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Realizing an IoT-Based Home Area Network Model Using ZigBee in the Global Environment

Ekele A. Asonye[1], Sarhan M. Musa[1], Cajetan M. Akujuobi[1], Matthew N. O. Sadiku[1] and Justin Foreman[1]

[1]Department of Electrical and Computer Engineering, Prairie View A&M University, Prairie View, Texas, 77446, USA

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Abstract: As devices become increasingly connected, the Internet of Things (IoT) concept becomes ever so prominent. For Device-to-Device (D2D) communications in the home and industry like for power, oil and gas, utility transmission and transport, the most profound challenge of the IoT has been organizing this large number of devices into a network of things. The Majority of these devices constituting the IoT setup are lightweight, low power wireless sensor nodes. The objective of the Home Area Network (HAN) is to continuously monitor connected devices, collect data, process data, and give feedback where and when needed. Within this chain of communication are numerous nontrivial and computational issues. In this paper, we demonstrate the proof of concept using the ZigBee protocol as a smart data collection element in IoT based HAN in global environment. A simulation study with different topologies and configuration using the ZigBee network platform in the global environment is presented. Based on traffic-demand, it is imperative to implement a network configuration that enables ideal network performance. To transfer the large volume of collected data from the HAN, we designate the Fifth Generation (5G) wireless device enabled with Mobile Edge Computing (MEC) connected to the cloud to process data.

Keywords: ZigBee, Internet of Things, Home Area Network, Wireless Sensor Network, 5G

1. Introduction

The IoT has been proposed as a concept to interconnect all devices globally, and into a smart network using the existing IT infrastructure. Consequently, the Internet of Things (IoT) is a term that refers to the next era of the Internet, which will serve as a platform hosting a variety of devices, from hand-helds, sensor devices, to supercomputers and large web servers. Such a technology will certainly represent the next move for the Internet and computing, integrating new technologies relevant to communications and computing. Since these devices are considered to undertake sensing operations among themselves, with minimal or no human involvement, the wireless sensor network will definitely be the foundation on which IoT is built upon.

The ZigBee network protocol has found major applications in wireless sensor networks because it possesses properties that make it standout to connect low power devices. It is a low cost, low power, low data rate, and reliable network. A lot of attention has been drawn to it, especially from IoT protocol developers. In recent years, the ZigBee Alliance, consisting of a number of top companies, have come together to improve interconnectivity through standardization. The latest development being the advent of ZigBee 3.0 to ensure all device types connect wirelessly in the same network. ZigBee is typically composed of two types of network devices namely; the Full Function Device (FFD) that implement in totality the specification of the protocol, and the Reduced Function Device (RFD) whose roles are reduced to consume less power and less memory use for the microcontroller.

Home Area Network (HAN) is a concept that will greatly benefit from this promising technology. It will be made to accommodate IPv6, ubiquitous computing, real-time localization, mobile communications technologies, Radio-Frequency Identification (RFID) technology and sensor networks. A smart gateway is needed to bridge the HAN to the WAN.

This paper illustrates the behavior of ZigBee protocol with about 70 devices, when in an IoT configuration. We have included a Fifth Generation (5G) device to serve as the transmission element. The expectation is that ZigBee and 5G are invaluable components of the HAN. We also show the impact of having two ZigBee Coordinators (ZCs) within a Personal Area Network (PAN) can have on the mesh, tree and star topologies respectively.

E-mail: easonye@student.pvamu.edu, smusa@pvamu.edu, cakujobi@pvamu.edu, msadiku@pvamu.edu, jforeman@pvamu.edu

The remainder of the paper is organized as follows: Section 2 gives an overview of the IoT architecture, describes the ZigBee network in further details, and highlight the home area network model. In section 3, we will present some recent related works and discuss results of the simulations in section 4.

2. INTERNET OF THINGS ECOSYSTEM

The Internet of things can be simply put as the extension of the traditional internet. It is a “future internet” concept that enables devices communicate with each other and share data directly. This new paradigm has also prompted consequent advancement in similar technological applications like Industrial automation, Smart City, Smart Home, Smart Healthcare, Smart Grid and Smart Government. Other applications are in fitness tracking, environmental protection, and fraud-free transactions. Subsequently, it has led to massive progress and solutions been provided in the fields of mobile computing (MC), pervasive computing (PC), wireless sensor networks (WSNs) and cyber-physical systems (CPS).

A. IoT Architecture

The IoT combines different technologies to achieve the purpose of collecting data and transmitting them for different applications. It involves many research fields such as network architecture design, sensor and object identification, information coding, data transmission, data processing, network planning and link/node discovery. The IoT architecture is basically divided into 3 layers (IoT device layer, IoT gateway layer, IoT cloud platform layer) as shown in Figure 1, which forms the core structure of the IoT framework. However, there are software considerations that need not be overlooked. With the heterogeneous nature of the IoT infrastructure, a middleware is essential to connect and manage the different components constituting it. It also requires some standardization for these components to interact. Therefore, the layers are addressed in four stages [1].

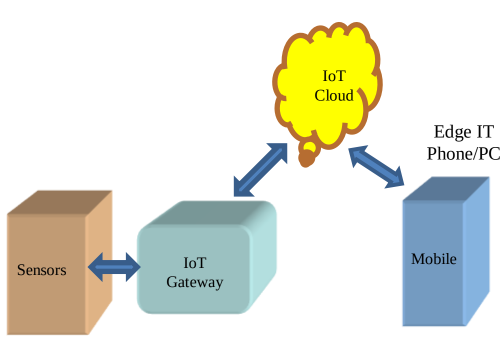


Figure 1. IoT Architecture

1) Three Layers of IoT Architecture

a) IoT Device Layer: In other transcripts, this layer is called the perception or sensing layer. It typically is a physical layer that uses sensors for sensing activities and gathering information from the environment.

b) IoT Gateway Layer: Also called the network layer. It has the job of connecting smart objects, network devices and servers for effective transmission and processing of data.

c) IoT Cloud Platform Layer: This is also known as Application layer, for delivering application specific services to the user. Different applications presented in the IoT are described here. For example, smart city and smart home.

2) The Four Stages of IoT Architecture

a) Sensors and Actuators: These enable the underlying fabric for establishing an internet-of-things network. Sensors convert information obtained from the outside world into data for analysis. IoT sensor are usually small sized, low power consuming and low cost devices. They are limited by their computational capability and complexity of deployment. Certain types of IoT sensors are neural sensors, environmental and chemical sensors, medical sensors and phone-based sensors [2].

Actuators are prompted to make the required adjustments based on physical reality. An actuator effects a change in the environment by converting electrical energy into a different form of energy. Actuators are classified into electrical, hydraulic or pneumatic, depending on the operation it is employed. Examples of actuators are electrical motors, heating and cooling elements and also speakers.

b) Internet Gateways and Data Acquisition Systems: Here, there is an aggregation and digitization of the enormous amount of data obtained from the previous stage. Data obtained from sensors are usually in analog form, and as such, are aggregated and undergo some conversion into digital streams. To perform this function, Data Acquisition Systems (DAS) sit in close proximity with sensors and actuators. DAS essentially collect data, organize and present them in an optimized format for further processing. The internet gateway receives the organized data and routes them over Wi-Fi, wired LANs or using other established means over the internet onto the next stage.

c) Edge IT: The massive amount of data passed on from the last staged is commonly moved to the cloud for analysis and storage because only the cloud possesses the resources to cater such amount of data. However, there may be certain challenges encountered along the communication line that will cause some disruption. Data may require some processing at this stage before cloud is employed. Hence, Edge IT systems perform enhanced analytics and preprocessing using machine learning and visualization technologies. Factors that bring about delay during communication with the cloud can be as a result of mobility of smart devices, which causes changing network conditions [2]. As smart devices change location from time to time, network conditions are also altered. In addition, communicating with the cloud and obtaining responses are latency-sensitive operations. This implies that real-time actuation might become non-existent and in other cases, generate unreliable responses due to lossy communication..

d) Data center and cloud: This stage handles analysis, management and provide secured storage of data. A more insightful processing and deeper analysis is required to deliver an accurate feedback.

This stage houses powerful physical data centers or cloud-based systems, which possess very potent IT equipment and operations that can analyze, manage and store data securely.

B. Data Transportation by 5G

With growing demand for a higher and faster network to handle the exponential surge in the amount of data generated per day, 5G network has become the preferred choice because it possesses the requirement to fulfill this need. The international telecommunication union has classified 5G services into three categories [3]:

1) Enhanced Mobile Broadband (eMBB) to compensate for services with high bandwidth like High definition, Augmented reality, and Virtual reality. The benchmark to measure the performance of wireless networks is speed. Here, speed can be interpreted as bandwidth capacity, data transfer rate or data connection rate. The expectation for 5G, under ideal situations, is to have its speed reach 10Gbit/s, up from the 300 Mbit/s that 4G/LTE currently offers.

2) Ultra-reliable and Low Latency Communication (uRLLC) – In an era where the viability of autonomous vehicles is investigated, latency for these connected objects should be extremely low. The target for 5G is to keep latency at one millisecond. An autonomous vehicle, which analyzes data with a latency of one millisecond will react one thousand times faster than a human will, and can cause the brakes to engage within one centimeter.

3) Massive Machine Type Communication (mMTC) deployed for high-density connectivity in smart city and smart agriculture. This is in contrast to the usual mobile phone communication among humans, because machine-type communication can have devices transmit at irregular intervals, small or large quantity of delay-sensitive or insensitive information. Machine type communications involve machines sending bits of information to other machines, servers, cloud or even humans. This will account for a large chunk of data to be transported using 5G.

5G network possesses certain features that make it easily deployable in the IoT. It presents capabilities to provide support for technologies and services that will greatly enhance IoT development. These characteristics are:

1) Millimeter Wave – 24GHz to 100GHz proposed for 5G.

2) Massive Multiple Input, Multiple Output (MIMO) – Wave frequency is inversely proportional to antenna size. Lot of transmitters and receivers installed on a small size cell or panel.

3) Small Cell – To fill in coverage gaps between base stations and users.

4) Beamforming – Less signal interference from nearby users.

5) Non-Orthogonal Multiple Access (NOMA) – Serve multiple users using the same resource in terms of time, frequency, and space.

6) Mobile Edge Computing – Can enable application service splitting.

C. Wireless Sensor Network (WSN)

WSN contains of a large amount of wireless networked sensors required to operate in a possibly hostile situation for an extreme duration without human intervention. WSN nodes comprise of low-power sensing devices, embedded processor, communication channel, memory and power module. The embedded processor typically does the collection and dispensation of the signal data obtained from the sensors. Sensor elements produce a quantifiable response to change in the physical attribute of a given area. Sensors have the ability to detect many physical units, such as length, area, volume, mass airflow, strength, temperature, heat transfer, voltage, electric current, resistance, flux density, magnetic torque, condensation, content, and oxidation/reduction. Sensor nodes sense and detect events and relate data to the base station.

Consequently, the wireless sensor network can be described as the basis of IoT and considered as key element in building a network in which sensing operations between things can take place, and also handle information processing and exchange with little or no human involvement. For the IoT, it is important to identify a reliable technology that will be used to network these devices. The wireless networking technologies currently available are the ZigBee, Near-Field Communication (NFC), Adaptive Network Topology (ANT), Wireless Fidelity (Wi-Fi), Bluetooth and RFID. In Table 1, we highlight some of these technologies based on certain parameters to determine what characteristics they offer to be considered for IoT environment [4].

D. ZigBee/IEEE 802.15.4 Standard

1) ZigBee Overview

ZigBee is one of today's most useful technologies in the wireless sensor network industry. It is a wireless communication standard based on the IEEE 802.15.4 standard announced by IEEE in 2003. ZigBee is established on a powerful physical and Media Access Control (MAC) layer structure as defined by the IEEE 802.15.4 standard as shown in Figure 2. It adopts the Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) media access mechanism and although wireless sensor networks usually support several topologies, the main ZigBee based sensor network topologies are star, tree and mesh.

ZigBee is distinguished from other communication standards like Wireless Fidelity (Wi-Fi), Bluetooth and Worldwide Interoperability for Microwave Access (WiMAX) when considering parameters like small-sized data transmission and low-power consumption. On the other hand, it has a greater advantage over other wireless sensor communication standards in terms of bandwidth, scalability and self-organization [5].

TABLE I. CHARACTERISTICS OF SOME WIRELESS SENSOR NETWORK TECHNOLOGIES

NAME	Wi-Fi	Wi-Fi	ZigBee	Z-Wave	Bluetooth
PHY/MAC Standard	IEEE 802.11n	IEEE 802.11ac	IEEE 802.15.4	ITU-T G.9959	IEEE 802.15.1
Network Topology	Star, mesh	-	Tree, star, mesh	Mesh	Star
Network Size	2007	-	65536	232	8
Maximum Data Rate	600Mbps with MIMO	100kpbs + 20Mbps with multi station mode	Up to 250kbps(2.4GHz)	200 kbps	1 Mbps
Radio Frequency Band	2.4 and 5 GHz	863 – 868 MHz (Europe), 902 – 928 MHz (USA) + Asian countries	868.0 – 868.6 MHz, 902 – 928 MHz, and 2.4 – 2.4835 GHz	868.42 MHz (Europe), 908.42 MHz (USA), 921.42 MHz (Australia) and 919.82 MHz (Hong Kong), 400 series chip 2.4 GHz	2.4 GHz
Range	70m indoors and 250m outdoors	1000m	10-100m	30m indoors and 150m in line of sight	5-100m
Error Control/Reliability	32-bit CRC	-	16-bit CRC, ACK, CSMA-CA	8-bit CRC, ACK, CSMA-CA	16-bit CRC
Transmit Power	722.7mW	255mW	52.2mW	108mW	72mW
Battery Life (Day)	0.5 - 5	-	100 – 1000+	90 - 270	1 - 7
Security	WPA2, EAP, TLS/SSL	-	AES-128	AES-128 (400-series chip)	AES-128

Three license-free frequency bands are defined for ZigBee according to IEEE 802.15.4. The first band utilizes the 2.4 GHz frequency band, and has 16 channels. The second band uses the 902-928 MHz frequency band with 10 channels. The third band uses 868-870 MHz frequency band with only one channel.

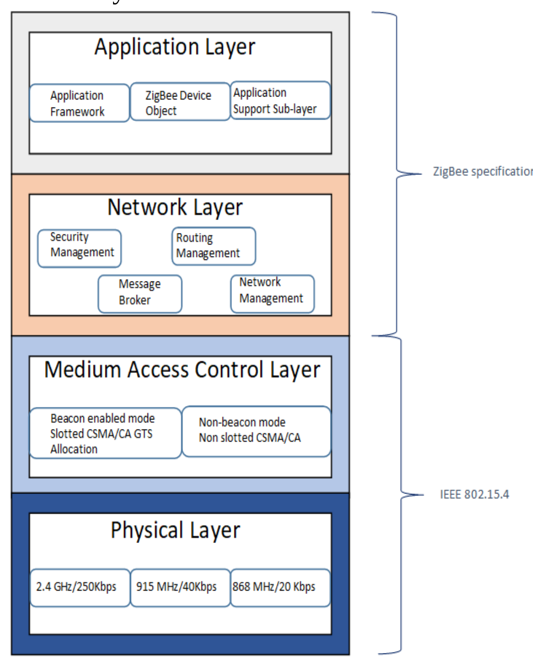


Figure 2. ZigBee Layers

The capacities of these frequency bands are 250 kb/s, 40 kb/s and 20 kb/s respectively [5].
ZigBee network also provides 128-bit key symmetric cryptography, thereby offering a high level of information network security.

2) ZigBee Network Types

The ZigBee architecture supports three different types of devices in an orientation that depends on different network setup. A ZigBee network consists of a Coordinator, Router and End device.

a) ZigBee Coordinator (ZC): The ZC is responsible for initiating the network. It administratively organizes traffic routing in the network, and performs handling and storing of information. It allows any device to connect to its node and may bridge to other networks. There is only one coordinator in a given network.

b) ZigBee End Device (ZED) – The ZED has limited functionality and communicates only to its parent. It cannot have a child or work as a router. This feature helps ZigBee network saves power [6].

3) ZigBee Network types

ZigBee networks are generally presented in three topologies as shown in Figure 3, namely star, mesh and tree.

a) Star Topology – Here the coordinator is central, and all routers and end devices are directly connected to it. It is a simple and easy to deploy.

b) Mesh Topology – The mesh set-up allows nodes to have different paths from source to destination. This feature gives it its self-healing characteristics and makes it the most reliable.

c) Tree Topology – In this structure, each cluster comprises a coordinator with leaf nodes. The coordinator is considered the root of the tree. Routers and end devices can connect directly to the coordinator. The router may have child nodes, which can be another router or an end device [6].

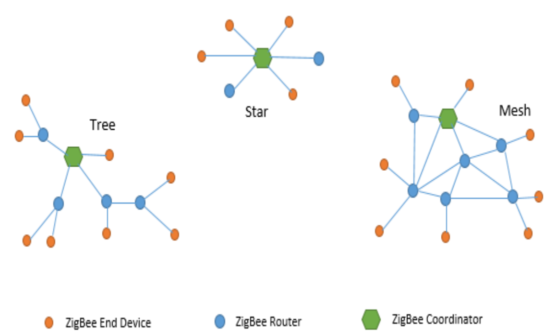


Figure 3. ZigBee Technologies

ZigBee network protocol has found significant applications in Industrial Automation, Smart Grid Monitoring, Smart Meters and Smart Homes. Figure 4, shows some areas where ZigBee is applied.

E. Smart Homes and HAN

Realizing a modern home that offers a comfortable and secure living requires two major ingredients, Automation and Intelligence. This can be achieved by analyzing the enormous data collected, applying artificial intelligence and providing feedback to homeowners. An aggregation of electronic devices from different technological platforms sets up a Home Area Network (HAN), seen in Figure 5. These devices communicate with each other without the need for the resident to visit each one individually. Hence, a Smart Home network is established in getting these devices to work together on a single network configuration [7].

A smart home consists of a variety of interconnected sensors, smart appliances, and metering systems that are controlled over the internet through a smart gateway.

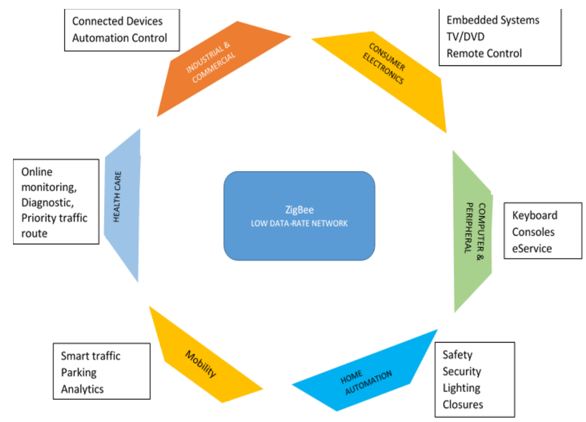


Figure 4. ZigBee Applications

The smart home setup achieves monitoring, providing a convenient, safe and secure environment, and inadvertently, helping the homeowner save money.

The elements making up smart home can be essentially characterized into three tiers [7]:

1) Cyber-physical: This refers to the sensor devices, metering systems, appliances, and energy management systems. These interact with the surrounding physical environment and obtain data required for monitoring.

2) Connectivity: Inbound and outbound communication within the smart home and the cloud require an IoT gateway. To do this, different communication protocols are applied to ensure smooth transfer of data.

3) Context-awareness: This refers to the user-defined rules and polices implemented to manage the smart home. It embodies event detection, predictive analytics, behavioral analytics, and activity recognition. These configurations are made in the smart home to preserve privacy and security measures.

3. RELATED WORK

Quite a number of research studies have been conducted regarding ZigBee, sensor nodes, and ways to collect, manage and analyze data in IoT. ZigBee enlarges the field of IoT by enabling Device-to-Device (D2D) communication wirelessly. It was presented for having low power dissipation capability for use in a wide range [8]. ZigBee finds significant utilization in the internet of things era in the area of industrial monitoring and control systems, smart home environment, Smart health automation, remote sensing, smart energy management and connected lighting.

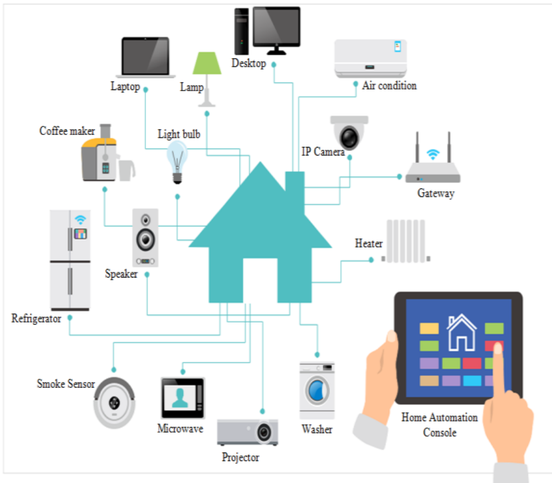


Figure 5. Typical IoT Smart Home Architecture

In [9], the paper examined topological features of Wireless Sensor Networks (WSNs). They compared two scenarios in determining the effect network topology can have on network packet data. They considered the end-to-end delay, number of hops and global throughput for each topology. Results were also shown for tree topology of thirteen nodes to compare a single PAN with two PANs.

In [10], wireless sensor network using ZigBee was integrated with 4G Technology for data transmission and reception using tree routing concept. The study aimed at reducing the delay for sensor nodes when data traffic is being transmitted in the Fourth Generation (4G) network.

IoT has been applied to Smart Agriculture to increase production efficiency and quality. It therefore finds significant implementation in and medium-sized farm and agriculture industries [11].

In [12], two different environments of wireless sensor networks were simulated for different ZigBee topologies in a view to choose the most appropriate topology for given applications.

Jun-Ho Huh et al highlighted the difference between the mobile wireless Worldwide Interoperability for Microwave Access (WiMAX) and ZigBee network based on their technology standards. The study showed mobile WiMAX had better functionality but ZigBee is better in terms of scalability.

There have been some interesting and increased trends in the area of wireless sensors network communication that relates radio frequency waves and optical waves. The authors in [13] designed and implemented a dispersion-managed soliton link. From the performance analysis, the soliton transmission was seen to be an attractive prospect for realizing a high-speed, long-distance communication.

Similarly, in [14] a 10Gbps optical communication system with dispersion-managed RZ pulse was designed and simulated. The return-to-zero (RZ) format outperformed the non-return-to-zero (NRZ) format in having better receiver sensitivity and fiber transmission.

A framework to manage Smart Homes was proposed in major challenges relating to data processing and interoperability of sensor devices were reviewed [15]. These limitations would impact the realization of fully automated homes. ZigBee technology deployment features and how can be deployed for IoT purposes in cloud were discussed [16-19]. The IoT cloud technology has been applied for long term surveillance with big data managements and sharing analysis for the collected data to enhance the applications of 5G technology [20-22]. Personalized applications of IoT for smart agriculture were discussed to improve the end-to-end reliability of its IoT communications network [23].

4. MODELING AND SIMULATION OF THE SYSTEM DESIGN

For our simulation, we use ZigBee as the single underlying network to connect devices together. We also recommend using 5G to data migration in and out the smart home network. The Riverbed Modeler OPNET simulation software can simulate different network parameters. In this paper, we focus on throughput, load, delay, data traffic received and number-of-hops as the metrics to evaluate the performance of the three network topologies in an IoT setup.

To go a step further, we also organize the ZigBee platform into Personal Area Networks, assign PAN IDs and observe what impact it has on the initial network configuration. We investigate individual topologies with one ZigBee Coordinator and two ZigBee Coordinators.

We present the Discrete Event Statistics in Global mode so as not to restrict communicating devices to within a limited reach.

A. Simulated Reference Model

The reference model, shown in Figure 6, depicts how data generated from the Home Area Network, is passed through a gateway to be processed in the cloud or using the mobile-edge technology. A 5G device is enabled with edge-computing application to manage data from the HAN. The simulation of the model, as elaborated in Figure 7, consists of a smart home structure that has 70 objects, including ZigBee Coordinators, ZigBee Routers, ZigBee End Devices, Switch, wireless Router and 5G Device. In Table 2, we set the parameters for simulation and observe the results obtained.

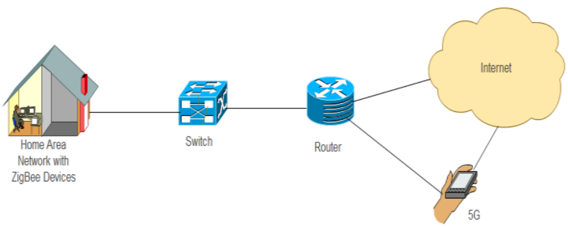


Figure 6. Home Area Network (HAN) Model in global mode

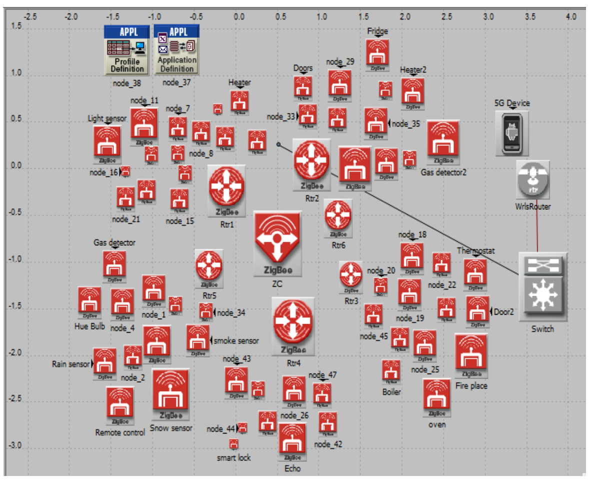


Figure 7. Simulating the HAN in global mode

TABLE II. SIMULATION PARAMETERS

Environment	Parameters
Simulation Time	3600 seconds
Range	100m × 100m
No. of Coordinator	1
No. of Router	5
No. of Object	70
MAC Wait duration	0.05s
Number of Retransmissions	5
Minimum Backoff Exponent	3
Maximum Number of Backoff	4
Channel Sensing Duration	0.1
Transmission Bands	2.45G
Transmit Power	0.05w
Packet Interarrival Time	1
Packet Size	1024 bits

B. Results and Discussion

In this investigation, we consider the performance description for mesh, star and tree Topologies and the performance description for single and multiple ZCs.

1) Performance Description for Mesh, Star and Tree Topologies in Global Mode

The throughput is defined as the total data traffic in bits/sec successfully received and forwarded to the higher layer by the 802.15.4 MAC. It is can be observed in Figure 8 that throughput for tree topology is more but is less in star topology in global mode. Generally, if the delay in the network is low, throughput is more. It is given by

$Th = \frac{N}{R}$, where Th is the throughput, N is number of bits sent, R is the runtime.

The load in bits/sec is shown in Figure 9. The statistic records the amount of data submitted to the 802.15.4 MAC by its higher layers in this node. The result in Figure 9 reveals efficiency in using Tree Topology among other network setup in global mode.

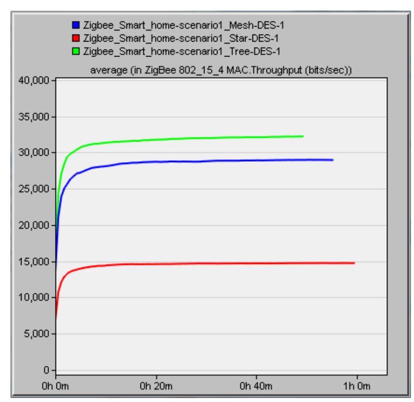


Figure 8. Average throughput for 1ZC ZigBee network in global mode

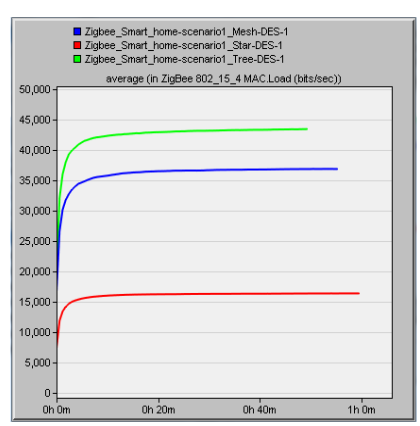


Figure 9. Average load for 1ZC ZigBee network in global mode

The delay represents the end-to-end delay of the packets received by the 802.15.4 MAC of this WPAN node and forwarded to the higher layer. Mesh topology shows higher End-to-End delay in Figure 10. This is because of the increased number of path for transmission between end devices and the Coordinator. Delay is given as: $D_{\text{end-edn}} = N_r \times \left(d_{\text{Proc}} + d_{trans} + d_{prop}\right)$, where N_r is number of routers + 1, d_{Proc} is processing delay, d_{trans} transmission delay, d_{prop} propagation delay.

The data traffic received is the total traffic successfully received by the MAC from the physical layer in bit/sec. This includes retransmissions. Figure 11 shows a low number of packets dropped for Tree Topology in global mode.

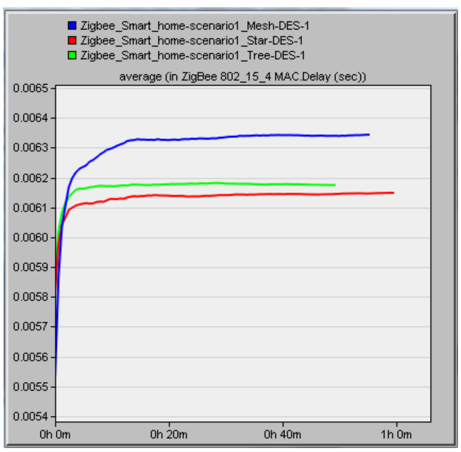


Figure 10. End-to-end delay for 1ZC ZigBee network in global mode

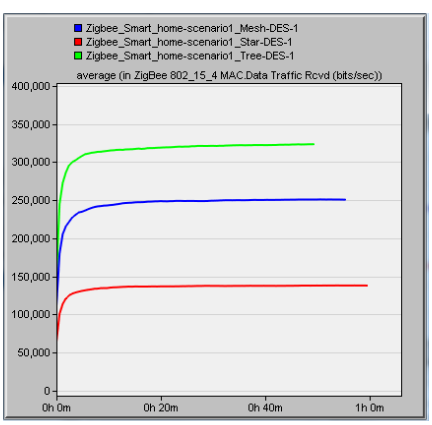


Figure 11. Data traffic received for 1ZC in global mode

The number of hops is the average number of hops travelled by the application traffic. Expectedly, as can be seen in Figure 12, star topology has between 1.5 and 2 because there might just be an intermediate node between source and a random destination. The number-of-hops for tree varies from 1 to 5, depending on the maximum depth of network structure, which for us is about five. Mesh uses a routing table.

2) Performance Description for Single and Multiple ZCs

We use Delay and throughput as our metrics to observe the network behavior having one ZC versus two ZCs for the different topologies in global mode.

In Figure 13, the average throughput in Tree topology with 1ZC is higher than 2ZC because, with 1ZC, there is only one path to destination that the end devices can take. However, with 2ZC, there really is no wait for pending packets to be transmitted since there is an alternate route. Consequently, higher throughput means lower delay.

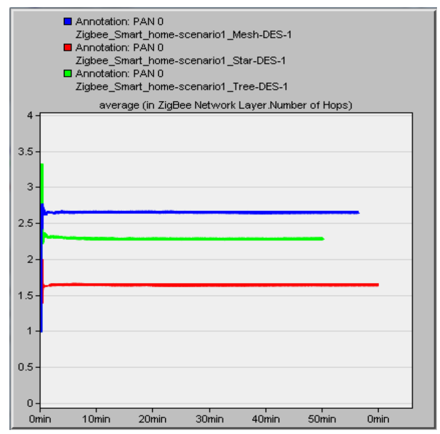
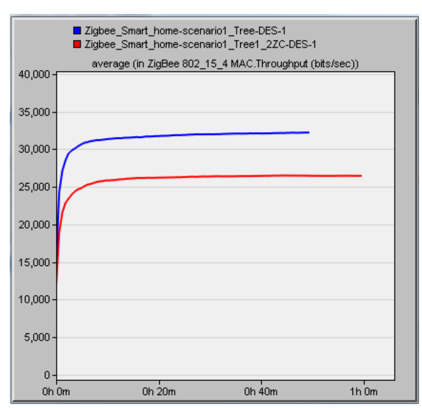


Figure 12. Number of hops in global mode

Figure 14 shows for Mesh topology in global mode, having 2ZCs increases the throughput and lowers delay.

Figure 15 compares the Throughput in Star Topology having 1ZC and 2ZCs respectively in global mode. A similar result is obtained when using Delay for comparison. The throughput and delay are higher when using 2ZCs than having 1ZC.



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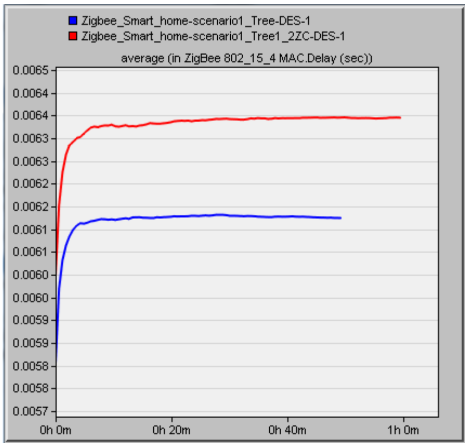
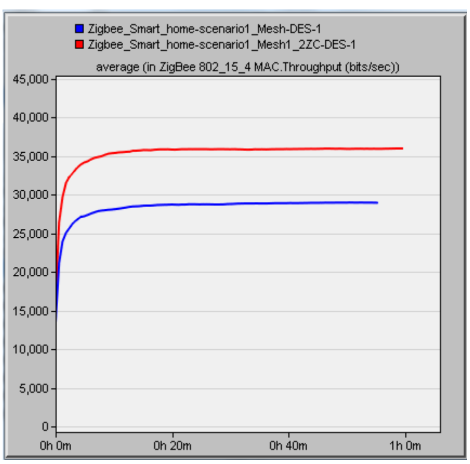
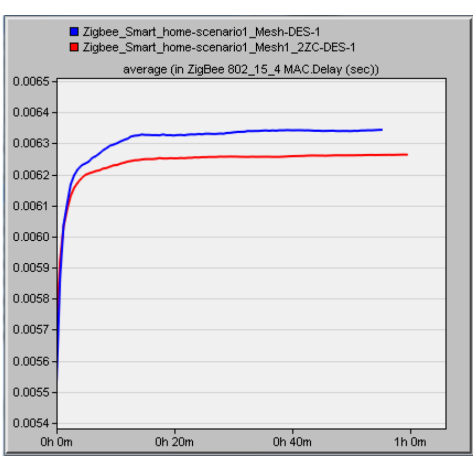


(b)

Figure 13. Tree topology comparison in global mode for 1ZC and 2ZCs (a) Throughput (b) Delay

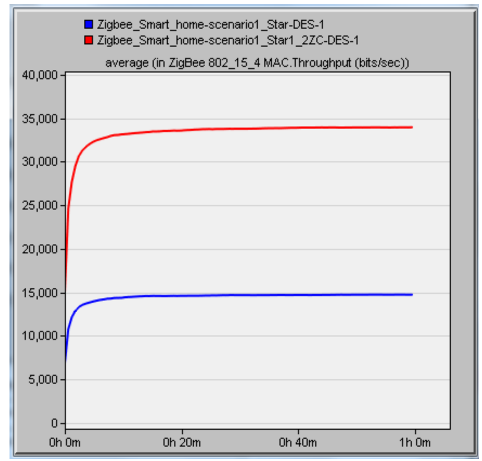


(a)

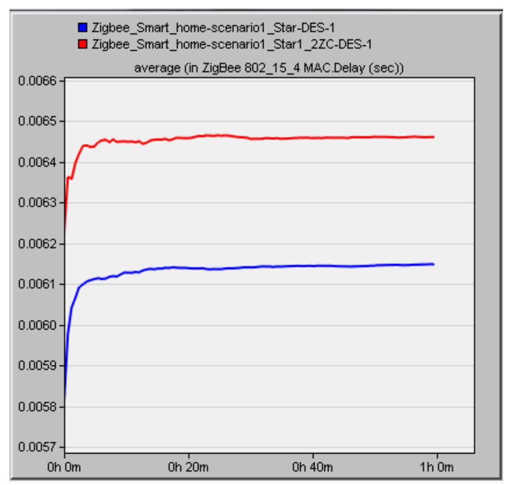


(b)

Figure 14. Mesh Topology comparison in global mode for 1ZC and 2Zcs (a) Throughput (b) Delay



(a)



(b)

Figure 15. TStar topology comparison in global mode for 1ZC and 2ZCs (a) Throughput (b) Delay

5. CONCLUSION

To evaluate the smart home configuration, we demonstrated a design and simulation study to show the connectivity and concept of the HAN using ZigBee protocol by applying different ZigBee Network Topologies in global environment. We described the proof-of-concept of the IoT infrastructure in collecting, transporting and processing, and also obtaining feedback as needed. It can be deduced based on the overall performance metrics used in the analysis, that the tree network topology outperforms the mesh and star topologies.

In the second part of the study, having two ZCs showed better throughput in star topology, however, it also experienced greater delay because of the number of ZEDs for each ZC. For mesh, having two ZCs improved the throughput and delay accordingly. In tree topology, the network with one ZC showed better throughput because in the tree structure, the ZEDs communicate only with the ZC and use one path to reach the destination, avoiding collision along the way.

Future studies will be to investigate extensively the characteristics of different IoT applications and the service requirements for these applications, in particular, the overall system energy consumption and quality of service.

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Ekele Arthur Asonye, received the B.Sc. degree in Electrical and Electronic Engineering from the reputable Federal University of Technology, Owerri, Nigeria in 2011. He obtained his M.Sc. in Electrical Engineering from Prairie View A&M University, Texas, USA, in 2015, and currently working to finish his Ph.D degree in Electrical Engineering also from Prairie View A&M University. His research interests include Internet-of-Things network application for low-power devices in Smart Home, Smart Health and Smart Cities, ZigBee protocol, Cybersecurity, Artificial Intelligence and Big Data, and other related fields.

Sarhan M. Musa, is a professor of Electrical and Computer Engineering Department at Prairie View A&M University and a senior member of the IEEE. He holds a Ph.D. in Electrical Engineering from the City University of New York. He is the founder and director of Prairie View Networking Academy (PVNA), Texas. Prof. Musa is LTD Sprint and Boeing Welliver Fellow. He has written more than a dozen books on various areas of study in Electrical and Computer Engineering. His research interests cover many topics in the computer communication networks, with his current research interests focusing on privacy protection techniques in networked information systems, Shortest Path Bridging and cross-layer security enhancement in wired/wireless networks, and Internet of Things.

Prof. Cajetan Akujuobi, is the former Vice President of Research, Innovation and Sponsored Programs at Prairie View A&M University (PVAMU), Texas, USA. He is a Professor of Electrical & Computer Engineering. He is the Principal Investigator and the founding Executive Director of the Cybersecurity Center of Excellence and the Center of Excellence for Communication Systems Technology Research (CECSTR). He is also the founding Directors of the Broadband (High Speed Network) Communication Systems Program; Analog & Mixed Signal Program (AMSP), the DSP Solutions Programs, and the founding Director of the Communication Control Research Programs at PVAMU. His research interests are in the areas of Cyber and Information Security, Communication Systems, Wavelets and Wavelet Transform Analysis and Applications, Compressed sensing/Compressive Sampling Applications to Communication Systems, Analog & Mixed Signal Testing and Design, Broadband (High Speed) Communication Systems, Digital Signal Processing, Signal and Image Compression, Reconstruction, Restoration and Segmentation; Fractals and Fractal Analysis of Signals and Images, Aeroelastic System Vibration Analysis, Sensor Research and Applications. He has written over 100 journal and peer reviewed publications and technical reports. He has also written several book chapters.

Matthew N. O. Sadiku, is presently a professor of electrical and computer engineering at Prairie View A&M University, Prairie View, TX. He is the author of over 660 professional papers and over 80 books. He was the recipient of the 2000 McGraw-Hill/Jacob Millman Award for outstanding contributions in the field of electrical engineering. He was also the recipient of Regents Professor award for 2012-2013 by the Texas A&M University System. He is a registered professional engineer and a fellow of the Institute of Electrical and Electronics Engineers (IEEE) His current research interests are in the areas of computational electromagnetic, computer networks, and engineering education.

Justin Foreman, is an Assistant Professor in the Department of Electrical and Computer Engineering at Prairie View A&M University, Prairie View, Texas. He received his Ph.D. in Electrical Engineering from North Carolina A&T State University. He has worked at NASA Langley Research Center as a National Research Council Research Associate and as an employee of GeoControl Systems, Inc. supporting various NASA Johnson Space Center efforts as a Test.