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Research Paper

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ABSTRACT

Traditional energy meters have suffered from a lack of automated analysis and inaccuracy in reading energy consumption, which has brought about smart metering systems. Developing economies such as in Africa. still experience a setback in electricity monitoring and load distribution because of existing traditional meter systems in use. Communication technologies play an important role to improve the monitoring of energy consumption and ensure a road map toward a smart grid. This paper reviews communication technologies used for Advanced Metering Infrastructure (AMI) emphasizing Wi-Fi and Cellular technologies. Metrics used to evaluate their performance include cost, energy efficiency, coverage, deployment, latency, payload, and scalability. The review presents a benchmark for research on AMI communication technologies in developing economies. When adopted, the expected AMI benefits are reduced energy theft, cost efficiency, real-time analysis, security, and safety of energy supply in developing economies.

Keywords

Advanced metering infrastructure, wi-fi technology, cellular (GSM) technology, cost, energy efficiency.

INTRODUCTION

The traditional electricity grid was developed based on a one-way power flow from the major power plants (fossil fuels e.g., gas, coal, nuclear materials) to users, via transmission and distribution networks. As a result of the rise in electricity demand in the world and the effect of global warming, fossil fuels are being replaced by green renewable energy i.e., solar and wind energy (Is, 2010; Li et al., 2010; Yu et al., 2011). The traditional grid lacks automated analysis, has sluggish feedback, and evidences a speedily changing load state, restricted control, and inadequate coordination between generated and used energy. This has led to various blackouts in recent years across several countries with developing economies.

The smart grid constitutes the succeeding generation of the power distribution grid that seeks to provide a solution to the limitations of the traditional grid (Amin & Wollenberg, 2005; Farhangi, 2010). A smart grid uses bi-directional communications, advanced sensing, computing infrastructure, digital technologies, and software capacities to better monitor, protect, and enhance all grid items, including generation, transmission and distribution.

An Advanced Metering Infrastructure (AMI) meter, also known as smart meter is a digital version of a traditional electrical meter often positioned outside residential/commercial buildings. These new meters measure how much electricity is used and at what times during the day. Smart meters are also designed to transmit pricing and energy information from the utility company to users (via two-way communication). Utility companies that provide their customers with smart meters can implement a variety of load-reduction and energy-saving programs, which help to reduce the cost of providing electricity in a community. This data is transferred from the meter to the utilities through wired or wireless communication technologies.

Smart metering is considered a vital component of the smart grid. This study aims to provide knowledge in comparing Wi-Fi and Global System for Mobile Communications (GSM) technologies, and in justifying their performance based on certain metrics. We pose the following research questions:

- What are the limitations of traditional meters without communication technologies?
- What are the justifications for choosing Wi-Fi and GSM technologies among wireless communication technologies?
- How can these two communication technologies help AMI in energy distribution to utilities and customers?

The following contributions were made by answering these research questions:

Firstly utility companies, regulators, and customers in many developing economies do not have access to real-time data to assist them in making accurate decisions (Maggie et al., 2015; Sagiroglu et al. 2016; SGIG, 2016; Vineetha and Babu, 2014). There is often no real-time data about power usage for accurate billing purposes, which makes customers prone to being unfairly charged due to the use of estimated billing (Chakraborty & Sharma, 2016).

Secondly GSM technology has matured, and the modules are widely available for transmitting mobile data services. It has extensive coverage according to GSMworld.com in over 128 countries, and it saves costs Wi-Fi technology on the other hand allows users to access network resources from a convenient location within their networking environment. Additionally, expansion is very easy whenever there is a sudden increase in users within the existing equipment on the network. The deployment is straightforward because it requires only an access point (AP); it saves costs, and reduces labor (Mahmood et al., 2015; Wi-Fi Alliance, 2009).

Thirdly Wi-Fi and GSM communication technologies can help AMI and ensure data reliability, and speed in real time. This allows for the interconnection and exchange of information between various network components such as generators, substations, transformer stations, storage systems, and consumers. It benefits all system stakeholders, and their impact is reflected in the reduction of generation costs and improved electricity supply to consumers (Abrahamsen et al., 2021; Mendes & Andrade, 2019).

Metrics, such as cost, energy efficiency, coverage, payload length, scalability, security, deployment, and latency will guide the selection of robust communication technology for AMI. Bi-directional communications enable energy users to receive precise real-time bills and prices. The grid operator can get users' real-time details of the quantity of energy consumed. The authentic actual-time details run between all grids' items are needed for the successful operation of the smart grid. This can be carried out by effective and dependable communication technologies, whether wired or wireless. The merits of wireless technologies compared to wired technologies are that they reduce costs and promote easy connection to remote areas (Alsharif et al., 2022; Abbasian et al., 2020; Basar et al., 2019). The demerits are the electromagnetic fields that are highly dangerous to health, which also cause interference with other signals, and the dependence on batteries which increase the cost. The merits have attracted increasing attention over the years for practical performance. The smart grids link traditional power grids with the internet of things (IoT) to provide more accessible, accurate, flexible, and secure power grid systems where the management requirements of energy generation systems, observation, and user requests can be easily controlled (Sixto & Jorge, 2017). Smart metering systems (SMS) and sensors are the main components of smart grids. Wi-Fi and GSM communication networks play a vital role in power system management and can be employed to transmit data from the AMI to the cloud, where utility companies, regulators, and consumers can access real-time data and assist them in making accurate decisions. Therefore, this work will:

- assist the electricity company in deploying automated smart meters;
- help stakeholders and consumers to have real-time data about power usage for accurate billing;
- assist the regulators in formulating policies like electricity pricing reform rules and electricity supply regulations that regulate the retail sector;
- help regulators to make general policies regulating the generation, transmission, and distribution businesses to ensure orderly and fair competition in the market; and
- lead to customers being fairly charged and end the estimated billing regime (Kappagantu and Daniel, 2018).

A smart grid entails generating, transmitting, and distributing electric energy to the users. Smart grid improvement perception enhances electric power exchange for both users and utilities. In the United States and European Union, as developed economies, the useful features of the smart grid are self-healing transmissions and distribution power planning, that is, its resilience against natural disasters, attacks, and a peak power quality degree, along with a broader range of metrics beyond blackout. Countries with developing economies have recorded limited success in developing a smart grid architecture. The distribution level is crucial in order to cope with the high electricity demand, therefore, a paradigm shift in the design and operation of a smart grid must bring about a considerable change in the level of satisfaction given to consumers in developing economies (Karimi *et al*., 2015).

The fundamental expectations of the smart grid that has already emerged from developed economies, point the developing economies to a more customer-centric view, to keep them effective, empowered, and safe. To tackle these demands requires the latest designs and approaches built on enabling automated smart metering, known as AMI, which replace energy meters using a reliable wireless communication technology, specifically Wi-Fi and cellular, as well as the combination of data storage in static (cloud) and mobile platforms (Verma et al., 2016). This reliable network allows two-way communication among the grid, utilities, and users to optimize system reliability, quality, real-time and low-cost trading of electricity. The review study in this area is highly necessary, because it compares metrics like cost-efficiency, energy efficiency, coverage, deployment, latency performance, payload length, quality of service, scalability, and range between the two technologies (Wi-Fi and Cellular). This helps in choosing the better of the two technologies, making the survey unique, and serving as an improvement on previous research.

Wireless technologies have been proposed by the National Institute of Standards and Technology (NIST) as essential networks to be employed for a smart grid (Xu & Wang, 2013). The relevance of information systems (IS) in this research is that its key feature, viz. demand management, provides proficiency and dependability to the smart grid, mostly by selecting better communication technologies to improve the management. The main measures of selecting accurate technology are correlated to technological and economic feasibility. IS helps to improve e-commerce by allowing an enhanced technology alliance between electricity stakeholders and users. E-commerce is not limited to trading products, information, and services through computer networking, but also employs communication technologies to share information between stakeholders. The availability of data to both utility and customers helps to improve the user's experience by ensuring reliable and efficient delivery of energy for commercial gain (Brou & Janssen, 2015). Wireless communication networks are one of the most-researched areas in the power systems smart grid. Wireless networks have certain merits in terms of both coverage and installation (Xu & Wang, 2013).

Related work has been carried out in this area of research in other countries such as the US, Italy, Germany, the UK, and Pakistan (Aboumalik et al., 2019; Bagdadee & Zhang, 2019; Hilorme et al., 2019; Hlaing et al., 2017; Jukaria et al., 2017; Masood et al., 2013; More et al., 2019) and was successfully implemented. In countries with developing economies, electricity still suffers a setback in monitoring and load distribution, due to not having that which can enhance the smart operation of the existing traditional meter system. This research surveys wireless communication technologies Wi-Fi and cellular in developing economies' existing conventional grids for an advanced meter reading. Recent developments in this area provide the opportunity to implement energy-efficient metering technologies that are more precise and accurate, and error-free. The AMI system provides many aspects compared to reading an analog utility meter.

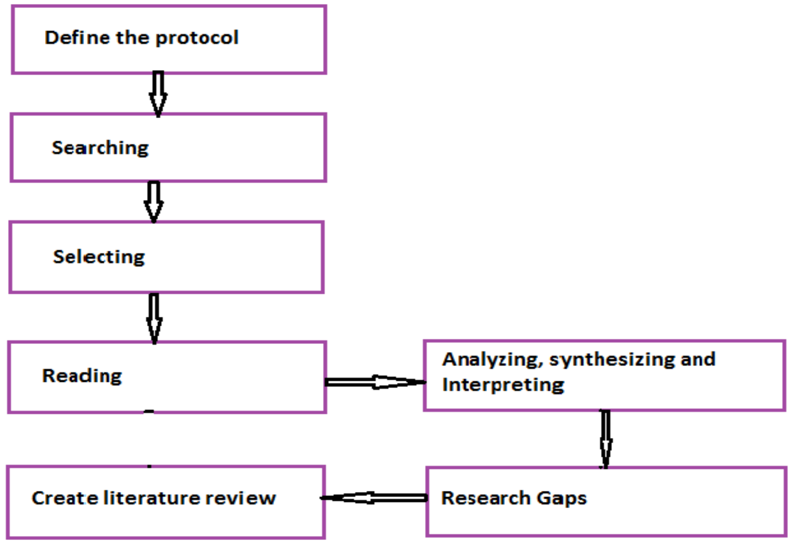
RESEARCH METHODOLOGY

Systematic review guidelines from journals in information systems (IS) such as those synthesized by Oosterwyk *et al*., (2019) and evident in Nguyen et al., (2020) show five important stages which are: (1) Define the protocol (2) Search the literature (3) Select the papers (4) Analyze, synthesize and interpret the data, (5) Create the literature review. Guiding principles for conducting literature reviews in IS are also apparent in other papers (Baghizadeh et al., 2019; Chipidza & Leidner, 2019). Stages in Figure 1 were carried out.

A comprehensive literature search was conducted, and selected papers were reviewed for inclusion (Snyder, 2019). Papers were searched on Title and Topic with the keywords "AMI, Wi-Fi Technology, Cellular Technology, Cost evaluation, Energy, Efficiency, Coverage, Payload length, Scalability, Security, Deployment, and Latency". Many papers were searched from 2002-2022, and some that have little or no relevance to the titles and keywords were excluded. The reviewed papers were considered satisfactory and enough to prepare this review.

Critical appraisal of the selected papers was done through reading. Reading entails interpreting what has been read from journals, proceedings, books, and others followed by classifying them accordingly. This helps to pinpoint where there are gaps/limitations in the papers read. The research gaps/limitations form the basis of creating a literature review.

Figure 1
Literature Review Process Framework

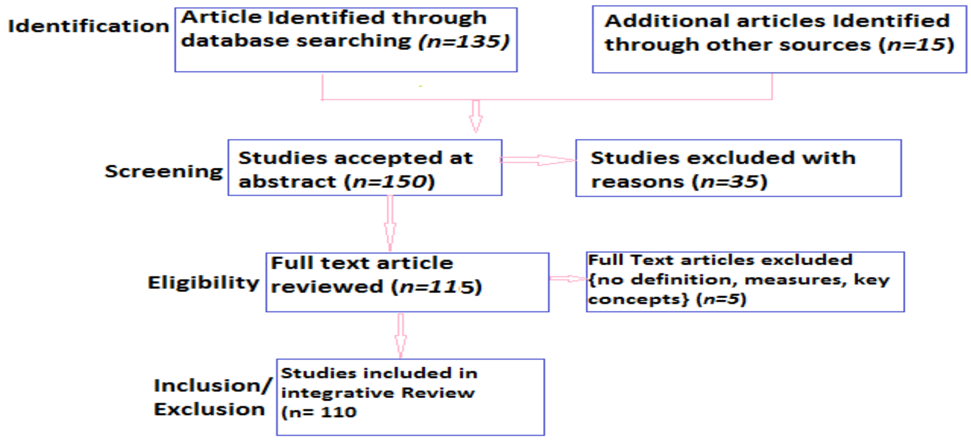


Note. Adapted from Oosterwyk et al., 2019.

The search and selection procedure is shown in Figure 2 (Pillay, 2017; Yorks, 2008). We adopt an integrative approach which identifies both emerging and mature topics and permits the inclusion of a broad range of methods, empirical and theoretical literature, and several views which are important for review (Callahan, 2010). An integrative review assesses the strengths of proof, identifies gaps in future and present research, generates research questions and bridges related published works, identifies a theoretical framework and a conceptual framework, and looks into methods that have been used successfully (Schimanski et al., 2020). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was the basis for search and selection (Snyder, 2019). Four steps were followed including spotting the appropriate literature, screening abstracts, reading the whole text to check for eligibility, and applying inclusion and exclusion criteria (Inayat et al., 2015; Meline, 2006; Patino & Ferreira, 2019). The first search resulted in 135 articles after duplicates were removed. A book was included (i.e., Statovci, 2015), with summary reports on energy from the U.S Department of Energy which was also captured at the initial selection (SGIG, 2016).

Figure 2

PRISMA Flowchart for Search and Selection of Papers



Note. Adapted from Pillay, 2017. PRISMA = preferred reporting items for systematic reviews and meta-analyses

Another 15 were identified through other sources. The abstracts of these 150 papers were read, while 35 were excluded because they focused on topics other than Communication Technologies for AMI. The full texts of the remaining 115 papers were reviewed thoroughly to see whether they could be included or excluded from the final review. To be included, articles needed to be published in English, and peer-reviewed with the definitions of the keywords, and the key concepts. Five papers were excluded at this stage, leaving behind a sample of 110 papers for final review. This is not a detailed list of all the papers. They only give an overview that represents what has been published on the topic.

The review study is centered on the expert's opinion with validated knowledge and is investigative to establish the fundamental facts (Albashrawi, 2021; Ofosu *et al*., 2021). For quantitative research, figures offer a graphical analysis of the findings. Tables were employed to summarize data that helps understand some metrics which best compared the two research communication technologies.

Google Scholar was employed as the search engine in this study, and articles on Smart Grid and AMI communication technologies were identified. Journals, conference proceedings, books, and magazines, were searched, e.g. *IEEE Network*, *IEEE Transactions on Smart Grid*, *Energy Policy*, *Applied Energy*, *Journal of Engineering Technology*, the *International Conference on Communication Systems and Network Technologies*, the *International Renewable and Sustainable Energy Conference*, and the *Electric Power Systems Research*, etc.

METERING SYSTEMS AND AMI: CONCEPT AND DEVELOPMENT

Metering Systems in Developing Economies

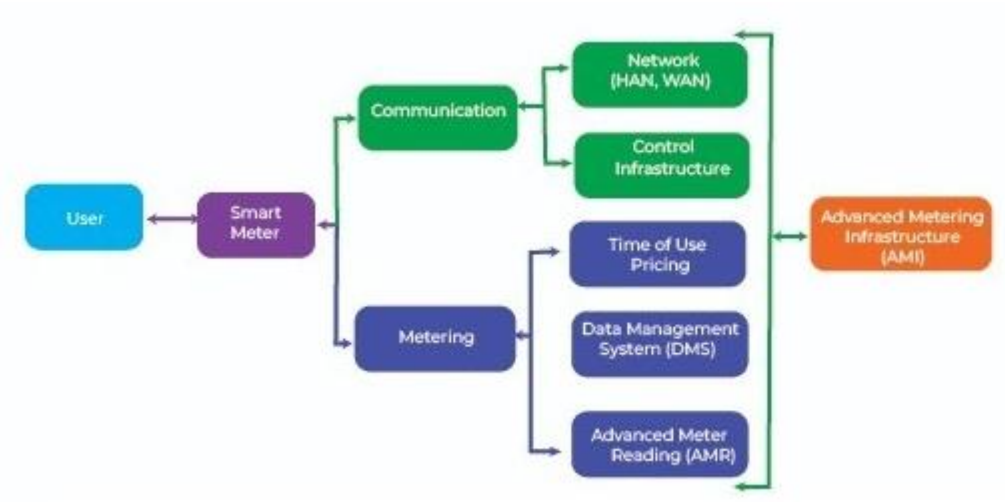
The metering system consists of components of metering tools like meters, current transformers, voltage transformers, the wireless and wired connections between the components, and how to send data recorded by the meter to the cloud through modems and communication cables (wirelines).

In countries with developing economies most metering systems have been based on electromechanical meter technology. This works by adding up the revolutions of a metal disc, which revolves at a speed proportional to energy drawn by the main fuse box. Neighboring coils rotate the disc by inducing eddy currents and a force proportional to the voltage and instant current. A permanent magnet uses a damping force on the disc, and thereby halts its rotation when power has been taken away. Reactive energy meters, referred to as sine meters, measure reactive energy. Maximum demand meters are used in energy billing for bulk users, and the extra cost is usually received from the users. Electronic meters like AMI can measure energy expended using smart meters and send measured data over a communication system, making it better than reactive energy meters and maximum demand meters. The latter type of meter has many drawbacks in smart energy, including its level of imprecision (Ezeodili & Adebo, 2018; Ndinechi et al., 2011). Electricity management is experiencing significant positive changes through the years, and technological advances in electronic metering systems has brought about smart metering systems (Odusami et al., 2019).

The smart metering method estimates the consumption and other similar billing variables in preset intervals. The data are modulated according to the communication protocol and transferred to management through wireless or wireline networks (Mir et al., 2019). The measurement is done by using a smart meter that measures the amount of energy consumed by the customer. Thus, the smart metering method ought to obtain the consumption rates in real-time by capturing the frequency, voltage, and phase angle. The smart metering system shown in Figure 3 is made up of communication infrastructures and metering. The metering part of a smart meter is the data management system, AMI framework, and time-of-use pricing control. Wireless communication and Wireline methods like power line communication (PLC) constitute the communication components of a smart grid. The communication technologies ought to allow two-way data flow, based on which smart meters can generate data about the utility grid and the users (Depuru et al., 2011; Wang et al., 2018). Therefore, the communication part of the smart meter comprises control infrastructure and network connections. This enables the meter to run the control commands and interact with remote centers. Apart from the two main sections, the smart meter modules are the timing module, control module, power supply module, metering module, encoding module, and communication module (Yang et al., 2014).

Additional attributes of a smart meter are the module logs for a user’s data, which are date, energy consumption, power factor, etc. The metering module immediately obtains and measures the current and voltage values by removing the smart meters from the utility grid. The billing module shows the energy bill in real-time. Smart meters hold important roles for smart grid in future application due to their real-time management, security features, and scalability (Yaacoub & Abu-Dayya, 2014). The remote monitoring smart meters will help utility companies curb unlawful electricity usage. The AMI attributes of smart meter’s bidirectional communication management mean that the smart meter is able to operate control commands and provides the opportunity to control smart meters. However, they carry the threat of unauthorized access, prompting concerns over privacy, safety, and security.

Figure 3
A Smart Grid Perspective

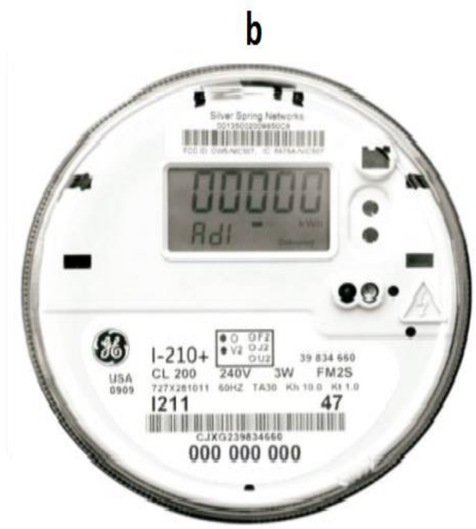


Note. Adapted from Depuru et al., 2011.

Figure 4(a)
Commercial Smart Meters which Records the Amount of Electric Energy Consumed

Note. Adapted from Yaacoub & Abu-Dayya, 2014.

Figure 4(b)
Commercial Smart Meters that Cuts the Electricity and Power Bills



Note. Adapted from Yaacoub & Abu-Dayya, 2014.

Figure 4(a) shows the actual model of the smart meter, which records the amount of electric energy consumed and communicates the data directly to the electricity supplier for billing and monitoring. Smart meters frequently record energy used and allow bi-directional communication between the central system and the meter.

Figure 4(b) above reveals the two-way communication smart meters that cut electricity and power bills. Some of its features are time of use; power quality analysis; prepaid billing; disconnect/reconnect switch; and remote control. Tamper events are detected, communicated, and logged when there is a power failure; load profiling; power measurement system, under and over-voltage detection with configurable voltage and duration thresholds. There is also detection with measurement up to the 10th harmonic to reveal unusual conditions (Yaacoub & Abu-Dayya, 2014).

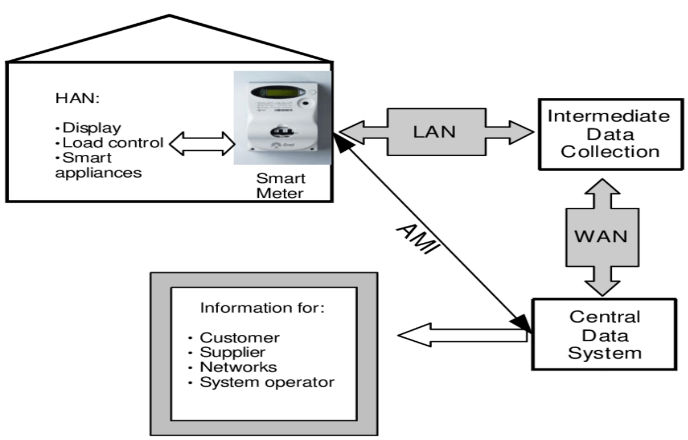
AMI

AMI is a better technology for analyzing, measuring, and collecting big data of big networks like transmission and distribution electricity networks. AMI is a merged system of smart meters, data management systems, and communications networks that allow for bi-directional communication between customers and energy suppliers. This system plays many core roles that were previously impossible or performed laboriously, for instance: the capacity to remotely and automatically measure the amount of electricity use, disconnect and connect the service supplied, isolate and identify outages, monitor voltage and detect tampering, integrate with users' technologies like programmable, communicating thermostats and in-home displays. AMI also allows energy suppliers to offer incentives and new time-based rate programs that motivate users to decrease demand peak and also to control costs and energy consumption (Kabalci, 2016; Palaniappan et al., 2015).

AMI systems are a vital technological development that can result in a better standard of living in a developing economy; metering has become an integral part of developed economies' everyday lives. This resolves many cases of the conventional meter reading system for accuracy, delayed work, human resources and efficiency, due to the fact that customers are not always available during a visit at the metering locations. Besides this, it is cheaper, and saves electricity both efficiently and effectively. It has the advantage of the ability to foretell the future energy demands from different households (Shrestha et al., 2020). The AMI method has been executed using different wired and wireless technologies e.g. GSM, Wi-Fi, ZigBee, PLC, D-SCADA, WiMAX, and hybrid technologies that comprise LAN and WAN.

Figure 5

Advanced Metering Infrastructure



Note. Adapted from Siano, 2014. LAN = local area network; WAN = wide area network

Figure 5 above shows that the establishment of a direct connection between the central data system and the meter is possible through the use of the ethernet/internet interfaces, public switched telephone network (PSTN), and a mobile data connection (GSM/GPRS) with a range of communication protocols that can be used for the home area network (HAN), for example Wi-Fi, and wide area networks (WAN) like GSM.

AMI solves many problems of traditional meter reading systems, such as accuracy of data, delayed billing, needless manual reading, efficiency, unavailability of a customer for energy capture, and many more. It has been shown to be more effective and economical and offers intuition to customer's load profiles, and energy-saving opportunities within the network (Popovi & Raki, 2022)

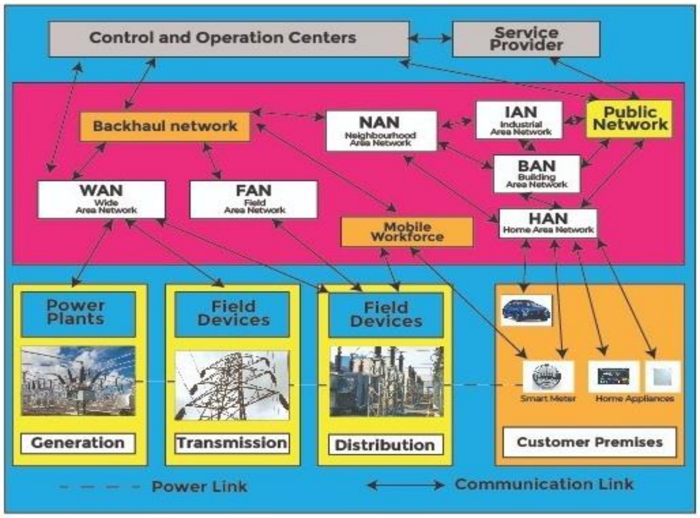
The AMI solution offers the platform with a proven technology through which the electricity distribution companies (DisCos) can fully automate their billing processes more reliably and transparently with approved cost reductions, optimization of the revenue life cycle, and improved collections. This technology mainly retrieves data, including energy theft-related data, from the meter's memory registers, and transmits the same to a secured central server location at various pre-configured time intervals, where it can be retrieved for network analysis, billing, business intelligence/analytics, and business loss management. It is reliable, robust, and scalable. After a few successful implementations in a developing economy like Nigeria, it has been demonstrated that a sector-wide acceptance will result in significant value to all stakeholders (Amuta et al., 2018; Hussain et al., 2022).

In addition, metering has developed from billing and revenue activity to a complete business enabler for DisCos. Extra facets of services of an effective AMI system allow utilities to provide value-added services to their customers, for example, by elevating monthly billing with load profiling and interval reading. Customer information systems can be improved by updating marketing systems and customer relationships. The depths of services that can be derived from AMI are: billing, collections, load forecasting, marketing, customer care, demand side management, repair and dispatch, and other intelligence-based targets (Diegbegha & Ayibapreye, 2021; Parra et al., 2019).

Smart Grid Communication Networks

Several research studies have been focused on communication networks for smart grid technology (Xu & Wang, 2013; Shaista et al., 2019; Wang et al., 2018; Hilorme et al., 2019; Kogias et al., 2016). The communication infrastructure and networks for smart grid systems employ a broad range of communication technologies that follow the order starting from wired to wireless and eventually to hybrid technologies. The real electrical grid already has between its control centers and substations a communications network that supports its operations, but this network is costly, inflexible, and inadequate because it covers generation and transmission only. The intended smart grid method involves enveloping all the sections of the networks, and most importantly, the area of its distribution. Consequently, the latest extended and improved communication technology is required in order to support and substantiate the smart grid systems and applications. Communication technologies for the smart grid are believed to be a hybrid mesh that consist of many different networking technologies and topologies, as shown in Figure 6 below.

Figure 6
Multi-Tier Communication Networks for Smart Grid



Note. Adapted from Eleyengui et al., 2014.

To control, monitor, and have two-way data flow between smart grid utilities and end devices, a dependable, unified communication network is required in order to envelop all the smart grid territory. The following section focuses on the two most prominent smart grid communication technology in order to allow for better comprehension of SG communication networks.

Table 1

The Similarity Between HAN and NAN Wireless Technologies

Coverage	Technology	Range	Latency	Reliability	Ease of Deployment and Cost
NAN	802.22	30 km	Medium	Medium	Medium/High
	WiMAX	30 km	Low	High	Low/Medium
	UMTS/LTE	30 km	Low	High	Medium/Medium
HAN	Bluetooth	100 m	Low	Medium	Low
	Wi-Fi	100 m	Low	Medium	Low
	ZigBee	200 m	Medium	Low	Low

Note. Adapted from Li et al., 2012; Elyengui et al., 2014.
HAN= home area networks, NAN= neighborhood area networks.

In Table 1 above, examples of neighborhood area networks (NAN) are WiMAX, UMTS/LTE, 802.22, and home area networks (HAN) are Wi-Fi, ZigBee, and Bluetooth. Their range, degree of latency, reliability, cost, and ease of deployment are respectively indicated.

Wired Communication Technologies for Smart Grid

This technology deals with the transmission of data through a wireline network for Smart Grid, they are regarded as the most reliable of all types of communication services in existence and highly resistant to unfavorable weather conditions. Three types of wired communication technologies are hereby explained.

PLC

The PLC technology uses the modulated carrier through the power line wire to create bi-directional communications. It can be grouped into two main classes: Broadband PLC and Narrowband PLC. In this method, utilities can employ power infrastructure for data flow exchange and monitor all control messages. It is regarded as a cost-efficient smart grid communication system that is broadly used in AMI applications. PLC technology has been employed in many smart grid areas from heavy generation to distribution, and finally to the consumers. Consequently, it can be a practical way of solving smart grid communication infrastructure problems (Galli et al., 2011). PLC is not suitable in the home area network environment, but it has become an appropriate solution due to the lack of standards and interoperability, the numerous protocols, and the numerous vendor environment in home area networks (Tonello & Pittolo, 2016). Energy operators normally use PLC technologies, because they have an advantage over the rest of the communication systems. Narrowband PLC is communication that has a low bandwidth, and makes use of a frequency band that is lower than 500 kHz and gives up to data rates of tens of Kbps, whereas broadband PLC uses ample broader frequency band, usually between 2MHz and 30MHz, and also gives space for hundreds of data rates of Mbps. The narrow band is commonly used in advanced metering, smart grids while broadband is commonly used in gaming, audio, and the internet. They have their standard globally in the IEEE and the International Telecommunication Union (Kabalci, 2016).

Fiber-Optic Communication

Fiber-optic communication is broadly employed when there is a need to connect the network's operation, substations, and control centers. Many advantages make it a better choice in high voltage environments, viz. robustness against electromagnetic interference and radio, and the capability to transmit through large distances with very high bandwidth. Fiber-optic communication plays a significant role in smart grid communication infrastructure by using a technology called Optical Power Ground Wire in the distribution and transmission lines and shows a high degree of efficacy in the context of smart grid when the connection of optical communications and grounding permit transmissions of long-distance together with high data rates. Fiber-optic technology is also used to provide customers service (Wang et al., 2020) by using passive optical networks, since the splitters they use to obtain optical signals do not require switching equipment. The ethernet passive optical network comes with access network technology that provides a method of low-cost to deploying its access lines between a customer site and the carrier's central office, and is the best technology for accessing the smart grid section; it also authorizes using internet protocols based on optical networks technology (Richardson, 2016).

Digital Subscriber Lines

Digital subscriber lines allow data transfer over telephone lines. Their major merit is their ease-of-use in the context of the smart grid, since energy utilities can instantly have their advantage without the additional deployment costing them anything. There are several alternatives with digital subscriber lines, such as asymmetric digital subscriber lines with between 1Mbps and 24Mbps downstream, and 640Kbps to 8Mbps upstream. Very high bit digital subscriber lines allow for up to 16Mbps upstream and 52Mbps for downstream over very short distances (Statovci, 2015).

Wireless Communication Technologies for Smart Grid

The area of interest in this research is wireless communication technologies suitable for automated meter reading, i.e. Wi-Fi and cellular technologies, but other wireless technologies will also be discussed briefly.

WiMAX

WiMAX is known as the IEEE 802.16 standard (Pa, 1967). It gives support to long-distance broadband of up to 10 Km and a 100Mbps data rate (Pareit et al., 2011). IEEE 802.16 was created to manage many users that are synchronized over wide distances. The recent version standard is 802.16j of WiMAX, which supports broadcast and multicast methods with mobile users' seamless handover. It strengthens higher coverage and easy distribution, making it a good choice for NANs and AMI applications. WiMAX low version named 802.16m gives a data rate of 100Mbps with greater mobility up to 350 km/h, while it also supports handover with long-term evolution and Wireless-Fidelity (Wi-Fi), demonstrated in a long-term evolution simulation (Al-hawawreh, 2017).

Long-term Evolution (LTE)

Long-term evolution (LTE) or 4G standard-advanced, is a standard of wireless communication (Grigoriou & Chatzimisios, 2014), introducing various abilities like easing handover among different networks, bandwidth, and proficiency in advanced networking. LTE has many merits that make it the best choice for NANs e.g. rates of peak upload near 75 Mb/s, end-to-end quality of service, and download rates of up to 300 Mb/s.

The use of LTE technology in the smart grid framework can be in two ways. The simplest is for instant implementation. It is a cost-effective and efficient method, as it entails carrying the data over the main mobile architecture of mobile network operators (MNOs) with techniques from smart grid end devices in HANs, over NANs, to wide-area networks, and then on to the utility. Unique network architecture for data transfer is the second method, whose execution is very close to the mobile virtual network operator's method. This can be done by implementing the basic smart grid utility network architecture employing LTE technologies (Bou-Harb et al., 2013). The ease of implementation, low cost, and security make LTE a better choice for communication techniques in NANs.

Low-rate Wireless Personal Area Network (LRWPAN)

A low-rate wireless personal area network (LRWPAN) has a standard IEEE 802.15.4 for MAC and physical layers. It supports many network topologies like mesh, tree, or star multi-hop and provides up to 250 kbps over 10m. LRWPAN is the foundation for most standards for control and monitoring applications; the main standards are wireless HART, ZigBee, and ISA 100.11a, but the most widely adopted for wireless personal area networks is ZigBee, for both industrial and commercial environments (Mubashar et al., 2021).

IEEE 802.15.4 (ZigBee)

IEEE 802.15.4 known as ZigBee is a standard communication technology that defines the medium access and physical layer. It is also known as a LRWPAN (Ejaz et al., 2013). The network consists of three basic types of nodes: the router, coordinator, and end device. The router carries the traffic between the coordinator and the end device and the coordinator manages and establishes the network. Routers and coordinators are powered by battery devices so that they will not go to sleep mode, and they have the capability of communicating with other smart devices in the network. The end devices can only connect with the coordinator and the router. ZigBee network sleep mode at the nodes helps make the network energy efficient and consumes less power than other communication networks.

Cognitive Radio Networks (CR)

This is a separate standing radio, which is predominantly based on IEEE 802.22 standard. It is a key technique for optimizing a spectrum that is not utilized well, and making use of these instead of requiring complex sensing (Ancillotti et al., 2013; Kogias et al., 2016). As a result of increasing demands in the spectrum caused by expansion of wireless technologies, cognitive radio networks allow secondary users to enter the spectrum when not utilized well by the licensed primary users, without interfering with primary users. In a smart grid-wide area network, the system that senses the spectrum can be broadly deployed. Cognitive radio technology is composed of opportunistic access to the spectrum that has not been utilized. This technology will lend the smart grid greater longevity, due to its high performance, and data transmission with high speed. With cognitive radios, the smart grid is smarter, more reliable, robust, scalable, secured, and sustained (Qiu et al., 2011).

Dash 7

Dash 7 technology is based on ISO/IEC 18000-7 standard for wireless sensor networks which Dash 7 Alliance promotes. Its coverage area is between 250m-5km and also operates between 28kbps-200kbps. It has very low power, with a battery that lasts for several years, making it highly cost-effective. Dash 7 uses energy of up to 30-60 MW for a wake-up signal, and it has low latency within the range of 2.5-5s. It is justified by its robustness, interoperability, cost-effectiveness, and shorter communication time. All these advantages make it broadly deployed for military, and commercial uses e.g. smart home, building automation, smart energy, monitoring, and logistic control (Ayoub et al., 2019; Ajah et al., 2015). In the smart grid system, Dash 7 seems an alternative to ZigBee, but the limitation of Dash 7 technology is that it permits fewer nodes.

Wi-Fi (IEEE 802.11)

Wireless-Fidelity (Wi-Fi) is based on the IEEE 802.11 standard that is used to connect various types of devices with wireless capabilities like tablets, smartphones, laptops, and other wireless devices to each other on the internet through an access point (AP). It is a technology of wireless local area network (WLAN). It has benefits like high data rate, ease of setup, low cost, and short round trip delay, making it the most recognized and commonly used technology (Mekonnen et al., 2018).

Wi-Fi has a simple and easy access structure that is based on Carrier Sense Multiple Access/Collision Avoidance (CASMA/CA) technology. This works when Wi-Fi devices sense the channel first before transmission, Clear Channel Assessment (CCA) mechanism is completed, a channel is checked whether it is free or idle in the process for a period, after which this device begins to transmit. If a collision occurs when transmitting, the Wi-Fi device will enter a mode called back-off and stay for another time before trying again. Its unlicensed frequency bands are 2.4 GHz and 5 GHz, respectively (Poulose & Han, 2021). Wi-Fi standards family are IEEE 802.11n, which support the highest data rates of 150 Mbps and is the latest, IEEE 802.11a/g also supports a maximum of 54 Mbps. Standard 802.11e is very important for smart grid applications, due to its high quality of service. This technology uses a medium access control layer mechanism for deployment in an unlicensed spectrum. Medium access control refers to the protocol layer of Wi-Fi that maintains and controls various Wi-fi networks by properly coordinating their access to a shared channel (Parvez & Sarwat, 2019).

EDGE, GPRS, and GSM

The major advantage of cellular technology as compared to other wireless technologies is that it covers a larger area. This is the reason why utilities always utilize them mostly in supervisory control and data acquisition (SCADA) and in automated meter reading (AMR) systems (Ancillotti et al., 2013; Ananthapadmanabha et al., 2011).
This technology has disadvantages, like high cost and latency, when only a base station is available to serve many or a large number of users. This technology has had massive development in recent years with the evolution of 3G standards with a standard of very high packet access (HSPA+), providing up to 22 Mbps of data rate in the uplink and up to 168Mbps in the downlink (Borenius et al., 2021; Manam et al., 2019).
Table 2 summarizes wired and wireless communication technologies for Smart Grid.

Table 2

Summary of Communication Technologies for Smart Grid

Communication Technologies	Coverage	Applications	Merits	Demerits
PLC	Narrowband (NB) PLC: 150 km Broadband (BB) PLC: 1 5 km	NB PLC: Advanced metering infrastructure, Field area networks, Wide area network BB PLC: AMI/Home area network	Communication infrastructure for SG has been established already Low costs Separation from other communication networks	Non-interoperable High signal attenuation Channel distortion Interference with electric appliances and electromagnetic sources High bit rates difficulties Complex routing
Fiber optic communication	This depends on the standard used usually between 10 and 60 km	Wide area network, Advanced metering infrastructure	The distance is very long Uses ultra-high bandwidth Interference is very low	The cost is very high Not easy to upgrade Not fit for metering applications
Digital subscriber lines	This depends on the variant used Usually between 300 m and 7 km	Advanced metering infrastructure, Field area network	Usually deployed for residential customers Infrastructure has been established already	Unfit for very long distances
Wi-Fi	Based on the versions, it is usually between 300 m and 1 Km	Home area network, Advanced metering infrastructure	Low-cost deployments and flexibility of equipment It has many use cases	The interference is high Power consumption is very high It has simple quality of service support
WiMAX	Between 10 and 100 km depends on performance	Advanced metering infrastructure, field area network, Wide area network	Fit for a wider range When compared with Wi-Fi it has a longer distance It is connection-oriented	Very complex There is a network management The cost of terminal equipment is very high Makes use of licensed spectrum

Communication Technologies	Coverage	Applications	Merits	Demerits
EDGE, GPRS, GSM, 3G	HSPA+: between 0 to 5km	Home area network, Advanced metering infrastructure	Sophisticated QoS Devices like cell phones, smartphones, etc. are supported Power consumption is very low Cellular smart grid-specific service solutions High flexibility, suitable for different use cases Licensed spectrum use reduces interference Open industry standards	It may have a very high price for Telco operators' network Make use of licensed spectrum High latency
Long Term Evolution (LTE) 4-4 5G	0 and 100 km	Home area network, Advanced metering infrastructure	This also supported devices like cell phones with enhanced technology, handover, and higher flexibility	High latency The cost is very high
IEEE 802 15 4 Wide personal area network	10 and 75 m	Home area network, Advanced metering infrastructure	The power consumption is low, the cost is very low Good for devices with low resources	The bandwidth is very low Cannot perform well with large networks
ZigBee	0-100 m	Home area network, Advanced metering infrastructure	The new version of ZigBee SEP 2 0 standards, IPv6 networks with full interoperability	It has a very low bandwidth Unfit for large networks
Cognitive Radio	0-100 km	Advanced metering infrastructure, wide area network	It has long distances The performance is very high It is reliable It is scalable The broadband access has fault tolerance	The high sensitivity of the nature of wireless medium which generates information causes an increase in channel interference
Dash 7	Typically, 250 m - 5km	Home area network, Advanced metering infrastructure	The cost is very low Very low power The range is lower than ZigBee Efficiency	Unfit for large networks

Note. PLC = power line communication; SG= smart grid; GSM = global system for mobile communication; EDGE = enhanced data rate for GSM evolution; GPRS = general packet radio service; 3G = third generation of cellular technology; 5G = fifth generation of cellular technology; HSPA = high speed packet access; Wi-Fi = wireless fidelity; QoS = quality of service.

COMPARATIVE ANALYSIS OF WI-FI AND CELLULAR NETWORK FOR AMI IN DEVELOPING ECONOMIES

Context

Table 3 compares the standards between Wi-Fi and GSM wireless technology used for AMI. These standards are essential in analyzing the performance of each communication technology. It details the quality and evaluation assessment and accurately maps each technology for its reliability and efficiency.

Table 3

Comparison of Wi-Fi and GSM for Technology Based on Developing Economies

Standard	Wi-Fi	Cellular (GSM)
Application Focus	hotspots, email, SMS	audio call, video call, email, SMS
IEEE standard	802.11 a/b/g/n/ac/Wi-Fi 6	EDGE, GPRS, 3GPP, 4G, 5G
Technology Generation	WLAN	2nd Generation
Range	Middle-range technology 2.4 GHz, 5GHz	Long-range technology 900-1800 MHz
No. of Channel	14 (2.4 GHz)	125 900 MHz
Access Technique	CASMA/CA	TDMA
Spread Technique	DSSS, FHSS	TDMA
Modulation Technique	OFDM	0.3 GMSK
Encryption	128-bit RC4, stream cipher (WEP)	Inbuilt A5 and A8 security algorithms
Maximum data rate	54 Mb/s	9.6-14.4 kb/s
Coverage	100 m	0.5-35 km
Channel bandwidth	22 MHz	200 KHz
Data Protection	32-bit CRC	3-bit CRC with ½ convolution
Network Topology	Star topology	Multipoint to multipoint
Maximum no of cells node	32	7 cells/cluster
Power Consumed	3.16-100 MW 15-20 dBm (Medium power)	0.5-2 W 27-33 dBm (High Power)

Note. Adapted from Borenius et al., 2021; Elyengui et al., 2014; Ibrahim et al., 2017; Manam et al., 2019.
IEEE = The Institute of Electrical and Electronics Engineers; SMS = short message service; 3GPP = the third generation partnership project; 4G = fourth generation of mobile systems ; CASMA/CA = carrier sense multiple access/ collision avoidance; DSSS = direct sequence spread spectrum; FHSS = frequency hopping spread spectrum; OFDM = orthogonal frequency division multiplexing; TDMA = time division multiple access; GMSK = Gaussian minimum shift key; RC4 = rivest cipher 4; CRC = cyclic redundancy check; WEP = wired equivalent privacy.

Cost

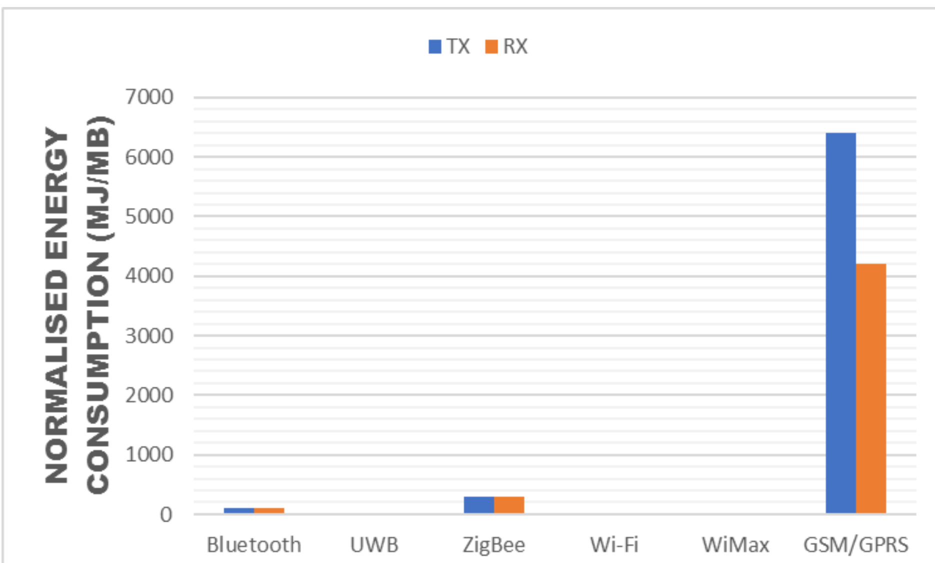
GSM networks operate in a licensed frequency of 900-1800MHz, where, in a developing economy like Nigeria, spectrum cost need to be considered, along with network/deployment cost and device cost (Manam et al., 2019), while with Wi-Fi communication technology, there is no spectrum cost to be considered, because it operates in an unlicensed industrial, scientific, and medical frequency band of 2.4 MHz. Only network/deployment cost and device cost will be considered. The major advantage of Wi-Fi is its cost-effectiveness. Wi-Fi provides low-cost communication as compared to cellular technology (Ibrahim et al., 2017).

Energy efficiency

The major determinant of whether or not energy is efficient in cellular devices is the power needed for data transmission. In Wi-Fi technology, the network is mostly uniform at a single access point (AP) across all the nodes on the network communicating through it. The AP is normally attached and connected to the internet through the distributed system. This type of network AP is usually one that uses energy regularly, regardless of traffic level. The topologies of the new network give better energy strategies that are more efficient (Li et al., 2011; Wan et al., 2020). Different-sized cells can be used to build a network and several radio technologies that meet the needs of the sized cells. Levels that possess different power that is needed have been shown to provide better energy efficiency. Current nodes can be replaced with femtocells, i.e. smaller cells. Femtocells are small, low-power devices that are designed mainly to work in the home, and these come with the advantage of reducing the consumed power and the network operational cost. The deployment of a Wi-Fi access point and femtocells have attracted notable interest. Wireless local area networks and long-term evolution can provide service to the same coverage area with different coverage ranges. Wi-Fi networks can save energy with less interference, provide improved waveforms, and have better energy efficiency (Baviskar et al., 2015; Feng et al., 2013; K & E, 2015; Saad et al., 2014).

Figure 7

Comparing the Chipset Normalized Energy Consumption for Each Protocol



Note. Adapted from Baviskar et al., 2015; Cai & Ugweje, 2002; Saad et al., 2014.
TX= transmitter; RX = receiver; MJ = megajoule; MB = megabyte.

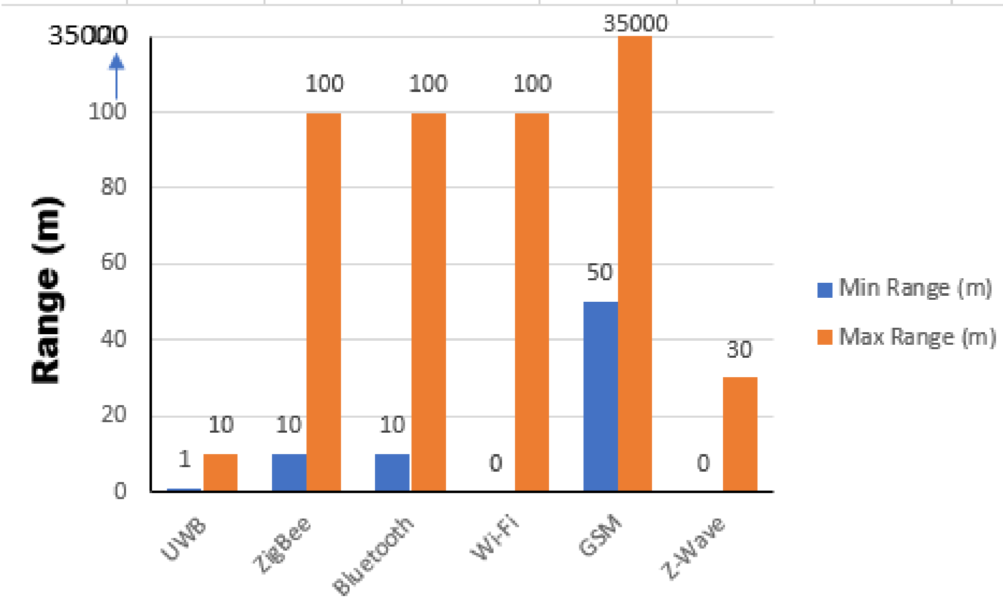
In Figure 7 above, the energy consumption measured in MJ/Mb and the data rate were shown and identified. The energy efficiency of a Wi-Fi network is more favorable, and would be the best solution for the implementation of a high data rate as a result of its normalized energy consumption, which is very low.

Coverage

Wireless signals are strong within a certain physical parameter, e.g. distance, where the signal strength significantly weakens beyond that parameter. Other physical factors are trees and walls. This leads to slowing, intermittent or total breaks in network connectivity. Within a Wi-Fi wireless network, depending on the router specifications, there is a fixed recommended coverage perimeter (Mubashar et al., 2021). Depending on its system specifications and setup, the Wi-Fi network can yield a solid and high-speed connection within the specified coverage. The coverage of the network and the cell will depend for the most part on some natural factors like propagation situations/geographical area and human factors, e.g. the subscriber altitude, the landscape (rural, urban, and suburban), etc.

Figure 8

Graphical Representation of Wireless Communication Coverage



Note. Adapted from Baviskar et al., 2015; Cai & Ugweje, 2002; Obelovska et al., 2021.

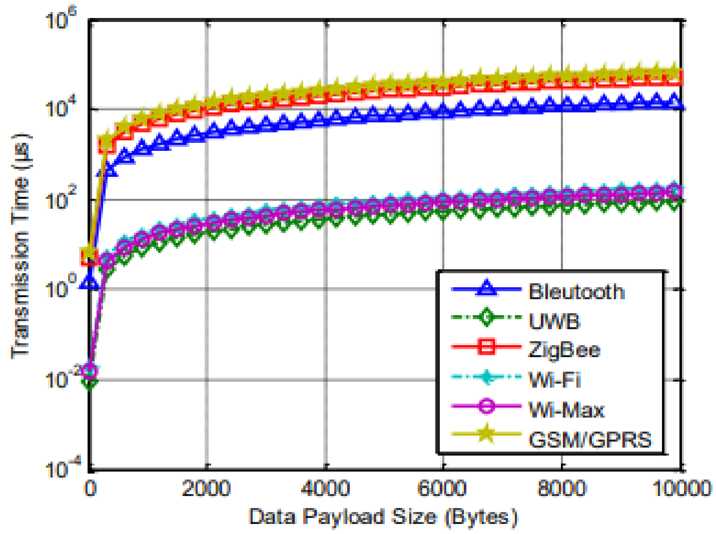
Figure 8 shows the minimum and maximum range of coverage area in each wireless communication. Wi-Fi communication has no minimum range but has a maximum range of 100 m in coverage area while GSM has a minimum range of 50 m and a maximum range of 35 km in coverage area, which establishes that GSM networks have wider coverage than do Wi-Fi networks.

Payload length

The payload length parameter explains the data payload length. The number of bytes in the payload depends on the type of packet selected. The standard length of the payload field of internet protocol version 6 and version 4 (IPv6 and IPv4) are16 bits, which have the capability of identifying the peak length octets of 65535 for the payload (Cai & Ugweje, 2002; Mubashar et al., 2021; Saad et al., 2014). In reality, the hosts ascertain the maximum operational length of the payload by applying path maximum transmission unit (MTU) discovery, yielding the minimum MTU along the path from sender to receiver to avoid having an incomplete packet.

Figure 9

Transmission Time Versus Data Payload Size



Note. Adapted from Cai & Ugweje, 2002; Saad et al., 2014.
UWB = ultra - wideband

From Figure 9 above, the time of transmission for the general packet radio services/global system for mobile services (GPRS/GSM) is not the same i.e., longer than the rest of the wireless technologies, as a result of its low data rate of 168 Kb/s, whilst ultra-wideband (UWB) require a small transmission time compared to the other wireless technology, because this has a better data rate. This shows that the requisite time of transmission is proportional to the data payload size of the data and not proportional to the maximum data rate. Therefore, the payload length of the GSM network is higher than that of a Wi-Fi network.

Scalability

Scalability is defined as the ability to increase the network size and modify the network for future development. When scalability is limited, a bar is placed on how wide a network can be increased or grown. Wi-Fi networks allow the use of hardware access points ad-hoc (routers), a mesh-based network such as ADRAN or Meraki, which is endlessly scalable and incredibly easy to manage. Wi-Fi expands in terms of both speed and distance from 802.11a-g from 11 to a high speed of 54 Mbps, thereby reducing interference. It also expands in terms of bandwidth and compatibility. Cellular networks also expand in terms of speed and distance from 2-5G, bandwidth, and incompatibility. One of the requirements for communication technologies and networks is scalability, which both Wi-Fi and cellular networks satisfy (Ibrar & Wang, 2015; Mohammadkhan et al., 2019).

Security

Security protects privacy to ascertain the right protection and operation of user's personal information/data since comprehensive information about private lifestyles and habits can be inferred by analyzing the user's profile of electrical load. Encryption is one of the ways to achieve security. For Wi-Fi technology, most contemporary routers are manufactured to have encryption turned on by default, which come in two types WPA1 and WPA2. WPA1 works with 802.11a/g, and WAP 2 works with 802.11n. Both types use a private key to encrypt and decrypt the data, which the sender and receiver ought to know. Encryption in GSM uses an inbuilt A5 and A8 security algorithm as shown in Table 3 above (Bakare et al., 2020; Cai & Ugweje, 2002; Hlaing et al., 2017; Olakanmi, 2020; Saad et al., 2014).

Deployment

The mode of communication can either be permanent or temporary, through the means of communication technologies. When planning to deploy a Wi-Fi wireless network, the number of clients, the expected traffic type on the network, the throughput amount on the network, and the access points number, where they can be mounted for maximum coverage, ought to be determined. The most important step in a Wi-Fi deployment is the site survey. The deployment cost of Wi-Fi is lower compared to GSM, because it operates via an unlicensed, industrial, scientific, and medical frequency band of 2.4 MHz (Bakare et al., 2020; Cai & Ugweje, 2002).

Latency

Wireless communication technology's latency refers to the delay in sending packets of data from one place to another. The unit of latency is milliseconds (ms). The ping rate when carrying out speed tests also determines latency. Latency is a factor that is important when planning the deployed remote control. Ideally, latency must be very close to zero. The latency of the network can be determined by measuring the cycle of time for a packet of data to travel from source to destination. Low latency is related to a positive user experience, while high latency is associated with poor user experience. Latency in Wi-Fi networks should not be more than 2-3 ms, which is just processing time on AP/Router. If it is heavily congested or has many collisions on wireless, it can be as high as 4-6 ms. Any higher latency indicates a poor connection or interference. Latency in cellular networks especially for GSM should not be more than 100 ms (Aburukba et al., 2020; Hlaing et al., 2017; Ma et al., 2019; Velasquez et al., 2017; Zhang et al., 2018). Wi-Fi performs better in terms of latency when compared to GSM networks.

Quality of service

Quality of service (QoS) can be measured based on the operations and capacity of base transceiver stations (BTSs) within a location. Key performance indicators (KPIs) are parameters retrieved from BTS to analyze QoS provided over a given time period. They are data measured and data-logged, usually on an hourly basis, and then retrieved from BSC when desired. The values of KPIs recommended by Nigeria Communications Commission (NCC) for effective communication in Nigeria are shown in Table 4 below. The following are the major KPIs used for analyzing QoS.

Table 4

KIPs Value for NCC Recommendation

KPIs	NCC Recommendation (%)
Control Channel Set-up Failure (CCSF)	≤ 1.2%
Drop call rate (DCR)	≤ 2.0%
Hand Over Success Rate (HOSR)	≥ 99.0%
Call set-up success rate (CSSR)	≥ 98.0%
Traffic Channel Congestion Rate (TCHCR)	≤ 2.0%

Note. Adapted from Lawal et al., 2016.
CCSF = control channel set-up failure; DCR = drop call rate; HOSR = hand over success rate; CSSR = call set-up success rate; TCHCR = traffic channel congestion rate

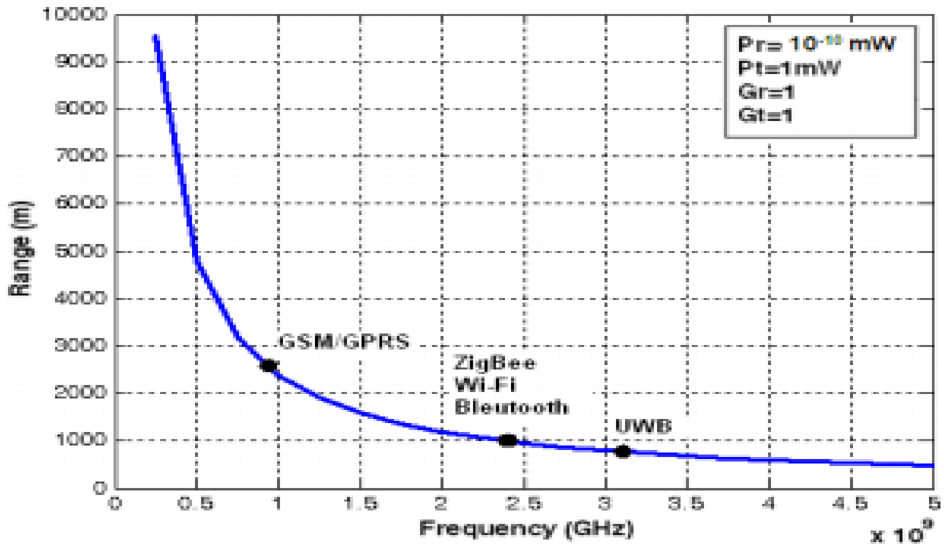
TCHCR measures how busy a cell is while setting up a call due to traffic congestion. A higher TCH congestion rate indicates difficulty in establishing a channel. Every BTS has a definite number of channels that can run simultaneously. Once the channels are exhausted, it becomes impossible for a new caller to establish a call with the other party. BTS is usually configured with a high number of TCHs, which must outweigh the expected maximum number of users within the BTS coverage zone. The maximum NCC-recommended TCH congestion rate is 2% or less. It should be noted that a higher TCHCR does not imply a call and cannot be set up unless the TCHCR is 100%, which is practically impossible. CSSR refers to the ratio of successive calls initiated by callers to the total number of attempted calls. The higher the CSSR, the better the performance of a cell. DCR is the ratio of the number of live calls prematurely terminated by the network to the total number of live cells within a particular time. It is usually calculated on an hourly basis. Hand Over Success Rate (HOSR) refers to the ability of live calls (established channels) on a particular network core to be transferred successfully to another network core. The user performance is directly affected by the handover success rate, which is an important key performance indicator to hold call type. When the user crosses different cells, this key performance indicator allows the user to communicate endlessly. It is the ratio of handover that is successful for the total of handover requests. Control Channel Set-up Failure (CCSF) captures the percentage of unsuccessful control channels set up in a given period (usually 60 minutes), referred to as CCSF. Key performance indicators could be technical, such as call drop rate, connection speed (upstream and downstream), SMS delivery time, call success rate etc.; or non-technical like customer faults and billing accuracy, etc. Key performance indicators help for monitoring purposes (Lawal et al., 2016; Li et al., 2016; Vucinic et al., 2020). The dynamism of the Wi-Fi network enables the users to join and then leave the network at any time. Non-homogeneous service quality demands differentiate traffic within this network and since its spectrum has minimal resources when the data traffic is high, there will be congestion in the network, which automatically affects the quality of service (Wortmann & Flüchter, 2015). Therefore, QoS in GSM technology is better than that of Wi-Fi technology.

Range

Range refers to a communication system that covers the largest distance the signal can travel between a source and destination up to the signal being received with sufficient strength. Figure 10 explains the differences in signal range based on the transmission frequency for a fixed power. GSM/GPRS signals with a frequency of 900mhz penetrate better than Wi-Fi, Bluetooth, ZigBee with a frequency of 2.4GHz, and ultra-wideband (UWB), which has a frequency of 3.1Hz.

Figure 10

Range Versus Frequency of Transmission



Note. Adapted from Malchi et al., 2021; Saad et al., 2014

Table 5 shows the summary of the research findings and studies.

Table 5

Summary of the Research Findings and Studies

S/N	Research Title	Motivation	Objectives	Methodology	Result	Limitation/ Gap	Author
1	Role of Information and Communication Technologies in the smart grid.	The smart grid needs communications in real-time with a better reliable communication infrastructure.	To realize better efficiency and reliability with the integration of alternative energy and renewable energy for the smart grid.	Bringing together information and communication technologies infrastructure, sensing, and metering technologies, automated control, and management of energy methods.	ICT that is enabled by Power consumption helps the shareholders to have better communication in two ways and to manage the grid efficiently.	Parameters for analyzing traffic analysis were mentioned but were not properly analyzed and there is no current math-ematical model.	Kabalci, 2016; Cavalieri, 2021
2	Evolution of communication technologies for smart grid application.	To realize a sustainable and acceptable standard and solution in smart grid communication infrastructure.	To study the environment and domain like automation of home area, automation of substation and metering communication that is automated	Discussion on major wireless communication technologies and PLC IEEE specified and their application in the Smart Grid.	The result shows that international regulatory authority, academia, and power utility companies are still striving towards sustainable and acceptable	This paper did not cover the area of smart metering using the best wireless technologies with AMI and elaborate on how to develop any of these	Usman and Shami, 2013

S/N	Research Title	Motivation	Objectives	Methodology	Result	Limitation/ Gap	Author
			in developing a smart grid		standards and solutions worldwide.	technologies to propose the best at a reduced cost.	
3	Execution of Single-Phase Smart Meter with Wi-Fi technology	To manage and control a large amount of data generated in IoT for smart meters.	To implement wireless sensors at a low-cost network and protocol for smart energy and web application with the capability of automatically reading and sending the data for the users to see their current reading on the energy meter.	The methodology consists of an ESP8266 Wi-Fi module, a digital energy meter, and web applications that manage the system. ESP8266 Wi-Fi module is connected to the meter and establishes the TCP/IP protocol between the web application and the meter.	The result shows that the method works efficiently, and can be implemented practically for a very low-cost automatic energy meter reading.	The efficiency at which the proposed system works well should be known to know the reliability of the method used.	Hlaing et al., 2017
4	Overview of smart grid communication technologies.	To know the best communication technology for smart grids.	To give a summary of the smart grid model, and a full explanation of the review of IoT and wired communication technology for smart grid communication infra-structure.	Research on end-to-end communication infrastructure for HANs, NANs, and WANs.	To choose the best communication technology for smart grid communication networks through their merits and demerits.	Wireless technology widely used in smart grids needs analysis and comparison.	Elyengui et al., 2014
5	Intelligent electricity with wireless metering and costing system.	To provide a solution to multiple challenges facing electricity in Nigeria.	To confirm meter functionality, accuracy, and efficiency using GSM communication technology.	The micro-controller meter with GSM module (AMI) communicates with the utility company through SMS using the LCD /accessible web.	The result shows the functionality of the meter, its efficiency, and its accuracy. The meter is used in two-mode and allows customers easy access history of energy expended.	There is no proposed architecture on how AMI with a GSM modem will automatically send data through SMS to the cloud where customers and utilities can access it.	Matthews et al., 2018
6	Smart energy meter billing, monitoring, and controlling system.	The system user can manage the power by knowing energy use always.	To check the use of energy through an energy meter with Wi-Fi technology.	Using a smart meter embedded with a Wi-Fi ESP8266 module that can connect globally for updates sent through SMS service.	AMI avoids costly mistakes and reduces maintenance, giving an efficient meter reading. It displays the corresponding information on the LCD for user notification.	Wi-Fi communication technology was not well analyzed, the (APs) with antenna and the number of nodes that can be connected where all the signals.	More et al., 2019

S/N	Research Title	Motivation	Objectives	Methodology	Result	Limitation/ Gap	Author
						through wireless will converge before transmitting to the cloud was not mentioned.	
7	A survey of communication/ networking in smart grids.	To resolve some issues like voltage sags, blackouts, and overloading.	To propose better communication networks based on QoS, control, and management.	The methodology used is reviewing different communication /networking technologies including their architecture, evaluation of QoS, control, and management.	reliable communication infrastructure of large capacity in real-time was achieved with integrated IT that handles big data of information across the smart grid.	This work was a proposed work that has not been carried out, the challenges mentioned were based on people's literature review.	Mir et al., 2019; Vaidya et al., 2020
8	Design and Construction of a GSM-based energy meter.	A sluggish and laborious system of manually reading meters and a high energy theft rate.	To design a system that monitors continuously meter reading and Automatically send SMS to utility companies and the customers.	The technique used is AMI with embedded GSM modules through serial communi-cation.	The meter provides a solution to the setback caused by the traditional metering system i.e billing reduction and power theft.	Other wireless communication systems were not considered that may allow compara-tive analysis to ensure that GSM is the best technology for the energy meter in this research work.	Akpofure, A.; Enughwure, 2019
9	Hybrid-cloud-based data processing for power system monitoring in smart grids.	Increase in energy demand and communication technology in the smart grid.	To investigate communication technology techniques and devices by using hybrid-cloud-based data. processing.	Construction of an accurate and reliable wireless sensor network that has good performance to monitor some important parameters in the power grid.	The metering devices were installed on the power grid to measure variables like voltages, currents, frequency, etc., which were stored in the cloud in real time.	The proposed method used is not cost-effective.	Talaat et al., 2020
10	GSM-based Automatic Energy Meter Reading Using Smart Energy Meter.	To curb a lot of flaws and errors in manual billing.	To verify the energy meter's performance and accuracy, obtain meter readings when desired by the users, and enable them to check the status of the load from anywhere.	The smart meter was used with a GSM module, which monitored and recorded the readings on the meter so that the users can check the state of energy expended anywhere.	The testing of the Smart Energy Meter (SEM) provided accurate results. It compares readings displayed on liquid crystal displayed (LCD) of a smart energy meter (SEM).	the process of transmitting the data from the smart meter through a GSM modem to the cloud, where users and utilities will have access to it was not analyzed.	Mortuza et al., 2020

Prospects

From the literature reviews presented above, a lot of work has been practically executed by interfacing microcontrollers i.e., Arduino UNO board with GSM or Wi-Fi module (smart metering), while some countries like the US, Italy, Germany, the UK, and Pakistan with existing meters, recorded outstanding success (Aboumalik et al., 2019**;** Abrahamsen et al., 2021; Bagdadee & Zhang, 2019; Elyengui et al., 2014**;** Hilome et al., 2019; Hlaing et al., 2017; Jukaria et al., 2017; Kabalci, 2016; Masood et al., 2013; Mendes & Andrade, 2019; Mir et al., 2019; More et al., 2019; Wi-Fi Alliance, 2009). Limitations noted in the review led to an extensive survey on Wi-Fi and Cellular Communication Technology for AMI in a developing economy, based on certain metrics, which are: cost efficiency, energy efficiency, coverage, payload length, scalability, security, deployment, latency, quality of service, and network range for proper comparative study of both technologies (Ali Khan et al., 2020; Arif et al., 2013; Ghosal et al., 2018; Gallardo, 2021; Haider & Saleem, 2018; Hussain et al., 2017; Jansen et al., 2020; Javed et al., 2017; Madueño et al., 2014; Mahmood et al., 2015; Mahmood et al., 2019; Puskar & Aanstoos, 2012; Van Bloem et al., 2012; Weiss et al., 2009).

Theoretically, the outcome of this research is as follows:

- it suggests how to bring about improvement in energy distribution, where utility companies are experiencing failures, and suggests how to overcome inadequacy in electricity supply to users;
- it provides information that will allow customers to manage cost, consumption, and other decisions about service and usage;
- it suggests how to help customers access their energy usage in real-time and meter recharge anywhere in the world where internet services are available (Jukaria et al., 2017; Masood et al., 2013); and
- it helps researchers to choose which technology best suits a particular area due to its geographical location in a developing economy like Nigeria.

CONCLUSION

A survey of communication technologies for smart metering systems was conducted emphasizing Wi-Fi and GSM technologies for automated meter reading in a developing economy. A thorough investigation has been carried out on performance analysis of some critical metrics like energy efficiency, coverage area, deployment, latency performance, payload length, quality of service, scalability, range, and security, which serve as determinants in choosing the best technology that provides reliable and affordable solutions.

This research:

1) suggests opportunities for consumers to employ AMI to access their bills whenever they wish to do so at any location they find themselves,
2) elaborates on the effectiveness and reliability of electricity distribution and creates a sense of convenience for the users of electricity and the utilities (Generation and Distribution Companies). The benefit would come from improvements in key value areas, such as reduced energy theft, cost, efficiency, security, and safety,
3) suggests how utility companies can have data on individual residential energy usage, which can be used for future forecasts; and lastly,
4) suggests how energy regulators can have direct access through Wi-Fi and GSM-based technology to customers' energy usage information. They could plan optimal energy dispatch, and economic

effectiveness of operation and have a monitoring system that provides a technical usage profile feedback in order to detect the case of electricity threat scenarios and fault locations.

FUTURE WORK

Researchers can improve on this review by considering higher technologies like 4G and 5G that allow carrying information at a faster data rate with lower latency. This makes more data available on electricity used in residential and commercial buildings in order to make informed energy forecasts.

RECOMMENDATIONS

It is recommended that the architecture for sending data to the centralized data center must be strictly IoT based; as this will help to reduce installation time, installation cost, maintenance cost, and ease o installation that is less labor intensive, unlike wired communication technologies with cumbersome and intensive human resources installation activity.

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