Analysis of Personal Area Networks for ZigBee Environment Using Random Early Detection-Active Queue Management Model

Ekele A. Asonye and Sarhan M. Musa
Electrical and Computer Engineering Department
Prairie View A&M University, Texas, USA
easonye@student.pvamu.edu, smmusa@pvamu.edu

Abstract

So much interest has been drawn to producing more devices that will constitute the Internet of Things (IoT), however, the means to organize these devices into a network of things has remained a grey area. With the bulk of the emphasis channeled towards proliferating the number of embedded systems to compensate their growing demand, designing different IoT concepts and applications, and also prototyping different wireless sensor networks, a little concern has been directed to the study of quality of service relative to the exploding amount of data expected in the IoT network. In a typical IoT-based Smart Home Network, just as in our case, a ZigBee network, end devices send an enormous amount of data to the coordinator and other end devices through intermediary devices like routers. This, as a result, creates overhead application traffic in the coordinator's queue. The built-up queue causes congestion and subsequent dropping of packets, increasing delay and reducing throughput. Therefore, it becomes imperative to develop an operative active queue model that will ensure quick and reliable data mobility within or by across multiple Personal Area Networks (PANs).

This paper investigates a power-efficient ZigBee-enabled Smart Home Network that employs the Random Early Detection-Active Queue Management (RED-AQM) model to provide reliable data transport in the Smart Home context. We focus on the simulation of different network topologies for single and multiple PANs and identify the optimal network setup when using RED-AQM.

Keywords
Random Early Detection, Internet of Things, ZigBee, Personal Area Networks, Queuing

1. Introduction

ZigBee is a standard wireless protocol that enables the communication of smart devices in the IoT. It offers low-cost, low-data rate, and ultimately low-power consumption is needed in a wireless sensor network and control networks. Its security, interoperability, reliability, ease of network deployment, and reduced power consumption, draws the attention of researchers to it. ZigBee can expand its network size by allowing more device connection to the Coordinator. This scalability feature is desired as the market for IoT and Smart Homes continue to grow.

Within the Smart Home structure, several applications are executed concurrently in the same network or when interconnected to other networks through the internet. This causes new classes of problems to be encountered within these complex connections, especially as it relates to capacity planning and scheduling. To ensure optimal quality of service, it is important to examine several objectives such as minimizing collision rate, fault detection, decreasing energy consumption and prolonging battery life expectancy, increasing throughput, minimizing end-to-end delay and thereby ensuring reliability.

Different approaches have been proposed and with further studies still ongoing to provide an ideal queuing mechanism that answers to the concerns already expressed. The ZigBee protocol adopts the Random Early Detection (RED) algorithm to route information packets within its network. The RED algorithm has been clearly defined, established, and deployed to several internet protocol schemes. It has been mainly applied for congestion control in a TCP-enabled network. Other variants of RED have also been presented over the years to enhance and expand on RED's attributes.

While both commercial and open source simulators have been developed to define with fine granularity the interactions among the different elements of Wireless Sensor Networks (WSNs), one simulating tool stands out in presenting its results in very unambiguous form. The results enable protocol developers and network architects pay particular attention to levels of abstraction that are usually less considered. By observing the behavior of lower layer components of IEEE 802.15.4 networks, the problems usually encountered in higher layers of complex networks with thousands of units and a multiclass workload can be deduced. The Riverbed Modeler is used for designing and analyzing the RED-enabled ZigBee environment.

This paper is organized as follows. Section 2 presents some related works that have been done to improve the queuing system for WSN. In Section 3, certain terms are illustrated to give clarity about the article in general. Finally, we illustrate the modeling and simulation with the experimental results in Section 4.

2. Related Work

Quite a number of studies have been previously done regarding managing ZigBee's data traffic, queue management, data-bit handling, QoS and other performance enhancement based on different techniques. Abdel-Jaber [1] compared three Active Queue Management (AQM) techniques, Adaptive Gentle Random Early Detection (Adaptive GRED), Random Early Dynamic Detection (REDD), and GRED linear analytical model, to evaluate their effectiveness for congestion control. For modeling new complex networks, Bellasi [2] presented an alternative model to the original simulation for WSN, which is based on Queuing Network (QN) method. The method is particularly suited for capacity planning problems.

In Yousefi'zadeh et al [3] and Ajgaonkar et al [4], various traffic patterns and scenarios were analyzed using Marov Chain models and Ad-hoc On-Demand Distance Vector (AODV) routing technique. Lin et al [5] presented a Beacon Ordered-Based Random Early Detection (BOB-RED) algorithm which was proposed for the gateway node in IEEE 802.15.4 wireless sensor network.

The RED algorithm has shown viability in not only being solution for Transmission Control Protocol (TCP), but also for Ad-hoc networks. Burchfield [6] presented a 3-phase approach to maximize throughput in a large ZigBee network. Rao [7] examined Scheduling algorithm and the comparison of Guaranteed Time Slot (GTS) allocation on the ZigBee network on various parameters that includes Delay, Bandwidth, traffic, and energy efficiency.

Islam et al [8] et al introduced a stochastic model based ZigBee network design that improves Quality of Service (QoS) with respect to various ZigBee's parameter analyses like increasing throughput, lowering queuing latency, and lower MAC load. Islam also presented in [9] a region based priority method to improve ZigBee network performance where load was reduced for the priority based network for application traffic synchronization.

Jayakumari et al [10] developed a Priority Based Congestion Control Dynamic Clustering (PCCDC) protocol to conserve energy and avoid congestion during multiclass traffic. The protocol computes congestion at intra- and inter- cluster level using linear and binary feedback method. The protocol was designed with mobile nodes that are dynamically arranged into clusters to give thorough coverage and connectivity.

In [11], a node Priority-based Congestion Control protocol, which introduces a node priority index, was proposed for wireless sensor networks. The protocol uses packet inter-arrival time together with packet service time to measure the congestion degree, and subsequently imposing a hop-by-hop control based on the congestion degree and node priority index. An analytical model that uses internet traffic to represent sources of different traffic was proposed in [12]. This model operated as a queue management scheme to sustain queuing delay at a particular level within the buffer of a router. It used a closed-loop feedback control to set the limit for the average queuing delay by moving the queuing threshold based on packet arrival rates.

To improve sensitive delay in QoS application, [13] introduced an analytical method based on discrete-time queues for a single buffer to determine a relationship between queuing delay and queuing threshold. It measures queuing delay and estimates a set value to control average queuing delay. The model uses binomial distribution to approximate arrival process. Packets are dropped as a congestion notification indicator to update the rate for the arrival process.

3. Architecture and Functional Overview

Controlling the activities within an IoT network can bring about some desirable effects on network performance. The network duty cycle determines the active and inactive period within the network. Beacons are control packets that are sent by fully functional devices to synchronize the duration of activity within the network. IEEE 802.15.4 networks can be setup as beacon or non-beacon enabled.

3.1 ZigBee Technology

ZigBee is a low data rate, low power network communication standard for resource-constrained devices that is built on the IEEE 802.15.4 specification. It is a reliable wireless communication technology that can be setup in a Star, Tree or Mesh topology. It has a maximum data rate of 250kbit/s and can support up to about 65,536 nodes, where the node types in a ZigBee network can be a ZigBee coordinator, ZigBee router, or ZigBee end device.

3.1.1 ZigBee Coordinator

This is the device with the authority and responsibility of creating synchronization services within an established network. A coordinator can be one of two types depending on the scope of operation. The first is the PAN-coordinator, which coordinates activities for an entire PAN, while an ordinary coordinator functions within the scope of a cluster.

3.1.2 ZigBee Router

This device handles the routing of packets received from end nodes. However, it is not necessary to have a router in a network because traffic can travel from an end-device to a coordinator directly or between end devices using the coordinator's routing features.

3.1.3. ZigBee End Device

These are end points of a ZigBee network. They have limited functionality to talk to their parent nodes, and as such, do not have routing capabilities. They can sleep mode during periods of inactivity.

3.1.4 ZigBee Layers

ZigBee is a well-developed protocol composed of distinct layers. The ZigBee Alliance develop ZigBee technology and provide specification for Application and network security layers, whereas IEEE 802.15.4 defines the Media Access Control and Physical layer respectively. Fig. 1 describes the functionalities undertaken at each layer.

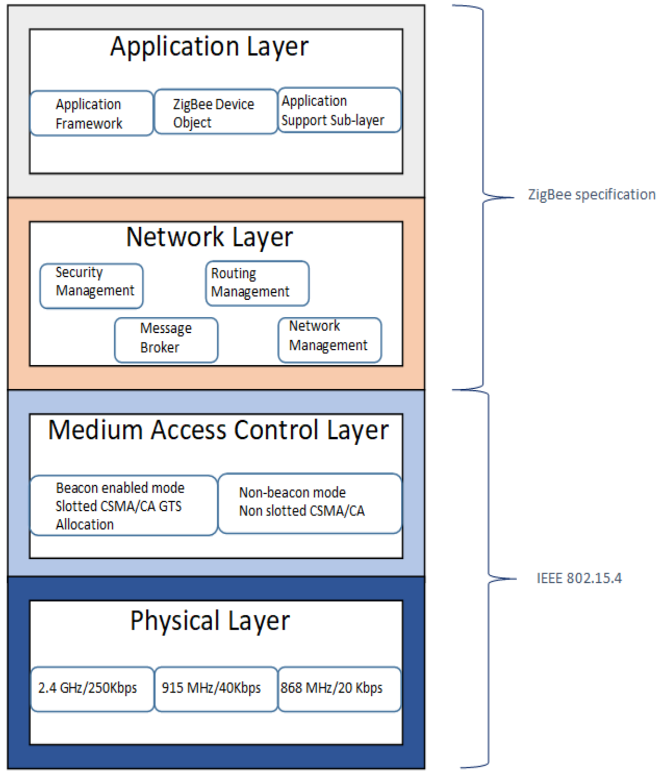

Fig. 1. ZigBee Layers

3.2 The Superframe Structure

The superframe is the time interval between two consecutive beacons. The coordinator determines the structure of the superframe. It can switch off the use of the superframe by not transmitting beacons, and this reason makes superframe an optional part of a WPAN. The superframe duration is divided into 16 corresponding slots, with the beacon transmitted in the first slot. The CAP, CFP and inactive, all describe the remaining slots respectively [14].

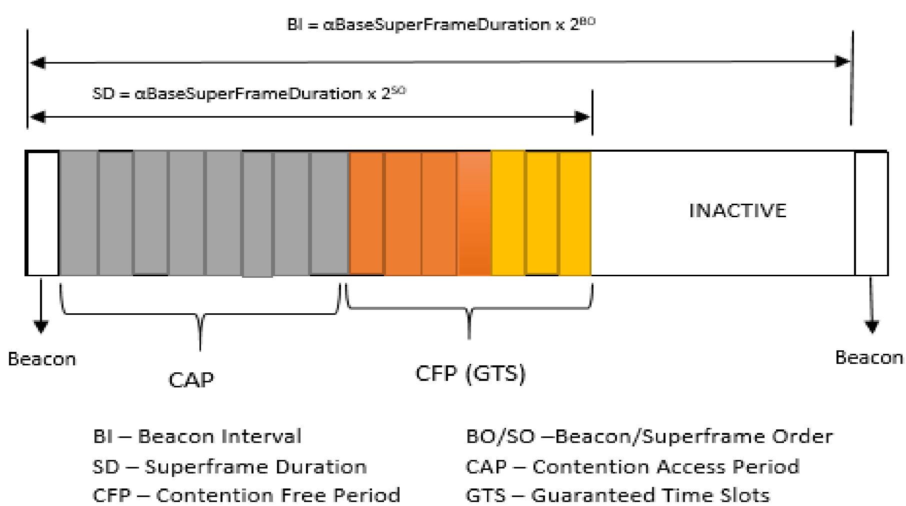

Fig. 2. The Superframe Structure in a beacon enabled ZigBee Network

Certain statistics are critical for the operation of the PAN in a Beacon-enabled network. This information is provided by the superframe shown in Fig. 2. They include synchronization information, identifying the PAN and the superframe structure, and connected devices in a wireless PAN [14].

Contention Access Period – This refers to the time duration in symbols where devices can compete with each other to use the channel using CSMA-CA to transmit data.

Contention Free Period/Guaranteed Time Slots – This is the time duration where low-latency application devices get the exclusive right to transmit data over the channel. These transmissions start just after the contention access period and have about seven slots allotted for GTS transmissions.

Inactive Period – The time duration when the coordinator goes to power-saving mode and does not interact with the PAN. Here, there is no beacon transmission, and devices enter the sleep mode during this period.

Superframe Duration – This refers to the aggregate time duration of the CAP, CFP (GTS) and a Beacon. It excludes the inactive period.

Beacon Interval - This is the time duration between two successive beacons.

To have better throughput in the network, synchronization is vital. Every device in the network should know when the contention access period starts so they can compete for the channel. This is what the superframe structure, or in essence, the beacon transmission does. The devices extract the information for access to channel from the beacon and get ready to compete. The same is true when the coordinator assigns a device access to transmit exclusively in GTS mode[14].

The Superframe Order (SO) and the Beacon Order (BO) are two parameters that determine the superframe structure. The SO is the variable that determines the length of superframe duration, while the BO determines the Beacon Interval.

$$1 \leq SO \leq 15; 1 \leq BO \leq 15$$

When BO = 15, there are no beacon transmissions. Also, when SO = BO, the superframe duration is same as Beacon Interval and there is no inactive portion.

3.3 Queue Management Algorithms

The functioning of a network is fundamentally hinged on a store-and-forward technology with statistical multiplexing to handle inherently unexpected data packets [15]. Some type of mechanism is put in place to accommodate the unexpected data. This accommodation comes in the form of a Queue. A Queue with a large queue size absorbs more data but also increases data latency. Thus, there must be efficient ways to manage queue length, even with increasing data volume as each day passes by.

Current queue management algorithms can be divided into Passive and Active Queue Management algorithms, which we will explain briefly below.

3.3.1 Passive Queue Management Algorithms (PQM)

This is the conventional way of managing queue length. A maximum limit is set for each queue, and packets are accepted into the queue until the point where maximum limit is reached. Thereafter, any packet coming in is discarded until the queue length has decreased. The Drop-Tail Algorithm is the most widely known passive queue management algorithm still in use today [15].

3.3.1.1 Drop-Tail Algorithm

This is the representative passive queue algorithm and is widely used in IP networks because of its ease of implementation and high efficiency. The algorithm sets a maximum length for the queue, and accepts arriving packets into the queue as long as the queue length is smaller than the maximum length. If the queue reaches maximum length however, all subsequent incoming packets will be dropped. The sending nodes will eventually detect the packet loss and consequently shrink their sending window [15].

Despite its simple execution, Drop-tail has a number of drawbacks. First, the average queue length is large for a long expanse of time, and this brings about large end-to-end delay. Secondly, the algorithm typically provides congestion control but not a way of congestion avoidance. Lastly, it brings about the problem of global synchronization and lock-out. This situation arises when all sending nodes sharing the same bottleneck link or router, shut down their transmission window at the same time.

3.3.2 Active Queue Management Algorithms (AQM)

The idea here is that data packets are discarded before the queue is full. This, it does to regulate the data rate from the transmitting source. AQM was proposed to deal with the shortcomings of the passive queue method. The technique aims to detect and react to congestion before it occurs. This approach controls congestion by avoiding packet loss and long end-to-end delays that may be caused by queues that are filled up, and a reduction to utilization ratio [15].

The common active queue management algorithms are Random Early Detection (RED) and Random Exponential Marking (REM). There are other variations of the Random Early Detection method, which have been developed over the years to enhance RED. These include Random Early Dynamic Detection (REDD), Adaptive Gentle Random Early Detection (Adaptive GRED), and GRED Linear Analytical Model.

3.3.2.1 RED Queue Management Algorithm

This uses the average queue length to predict impending network congestion and drops packet correspondingly using random selection. This arbitrary selection of packets influences the transmitting sources, which have the task of congestion control, to regulate their discharge rate in order to avoid congestion [15].

RED uses the weighted average method to calculate the average queue length using the formula below:

$$QL_{avg} = \left(1 - w_q\right) QL_{avg} + w_q q \qquad (1)$$

Where QL_{avg} refers to the average queue length, q refers to the current queue length, w_q refers to the current weighted coefficient of the queue, whose value must satisfy the condition $0 < w_q < 1$. Usually, the value of w_q is set to be very small so the value being calculated for average queue length changes very slowly. This helps to avoid the problem of dropping a large number of data packets due to arrival of unexpected discharges.

When the average queue length is between the shortest queue length min_{th} and the longest queue length max_{th}, packets are dropped with relation to the probability function;

$$P_b = Max_p \left(\frac{QL_{avg} - \min_{th}}{Max_{th} - \min_{th}} \right) \qquad (2)$$

3.3.2.2 REDD

REDD was developed as an improvement of RED to overcome the challenges that could not be addressed using the RED algorithm. These challenges are in terms of the congestion measure, and the probability of exceeding the maximum threshold of the coordinator's queue as the number of sending nodes increases, causing arriving packets to be dropped. REDD overcomes these drawback using a dynamic approach of varying the aql value (average queue length in relation to the congestion level. Thus, when there is heavy congestion, the value of aql is close to minimum threshold, whereas, in the event of light congestion, aql value is closer to the minimum threshold. To overcome the second challenge, REDD uses adaptive max threshold position. It decreases the max threshold value by 2 when the aql value is between the min threshold and target aql value, and the adjusted max threshold value is at least two times the value of min threshold. The reduction moves the aql value closer the target value. On the hand, the max threshold value is increased by 2 if the aql value is larger than the target and max threshold value is less than or equal to the difference finite buffer capacity K_c and the value of min threshold [16].

Packet arriving at coordinator's buffer

If (aql < Target aql and max threshold value $\geq 2x$ min threshold)

{max threshold = max threshold – 2; //Decreasing max threshold }

If (aql > Target aql and max threshold <= (K_c – min threshold))

{max threshold = max threshold + 2; //Increasing max threshold}

3.3.2.3 Adaptive GRED

This was made to enhance the performance measures of GRED. It was developed as a congestion control method to detect congestion early within the network [17]. It utilizes aql as a performance measure that enables tuning of max threshold and the maximum dropping probability value. For an arriving packet, the coordinator's buffer computes the aql, compares with the min threshold, max threshold, and double max threshold positions. Congestion happens when the aql, is equal or larger than the min threshold value but less than the double max threshold value [17]. There is no congestion if the aql is less than the min threshold value. The dropping probability at (max $\leq$ aql < double max threshold) is given by

$$D_{\max} + \frac{\left(1 - D_{\max}\right)\left(aql - \max threshold\right)}{\max threshold} \quad (3)$$

3.3.2.4 GRED Linear analytical model

This is a discrete-time analytical model developed for analysis of performance for a single queue node. It is a congestion control method that measures the current queue length and compares with the min and max threshold values. It also considers arrival packet probability and queue state to control congestion [18].

4. Simulation and Discussions

The Riverbed Modeler OPNET simulation software can simulate different network parameters. It has available as a new attributes the Random Early Detection algorithm for use in the ZigBee Network. For this work, we focus on data traffic received, Delay, Throughput, MAC Delay and Data Dropped as the metrics to evaluate the performance of the three network topologies in an IoT setup.

To further examine other characteristics, 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 study individual topologies with one ZigBee Coordinator and two ZigBee Coordinators respectively.

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

4.1 Simulated Reference Model

The reference scenario, shown in Fig. 2, has a smart home structure that consists 70 objects, including ZigBee Coordinators, ZigBee Routers, ZigBee End Devices, Switch, wireless Router and 5G Device. In Table 1, we set the parameters for simulation and observe the results obtained.

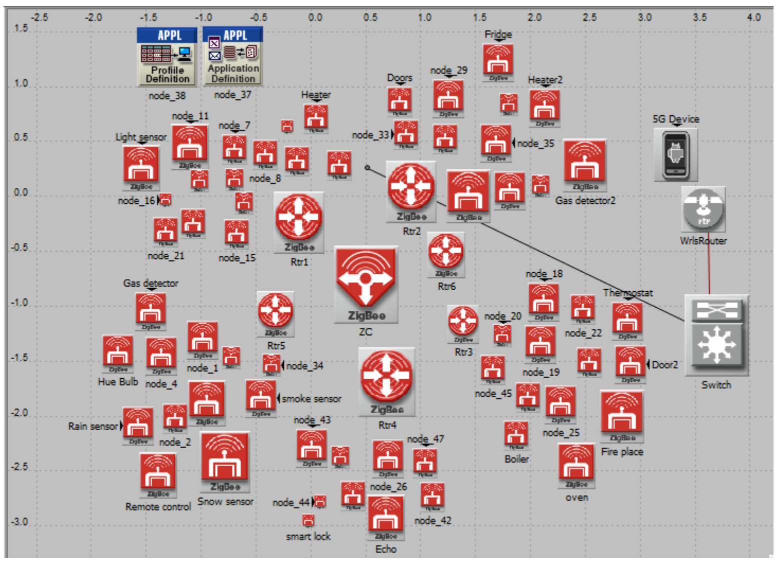

Fig. 3. Simulating the Smart Home

TABLE 1: SIMULATION PARAMETERS

Parameters	Descriptions
ACK Status	Enabled
ACK Wait Duration	0.05 sec
Number of Retransmissions	5
Channel Sensing Duration	0.1 sec
Data Rate	Auto Calculate
Packet Size	1024 bits
Packet Interval Time	Constant (1,0)
Queueing Model	Random Early Detection Method
Minimum Threshold	1
Maximum Threshold	50
Traffic Marking	Enabled
Traffic Destination	All Nodes
Number of Objects	70
Number of Coordinator	1
Number of Routers	5
Network Dimension	1 km x 1 km
Simulation time	3600 sec

4.1.1 Performance Description for Different Network Topologies

We investigate the performance of Random Early Detection Algorithm using different metrics for different network topologies.

Data Dropped (Retry Threshold Exceeded): This is the higher layer traffic (in bits/sec) dropped by the IEEE 802.15.4 MAC due to consistently failing transmissions or retransmissions. This statistics also reports the outstanding packets in the buffers that are dropped during roaming. In Fig. 4. Tree topology showed an advantage of having a lower amount of packet data dropped than Mesh Topology.

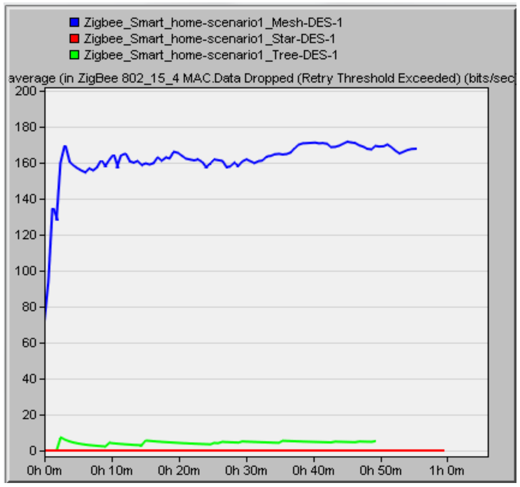

Fig. 4. Data Dropped for 1ZC ZigBee Network

Data Traffic Received in bits/sec.: Represents the total traffic successfully received by the MAC from the physical layer in bits/sec. This includes retransmissions. It can be observed in Fig. 5 that Tree topology performs better than the rest.

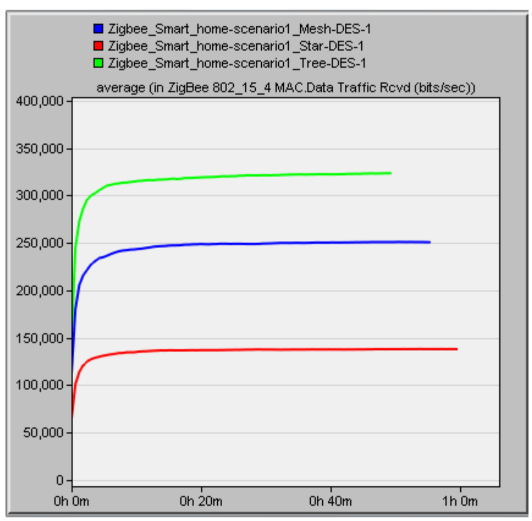

Fig. 5. Data Traffic Received with 1ZC ZigBee Network

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. The End-to-End delay in Fig. 6 is higher in the mesh network than the others because of increased number of data communication paths between end devices and the coordinator.

$$D_{end-end} = N \times \left(d_{proc} + d_{trans} + d_{prop} \right) \quad (4)$$

where, N is number of routers + 1, d_{proc} is processing delay, d_{trans} is transmission delay, d_{prop} is propagation delay.

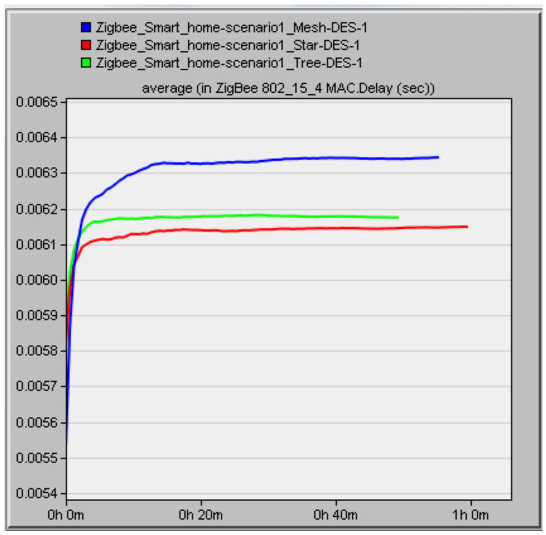

Fig. 6. End-to-End Delay for 1ZC Network

Media Access Delay (secs): This is the total of queuing and contention delays of the data frames transmitted by all the 802.15.4 MAC. Fig. 7 shows a higher queuing and contention delay within the mesh network compared to the others.

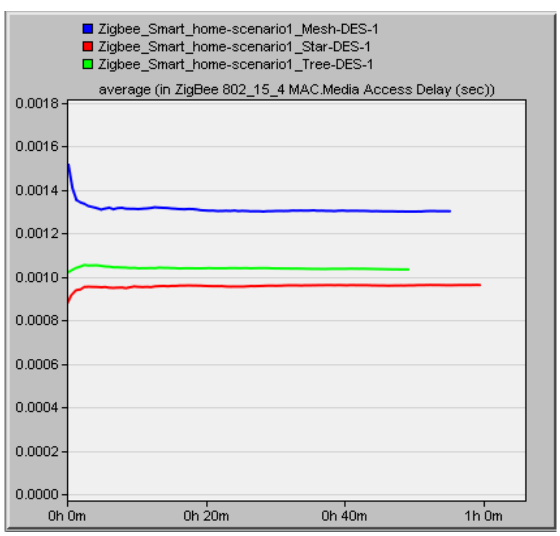

Fig. 7. Media Access Delay for 1ZC ZigBee Network

Throughput: Total data traffic in bits/sec successfully received and forwarded to the higher layer by the 802.15.4 MAC. The throughput is highest in Tree topology for the given network setup as seen in Fig. 8. It is given by

$$Throughput = \frac{Number\ of\ bits\ sent}{Runtime} \qquad (5)$$

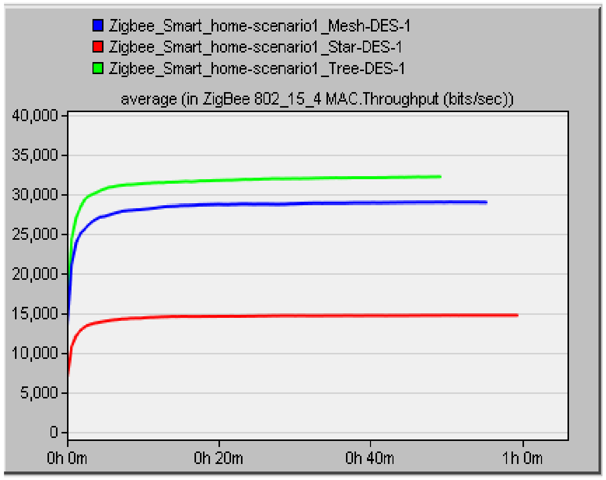

Fig. 8. Throughput for 1ZC ZigBee Network

Management Traffic Received (bit/sec) – This is the sum of management traffic successfully received by the MAC of all nodes from the physical layer in bit/sec. This includes the beacons and beacon requests. Fig. 9 indicates Tree topology has better traffic management operation.

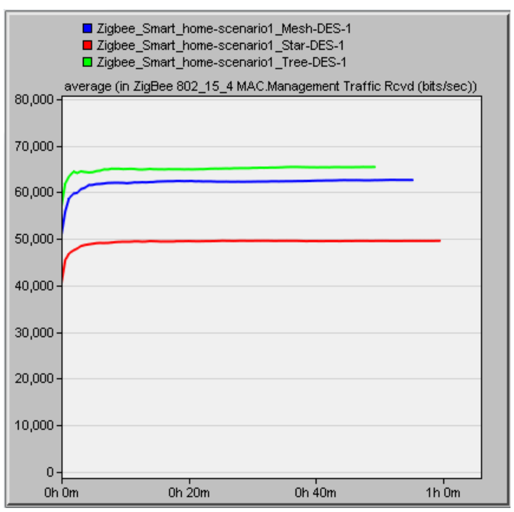

Fig. 9. Management Traffic Received for 1ZC ZigBee Network

4.3.2 Performance Comparison for Single and Two ZCs using Tree Topology

Having observed from the overall evaluation that the Tree topology outperforms the other network topologies, we go a step further to investigate the behavior of tree topology when there are two ZigBee Coordinators and got some interesting results.

Fig. 10 shows more number of data dropped when using two ZigBee Coordinators than using one. Consequently, in Fig. 11, there is a higher number of data received when using one ZC than using with two ZCs.

The inverse relationship between Delay and throughput is shown in Fig 12, where MAC delay for 2ZCs is higher than that for 1ZC, while throughput in Fig. 13 is higher in 1ZC than with 2ZCs. This is because the presence of an additional ZC ensures there is no waiting for pending packets looking for transmission path to destination.

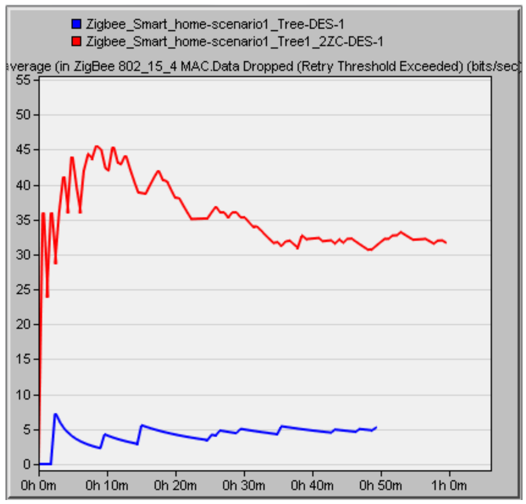

Fig. 10. Data Dropped for 1ZC and 2 ZCs ZigBee Network

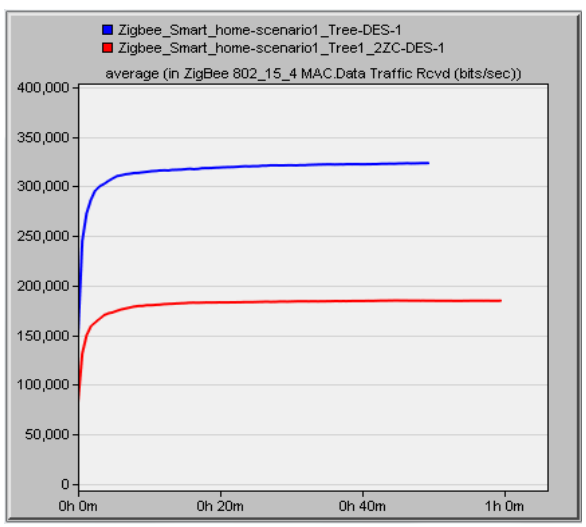

Fig. 11. Data Received for 1ZC and 2 ZCs respectively

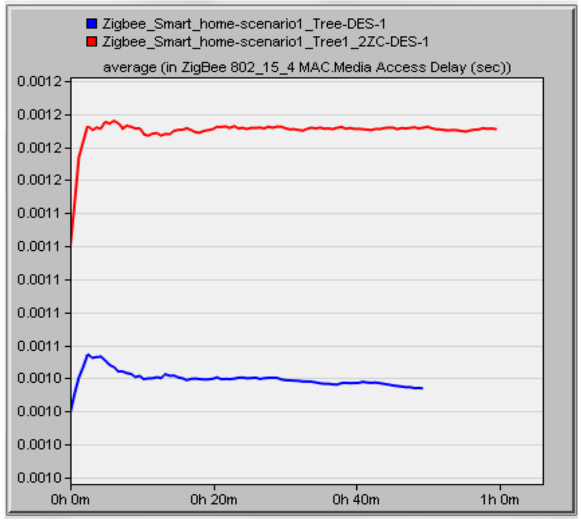

Fig. 12. Media Access Delay for 1ZC and 2 ZCs respectively

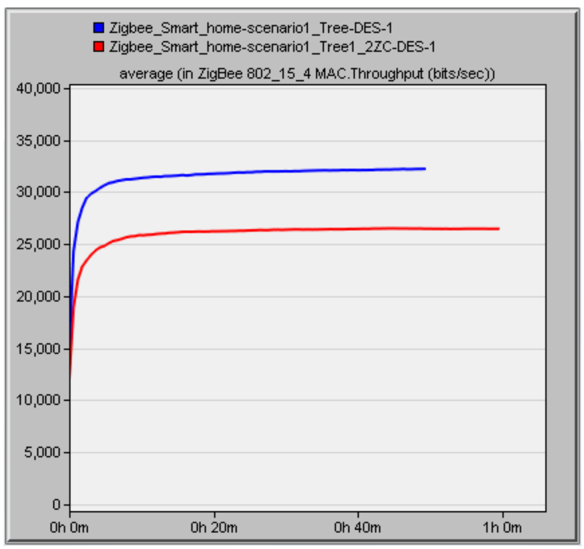

Fig. 13. Throughput for 1ZC and 2 ZCs respectively

5. Conclusion

This paper analyzes the RED algorithm in ZigBee network for queue management. It also reveals the effect of having more than PAN for a given number of nodes in a tree topology setting. The analysis shows that when RED active queue management is deployed in Tree Topology, there is improved throughput, less delays and data traffic dropped.

Having settled that Tree topology outperformed Mesh and Star, we decided to examine the effect of having two ZigBee Coordinators, creating two different PANs, in the existing network. Interestingly, this did not indicate any enhancement for the Tree topology, although it did for Mesh by having 2ZCs.

The RED algorithm is not only an effective way for queue management, but also a handy technique for improving the performance of ZigBee network in this IoT era.

References

1. Abdel-Jaber H, "Performance study of Active Queue Management methods: Adaptive GRED, REDD, and GRED-Linear analytical model", Journal of King Saud University, Computer and Information Sciences, pp 416 – 429, Jan. 2015.

2. Bellasi P, Faisal A, Fornaciari, Serazzi G, "Queueing Network Models for Performance Evaluation of ZigBee-Based WSNs" EPEW 2010, Springer-Verlag, Berlin, Heidelberg, pp. 147- 159, Sep. 2010.

3. Yousefi'zadeh H, Habibi A, Jafarkhani H, Bauer C, "Optimal Statistical Tuning of the RED Parameters", in 2008 IEEE International Conference on Communications (ICC'08), Beijing, China, May 2008.

4. Ajgaonkar P, "Simulation Studies on ZigBee Communications for Home Automation and Networking", M.Sc Thesis, The University of Toledo, 83 p, Toledo, ABD, USA, 2010.

5. Lin M. S, Leu J. S, Yu W. C, Yu M. C, Wu J. L. C, "BOB-RED Queue Management for IEEE 802.15.4 Wireless Sensor Networks", EURASIP Journal on Wireless Communications and Networking, vol. 2011, no. 1, pp 1-16, 2011.

6. Burchfield T. R, Venkatesan S, Weiner D, "Maximizing Throughput in ZigBee Wireless Networks Through Analysis, Simulations and Implementations," in Proc. International Workshop Localized Algor Protocols, WSNs, Santa Fe, NM, USA, June 2007.

7. Rao S, Keshiri S, Gangwar D, Sundar P, Geetha V, " A Survey and Comparison of GTS Allocation and Scheduling Algorithms in IEEE 802.15.4 Wireless Sensor Networks", in 2013 IEEE Conference on Information and Communication Technologies (ICT), Tamil Nadu, India, April 2013.

8. Islam N, Biddut M. J. H, Swapna, Rahman M. M, "An Analytical Study to Minimize Load of ZigBee Network Based on Statistical Modeling", in2015 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE), BUET, Dhaka, Bangladesh, Dec. 2015.

9. Islam N, Biddut M. J. H, Swapna, Jany M. H. R, "A Study on Priority Based ZigBee Network Performance Analysis with Tree Routing Method", Journal of Computer and Communications, vol 3, no. 08, pp. 1-10, 2015.

10. Jayakumari B. R., Senthikumar J. V., "Priority Based Congestion Control Dynamic Clustering in Mobile Wireless Sensor Networks", The Scientific Journal, Vol 2015, Article ID 596138, Sept 2015.

11. Wang C, Sohraby K, Lawrence V, Li B, Hu Y, "Priority-based Congestion Control in Wireless Sensor Networks" proceeding of IEEE International Conference on Sensor Network, Ubiquitous, and Trustworthy Computing, July 2006.

12. Lim L. B., Guan L., Philips I. W., Wang X. G., Chi X., Awan L. U., "Controlling Mean Queueing Delay Under Multiclass Bursty and Correlated Traffic" J. Computer System Sci.77(5), pp. 898-916, 2011.

13. Wang J., Guan L., Lim L. B., Wang X. G., Grigg A., Awan L., Philips L., Chi X., "QoS Enhancement and Performance Analysis for Delay Sensitive Applications" J. Computer System Sci. 77(4), pp. 665-676, 2011.

14. Rao V. P, "The Simulative Investigation of ZigBee/IEEE 802.15.4" M.Sc Thesis, Dresden University of Technology, Nov 2005.

15. Wei W, Song H, Wang H, Fan X, "Research and Simulation of Queue Management Algorithms in Ad Hoc Networks Under DDoS Attack" IEEE Access, Special Section on Future Networks: Architecture, Protocols, and Applications, vol. 5, March 2017

16. Abdeljaber H., Thabtah F., Woodward M., Jaffar A., Al bazaar H., "Random Early Detection Approach for Congestion Control. Baltic Jod. Comput. 2(1), pp 16-31, 2014.

17. Abdeljaber H., Ababneh J., Thabtah F., Daoud A. M., Buklizi M., "Performance Analysis of the Proposed Adaptive Gentle Random Early Detection Method under Non Congestion and Congestion Situation", The International Conference on Digital Enterprise and Information Systems (DEIS), Springer-Verlag, Berlin Heidelberg London, U.K, 2011.

18. Agdeljaber H., Thabtah F., Woodward F., "Traffic Management for the Gentle Random Early Detection Using Discrete-time Queueing", International Business Information Management Association (9th IBIMA) Conference, ISBN: 0-9753393-8-9, pp 289-298, 2008.

19. Floyd S., "Recommendation on Using the Gentle Variant of RED, http://www.acriri.ord/floyd/red/gentle.html, May 2000.

20. Deepika, Sharma M., Parmar A.S., "Performance Evaluation of ZigBee Protocol with OPNET", International Journal of Advanced Research in Computer Science and Software Engineering, ISSN: 2277 128X, vol. 4, Issue 10, pp. 808-812, October 2014.

21. Biddut M. J. H., Islam N, Arif M. F. H, Rahman M. S, "On the Analysis of RED Algorithm in ZigBee Network for Queue Management" in 5th IEEE International Conference on Informatics, Electronics and Vision (ICIEV), Dhaka, Bangladesh, May 2016.

22. Burda R, Wietfeld C, "A Distributed and Autonomous Beacon Scheduling Algorithm for IEEE 802.15.4/ZigBee Networks", proceeding of IEEE-Vehicular Technology Conference, April 2007.

23. Biddut M. J. H, Arif M. F. H, Islam N, "Queue Management of RED Enabled ZigBee Network Based on Packet Size Variations and Distribution Techniques", IEEE International Conference on Electrical, Computer and Communication Engineering (ECCE) Feb. 2017.

Biographies

Ekele Arthur Asonye is a doctoral candidate at Prairie View A&M University, Texas. He received the B.Sc. degree in Electrical and Electronic Engineering from the reputable Federal University of Technlogy, Owerri, Nigeria in 2011. He got his M.Sc. in Electrical Engineering from Prairie View A&M University, Texas, USA, in 2015, and currently working to obtain his Ph.D degree in Electrical Engineering also from the same institution. His research interests include Internet-of-Things network application for low-power devices in Smart Home, Smart Health and Smart Grid, 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 cybersecurity field, with his current research interests focusing on privacy protection techniques in networked information systems and cross-layer security enhancement in wired/wireless networks, and Internet of Things.