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A Review of Wireless Communication Technologies for applications in Smart Metering

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ABSTRACT

With the advancement in automation and smart systems, many problems that occur due to human error and inefficiency has been reduced prominently in different fields. In the field of power system, smart metering is a revolution to overcome problems of human inefficiency and to create awareness for consumers about their energy usage. It is possible due to Internet of Things technology under industrial revolution 4.0. This paper addresses the various aspects of different wireless communication technologies utilized in the IoT integration of smart meters and analysed the performance of these technologies on the parameters which is essential for smart metering application. In the country like India, where most of the populations are living in the rural areas and the network connectivity is still a big challenge. The installation of smart meters in various household is still in progress and various communication technologies have been used for the integration in smart meters but still we are facing many issues which are discussed in this paper. Although there are numerous review papers on wireless communication technologies, none of them have specifically addressed how to incorporate these technologies into applications for smart meters. Based on the issues and challenges associated with existing smart meters, a detailed analysis of wireless communication technologies on multiple aspects which are essential for the integration of communication technologies are discussed in this paper which can be helpful for the researchers and companies working in this area. Since not a single technology is perfect in all parameters, we found LoRaWAN- a viable option for smart metering application.

Keywords: Smart Energy Meter, Internet of Things (IoT), Wireless Communication Technologies, LoRaWAN

I. INTRODUCTION

A. General introduction about importance of Smart Meter, IoT and Wireless communication technology

The Power Grid is the network of interlinked infrastructures which transfers electricity from producers to the consumers. The conventional grid has been in place for more than 100 years, even though its basic infrastructure has not been much improved. Despite both usage of electricity and requirements have significantly expanded over the past several decades, necessitating the effective management and control of both its production and consumption on a greater scale [1]. Global energy demand rose by 4.6% in 2021 compared to 2020 [2]. A significant revolution in TEG (Traditional Electric Grid) is needed to address the issues. A TEG's technological advancement for meeting future energy demands is the Smart Grid (SG) [1], [3]. A smart grid system is an Internet of things-based system where various parameters would be monitored end-to-end and controlled for effective utilization. The SG enables real-time grid surveillance using digital technology and improved 2-way communication to recognize & react to the variations in electricity demand, revolutionizing the distribution, transmission & generating components of a TEG [4]. Smart Grids are created by connecting the parts of the electricity grids with communication networks that utilise sensors and the Internet. For power plants to monitor end-user parameters in real-time, there is an intensive development in the communication technologies. Internet of Things (IoT) is a platform, where all the users can relate to the power plant and their real – time parameters can be monitored by using internet

[5]. The Smart Grid's most important component is the Smart meter. As a substitute for conventional electricity meters, the Smart meter has been introduced. In recent times, there is a significant growth in the consumption of electrical energy due to economic development and growing population [6]. With the use of IoT-enabled smart meters, costumers may track and control their energy use [7], [8]. The Smart meter encourage substantial & affordable consumer's participation to raise end-user involvement in energy conservation [9]-[11]. Additionally, smart meters can help with a variety of objectives aimed at decreasing climatic change and supplying energy conservation. Consequently, development of smart meters has drawn significant interest [12]. These smart energy meters are implemented at households and they provide reports related to energy consumption in real – time [13-15]. The smart meter allows consumers to track energy consumption which will enable them to set usage limits & spending and at the same time, the service provider will have the forecasting data to maintain power outage, distribution, scheduling or to have the power backup based on predicted consumption. In accordance with recent trends and forecast, smart grids can save billions of dollars for generators as well as consumers [16], [17]. Demand response, real-time costing, automated measurements & applications linked to electric vehicles are examples of smart grid applications. The key to realising these applications is to adopt the suitable network topologies and communication technologies which enable bidirectional data transfers [18]. There are various range of communication technologies available which can help to implement the smart grid system such as ZigBee, GSM, RFID, cellular networks, LPWAN, GPRS, etc. Smart grid (SG) performance is primarily dependent on a system of established communications network and secure communication protocols [19].

B. Literature Survey

Since its inception, the use of electricity has expanded dramatically every decade [15]. Therefore, it is crucial to keep an eye on the electricity usage if we want to use it efficiently. This led to the development of analog electric meters. Following that, technological advancements cause the analog meter to be replaced by a digital meter. Demand for effective use of electric energy is rising along with the amount of electricity used commercially [1]. This opens a new pathway that calls for the smart energy meter (SEM). Nowadays, smart energy meter is installed in several nations throughout the world [20]. India is still installing SEM, and because of the country's diversified economic structure and enormous population, SEM's acceptability is challenging. Additionally, employing SEM presents certain technical challenges due to interference and compatibility problems because many nations utilise different communication technologies and design techniques [1].

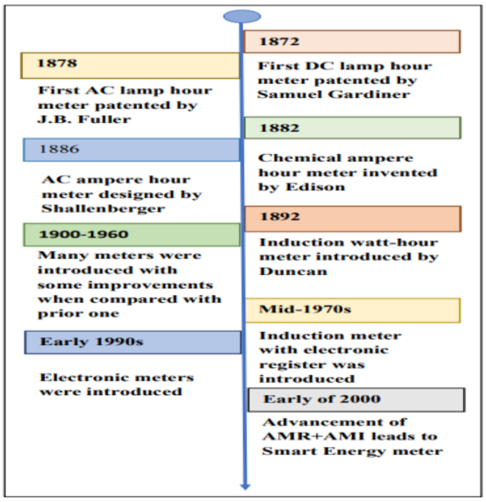

Fig. 1. Evolution of Smart Energy Meters [19]

Figure 1 shows how smart meters have been evolved. A smart meter is a basic component of AMI which collects and transmits data bidirectionally. The first smart meter was manufactured by Metretek Inc., which Theodore Paraskevakos founded in 1977. This meter was created before the internet and makes use of an IBM series 1 mini-computer [21]. Smart grid (SG) and consequently Smart meters' overall performance are largely dependent on a secure communication infrastructure and protocols. Over the years, numerous research studies on networking, security, and standards in SG communications have been undertaken. [22, 1] provided an explanation of communication architecture, functional requirements, and supporting technology. [20] gave comprehensive information on the various wired & wireless communication types in the Smart Grid. SEM is essential for the intelligent communication of SG architecture. In [23, 24, 25], the authors concentrated on SEM-related communications. The comprehensive survey [24] Liposcak. Z conducted covers both paid-for (licenced) and open-source protocols used in SEM communications. In this article, the author covered all the fundamental and important features of the wired and wireless communication protocols related to SEM. Previous work involving the wired and wireless methods for AMR was discussed by Tarek Khalifa et al. [26]. Wired communication involves the transfer of data across specific physical lines. Stefano Galli et al. [27] provided a thorough explanation of the historical background and function of PLC technologies in SG. When compared to traditional wired communications, the advantages of optical communication over other types of transmission include its higher bandwidth, low attenuation, low levels of interference, and improved signal-to-noise ratio [28]. As per [29], Digital Subscriber Line' efficiency deteriorated with distance, making it challenging to connect long-distance customers. Due to advancements in information technology, wireless communications experience great expansion in the 21st century. When compared to wired technologies, wireless technologies are thought to be a viable option because of the lower cost of cabling, ease of deployment, wider availability, and flexibility [30]. Numerous in-depth studies and surveys on wireless communication for SG have been carried out [30, 31].

C. Issues and Challenges associated with existing smart meters

Electricity has traditionally been considered as a source of growth, economic growth, even social well-being. The highest rates of electrification and energy consumption are seen in the most developed nations [32]. The demand for electricity is expected to rise by more than 2600 billion KWh by 2040 due to the growing population [33]. The transition to new power systems begins with distribution networks because they are responsible for over 90% of all power outages and disruptions [34]. Electricity metering is an essential part of distribution systems since it monitors consumer electricity usage and generates a bill that acts as a source of revenue [35]. The energy crisis has intensified and turned into a significant problem due to growing expansion and development [36]. Additionally, the main energy sources used to generate electricity, namely non-renewable ones, are becoming more and more scarce. Hence, the need of smart meters arises which not only generate real-time bills which serve as a revenue for service providers but also create awareness about the energy usage to the customers. Additionally, we can decrease energy waste and increase energy conservation. In India, the adoption of smart meters results in an overall decrease of 11–13% in both technical and commercial losses. Additionally, billing efficiency is increased by 21%. By deploying 1.1 million smart meters, India's overall revenue has been increased by INR 2640 million annually. The pre-paid meters boost Bihar's revenue by 140–150% [21]. The use of wireless technology for smart meters provides numerous benefits over wired ones, but there are challenges with each technology that must be addressed. Regarding wireless technologies, there are several common concerns that include: 1) Wireless technologies employing unlicensed spectrum are more vulnerable to interference as well as noise impacts; 2) Wireless technologies utilizing licenced spectrum are less susceptible to interference but are often more expensive. The use of pre-paid smart meters in Bihar has resulted in increase of revenue by 140-150% but as per [37], the customers are facing issue related to increase in bills of their energy consumption. In Bihar, both distribution companies namely North Bihar Power Distribution Company Limited and South Bihar Power Distribution Company Limited were using GSM based modem in feeders, distribution transformers meters and consumer meters. It was observed that the communication of data was major issue and as a result of this, they have replaced GSM based modem by NB-IoT based modem which has given good results in terms of data communication. However, the possible reason behind [37] could be the communication issue. Whenever there is any break/interruption in communication with the server, the server does not receive any data from meter and due to this interruption, the data related to energy consumption will not also be received in the meter application. This is to be noted that the consumer is continuously consuming electricity. Hence, when the issue related to communication is resolved or service related to communication is restored, the amount proportional to energy consumed during non-communication period of their meter is suddenly deducted from their concerned wallet/account. In order to successfully integrate smart meters, we must focus on multiple factors before selecting any communication technology. Thus, this encourages the motivation behind the current review work.

D. Contributions and novelty of the present work

The integration of wireless technologies is still a big issue for successful deployment of Smart meters. Based on the survey as discussed above, recent research papers & existing issues related to communication modules presented in section 1.3, a detailed analysis of wireless communication technologies on the aspects which are essential for the integration of communication technologies in smart meter are presented.

E. Organization of present work

The remainder of this work is organized into sections. Section 2 explores the different aspects of smart metering. The detailed analysis of different communication technologies for the deployment in smart meters are presented in section 3. Section 4 compares and discuss the aspects of different wireless communication technologies required for the deployment in smart meters. Section 5 presents the conclusion at the end.

II. SMART METERING

Smart energy meters provide real-time data of energy consumption, have been implemented in many developed countries to overcome this deficiency [13]-[15]. Additionally, studies [38-40] have shown that by monitoring energy consumption in real-time, as opposed to indirect feedback i.e., monthly bills, could reduce residential energy consumption. Smart meters are an essential part of Smart Grid's communication platform. It regularly communicates all the required data to the data centre for analysis purpose [41]. A smart meter is a device that provides functions such as real-time data monitoring, an automatic data gathering, user interfaces, and power control [42]. It enables 2-way data transfer between producers & customers, improving control and effectiveness [43]. It provides real-time data consumption and enables you to control your energy use [44]. When a smart energy meters notices that the customer's maximum load demand exceeds its peak value, the customer's electrical supply is cut off [45]. Under ideal circumstances and a typical workload, the lifespan of a smart meter is 5-6 years [46], [47]. The lifespan of the smart energy meter is also shortened by anomalous energy usage, which has negative environmental effects [48].

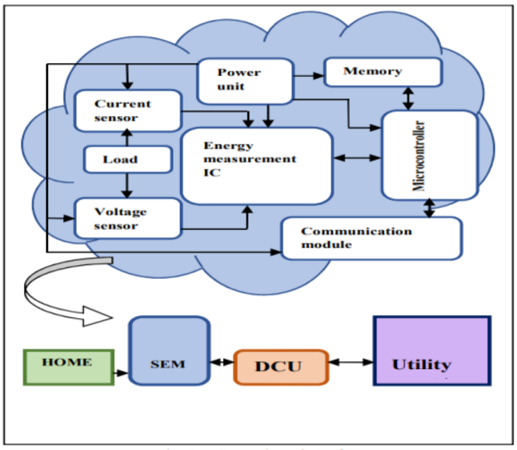

Fig. 2. General design of Smart Meter [19]

Figure 2 above shows the general design of Smart Meter in which common components of the Smart meters' design include; current sensor, voltage sensor, measuring ICs, and microcontrollers, communication system & internal memory. The voltage & current are measured by sensors correspondingly load consume & measured data feeds into energy measurement's IC for calibration purpose. Data is now sent to the microcontroller unit, that determines how transmission & reception of data are generally handled using a communication system.

III. COMMUNICATION TECHNOLOGIES

For smart grids, there are various communication-based technologies available. These technologies are classified as; wired communication and wireless communication. Wide area network, neighbourhood area network & customer premises area network are types of communication networks which can be used in smart grids [18],[49]. A smart grid's backbone communication is provided through WAN [50],[51]. Information transmission between Wide area network and client premises area networks is managed by NAN [52]. Customer premises area networks can categorise as residential, commercial/industrial area network [25]. They make it possible for customers to communicate inside their facilities [53]. WAN communication network include fibre optics, powerline communications (PLCs) & wireless media via cellular networks [22]. NAN technologies include ZigBee, wireless local area network (WLAN), PLC & a few long-distance ones like cellular and data over cable services interface specification [54]. There are several different communication technologies in use, including ZigBee, WLAN, Z-Wave & PLC [55]-[58].

A. Wireless Communication Technologies

TABLE I

SUMMARY OF LITERATURE REVIEWED RELATED TO WIRELESS TECHNOLOGIES FOR SMART METERS

Author(s) & reference no.	Year of publication	Technology name	Focus & findings
Folasade M. Dahunsi et. al [59]	2022	GSM, Wi-Fi, LoRa	Based on their power consumption, RSSI, network range, and cost, this study compared the usefulness of GSM, Wi-Fi, LoRaWAN communication modules for smart metering communication. The LoRa communication module distinguishes out as being the most energy-efficient. The GSM technology is based on the coverage provided by the Mobile Network Operator and has the largest coverage area. A properly positioned antenna can increase the LoRa module's network range, which is up to 12 kilometres between the transmitting node and the gateway as per the findings.
Amriane Hidayati et. al [60]	2019	NB-IoT	Implementation of smart meter using NB-IoT has been examined from a technical and financial perspective. Once several factors with a high degree of uncertainty have been transformed into an optimistic scenario, we can get positive outcomes from the NPV (Net present value) calculation and sensitivity analysis.
Hedi Krishna et. al [61]	2022	LoRa	LoRaWAN has become a potential connectivity option. LoRaWAN's increased range, low-power, and low-cost make it ideal for DLMS meters. Our modem design addresses the low payload issue with LoRa while still transmitting the most crucial parameters & providing the electricity providers with controls.
Yosia Bagariang et. al [62]	2020	LoRa	For improved metering infrastructure for gas, water, and electricity that might be used in urban, suburban, and rural locations, an integrated IoT architecture based on LoRa is outlined. The number of gates computed in this paper needs to be modified to the actual environment and needs in order to acquire an accurate total gateway and give consumers the best service possible.
Amit Jain et. al [63]	2019	Wired & Wireless	An AMI based on several communication technologies has been proposed. Due to the DCU's ability to communicate with more wireless smart meters than wired ones, it is excellent for apartments and areas where houses are close together.
E. Sisinni et. al [64]	2020	LoRa	In order to maximize battery utilization, by using LoRaWAN an inventive adaptive technique for equating message time-duration. The simulation findings show that a better battery utilization is feasible, resulting in 10 times increase in the number of meaningful user data bytes transferred by meters.
Imtiaz Parvez et. al [65]	2016	Zigbee & LTE	ZigBee and LTE compatibility in multi-layer networks is examined. According to the findings, the criterion for smart meter communication is satisfied by the cohabitation of LTE & ZigBee on an unlicensed 2.4 GHz band.
Lorenzo Vangelista et. al [66]	2019	LoRa & MBus	The LoRaWAN meters in this research have a substantially longer life-duration than WM-Bus meters, as shown by a measurement campaign on actual carrier-grade networks. Even though both technologies are increasing battery life with the new models, LoRaWAN meters still outperform WM-Bus meters.
Yang Yongyong et. al [67]	2020	Zigbee	A data collecting system based on ZigBee wireless technology is developed. This technology has excellent development potential and is inexpensive and very reliable.
Edgar Saavedra et. al [68]	2020	Sigfox	A self-powered smart meter that complies with Sigfox standards is presented. It is the best option for developing nations and rural locations due to the ease of installation, scenario adaptability, and low cost.
Fatma Ben Hlima et. al [69]	2020	Sigfox, LoRa, NB-IoT	The authors surveyed and compared three most promising LPWAN Technologies i.e., Sigfox, NB-IoT, LoRa and after reviewing different deployment approaches, conducted experiments on LoRa and found LoRaWAN a viable communication protocol for smart metering
Giovanni Stanco et. al [70]	2022	Sigfox, LoRa, NB-IoT	Using a single development board, authors assessed the effectiveness of Sigfox, LoRaWAN, NB-IoT in terms of energy efficiency, the no. of accurately delivered messages, and message latency. Every communication sent by Sigfox is delivered accurately, but the findings highlight the delay brought on by Sigfox Cloud. NB-IoT provides improved latency performance and satisfactory results for packet losses. In contrast, there are a no. of drawbacks with this technology that are clearly not minor. LoRaWAN is the technology with the best average and maximum latency performance.

A comprehensive survey on communication technologies for deployment in Smart Meter is presented in table 1.

The following table i.e., table 2 shows the merits and demerits of different wireless communication technologies which have been used for the implementation of smart meters.

TABLE II
MERITS & DEMERITS OF DIFFERENT WIRELESS COMMUNICATION TECHNOLOGIES [71], [72]

Technology	Protocol	Merits	Demerits
Wireless IoT technology	Zigbee	Minimal complexity, lower deployment cost, low-power consumption	low data rates, short range, interference issue
	LoRaWAN	Low power consumption, high battery life, long range, interference immunity, low-cost secure bi-directional communication	Lower data rate
	NB-IoT	Better data rate, long range, low complexity	Latency, high cost as a result of licensed spectrum
	Sigfox	High range, low-power consumption	Lower data rate, one-way communication, interference issue
Wireless Non-IoT technology	WiMAX	High data rates, long range	Distance vs. performance trade-off, expensive RF hardware, high implementation cost
	Wireless Mesh	Low cost, self-healing capability, and high data rate	Interference issue, network coverage issue

IV. DISCUSSIONS

Based on issues and challenges of existing smart meters which is presented in section 1.3, we must choose a wireless technology which can be integrated with IoT for the deployment in smart meters. There are multiple aspects such as cost, coverage range, power consumption, ease of deployment, interference, data rate, battery life, latency etc. which we must consider before finalizing any suitable wireless technology for smart meters. This to be noted that not a single technology is perfect in all parameters, we must optimally choose any technology which suits our requirements. The Low Power Wide Area Network technologies including LoRaWAN, NB-IoT, Sigfox etc. are very popular nowadays because of their multiple features which is very suitable for IoT communications. GSM based modem is also very popular for the implementation of Smart meters but network related issue and high-power consumption is the major issues associated with GSM technology used for smart meters.

According to [59], employing LoRa is the key to creating an energy-efficient smart meter which consumes low power. As compared with other competing technologies, LoRa communication modules have a very low power consumption, which results in a high battery life. Along with flexible deployment options, excellent interference immunity, operates on free unlicensed spectrum, LoRa also offers several benefits. Packets with different spreading factors while using LoRa are orthogonal, or invisible to one another and interpreted as noise by the other. Two packets arriving concurrently within the same receiving channel but with various spreading factors will not clash as a result, and the gateway modem chip will be able to demodulate both. Hence it has high interference immunity. Compared to LoRaWAN, NB-IoT is more expensive and better suited to delay-tolerant applications. It also works on licenced spectrum, which is more expensive. NB-IoT utilizes LTE cellular infrastructure and the network expansion is very expensive. Despite the low cost of the Sigfox terminals, the base station that controls and regulates the Sigfox network is more sophisticated than the equivalent component in

LoRaWAN. Interference is a big problem for Sigfox. WLAN/Wi-Fi has a very high-power consumption. LTE has a higher power consumption and higher implementation costs. Zigbee, which can connect many devices to a network but only covers a very small region.

The table 3 represents wireless technologies is compared on multiple parameters. Table 4 represents a comparison of power consumed by communication modules in different modes of power consumption.

LoRa is a strong modulation technique for long-range, low date rate, long battery life, low cost, secure bi-directional, ultra-low power wireless communication technologies. Furthermore, LoRa technology fills a gap created by the NB-IoT next-generation cellular proposal for Internet of Things applications, which has not yet attained widespread global adoption [74]. LoRaWAN employs AES encryption on two levels of security, i.e., network level and application level. The distinct device ID and two keys form the foundation of the LoRaWAN provisioning procedure. The first is the network session key, which is employed to secure communication between device & shared network server, & the second is the application session, employed to secure information exchanged between both the end node as well as application server [75]. Interoperability, which enables customers to include equipment from several manufacturers into a single system, is another advantage of LoRaWAN smart metering [76]. LoRaWAN addresses the essential IoT requirements for open interoperability amongst smart devices without requiring a complicated implementation [74]. Though LoRaWAN offers low data rate but LoRaWAN is a viable communication protocol for smart metering [69], [70], [77].

TABLE III
COMPARISON OF DIFFERENT WIRELESS TECHNOLOGIES [73]

Technology	Spectrum	Data Rate	Latency	Coverage range	Cost
Zigbee	2.4 GHz to 868-915 MHz	250 kpbs	15 milliseconds	30 to 50 meters	Low
WLAN	2.4 GHz	2 to 600 Mbps	3.2 to 17 milliseconds	100 meters (indoor)	Low
Z-wave	2.4 GHz to 868-908 MHz	9.6 to 40 kpbs	100 milliseconds	30 meters (indoor) 100 meters (outdoor)	Low
Wireless Mesh	many	Depends on selected protocols	Depends on selected protocols	Depends on deployments	High
WiMAX	2.5 GHz 3.5 GHz 5.8 GHz	75 Mbps maximum	10 to 50 milliseconds	10 to 50 km (LOS) 1 to 5 km (NLOS)	High
LoRa	868-915-433 MHz	0.3 to 50 kbps	Average 2 seconds	3 to 8 km (urban) 15 to 22 km (rural)	Low
NB-IoT	900-1800 MHz	Uplink- < 250 kbps Downlink- < 230 kbps	Less than 10 seconds	1 km (urban) 10 km (rural)	Low

TABLE IV
COMPARISON OF POWER CONSUMED BY DIFFERENT COMMUNICATION MODULES [59]

Modes of power consumption	Communication Modules		
	SIM 800L GSM Module	ESP-01 Wi-Fi Module	SX-1278 LoRa Module
Power down	60 µA	10 µA	0 µA
Sleep mode	1 mA	0.9 mA	0.2 µA
Standby mode	18 mA	15 mA	1.6 mA
Active mode	453 mA	170 mA	60 mA
Transmission burst	2 A	None	None

V. CONCLUSION

We have compared and analyzed different communication technologies on the parameters such as such as cost, coverage range, power consumption, ease of deployment, interference, data rate, battery life, latency etc. before finalizing any communication technology which can be integrated with IoT for the deployment in smart meters. Since not a single technology is perfect in all parameters, we found LoRaWAN- a viable option for smart metering application. The existing issues related to communication modules for the implementation of smart meter can be overcome using LoRaWAN. A gateway can collect data from many end nodes i.e., energy consumption of multiple users. The end nodes (smart meters) do not require any internet connection to send data to gateway i.e., our smart meters (end

nodes) are not dependent on any network or internet to transmit data. As a result, we are developing a local communication area network using LoRa, which enables us to connect with numerous nodes through a single gateway. Data collected at the gateway is then readily forwarded to the server over the internet so that data can be processed, saved, and continuously monitored. So, we require internet connection at one position only i.e., at the gateway.
LoRa based smart meters can be installed in the rural areas as well where communication network is the biggest challenge. Thus, LoRaWAN-based Smart Energy meter offers numerous cost-effective features. Furthermore, an improved LoRaWAN based communication modem can be developed in future to improve the data rate of LoRaWAN.

Competing interests

All authors declare that they have no competing financial interests.

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Author contributions/ Acknowledgments

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Md Atiqur Rahman and Jayanti Choudhary. The first draft of the manuscript was written by Md Atiqur Rahman and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. Considering the existing issue of communication breakdown in smart meters, this topic has been selected. Not a single technology is perfect in all parameters and hence, the study of all the existing wireless technologies is required to overcome this issue.

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