard for secure and carrier-grade LPWAN connectivity representing the different layers of an ecosystem, from chipsets, modules, devices, and gateways to network and application servers.

2.2. NB-IoT technology

NB-IoT is a new narrow-band IoT system built from existing LTE functionalities. The technology standard was announced by the 3rd generation partnership project (3GPP) in 2016, which promises to provide improved coverage for a massive number of low-throughput low-cost devices with low device power consumption in delay-tolerant applications.

NB-IoT technology makes use of narrow-band channels to provide higher sensitivity and long range at the expense of limited data rates—typically below a few hundred bits per second (bps) [21,22]. The demodulated spectrum is much wider than individual transmissions so that multiple uplinks can occur simultaneously. The base station carries the complexity to decode multiple narrow-band channels simultaneously without knowing the exact frequency of these channels. The advantages of NB-IoT technology include its enhanced indoor coverage, which is targeted at an MCL of 164 dB, and its ability to connect a massive number of low-throughput devices with an adapted data rate. As indicated by the 3GPP guideline, the design objectives of NB-IoT technology include low-cost devices, high coverage (a 20 dB improvement over the general packet radio service (GPRS)), long device battery life (more than 10 years), and massive capacity (more than 52 000 devices per channel per cell). Latency is relaxed, although a delay budget of 10 s is the target for exception reports.

In addition, NB-IoT network supports three deployment operation modes to provide flexibility based on existing cellular infrastructure [23]:

(1) Acting as a standalone and dedicated carrier. In standalone operation, NB-IoT network can be used as a replacement for one or more GSM carriers. This allows the efficient re-farming of GSM infrastructure for IoT.

(2) Acting in-band within the reserved physical resource block (PRB) of a wideband LTE carrier. Here, all communication channels