Chapter

Smart Metering in Infrastructure-Less Communication Environments and Applicability of LoRa Technology

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Abstract

Advanced-Metering-Infrastructure (AMI) is an integral part of Smart-Grids (SGs). It enables accurate consumer billing in presence of dynamic pricing, and improves efficiency and reliability of electricity distribution in presence of distributed generation. Value-added features of AMI such as diagnostics and maintenance service can identify the anomalous power consumption patterns of appliances at the end of their life cycle. Water and gas utility distribution networks in smart cities will incorporate AMI as an application of Internet-of-Things (IoT). The communication infrastructure plays a crucial role in enabling two-way communication between Smart-Meters (SMs) and the utility. AMI's bi-directional communication facility supports precise modeling of load information and data management system facilitating demand-response applications to reduce energy wastage. Researchers have investigated the role of wireless technologies in Home-Area-Networks (HANs), Neighborhood-Area-Networks (NANs) and Wide-Area-Networks (WANs) in AMI. The arrival of new Low-Power-Wide-Area-Networks (LPWANs) technologies has opened up new technology integration possibilities in AMI. However, it is essential to understand the AMI architecture, envisioned application types, network requirements, features and limitations of existing technologies to determine a technology's integration suitability in an application for smart metering technology. This chapter discusses LoRa for smart metering in infrastructure-less environments and the possible use of our multi-hop routing scheme.

Keywords: Smart-Grids, Advanced-Metering-Infrastructure, Smart-Meters, IoT, LPWANs, LoRa, Routing

1. Introduction

Advanced-Metering-Infrastructure (AMI) is an electronic system capable of providing more information than a conventional meter besides measuring energy consumption and supporting electronic communication to transmit and receive data [1]. Initially, SMs could measure the electricity used and generated, and remotely control the supply and cut-off whenever necessary. Automated monthly reads, one-way outage, tamper detection and uncomplicated load profiling were possible using one-way communication. AMI integrated two-way communication technology and upgrading SMs, including service switching, time-based rates, remote programming, power quality measure, user interface, etc. Current SMs should be capable of: (i) capturing electricity usage in a real-time and possibly distributed generation; (ii) providing local and remote meter reading; (iii) remotely controlling the meter and even cut off the supply and (iv) providing facilities to link with other commodity supply such as gas and water [2]. AMI's two-way communication system will enable some services such as collecting data related to the power grid status and the delivery of commands in the electricity distribution grid [3]. A wide array of energy resources, including renewable energy producers and mobile energy storage, can be linked and utilized by SGs' infrastructure [4]. Since non-renewable energy resources are limited, energy-efficient and effective use of renewable resources to make smart energy become crucial for social and economic developments, and the SGs are considered a key enabler for smart energy [2]. Acquiring accurate information, automated decision support and handling events in a timely fashion are required for delivering smart energy, which is not possible without SGs.

The SGs can be used for (i) improving situational awareness and operator assistance; (ii) enhancing reliability using autonomous control actions; (iii) enhancing efficiency by maximizing asset utilization; (iv) designing superior defense mechanism against malicious attacks; (iv) incorporation of renewable resources into power grids; (v) integration of different types of energy storage and other resources; (vi) bi-directional communication between the consumer and utility; (vii) enhancing market efficiency and ensuring a higher quality of service to influence an increasingly digital economy [5]. The utility companies can detect peak load demand and control them via the Demand-Response (DR) program using the load management system [6]. In the DR program, SMs enable customers to control energy use within the HANs, and act as active participants in overall grid load management [6]. The outage notification using the SG metering network helps the whole grid system efficiently respond to the power outage condition of SMs [6]. It is possible to identify the equipment, communications and processes for Electric-Vehicle's (EV) charging control [7]. Information-and-Communication-Technologies (ICT) planning approach can be combined with distributed network planning processes and tools. New business models for SGs' can be generated to support customer-side participation, increase penetration of renewable energy sources, and foster the electricity market's participation [7].

Smart metering is one of the most promising applications of IoT, foreseen by some industries and researchers. In AMI, IoT can be utilized to collect data, measure abnormality in the SGs, exchange information among SMs, monitor electricity quality and distributed energy, and analyze user consumption patterns. Interactions among users and SGs, enhancing SG services, meeting marketing demand, improving Quality-of-Service (QoS), controlling smart appliances and monitoring renewable energy sources can be made feasible in a smart home. The monitoring center in EV assistant management systems will manage car batteries, charging equipment, charging stations and optimize resources. SGs' abilities such as processing, warning, self-healing, disaster recovery, and reliability can be enhanced using the comprehensive sensing and processing abilities of IoT [8]. The extensive scale deployments of network-connected smart electricity meters in households and commercial/industrial locations represent IoT devices [9]. The forecast on a large-scale IoT network deployment indicates potential challenges such as connectivity and traffic requirements for resource-constrained wireless networks. The heterogeneous nature of traffic, e.g., static, intermittent, delay-sensitive, delay-tolerant, small or large packets, will make wireless network design more complicated. The integration of various IoT enabling technologies will be necessary to address the connectivity issue in Machine-Type-Communication (MTC). According to Ericsson, there will be 28 billion smart devices by 2021, and 15 billion of them will be connected through Machine-to-Machine (M2M) and consumer electronic devices [10]. 7 billion of those devices will be connected through cellular and LPWAN technologies.

It is essential to guarantee communication between SMs and utility companies for AMI to become an efficient and reliable SG component. Besides technical and economic considerations, issues such as customers' geographic location, population density, and reducing connectivity costs using existing communication infrastructure, especially in the last mile, will have to be considered in providing full coverage to the SMs [11]. Integration of millions of stakeholders in rural/remote areas globally requires developing last-mile telecommunication technologies. Providing cost-effective last-mile connectivity to rural areas remains a challenging issue as rural/remote areas are characteristically influenced by factors such as scattered user base, resistance to adopt new technology, and affordability. Also, economic and social disparities across regions lead to a digital divide between urban and rural/remote locations resulting in a lack of access to computing infrastructure. Several factors are crucial in determining a viable technology solution for last-mile connectivity in rural scenarios, such as geographic location, economic condition, motivation/incentive and adaptability, sustainable business framework etc. [12]. However, QoS requirement analysis of service is important in determining viable technologies in infrastructure-less environments. As an example of varying QoS requirements, two categories of services are required in Power-Wireless-Private-Network (PWPN): (i) latency tolerant services whose characteristics are low data rate and massive access devices, and (ii) the mission-critical services which require the data transmission in real-time or near real-time, such as distribution automation [13].

Due to low installation costs, the possibility of rapid deployment over wide areas, improved data rates and network capacities, increasing portions of utilities' AMI systems will rely on wireless communication technologies [3]. There is no single communication technology that can meet the requirements of all the diverse AMI deployment scenarios [3]. Narrowband transmission is more suitable than wideband transmission on the consideration of hardware cost for some SM applications that require infrequent packet transmissions [13]. In [13], almost similar performances were achieved for two popular narrowband transmission technologies, NB-IoT and LoRa but according to the authors, NB-IoT may be more suitable for the narrowband PWPN considering the cost, evolution and possibility of integration into the LTE system. According to LoRa Alliance, LoRaWAN can complement LTE variations in serving different application segments to achieve a + 20 dB gain over the legacy cellular system in providing extended network coverage [14]. LoRaWAN has been explored in the context of an SM in [15–17]. In [15], the authors found that LoRaWAN was scalable, configurable, the setup process was easy, and performed well for real-time smart metering applications. An SM prototype was developed in [16] to monitor the energy efficiency of induction motors. Enhancing the security of meter-reading systems based on LoRa technology through an improved session key management was proposed in [17].

Multi-hop wireless technologies' capabilities for routing traffic from the SMs to the Universal-Data-Aggregation-Points (UDAPs) will play an important role in ensuring full network coverage [11]. Although explored for harsh battlefield environments [18], where access to the environment may be limited with no preexisting communication infrastructure; employing relay nodes in acquiring a larger coverage area for applications with relaxed QoS requirements can be explored for similar SM application scenarios. The required number of SMs should be large enough to provide multi-hop connectivity to ensure 100% coverage when UDAP capacity is low [11]. Also, for small populations and high UDAP capacity, full connectivity to the SMs cannot be ensured unless the number of SMs is large enough to enable multi-hop connectivity [11]. Designing a routing protocol for AMI is not easy as typical SMs are resource-constrained embedded devices with limited processing power and storage capabilities. The links between the devices are generally characterized by high packet loss rates, low bandwidth, and instability due to unplanned network deployments and the use of low-power link-layer technologies [3]. Discussion on a scalable route map for AMI to achieve target coverage of SMs with a reduced cost in terms of technological resources can be found in [11], where the authors emphasized optimal routing in heterogeneous wireless networks.

SMs are integral components of SGs and future smart cities. However, there are diverse sets of requirements for various potential applications of SMs. It is important to understand different application types, varying requirements and enabling technologies for determining suitable technologies under different circumstances. LoRa technology, according to our literature review, can be considered for potential last-mile SM applications with relaxed QoS requirements. While low-cost deployment and extended network coverage are the most attractive features of LoRa technology, careful examination of SM application requirements, and coverage and transmission reliability of LoRaWAN are required. Multi-hop routing can improve certain issues in LoRaWAN such as improving energy efficiency and network coverage. Although the performance of our multi-hop routing scheme was explored for LoRa technology, its possible use in other wireless mesh and cognitive networks in improving certain parameters requires further investigation. The chapter is organized as follows: AMI architecture, applications, requirements and enabling technologies are explored in section-II. Technological features of LoRaWAN and our developed multi-hop routing scheme [19] are presented in section-II. Conclusions are drawn in Section-IV.

2. AMI and enabling technologies

The Pioneering works of Smart-Grid-Architecture-Model (SGAM) focused on (i) creating a methodology to elicit applications for future and emerging SGs and (ii) reaching a solution and a blueprint for technical architectures of future technology portfolios. The massively interconnected, complicated SG system is a complex system with the diversity, variety and scale of its constituent subsystems and a specific dynamic and alterability of its structure [7]. The SGAM acts as a reference designation system, and the three principal axes of the dimensions are: (i) value creation chain (“Domains”), (ii) automation pyramid (“Zones”) and (iii) interoperability [7]. The individual domains in the energy conversion chain can be described as: bulk generation, transmission, distribution, distributed energy resource and customer premises. The individual zones representing ICT to control the energy conversion chain can be described as the market, enterprise, operation, station, field and process. The interoperability layer includes the business layer, function layer, information layer, communication layer and component layer. SGAM allows studying the system across several domains such as electrical power systems and communication infrastructures, and in this chapter, our focus is on communication infrastructures.

2.1 AMI architecture

AMI components are a central system, two-way communication networks, data concentrators, and SMs [8]. Generally, communication in AMI can be divided into

[20]: (i) Wide-Area-Networks (WANs), (ii) Neighborhood-Area-Networks (NANs) or Meter-Local-Area-Networks (MLAN) [6] and (iii) Home-Area-Networks (HANs). The HANs provide connections among distributed energy resources, Gateways (GWs), EVs, SMs, etc., while the NANs facilitate connections for several SMs that need to send their data to the corresponding data concentrator. SMs are installed at customers' locations or other positions in SGs, which need to send data to the central system. A group of appliances, entertaining systems, lighting systems, energy storage and generation (solar, wind etc.), electric vehicles constitutes HANs where a smart meter acts as a home GW that links the HANs with the NANs [4] or in other words, transmit collected data to the utility and receive control commands from the utility [6]. The NANs contain several homes supplied by one transformer, and thus, they should carry a massive volume of data with satisfactory service requirements [8]. Data from SMs are aggregated and compressed in uplink connection, and data are relayed to SMs in downlink connection by the data concentrator. Despite increasing SMs' data transmission time, data concentrators improve the scalability and reliability of the SGs, reduce SMs' power consumption and data collision. In [6], The MLAN refers to the communication between the SMs and the data concentrator and is mainly located at (i) the energy distribution domain comprised of the data concentrators and (ii) the field area network that includes devices such as monitors, re-closers, switches, capacitors, controllers etc. The WANs provide connections among some data concentrators and the central system. SMs' data are collected, stored, analyzed and processed by the central system, which may have several components such as Meter-Data--Management-System (MDMS) [8, 6], geographic information system, outage management system, consumer information system, power quality management, and load forecasting system [8]. The communication architecture in AMI is shown in **Figure 1**.

Several proposed IoT architectures for integration into the SGs were discussed in [8]. In a three-layers-architecture, Layer-1 includes SMs, network devices, and communication protocols. Devices that are responsible for data reception at the central system constitute Layer-2, while artificial intelligent systems that provide information to decision and billing systems make up Layer-3. Some researchers recognized the three layers as the perception layer, network layer and application layer. Different types of sensors, such as GPS devices or cameras, are used in the perception/device layer. Different types of wired and wireless communication networks and the internet constitute the network layer responsible for mapping sensors' information to communication protocols [8] and delivering the mapped data to the application layer. Information received from the network layer is processed

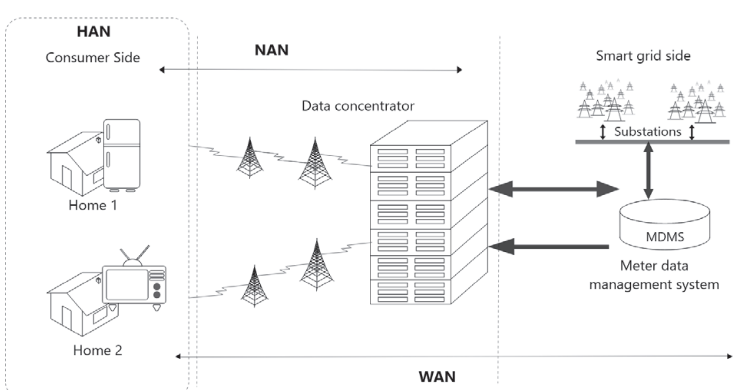

Figure 1.
AMI architecture.

by the application layer to monitor IoT devices. Some researchers proposed a four-layers-structure that included a cloud management layer and the device layer, network layer and application layer. Data storage, analysis, data and user management, etc., are performed in the cloud management layer. The device layer was further subdivided into two layers: the thing layer, which contained sensors, SMs, actuators, etc. and the gateway layer, which contained microcontrollers, communication modules, storage, etc. [8]. In another work, a four-layer model was divided into a terminal layer, filed network layer, remote communication layer, and master station system layer. Remote terminal units, SMs, etc., made up the terminal layer while different wired and wireless technologies constituted the field network layer. The control systems for generation, transmission and distribution in SGs were included in the master station system layer.

2.2 AMI requirements

Although smart metering technology opens up new possibilities, there are some specific issues, e.g., security, privacy, scalability, energy-efficiency, that need to be addressed.

Addressing the SGs' cyber-security aspect is extremely important, specifically the communication mechanisms that deal with the distribution subpart [4]. SG and smart home security were presented in [21], where the authors discussed some representative threats and evaluated theoretical impacts from smart homes to SGs and vice versa. The authors in [22] discussed data generation security, data acquisition security, data storage security, data processing security and security analytics in the SG networks and analyzed the suitability of various security analytics techniques, [23]. IoT-enabled cyber-attacks in several critical infrastructures, including SGs, were discussed in [24].

The energy consumption data collected by SMs can reveal sensitive consumer information, and thus, privacy is a key concern and a significant inhibitor of real-time data collection in practice [25]. The SMs' data can be used to invade consumers' privacy through disclosing information such as household occupancy or economic status. The authors in [6] argued that consumers' privacy could be breached at the network level as the SMs' data travels through insecure networks. Privacy was defined by information leakage rate in [26], and the impacts were explored in the context of renewable energy sources and energy storage devices. In [27], the authors quantitatively measured the information leakage of appliances' status from any reading stream and proposed a privacy-preserving streaming algorithm. Breach of privacy is a concern in IoT networks too [28].

A system's ability to gracefully handle growing amounts of work depends on effectively addressing scalability, which can be measured in various dimensions such as administrative scalability, functional scalability, geographic scalability, and load scalability [29]. AMI in SGs is an example case of a cyber-physical system, and an AMI communication infrastructure has to collect and process a massive amount of data from hundreds of thousands of SMs [29, 30]. Therefore, scalability is one of the most significant considerations for the AMI deployment in the SGs. Many deployed AMI systems collect data from SMs every 15 minutes [29]. However, more frequent communications are expected for advanced distribution automation and advanced asset management.

Communication reliability is one of AMI's fundamental blocks, particularly in the NANs, which transport traffic of varying requirements [31]. In some cases, the NANs' traffic sources such as SMs are required to collect time-based data for real-time, reliability-sensitive applications from customers. Interference and channel errors associated with IEEE 802.11 and the nature of SGs make the static multi-hop wireless mesh network a potential technology for AMI applications [31]. If a wireless mesh network is used, it must guarantee the QoS level required by respective application traffic to deliver an acceptable level of reliability and latency [31]. Determining a suitable data collection strategy and GW location in a wireless mesh network is essential to meet some SG performance requirements [32].

Green wireless communication which is essential to reduce environmental impacts of CO2 emissions from increased energy consumptions requires energy-efficient smart metering techniques in SGs [33]. ICT is responsible for 3% of energy consumption, and 2% of CO2 emission worldwide [34] and the AMI networks' energy consumption may worsen the issue [34].

2.3 AMI enabling technologies

The information flow in AMI requires communication technologies to establish and maintain the information exchange among different components. Each technology comes with its features and limitations, and integrating technology in AMI requires careful evaluation of application requirements. Organizations such as the NIST and the IEEE have been developing interoperability standards in SGs as the grid has to incorporate electrical, electronic, power electronic and networking components [35]. Three major infrastructure categories are observed in a typical telecommunication network: access network, metropolitan area network and core network [12]. The access network connects end users to the rest of the network, and it typically spans a few kilometers while the backhaul network consisting of metropolitan and core networks, connects the access network to the rest of the network. The metropolitan network covers of a few tens to a few hundreds of kilometers and the core network provides global connectivity. In the access segment, Power line communication (PLC) can be a viable solution for last-mile connectivity as it provides high-speed transmission facilities in houses or offices, and reduces the telecommunication capital expenditure [12]. Copper or fiber based wired telecommunication technologies provide higher data rates, and unlike wireless technologies, they are less susceptible to interference, signal loss, and Line-of-Sight (LOS) requirements. However, most deployments to provide last-mile broadband access in rural areas are based on wireless technologies due to their cost effectiveness, flexibility, and ease of installation, especially in challenging terrains while the backhaul connection from the wireless terminal to the core network uses wired connectivity [12].

Some technologies and their limitations for achieving last-mile connectivity have been discussed in [12]. WiFi is a mature technology due to commercialization but the IEEE 802.11 Medium-Access-Control (MAC) protocol give poor end-to-end performance for long range communication. Cellular networks can be an efficient last-mile solution for rural areas due to significant cellular penetration in many rural areas across the world and ability to provide voice as well as data connectivity. Small low-power cellular base station, called a femtocell, can be used to provide cost-effective cellular connectivity within its coverage range. LTE, a 4G cellular technology, allows high user mobility and can extend the battery life of mobile terminals. WiMAX supports broadband applications in both LOS and non-LOS (NLOS) as well as provides large coverage, and deployment of a WiMAX network is much cheaper than deployment of an LTE network for last-mile connectivity in rural areas. Low-cost connectivity alternatives which employ store and-forward networking are suitable for rural areas with minimum or no existing infrastructure and time-insensitive applications where basic data communication is more important than a large response time. Cognitive radio technologies can achieve large coverage with non-LoS links in last-mile connectivity while resolving cost-demand mismatch in rural areas utilizing unused licensed spectrum.

Narrowband power line communications and wireless communications are two leading technologies for SG applications as the overall system reliability can be enhanced by exploiting the diversity achieved from the simultaneous transmission of the same signal over power line and wireless links [35]. The Low-cost-deployment and multiple functionalities of WSNs make them an attractive technology for AMI applications, and a typical application of WSNs is remote power line monitoring. However, ensuring QoS requirements of SM applications is a challenging task for WSNs. A ZigBee-based communication for multifunctional electronic-current-transformers used in overhead and underground line monitoring was discussed in [36]. The optimized configuration of the WiGrid profile, an amended form of WiMax, was studied in [37], where the authors discussed the choice of frame duration, type-of-service to traffic mapping, scheduling strategies and the system architecture to meet the SGs' communication requirements. In the context of SMs, discussions on cognitive radio networks and satellite communications can be found in [38, 39], respectively.

SMs are typically connected to the Distribution-System-Operators (DSO) backend system using either: 1) a concentrator gathers the data from the SMs in its neighborhood using Wi-Fi or PLC connections, and then relays it using cellular or a wired connection to the DSO backend; or 2) Each SM sends data to the DSO backend using cellular network [9]. Although the concentrator based approach reduces the load of access network by aggregating data locally, it is not suitable for real-time applications [9]. Some of the wireless technologies which can be used in HANs include IEEE 802.15.4 (e.g., ZigBee and Zwave), IEEE 802.11 (WiFi) [6] etc. PLC has been the primary choice for communication between the SMs and data concentrators. However, wireless mesh networks in AMI have been proposed and deployed widely [6]. IEEE 802.16 (i.e., WiMAX), IEEE 802.20 (MobileFi), PLC, IEEE 802.11 (WiFi) and IEEE 802.15.4 (ZigBee) are some of the potential technologies for providing communication in WANs [6]. LTE as a NAN technology can transfer data to the utility in two ways: (i) using existing mobile network architecture of established mobile network operators and (ii) utilizing specialized network core architecture [4].

Technology	Frequency Band	Range	Maximum Data Rate	Channel Bandwidth
LoRa	868 MHz, 915 MHz	15 km	30 kbps	125, 250, 500 KHz
SigFox	915 to 928 MHz	20 km+	100 bps	100 Hz
INGENU-RPMA	2.4 GHz	15 km	20 kbps	1 MHz
eMTC	700–900 MHz	< 15 km	1 Mbps	1.08 MHz (1.4 MHz carrier bandwidth)
NB-IoT	700–900 MHz	< 35 km	DL: 170 kbps UL: 250 kbps	180 kHz (200 kHz carrier bandwidth)
EC-GSM-IoT	800–900 MHz	< 15 km	74 kbps (GMSK), 240 kbps (8 PSK)	0.2 MHz
Bluetooth	2.4 GHz	50 m	2 Mbps	2 MHz
ZigBee	868 MHz, 915 MHz and 2.4 GHz	Typically less than 1 km	250 kbps	2 MHz
Wi-Fi	2.4 GHz, 5 GHz	100 m	54 Mbps	22 MHz

Table 1.
Features of some wireless technologies.

The traffic profile generated by SMs can be categorized as M2M traffic as it consists of transmissions of small amounts of data from a very high number of devices [9]. Uplink communication is more challenging than downlink communication for M2M traffic for the commonly perceived application scenarios. LPWANs are considered suitable for massive IoT applications such as logistics, utilities, smart cities, consumer electronics, smart buildings, environment, agriculture and industry. LoRa, Sigfox, Ingenu Random Phase Multiple Access (RPMA), DASH-7 are some of the non-cellular-based LPWAN technologies. IEEE working group 802.11ah enhanced communication development for Bluetooth Low Energy 4.0, ZigBee and WiFi/IEEE802.11 to support short-range communication for MTC [10]. On the other hand, EC-GSM-IoT, NB-IoT, LTE Cat-M1 are cellular-based LPWAN technologies. In terms of addressing key network performance indicators, cellular-based technologies having better resources can outperform the non-cellular-based LPWAN technologies in most cases. **Table 1** summarizes some of the critical features of some enabling IoT technologies [40].

3. LoRaWAN and multi-hop routing

The communication protocol and system architecture for the LoRa networks are covered by LoRaWAN. Researchers investigated LoRaWAN from several different perspectives. Theoretical analysis of LoRaWAN scalability for European and North American bands was presented in [41, 42]. A robust physical layer in LoRaWAN ensured better scalability than pure ALOHA as some packets could be recovered under concurrent transmissions as conditions were met [43]. They claimed that packet loss depends on transmissions' timings, the Received-Signal-Strength-Indicator (RSSI) of the interferer, and the interfered transmission. However, in contrast to the notion of immunity of a particular data rate transmission from interference produced transmissions with different data rates, the authors in [44] found transmissions with different data rates in the same frequency channel could negatively impact each other. Packet delivery rate for each sensor improved as the sensors used relay nodes in the absence of direct communication between End-Devices (EDs) and the GW. The feasibility of concurrent transmission in the LoRa multi-hop network was studied in [45]. The authors in [46, 47] studied localization in LoRaWAN. The authors in [48] focused on electricity grids, where LoRa nodes were used as SMs that sent the average power demanded by their respective households during a given period. The low-cost transceivers' capability to schedule the frame transmissions, and long-term clock stability of nodes and packet forwarders were explored in [49], and the authors found LoRa networks to be suitable for IoT applications such as smart metering, smart building, and process industry.

Although LoRa is a candidate technology for last-mile coverage in applications with relaxed QoS requirements, some issues such as reliability of packet transmissions and dependence of achievable transmission range on network environments and data rates in LoRaWAN deserve attention. The node distribution scenario in LoRaWAN could be imagined by placing concentric circles around the GW, where the maximum distance supported by an SF served as the radius of each circle [50]. The authors in [51] found that Packet-Error-Rate (PER), maximum transmission distance and payload sizes are not independent factors in LoRaWAN while conducting experiments with 250-kHz-LoRa-channels. 10-bytes-payload Packets were successfully delivered with zero PER up to 8 km, while 100-bytes-payload Packets were successfully transmitted up to 6 km with near-zero PER. In one reported coverage test in [51] resulted in 2.2 km connectivity in one direction and 1.6 km in another direction with a hill in between the end-devices (EDs) and the

Gateway (GW). Placing the GW at the top of a tall building (19 floors), another reported experiment in [51] could receive packets up-to 2 km. At present, single-hop routing (i.e., direct transmission from EDs to the GW) is used in LoRaWAN for EDs-to-GW communication. It is expected that a single GW in LPWAN networks will handle several hundreds of non-rechargeable battery-powered EDs. Arbitrary node distributions in LPWAN applications make the non-uniform nature of energy consumption unavoidable as some nodes can be a few hundred meters away from the GW, while other nodes could be a few kilometers away. A significant amount of energy is consumed in packet transmission and reception, and nodes with large transmission distances become the critical nodes in the LPWANs under single-hop routing. It was argued in [19] that critical nodes, which have higher energy consumption rates compared to other nodes, are critical for network lifetime. Researchers are looking for feasible multi-hop routing schemes for extended network coverage and improving network lifetime.

Multi-hop routings in LPWANs are required to avoid complex algorithms that need huge computational facilities in EDs, to facilitate low-cost network deployment. Flexible node distribution scenarios, network connectivity, network coverage were addressed by our Extended-DRESG routing scheme [19]. Better performance in terms of energy efficiency was achieved with a multi-hop routing model over single-hop routing while maintaining a high network connectivity level. Payload aggregation in Extended-DRESG offered increased energy efficiency. Necessary calculations and decisions for routing in Extended-DRESG can be performed in the network planning stage, which is a desired feature for low-cost-network-deployment.

3.1 LoRaWAN

LoRa has two distinct layers (i) a physical layer using the Chirp-Spread-Spectrum (CSS) radio modulation technique and (ii) a MAC layer protocol (LoRaWAN). However, LoRa is widely known as a physical layer technology that utilizes a proprietary spread spectrum technique to modulate the signals in the sub - GHz ISM band [52]. The bidirectional communication in LoRaWAN is provided by the CSS technique, which spreads a narrowband input signal over a wider channel bandwidth. Transmitters generate chirp signals that vary of various frequencies over time without changing their phase between adjacent symbols. The need for expensive components to generate a stable local clock in a LoRa node is eliminated due to more uncomplicated and more accurate timing and frequency synchronization by ensuring phase continuity between different chirp symbols preamble part of the physical layer packet [10]. A severely attenuated signal several dB below the noise floor can be decoded by a distant receiver if the frequency change is slow enough to put higher energy per chirp symbol. The payload can range from 2255 octets for each transmission, and packet transmission is similar to ALOHA. LoRaWAN provides the required medium access control mechanism for communication among many EDs and GWs. LoRa MAC design aimed to mimic the IEEE 802.15.4 MAC interface to accommodate some major protocols such as 6LoWPAN and Constrained-Application-Protocol (CoAP). A good overview of LoRaWAN can be found in [52].

Three types of devices are found in a LoRa network: (i) EDs, (ii) GW(s), and (iii) LoRa network server. A star-of-stars topology is formed as EDs communicate with the GWs, using LoRa modulation following LoRaWAN and GWs forward the EDs' frames to a network server decoding and regeneration over a backhaul interface typically through Ethernet or 3G. IEEE 64bit Extended-Unique-Identifier (EUI) is used to assign IPv6 addresses to LoRa nodes. LoRaWAN ensures security by employing several layers of encryption using (i) a unique network key for the network layer, (ii) a unique application for end-to-end security at the application layer and (iii) a device-specific key for a node to join the network. EDs can be activated either via Over-TheAir-Activation (OTAA) or via Activation-By-Personalization (ABP). EDs need to be personalized first with the required information: a globally unique enddevice identifier (DevEUI), the application identifier (AppEUI) and an AES128 key (AppKey) before the OTAA process allow Eds to join the network and exchange data with the network server. LoRaWAN supports ClassA, Class-B and ClassC devices to address various application requirements and bi-directional traffic is controlled in different manners in networks utilizing different device types [10]. GW works as a bridge between end EDs and network servers. More than one GW in a LoRa network and multiple GWs can receive a single packet.

SFs, coding rate, signal bandwidth, and Adaptive-Data-Rate (ADR) are the factors that impact LoRa link design. Spread-spectrum modulation is performed by representing each bit of payload information by multiple chips of information [52]. The rate at which the spread information is sent is represented by symbol rate (RS). The ratio between the nominal symbol and chip rates defines SFs, and different SFs can send different numbers of symbols per bit of information. LoRa supports seven SFs, while SF7 to SF12 is used for uplink transmission. Four different cyclic error coding rates are supported in LoRaWAN for forward-error-detection and correction. LoRa also supports different bandwidth options for channels such as 125-kHz-LoRa-channel, 250-kHz-LoRa-channel, 500-kHz-LoRa-channel, 250-kHz-GFSK-channel. Higher signal bandwidth ensures a higher effective data rate, which reduces transmission time at the expense of receiver sensitivity. The ADR scheme allows EDs to transmit on any available channel using any available data rate, which can maximize EDs' battery life and improve network capacity. Currently, there is no time restriction on EDs or GWs for packet transmission. However, there is duty cycle (European band) and dwell time (North American band) restrictions depending on geographical locations. The Time-on-Air (ToA) is the time interval between the first bit of a message frame leaving the ED and the last bit of that message frame leaving the ED.

There are a preamble, an optional header and the data payload in a LoRaWAN packet [52]. The preamble is responsible for synchronization between the receiver and the incoming data flow. The preamble length is extendable as required by applications, while the default configuration is a 12 symbol long sequence. The receiver, which periodically restarts, undertakes the preamble detection process, and the receiver's preamble length should be configured identically to the transmitter preamble length. The maximum preamble length should be programmed on the receiver side if the preamble length is a variable or cannot be known beforehand. There are explicit and implicit header modes available in the packet header. The default mode of operation is explicit header mode, where information about the payload length, the forward error correction code rate and the presence of an optional 16 bits CRC for the payload are provided. Implicit header mode can be chosen to reduce transmission time if the payload length, coding rate and CRC presence are fixed or known in advance. The packet payload length can vary, and the payload contains the actual data coded at the error rate.

3.2 Multi-hop routing

The Extended-DRESG Scheme considered single-gateway-LoRaWAN-deployment with the GW placed at the center of the circular network coverage, and the maximum achievable transmission distance of the SX1272 transceiver is considered the radius of the circle [19]. The optimal single GW placement for constant and variable data rates was studied in [53], and the GW placement at the center of the single-gateway-LoRaWAN-deployment appeared logical and consistent with other available works. The routing scheme in [19] was evaluated for uniform node distribution. In multi-hop routing, nodes can use a different number of hops to reach the GW instead of single-hop routing. An evaluation framework evaluates the best ring-hop-combinations from R! combinations following extensive simulations, where R clusters are formed through virtual rings. The critical nodes in the optimal-ring-hop combination consume less energy than the critical nodes in any other ring. Network connectivity is an important issue that is often ignored. However, the Extended-DRESG scheme ensured at least 99% network connectivity for simulation results. The work-flow of Extended-DRESG is presented in **Figure 2**.

The total energy consumptions for nodes in different rings for different routing processes, for example-case of four-rings, were presented in **Figure 3(a)**. Among Direct-Hop (DH), Next-Ring-Hop (NRH) and Variable-Hop (VH) routings, NRH performed the worst, while VH routing can almost double the network lifetime if used of DH routing instead. The impact of the number of rings on network lifetime for different routing processes was shown in **Figure 3(b)**. When rings were placed following the 'Equidistant' distance spreading model, VH routing achieved significant energy efficiency over DH routing, for example, 96% and 67% improvements for selecting 8 and 4 rings, respectively. However, 3 or 4 virtual ring selections appear more practical considering other network-related issues. If network connectivity was not given priority, VH routing could be even more energy-efficient, reflected in **Figure 3(c)**. Also, it was shown that payload aggregation could further improve network lifetime in VH routing in **Figure 3(d)**. For the example case of four rings, network lifetime in VH routing was improved by approximately 1.67 times with payload aggregation.

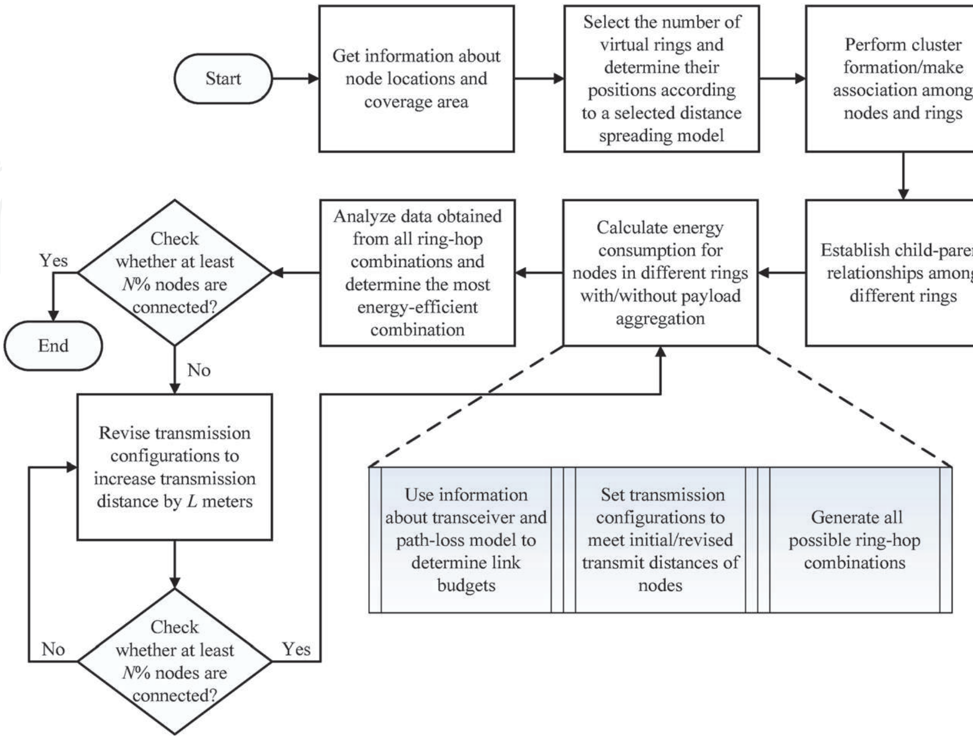

Figure 2.
Performance evaluation framework.

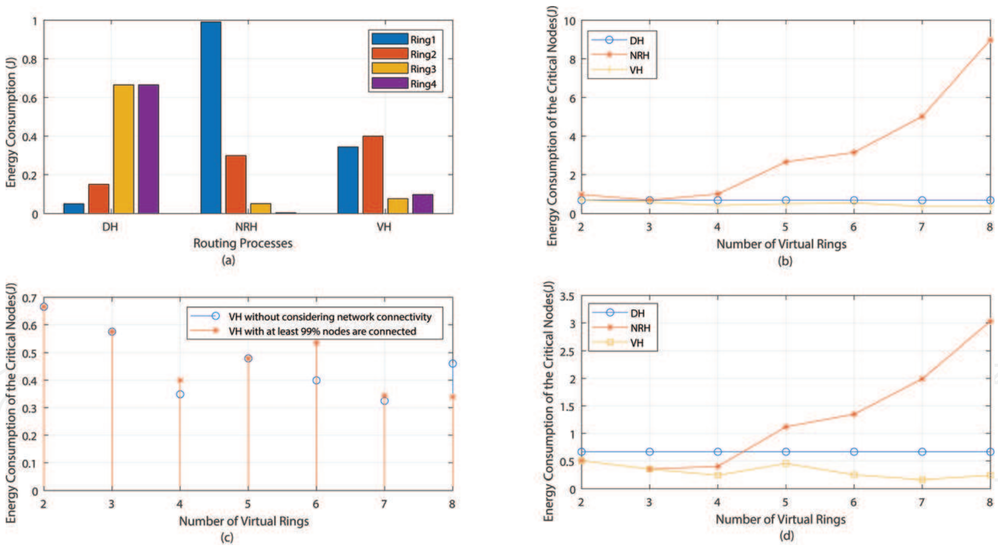

Figure 3.
Performance of extended-DRESG. (a) Energy consumption of critical nodes, (b) Impact of number of virtual rings, (c) Energy compensation to increase network connectivity and (d) Impact of payload aggregation.

4. Conclusions

This chapter discussed the communication infrastructure for AMI architecture and features of different wireless technologies in determining their suitability in HANs, NANs and WANs. Security, privacy, scalability, reliability, and energy efficiency of AMI are vital concerns in implementing smart metering technology. The suitability of wireless technologies in HANs, NANs or WANs depends on its ability to effectively address the concerning issues. Besides, the integration of smart metering technology in IoT demands exploring existing and new technologies carefully as lack of comprehensive analysis in the presence of an enormous amount of information available in literature makes the process complicated. However, technology choice may also depend on geographical locations, accessibility to existing wireless technologies, infrastructure availability, and many more. LoRa technology has been explored in detail in this chapter for its potential use in AMI. Based on our observations, LoRa can be a potential replacement where lack of appropriate infrastructure hinders using other more appropriate technologies. Several issues have been identified in the literature that will have to be addressed by LoRa technology to become more inclusive. The Extended-DRESG multi-hop routing scheme can help LoRa address some of these issues such as network lifetime, coverage and connectivity.

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Abbreviations

AMI	Advanced-Metering-Infrastructure
SGs	Smart-Grids
IoT	Internet-of-Things
SMs	Smart-Meters

HANs	Home-Area-Networks
NANs	Neighborhood-Area-Networks
WANs	Wide-Area-Networks
LPWANs	Low-Power-Wide-Area-Networks
DR	Demand-Response
EV	Electric-Vehicle
ICT	Information-and-Communication-Technologies
QoS	Quality-of-Service
MTC	Machine-Type-Communication
M2M	Machine-to-Machine
PWPN	Power-Wireless-Private-Network
UDAPs	Universal-Data-Aggregation-Points
SGAM	Smart-Grid-Architecture-Model
MLAN	Meter-Local-Area-Networks
GWs	Gateways
MDMS	Meter-Data-Management-System
WSNs	Wireless-Sensor-Networks
PLC	Power-Line-Communication
LOS	Line-Of-Sight
MAC	Medium-Access-Control
DSO	Distribution-System-Operator
RSSI	Received-Signal-Strength-Indicator
EDs	End-Devices
PER	Packet-Error-Rate
CSS	Chirp-Spread-Spectrum
CoAP	Constrained-Application-Protocol
EUI	Extended-Unique-Identifier
OTAA	Over-The-AIR-Activation
ABP	Activation-BY-Personalization
ADR	Adaptive-Data-Rate
ToA	Time-on-Air
DH	Direct-Hop
NRH	Next-Ring-Hop
VH	Variable-Hop

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