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Deep Learning-Enabled Embedded Systems for Edge Intelligence and Smart Automation

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ABSTRACT

The lightning-fast advancement of technology such as digital transmission, electronics, and miniature technologies has made it possible for our society to make significant strides forward. As a consequence of this, the prices of producing electronic devices have reduced, the utility of these devices has increased, and the digital world has displaced the physical world. As a direct result of this, the ways in which we interact with one another and the environment have developed. We make use of sophisticated equipment improve our understanding of the world around us. In today's world, scientific institutions and technology advancements are continually working to produce more complex living environments. It is now possible for any system to gain intelligence as a result of technological breakthroughs in fields such as energy, communication, embedded systems, the internet of things, and wireless sensor networks. These technical breakthroughs have made it possible for systems to become more native, robust, autonomous, and limited compared to their previous state. In real time, these systems are able to maintain their concentration on the tasks at hand, even while operating in the most difficult conditions. As a result of the fact that we are now living in a digital age, the norms and systems that we depend on continue to function reliably and make our lives easier. As an illustration of this kind of application, consider the integration of embedded systems with power and energy networks. All of the gear that was used in this transformation has been updated and converted into digital form. This includes anything from enormous transportation hubs to everyday home products. The local customers need to anticipate a system that is both more secure and more intelligent as a whole. Automation and improvements in information and communication technology (ICT) have made it possible for any energy system to have far less space for mistake or loss than it did in the past. The Internet of Things (IoT), wide area networks (WSN), and artificial intelligence (AI) are examples of trustworthy technologies that have made it possible for businesses and households to make more efficient use of energy and save money on it. a new design line

Keywords: Smart Automation; Internet Of Things(IOT), Wide Area Networks(WSN), Information Communication And Technology(ICT) And AI.

INTRODUCTION

The passage of time and the pace of change are both speeding at an increasing rate. Things that were previously considered desirable now have a significant influence on things that people do on a daily basis. In the year 2000, for instance, just 14% of homes had access to the internet, although 26% of businesses made use of robots and many other forms of automation. In the years that followed, developments in technology made it impossible to expand in the domains of communication and information technology.

People had reached the critical milestone of automating both their homes and their office buildings, and within a span of just 15 years, 86 percent of businesses had automated their work units. At the present day, it is present in the majority of families as well as in practically every business. The cumulative effect of all of these improvements teaches us more about the hidden benefits of technology and its ability to save energy in real time across the board, from power plants to the distribution network. In spite of the fact that automation may be more user-friendly than control and maintenance, it nevertheless raises the necessity of running a whole unit, regardless of whether it is a corporate or residential establishment.

Both big information technology companies and energy grids have seen an increased focus on the automation of controls and processes achieve energy savings. This is due to the fact that embedded agents have made it possible for automation to take place in just about any environment. For the time being, the holy grail of robots is to reduce costs without compromising efficiency. This is the reason why they devote a significant amount of resources to the research and development of energy collecting systems, as well as energy-aware technologies that may be used in commercial and HAN settings. Because of its immediate and prospective societal effect, energy conservation and resource management is just as vital as automation. It changes people's economic circumstances and way of life.

By implementing automated controls in your home, you may be able to reduce the amount of money you spend on your monthly energy bills. It has the potential to assist you in increasing your revenue. Additionally, it gives the user the ability to multitask and is speedier than it was previously. As a result of developments in sensors and integrated agents, the HAN is now able to easily include any communication channel and protocol into its system for conserving energy. By connecting to consumer electronics such as laptops, tablets, and mobile phones using technology such as Bluetooth and Wi-Fi, as well as by utilizing Internet Protocol (IP) to control things, they are able to continuously monitor energy use and conserve resources. Currently, cables are not always required for the purpose of regulating utilities and monitoring energy use. The purpose of this chapter is to examine a literature review of several studies that have the potential to shed light on the ways in which technology assists in the management and control of energy for utilities and waste.

Building design, connection construction, and networking protocols are some of the issues that are being researched. Topology analysis for wide coverage is also being researched. Several different methods and their source codes were put through their paces in real-world circumstances, which included homes and other business enterprises, to see how successful they were.

To be more exact, the term "Grid connected-Home Area Networking" refers to homes in which practically all of the appliances are connected to a networking environment that is easily accessible, can be controlled remotely, and is continuously monitored. Electricity, tools, plugs, and heating, ventilation, and air conditioning systems are all included in this category. It is the Advanced Metering Infrastructure (AMI), which is a component of networking standards and protocols, that is responsible for handling significant tasks that must be finished by a certain time or independently. It is possible for people and businesses to monitor the operation of integrated devices and smart products in the workplace by using high-quality networking protocols and standards in combination with a topological design that is standardized. It's possible that the electronic device used by an organization has a wireless network connection built right in; for instance, it may be moved into a residential area. It is possible to perform continuous monitoring of the machine by connecting it to the home computer of the enterprise via the use of the internet. Modern home networks are able to establish connections with gadgets that are considered to be state-of-the-art. In respect to the same activity of self-driving vehicles, people and organizations alike are experiencing concerns over safety and security.

For the purpose of establishing a controlled environment, it is absolutely necessary to maintain precise records of power transfers, uses, and disposals. In the past, major organizations and a select few very rich houses were the only ones who had access to control and automation of equipment that functioned across the whole building. Building automation was only able to control mechanical systems in the past, such as heating, ventilation, and air conditioning (HVAC), lighting, and other mechanical systems. A limited number of access points were available, and the system offered only the most fundamental capabilities in terms of scheduling, monitoring, and control.

With the assistance of a communication channel and the establishment of the appropriate network connection, the automation gives users the ability to create and activate events for a variety of electrical components located inside the perimeter. Automation enables people to monitor their energy use inside a system that picks times at random. This is accomplished by enhancing the intended programmability of the system. When electrical equipment, smart devices, and even individual integrated components are able to self-organize, charge, and examine themselves, they may be able to work with more autonomy and flexibility.

LITERATURE REVIEW

When it comes to the two most important aspects of energy supply and demand side regulation, it is absolutely necessary to function independently. Additionally, these key areas need to be subjected to continuous surveillance monitoring. There are a number of factors that contribute considerably to the creation of energy, including but not limited to large-scale industrial facilities, dispersed public services, and private dwellings. "Energy can neither be created nor destroyed; it can only be transferred or used as such." By making this assertion, the actual nature of energy is brought to light.

The result of this is that the equilibrium between the amount of energy that a nation produces and the amount that it consumes will always be unstable. Because of this, a significant amount of research may be focused on energy and power, including matters such as the incorporation of intelligent products and the automation of energy systems, either in their whole or in part. Reduce the amount of energy that is wasted, the most effective technique would be to manage the amount of power that is used during both production and consumption. It is the Distributed Control System (DCS) and the Supervisory Control and Data Acquisition (SCADA) that are responsible for keeping track of the present condition of the distribution units and residential lines that make up the power grid. Specifically, they do this by carefully monitoring and regulating every component. Innovative developments in the field of communication are contributing to the enhancement of the energy grid. As a result of these improvements, rigid systems are changed into sensing units that are fully automated and trustworthy.

Within the scope of their study, João Figueiredo and Martins (2009) investigated the concepts of distributed power management and demand-side energy management. Within the home market, there is a constant competition for both the production of energy and the use of energy. The degree of complexity that can be achieved in real time production and distribution is not constrained in any way. Consequently, cut down on the amount of energy that was used, they came up with a method that could be engaged automatically from any utility setting.

Both Paria Jokar and Victor C. M. Leung were responsible for the development and implementation of the Bluetooth-based smart home energy management systems in the year 2018. In 2010, Dae-Man Han and Jae-Hyun Lim were both successful in accomplishing this goal, while Mario Collotta and Giovanni Pau were successful in completing it in 2012. Through the use of linked devices and the Internet of Things, customers are able to view the statistics and information on their power consumption from any place and at any time. In the smart home configuration that the authors have recommended, the transmission and reception of data are made easier via the use of DMPR, which is an acronym that stands for Disjoint Multi Path-based Routing.

Problem Statement

The purpose of this thesis, which is titled "Design and Development of Energy-Aware Automation for Embedded Applications," is to explore the strategies, methodologies, algorithms, and techniques for analysis, control, and grid connection that are required develop an automated, energy-aware HAN. They plan to use the Internet of Things (IoT), wireless networking standards, and a few machine learning principles enhance the design and development of a high-level HAN system. This will allow them to bring about desired improvements. In addition to this, it discusses several security tactics and safeguards that may be used guarantee the safety of the home control system that you build.

Structural Exploration

An investigation of the feedback responses and channel capacities of the network cells was carried out by Bradford Campbell et al. (2016). This investigation focused on the existing structure and design of the components of the network. Using the stated area coverage and spontaneous signals, the channel capacity and execution time are calculated at each design junction and crossing point. This is done ensure appropriate operation.

Data Collection And Interpretation

A multitude of data and information on device contacts, status, coverage, and route planning is compiled for each and every instance of the HAN. During the transmission of these files, we make use of the appropriate link method. There is a certain processing department inside the processor or control center that needs to receive these files do maintenance and analysis on them.

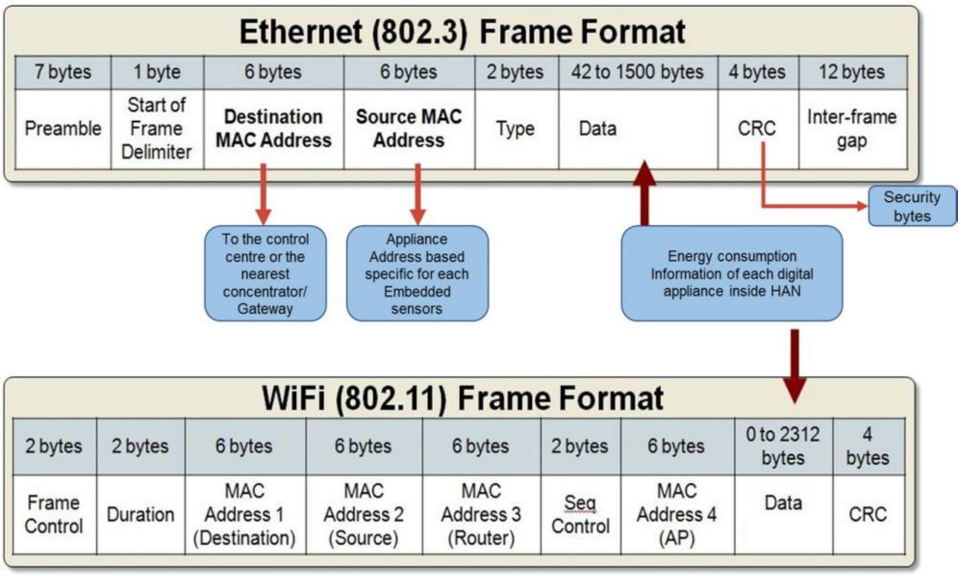

Figure 1 Standard Data Format for IEEE 802.11 a and IEEE 802.3

Every single one of the server's control packets and IP frames are necessary. It is the gateway or control center that is responsible for the configuration and continual monitoring of these addresses. It is of the highest essential to get the messages at the appropriate frame length and with the title message included. A Cyclic Redundancy Check, often known as a CRC, is an intrinsic security precaution that ensures the integrity of each and every one of your communications. There is the possibility of using a data pooling method in situations when there is sufficient time for several connected devices to send data to the network gateway. The control center may choose to handle the data using a home address rather than forwarding it to a local gateway. This decision is made based on the significance of the nodes and the speed at which they operate.

Framework Control And Area Coverage Mechanism

A comprehensive investigation is conducted into the capability of the newly constructed framework to handle channels and respond to feedback signals. During the process, the technique takes into consideration not only the size of the area that has to be covered but also the manner in which signals are sent on the spot. When it is necessary to compute the execution time and channel capacity at each design junction and crossing, it is not possible to position cells only based on their operational loads.

To complete the machine setup process, further needs include the networking ID and the priority mode. Testing for data transmission and analysis across several nodes is a typical practice (Jianli Pan et al., 2014). This is due to the intricacy of the connections that exist between the concentrator and the sensors that are built into the gateway.

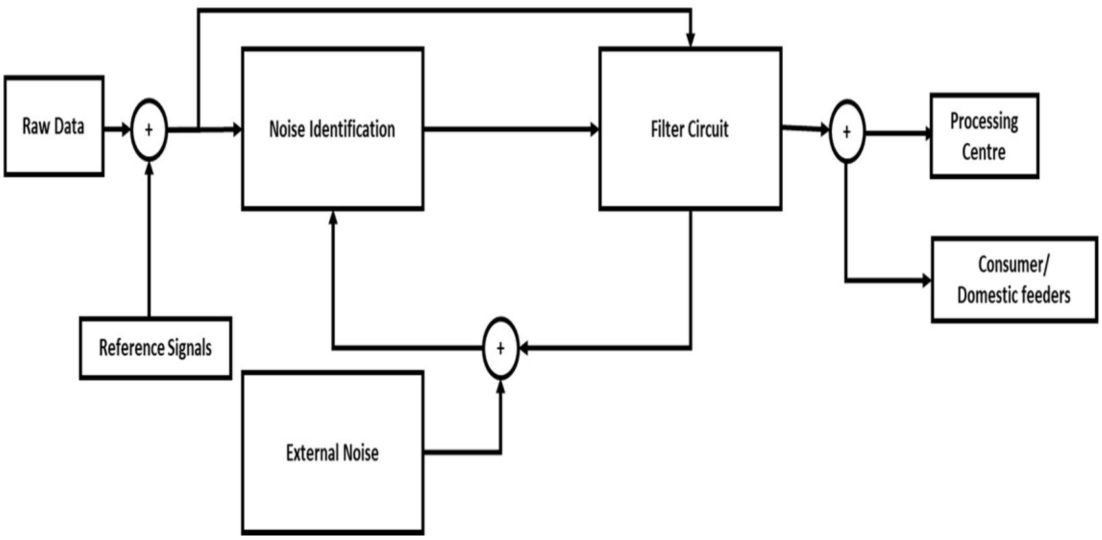

Figure 2 Signal Correction and Noise Cancellation Workflow

Power Consumption Modelling

There are a few numbers that are encoded into the smart meter, and these numbers reflect the preferred network structure and connecting technique. Through the use of their respective IP addresses, it instantly becomes connected with all of the HAN components. The data on energy consumption from residential and commercial streams is monitored by the control center via the use of their IP addresses. The manipulation of the real-time data of a wide variety of integrated products is accomplished via the employment of equations

A single MATLAB An additional check is performed to ensure that the logical framework that was constructed before is functioning before an experiment is carried out using Simulink. A single HAN configuration is used get a comprehensive view of the whole system. Accurate embedded sensors and metering setups are utilized investigate the energy consumption of every component included inside the HAN. A visual evaluation of the proposed network design is performed to determine how effective it is. The virtual world may be used to monitor the amount of energy that is used by various equipment, including air Conditioners, stoves, washing machines, and others. Following completion of the processing of the data by the chosen gateway and repeater configurations, the information is then sent to the central control center. On top of that, an error-handling system has been built.

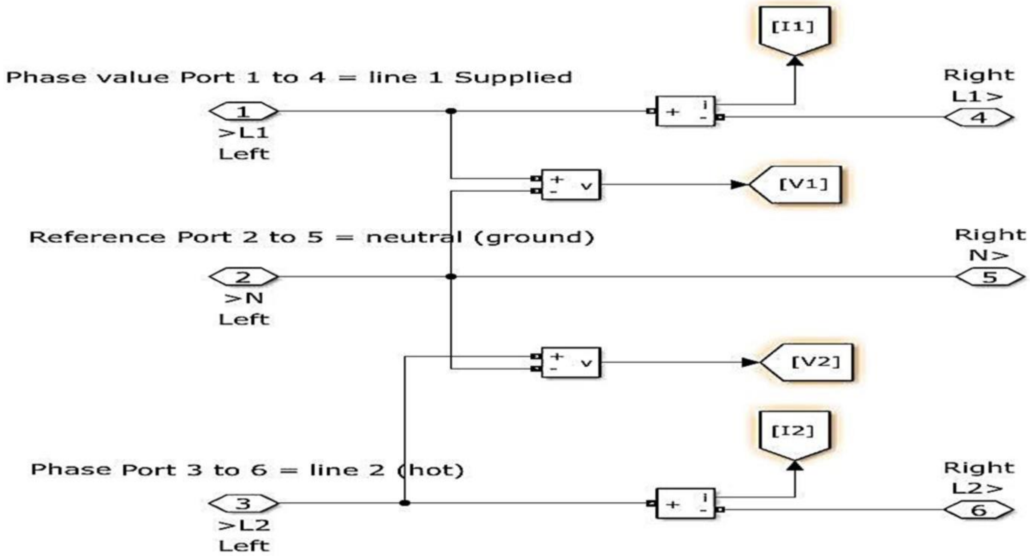

Figure 3: Smart meter Voltage and Current Measurement Circuit

PERFORMANCE EVALUATION

It is possible for us to validate the functioning of the system by collecting data from a single HAN and conducting tests with all of the appliances that are linked with, respectively. When a large number of devices broadcast data at the same time, the results of the experiment show that the signals may be recovered in a variety of different ways owing to even a minute inaccuracy in the model.

When the model mistake manifests itself as a persistent spike, the data bits can only be partly retrieved by the use of filtering and smoothing distributions. As a consequence of this, aliasing and congestion are both possibilities that may arise during the processing of the data bits by the control center. Three metrics are used to assess the proposed network design in both datasets. These metrics are the packet loss ratio, the average end-to-end packet delay, and the route cost. The first set of data consists of an examination of a virtual area that is about fifty meters square and uses the node density as a variable.

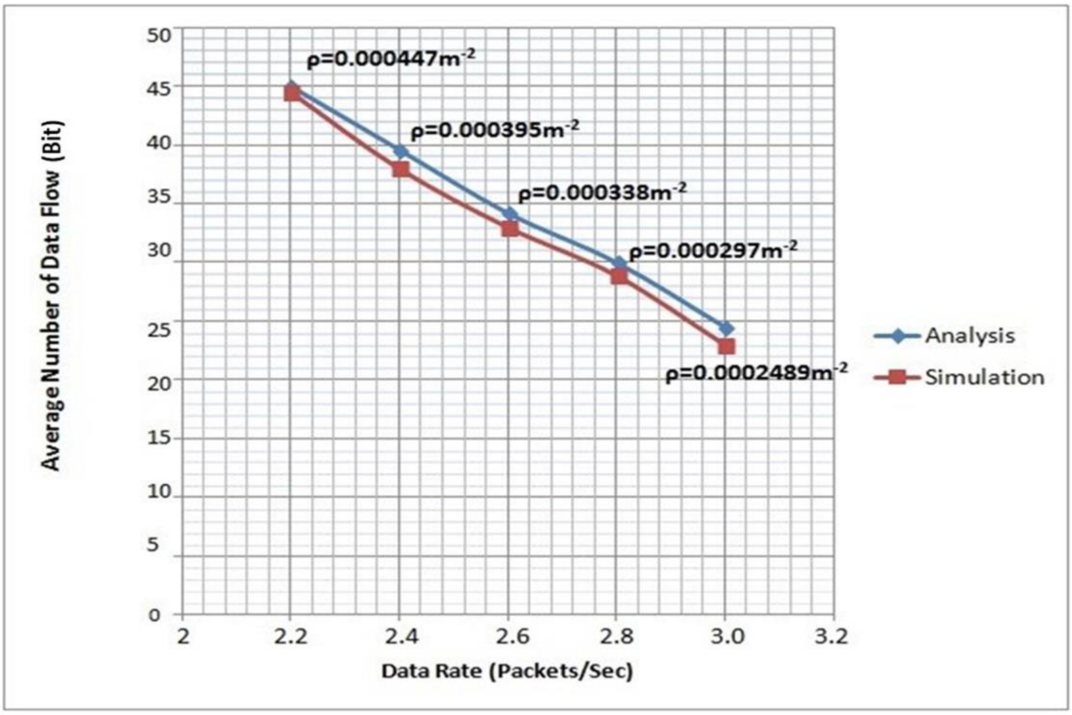

Figure 4: Data Flow VS Data Rate

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When a limit is reached, the delay for each device number stays the same and repeats itself over and over again. It is possible to simplify the procedure by applying uniform evaluation criteria and a time restriction to all of the appliances, regardless of how important or urgent the appliance may be. As illustrated in Figure 3.13, the various digital and integrated components that make up HAN require different amounts of power while they are connected and doing their respective functions. A smart meter that has been set up to record and store to a computer the amount of energy that each appliance uses is the source of the information that has been gathered.

Utilization of electronic devices on a daily basis may be calculated and shown with the help of the data set and the graphical numbers that result from it. The same data is accessible to both clients and providers that are located inside the same country. In the case of HAN, for example, the refrigerator is constantly functioning, and the power signature of the system is quite consistent. Motion plots, on the other hand, show that there is an increase in energy consumption for a few days in the middle of the process. The precise duration of this rise is determined by the length of the line plot. We collect data from a variety of embedded computers that have been installed and then examine the performance of those computers over the course of a period of twenty-five days.

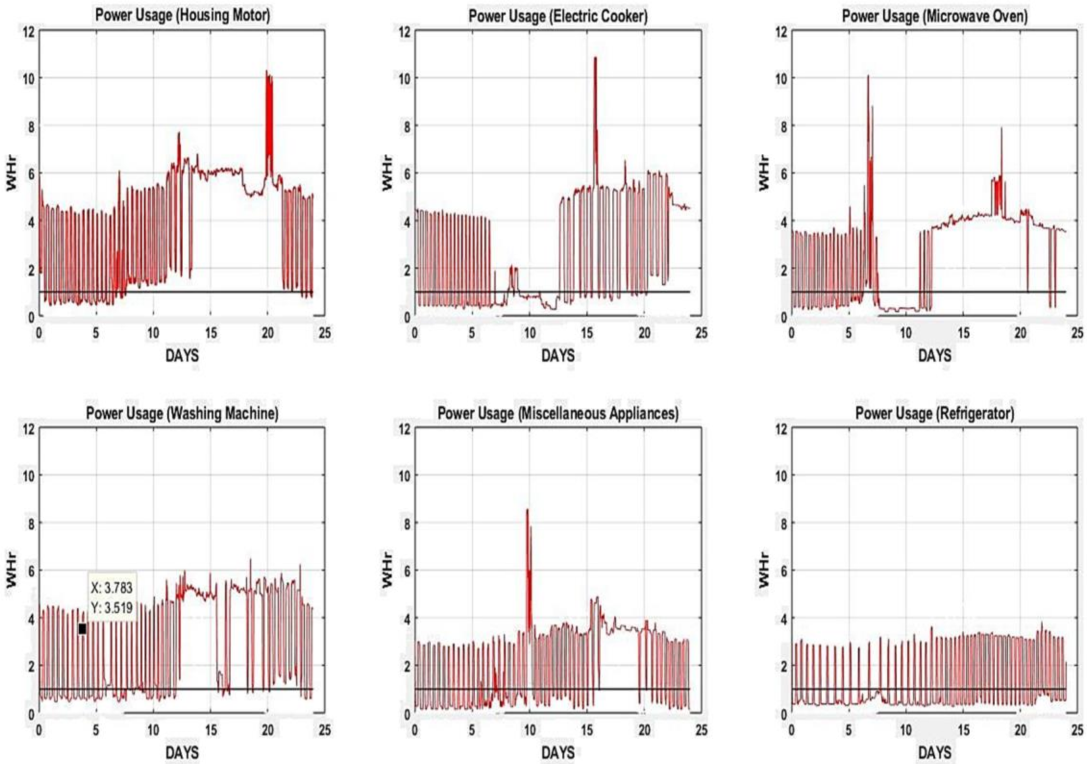

Figure 5: Day wise Energy usage by different Appliance inside HAN

Section Overview And Techniques Applied

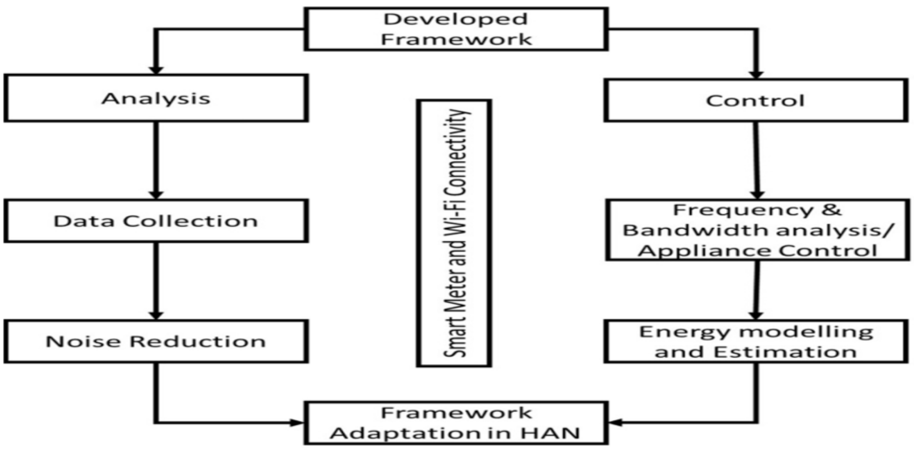

Figure 6: Overall View of Section 3

The methods of proactive data gathering and appliance synchronization are investigated in this chapter. The created system is the subject of this chapter. In this section, the procedure for removing or significantly reducing signal noise is broken down in depth. The last step is for the software system to simulate the energy consumption of the device by using the sensor technology and design as the basis. You are able to observe the overall picture as well as the outcomes. All of the following are shown graphically: time, data flow, and packet loss. In addition to this, they provide evidence that the system is suitable for testing and deployment in operational environments.

The very advanced information and communication technology (ICT) that was used to make the framework's star-mesh integrated design connections conceivable functioned exceptionally well and gave the best results under the parameters that were set for the test.

Security And Signaling

To get access using a system of sensors There may be differences between the Application Programming Interfaces (APIs) that are used by different applications on a network device and the operating systems that are utilized by those programs. Through the use of a web-based graphical user interface (GUI), it is made simpler to get access to critical information in real time. It has been said by Seong-Joong Kim (2017) that this particular kind of stacking architecture ensures the safety of all of the digital devices that are located below it. A severe and sophisticated security policy is required because of the digital nature of the network and the continual upgrades that it receives.

Time is selected in the modeling environment, and for each period, the packet delay for each device is analyzed according to its priority and significant power values. This process is repeated for each different device. Latency refers to the amount of time that passes between a node and the cell or repeater that comes after it. There are two aspects that will determine the outcome: the strength of the network and the rates at which the nodes transmit data packets.

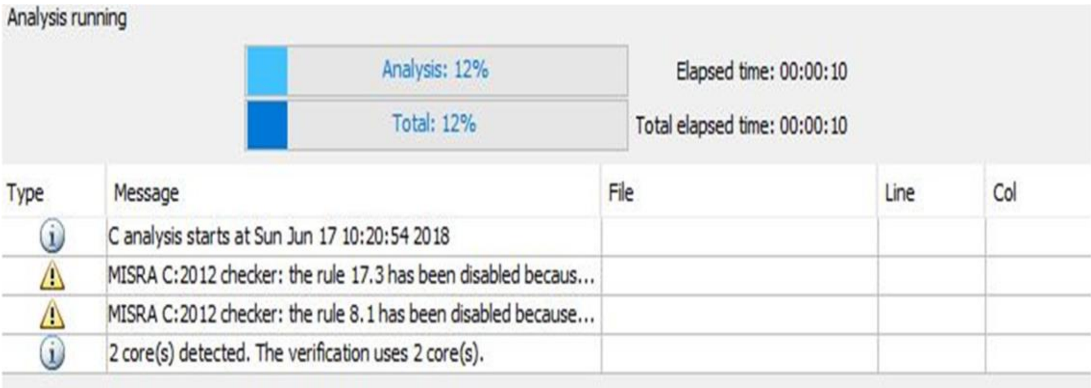

Figure 7: Operation Window for Component Analysis

The Simulink system allows for the comprehensive examination and testing of the functioning of any embedded component. The relevance of their duties and the results they received on tests are used to determine their ranking. As can be seen in Figure 4.2, the length of time that is required to test each device provides insight into the effectiveness with which it handles data bits that are flowing between nodes that are part of the same HAN design.

The Internet of Things (IoT) with connected gadgets takes the concept of a smart home to a whole new level. This is accomplished by including features such as comprehensive administration, online help, and data security. However, defend against unauthorized access, the system has to be protected with particular safeguards (Yang Liu et al. 2016). It is not always straightforward to determine which wireless connection or file is a potential attack vector, and the system as a whole is not as well secured as it might be.

A layered strategy that includes the establishment of multiple security goals is the most effective method for protecting against attacks on the Internet of Things (IoT), according to a technical review of many articles (Abdul Basit et al., 2017). This review was conducted by Abdul Basit and colleagues. In the United States, the National Security Administration (NSA) has a hierarchical organizational structure that is broken down into seven distinct levels, as shown in Figure 4.3. Involved levels include data integrity, data privacy, trusted relationships, network segmentation, and authorization. Data integrity is the most important of these. A host has the ability to assign a one-of-a-kind key or name to each individual device found in a cloud server bank. In this regard, the position of a device on the network's or server's perimeter has no effect on the situation. Given that it is anticipated that the number of connected Internet of Things devices will approach 20 billion by the year 2020, this is a huge achievement. The authorization of the following crucial link in the chain of security is required. The devices have reached an agreement to work together at this point in time. accept and approve the information of the other device, it is necessary for both the connected device and the "host" device to work together.The existence of a limited number of reciprocal rights or privileges is essential for the.

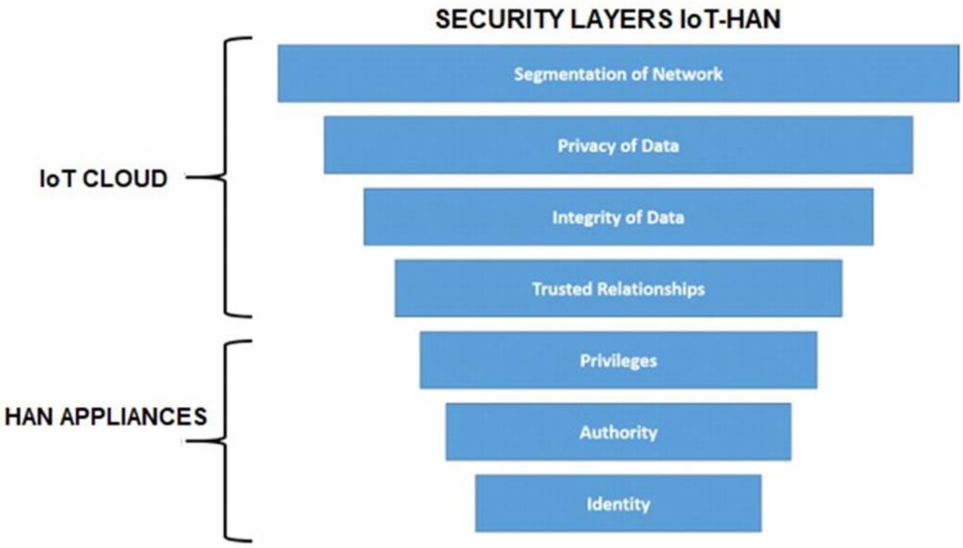

Figure 8: Layers of IoT Security for enabling Inside HAN

Gateway Architecture And Data Exchange Process

The HAN-IoT setup that was discussed before lays the burden of connection formation and data exchange on the computer that is connected to the Internet of Things. The Central Gateway Unit (CGU) is responsible for controlling and monitoring the concentrators and sensors. This is accomplished by the gateway via the use of segmented parts when transmitting network communications over TCP/IP.

The CGU and the Internet of Things server are not as noticeable in HAN as the sensors that are installed on the devices and the server itself. This framework has been improved with new features that are depending on elements such as location, sensor limit range, smart meter capacity, and gateway connection, as stated by Sultan Shoaib et al. (2017). These features have been included to expand the capabilities of the framework.

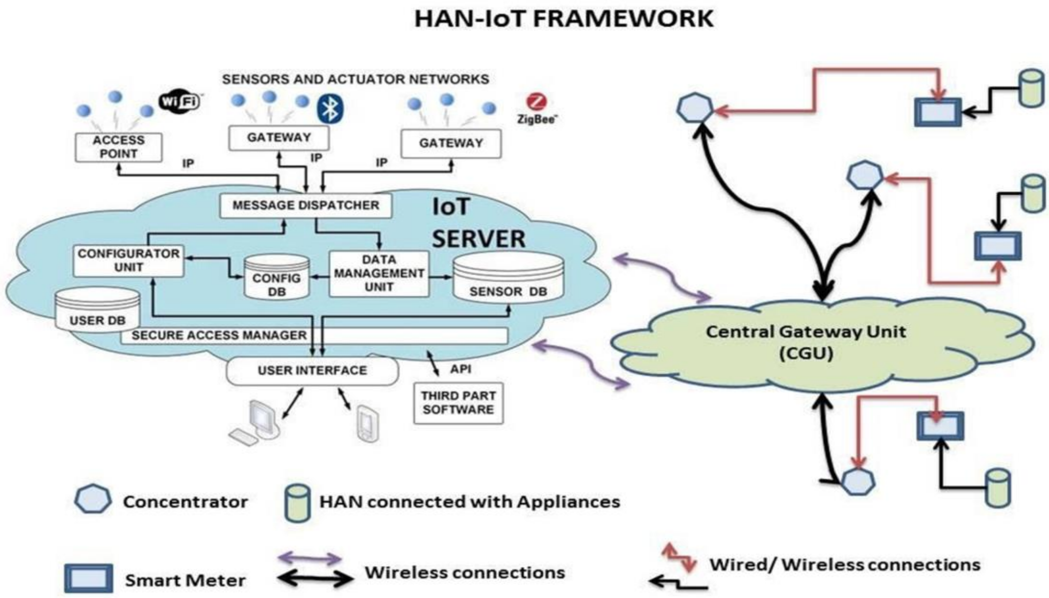

Figure 9: New HAN-IoT Architecture

DISCUSSION

Smart Automation system lies in the integration of embedded systems, wireless networking standards, and intelligent energy management frameworks that together enable the development of energy-aware Home Area Networks (HANs). The document establishes that modern automation is driven by advances in the Internet of Things (IoT), Artificial

Intelligence (AI), and Information and Communication Technologies (ICT), which collectively support real-time monitoring, data transmission, and system optimization. At the heart of the proposed design is a grid-connected HAN architecture that facilitates efficient energy tracking, distribution, and control among residential and commercial consumers. The system depends heavily on IEEE 802.11af-based Wi-Fi networks, which provide long-range, low-interference communication between gateways, concentrators, and distributed sensor nodes. This architecture ensures that smart devices within the network can communicate seamlessly while maintaining minimal power loss and high reliability during transmission.

The design introduces a multi-hop, full-duplex wireless communication model using a star-mesh hybrid topology to link sensors, concentrators, and gateways across the grid. Each HAN node acts as both a data collector and a relay station, enabling continuous data flow between distributed devices and central control systems. The use of Orthogonal Frequency Division Multiplexing (OFDM) as the modulation technique ensures robust communication even in the presence of noise and interference, while Rate Adaptive Algorithms (RAA) dynamically adjust transmission rates according to signal-to-noise ratios (SNR). This dynamic rate adaptation minimizes packet error rates (PER) and maintains stable connectivity under varying load conditions. By incorporating Greedy Perimeter Stateless Routing (GPSR) within a Quality of Service (QoS)-aware framework, the network achieves optimized routing decisions based on node position, link quality, and bandwidth requirements. This mechanism supports adaptive load balancing, efficient data delivery, and low latency in complex network topologies.

The system also emphasizes energy management and loss reduction within smart grids. Traditional Supervisory Control and Data Acquisition (SCADA) and Distributed Control Systems (DCS) are integrated with IoT-enabled monitoring modules to enhance visibility over energy flow and consumption patterns. The document highlights the significance of real-time decision-making in maintaining voltage stability, managing power distribution, and minimizing transmission losses. The adoption of Advanced Metering Infrastructure (AMI) plays a crucial role here, allowing continuous measurement, data collection, and automated control of energy consumption across connected devices. Embedded agents and smart meters are employed to monitor voltage, current, and frequency variations, thereby reducing wastage and optimizing the grid's efficiency. The Machine Learning (ML)-based algorithms incorporated into the HAN framework further contribute to predictive analysis and anomaly detection, allowing the system to anticipate load fluctuations and adapt control mechanisms dynamically.

The network's physical layer design focuses on reliability and scalability. Using Wi-Fi frequency bands in the 16–18 MHz range, as defined by IEEE 802.11af, enables long-distance data transmission with minimal interference and reduced signal dropouts. Each transmission unit operates using the RTS-CTS-DATA-ACK handshake protocol to manage congestion and prevent data collision between nodes. The concentrators, positioned in hexagonal arrangements, act as intermediaries that balance channel loads and handle mixed-signal routing from various HAN cells. The document also details how concentrator placement and signal frequency optimization help eliminate dark zones and improve overall network throughput. Moreover, the Marginal Signal Selection Rate (MSSR) concept improves signal strength management and ensures equitable bandwidth distribution across the network. The topology design strategically assigns distinct channels for uplink and downlink communication to reduce congestion and interference, particularly near concentrator borders.

The technical framework includes an innovative sensor positioning and routing algorithm that facilitates optimal data transmission paths based on signal strength and energy availability. The algorithm, outlined in the document as "Algorithm 2.1," defines procedures for channel selection, sensor placement, and packet delivery using iterative time slots and signal validation loops. This approach ensures synchronization among nodes and minimizes the likelihood of redundant transmission or packet loss. The use of Call Admission Control (CAC) in the QoS routing layer guarantees that each new connection meets latency and throughput constraints before joining the network, thereby maintaining system integrity during peak operations. Additionally, the network's distributed concentrator structure supports multi-cell connectivity and allows energy data from different households or units to be aggregated and analyzed centrally, improving accuracy in energy tracking and forecasting.

Security and stability form another crucial component of the technical discussion. With smart grids and HANs increasingly connected to the internet, cybersecurity risks such as malware, unauthorized access, and load redistribution attacks (LR attacks) become significant. The document references various studies emphasizing the need for three-tier security models integrating encryption, authentication, and anomaly detection. The use of Enhanced Identity-Based Cryptography (EIBC) and Secure Remote Password (SRP) protocols ensures that data exchanges between HAN devices and cloud servers remain secure and verifiable. Furthermore, non-intrusive load monitoring algorithms are applied to differentiate between normal and abnormal energy usage behaviors, providing early detection of inefficiencies or cyber intrusions. These technical safeguards enhance the reliability of energy-aware automation systems and make them resilient to both digital and physical threats.

From an implementation perspective, the framework also introduces Distributed Energy Storage Systems (DESS) and renewable energy integration to stabilize voltage and reduce dependence on centralized power plants. Through optimal load routing and dynamic control of power flows, the HAN can support bidirectional energy exchanges between the grid and households. The control algorithms manage both active and reactive power to maintain voltage balance and reduce phase differences during high-load conditions. Simulation studies mentioned in the document demonstrate how wireless sensor networks (WSN) and IoT gateways can be used to gather and process data across multiple home units, enabling efficient demand-side management and real-time response to grid fluctuations. The Bayesian network models and Support Vector Machines (SVM) referenced in related research provide further precision in load forecasting and device classification, contributing to the adaptive and intelligent nature of the automation framework.

The proposed energy-aware automation framework represents a significant step toward achieving sustainability through technological convergence. Its modular design supports interoperability between traditional and modern communication protocols, enabling legacy systems like SCADA to coexist with IoT-based platforms. The implementation of multi-hop routing, machine learning decision models, and real-time monitoring creates a resilient infrastructure capable of handling vast amounts of data with high reliability. In addition, the inclusion of cloud-based analytics allows long-term storage and pattern recognition, supporting predictive maintenance and strategic energy planning. The resulting system not only improves operational efficiency but also contributes to environmental conservation by minimizing power waste and promoting optimal resource utilization.

CONCLUSION

This thesis will focus on the planning and implementation of artificial intelligence (AI) with smart energy utilization for HAN. In addition to transmitting data and messages via the use of IEEE 802.11a and Zigbee wireless protocols, the system that was built has the ideal layout combinations (Star-Mesh technology).

calculate the amount of data loss, error handling, and signal enhancement, this study makes use of the most effective adaptive filters. The Dijkstra algorithm utilizes the sensors and nodes that are located in close proximity to the HAN discover the most effective way for transmitting a message. The only objective of this tool is to identify the path that is both the most energy- and data-efficient.

The fact that the system is fully digital and automated makes it more susceptible to being attacked by cybercriminals. The implementation of a three-tiered security strategy inside the framework that is already in place would prevent this from happening. This cutting-edge security configuration guarantees that all of the data from each device will be preserved in its original condition. Each and every piece of apparatus is able to communicate with the central hub. The setting of the HAN makes it possible to provide cloud services and remote help. Customers are provided with a link to the cloud as well as help with their data in real time by the platform. A wait time of no more than ten seconds is the very minimum, and users may access their data online at any time, day or night. Each and every item operates on its own.

Machine learning has been experimented with in a variety of domains, including but not limited to the processing of data, the management of errors, the identification of appliances, and the creation of maps. The report offers a detailed and thorough overview of the results and findings that were obtained from the testing. A programmed robot that is capable of operating on its own is also used for the aim of testing the suggested technology. Individuals have the ability to remotely monitor and change the robot's energy consumption via the use of wireless sensor networks. The implementation of the energy-aware automated system results in a considerable improvement in both the energy consumption of the robot as well as its efficiency and effectiveness.

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