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A survey and bibliometric analysis of different communication technologies available for smart meters

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ABSTRACT

A smart energy meter is one of the most significant smart grid products. The smart energy meter (SEM) is an advanced energy meter that collects data from end users' load devices, monitors energy usage, and then sends the data to the smart grid. Advanced Metering Infrastructure (AMI) is used by smart energy meters to send real-time consumption data to utilities and customers. It is made possible by the Internet of Things (IoT), which expands the internet's capabilities to enable machine-to-machine or machine-to-server communication. Smart meters can communicate with each other using a variety of communication technologies. This paper presents a survey on communication technologies to determine the suitable technology based on a few parameters like cost-effectiveness, security, long-range, low power consumption, and data rate that are pre-requisite for smart meter communication. Firstly, a short literature survey is conducted to investigate the previous researches and challenges associated with communication technologies. The findings and future work of these articles are then summarized in a separate table for a clear understanding for the readers. Following that, an overview of communication technologies and their pros and cons are presented to understand critical aspects of each technology. A bibliometric analysis is also done to find the top countries, universities, and authors with greater incidence in this subject area worldwide by extracting citation data from Scopus and Web of Science. Besides, a comparison of major communication technologies is made in the discussion. Additionally, based on the parameters and literature reviewed, this paper suggests some suitable communication technologies for smart meters. It presents a model of a cost-effective hybrid communication system for smart metering and AMI. Finally, the possible issues and challenges related to communication technologies are discussed. Based on the challenges, several future research directions are also provided, which may lead to promising findings in the near future.

1. Introduction

Today, technology is being expanded and used for our convenience in our everyday lives. For simplicity, stability, saving energy, and time our life is autonomous (Karthick et al., 2021). Electricity is the nation's heart, and to save the national environment; energy should be saved. To save energy, the energy system should be smart. Whereas implementing the smart energy monitoring system requires a smart energy monitoring process (Govindarajan et al., 2019). The current system is open to error, time-consuming, and labor-intensive. Although it may be a digital form, the values received from the current system are not perfect and error-free. It is always important that an individual from the power department visit the customer's house to notice the meter data, and due to this, the chances of error are increased. Wherefore, introducing the Smart Energy Meters (SEMs) is a solution to all these problems (Santhosh et al., 2021).

A Smart Energy Meter or SEM is an electronic device used to monitor and record energy consumption and then transfer that information to a cloud server for the purpose of visualization for utilities and customers (Sreedevi et al., 2020). It also offers a bi-directional flow of information

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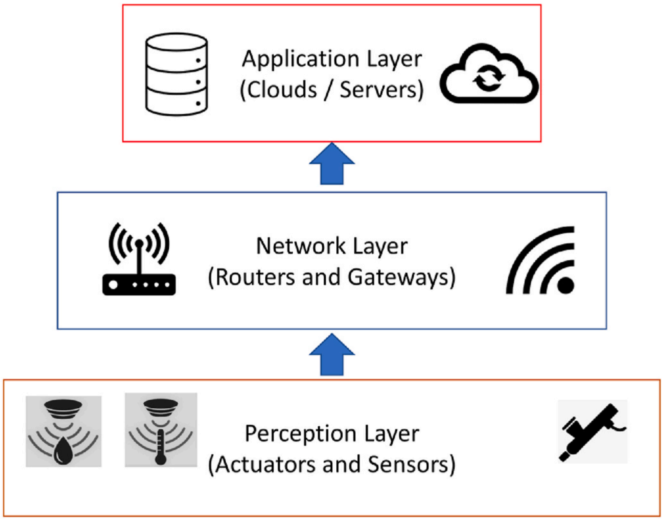

Fig. 1. Fundamental 3-layer architecture of IoT.

that delivers excellent reliability and quality between customers and utilities (Neeraj and Vasundhara, 2021). There are many other features that SEMs provide, like remote disconnection of the meter, detecting the threshold values, theft and tamper detecting, real-time pricing, accurate and automatic billing, and much more.

On the other hand, IoT is a contender to bring new services by enabling internet-based communication with intelligent objects and vice versa (Ahmed, 2021). It is fundamentally the internet-based relationship between intelligent and addressable physical objects and individuals. It has a 3-layer architecture, as shown in Fig. 1. The perception layer is where various sensor systems and actuators generate and ingest data. The network layer is the second layer, and it is responsible for the synchronization and interactions of sensor systems and actuators through participation in local and WAN (Wide Area Networks). Finally, user's request services are fulfilled by the third layer called the application layer (Kazeem et al., 2017).

On the other hand, to make a communication channel between consumer and utility, a technology was developed that is called AMR (Automatic Metering Reading), which gathers energy usage data from customer's energy meter and then sends it to a utility for billing purposes (Kumar et al., 2018). AMR meters are like traditional meters, but they automatically read the consumption details. These details are then transmitted to the utility database through wired (PLC) or wireless (GSM, ZigBee, etc.) communication or a hand-held device used to download the meter data by a utility worker. As a result, human errors caused by workers are minimized. AMR only allows one-way communication from consumer to utility. The financial condition has gradually improved over the years because the AMR system boosted billing effectiveness and lowered the resources required. In addition to billing systems, the AMR system's information does not help improve the system functionality or can be used in other applications as input, resulting in that AMR data is not real-time data (Jain and Singabhattu, 2019).

Advanced Metering Infrastructure (AMI) is an information and communications network (ICT), and it is also known as a smart metering infrastructure (Jain and Singabhattu, 2019). AMI's concept and technology have evolved since AMR was founded. Generally, AMI is more autonomous and provides real-time energy consumption surveilling as it applies a communication layer to the distribution network already in place. It does not calculate how much electricity is used but can provide information about the usage duration throughout the day. It also broadcasts price and electricity information to the customer from the utilities for analysis and consumption management (Kumar et al., 2018). A basic structure of AMR and AMI has been presented in Fig. 2.

Moreover, AMI introduces bi-directional communication between utilities and customers. This communication is done through different communication networks like HAN (Home Area Network), LAN (Local Area Network), and WAN (Wide Area Network). In this case, the customer will be conscious of his consumption habits and be informed about the tariff schemes. It has the benefit for utility companies as well that they can ask customers to change their load consumptions patterns to optimize the load curve. Its other features are auto-billing, control over customer usage, tariffs based on demand, theft identification, power quality assurance, and device failure detection (Zhang et al., 2020).

Since smart meters offers the functionality of both AMI and AMR, so, the implementation of these two technologies is also possible with the aid of IoT. To introduce the concept of IoT, we need a communication network or technology.

The following is how the rest of the paper is organized: A short literature review is presented in SECTION II. SECTION III includes methodology; SECTION IV contains discussion and SECTION V will conclude the paper.

2. Literature review

Before moving towards the brief explanation of available communication technologies for smart meters. A short literate survey of previously published surveys and review studies will be presented in this section.

A comparison on the regularly used wireless networking and

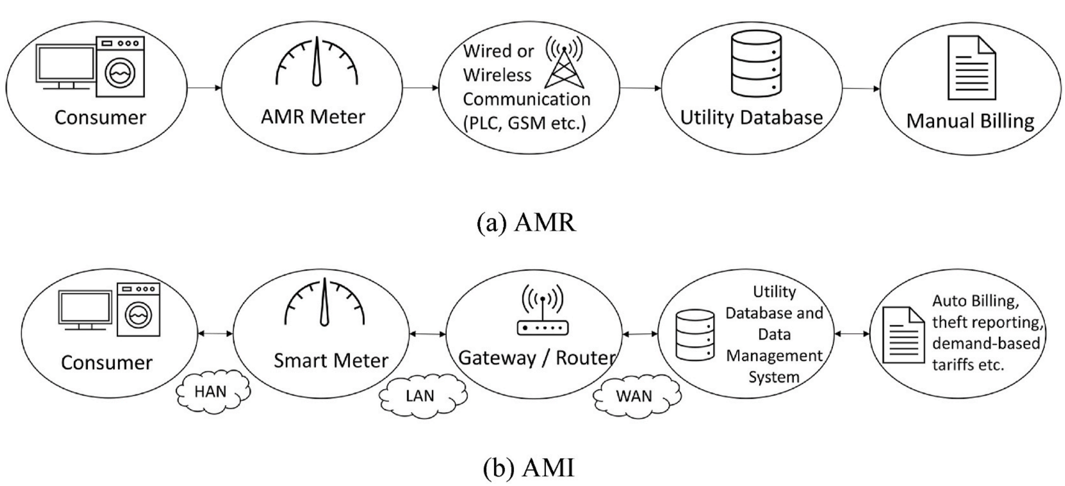

Fig. 2. Basic structure of AMR and AMI networks.

Table 1
Power consumption test results of BL, Wi-Fi, and ZigBee modules.

	Bluetooth	ZigBee	Wi-Fi
IEEE Spec	IEEE 802.15.1	IEEE 802.15.4	IEEE 802.11 b
Type of Module	HC-05	XBee Series 1	Arduino Yun
Sleeping Mode	9 μA	12 μA	30 μA
Awake Mode	35 mA	50 mA	245 mA
Transmitting Mode	39 mA	52 mA	251 mA
Receiving Mode	37 mA	54 mA	248 mA
Power Supply	3.3 V	3.3 V	5 V

Table 2
Range test findings of BL, Wi-Fi, and ZigBee modules.

Distance (m)	Signal Strength		
	Bluetooth	ZigBee	Wi-Fi
1	Very Strong	Very Strong	Very Strong
5	Strong	Very Strong	Very Strong
7	Weak	Strong	Very Strong
9	Very Weak	Strong	Very Strong
11	Unavailable	Strong	Very Strong
30		Weak	Strong
60		Very Weak	Weak
70		Unavailable	Weak
100			Unavailable

standards to promote IoT cloud development objects was done by Kazeem et al. (2017). They have mentioned four past research studies on evaluating these commonly utilized technologies. In this study, they have compared Bluetooth, ZigBee, and Wi-Fi, and their comparison was based on a few parameters like power consumption, cost, range, and topology. In sleep mode, awake mode, receive mode, and transmit mode, the power consumption of each module was tested. The ZigBee range test used the ZigBee radio module software, and the signal indicator bar was used for Wi-Fi and Bluetooth. The costs were dependent on the module's price, and topology comparisons were carried out using existing literature and device specifications.

They explained that Bluetooth requires the least energy from other networking modules used. However, when transmitting data, Bluetooth and Wi-Fi consume more power. Although ZigBee consumes more power when receiving data and consumes less when transmitting. They say that the power consumption of modules in idle mode is very similar to the of modules in active mode. When the modules are not transmitting or receiving data, they recommend putting them to sleep. The power consumption and range test were conducted, which are represented in Table 1 and Table 2. Table 1 represents that Wi-Fi consumes more current when in transmitting mode and is more petite in sleeping mode, while ZigBee and Bluetooth have less consumption than Wi-Fi. The maximum and minimum current drawn by Bluetooth is 39 mA in transmitting mode and 9 μA in sleeping mode. On the other hand, ZigBee has 54 mA consumption in Receiving mode and 12 μA in sleeping mode. So, it suggests that all modules of these devices should be put in sleep mode when not used to preserve power. From Table 2, it is evident that Wi-Fi has more range than the other two technologies mentioned. The maximum range of Wi-Fi can be 70 m, while Bluetooth and ZigBee are unavailable at 11 m and 50 m. They suggested that further experiments could be carried out in IoT applications to determine the relationship between the distance and power consumed through these modules.

Their research concludes that Bluetooth is only suitable for PAN (Personal Area Network) applications such as wearables due to its short range. Also, ZigBee supports the Mesh topology, allowing nodes to interact without the need for an AP (Access Point). As a result, it is ideal for WSN (Wireless Sensor Networks). Finally, Wi-Fi is suitable for smart home applications because wireless devices or nodes will link directly to the internet.

The following year, in India, a group of researchers (Jain and Singabhattu, 2019) experimented with developing a multi-communication-based AMI device for smart metering. They developed a system and placed various smart meters with different technologies for field experiments and a DCU. According to them, AMI can be implemented in two ways. One way is that smart meters can use cellular technologies to communicate with the HES (Head End System) or utility server. Secondly, a DCU (Data Concentrator Unit) that uses low-power communication technologies can be used by smart meters to connect with a utility server. They have developed an AMI system using a DCU to connect smart meters with utility servers in their work which is

Table 3
Communication technologies lying under each network type.

Network	Technologies	
	Wired	Wireless
HAN	Ethernet, PLC, RS-232, RS-485	ZigBee, Wi-Fi, 6loWPAN, Z-Wave, Bluetooth, NFC
FAN/ NAN	Ethernet, PLC, RS-232, RS-485, DSL	6LoWPAN, Wi-Fi, ZigBee
WAN	Optical Fiber, Ethernet	Cellular Communications, Satellite Communications

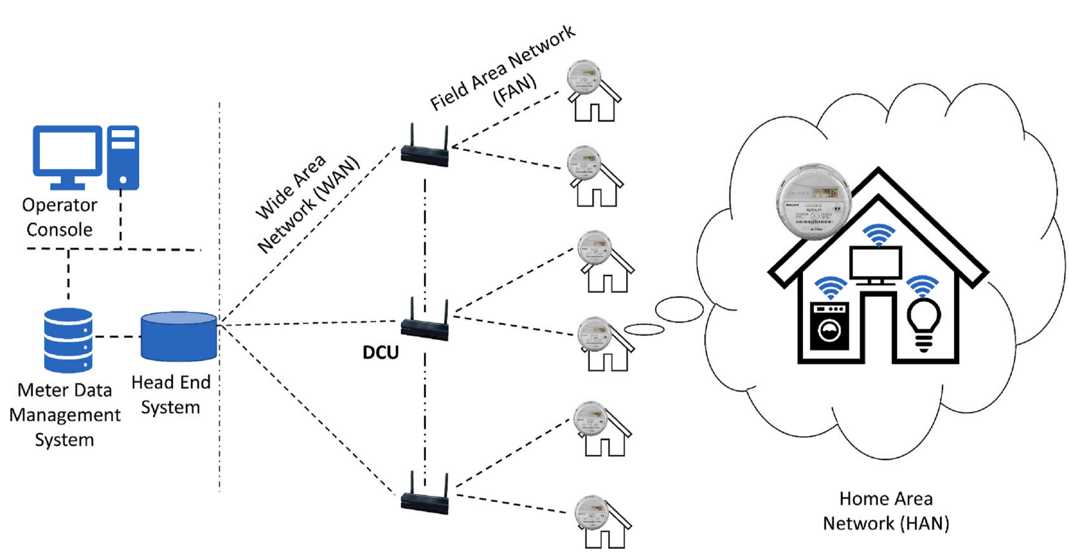

Fig. 3. Overview of advance metering infrastructure.

shown in Fig. 3. Three main types of AMI networks are presented later in their research. HAN (Home Area Network) is described as a network of devices that communicate within a home. Smart appliances, smart thermostats, smart plugs, and In-Home Displays or IHDs are common examples of HAN. Second, due to the duplex communication nature, FAN (Field Area Network) or NAN (Neighborhood Area Network) is commonly used for smart meters and DCUs or Gateways. Finally, as the electricity may be supplied to remote areas where DCUs or Gateways are far from utility control centers, WAN (Wide Area Network) is best suited. Both wireless and wired technologies lying under each network are presented in Table 3. Further, their research findings were as follows: 1) Packet losses were discovered, resulting in missing data points from wireless meters. 2) When using wireless technology, if the data rate is too high, then data throughput will suffer 3) Packet data losses were reduced even at high data rates when wire technologies were used, but DCU availability is limited since only two or three wired technology meters can be attached.

In addition, they have suggested that wireless technologies are best for homes and apartments, whereas wired technologies are best for situations where data loss is unavoidable.

Moreover, Anita and Raina (2019) evaluated the latest technologies used in smart grid communication based on the IEEE 802.15.4 standard to the SG and how they were changed to enable effective, efficient, cheap, and secure communication of the extensive real-time data from smart meters. They compared WSN, SCADA, and Cloud Computing as the communication networks in smart grids and the use of blockchain for security purposes. They concluded that the WSN for SG lowered the size, operation, and maintenance costs while increasing throughput per dollar invested. The SCADA Programme collects data, and the security of the data is secured via cross cryptographic encryption. The switch from SCADA to SG improved the power system's reliability. With the effective real-time transfer of meter readings and sensor control signals, cloud computing has proven to be suited for SG. There are no substantial architectural modifications required to convert block chain to SG. In addition, they recommend using Artificial Intelligence (AI) for scheduling DG sets and roof-top PV generation due to block chain's quick real-time data transfer.

An overview of Smart Grid enabling technologies, Smart Grid metering and communication, Smart Grid cloud computing, and Smart Grid applications was done by Dileep (2020). This study also discussed the Smart Grid's opportunities and prospects. Enabling technologies for smart grids Sensor and actuator networks, smart meters, smart sensors, car to the grid, plug-in hybrid electric vehicle technology, and smart meters are all investigated. For Smart Grid metering and communication, researchers investigated advanced metering infrastructure, intelligent electronic devices, phasor measurement units, wide-area measurement systems, local area networks, home access networks, neighborhood area networks, wide area networks, and cloud computing. Home and building automation, smart substation, and feeder automation were investigated for smart grid applications. They concluded that while it is challenging to forecast the Smart Grid's exact future, present advances demonstrate an active blending of sectors, mechanics, and communities for a single aim.

Finally, future Smart Grid research prospects were discussed. They also said that Smart Grid might be more effective in assisting environmental conservation and energy sustainability. Time-series forecasting, power quality and reliability studies, battery systems, cloud computing, power flow optimization, and renewable energy integration are all areas where the study is possible.

A study on various communication technologies used in the power system was done by Sharif et al. (2020). They reviewed modern Smart Grid (SG) communication methods based on the IEEE 802.15.4 standard to the SG and how they have been adapted to enable effective, efficient, cheap, and secure exchange of large amounts of real-time data from smart meters. They mentioned that integrating wireless communication with traditional power systems is the biggest challenge that smart grids have faced. According to them, identifying different communication technologies suitable for different system parts and ensuring data transfer security are essential requirements. They reviewed Wireless Sensor Networks (WSN), Supervisory Control And Data Acquisition (SCADA), and Cloud Computing as communication technologies for smart metering. The advantages and disadvantages of these three-communication systems were also done in this review.

They concluded that WSN for smart metering reduced the size, operation, and maintenance cost and resulted in more throughput per dollar investment. RF interference due to harsh environmental conditions, packet errors, memory and resource constraints energy, are constraints of WSNs. Besides, SCADA software can acquire data, and cryptographic encryption ensures data security. However, the investment cost for SCADA is very high. It requires skilled workers due to its complexity and limitation of specific hardware and software is a vital issue of using this system.

On the other hand, cloud computing is suitable for smart metering because it efficiently transfers meter readings and sensor control signals with assured security. However, the downtime of the network is a significant drawback, and migration from one cloud to another is a complex process and can cost more. Finally, the integration of blockchain in the smart grid does not require any major architectural changes, and the scalability of the power system can be enhanced. Wherefore, the possible research direction suggested was faster real-time data transfer using blockchain technology.

Further analysis of smart grid connectivity technologies was carried out by Gupta and Bhatia (2020). The implementation of HAN in the smart grid was a fundamental goal of this research. As a result, the available communication technologies for HAN were examined in this report. Short-range technologies are ideal for HAN implementation. HAN technologies include Bluetooth, WLAN, 6LoWPAN, Z-Wave, and ZigBee. Due to its low price, small size, and small bandwidth, ZigBee was identified as a very appropriate option for short-term applications.

However, ZigBee's drawbacks have been identified as a small battery, low data rate, limited memory, and limited processing capabilities. Moving forward, the second technology examined in this study was Wi-Fi, which is the most common technology due to the high data rate and its ability to provide internet connectivity to users via an access point. The only drawback of Wi-Fi is its high energy consumption for specific smart metering applications. Bluetooth was introduced as a fourth technology for short-range applications. It is widely used because of low power consumption, high data rate, and short-wavelength operation in ISM and industrial bands. Bluetooth has a limitation when long-distance communication is needed in HAN. 6LoWPAN, which enables IEEE 802.15.4 and IPv6 to achieve IP functionality for small electrical appliances, was also addressed. Besides this, Z-Wave is an excellent option for controlling home appliances due to its low power consumption and low data rate. Another high data rate and range with the primary purpose of achieving an overall microwave access exchange has been demonstrated. It has a 3.5 GHz and 5.8 GHz operating range with a licensed spectrum at 2.3 GHz, 2.5 GHz, and 3.5 GHz and 5.8 GHz at unlicensed spectrum. Finally, ISM-compatible LPWAN technologies were demonstrated. LPWAN technologies such as NB-IoT and LoRa are more appealing due to the requirements of available standards at no cost and a low data rate.

The findings of this study were that wireless internet access is used where broad access and vast areas are required. 6LoWPAN is common due to IP accessibility on the WLAN. ZigBee is a low-cost, low-power system with a more significant number of connections. WiMAX, LoRa, and NB-IoT are used in smart grids in NAN and WAN applications. On the other hand, wired technologies such as DSL and PLC are ideal for fast and safe communications, but their cost is very high. Future research direction by this study is to concentrate on developing better security architecture algorithms that can be modified to reduce or eliminate the interference for smart grid communication, protocols, and techniques.

A comprehensive survey was done by Abrahamsen et al. (2021).

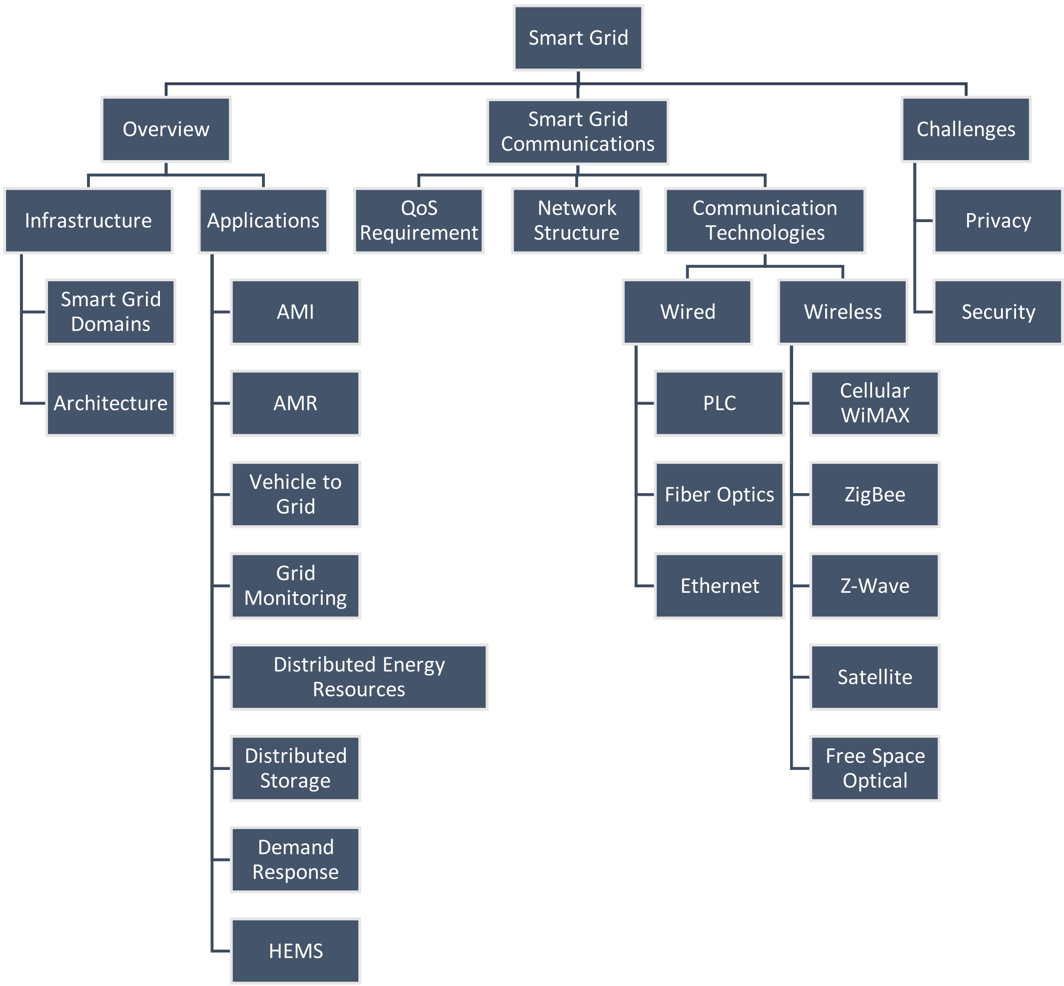

Fig. 4. Structure representing technologies reviewed, challenges, and applications.

Table 4
Communication application requirements and technologies.

Communication Network	Data Rate Requirements	Communication Technologies
HAN	Usually contains low bitrate control information	ZigBee, Wi-Fi, Ethernet, PLC
NAN	It depends on the density of nodes in the network	ZigBee, Wi-Fi, Ethernet, DSL, Cellular, PLC
WAN	It includes high-capacity devices	Ethernet, WiMAX, GSM, WLAN, Fiber Optic Cables

They present a thorough and up-to-date assessment of smart grid communication technologies, covering communication requirements, physical layer technologies, network architectures, and research issues. This survey was designed to assist readers in identifying potential research issues in the ongoing research on smart grid communication. They reviewed major communication technologies, and an overview of these technologies was presented in a separate table along with their applications, pros, cons, and network type that provide concise information to readers. The structure of this study is shown in Fig. 4 that represents the technologies reviewed, applications, challenges. The highlighted challenges with smart metering communications were robust transmission, security, and privacy. The possible security concerns were cyber-attacks that include Daniel of Service (DoS), Use of encryption, Authentication, and authorization. According to the Norwegian Electrotechnical Committee (NEK), proper encryption recommends overcoming privacy and security issues. For robust transmission, they explain that both wired and wireless communication techniques consist of important parts of smart metering and smart grid communication with its own advantages and disadvantages. Wherefore, in many cases, a hybrid communication technology mixed with wired and wireless solutions can be used to provide a higher level of system reliability, robustness, and availability.

In the same year, a general overview of area networks and communication technologies in smart grid applications was conducted by Kocak et al. (2021). This study presented the data rates, range areas, and applications of communication technologies. Communication application requirements and technologies were also presented, shown in Table 4 that summarizes data rates and communication technologies applications. Besides, the applications of smart grids, area networks, and communication infrastructure were described in depth. It has been demonstrated that these applications and the networks on which they run are critical for public services and customers to enable communication and data transmission between devices. On the other hand, device interoperability or usage of numerous technologies is necessary for the development of the SG communication technologies.

They concluded that the required scenario could be accomplished with current infrastructure without requiring additional infrastructure in these cases. They suggested that due to wide frequency range, bandwidth, data rate, and long-distance, PLC technology is the most appropriate component for smart metering and smart grid. Also, the susceptibility of other technologies to noise or damping against obstructions is a critical issue that must be investigated.

Likewise, Sharma D. K. et al. (2021) shows how several Smart Grid

Table 5
Summary of the literature reviewed.

Author	Year	Work	Findings	Future Work
Kazeem et al.,	2017	Comparison on the regularly used wireless networking and standards to promote IoT cloud development objects	• Bluetooth is only suitable for PAN • ZigBee is ideal for WSN • Wi-Fi is suitable for smart home applications	More experiments in IoT applications to determine relationship between distance and power consumed of modules
Jain and Singabhattu	2019	Experimented with developing a multi-communication-based AMI device for smart metering.	• Wireless technologies are best for homes and apartments. • Wired technologies are best for situations where data loss is unavoidable	N/A
Anita and Raina	2019	Evaluated the latest technologies used in smart grid communication based on the IEEE 802.15.4 standard	• WSN for SG lowered the size, operation, and maintenance costs while increasing throughput per dollar invested. • SCADA Programme collects data, and the security of the data is secured via cross cryptographic encryption • Cloud computing is suited for SG due to effective real-time data transfer and sensor control	Recommended to use Artificial Intelligence (AI) for scheduling DG sets and roof-top PV generation due to block chain's quick real-time data transfer.
Dileep G	2020	Presented an overview of Smart Grid enabling technologies, Smart Grid metering and communication, Smart Grid cloud computing, and Smart Grid applications	• It is difficult to forecast the Smart Grid's exact future, present advances demonstrate an active blending of sectors, mechanics, and communities for a single aim. • SG might be more effective in assisting with environmental conservation and energy sustainability	Time series forecasting, power quality and reliability studies, battery systems, cloud computing, power flow optimization, and renewable energy integration are all areas where study is possible
Sharif et al.,	2020	Study of various communication technologies used in the power system	• WSN for smart metering reduced the size, operation and maintenance cost and resulted in more throughput per dollar investment. • RF interference due to harsh environment conditions, packet errors, memory • Data acquisition can be done by SCADA software, but its cost is very high and requires skilled workers. • Data security of SCADA can be ensured by the cryptographic encryption. • Cloud computing is suitable for smart metering due to real-time data transfer and sensor control with ensured security, but downtime of network is major drawback	Faster real time data transfer with the use of blockchain technology.
Gupta and Bhatia	2020	Analysis of smart grid connectivity technologies	• Wireless internet access is used where broad access and wide areas are required. • 6LoWPAN is common due to IP accessibility on the WLAN. • ZigBee is a low-cost, low-power system with a more significant number of connections. • WiMAX, LoRa and NB-IoT can be used as NAN or WAN. • Wired technologies like DSL and PLC are ideal for fast and safe communications but their cost is higher	Concentrate on developing the better security architecture algorithms that can be modified to reduce or eliminate the interference for smart grid communication, protocols, and techniques
Abrahamsen et al.,	2021	A comprehensive survey to present a thorough and up-to-date assessment of smart grid communication technologies, covering communication requirements, physical layer technologies, network architectures and research issues	• For robust transmission they explain that both wired and wireless communication techniques consist important parts of smart metering and smart grid communication with its own advantages and disadvantages. • The highlighted challenges with smart metering communications were robust transmission, security, and privacy. • A hybrid communication technology mixed with wired and wireless solutions can be used to provide higher level of system reliability, robustness, and availability.	Use of proper encryption according to Norwegian Electrotechnical Committee (NEK) are recommend overcoming the privacy and security issues
Kocak et al.,	2021	Overview of area networks and communication technologies in smart grid application	PLC technology is the most appropriate component for smart metering and smart grid due to wide frequency range, bandwidth, data rate, and long distance.	Susceptibility of other technologies to noise or damping against obstructions is a critical issue that must be investigated
Sharma D. K. et al.,	2021	Showed how several smart grid connectivity technologies are used	Choice of technology is based on a variety of factors, including the smart Grid's network duration, data rate, protection and dependability, number of channels, available bandwidth, and so on.	N/A
Kawoosa and Prashar	2021	Review of cyber security in smart grid technology	• Adoption of new technologies with features such as two-way communication between customers and the grid has increased the risk of cyber-attacks in smart grids.	• CIA triad of the system be improved in order to identify and prevent cyber-attacks. • Developing a global uniform standard framework for safe data communication.

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Table 5 (*continued*)

Author	Year	Work	Findings	Future Work
			• Depending on the characteristics and design of the smart grid, customized design and tailor-made solutions are recommended	• Developing new protocols for smart grid applications or modifying existing ones. • Analyzing cyber-security approaches, examine data using machine learning, knowledge detection, statistical methods, and novel techniques and calculations. • Assess issues that have occurred as a result of the integration of DERs into smart grids, and to improve security by developing answers to zero-day attacks. • Provide AMI with dynamic and tailored cyber security solutions. • Cloud-based resilience, for example, has the potential to learn dynamically from prior attacks and self-heal after faults and malfunctioning.

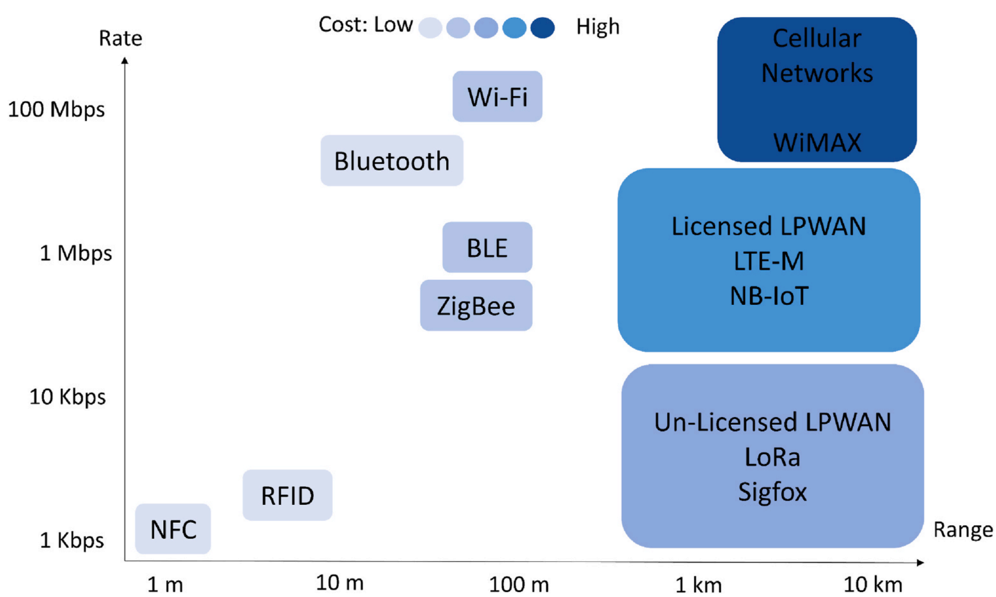

Fig. 5. Comparison of coverage and rate for wireless communication networks.

(SG) connectivity technologies are used. An overview is done to identify the characteristics of various communication technologies and a comparative analysis of communication protocols that can be used in this area, which primarily raises critical questions about smart grid technology, particularly in terms of information and communication technology ICTs. They have described a variety of wireless developments, such as WiMAX, ZigBee, and wireless meshes, as well as their benefits and limitations, compared to the intelligent network. This study provides a thorough examination of the implementation of a specific wireless technology in the context of the smart grid application spectrum. It was concluded that the choice of technology is based on a variety of factors, including the smart grid's network duration, data rate, protection and dependability, number of channels, available bandwidth, and so on.

In the same year, A review of cyber security in smart grid technology was conducted by (Kawoosa and Prashar, 2021). This report provides a complete overview of Smart Grids, including its design, methodology, and communication protocols, focusing on cyber-attacks and solutions for smart grids. They cover almost 20 research papers and reviewed the cyber-attacks and their solutions according to the principle of the CIA (Confidentiality, Integrity, Availability) triad. According to them, adopting new technologies with features such as two-way communication between customers and the grid has increased the risk of cyber-attacks in smart grids. As a result, they propose that the CIA triad

Table 6
Overview of features and characteristics of different bluetooth versions.

Features	Bluetooth 1.0	Bluetooth 2.0	Bluetooth 3.0	Bluetooth 4.0	Bluetooth 5.0
Release	1998	2005	2009	2010	2016
Range	Up to 10 m	Up to 30 m	Up to 30 m	Up to 60 m	Up to 240 m
Basic Rate (DR)	YES	YES	YES	YES	YES
Enhanced Data Rate (EDR)	NO	YES	YES	YES	YES
High Speed (HS)	NO	NO	YES	YES	YES
Low Energy (LE)	NO	NO	NO	YES	YES
Slot Availability Masking (SAM)	NO	NO	NO	NO	YES

Table 7
Comparison and key aspects of communication technologies in smart grids.

Technology	Spectrum	Data Rate	Latency	Coverage Area	Cost	Advantages	Limitations
Fiber Optics	~35,300 GHz	~40 Gbps	3.34 μs/km	~100 km	HIGH ~$28,000/km	High data rate Long range Long term stability High accuracy	Costs of network deployment are large Terminal equipment is expensive
DSL	20 kHz – 1 MHz	ADSL: 1–8 Mbps HDSL: 2 Mbps VDSL: 15–100 Mbps	10–70 ms	ADSL: ~5 km HDSL: ~3.6 km VDSL: ~1.2 km	LOW ~$50 – ~$150 Depend on provider	Does not require new wiring setup, Minimal downtime	Telecom companies will charge utilities a lot of money to use their networks
PLC	1–30 MHz	2–3 Mbps	5–7 ms	1–5 km	MEDIUM ~$13 - ~$15/module ~$1000 for SCADA system	Already Established Network, Widespread Infrastructure, Reduce installation cost	Harsh and noisy, High Maintenance Cost
ZigBee	2.4 GHz–915 MHz	250 Kbps	15 ms	30–50 m	LOW ~$20 - ~$35/module	Low cost and small size	Short range
Wi-Fi	2.4 GHz	2–600 Mbps	3.2–17 ms	100 m (indoor)	LOW ~$30 - ~$100 Depend on provider and equipment	Low cost, Vast deployment around world	High power consumption for few devices
Wireless Mesh	Various	Depend on protocol selected	Depend on protocol selected	Depend on deployment	HIGH ~$200/module for smart grid at least ~ $30,000 - ~$50,000	Better Coverage, Easy Configuration	Complex network management, High Cost, Constant Surveillance
NFC	13.56 MHz	424 Kbps	100–250 ms	10–20 cm	LOW ~$40	Low Cost	Short Range
BLE	2.4 GHz	1 Mbps	6 ms	30–10 m	LOW ~$14 - ~$18	Low Cost, Low Power Consumption	Limited Range, One-way communication
Bluetooth	2.4 GHz	1 Mbps – 3 Mbps	34 ms to 100–300 ms	10 m later versions have high range	LOW ~$5 - ~$8	Low Cost, Low Power Consumption, Offers Easy and Cheaper Monitoring	Short Range, One-way communication
RFID	433, 860–960 MHz	Up to 100 Mbps (max)	~36 ms	12 m–100 m	LOW ~$5 - ~$7	Automate Date Collection, Read multiple tags simultaneously	One-way communication
WiMAX	2.5 GHz 3.5 GHz 5.8 GHz	~75 Mbps	10–50 ms	10–50 km (LOS) 1–5 km (NLOS)	HIGH ~$25,000	High Data Rate	Implementation cost is high and Performance is affected due to weather conditions
LoRa	433, 868, 915, 923 MHz	0.3–50 kbps	Avg 2 s	8–10 km (City) ~22 km (Rural)	LOW ~$50 - ~$90	Long Range, Consume Less Power, Cost Effective	Lower Data Rate
NB-IoT	900–1800 MHz	250 kbps (Downlink) 20–66 kbps (Uplink)	Less than 10 s	35–50 km	MEDIUM ~$12/device & ~$300 - ~$1500 (data plans and SIM charges but depend on provider)	High Penetration, Long Range	Lower Data Rate and High Cost due to licensed spectrum
Sigfox	433, 868, 923 MHz	100–600 bps	200 ms	10 km (City) 40 km (Rural)	LOW ~$18/device/y (Subscription charges depend on provider)	High Range, Low power Consumption	One-way communication and Lower Data Rate, active in few countries
LTE-M (Cat-M1/M2)	1.4 MHz	1 Mbps – 7 Mbps	10–15 ms	30 km–40 km	MEDIUM ~$15/module ~$800 - ~$4000 (depend on plan and provider)	High Range, High Data Rate	Higher Cost than other LPWAN technologies

of the system be improved to identify and prevent cyber-attacks in these critical national infrastructures, which may be done by dynamically constructing a dependable and robust cyberinfrastructure in these smart grids. They also classified cyber-attacks in terms of their behavior and proposed countermeasures in order to deliver effective and dependable solutions.

They noted that, depending on the characteristics and design of the smart grid, customized design and tailor-made solutions are recommended as the task is to create a secure and resilient IT infrastructure for smart grid system communication and operations. It is recommended that embedded ICT use a bespoke security platform for secure data transfer, preventing component failure and hostile data agents from accessing the system. The challenges for researchers described in this review are as follow:

- Developing a global uniform standard framework for safe data communication.
- Developing new protocols for smart grid applications or modifying existing ones.
- Analyzing cyber-security approaches, examining data using machine learning, knowledge detection, statistical methods, and novel techniques and calculations.
- Assess issues that have occurred due to the integration of DERs into smart grids and improve security by developing answers to zero-day attacks.
- Provide AMI with dynamic and tailored cyber security solutions.
- Cloud-based resilience, for example, has the potential to learn dynamically from prior attacks and self-heal after faults and malfunctioning.

Table 8
Comparison of Wi-Fi, LoRa and NB-IoT.

Technology Parameters	Wi-Fi	LoRa	NB-IoT
Bandwidth	20–40 MHz	125 kHz	180 kHz
Coverage	100 m	10–22 km	50 km
Frequency	Un-licensed (2.4 GHz)	Un-licensed (Sub-GHz)	Licensed (Sub-GHz)
Battery Life	9–10 h	15 + y	10 + y
Power Consumption	2–20 W	0.042 W	0.14 W
Data Rate	2–600 Mbps	50 kbps	66 kbps (uplink)
Latency	3.2–17 ms	Avg 2 s	<10 s
Security	WPA2 – AES/TKIP	AES 128 Bit	3GPP (128–256 Bit)
Shield/Module	~$10	~$22.85	~$70
Technology	Non-cellular	Non-cellular	Cellular
Internet Access	Need a gateway	Need a gateway	Direct Connection
Cost Efficiency	LOW	LOW	HIGH

After individually presenting and evaluating the recent research studies on communication technologies, a summary of these studies along with their findings and future directions is presented in Table 5 below.

3. Methodology

This article is written using two different approaches. First, an overview of communication technologies is presented, allowing users to learn about each technology and easily grasp it. Following that, a bibliometric analysis is carried out to determine global trends in the field and to assess the quality of the work by gathering and evaluating data on the number of documents published by institutions, countries, research groups, and individuals with the highest scientific productivity.

3.1. Overview of communication technologies

A main feature of the realization of the Internet of Things (IoT) idea is Machine-Machine (M2M) or Machine-Server communication. It is focused on connecting different devices to the network and exchanging data between them (Challa and Reddy, 2021). There are two types of networks available for communication: (1) Wired Communication Network (2) Wireless Communication Network.

3.1.1. Wired Communication Network

The most common wired network technologies are PLC, Fiber Optics and DSL.

3.1.1.1. Power line communication (PLC). This technology allows data transmission between smart energy meters and the utilities using existing power lines. PLCs have long latencies for transmitting data than Radio Frequency (RF) technology, less bandwidth, and high cost in cities (Al-Waisi and Agyeman, 2018). The power line technology works on the power transmission lines by transmitting regulated carrier signals. Data signals will typically not spread through transformers and contact between transformers is restricted to each connected line segment (Slacik et al., 2021). The PLC signal transmitting system is rough and disruptive. PLC bandwidth is 1–30 MHz with a latency of 5–7 ms, and it has a 2–3 Mbps data rate with 1–5 km of distance coverage (Li et al., 2018). Line frequency amplitude decreased due to the line attenuation in PLC that can influence the frequency of the carrier signal. Due to weather conditions, the skin effect occurs, especially heavy frost that depending on the frequency size, changes the frequency ratio to 5:1. In addition, to receive and transmit the data through PLC, modulator and demodulator circuits are required that are costly (Li et al., 2020). PLC was ignored as a full-scale alternative for smart meters as a communication technology because several repeaters are required for a particular throughput level for utilities and smart meter communications, as well as splicing and conductor diversity in power distribution lines which also results in an expensive solution for smart meters (Mlynek et al., 2019).

3.1.1.2. Fiber-optic. It provides up to 40 Gbps of high data transfer rate, high reliability, the frequency spectrum of up to 353000 GHz, coverage range (up to 100 km), and very low latency of 3.34 μs per km. It is frequently used to transmit real-time information or huge data over long distances, and it acts as a backbone communication system. However, installing and maintaining a fiber-optics network can be costly (Li et al.,

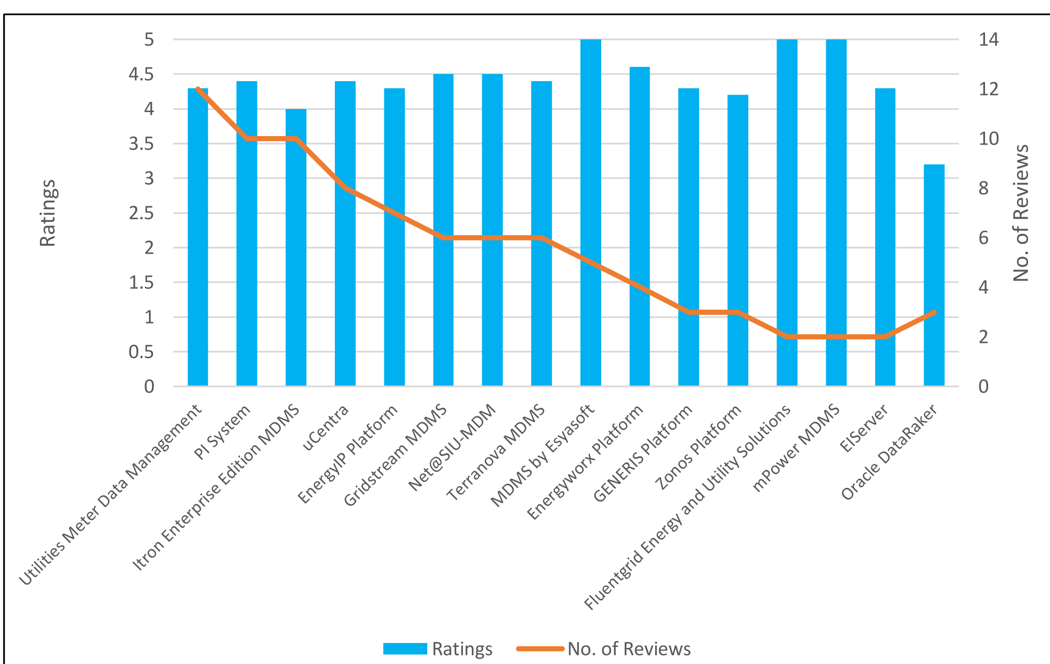

Fig. 6. Comparison of different meter data management systems.

Table 9
Energy optimization apps available for users.

App Name	Description	Platforms		
		iOS	Android	PC
Energy Consumption Analyzer	On a monthly, weekly, daily, or hourly basis, this app can calculate the average rate of usage for a home. The complete history of power use is represented on a graph. Color coding can be used to emphasize abnormally high periods, and remarks can be added to the app for future reference.	×	✓	×
CodeGreen Energy	This app uses the ENERGY STAR® score to assess the energy efficiency of thousands of buildings to see if they are following current rules.	✓	✓	×
Energy Tracker	It can track energy, water, gas, and heat consumption by managing and analyzing meter readings. It automatically recognizes dates and meter readings to generate a graphical overview of daily, monthly, quarterly, and yearly readings. It then generates a report with possible savings by comparing daily and monthly patters for up to three years.	✓	×	×
Energy Cost Calculator	It can figure out how much electric equipment and machines cost to run and how much energy they use. The app can compute the cost per day, week, month, or year, to better budget the energy bill.	✓	✓	×
Smart Thermostats	It allows to regulate the air conditioning and heating systems remotely. They can also be set to respond to changing weather conditions while monitoring the energy consumptions in real time. Nest Mobile, EnergyHub Thermostat and Ecobee Smart Thermostat are only three of the smart thermostats on the market right now.	✓	✓	×
EnergySaver	It provides precise reports on power, water, and natural gas usage. It also allows to build profiles for different times of the year so that expenditures can be tracked throughout the season. It can estimate how much it will cost to run an appliance if you want to add one. It can also detect phantom loads and make recommendations for reducing them.	✓	✓	×
Energy Monitor Pro	It connects consumers and utility providers together to reduce peak energy demand and improve grid efficiency. The comprehensive demand management system for utilities makes energy use visible, allowing you to better understand the energy usage for everything from electric vehicle to solar panels.	✓	✓	×
Light Bulb Finder	An app that allows to choose the most appropriate lighting technology according to needs. This app shows how much each lighting technology costs, how much it saves money, and how it affects the environment.	✓	✓	×
ENERGY STAR®	It is part of Environment Protection Agency (EPA) goal to assist consumers save money on energy while also protecting the environment through policy-driven appliance innovation. The website and its mobile app are a resource for making homes more energy efficient by providing information on how to get tax credits for purchasing and implementing the most energy-efficient solutions.	✓	✓	✓
Ohm Connect	It is a free service that rewards for conserving energy at specified times. The service compensates for the negative consequences of polluting power plants by alerting when to conserve energy.	×	✓	✓
Panoramic Power	It gives the real-time insights into the electrical energy consumptions at the circuit level. By monitoring and reporting excessive energy usage, the technology discovers and decreases energy and operating expense across numerous sites.	✓	✓	✓
Entronix	It provides problem detection, billing, maintenance, budgeting, and more with automatic reporting. The energy dashboard can be modified to show a variety of statistics in the form of charts, graphs, and gauges. The software can be set up to send the reports it generates by email or when certain events occur. If billing or other data being tracked goes above the predefined settings or if there is a fault, it can create alarms and notifications that can be given through text message or email.	✓	✓	✓
Hancock Software	This software has several features that help to maximize the energy savings by advertising upgrades, calculating savings, automating incentives, and receiving reimbursements for retrofitting.	✓	✓	×
Energy Watchdog	All the utility costs, including electric, natural gas, fuel oil, steam, propane, water, sewer, and even telephone is tracked, analyzed, and reported on using this app. This platform allows users to track any utility bill from any utility company with automated bills audits. Users can utilize benchmarks to identify cost-cutting possibilities, forecast usage, and identify areas where too much energy is being consumed.	×	×	✓
Gridpoint Energy Management System	It monitors energy usage during billing periods to find waste or inefficiencies to reduce electricity expenses. For a complete view of energy use in a facility, the platform provides asset-level sub-metering, monitoring, and data collection.	✓	✓	×

2018). However, if a utility company has already a framework of fiber-optics, then it can be used for smart meters due to more security and high data rate.

3.1.1.3. DSL. Digital Subscriber Line (DSL) is cited as a suitable communication technology that empowers the digital transmission of

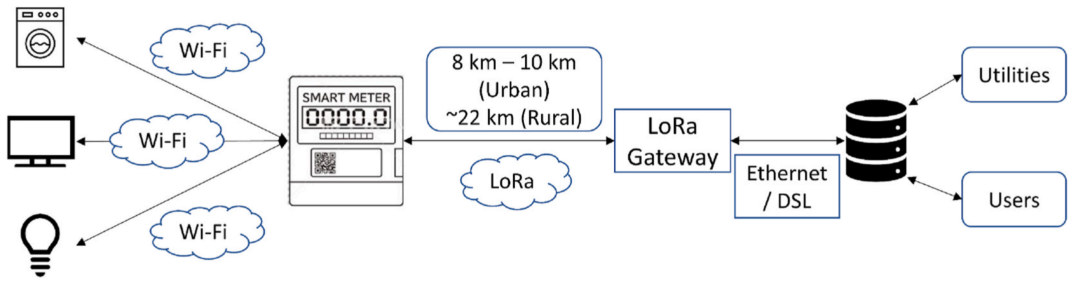

Fig. 7. Proposed model of hybrid communication Network for smart metering.

Table 10
Cost of proposed hybrid communication network.

Technology	Modules	Cost
Wi-Fi	3	~$30
LoRa	1	~$52
Ethernet/DSL	1	~$60
		Total = **$142**

data through telephone lines, which prevents the increased costs of implementing a separate communication network of electrical utilities. VDSL, HDSL, and ADSL are the three types of DSL available. DSL has a frequency range of 2 kHz to 1 MHz and a latency of 10–70 ms. Distance and efficiency for DSL, on the other hand, are inversely proportional, as three types of DSL demonstrate it. VDSL has a data rate of 15–100 Mbps and a coverage range of up to 1.2 km. HDSL and ADSL, on the other hand, have a greater coverage range of up to 3.6 km and 5 km, sequentially, but both have low data rates of 2 Mbps and 1–8 Mbps. Besides, the cost of DSL can be high as telecommunication providers can charge utilities exorbitant fees for using their networks (Li et al., 2018).

3.1.2. *Wireless communications network*

Many wireless communication systems have been developed for different applications through the advancement of Information Technology (IT). These networks are typically categorized into three main groups by distance: short (<10 m), medium (10–100 m), and long (>100 m) distance. Fig. 5 compares the coverage and rate for available wireless technologies. Short-range networking technologies for wireless applications include RFID, NFC, Bluetooth, and BLE. Two big medium-range wireless networking technologies are Wi-Fi and ZigBee. Cellular technologies (2G/3G/4G), LPWAN, WiMAX, and Wireless Mesh are long-range wireless communication technologies (Feng et al., 2019).

3.1.2.1. RFID. Radio Frequency Identification or RFID is the wireless technology most used for inventory monitoring and supply chain purposes. On goods and boxes, passive RFID tags provide logistical information that a particular handheld reader can only view up to 100 m. It operates at 433 MHz and 860–960 MHz, and it provides a data rate of up to 100 Mbps with a latency of almost 36 ms. RFID only allows single-way communication. It typically operates in the ultra-high frequency band and provides a range of up to 100 m. Due to its one-way communication and short-range it cannot be used in smart metering.

3.1.2.2. NFC. NFC stands for Near Field Communication and is a wireless protocol like RFID and Bluetooth. However, there are a few main distinctions to note. NFC can read unique tags like RFID, but these tags in NFC can be used for a nearly infinite number of applications and must be read by a regular NFC-enabled computer. It gives the data rate of 424 Kbps with a latency of 100–250 ms. It operates at 13.56 MHz frequency. Its range is almost 10 cm–20 cm, and due to this short-range, it provides security by only allowing devices to communicate within proximity of each other. Its short-range does not allow the researchers to use it for IoT projects.

3.1.2.3. Bluetooth. A wireless standard originally developed to substitute data cables is Bluetooth. It facilitates bi-directional communication within 10 m (Sharma et al., 2021). It uses less power than Wi-Fi and far

Fig. 8. Representation of the no. of publications and cumulative publications on yearly basis from Scopus.

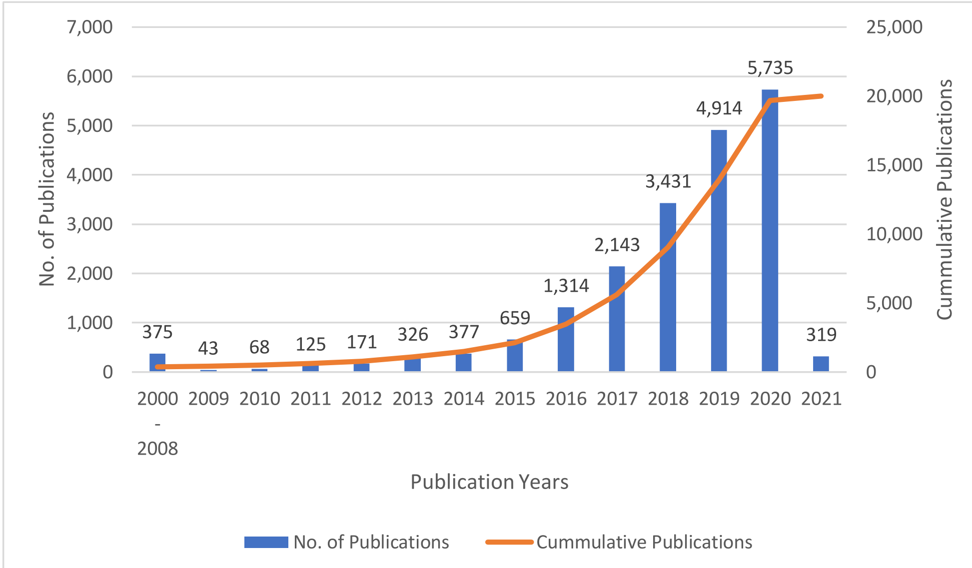

Fig. 9. Representation of the no. of publications and cumulative publications on yearly basis from web of science.

Table 11
Top countries with minimum 5 publications from Scopus data.

No.	Country	Publication	Percentage (%)	citations	Avg. Citations/Publication	TLS
1	United States	399	13.84	16,998	42.6	1913
2	China	394	13.67	10,486	26.6	1656
3	Canada	146	5.07	7681	52.6	1055
4	Italy	101	3.50	5838	57.8	579
5	Turkey	44	1.53	4808	109.3	493
6	Australia	101	3.50	4020	39.8	585
7	United Kingdom	119	4.13	3718	31.2	644
8	South Africa	11	0.38	3712	337.5	286
9	India	241	8.36	2874	11.9	808
10	Germany	82	2.85	2234	27.2	242
11	South Korea	121	4.20	1986	16.4	299
12	Singapore	48	1.67	1772	36.9	397
13	Spain	74	2.57	1743	23.6	235
14	France	31	1.08	1689	54.5	270
15	Sweden	32	1.11	1643	51.3	264
16	Taiwan	54	1.87	1360	25.2	325
17	Hong Kong	28	0.97	1312	46.9	166
18	Japan	47	1.63	1217	25.9	144
19	Brazil	60	2.08	1213	20.2	336
20	Norway	26	0.90	1191	45.8	177
21	United Arab Emirates	42	1.46	1191	28.4	210
22	Saudi Arabia	64	2.22	1107	17.3	400
23	Pakistan	68	2.36	1097	16.1	367
24	Portugal	27	0.94	943	34.9	231
25	Iran	62	2.15	785	12.7	237
26	Malaysia	44	1.53	683	15.5	146
27	Russian Federation	17	0.59	632	37.2	84
28	Finland	18	0.62	532	29.6	75
29	Netherlands	19	0.66	532	28.0	47
30	Greece	29	1.01	497	17.1	106
31	Switzerland	24	0.83	471	19.6	33
32	Egypt	45	1.56	463	10.3	121
33	Qatar	23	0.80	412	17.9	156
34	Denmark	27	0.94	409	15.1	107
35	Austria	31	1.08	405	13.1	74
36	Other 21 Countries	183	6.35	2954	335.4	758

less than cellular technologies because of its comparatively less operating radius (Kurfess et al., 2020). It operates in a 2.4 GHz spectrum and provides a data rate of 1 Mbps to 3 Mbps with latency from 34 ms to 100–300 ms. There are different versions of Bluetooth available nowadays that provide more range than classic Bluetooth. The features and characteristics of different Bluetooth models are summarized in Table 6, where it can be observed that different versions of Bluetooth have a diverse coverage range. With the advancement in previous versions, Bluetooth 5.0 focuses on enhancing the connectivity and experience of the Internet of Things (IoT) by delivering a seamless data flow as it offers all possible features. But due to the short-range and device-to-device communication nature, it cannot be used in smart metering (Padiya and Gulhane, 2022).

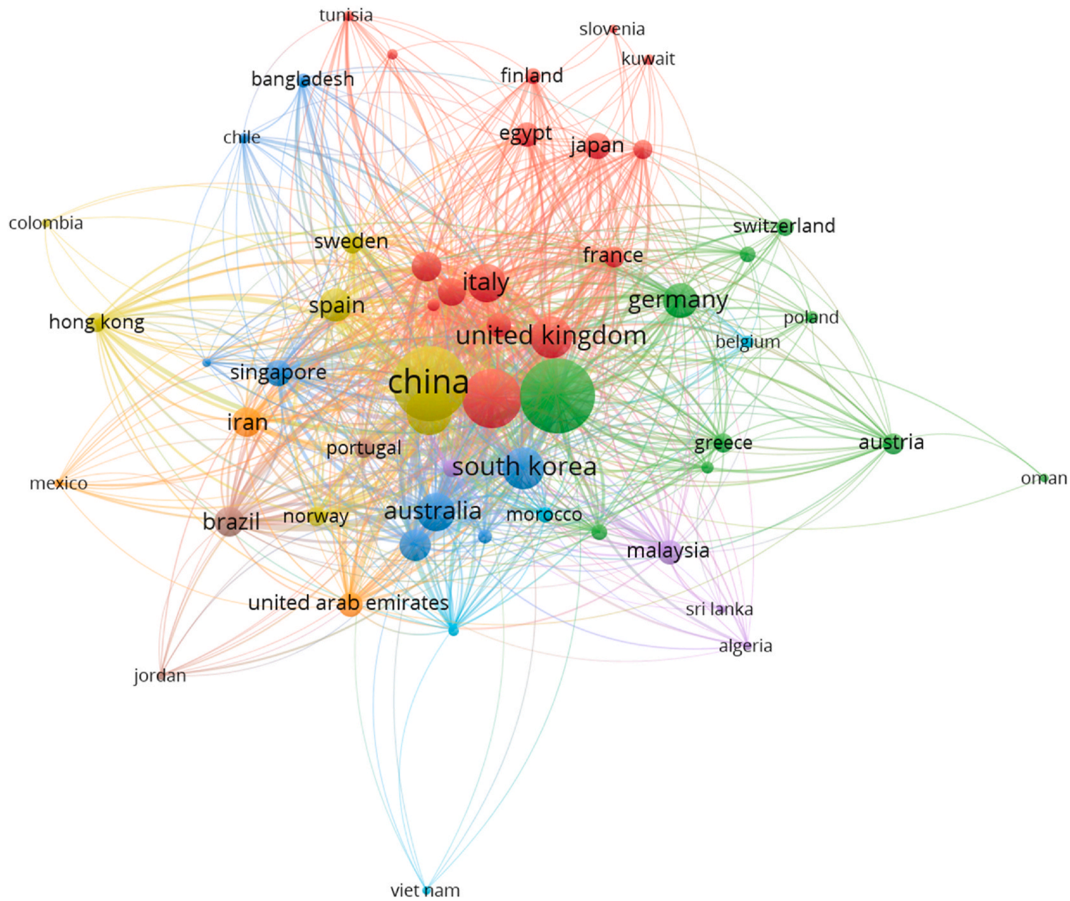

Fig. 10. Cooperation map of countries from Scopus data.

3.1.2.4. BLE. BLE (Bluetooth Low Energy) is something more than a low-energy version of Bluetooth. In reality, its implementations are diametrical to standard Bluetooth applications. It is probably the most apparent form of wireless technology for sending and receiving small amounts of data with very little power consumption. It operates in a 2.4 GHz frequency spectrum with a latency of 6 ms. It can handle 1 Mbps, while traditional Bluetooth can handle up to 3 Mbps. BLE devices are often powered by a small battery with a coin cell, making them more energy-efficient than ZigBee, classic Bluetooth, and Wi-Fi (Panetas et al., 2020). It supports mesh networking and enables mesh networks with a capacity of 32,767 systems or nodes. Due to its low bandwidth and limited range (typically 30 m–100 m), it cannot be implemented in IoT projects. Its application includes fitness trackers, smartwatches, and medical devices (glucose meters, insulin pumps) (Jonck et al., 2021).

3.1.2.5. WLAN. WLAN stands for Wireless Local Area Network and is a wireless internet and data networking service often referred to as Wi-Fi. It provides secure and fast transmissions. It has a data transfer rate of 2 Mbps to 600 Mbps and can cover up to 100 m of indoor space. Wi-Fi or WLAN is best for home and local area applications with reasonably high transmission rate requirements, such as video surveillance. It is cost-effective since it transfers data over an unlicensed spectrum of 2.4 GHz with 20–40 MHz bandwidth. The only issue with Wi-Fi is that its power consumption may be higher for a few smart grid devices (Li et al., 2018). In terms of security, the Wi-Fi uses WPA2 – AES/TKIP as a security protocol, and its power consumption is between 2 and 20 W, allowing it to last for nearly 9–10 h (Lindroos, 2021).

3.1.2.6. ZigBee. ZigBee is a wireless mesh network based on the 8.2.15.4 standard of IEEE. It was commonly used in smart grid applications because of its low energy consumption and implementation costs. ZigBee operates in the unlicensed ISM (Industrial, Scientific, and Medical) bands. The approximate data transfer speed for a 2.4 GHz band channel is 250 kbps, 40 kbps for a 915 MHz band channel. And 20 kbps for an 868 MHz band channel. ZigBee is a good choice for home automation and home appliance applications. It has practical limitations like limited processing power, small memory space, small latency demands (15 ms), low data transfer rate, and short coverage (30–50 m). As it uses unlicensed spectrum, it can experience interference from other devices using the same unlicensed spectrum (Li et al., 2018).

3.1.2.7. WiMAX. It is based on IEEE 802.16 standard set, and primarily it is a 4G technology. It can transmit data at up to 75 Mbps and latency 10–50 ms. It has a line-of-sight (LOS) range of 10–50 km and a non-line-of-sight (NLOS) range of 1–5 km. It was designed to make duplex broadband transmissions with a high data rate possible, such as for real-time pricing and remote monitoring. However, since WiMAX towers are based on costly radio systems, their implementation can be very costly. It works in the frequency bands of 2.5 GHz, 3.5 GHz, and 5.8 GHz, and the frequency of WiMAX above 10 GHz makes it challenging to overcome obstacles, resulting in short wavelengths. Also, unfavorable weather conditions will influence its performance. Due to the limitations stated above, it might not be the proper choice for smart metering (Li et al., 2018).

3.1.2.8. Wireless mesh network. It is a scalable network consisting of a class of nodes in which new nodes can be joined, and every node is a single router. This topology significantly improves the stability of the network by self-organization and healing properties. The mesh network can achieve a wide coverage range and high volume because of its ability

Table 12
Top universities with minimum 4 publications from Scopus data.

No.	Universities	Country	Publications	Citations	TLS
1	Department of Computer and Information Sciences, Towson University, Towson	United States	7	1397	15
2	Department of Electrical and Computer Engineering, University of Waterloo, Waterloo	Canada	6	844	8
3	Simula Research Laboratory	Norway	4	626	4
4	School of Electrical Engineering and Computer Science, Washington State University, Pullman, WA	United States	5	479	4
5	Center For Security, Theory and Algorithmic Research, International Institute of Information Technology, Hyderabad	India	5	380	8
6	School of Electrical Engineering and Computer Science, University of Ottawa, Ottawa	Canada	4	354	2
7	Department of Electrical Engineering, University of South Florida, Tampa	United States	4	291	6
8	Electrical And Computer Engineering Department, Illinois Institute of Technology, Chicago	United States	4	254	2
9	University of Idaho	United States	4	252	3
10	School of Control and Computer Engineering, North China Electric Power University, Beijing	China	5	225	7
11	College of Electrical Engineering, Zhejiang University, Hangzhou	China	4	162	1
12	Department of Electrical and Computer Engineering, University of Toronto, Toronto	Canada	4	151	1
13	Department of Electrical and Computer Engineering, North Carolina State University, Raleigh	United States	4	149	1
14	Department of Information Engineering, University of Brescia, Brescia	Italy	4	134	0
15	City University of Hong Kong	Hong Kong	4	117	2
16	Instituto De Telecomunicações,	Portugal	4	108	2
17	School of Electrical Engineering and Telecommunications, University of New South Wales, Sydney	Australia	4	93	2
18	School of Electronic and Information Engineering, Xi'an Jiaotong University, Xi'an	China	4	90	8
19	School of Electronics Engineering, Kyungpook National University, Daegu	South Korea	5	87	7
20	Department of Electrical and Computer Engineering, National University of Singapore, Singapore	Singapore	4	84	9
21	Department of Electrical Engineering, Princeton University, Princeton	United States	4	83	0
22	Department of Computer Science and Engineering, Qatar University, Doha	Qatar	6	75	5
23	Department of Energy Technology, Aalborg University, Aalborg	Denmark	4	74	4
24	School of Control and Computer Engineering, North China Electric Power University, Beijing	China	4	21	2
25	School of Electrical and Information Engineering, Tianjin University, Tianjin	China	4	7	1

to do multi-hop routing. Mesh networks can be implemented using various wireless architectures, such as 802.11, 802.15, and 802.16. Their coverage range, latency, and data rate are all dependent on the protocols used. However, it is very hard to establish and maintain this topology. It requires constant surveillance due to the excessiveness in the job. Therefore, its maintenance and management can involve a third-party organization (Li et al., 2018). Which increases its cost, and due to this factor, it cannot be implemented in smart metering.

3.1.2.9. Cellular technologies. Cellular Technologies (2G/3G/4G) use licensed spectrum to transfer the data through radio frequencies. Consequently, they are costly and consume more power than other wireless communication technologies. For a long time, the most widely used cellular technology for goods that do not need vast quantities of data transmission has been GSM (Global System for Mobile Communication) combined with GPRS (General Packet Radio Service), which is primarily due to the widespread availability and low cost of GSM/GPRS hardware. So, cellular technologies for smart metering are not suitable due to their higher cost and more power consumption. Regrettably, this is coming to an end.

Moreover, most network operators worldwide have removed GSM so that 4G and 5G smartphones with large quantities of data transmission will release more bandwidth. However, this transition will come with a hefty price increase. Due to high power consumption and cost, cellular technologies are not suited for smart metering (Arshad et al., 2019). In addition, cellular systems have latency ranging from 1 to 1000 ms and data rates ranging from 100 to 10 Gb/s. The latency ranges from 500 ms to 1000 ms for 2G, GSM, GPRS, EDGE, and CDMA with a data rate of 100 kbps. The data rate for 3G, UMTS, and CDMA2000 is between 384 and 2 Mb/s with 200 ms latency. On the other hand, the latency and data rate for 4G, LTE, and LTE-A are 100 ms and 150-45- Mb/s correspondingly. Finally, 5G is a revolutionary technology with a low latency of 1 ms and a data rate of 10 Gb/s (Storck and Figueiredo, 2020).

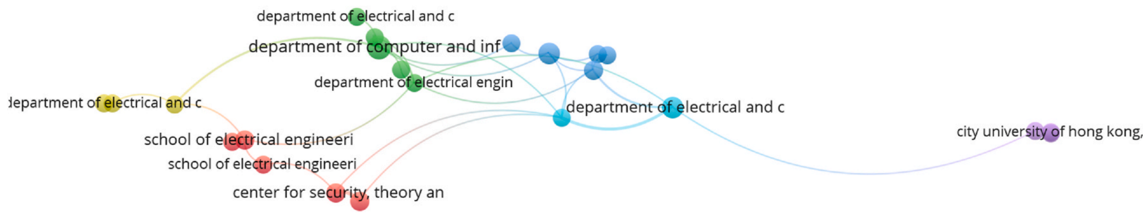

Fig. 11. Collaboration map of universities working on communication technologies around the globe from Scopus data.

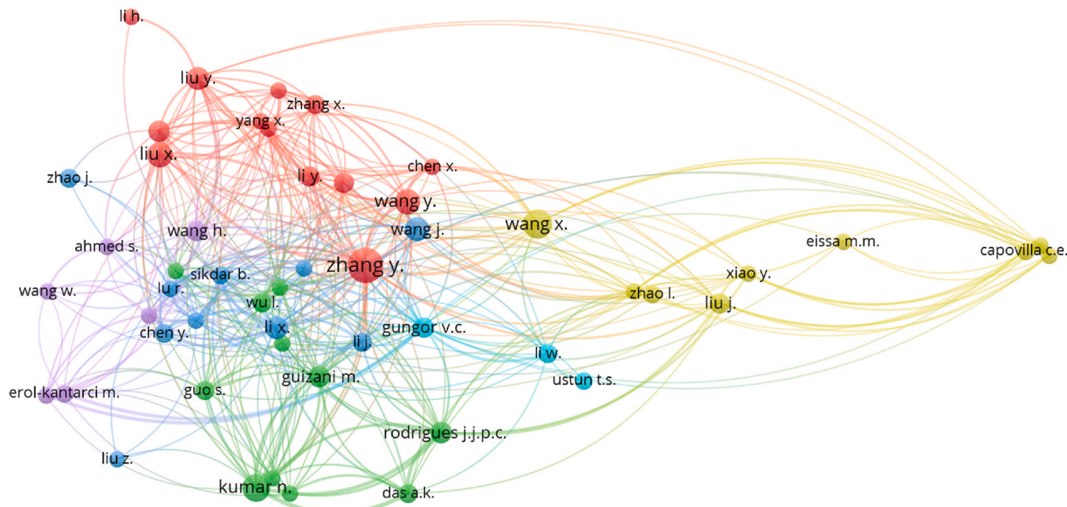

Fig. 12. Collaboration map of authors working on communication technologies around the globe according to Scopus data.

3.1.2.10. LPWAN. Researchers can use the Low Power Wide Area Network (LPWAN) technology if other wireless technologies like Bluetooth, Wi-Fi, BLE, and ZigBee are not suitable for case studies. Cellular M2M networks are costly as they use licensed spectrum and consume more power, but at the same time, they are more secure than other available wireless technologies. This technology is appropriate for devices that transmit small data over long distances and hold long batteries. LPWAN can also divide into LoRa, NB-IoT, Sigfox, and LTE-M.

3.1.2.10.1. LoRa. LoRa stands for Long Range and is also known as LoRaWAN. It is a reliable modulation system created by Cycleo, a French company that Semtech later acquired. It is used in LoRaWAN networks for low power and long-range wireless communications. Usually, LoRaWAN networks are arranged in a star topology in which gateways are responsible for transmitting messages between nodes to a central server. Gateways are connected via IP links to the network server, while nodes connect to one or more gateways using single-hop LoRaWAN communications. Uplinks to network servers are highly appreciated, but all communications are generally bifacial (Jain et al., 2018). It uses the AES 128-bit encryption standard as security. LoRa is an unlicensed LPWAN technology that operates on the ISM bands 433, 868, 923, and 915 MHz with a bandwidth of 125 kHz. CSS or Chirp Spread Spectrum is the base for LoRa modulation because it aids in the prevention of multi-path vanishing. LoRa covers 8–10 km in cities and 22 km in rural areas, depending on the hardware used. It has a versatile data range of 0.3–50 kbps, determined by orthogonal spreading variables, and a 2 s average latency. Because of its low data rate, LoRa is only suitable for small payloads (Li et al., 2018). It has a power consumption of about 0.042 W and can last for more than 15 years (Nurgaliyev et al., 2020).

3.1.2.10.2. NB-IoT. Narrow Band IoT (NB-IoT) is an LPWAN cellular technology that uses licensed spectrum. It works almost everywhere by producing more stable and secure transactions. It quickly and effectively links devices on existing mobile networks using a narrow band between the carrier signal and handles a small amount of infrequent 2-way data securely and reliably (Jain et al., 2018). It is more secure than other wireless communication technologies because it uses 128–256-bit 3GPP LTE encryption as a security standard. It has less latency and more throughput than the LoRa. As NB-IoT uses a licensed frequency spectrum, it increases its cost as compared to LoRa as well as the power consumption of NB-IoT is greater than LoRa. It transfers large amounts of data, especially in inaccessible areas – remote or rural locations. In addition, it uses 180 kHz of bandwidth and a spectrum of 900–1800 MHz with a coverage area of between 35 and 50 km. The data rate of NB-IoT is 250 kbps for downlink communications and 20–66 kbps for uplink communications with a latency of less than 10 s (Li et al., 2018). Nb-IoT has a significant drawback in that it does not allow handover, making it unsuitable for mobile IoT applications. Another problem is the implementation of NB-IoT, which necessitates a hardware upgrade of the current LTE framework (Islam et al., 2020). Finally, NB-IoT has a power consumption of about 0.14 W and can last for more than ten years (Yang et al., 2020).

3.1.2.10.3. Sigfox. Sigfox is a one-way communication protocol and an end-to-end IoT networking solution. It uses the Ultra Narrow Band carrier of the sub-GHz ISM bands (433, 868, 915 MHz) and the Binary Phase Shift Keying (BPSK) modulation technique. By lowering the noise levels, this extremely narrow band improves the communication range (Li et al., 2018). Sigfox limits the downlink communications to 4 transmissions of 8-byte payload and uplink communication to 140 transmissions of 12-byte payload for each end device or node, giving it a data rate of 100–600 bps with a latency of 200 ms. The coverage range for Sigfox is high in rural (40 km) and more minor in urban (10 km) areas. It has been introduced and deployed in certain nations, but no roaming is concerned when using it in various countries. Inclusively, Sigfox's main drawback is that it is not ideal for duplex communication (Islam et al., 2020).

3.1.2.10.4. LTE-M. In LTE release 13, the LTE-machine type communication or LTE-M is introduced by 3GPP and NB-IoT as a cellular

Table 13
Top authors with minimum 8 publications from Scopus data.

No.	Author	Publications	Citations	Avg. Citations/ Publication	TLS
1	Gungor V.C.	13	2504	192.6	76
2	Zhang Y.	37	1868	50.5	98
3	Yu W.	9	1421	157.9	60
4	Yang X.	9	1323	147.0	41
5	Shen X.	8	1245	155.6	47
6	Kumar N.	23	1175	51.1	59
7	Lu R.	9	1168	129.8	54
8	Li X.	16	1134	70.9	65
9	Erol-Kantarci M.	10	899	89.9	39
10	Liu Y.	16	848	53.0	43
11	Liu J.	12	777	64.8	33
12	Mouftah H.T.	9	695	77.2	32
13	Wang X.	26	648	24.9	41
14	Rodrigues J.J. P.C.	14	627	44.8	58
15	Li Z.	15	573	38.2	34
16	Qian Y.	9	541	60.1	33
17	Wu J.	8	536	67.0	24
18	Wang J.	18	530	29.4	25
19	Guo S.	11	525	47.7	23
20	Guizani M.	14	523	37.4	46
21	Xiao Y.	9	521	57.9	22
22	Liu X.	19	473	24.9	45
23	Wang Y.	20	467	23.4	51
24	Das A.K.	11	460	41.8	36
25	Li W.	11	405	36.8	19
26	Sikdar B.	10	390	39.0	48
27	Garg S.	8	381	47.6	40
28	Wang H.	13	374	28.8	33
29	Wu L.	11	342	31.1	27
30	Zhang X.	11	318	28.9	23
31	Li J.	11	278	25.3	25
32	Wang W.	8	271	33.9	12
33	Zhang J.	9	254	28.2	25
34	Sun H.	9	213	23.7	9
35	Ustun T.S.	10	211	21.1	2
36	Li Y.	13	198	15.2	18
37	Li H.	9	180	20.0	4
38	Ahmed S.	8	155	19.4	22
39	Yang Q.	9	141	15.7	27
40	Eissa M.M.	9	140	15.6	7
41	Yang Y.	9	129	14.3	27
42	Li B.	8	124	15.5	18
43	Chen X.	9	123	13.7	27
44	Capovilla C.E.	10	115	11.5	64
45	Zhao L.	10	115	11.5	20
46	Casella I.R.S.	9	114	12.7	60
47	Sguarezi Filho A.J.	8	114	14.3	55
48	Kaddoum G.	8	101	12.6	27
49	Zhao J.	11	99	9.0	5
50	Chen Y.	11	83	7.5	25
51	Zhang Z.	12	66	5.5	28
52	Liu Z.	8	63	7.9	4

IoT technology. A new UE category called the mobility category (CAT-M1) was created by LTE-M. CAT-M1 is made for high data applications, unlike NB-IoT. It supports a data rate of up to 1 Mbps and has a bandwidth channel of 1.4 Mhz. Its coverage range is between 30 and 40 km with a 10–15 ms latency. These features have made it more suitable for applications with smart devices rather than basic sensors. NB-IoT UE (NB1) is only available in 200 kHz bandwidth, primarily used by devices with low complication. CAT-M1 supports more features that have not been introduced with NB-IoT. It has introduced Voice over LTE (VoLTE), allowing voice calls for IoT devices. The transfer function allows smooth system movement between cells without disturbing the connection. Both NB-IoT and LTE-M share specific standard characteristics: increased signal coverage extended discontinuous reception transmission (eDRX), and low energy consumption. In which devices have expanded sleeping modes where they remain active while transmitting and receiving while they sleep for the rest of the time to save battery and free bandwidth for other devices. The 3GPP standard has introduced a new LTE-M category called CAT-M2 in LTE release 14. It offers high data rates than CAT-M1, uplink speed of 7 Mbps, and downlink speed of 4 Mbps. It helps CAT-M2 devices to perform more high-performance applications, including video transmission. LTE-M (CAT-M1 and CAT-M2) are used for high data rates applications. Ergo, its cost is much higher than the NB-IoT, which is used for low data rate applications (Borkar, 2020).

3.2. Bibliometric analysis of communication technologies

After a brief discussion of previous research studies and their findings, a systematic literature review is necessary. It helps researchers gather a significant quantity of knowledge in a specific subject in a relatively short period. Bibliometric analysis is one of the easiest ways to conduct a literature evaluation of many publications. The bibliometric analysis can help researchers understand the numerous relationships (for example, author, universities, author-citation relationship, and so on) and the current research trends in a particular field of study. As a result, a bibliometric analysis of communication technologies was conducted, with publication records obtained from Scopus.

3.2.1. Data source

The bibliometric analysis was carried out by obtaining published records from the Scopus database for the last 20 years. On November 30, 2021, the publications were retrieved from Scopus and Web of Science by using the following keywords and logic operators from article title, abstracts, keywords ("Communication Technologies" OR "Wireless Communication Technologies" OR "Wireless Technologies" OR "Communication Protocols" OR "Wireless Technologies") AND ("Smart Meter" OR "Smart Metering" OR "Smart Grid") OR ("Internet of Things" OR "IOT") OR ("Cyber Security" OR "Security Issues" OR "Security Solutions" OR "Cyber Attacks"). After searching, a total of 7811 documents were found, and by screening for only journal publications, research articles, review papers, and articles written in English, 2670 documents from Scopus were filtered. Out of these, only 2000 are included in the analysis. Besides, 59,100 documents were found on the Web of Science, and by applying the same filters, only 20,000 documents were extracted. The data from Scopus and Web of Science was exported in CSV and tab-delimited text file format that includes the citation data, bibliographical data, abstracts, keywords, funding information, and other data.

3.2.2. Method & process

The VOSviewer software was used to conduct the bibliometric analysis, which Van Eck and Ludo Waltman developed. It gives an easy-to-understand graphical representation of the bibliometric data in the form of maps. The distances between the nodes of the bibliometric map are proportional to their closeness. In other words, if the distance between two nodes is smaller than the distance between two other nodes, this information indicates that the first pair of nodes are more closely associated than the second pair. This software created different bibliometric maps based on relationships between authors, universities, and countries with citations. The discussion for the results of this bibliometric analysis is done in section 4.3.

3.3. Possible issues and challenges

The use of the internet contributes to the smart metering configuration and control in real-time. The concept of IoT is supposed to share the data from the smart meter to the smart grid through the internet to improve the smart grid's performance, usually described as efficiency, reliability, and safety (Avancini et al., 2019). Communication technologies face some challenges like privacy and security. As data is transferred through the internet, communication technologies face some challenges like data privacy and network security. Moreover, these

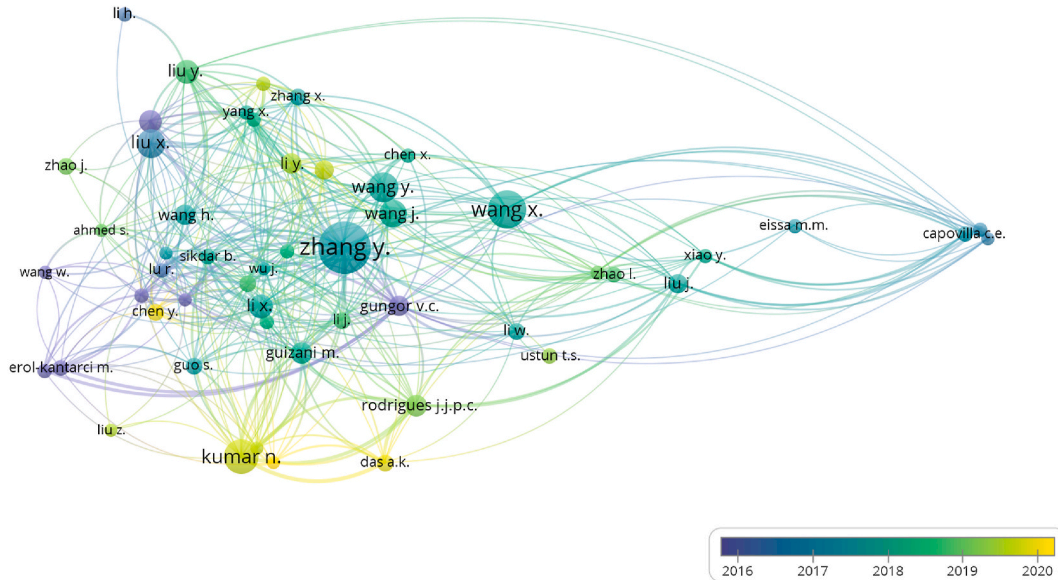

Fig. 13. Overlay visualization map of authors working on communication technologies according to Scopus data.

communication technologies are affected by interference resulting in unreliable data such as PLC can be affected by harmonics, and wireless networks can be affected by the interference in the frequency bands from other networks or devices.

Since smart meters gather a variety of information from users, including their location, payment information, power usage, and preferences, this information can be used to track and harm people for malicious purposes. Even seemingly insignificant information can be exploited against the customer (Qarabash et al., 2020). For instance, a user's power usage patterns can be used to forecast when they leave the house, allowing criminals to target it, or an electrical device firm can utilize the user's preferences to advertise directly to them and gain an edge. As a result, safeguarding users' privacy and information is critical (Armoogum and Bassoo, 2019).

Moreover, the most common types of cyber-attacks include DoS (Daniel of Service), Man in the Middle, Phishing, KillerBee Attack, malicious coding, and so on (Abrahamsen et al., 2021). One of the most severe attacks is security, and impersonation/identity spoofing is one of the many issues. It allows an attacker to impersonate a smart meter and pay for the user's energy consumption. Second, eavesdropping allows an attacker to gather information about a household's energy consumption readily. Another security attack is data tampering, which could produce an overloaded power network by increasing rather than decreasing a household's energy use because of the assault (Babuta et al., 2021). Additionally, a detailed analysis on cyber-attacks can be found in (Kumar et al., 2019), and analysis on cyber securities can be studied in (Kawoosa and Parachar, 2021).

4. Discussion

Following a brief description of the available communication technologies, Table 7 provides an overall comparison of communication technologies used in smart grid to understand the main aspects of these technologies.

From the explanation of all significant and useable communication technologies, it is evident that no single technology would satisfy all requirements. A brief explanation on all these technologies along with their use cases has been done in (Gupta and Bhatia, 2020), where each parameter of technology is compared with other technology that gives a good idea on what type of technology should be adapted as per requirement.

Inherently, selection of communication technology for smart meters is based on the few parameters like long-range, high security, low power consumption, data rate and cost-effectiveness. As a result, Wi-Fi, LoRa and NB-IoT are three technologies that can meet these requirements. Table 8 shows a comparison of these three technologies.

The table illustrates that Wi-Fi has a high-power consumption and data rate and a limited coverage range of just 100 m. On the other hand, NB-IoT uses less power than Wi-Fi but has a lower data rate of 66 kbps. LoRa, like NB-IoT, uses much less power and has a low data rate of 50 kbps. When it comes to latency, NB-IoT and LoRa both have lower latency than Wi-Fi. Similarly, the data rate of Wi-Fi is higher than LoRa and NB-IoT. When comparing the costs of these technologies, NB-IoT is more expensive than the other two. Prices for modules are checked on Amazon.com at the time of writing this article, so they could slightly change.

According to the comparison, there are a few scenarios where different communication technologies can be used. Wi-Fi is recommended if the primary criteria are high data rate and severe cost-effectiveness. LoRa, on the other hand, is the best option for low power consumption, long-range, and cost-effectiveness. NB-IoT is ideally suited for security and very-long distance coverage with high penetration across obstacles and can be suitable for remote areas.

Turning to confidentiality, modern Wi-Fi routers and LoRa use AES encryption as a security standard. Wi-Fi routers use WPA2 (Wi-Fi Protected Access II) along with Advance Encryption Standard (AES), Temporal Key Integrity Protocol (TKIP), or both AES and TKIP with WPA2 for more security. In comparison, LoRa supports AES (128–256 bit) for more security. On the other hand, NB-IoT uses 3GPP LTE encryption and the UDP protocol, making it more stable. Finally, although the cloud server for Wi-Fi and LoRa is accessible, the cloud server for NB-IoT data monitoring software can charge a fee from $25 to $405. These prices are taken from the official website of NB-IoT called the things.io. Since NB-IoT operates on a licensed spectrum, consumers must pay an extra subscription fee, which may inevitably boost the cost.

4.1. Meter Data Management Systems (MDMS)

Fig. 6 shows the comparison of different Meter Data Management Systems (MDMS) based on the reviews and ratings provided by users on the Gartner peer-insights reviews home page. Where it can be seen that the Utilities Meter Data Management and PI Systems are the top-ranked MDMS.

On the other hand, one of the purposes of communication

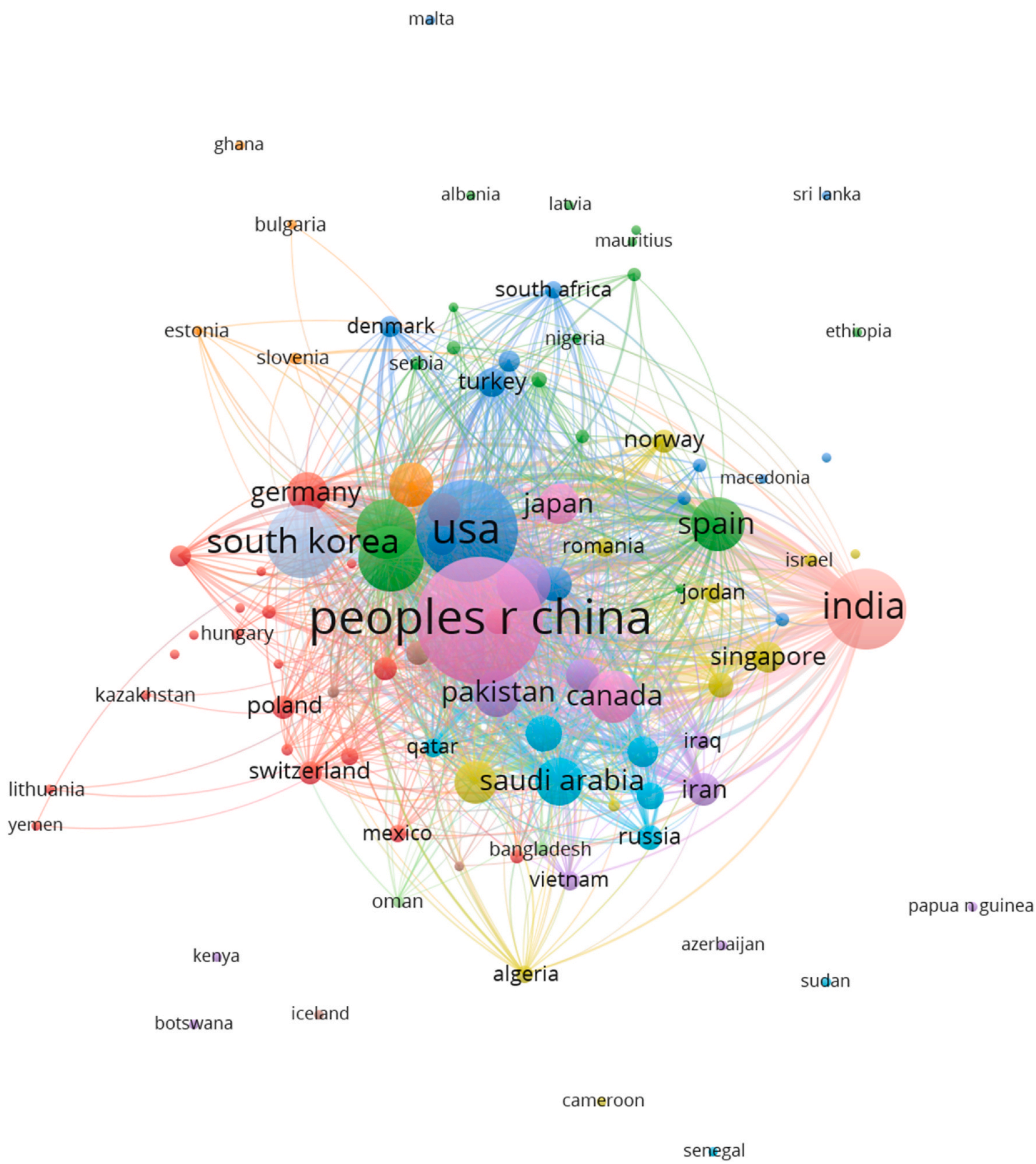

Fig. 14. Cooperation map of countries from WoS data.

technologies in smart meters is to transmit the data on a server to plan for energy efficiency schemes. Table 9 presents the apps that the users can use to optimize their energy usage in homes. These apps are available at no cost where the majority of the apps are available on both iOS and Android, but few are just available for iOS and PC.

4.2. Proposed model of smart meter communication network

Based on the comparison of communication technologies and different MDMS systems, this paper has proposed a model of hybrid communication network for smart meters while considering the heterogeneous networks and cost of technology, which will help the researchers to find the most suitable communication system for smart meter in user premises. The proposed model is shown in Fig. 7, which combines Wi-Fi, LoRa, and Ethernet to provide a fast, reliable, secure, and cost-effective communication network for smart meters. Since Wi-Fi has a high data rate and good range, the communication between the smart meter and devices is swift and secure. LoRa is used for sending the data from a smart meter to a server via a gateway. It is low power and long-range technology that can help the utilities connect different nodes over a single gateway through long distances. The gateway can transmit the data to a server through Ethernet. The only problem is the vulnerabilities of these technologies to hacking attempts and cyber-attacks. However, as described earlier in this section, these technologies are secure enough to protect the data. Anyhow, developing the security algorithms will make these technologies more suitable for smart metering.

Additionally, as the Wi-Fi and LoRa both are low in price, they can make the end device more cost-effective. A price chart is given in Table 10 which gives an overview of cost required to build up a hybrid communication network using these technologies.

Table 14
Top countries with minimum 5 publications from WoS data.

No.	Country	Publications	Percentage (%)	Citations	Avg. Citations/Publication	TLS
1	China	5205	17.54	105,611	20.29	56,498
2	USA	3371	11.36	108,537	32.20	50,061
3	India	2080	7.01	31,752	15.27	26,643
4	South Korea	1780	6.00	28,544	16.04	21,321
5	England	1432	4.82	41,065	28.68	24,169
6	Italy	1133	3.82	43,431	38.33	23,238
7	Australia	953	3.21	31,267	32.81	19,358
8	Spain	950	3.20	19,218	20.23	13,425
9	Canada	887	2.99	21,648	24.41	13,752
10	Saudi Arabia	743	2.50	13,884	18.69	12,900
11	Pakistan	685	2.31	12,413	18.12	11,745
12	Taiwan	654	2.20	9919	15.17	7381
13	France	613	2.07	14,787	24.12	9553
14	Germany	553	1.86	14,091	25.48	7553
15	Japan	550	1.85	9142	16.62	5125
16	Brazil	436	1.47	7248	16.62	6994
17	Sweden	381	1.28	12,802	33.60	8042
18	Iran	374	1.26	5337	14.27	6792
19	Malaysia	353	1.19	7851	22.24	7453
20	Greece	340	1.15	8249	24.26	5474
21	Portugal	338	1.14	7616	22.53	6614
22	Singapore	309	1.04	8109	26.24	4998
23	Turkey	295	0.99	8041	27.26	4624
24	Finland	293	0.99	9963	34.00	6566
25	Egypt	250	0.84	3834	15.34	3254
26	United Arab Emirates	223	0.75	4697	21.06	3748
27	Belgium	215	0.72	4516	21.00	2463
28	Russia	204	0.69	3494	17.13	3173
29	Norway	190	0.64	5919	31.15	2612
30	Poland	189	0.64	2036	10.77	1662
31	Switzerland	182	0.61	5876	32.29	3221
32	Ireland	180	0.61	4441	24.67	2844
33	Netherlands	180	0.61	3411	18.95	2229
34	Denmark	161	0.54	2885	17.92	2417
35	Scotland	149	0.50	4310	28.93	2541
36	Austria	147	0.50	3414	23.22	2109
37	Jordan	139	0.47	2243	16.14	1943
38	Romania	136	0.46	1305	9.60	1224
39	Vietnam	128	0.43	1184	9.25	1797
40	Qatar	127	0.43	6007	47.30	4235
41	South Africa	110	0.37	5454	49.58	2527
42	Mexico	104	0.35	1079	10.38	1260
43	Algeria	102	0.34	2079	20.38	1893
44	Iraq	102	0.34	1970	19.31	2097
45	Tunisia	95	0.32	1119	11.78	1096
46	New Zealand	87	0.29	3765	43.28	1776
47	Israel	74	0.25	977	13.20	498
48	Morocco	73	0.25	1047	14.34	897
49	Serbia	73	0.25	788	10.79	741
50	Czech Republic	70	0.24	1148	16.40	866
60	Other 49 Countries	1281	4.32	22,780	814.57	18,834

4.3. Results and discussion for bibliometric analysis

4.3.1. Distribution and growth trend on yearly basis

The number of articles published yearly gives an excellent indication of the research trend in a particular field of study. Analyzing the number of articles published throughout time can provide insight into the likely research trend soon. A graph of the no. of publications and cumulative publications yearly from Scopus and Web of Science (WoS) data is plotted to examine the research trend on the application of communication technologies in smart metering, shown in Figs. 8 and 9. From the trend line in Fig. 8, the research on the application of communication technologies in smart metering from 2000 to 2009 with only seven publications has started increasing exponentially and ended up with 2121 publications in 2020. But in 2021, it reached up to 2652 publications, and more research studies are still publishing, which means this field is becoming more popular in different research groups throughout the Globe.

Additionally, looking at the trend line in Fig. 9, from 2000 to 2008, there was a total of 375 publications, which decreased to only 43 in 2009. However, the number of publications gradually increased from 68 in 2010 to 377 in 2014. The following year, it nearly doubled to over 659 articles, with a fast upward trend continuing until 2020 when it reached 5735 publications. From 2016 to 2020, researchers exhibited a higher level of interest. However, with only 319 publications this year, there has been a sharp fall.

In short, by combining the data from both Scopus and Web of Science, it can be assumed that the different groups around the Globe began showing interest in communication technologies and smart meters in 2012, resulting in an exponential rise till 2020. Besides, their interest has been decreased in the current year, but it is expected that it will be bullish again in the coming years, allowing researchers to contribute more to this field.

4.3.2. Classification of publications on country level from Scopus data

The total number of articles are published from 234 countries, out of which 56 countries with at least five publications are evaluated. Out of these 56 countries, only 55 collaborated except Serbia. The highest number of publications (399 articles, 13.84% of entire documents) are

Table 15
Top universities with minimum 50 publications from Scopus data.

No.	Universities	Publications	Citations	TLS
1	Beijing University Posts & Telecommunication	325	6312	2232
2	Chinese Academy of Science	288	13,385	3472
3	King Saudi University	273	8145	2770
4	University of Electrical Science & Technology, China	220	4725	1344
5	Xidian University	216	4781	1593
6	Tsinghua University	172	5398	1130
7	Huazhong University Sci & Technol	157	5344	1177
8	Nanjing University Posts & Telecommunication	146	3286	1038
9	Shanghai Jiao Tong University	145	9762	2707
10	Dalian University Technology	144	4436	1337
11	Southeast University	128	2462	783
12	Islamic Azad University	127	1802	1177
13	Sejong University	126	3017	1071
14	Zhejiang University	123	2939	787
15	Nanyang Technol University	114	3041	964
16	Kyungpook Natl University	114	2812	788
17	Inst Telecomunicacoes	113	2855	1101
18	Beijing Jiaotong University	113	2096	983
19	Korea University	113	1510	459
20	Beihang University	108	3867	1144
21	University Technol Sydney	107	2268	824
22	University Sci & Technol Beijing	105	2842	915
23	Vit University	103	2517	765
24	Aalto University	98	3652	987
25	University Texas San Antonio	98	2934	739
26	Northeastern University	98	2314	684
27	Guangzhou University	97	1957	633
28	Qatar University	96	5037	1361
29	Deakin University	95	2204	801
30	University Politecn Valencia	93	1741	481
31	Sungkyunkwan University	93	1716	535
32	Vellore Inst Technol	93	1187	493
33	King Abdulaziz University	92	1564	599
34	University Surrey	90	4257	799
35	Tianjin University	90	1788	789
36	Wuhan University	90	1484	441
37	Hong Kong Polytech University	89	2386	706
38	Natl Chiao Tung University	89	1316	313
39	Comsats University Islamabad	87	1088	575
40	Beijing Inst Technol	86	2797	948
41	University Murcia	86	1874	523
42	Georgia Inst Technol	85	3256	422
43	University Bologna	84	2086	339
44	Kyung Hee University	83	2026	746
45	University New South Wales	82	1531	493
46	Soonchunhyang University	82	1008	469
47	Harbin Inst Technol	80	1476	471
48	University Chinese Academy of Science	80	1222	503
49	Purdue University	79	2006	473
50	Xi An Jiao Tong University	77	2422	737
51	University Sydney	77	1976	598
52	Chung Ang University	77	1195	298
53	Old Dominion University	76	9781	2933
54	University Waterloo	76	3132	841
55	Natl University Singapore	73	2135	476
56	University Malaya	72	3432	1131
57	Swinburne University Technology	72	3239	684
58	South China University Technology	72	2198	681
59	Natl Inst Technology	72	780	414
60	Sun Yat Sen University	71	2311	623
61	City University Hong Kong	71	1988	392
62	Natl University Def Technol	71	1461	353
63	University Florida	71	1306	414
64	Other 61 Universities	3533	98,885	26,777

from the United States (US), followed by 394 articles (13.67%) from China. India and Canada shared third and fourth rank with 241 and 146 publications. After that, South Korea and United Kingdom are at fifth and sixth rank, having 121 and 119 publications individually, and right after that, Italy and Australia shared the same rank. Nine countries published 50–82 articles, 19 countries with 18–48 articles, and 21 countries with less than 15 articles. The total number of publications by contributions from each country is 2,882, which is higher than the total number of articles which are 234. This suggests that there is collaborative work between these countries. The statistics of these countries are given in Table 11. Turning to the citations, India has many publications; it receives only 2874 citations, and on the other hand, the US is at first place with 16,998 citations of just 399 articles. China is in second place with 10,486 citations by publishing only 394 articles, followed by 7681 citations received by Canada with just 146 publications. It is important to note that the United States and China are ranked 1st and 2nd in terms of no. of documents published and citation, but India ranked 9th due to low citations.

Besides, it can be seen in Fig. 10 that India, China, Canada, and the US belong to three different clusters. However, they are very close to each other, which suggests that they have done more collaborating work than other countries.

In addition, the Total Link Strength (TLS) is a measurement of how well two countries collaborate on research. The analysis of TLS says that with a TLS of 1,913, the United States is the most superior country in terms of collaborative research. The countries with at least five publications are evaluated in this mapping technique shown in Fig. 10. The US has published articles by collaborating with China, Japan, Singapore, Oman, Russian Federation, Denmark, Poland, Malaysia, Pakistan, France, Hong Kong, UK, South Africa, Canada, India, Germany, Italy, Ireland, Iraq, Sweden, South Korea, Portugal, and Australia. China is at second place with a TLS of 1,656, and Canada is at third place with a TLS of 1055. China has collaborated with the same countries the US did except Sri Lanka, Kuwait, Slovenia, Columbia, and the Czech Republic. On the other hand, researchers from Canada had publications with all countries except Romania, the Czech Republic, Sri Lanka, Ireland, and Oman. From the TLS score and collaboration of countries, it is evident that most of the countries are interested in working with the US, China, and Canada.

4.3.3. Classification of publications on universities level from Scopus data

The total number of articles are published from 4437 universities, out of which 25 universities with at least four publications are evaluated. Out of these 25 universities, only two universities (University of Brescia, Brescia, Italy and Princeton University, Princeton, US) are not collaborating, and the remaining universities are connected to each other. The statistics of these universities are given in Table 12. By analyzing it is noticed that Towson University, Towson, US, has published seven articles and gathered 1397 citations. On the other hand, the observation shows that the remaining universities have just published 4–6 articles each. However, the University of Waterloo, Waterloo, Canada, took second place by getting 844 citations. Simula Research Laboratory placed 3rd with 626 citations with only four publications. Washington State University, Pullman, US, grasped the fourth position with 479 citations. International Institute of Information Technology, Hyderabad, India, ranks fifth with 380 citations. By this comparison, these universities have published quality articles, out of which Towson University, Towson, US, and University of Waterloo, Waterloo, Canada are the top institutions with a keen interest in the field. Fig. 11 shows the map of universities working on the communication technologies for smart meters, and they are collaborating with each other. The figure shows these 23 universities are grouped into six clusters, each of which is highlighted with a different hue.

The distance between the purple cluster and the other clusters indicates that the universities in this cluster are not closely related to the universities in other clusters, despite the fact that they have a close bond with one another, as shown in the figure, where the City University of Hong Kong has a fellowship with Tianjin University in China. In addition, while looking at other clusters, none of the members of each cluster are closely linked to members of other clusters except their own. For example, Xi'an Jiaotong University and Towson University Towson are

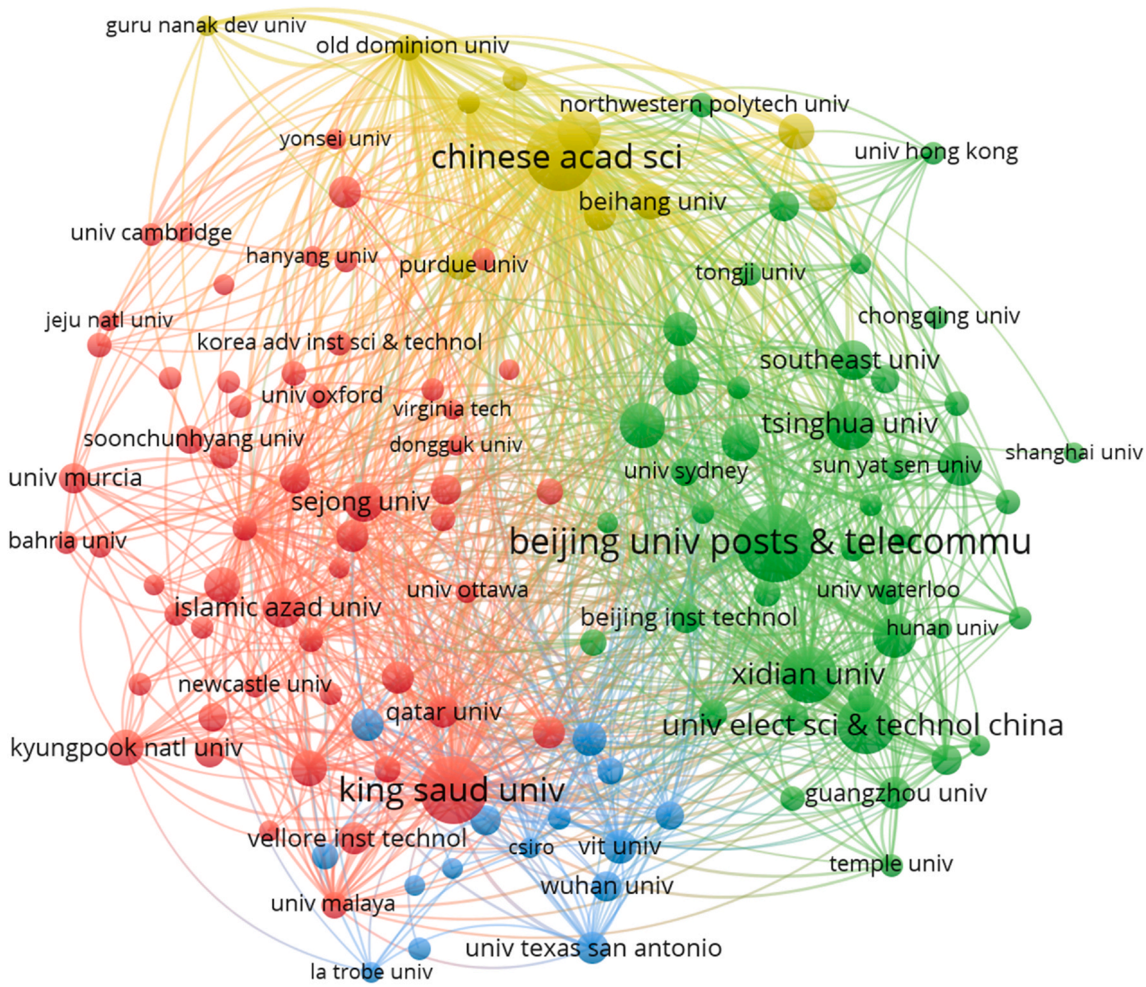

Fig. 15. Collaboration map of universities working on communication technologies around the globe from WoS data.

both members of the green cluster, and they are affiliated with one another rather than with other cluster members. It demonstrates that the universities in these clusters have strong relationships with their cluster partners and collaborate and cite each other's work internally. Also, the TLS shows that Towson University is the top university with outstanding connections, high publications, and more citations, indicating that this university publishes high-quality work that can aid researchers in the field of communication technologies and smart meters.

4.3.4. Relationship of authors and publications from Scopus data

The relationship between the authors, publications, and citations can be used to identify the primary research groups working on a given topic around the globe. It can be simply accomplished by mapping this relationship. The mapping technique creates a visual depiction of the link, making it easy to investigate the author's activities and the interconnection with other research groups. For this purpose, 5543 authors are evaluated globally. However, out of these, only 52 are selected while considering at least eight publications by each author to filter out the authors with quality work. The map of the selected authors is shown in Fig. 12, which divulged that the total numbers of groups working on communication technologies for smart meters are six while considering almost 6–8 authors in each group. The statistics of these authors are shown in Table 13 from where it is surveyed that the research group of Zhang Y., Wang X., Kumar N., Wang Y., and Wang X. with 37, 26, 23, 20, and 18 articles are the prominent groups in the said field followed by Liu X. and Liu Y. with 19 and 16 articles. Among all researchers, Zhang Y. has the highest number of articles (37) with 1868 citations, followed by Kumar N. with the second-highest rank in publications but with relatively low citations (1,175). Wang X. has taken the third rank in publications, but he got only 648 citations. Interestingly, Gungor V. C. received the highest number of citations (2,504) out of those top researchers by only publishing 13 articles which depict that he produced quality work back in 2016, but he is not an active researcher nowadays, as it can be seen in Fig. 13.

It is illustrated in Fig. 12 that there are six groups of researchers, with Wang J. and Wang Y. belonging to different groups but publishing articles together. Moreover, authors from other groups are linked to collaborating. For example, Wu L. and Sun H.'s research groups are connected to Li X.'s research group, and Li X.'s research group collaborates with Wang H.'s research group. At the same time, Chen Y. has an alliance with Qian Y.'s group. These findings show that these research groups are collaborating with each other to produce quality work. As well, it is evident from Fig. 13 that these groups are closely associated with one another, and those who have published the most articles have not produced any research papers after 2018. It demonstrates that these gems have lost interest in this field. However, Kumar N.'s research group is currently active and publishing high-quality work on the subject among these researchers. Since then, Kumar N. has collaborated with notable researchers such as Zang Y. and Gungor V. C. As a result, and it is safe to infer that he was trained by these two scholars and will continue to write high-quality work.

Finally, it is noted that Gungor V. C. has extensive field knowledge and has worked with and trained about 70% of the other researchers. Besides, he has written high-quality research that has received the most

Table 16
Top authors with minimum 8 publications from WoS data.

No.	Authors	Publications	Citations	Avg. Citations/ Publication	TLS
1	Zhang, Y	280	7535	26.91	1467
2	Liu, Y	212	5401	25.48	990
3	Wang, X	195	4019	20.61	778
4	Wang, J	194	3727	19.21	712
5	Li, Y	186	4858	26.12	839
6	Wang, Y	179	3299	18.43	615
7	Li, X	168	3200	19.05	781
8	Liu, X	160	3219	20.12	807
9	Li, J	155	2389	15.41	668
10	Wang, H	153	4042	26.42	698
11	Zhang, J	145	1918	13.23	505
12	Liu, J	143	3376	23.61	622
13	Chen, Y	138	2669	19.34	636
14	Zhang, X	134	2353	17.56	501
15	Chen, J	124	3322	26.79	519
16	Zhang, H	116	2868	24.72	557
17	Wang, Z	114	1829	16.04	358
18	Yang, Y	104	2139	20.57	471
19	Chen, X	100	2339	23.39	447
20	Wang, L	100	1764	17.64	388
21	Li, H	97	2282	23.53	439
22	Li, Z	96	2245	23.39	444
23	Wang, W	95	2062	21.71	346
24	Kim, J	94	942	10.02	132
25	Kim, S	93	680	7.31	137
26	Rodrigues, Jjpc	93	2388	25.68	498
27	Zhang, Z	93	1305	14.03	294
28	Liu, Z	90	1645	18.28	374
29	Sun, Y	86	2261	26.29	477
30	Zhang, L	84	2473	29.44	351
31	Wu, J	81	1885	23.27	533
32	Li, W	77	1180	15.32	246
33	Guizani, M	76	6234	82.03	799
34	Zhang, Q	76	3833	50.43	558
35	Li, S	74	5197	70.23	765
36	Park, Jh	74	2527	34.15	305
37	Liu, L	73	1044	14.30	184
38	Zhang, W	73	1441	19.74	216
39	Choo, Kkr	72	2532	35.17	430
40	Wang, C	68	1449	21.31	293
41	Wang, S	68	1029	15.13	206
42	Yang, J	68	1461	21.49	235
43	Kumar, N	66	2619	39.68	384
44	Lee, J	66	849	12.86	141
45	Liu, S	65	942	14.49	245
46	Kim, H	63	1103	17.51	112
47	Wang, T	63	1458	23.14	497
48	Li, D	61	1698	27.84	303
49	Li, F	60	1043	17.38	289
50	Liu, H	60	1159	19.32	287
51	Yang, Lt	60	2038	33.97	453
52	Zhou, Z	60	1174	19.57	247
53	Al-Turjman, F	59	1313	22.25	167
54	Chen, Z	58	1510	26.03	272
55	Kim, D	58	655	11.29	116
56	Zhang, S	58	742	12.79	268
57	Li, Q	56	670	11.96	145
58	Yu, H	56	1076	19.21	175
59	Li, M	54	915	16.94	179
60	Wang, Q	54	879	16.28	208
61	Zhou, Y	54	921	17.06	199
62	Chen, H	53	680	12.83	169
63	Yang, X	53	1846	34.83	398
64	Lee, S	52	307	5.90	60
65	Li, B	52	395	7.60	118
66	Liu, W	52	877	16.87	271
67	Zhang, C	52	859	16.52	198
68	Chen, S	51	1041	20.41	279
69	Li, L	51	1173	23.00	269
70	Park, S	51	556	10.90	111
71	Wu, Y	51	694	13.61	206
72	Zhang, D	51	1859	36.45	326
73	Liu, C	50	1010	20.20	187
74	Wang, B	50	571	11.42	182

citations, with an average of 192.6, although he is no longer publishing. Second, after being trained by Gungor V. C., prominent researchers such as Zhang Y., Wang X., Wang Y., and Wang X. published high-quality work, but they ceased publishing after 2018. Kumar N. is the active researcher who has collaborated with these eminent experts, and it is expected that he will continue to publish high-quality research.

4.3.5. *Classification of publications on country level from WoS data*

The total number of articles are published from 137 countries, out of which 99 countries with at least five publications are evaluated. Out of these 99 countries, only 77 collaborate except 18 countries. These countries have different TLS values, which suggests that they are collaborating with other countries. However, they are not collaborating with the countries included in this data, as illustrated in Fig. 14. It can be analyzed from the figure that China, the USA, India, Pakistan, Canada, South Korea, Italy, Saudi Arabia, Brazil, Spain, Germany, England, and Australia are prominent countries working on the subject which can also be verified from the Table 14. Out of these 14 countries, the USA had the first rank with 108,537 citations with 3371 publications. China is in second place with 105,611 citations with 5205 publications; third and fourth ranks are shared by Italy (1133 documents) and England (1432 documents) with 43,431 and 41,065 citations. After that, Australia took the sixth rank by publishing only 953 articles with 31,267 citations, right after India with 31,752 citations with 2080 articles. Later, Canada, Spain, France, Germany, Saudi Arabia, Sweden, Pakistan, and Finland have shared the remaining positions.

Moreover, from Fig. 14, it can be observed that China, India, and Canada belong to one group. They are collaborating with the countries of other groups, and the same goes for other groups also. For example, China has a strong affiliation with Australia, and Australia is close to Sweden. Also, Canada has fellowship with Malaysia while USA and Finland have strong connections with Greece. On the other hand, Italy, Taiwan, England, South Korea, Germany has done collaborative work by working together and citing each other's work. At the same time, Italy and England have fastened belts to work by staying in the same group. This analysis suggests, there are almost 14 countries that have worked since the year 2000 and have published quality work. Out of these, USA and China are the top countries working on the subject and have collaborated with other countries identified from Fig. 14 and TLS scores of 56,498 and 50,061.

4.3.6. *Classification of publications on universities level from WoS data*

The total number of articles are published from 10,146 universities, out of which 124 universities with at least 50 publications are evaluated to identify the major universities working on the subject. Table 15 and Fig. 15 show that these 124 universities are divided into four different groups, and only three are prominent ones. The top universities of these groups are Beijing University, Chinese Academy of Science, King Saudi University, and University of Electrical Science and Technology, China which has published more publications, and Beijing University is at the top with 325 articles. The universities with less than 70 publications have been grouped for the clarity of data which results in a total of 3533 publications with an average of 50 publications per country.

Further, the statistics differ in terms of the number of citations. As a result, Beijing University has been displaced and has moved to seventh place by the Chinese Academy of Science with 13,385 citations. Old Dominion University and Shanghai Jiao Tong University took the remaining top spots with 9781 and 9762 citations discretely, despite publishing only 76 and 145 articles. The University of Melbourne and King Saudi University, on the other hand, came in fourth and fifth place, individually, with 8146 and 8145 citations, despite publishing only 68 and 273 papers. These statistics indicate that while Beijing University published many articles (325), it did not receive enough citations. In contrast, the Chinese Academy of Science published only 288 articles and received 13,385 citations, averaging 46.4 citations per article, inferring that this institution published higher-quality work than other

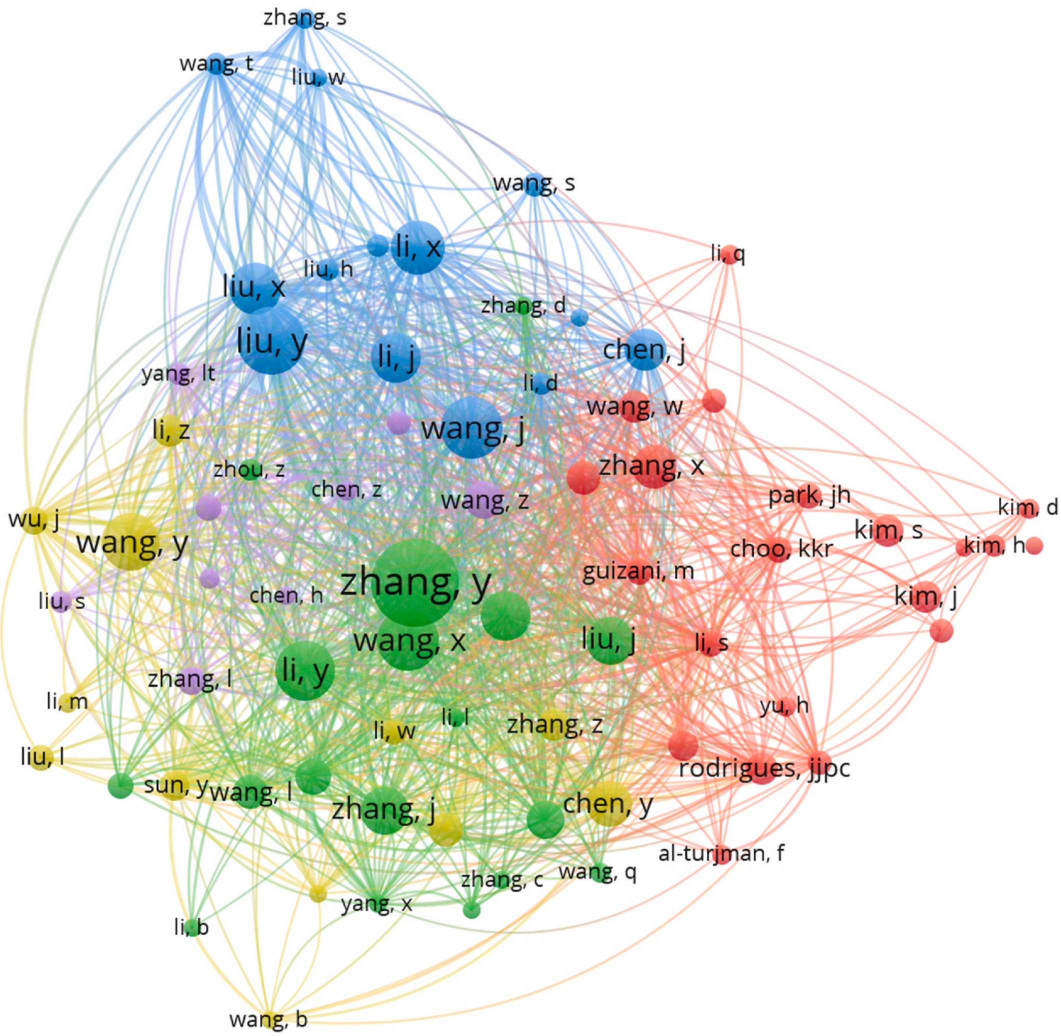

Fig. 16. Collaboration map of authors working on communication technologies around the globe according to WoS data.

top universities. This trend has been continued by Old Dominion University, University of Melbourne, and University of Science and Technology, China, by obtaining a higher number of citations by publishing only 76, 68, and 60 articles revealing that these universities are also producing quality work same as Chinese Academy of Science.

Three active groups of universities can be seen working with one another in Fig. 15. For example, a Beijing University research group is partnering with a Chinese Academy of Science group. University of Technology Sydney and Deakin University are collaborating to develop high-quality work. Despite the fact that King Saudi University's research group is larger than the other two groups, there is less interaction between the Chinese Academy of Science and King Saudi University, with only one university from each group communicating with each other.

4.3.7. *Relationship of authors and publications from WoS data*

The relationship between the authors, publications, and citations can be used to identify the primary research groups working on a given topic around the globe. For this purpose, 35,091 authors are evaluated globally. However, only 74 are selected while considering at least 50 publications by each author to filter out authors with quality work. From Table 16, Zhang Y. is the top author with a high no. of publications (280) and citations (7,535). He is followed by Liu Y. and Wang X. with 212 and 195 publications. But in terms of citations received, the stats are different except for Zhang Y., as he maintained his first position. Liu Y. is shifted one step downward as Guizani M. took second place with 6234 citations by publishing only 76 articles. Also, Wang X. has been downgraded from third place to seventh place. Li S. acquires the 4th by receiving 4858 citations with only 186 publications, and Li Y. maintained his fifth position with 186 publications and 1858 citations.

When looking at Fig. 16, these noteworthy authors are grouped into five huddles, with Zhang Y. being the most prominent among them due to his contributions to about 95% of other study groups. When the affiliation of each group is considered, however, only the research groups of Zhang Y., Wang Y., and Wang Z. are actively interacting. For example, Chen Y. has a good relationship with Zhang H., Zhang Z., and Li W. While Wang Y. has a coalition with Zhou Y., Liu S., and Zhang Q. Alternatively, Liu Y. and Zhang X.'s research groups, except for a few, are not interested in collaborating with other groups. Additionally, Fig. 17 shows that leading researchers who have produced high-quality studies and achieved notoriety have not produced anything since the middle of 2018. Li J., Zhang J., Rodrigues., Wang T., Zhang S., and Wu J. are active researchers who started publishing in 2019, yet their scientific contributions are minimal. Since these researchers have collaborated with famous researchers such as Zhang Y., Wang X., Wang J., and Liu Y., it is expected that they will continue to generate high-quality work.

4.4. *Future research direction*

As explained earlier, IoT implementation can result in some privacy and security concerns to users and the smart grid. Since communication technologies use different encryption and decryption techniques, they are still vulnerable to security and privacy issues. So, it is necessary to

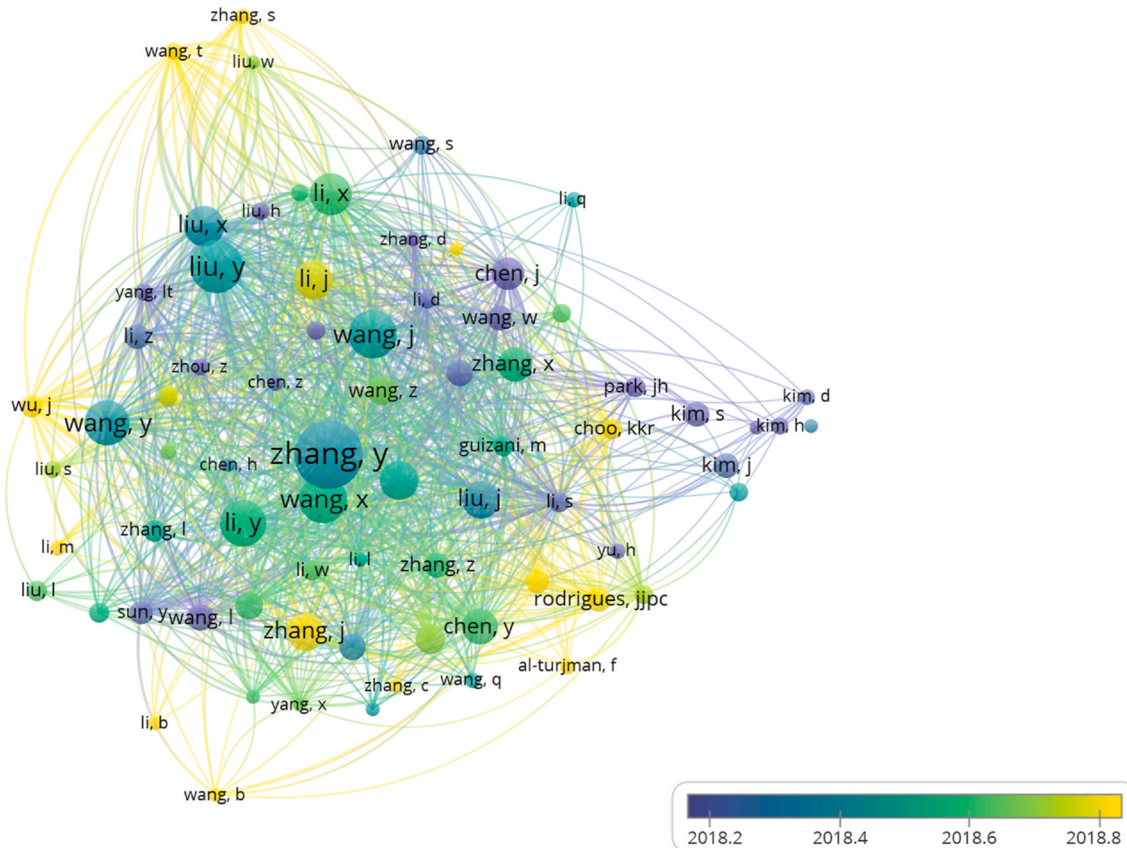

Fig. 17. Overlay visualization map of authors working on communication technologies according to WoS data.

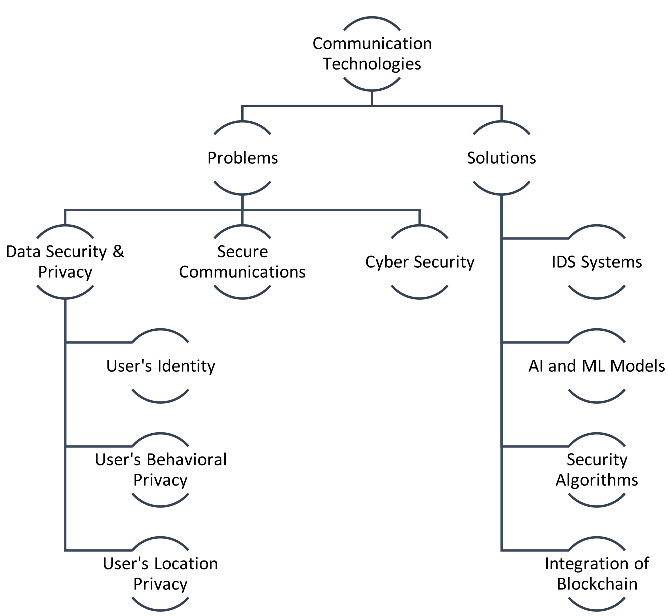

Fig. 18. Representation of problems and their solutions for communication technologies.

overcome these challenges. First, building some security algorithms using artificial intelligence, machine learning, and deep learnings are suggested to overcome the privacy issues in communication technologies. In addition, the problem of interference in communication technologies can be resolved by developing such algorithms that will eliminate or reduce this intercession. Fig. 18 shows the problems faced by communication technologies and their possible solutions.

As far as the cyber-attacks are concerned, there is a never-ending stream of newly found or evolving cyber-attacks. New tactics and recent technological breakthroughs are being utilized to bypass security systems, making it extremely difficult for smart grids, such as IoT-based smart grids, to detect such threats. As a result, studying these assaults on IoT-based smart grids and customizing remedies according to design is a considerable engineering effort for researchers. Customers' increased awareness of new tactics has resulted in increased security challenges. So, a tailored solution is required for each security issue in the smart grid application (Kawoosa and Parachar, 2021). Besides, Intrusion Detection Systems (IDS) based on rules and signatures have been widely utilized in the computer and network security. The IDS acts as a "first line of defense" against malicious agents and attacks. The IDS can protect smart meters from attacks and efforts to comprise their security and privacy of users.

Additionally, a decentralized medium is a good approach for improving security and privacy. Relatively new technology has been used in IoT research; the blockchain servers connect in the IoT ecosystem, allowing it to be distributed, trustless, and secure. By leveraging encryption without the use of centralized controls, the blockchain provides trustless networks and reduces latency in IoT connections (Ghorbanian et al., 2019).

5. Conclusion

AMI is a tried-and-true solution that gives utilities more visibility and control over their systems. It provides two-way communication and hands-on access to constantly updated data by connecting smart meters to a central hub. Ergo, this paper provides a concise overview of the communication technologies used in smart metering, which can help deploy AMI systems. Different approaches are applied to identify the right technology for a smart meter under the AMI system. First, a literature review on past research studies is done. Then a bibliometric analysis is done to find the top countries, universities, and authors with greater incidence in the subject worldwide. It is clear from a previous literature study and a brief explanation of the significant available communication technologies that no single technology will meet all smart meter requirements. The technology selection is based solely on demand for the proposed smart meter. However, a few main parameters can be kept in mind while selecting communication technology for smart meters. As a result, if the cost is not a significant concern, this study indicates that NB-IoT is the best option for smart metering projects because it has an extended coverage area, is highly secured, and can also be used in remote areas. LoRa or Wi-Fi, on the other hand, can be used to make smart meters more cost-effective. Also, to satisfy the requirements, hybrid communication systems are highly recommended.

Consequently, this paper has proposed a model of a hybrid communication system for smart meters while considering the cost of technology and heterogeneous networks. Also, if a utility provider already has a fiber-optics network in place, in that case, it is better suited for smart meters because it is more reliable, has a more extended range, and has a higher data rate. Further, by looking into the challenges of communication technologies, this study indicates the further research in developing the security algorithms for these technologies to prevent the cyber-attacks and use of blockchain technology to make the communication infrastructure more robust and secure.

Finally, a bibliometric analysis of data extracted from Scopus and Web of Science reveals the following information.

- It is reasonable to suppose that in 2012, various groups worldwide began to express interest in communication technologies and smart meters, resulting in an exponential increase until 2020. Besides, their enthusiasm has waned this year, but it is projected to rebound in the following years, allowing scholars to make more remarkable contributions to this topic.
- Classification of articles by country suggests that the United States, China, Italy, England, and Canada are the leading countries working on the subject, with most countries prepared to collaborate.
- According to a classification of publications at the university level, Towson University in the United States, the University of Waterloo in Canada, Chinese Academy of Science, Old Dominion University in the United States, University of Melbourne, and University of Science and Technology in China are the top six universities working in the field around the world.
- The research groups of Zhang Y., Wang X., Kumar N., Wang Y., Liu Y., and Wang J. are the most prominent in the field, with 317, 221, 89, 199, 212, and 194 articles, individually. Zhang Y. has the most publications (317) among these top researchers. At the same time, Gungor V. C. obtained the most citations (2,504) despite only publishing 13 articles, indicating that he produced high-quality work in 2016; he is no longer an active researcher.
- Although these famous researchers have not published any articles since 2018, Kumar N.'s research group is still active well as Li J., Zhang J., Rodrigues., Wang T., Zhang S., and Wu J. are also active researchers who started publishing in 2019; still, their scientific contributions are minimal. Since these researchers have collaborated with famous researchers such as Gungor V. C., Zhang Y., Wang X., Wang J., and Liu Y., it is expected that they will continue to generate high-quality work.

Credit author statement

Hadi Nabipour Afrouzi: Supervision, Revising the first draft., **Ateeb Hassan**: Preparing the first draft, Editing., **Kamyar Mehranzamir**: Validation, Reviewing and Editing, **Jubaer Ahmed:** Reviewing and Editing, **Chua Hong Siang:** Reviewing and Editing and **Chin-Leong Wooi:** Validation, and Reviewing.

Authors' contributions

All the authors had participated in preparing the manuscript.

Declaration of competing interest

The authors declare that there is no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clet.2022.100424.

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