International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-12 Issue-3, September 2023

Zigbee based Wireless Sensor Network for Smart Energy Meter

Pratham Sharma

Abstract: ***Wireless sensor networks are expanding across a wide range of application scenarios. The most widely used transmitter is "ZigBee," which is used in wireless sensor networks. Based on the IEEE standard known as IEEE 802.15.4, ZigBee is an enabling low-cost technology that offers minimal energy consumption and a low data rate. It is used for remote control, medical aid, home automation, industry control, and other wireless sensor applications, in addition to wireless sensor networks and personal area network applications. This paper aims to develop a wireless sensor network and a protocol for smart energy meter applications. Our proposed system comprises a digital energy meter, a ZigBee coordinator, and a management application. A terminal alert and a cover alarm can be automatically sent to the management software by the wireless meter reading system once it has read the unit. Mistakes from Errors in leakage metering reading to manual meter reading can be avoided. This proposed system will improve efficiency by reducing labor intensity to liberate labor and force. The system setup can accommodate a large number of energy meters with sufficient hop network depth to detect a new energy meter automatically. The technology can be widely used in wireless monitoring and control applications because of its low cost, low power consumption, extended battery life, and mesh networking's ability to extend high reliability to a broader range. To connect a variety of low-power devices wirelessly, ZigBee will satisfy the rising demand. For the future generation of industrial technologies, ZigBee will be deployed.***

Keywords: *Wireless Sensor Network, ZigBee*

I. INTRODUCTION

Wireless technology is currently advancing rapidly. Microelectromechanical systems advancement comprises RF capabilities, the integration of sensors, and signal processing on incredibly tiny devices. Without the usage of any cables, all types of mobile applications can communicate. The primary goal of wireless communication is to obtain data or carry out specific environmental tasks. Typically, a wireless sensor node has 3 Cs. The three Cs fundamentally stand for collection, computation, and communication units. The information obtained must be wirelessly transferred based on requests made by the sink.

Manuscript received on 09 July 2023 | Revised Manuscript received on 15 July 2023 | Manuscript Accepted on 15 September 2023 | Manuscript published on 30 September 2023.
***Correspondence Author(s)
Pratham Sharma*, Department of Electronics Engineering Aligarh Muslim University, Aligarh (U.P) India, E-mail: prathamsharmaamu@gmail.com, ORCID ID: 0009-0005-3213-4876

In the collecting unit, there are several sensors. A microcontroller and memory make up the computation unit. As a result, the communication unit has a transceiver and a receiver that can send and receive data, and different transceivers are present. The Zigbee got its name from the honey bees' zigzagging patterns between flowers, which stand for inter-node communication in a mesh network. Zigbee is used for a variety of purposes, including its extended battery life and simplicity of deployment, from being widely utilized to requiring little maintenance, among many other things.

II. MORE ABOUT ZIGBEE TECHNOLOGY

ZigBee has a set of standards crucial to wireless sensor networks (WSN) and many personal area networks (WPAN). In many WSN applications, ZigBee, a WPAN based on the IEEE 802.15.4 standard, is employed. The physical (PHY) layer and media access control (MAC) layer are described in IEEE standard 802.15.4. [7] Using the fundamental PHY and MAC layers as a starting point, the ZigBee Alliance defines the top application layer and network layer to deliver ZigBee. ZigBee specifies three frequency bands. There are 16 channels in the 2.4 GHz spectrum, ten channels in the 902–928 MHz band, and one in the 868–870 MHz range. The maximum data rates for each band are as follows: 250 kbps, 40 kbps, and 20 kbps, respectively. It can accommodate up to 64000 devices with a 50-meter range and extremely low power requirements so that ZigBee can create a vast network [5].

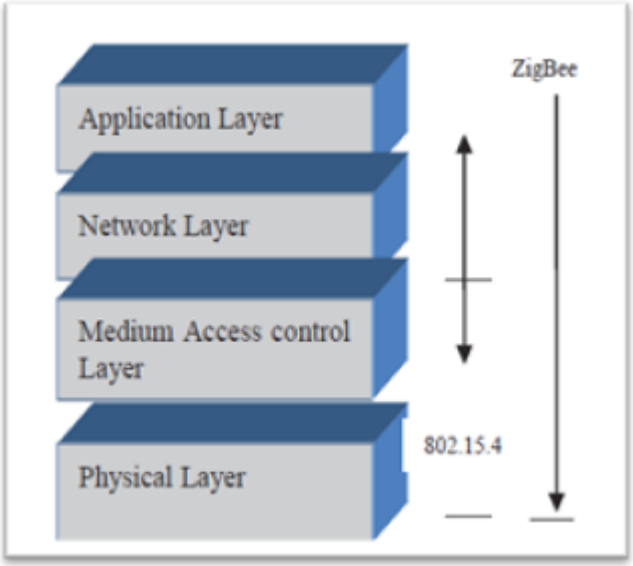

Figure No. 1: ZigBee Protocol Stack [5]

III. ZIGBEE DEVICES

ZigBee defines two categories of devices. The first category includes being physical devices and other logical devices.

3.1 Physical Devices

Physical devices can be divided into two categories based on how they handle data: fully functional devices (FFD) and reduced functional devices (RFD). Since FFD functions as a coordinator, router, or end device, it performs tasks including routing, sensing, and coordinating. It can always be operational because it is AC-powered and can listen to the network. RFD, however, only has a few tasks. FFD and RFD are associated with each other. RFD can only function as an end device because these devices cannot route packets. These gadgets can detect temperature and watch for lightning [5].

3.2 Logical Devices

ZigBee system has three categories of nodes, namely, Coordinator, Router and End devices.

3.2.1 Coordinator

The coordinator is the node at the top of the network tree and may connect to other networks. One node exists in each network. The coordinator is in charge of initiating the network and is also responsible for choosing the operational characteristics of the network, such as the radio frequency channel and unique network identity. Additionally, they keep network and security key information.

3.2.2 Router

The router serves as an intermediary node, relaying information from other devices. They may connect to an existing network, receive connections from other devices, and act as re-transmitters for the network. A network can be expanded using ZigBee routers or ZigBee Networks.

3.2.3 End Devices

End Devices are often battery-operated and low-power devices that may gather various data from switches or sensors. One of the crucial characteristics is the capability of children to communicate with their parents (either the coordinator or router) and not relay information from other devices. This has the leads to a reduction in functionality and enabled cost-cutting potential. However, better low-power models are supported by them. Unlike the gadgets in the other two categories, these devices are not always required to be awake. Each end device has a maximum capacity of 240 end nodes, which are independent applications that use the same radio.

IV. ACCESS MODES

The two methods of multi-access in the ZigBee protocol are beacon and non-beacon. In a beaconed network, nodes can only send data during specific timeslots, but in a network without beacons, nodes can only send data when the channel is open. Devices are only permitted to transmit data within the guaranteed time slots (GTS) that the PAN coordinator allows for each of them. All devices must be synchronized for this process, which may be done by sending beacon signals. For the devices connected to it to synchronize, the coordinator must transmit beacon signals [1]. In a non-beacon network, the coordinator does not send a beacon signal, as the drivers are not coordinated. It cannot have GTS or times of no conflict. Because beacon-enabled networks wake up their devices less frequently, battery life is better.

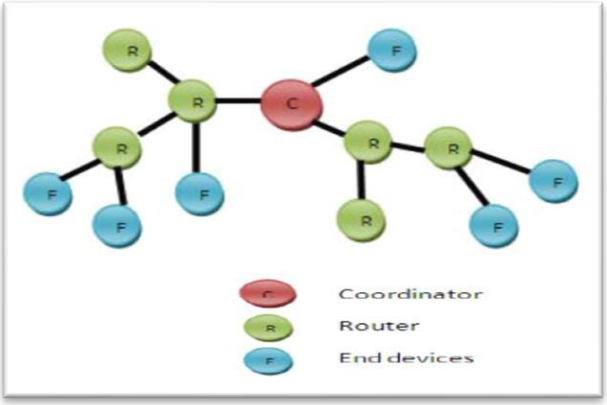

Figure No. 2: ZigBee Network

V. LAYER ARCHITECTURE

Here, the topic of discussion is ZigBee's four-layer layered architecture. ZigBee Alliance specifies the top two layers, whereas IEEE 802.15.4 provides the bottom two.

5.1 Physical Layer

The layer closest to the hardware is the physical layer of the IEEE 802.15.4 standard, which directly controls and communicates with the radio transceiver. It includes tasks related to granting access to the ZigBee hardware, such as initializing the channel selection, estimating connection quality, and hardware, measuring energy detection, and assessing clear channels to help with the channel selection. Supported frequency ranges in this layer are:

- The 2.45 GHz band has 16 channels.
- The 915 MHz band has ten channels.
- The 868 MHz band has one channel.

Everyone employs the Direct Spread Spectrum Sequencing (DSSS) access technique [5].

5.2 MAC Layer

The physical and network layers are connected via the MAC layer. Two services are offered: MAC data services and MAC management services that interface with the MAC sub-layer Management Entity (MLME) Service Access Point, or (MLME-SAP). MAC Protocol Data Units (MPDUs) can be sent using the PHY data service and received using the MAC data service. On the other hand, in a beacon-enabled service, the MAC layer creates beacons and synchronizes devices to the beacon signal. Additionally, it carries out association and dissociation tasks. The four frame structures described are the Beacon, Data, acknowledge, and MAC command frames. Star and peer-to-peer topology is the second kind. Depending on its limitations, the peer-to-peer topology permits many shapes. Peer-to-peer is known as mesh if there are no restrictions. Tree topology is another example. The interpretability of the ZigBee protocol stack contributes to its advantages.

Retrieval Number: 100.1/ijrte.C78610912323
DOI: 10.35940/ijrte.C7861.0912323
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Numerous uses exist for ZigBee, and ZigBee devices may communicate with one another from any manufacturer (even if the message is encrypted). [5]

5.3 Network Layer

Between the application layer and the MAC layer lies the network layer, which is interfaced. Here, network development and routing occur. As we all know, routing is the process of choosing a path for message relay to the target node. The network came into being due to the joining and departing of nodes, the upkeep of routing tables (coordinator/router), actual routing, and address distribution. The ZigBee coordinator or router will do the route finding. The network layer must provide security throughout the whole network. Low-power gadgets will be able to extend the life of their batteries as a result.

5.4 Application Layer

Since the application layer is the uppermost tier of the protocol, it hosts the application objects. The ZigBee Specification has divided the application support sublayer, ZigBee device objects, and application framework with manufacturer specified by application objects into three distinct sub-layers. The application layer also provides security mechanisms for the network and support layers. They are also in charge of fastening their frames. Some security approaches for key setup include key establishment, key transit, frame protection, and device management.

VI. THE PROPOSED SYSTEM

Since ZigBee is, a low-cost wireless networking protocol that has a large no-application profile. From industrial plant monitoring commercial building automation to home automation. From automatic meter reading to wireless sensor networks. Other includes personal home, hospital care, telecom services, and online shopping, among other things. The ZigBee network supports three different network topologies. [6]

6.1 Star Topology

The coordinator node in a star network is in charge of setting up the network such that it can control any device connected to it. In addition, a coordinator node facilitates communication between end device nodes

6.2 Mesh Topology

Mesh networks are among the most reliable networks. The mesh network's router node performs its routing job in addition to communicating with other nodes.

6.3 Cluster Tree Topology

When multiple star networks are organized by the coordinator then it is a cluster tree network. The coordinator is in charge of launching the network and selecting crucial network settings. End device nodes communicate with the coordinator in addition to each router node. However, the router nodes use a routing mechanism to communicate to the coordinator rather than other nodes directly.

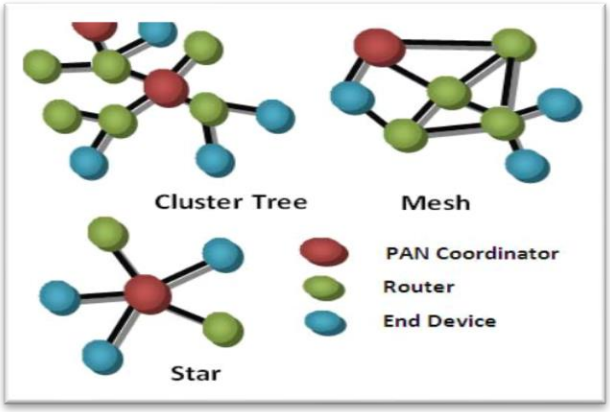

Figure No. 3: ZigBee Network Topologies

VII. MOBILITY IN ZIGBEE

Mobility is a crucial aspect of the ZigBee network and technology. Both mobile and stationary devices are present in ZigBee. As the name indicates, these gadgets are static and continue to function in the same manner as before. Mobile gadgets, on the other hand, may move. In a tree topology, the routing of mobile end devices entirely depends on its parent. When an end device leaves its parent's coverage area and enters the range of another parent, the child receives a new address allocation. After the route discovery and device discovery processes are activated, the new address allocation is only made to the end device once the transmission is halted and resumed. Because every child depends on its parent router, if the router moves and connects to a new parent, it will get a new address. Additionally, all children must also update their addresses. Therefore, recovery from inconsistency and device discovery processes is quite challenging. [5] If an end device travels out of its router's range and into the range of a new router in a mesh topology, a new address is allocated. Communication is halted when a device acquires a new address after losing its old address. The discovery process begins only then, and transmission is then restarted. Route recovery is a feature that routers in mesh topologies have built in. The new address is allocated when the routing table runs out of its capacity. [4]

VIII. SCHEME OF SYSTEM

The meter reading system constitutes the two significant characters. The system has a large amount of decentralized data because it is a widely spread communication network. The characteristics of the system determine the dispersed structure of the networked meter-reading system. The system comprises a server, sensor nodes, a data collector, measurement meters, and wireless communication networks. As the figure below indicates, a data collector may manage up to 100 households' remote meters, but the sensor node also includes a ZigBee transmitter module and MPU (Microprocessor Unit). According to the following approach, a traditional measuring device's analog signal is first transformed into a digital signal before being processed and sent into the sensor node's MCU.

Then, the ZigBee transmission module sends the digital meter data to the data collector. Whether we alter the system requirements in an hour or a day depends on the adjustments we make. In this arrangement, the ZigBee gateway also serves as a data collector. Protocol conversion occurs before transmitting a data packet in the ZigBee protocol to the TCP/IP protocol. The data collector also transmits meter data to the reception server using the TCP/IP Protocol over the Internet. A vital component of this long-distance communication is socket client/server programming. Since sensor modules always operate on a finite quantity of battery power, energy management in sensor networks is a crucial issue in the design of sensor networks. Therefore, every effort has been taken to maximize battery life. The main components of this system are the measuring meter and sensor node battery life. Having an energy source for each measurement device and sensor node is not practical. The measure meter and sensor node were formerly powered by lithium-based batteries, as is well known. Since then, for the past 8 to 15 years, better characteristics have been added to lithium-based batteries that have extended life. The sensor node's MPU is in charge of delivering alarm messages to the server regarding the battery's residual amount and evaluating its residual quantity. Consequently, utilizing the notice when changing the battery is possible. [8]

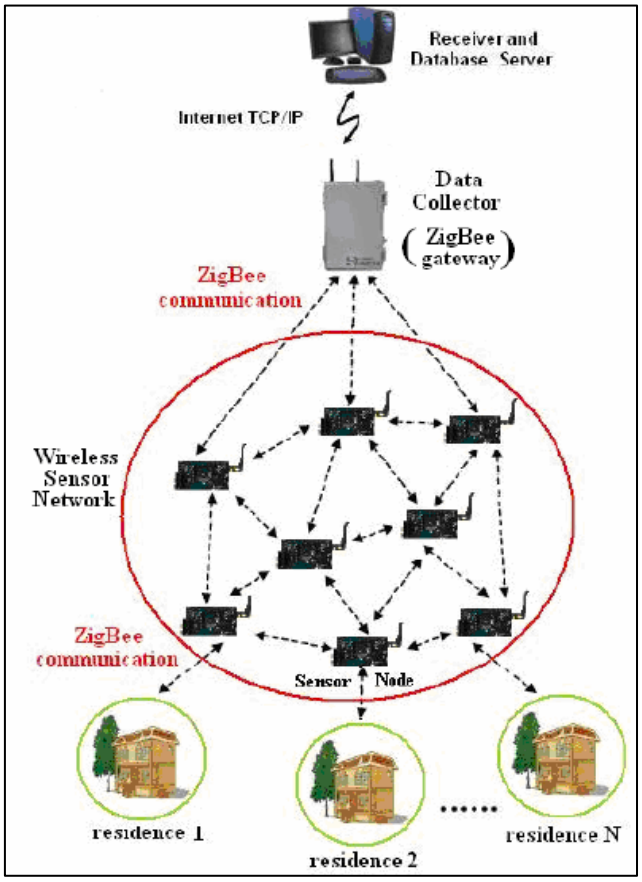

Figure No. 4: Diagram showing the structural elements of remote automatic meter reading system [8]

IX. OUR METHODOLOGY

The two primary components of the proposed system are a back-end processing system and an energy meter based on ZigBee. A digital energy meter model and ZigBee device model MNZB-2A2/B0, consisting of an Atmel MCU and an Atmel RF front end, are included in the ZigBee-based energy meter. [1] The digital energy meter is required to capture and store data on power usage in the internal memory. A ZigBee device aims to connect with the ZigBee coordinator and, via UART communication, read out the power consumption from a digital energy meter. The rear-end processing system comprises the ZigBee coordinator and the software. The system architecture of the proposed automatic energy meter reading system is depicted in the diagram below. [2]

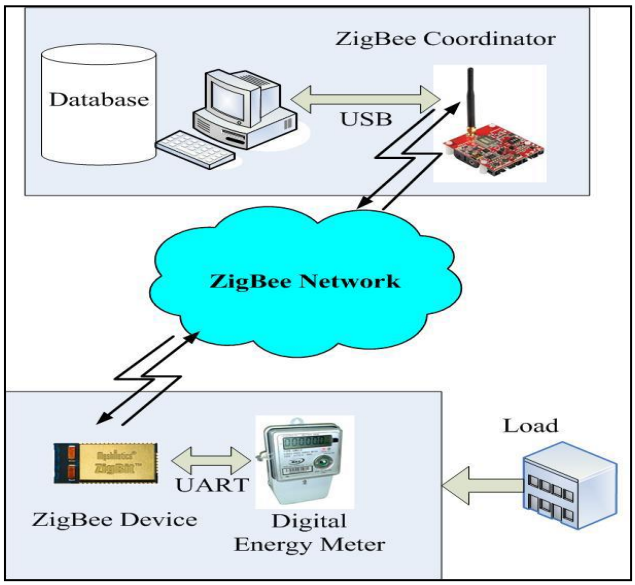

Figure No. 5: System architecture for the proposed automated metre reading system

X. IMPLEMENTATION

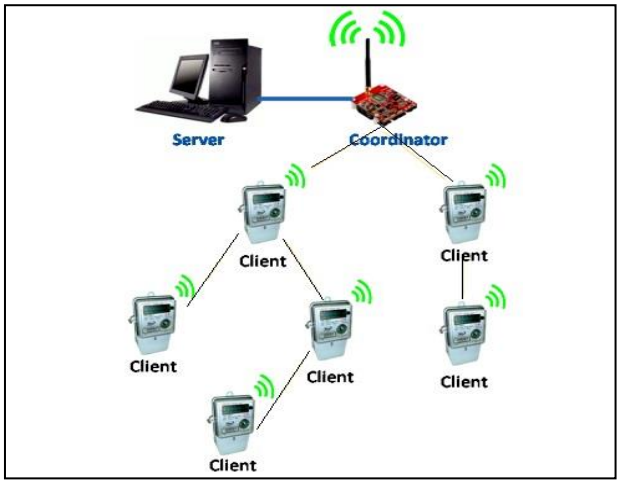

Figure No. 6: An automatic energy meter reading system network

The automated energy meter reading system in the proposed system is outfitted with a ZigBee coordinator, ZigBee end devices, ZigBee routers, and the ZigBee mesh network is used. The network design has 100 ZigBee-based energy meters, and the network depth is ten hops. There are two distinct components to the firmware created for ZigBee client nodes: 1) A network subroutine; 2) A subroutine for reading energy meters.

Retrieval Number: 100.1/ijrte.C78610912323
DOI: 10.35940/ijrte.C7861.0912323
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Figure 3 illustrates how a network with three hops of depth and six ZigBee-based energy meter devices is constructed for an autonomous energy meter reading system. The ZigBee coordinator's operational flowchart, which is connected to the computer through a USB connection, is shown in Figure 4. Figure 4 also illustrates how the ZigBee coordinator initially creates the network before initializing UART and synchronizing with the computer. [3] The ZigBee coordinator will initiate the connection processes to allow a new ZigBee-based energy meter to join the network as soon as the network discovers it. After that, it will maintain the network for other ZigBee-based energy meter devices. The coordinator's second role is to interact with the computer so that it can receive user commands and deliver information to the database system. The coordinator's final task is to operate the ZigBee-based energy meter so that data may be read out. The function of ZigBee-based energy meter devices is shown in Figure 5. Finding a network that the ZigBee coordinator has set up is the first step, and joining the network is the next. It will join the network if it is an automated energy meter reading system. A power consumption reading from energy meters is the next task. The ZigBee-based energy meter will read data as soon as it receives a command to do so and will then transmit the data to the ZigBee coordinator. [9]

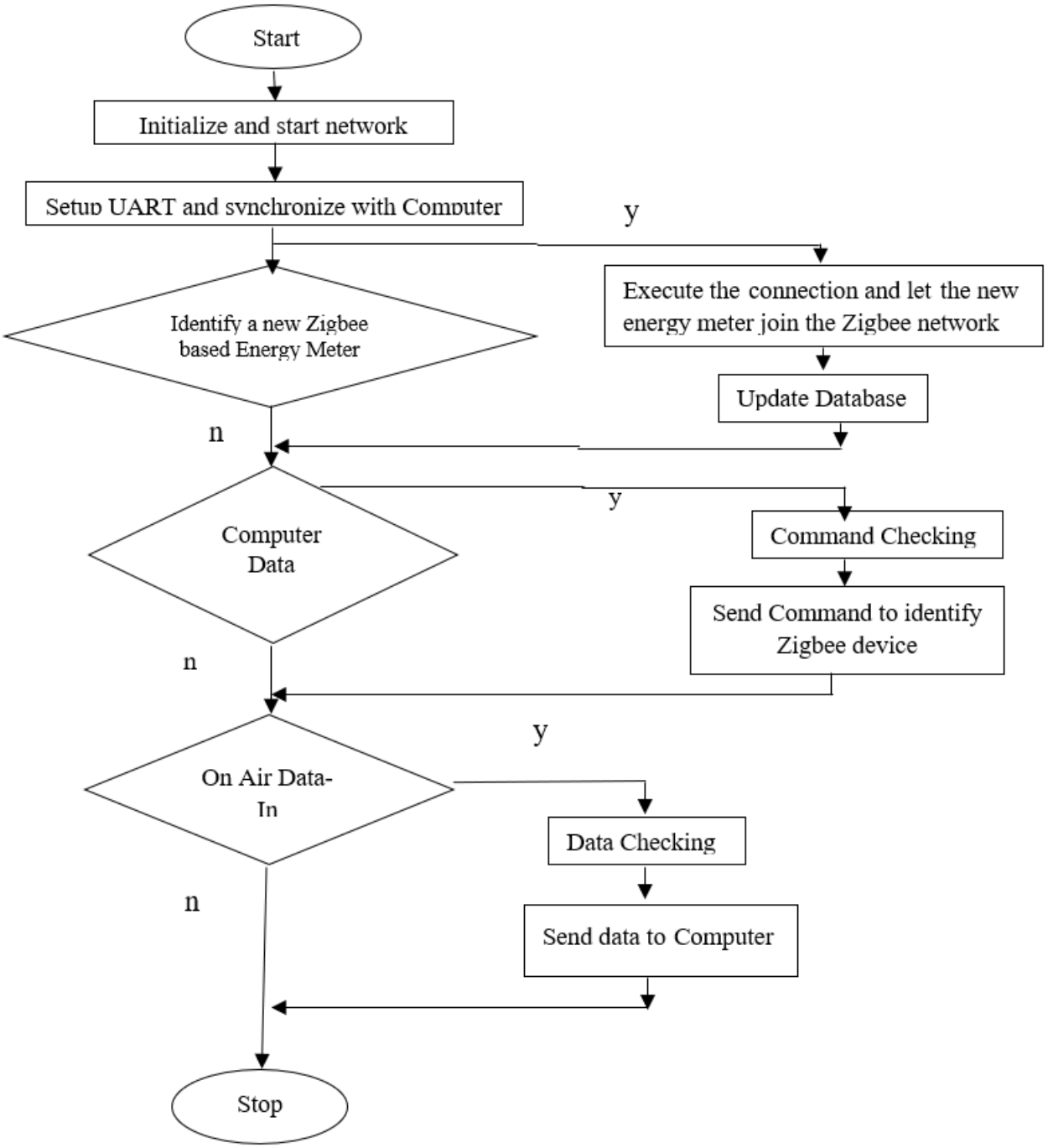

Figure No. 7: The operation flowchart of the ZigBee coordinator [4]

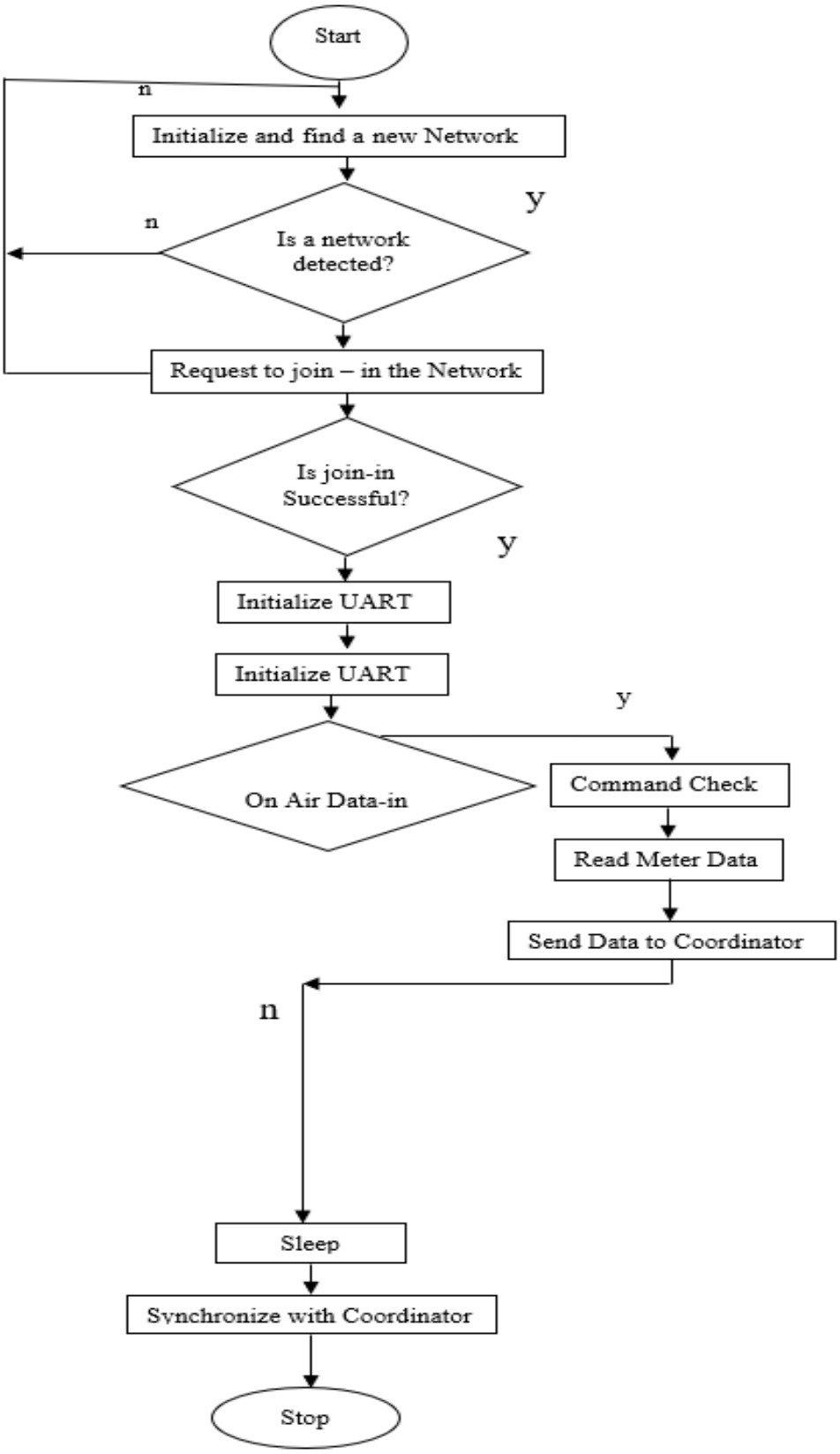

Figure No. 8: The ZigBee device operation flowchart [4]

The transmission data format in the proposed methodology can be divided into two groups. Data is sent using Group 1 between management software and a ZigBee coordinator. The meter ID is used to identify the energy meter's hardware. In the command, reading data and network synchronization are both included. Data packets in Group 2 consist of start byte 0x02. The Node type, a router or an end device, ZigBee short address, or ZigBee ID, is a functional network channel where LQI is a specific numeric value defined within the 0...255 range. This range is used to measure the link quality. More significant numbers indicate a better link, whereas values near zero indicate a bad connection. RSSI shows the link's current state. The RSSI has a 3-dB resolution.

Retrieval Number: 100.1/ijrte.C78610912323
DOI: 10.35940/ijrte.C7861.0912323
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

XI. FUTURE SCOPES OF ZIGBEE TECHNOLOGY

ZigBee plays a significant role in various applications, including those in the household, business, and medical sectors. Although much work has already been done on the ZigBee network, some issues like fading, interference problems with Wi-Fi, loss of synchronization, and delays in tree topology persist. Some issues like fading, interference problems with Wi-Fi, loss of synchronization, and delays in tree topology have been addressed in the ZigBee network. Several researchers provided solutions to these problems, and while they have been addressed to some extent, there is still room to enhance the proposed approach and develop a new scheme to address these problems. For the ZigBee Network to gain excellent traction in various applications, the hybrid topology may result in improved performance in terms of latency, throughput, packet delivery ratio, etc. [6] It is predicted that in the future, ZigBee technology will be found in every home. The ZigBee technology will be used to create new systems utilizing various parameters and ZigBee standards or to expand applications for existing systems to add additional automation. The number of components that can be automated would increase in a smart house, and location services might be included as features. Other novel topologies may be used in the MPMS system to boost performance significantly. Many features can be added to the intelligent bus query system, be it vacant seats or estimated reach times. For instance, an air pollution monitoring system can increase the list of pollutants.

XII. RESULTS AND DISCUSSIONS

The proposed wireless sensor protocol and network based on ZigBee for smart energy meter applications show encouraging results and have the potential for practical use. The technology exhibits time-efficient data collecting, even in closed homes, with automated meter reading, enhanced efficiency, and decreased human labor. Lower power consumption leading to longer battery life and low cost makes ZigBee based wireless sensor network an efficient choice to be used in variety of applications involving wireless monitoring and control. To improve the performance of ZigBee networks, ongoing research tries to solve issues including fading, interference, synchronization problems, and delays. Using ZigBee technology's benefits in connection, automation, and the potential for breakthroughs in wireless monitoring and control systems, the future scope involves extending its use in a variety of applications.

XIII. CONCLUSION

The system may automatically read the energy meter's unit, terminal alarm, and cover alarm according to the implemented wireless sensor network and protocol findings. The wireless energy meter system proves to be time efficient; it can take a large number of meter readings together within an appreciably large area, thereby reducing the time of data feeding process in the central system. The Zigbee-based wireless system, if implemented within a particular local area network, can thus prove beneficial as it would dramatically reduce the human effort of accumulating the readings of many energy meters at a time in a computer system. As a result, someone is no longer required to go to the consumer's location and record the meter readings. Even if residences are locked, meters can still be read. This system can also be implemented in practical applications like gas and water meters. Thus, in light of Zigbee technology's short-range, low power, low cost, and low complexity, the proposed system in this paper is viable for real-world applications.

ACKNOWLEDGEMENT

The living level of human beings is continually enhancing thanks to advancements in computer science, wireless communications, and microelectronics technology. Traditional meter readings, whether for homes at the top of tall buildings or luxury property plots, have yet to meet the demands of future residential growth. In addition to wasting human labor power, it also causes meter errors that humans create. Nowadays, humans complete the unit recording before the end of the month. The human error becomes the primary issue with the system because individuals carry out and measure the unit recording. The electrical industry has one of the most significant infrastructures in contemporary civilization since it provides electrical power for all electrical devices, appliances, and lights in homes. Using a wireless sensor meter reading device helps prevent errors caused by meter reading leaks from occurring during manual meter reading. Additionally, efficiency gains, a drop in work intensity, and the liberation of the labor force are all possible.

DECLARATION

Funding/ Grants/ Financial Support	No, I did not receive.
Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	I am only the sole author of the article

REFERENCES

1. I.F.Akyildiz, W.SuY., Sankarasubramaniam, E.Cayirci, "*Wireless sensor networks: a survey*", Computer Networks, Volume 38, Issue 4, 15 March 2002, Pages 393-422 [CrossRef]
2. Philip Rings, Lasse Thiem, Thomas Luckenbach, "*Wireless Energy Meter*", 2010, 1-3
3. Zoran Milivojevic, Djordje Saponjic, "*Programming dsPIC (Digital Signal Controllers) in C*", 2005, Chapter 10, UART module: 10.1-10.7
4. Li Quan-Xi, Li Gang, "*Design of remote automatic meter reading system based on ZigBee and GPRS*", Proceedings of the Third International Symposium on Computer Science and Computational Technology (ISCSCT '10) Jiaozuo, P. R. China, 14-15, August 2010, pp. 186-189
5. Manpreet, Jyoteesh Malhotra, "*ZigBee technology: Current status and future scope*", 2015 International Conference on Computer and Computational Sciences (ICCCS), 27-29 Jan. 2015 [CrossRef]
6. Dr.S.S. Riaz Ahamed, "*The role of Zigbee Technology in Future Data Communication System*", Journal of Theoretical and Applied Information Technology, 2009 ,10 :4-6.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

7. IEEE Std 802.15.14, "*Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low- Rate Wireless Personal Area Networks (LR-WPANs)*", IEEE Computer Society,2003
8. Liting Cao, Wei Jiang, Zhaoli Zhang, *"Networked wireless meter reading system based on ZigBee technology*", 2008 Chinese Control and Decision Conference, July 2018 [CrossRef]
9. Paolo Baronti, Prashant Pillai, Vince W.C. Chook, Stefano Chessa, Alberto Gott, Y. Fun Hu, "*Wireless sensor networks: A survey on the state of the art and the 802.15.4 and ZigBee standards*", Computer Communications 30 (2007) [CrossRef]

APPENDIX

A. Comparison Table

B. UART

Table No. 1 Detailed Wireless Technologies comparison chart

Standard	Bandwidth	Power Consumption	Protocol Stack Size	Stronghold	Applications
Wi-Fi	Up to 54Mbps	400+mA TX, standby 20mA	100+KB	High Data Rate	Internet Browsing, PC networking, file transfers
Bluetooth	1Mbps	40 mA TX, standby 0.2mA	~100+KB	Interoperability, cable replacement	Wireless USB, handset, headset
Zigbee	250kbps	30mA TX, standby 3#&956; A	4"32KB	Long battery life, low cost	Remote control, battery –operated products, sensors

The acronym UART stands for Universal Asynchronous Receiver Transmitter. The serial port is built out of an electrical circuit. Also known by the other name of "universal serial asynchronous receiver transmitter" (USART). It is in charge of converting the serial bits for transmission from the parallel bytes arriving from the CPU and vice versa. [3] Along with generating, it also removes the beginning. It stops the addition of bits to each character. Older UARTs, such as the 8250 or 16-450, need to be faster for modern modems. For transmission at up to 115 Kbps, you need a 16-550. (115,200 bps).

C. ZigBee

ZigBee is a specification for low power, small radios which are based on 2003's IEEE Wireless Personal Area Networks standard. i.e., IEEE 802.15. [7]

D. ZigBee Coordinator

The network formation is done by a ZigBee Coordinator. After the network formation it acts as a router in a Mesh stack. It is to be noted that only a network coordinator can be designated as a trust center.

AUTHORS PROFILE

Pratham Sharma is a Co-Founder & Product Manager at Neutrify. He holds a Bachelor of Technology (B.Tech) degree in Electronics Engineering from Aligarh Muslim University, Aligarh, India, a prestigious central university ranked 9th in the National Institutional Ranking Framework (NIRF). Pratham graduated in 2020 with First Division with Honours. Pratham began his career as a Research & Development Software Engineer at Keysight Technologies, where he played a pivotal role in building, designing, and delivering software drivers for various electronics and electrical equipment worldwide using Agile Methodology. He quickly became the subject matter expert within his team, showcasing his proficiency in programming languages such as C, C++, C# Python, and MATLAB. To further enhance his skills in Product Management, Pratham obtained the Certified Scrum Product Owner (CSPO®) certification and expanded his knowledge in product analytics, product-led growth, and data analysis. He has acquired diverse experience across domains such as climate, telecom, fin-tech, and IT. Pratham's ultimate aspiration is to become a product leader capable of solving problems at scale. In the near future, he envisions himself driving strategic initiatives and fostering innovation for technology companies. His goal is to develop impactful products that address customer needs and provide effective solutions.