UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES (UJEAS)

Research Article

A comparative study of energy efficient mac protocols in wireless sensor networks

Oborkhale, L.I.; Okoro C.K.; Brown O.J.; Odo K.O., David D.N

Special Issue

A Themed Issue in Honour of Professor Ekedimogu Eugene Nnuka on His retirement.

This themed issue honors Professor Ekedimogu Eugene Nnuka, celebrating his distinguished career upon his retirement. His legacy of exemplary scholarship, mentorship, and commitment to advancing knowledge is commemorated in this collection of works.

Edited by
Chinonso Hubert Achebe PhD.
Christian Emeka Okafor PhD.

UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 3(2), June (2024), 787-802
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

A comparative study of energy efficient mac protocols in wireless sensor networks

Oborkhale, L.I.; Okoro C.K.; Brown O.J.; Odo K.O. * and David D.N
Department of Electrical and Electronic Engineering, Michael Okpara University of Agriculture, Umudike, Umuahia, Abia State, Nigeria
*Corresponding Author's E-mail: kayceebby@yahoo.co.uk

Abstract
This paper conducted a comparative study on energy-efficient routing protocols in wireless sensor networks. Several MAC protocols based on channelization and random access were considered in this study. They include modified Carrier Sense Multiple Access with Collision Avoidance, Medium Access Control (CSMA/CA MAC), Carrier Sense Multiple Access with Collision Avoidance, Medium Access Control (CSMA/CA MAC) and modified Aloha MAC protocols. Matlab/Simulink modeling and simulation environments together with state flowchart applications were used to analyze energy-efficient routing protocols. The application of state flow diagrams and state flowcharts was extensively used for the logical contents of the MAC protocols. This paper improved the backoff time of the CSMA MAC protocol immediately after an Ack is not received. In the modified CSMA/CA MAC protocol, the average backoff period is typically doubled on each successive transmission attempt due to a failed transmission for a particular packet. The results obtained in this study showed that for radio node 1, peak backoff time at 0.02 sec of modified CSMA/CA, CSMA/CA and modified Aloha are 995 sec, 300 sec and 190 sec respectively., for radio node 2, peak backoff time at 0.02 sec of modified CSMA/CA, CSMA/CA and modified Aloha are 560 sec, 190 sec and 140 sec respectively and for radio node 3, peak backoff time at 0.02 sec of modified CSMA/CA, CSMA/CA and modified Aloha are 190 sec, 50 sec and 30 sec respectively. The modified CSMA/CA MAC protocol was shown to be more efficient in terms of energy consumption, traffic delays, and throughput than the modified Aloha MAC and the CSMA/CA MAC protocols. The implications of a higher backoff time in modified CSMA/CA suggest improved channel utilization and reduced collision probability at the cost of increased transmission latency, ultimately resulting in more stable and efficient network performance.

Keywords: Backoff time, CSMA/CA, Energy Efficient, Modified ALOHA, Modified CSMA/CA, Wireless sensor networks

1. Introduction

One of the most important technological advancements of the 21st century is the wireless sensor network. Micro-electromechanical systems (MEMS), combining cutting-edge communications and signal processing capabilities, make it possible for WSN to become a reality. As a result, cheap, compact sensor nodes with little power were produced. Using a gateway known as the sink, these tiny sensor nodes are able to sense, interpret, and communicate with a remote user. The third generation of of computer growth, known as ubiquitous computing, is supported by WSN. But despite being extremely powerful, its abilities are constrained by energy issues, (Chukwuka and Arshad, 2023). Wireless sensor networks are networks of spatially distrbuted autonomous sensors to monitor physical or environmental conditions. Wireless sensor networks consist of tiny, low-power sensors capable of sensing, processing and communicating data/information wirelessly. They find applications in various domains such as environmental monitoring, healthcare, industrial automation and smart cities, (Akyildiz et al, 2002, Yick et al, 2008).

The key components of wireless sensor networks are sensors nodes which is equipped with sensors, microcontrollers and transceivers and gatewaymor base station, which collects data/information from sensor nodes and communicates with the external network as shown in figure 1.

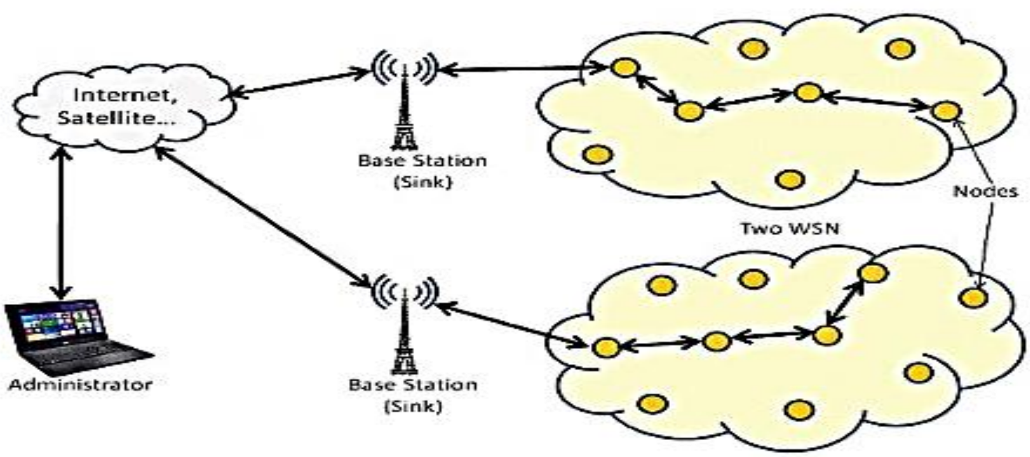

Figure 1: WSNs organization (Source: Djimli et al, 2019)

The merging of sectors is growing faster as a result of current IT technology advancement. The combination of conventional industries and information technology is ongoing. A key industry where ubiquitous technology is being applied is agriculture, where it is expected that converge to technology would increase the added value and production of agriculture (Lee et al., 2010). The establishment of core ubiquitous technologies that are optimized for agricultural fields, which include sensor hardware, middleware platforms, routing protocols, and agriculture the surroundings application services, would be absolutely required in order to set up such a E-agriculture surroundings successfully (Meong-hun et al., 2009).

The Medium Access Control (MAC) protocol governs how nodes in a wireless network access the shared communication medium. MAC protocols regulate access to the communication channel, minimizing collisions and maximizing network efficiency. The most common MAC protocols are Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and Time Division Multiple Access (TDMA), (Bian and Leung, 2010, Rachedi and Yassein, 2010, Bennis et al, 2011). Mobility in WSN raises new challenges and problems that occur at MAC layer due to the existing link failure and new link formation. Designing MAC protocol for mobile scenario is a difficult task, especially in case of WSN which are inherent resource constrained, (Choudhary and Sharma, 2016).

Power management of the radio has gained significant importance in sensor networks since the radio is a major consumer of sensor‘s energy. The major part of power is consumed in radio (transmitter and receiver), which is controlled by the MAC protocol, (Kabara and Calle, 2012). The effective MAC protocol proposes to reduce energy consumption, while supporting good scalability and collision avoidance resulting in improved lifetime of sensor networks. Security at Mac layer is another important concern because by attacking at a node, an attacker can waste the WSN node energy unnecessarily, steal, and interrupt data transmission, (Huang et al, 2013).

1.1 ALOHA MAC Protocols

The Aloha MAC protocol is a fundamental protocol in the field of computer networking, particularly in various wireless communications. It is known for its simplicity and effectiveness in handling multiple access in a shared medium, (Cheng et al, 2023). The basic idea of Aloha MAC protocol is that it allows multiple users to transmit data/information over a shared communication channel without centralized coordination. There are two types of Aloha namely, pure Aloha, which allows users to transmit data whenever they have it. If there is a collision (two or more stations transmitting at the same time), they detect it through lack of acknowledgement and retransmit after a random backoff time, (Medjahed et al, 2022). The second type of Aloha MAC protocol is the slotted Aloha, which divides time into slots and users can only transmit at the beginning of a slot. It reduces collision probability compared to pure Aloha. Slotted Aloha is twice as efficient as pure Aloha in ideal conditions, (Abdullah et al, 2020, Bhushau et al, 2021, Zhang et al, 2023).

1.2 CSMA/CA MAC Protocols

The Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) MAC protocol is commonly used in communication networks, including Wi-Fi networks. It aims to reduce the likelihood of collisions by having stations listen to the medium before transmitting and implementing mechanisms to avoid collisions, (Chen et al, 2023). The basic idea of CSMA/CA involves station sensing the medium before transmitting to avoid collisions. It employs a "listen before talk" approach. It's operation include carrier sense (CS) where stations listen to the medium to check if its busy or idle before transmitting and collision avoidance (CA) that involves before transmitting, stations wait for a random backoff period to further reduce the chance of collisions, (Kang et al, 2021, Choi et al, 2022, Liu et al, 2024)

1.3 Review of related works

Zhu et al. (2019) analyzed energy efficient: Media Access Control (MAC) layer protocols based on contention and channel polling in wireless sensor network (WSN). In their work, energy conservation is the main area that is important in wireless sensor networks (WSNs). The MAC protocol for media access control is essential for energy conservation. The sensor nodes are typically left unattended after being deployed in dangerous, unreceptive, or a remote environment. While minimizing idle listening and rising throughout, contention based MAC methods tolerate collision and control overheard. The findings of the simulation for MAC protocols are based on analysis and CSMA. The environment and simulation results indicate that D-MAC protocols will function well in wireless sensor networks in terms of energy efficiency but no suggestion was made on how to maximize network life while minimizing energy loss.

The work of Evangelakos et al., 2022 titled energy sustainability in wireless sensor networks wireless sensor networks (WSNs), which were the subject of an analytical analysis is regarded as one of the most significant scientific fields. However, the significant energy limitations of their electrical components make it difficult to utilize WSNs. According to research work by Krizanovic et al., 2023 titled an advanced energy-efficient environmental monitoring in precision agriculture using Lora-based wireless sensor networks. Sensor networks, a particular subtype of wireless networks, are made up of groups of wirelessly connected sensor nodes that are frequently positioned in challenging environments. As a result, it is anticipated that sensor nodes won't be powered by the electrical grid. Instead, sensor nodes have independent power supplies, whose repair is frequently impractical and expensive, necessitating the need for minimal energy consumption. Because of this, the energy efficiency of wireless sensor networks is crucial, especially in remote networking environments, where they are utilized to monitor environmental data. From all the literatures reviewed, it can be seen that none of the authors has done comparative study on wireless sensor networks; therefore, the purpose of this research work is to comparatively study energy efficient routing protocols in wireless sensor networks in order to improve the system's overall performance of wireless sensor networks.

2.0 Material and methods

The materials required for this research work include MAC protocol, Matlab computing software and HP laptop.

2.1 Methods

2.1.1 Analytical representation of MAC protocols

Analytical model for state diagram of MAC protocols using the cluster topology, where in each cluster a node traverses different states like await data Ack, idle state, backoff initiation, active Tx and the flow diagram for modified Aloha, CSMA/CA and modified CSMA/CA are shown in figures 2 to 4. Other states like sleep, awake are embedded into model with wake-up rates.

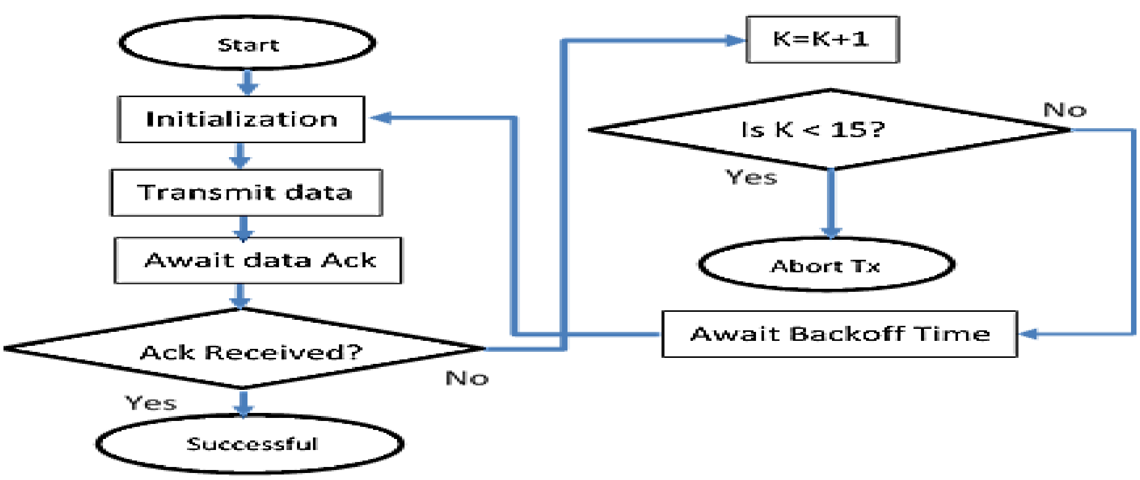

Figure 2: Flow diagram for the modified Aloha MAC protocol

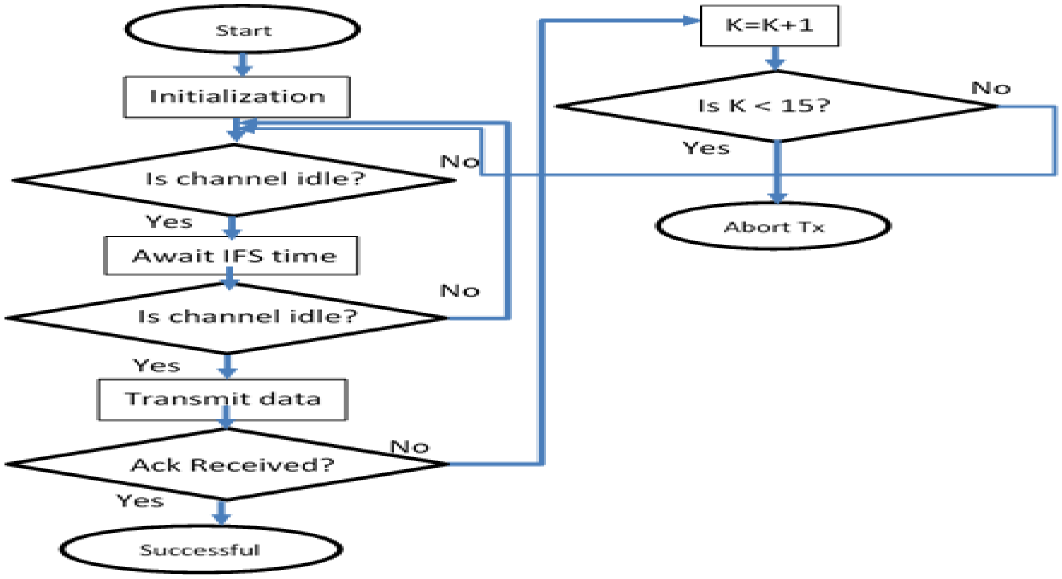

Figure 3: Flow diagram for the CSMA/CA MAC protocol

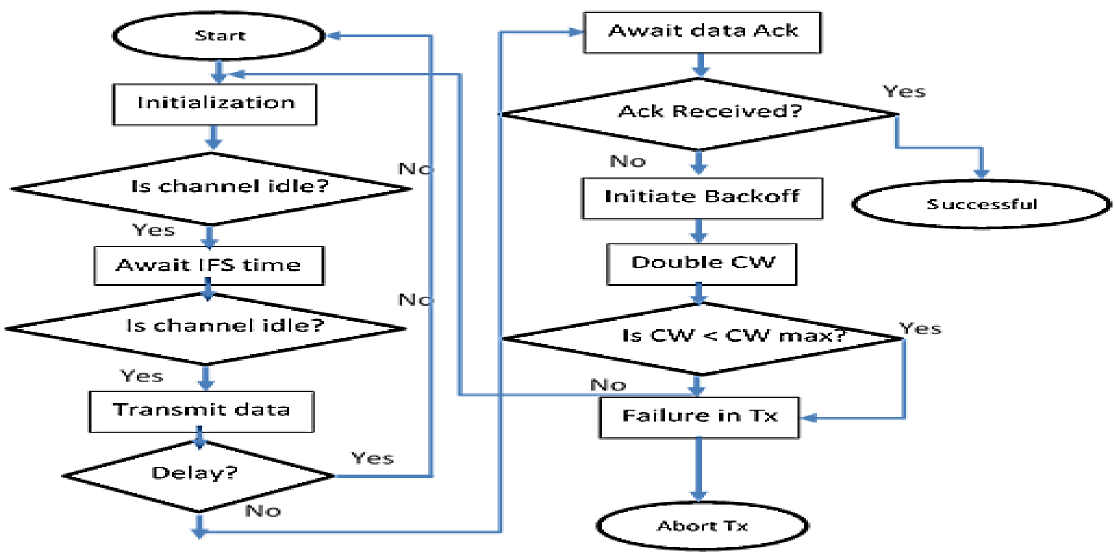

Figure 4: Flow diagram for the modified CSMA/CA MAC protocol

2.1.2 Implementation of MAC protocol using Stateflow charts

The following stateflow diagrams can be implemented on Matlab/Simulink

- MAC protocols
- Logical link controller
- MAC protocol selection scheme

Packet injection into the transceiver is done by the logical link controller (LLC). The Poisson process is represented by the exponential distribution of the packet interarrival time.

The analyzed MAC protocols are represented by a Stateflow chart, as seen in figure to. These protocols use the same initialization of MAC parameters and acknowledge the receipt of data frames (LHS).

Here, the transmitter initially waits for a brief interframe spacing (SIFS) on the LHS chart. Subsequently, it generates a positive "TxACKOn" signal that remains active during the acknowledgement frame.

The data frame transmission is handled by the charts' right side. The transmitter initially waits for a brief interframe spacing (SIFS) before sending the data frame. Next, it sends the signal by producing a positive "TxDataOn" signal for the duration of the data frame without detecting the wireless medium. The node then waits for an acknowledgment for a certain amount of time. The current data frame transmission ends if the acknowledgment is received prior to the timeout. When using the modified CSMA/CA protocol, the node enters a backoff state and doubles its contention window (CW) each time, with the exception of the first backoff occurrence, if the frame transmission is not completed. A random selection is made for the backoff period within the [0, CW] interval. Transceiver indicates failure in transmitting this data frame (Modified CSMA/CA) if maximum backoff attempts are achieved.

Because the backoff length is usually significantly shorter than the lifetime of a data frame, the MAC layer works at a very precise timescale (every 0.8 microseconds). As a result, the MAC/PHY layers do not handle frames, or batches of samples, and the Simulink model is scalar-based (that is, most signals have a length of one).
Figures 5 to 8 implement the state diagrams of the MAC protocol on Simulink using the Stateflow chart design environment.

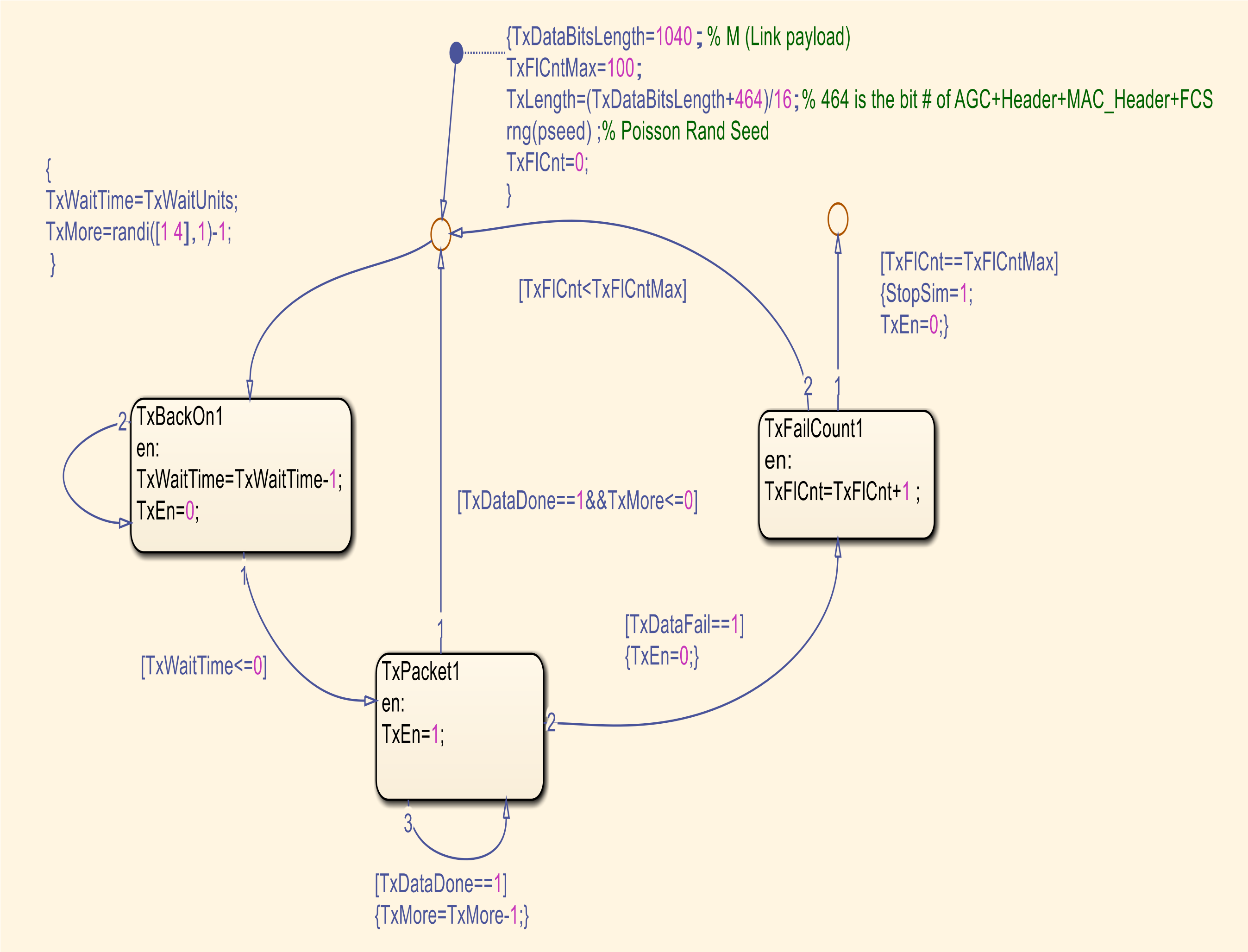

Figure 5: Logical link controller system for the MAC protocols

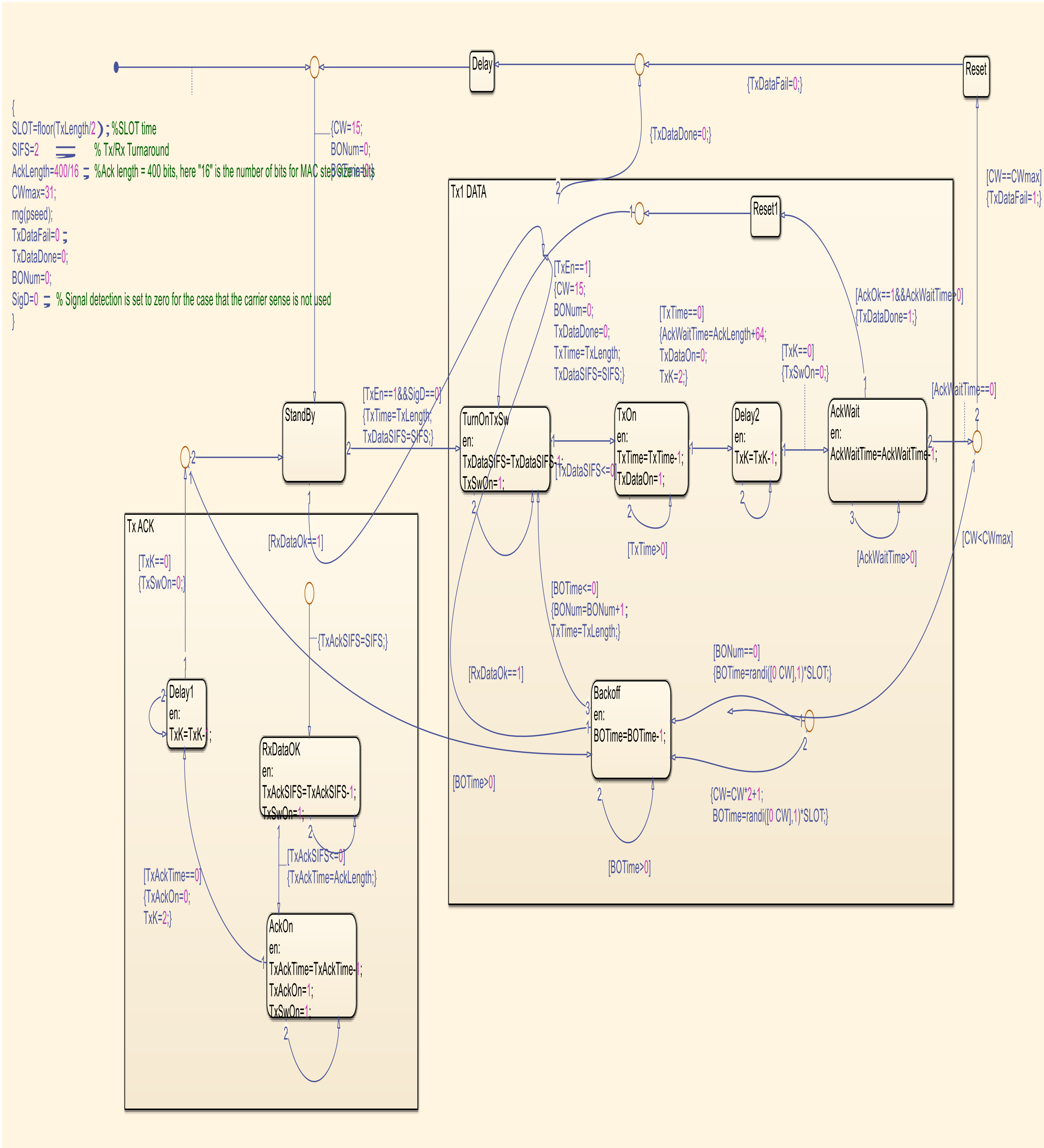

Figure 6: State flow chart implementation of modified Aloha MAC protocol

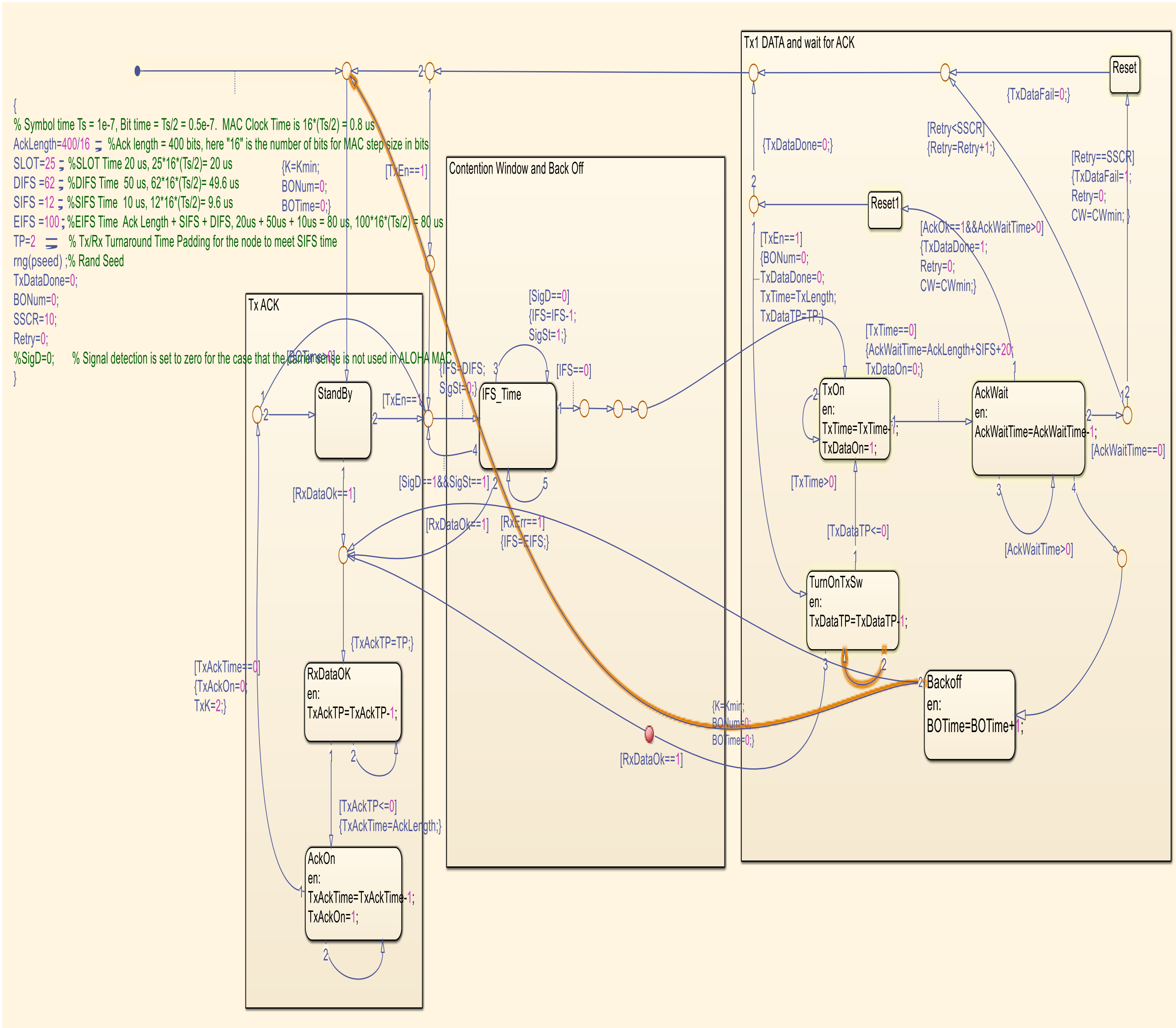

Figure 7: State flow chart implementation of CSMA/CA MAC protocol

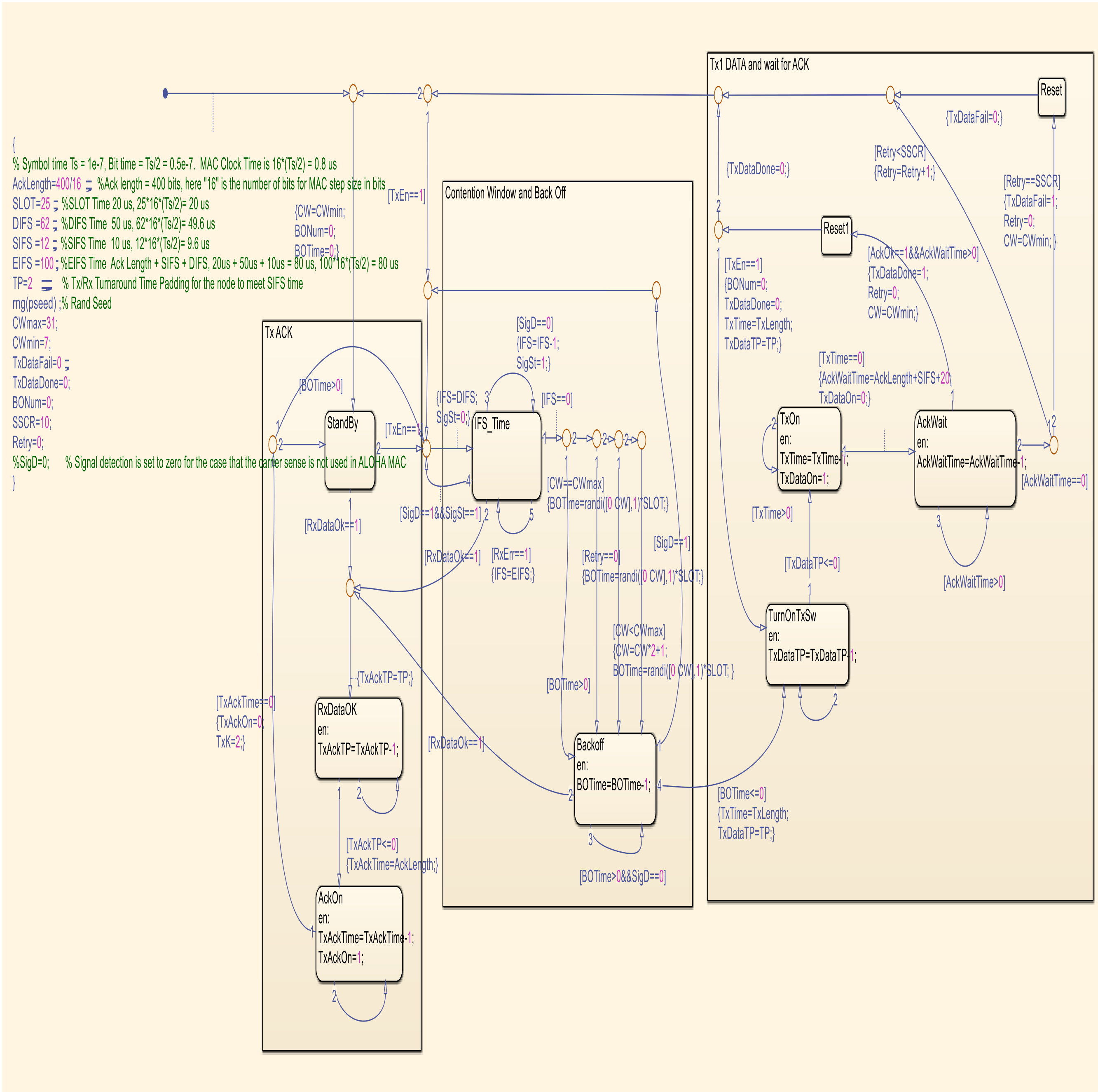

Figure 8: Stateflow chart implementation of modified CSMA/CA MAC protocol

The overall MAC selection layers as designed in simulink is as shown in figure 9, the system is designed to select amongst MAC protocols using the selector block

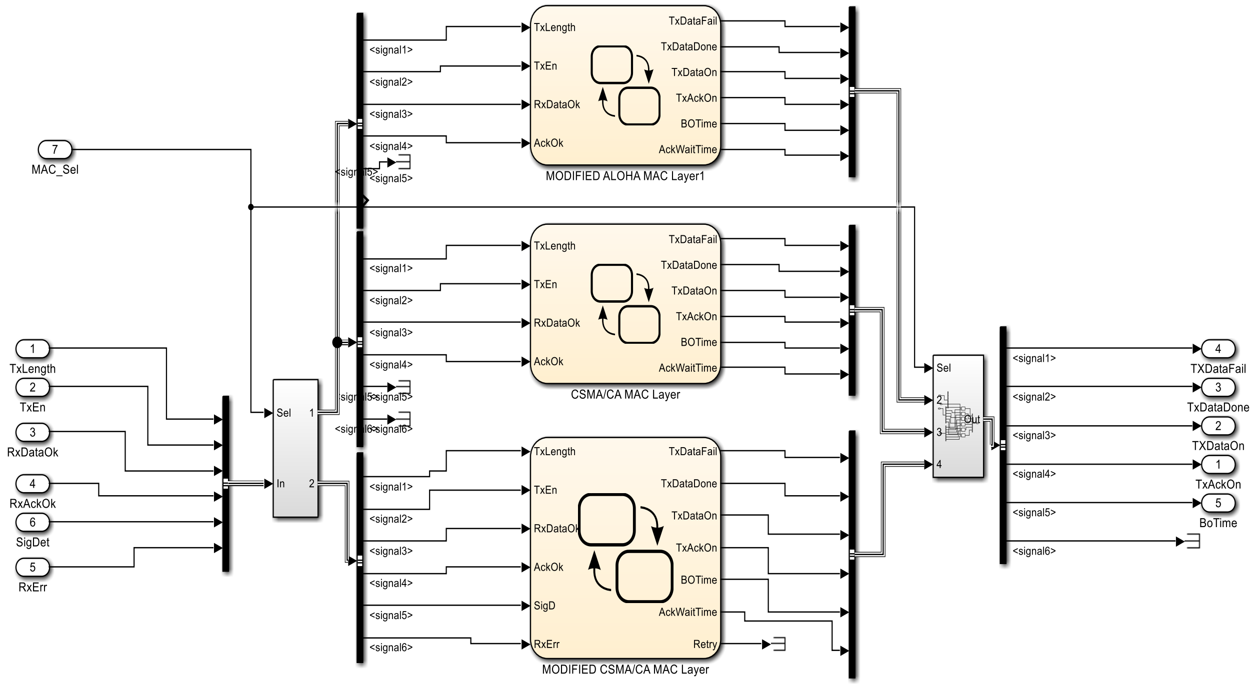

Figure 9: Overall simulink implementation of MAC selection layer

The overall WSN of the MAC protocol based monitoring system will consist of the following,
The overall implementation of the WSN system on Matlab/Simulink is shown in figure 13. It consists of the transceiver, the radio nodes/sensors and the monitoring protocols. The system structure of the WSN consisting of 3 radio nodes is shown in figure 14.

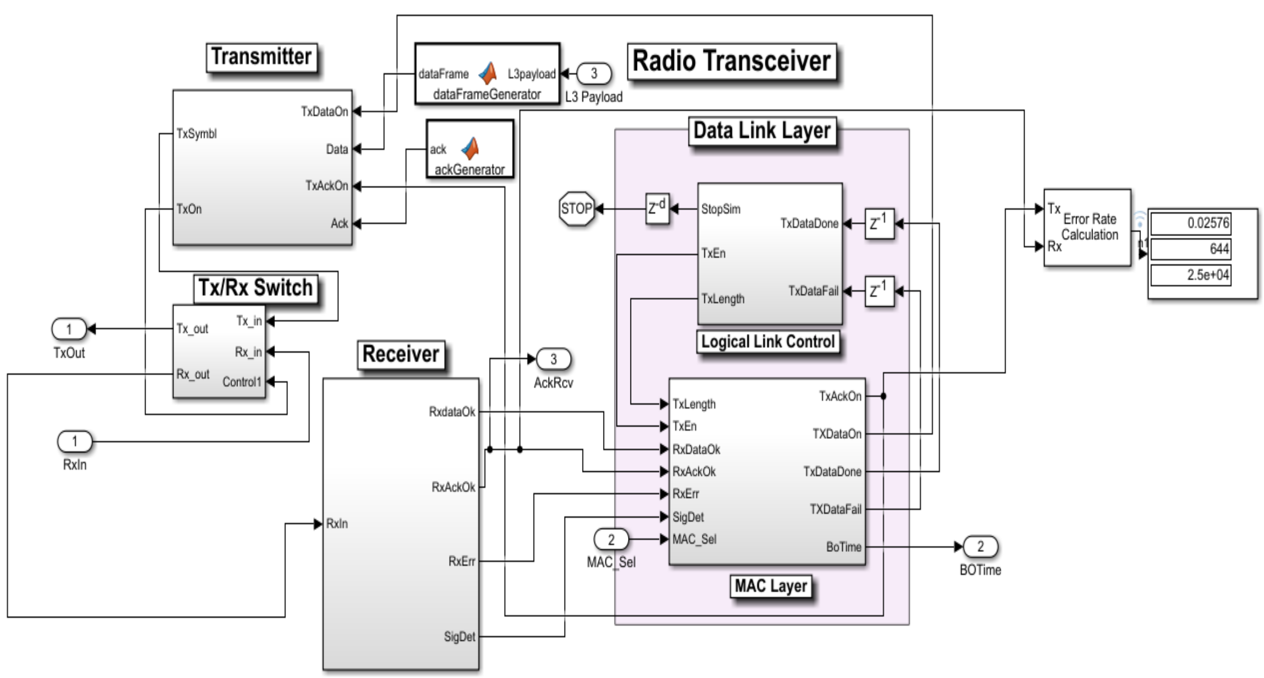

Figure 13: Simulink implementation of the WSN network using MAC layer

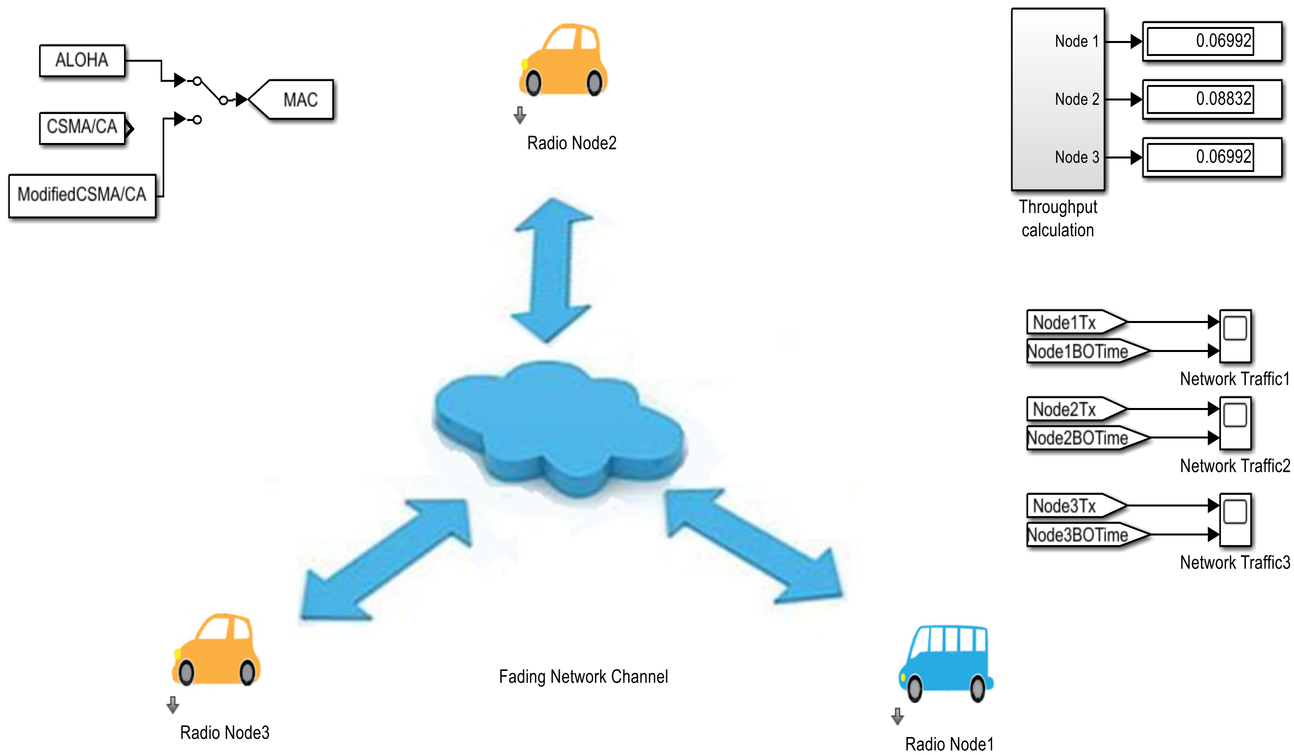

Figure 14: Overall WSN Architecture with 3 radio nodes/sensors.

3.0 Results and Discussions

3.1 Radio node model

Each Radio node can waste its energy in amplification(E_{amp}), reception (E_{RX}) and transmission(E_{TX}). Additionally, the (E_{amp}) can attain evident levels of Signal-to-Noise Ratio (SNR) in transmitting a single bit over a distance d. whilst, the required energy to transmit or receive s bits over a distance (d). Moreover, all other radio node parameters are presented in Table 1.

Table 1: Radio node parameters

Channel between radio node 1 and 2	**Value**
Maximum Doppler shift (Hz)	0.00000000525/Ts
SNR of channel (Eb/No)	40
Channel between radio node 2 and 3	Value
Maximum Doppler shift (Hz)	0.00000000525/Ts
SNR of channel (Eb/No)	45
Channel between radio node 3 and 1	Value
Maximum Doppler shift (Hz)	0.00000000525/Ts
SNR of channel (Eb/No)	50

The Radio node address gives the ID of the transceiver. For security purposes of monitoring, the data destination address specifies the recipients of the data packets originating from the transceiver. For the purpose of simulation the address assigned to the radio nodes indicates environmental physical parameters to be measured.

Table 2: Radio node link addresses

Radio Node 1	
Node address	[0 0 0 0 0 0 0 1]
Destination address	[0 0 0 0 0 0 1 1]
Ack address	[0 0 0 0 0 0 1 0]
Arrival rate	1000*8*Ts
Random speed	10
Radio Node 2	
Node address	[0 0 0 0 0 0 1 0]
Destination address	[0 0 0 0 0 0 0 1]
Ack address	[0 0 0 0 0 0 1 1]
Arrival rate	1000*8*Ts
Random speed	13
Radio Node 3	
Node address	[0 0 0 0 0 0 1 1]
Destination address	[0 0 0 0 0 0 1 0]
Ack address	[0 0 0 0 0 0 0 1]
Arrival rate	1000*8*Ts
Random speed	15

Table 3: WSN simulation parameters

MAC based WSN parameters	Values
AckLength (cm)	400/16
SLOT (us)	25
Distributed coordination function interframe spacing DIFS (us)	62
Short interframe spacing SIFS (us)	12
Extended interframe spacing EIFS (us)	100
Contention window CWmax	31
Contention window CWmin	7
TxDataFail	0(Aloha)
TxDataDone	0(Aloha)
BONum	0
BOTime	0 (initial)
Ack (us)	50
Single stage contention resolution SSCR	10
Speed	Random
Delay (us)	30
Network load G	100
Number of rounds	200000

3.2 Performance Evaluation

The proposed approach is extensively simulated using MATLAB software to evaluate the performance of the proposed clustering technique for effective monitoring and system efficiency. Furthermore, to check for efficiency of the modified CSMA MAC protocol, the 3 radio nodes were evaluated on their responsiveness to the transceiver following the action of each of the compared MAC protocols.

3.2.1 Backoff Timer

The primary challenge with MAC protocols arises when many devices broadcast simultaneously, leading to collisions, assuming that a set timeout will occur following the data frame's transmission. Because CSMA/CA accounts for both the SIFS and the acknowledgement frame transmission time, the timeout following the transmission of a data frame is extremely short.

The modified CSMA/CA relies on a backoff timer. This backoff timer is a random delay that is chosen by each device in a range that depends on the number of retransmissions for the current frame. The range grows exponentially with the retransmissions as in CSMA/CA. The initial value of backoff timer for all MAC protocol is 0. But after some microseconds time, the modified CSMA/CA MAC protocol exhibits a maximum backoff time of about 2 times the maximum backoff time of the CSMA/CA MAC protocol and about 4 times the maximum backoff timer of the modified Aloha MAC protocol. Table 4 shows the backoff values of the MAC protocols during collision of data packets along fames for a period of 0.02 sec. Figures 15 to 17 show the graphs of the backoff timer for the 3 MAC protocols with consideration of the radio nodes available. It can also be observed that as we modify the radio node address to that of radio node 3, the backoff timer reduces.

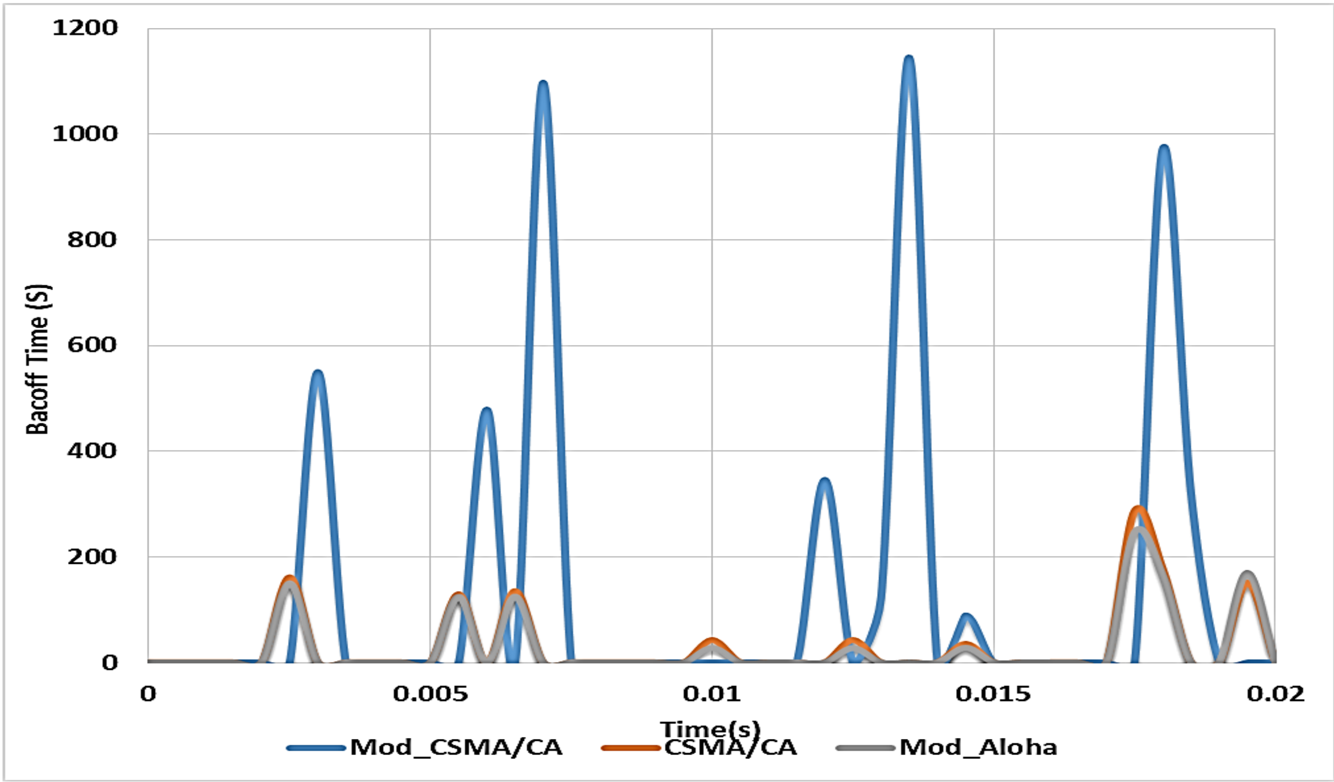

Figure 15: Graph of backoff time vs transmission time for radio node 1 at application of modified Aloha,

CSMA/CA, modified CSMA/CA MAC protocols. It is seen that peak backoff time at 0.02 sec of modified CSMA/CA, CSMA/CA and modified Aloha are 995 sec, 300 sec and 190 sec respectively. It is an indication that the modified CSMA/CA MAC protocol can achieve better channel utilization and throughput by minimizing the occurrence of collisions.

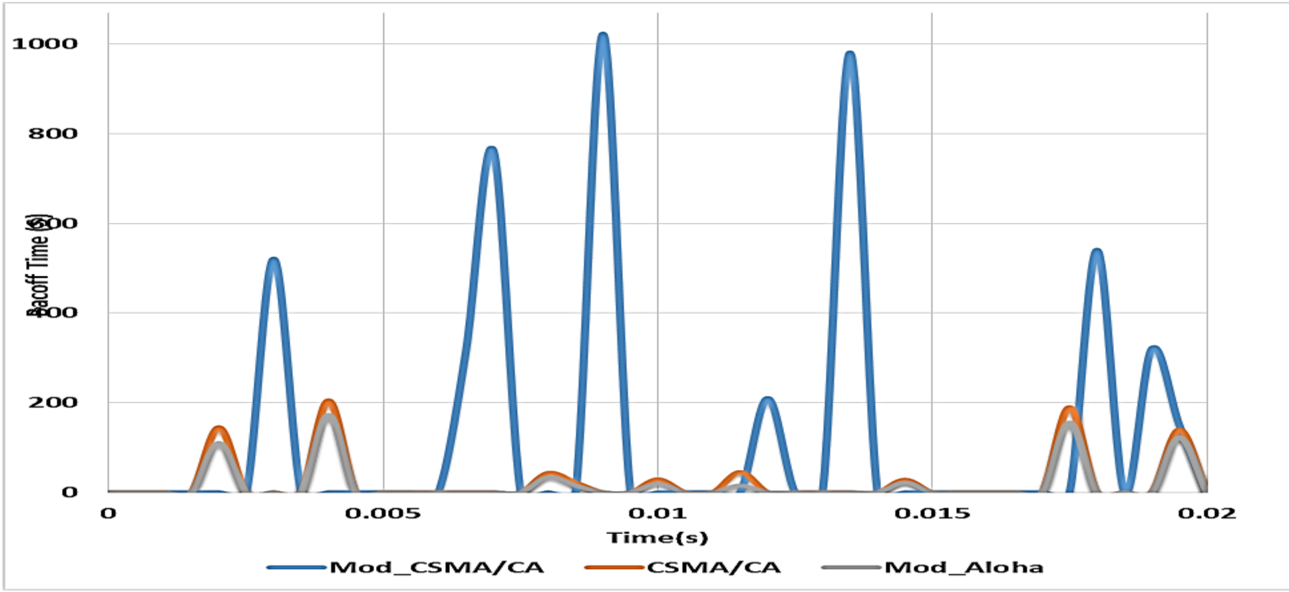

Figure 16: Graph of backoff time vs transmission time for radio node 2 at application of modified Aloha,

CSMA/CA, modified CSMA/CA MAC protocols. It is seen that peak backoff time at 0.02 sec of modified CSMA/CA, CSMA/CA and modified Aloha are 560 sec, 190 sec and 140 sec respectively. This implies that the higher backoff time in the modified CSMA/CA allows for a more balance trade-off between collision avoidance and channel access leading to more reliable and efficient communication compared to CSMA/CA and modified Aloha.

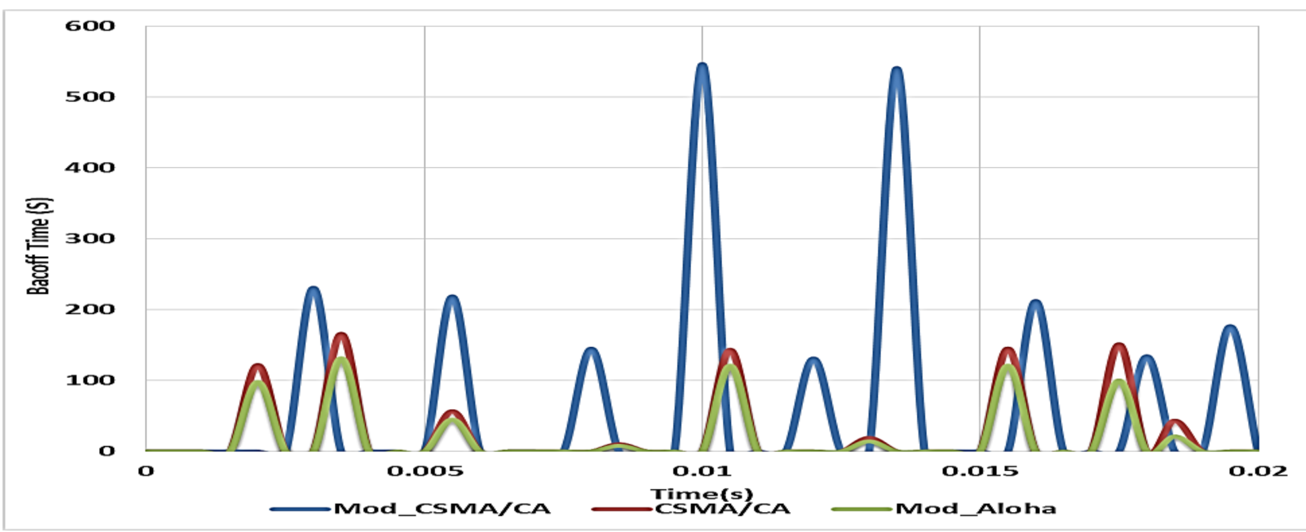

Figure 17: Graph of backoff time vs transmission time for radio node 3 at application of modified Aloha,

CSMA/CA, modified CSMA/CA MAC protocols. It is seen that peak backoff time at 0.02 sec of modified CSMA/CA, CSMA/CA and modified Aloha are 190 sec, 50 sec and 30 sec respectively. This implies that the stations have more time to sense the medium and avoid simultaneous transmissions, leading to improved channel efficiency.

3.2.2 Number of errors detected

During data frame transfer, the number of data bits resulting to the error rate is also a good metric to evaluate the performance of the WSN to be used for monitoring. Figures 18 to 20 present the number of bit errors detected. Furthermore it can be seen that the maximum error bit detected by the modified CSMA/CA MAC protocol is 630 bits error for the duration of 0.02 seconds. Comparing the number of bits detected in the modified CSMA/CA MAC with that of the CSMA/CA will generate the theory that the backoff time will necessitate fewer bits to be transferred through traffic leading to collision in the data frame. Also an increase in SNR of the radio nodes will result in a consequent decrease in the number of error bits detected.

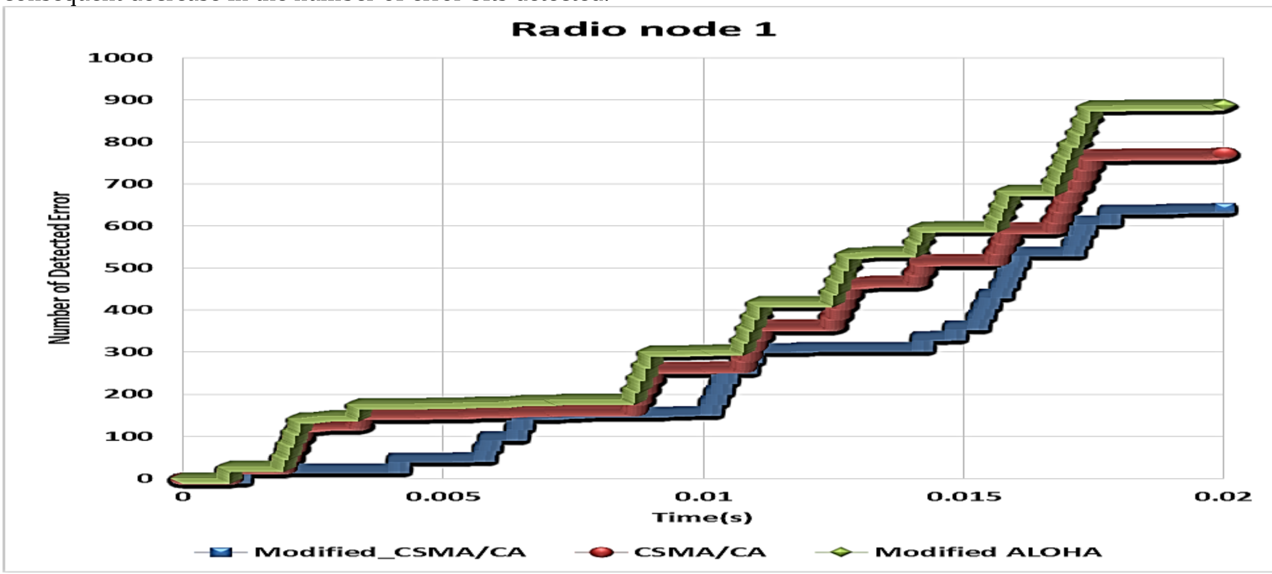

Figure 18: Graph of number of detected error bits vs transmission time for radio node 1 on application of modified Aloha, CSMA/CA, modified CSMA/CA MAC protocols.

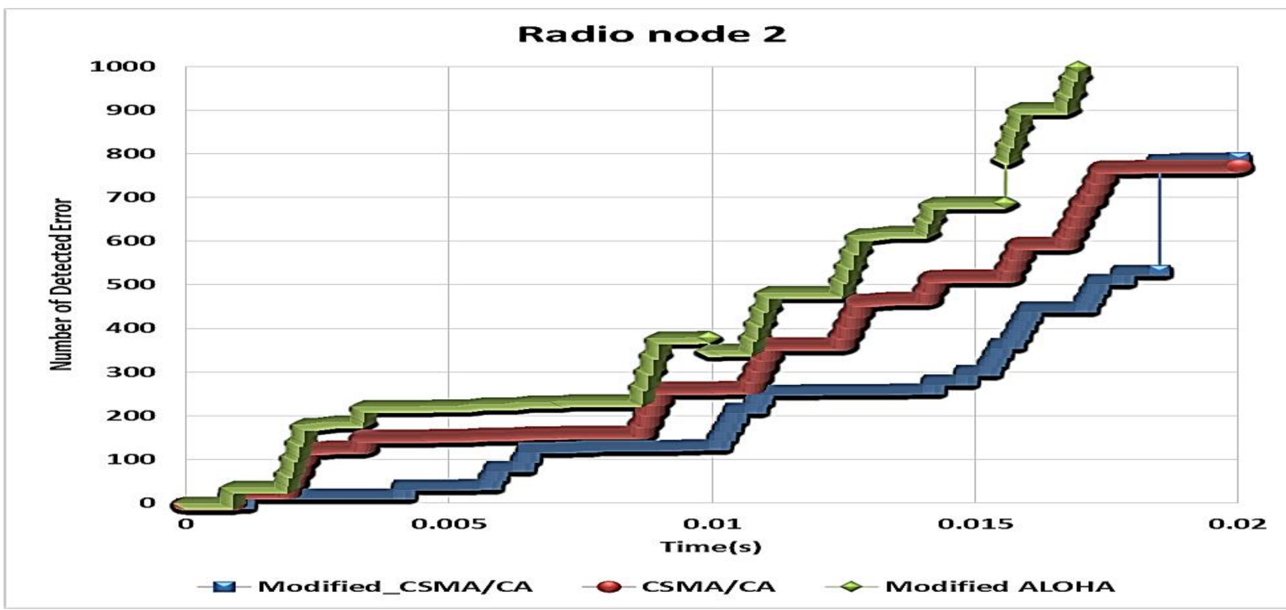

Figure 19: Graph of number of detected error bits vs transmission time for radio node 2 on application of modified Aloha, CSMA/CA, modified CSMA/CA MAC protocols

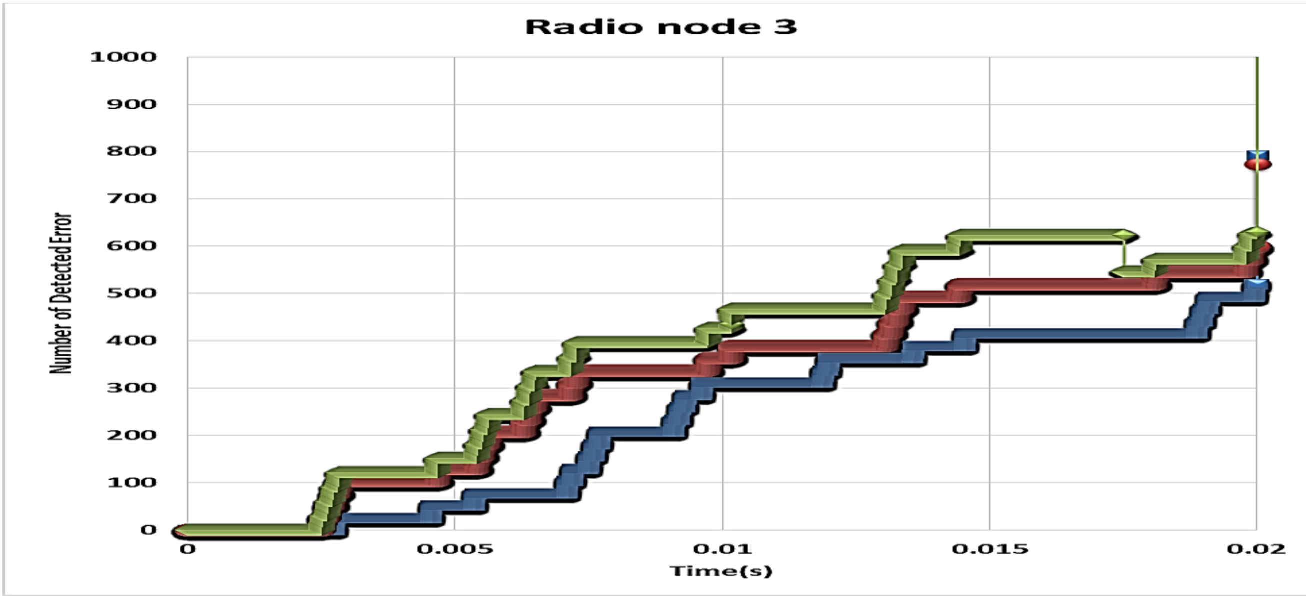

Figure 20: Graph of number of detected error bits vs transmission time for radio node 2 on application of modified Aloha, CSMA/CA, modified CSMA/CA MAC protocols.

4.0. Conclusion

Power management of the radio has gained significant importance in sensor networks since the radio is a major consumer of sensor‘s energy. The major part of power is consumed in radio (transmitter and receiver), which is controlled by the MAC protocol. This research work provided a comparative analysis for MAC protocols based on channelization and random access; however this analysis has considered the random access protocols in which all nodes and stations are at same priority. The modified Aloha MAC, modified CSMA/CA MAC and the CSMA MAC protocols are such protocols that have been considered in this paper. Matlab/Simulink modeling and simulation environments together with its stateflow chart applications has been used to properly analyze energy efficient routing protocols for the purpose of achieving the objectives of this research work. The application of stateflow diagram and also stateflow charts has also been extensively used for the logical contents of the MAC protocols. The results of this study showed that the modified CSMA/CA MAC protocol performed better than the CSMA/CA and modified Aloha MAC protocols. It was observed that the modified CSMA/CA MAC protocol results in lesser errors during transmission compared to the CSMA/CA MAC protocol as a result of reduction of data packets collision and lesser detected error bits been transmitted. Moreso, an increase in SNR of the radio nodes resulted in a consequent decrease in the number of error bits detected. The implications of a higher backoff time in modified CSMA/CA suggest improved channel utilization and reduced collision probability at the cost of increased transmission latency, ultimately resulting in more stable and efficient network performance.

5.0 Recommendation

It is recommended that other MAC protocols should be used in wireless sensor networks for energy efficiency.

Acknowledgements

The authors wish to acknowledge the assistance and contributions of the staff of Department of Electrical and Electronic Engineering, Michael Okpara University of Agriculture, Umudike towards the success of this work.

References

Abdullah, M.H., Bhuiyan, M.Z.A and Saha, S. 2020. Performance analysis of slotted Aloha protocol under non ideal conditions, In 2020 11th international conference on computing and networking technologies (ICCCNT), pp. 1-5

Akyildiz, I., Su, W., Sankarasubramaniam, T., and Cayirci, E., 2002 A survey on sensor networks, IEEE communications magazine 40 (8) 102–114.

Bennis, M., Taleb, T. and Debbah, M. 2011. A cache-enabled MAC protocol for cooperative diversity in wireless networks. IEEE wireless communications letters, 1(4), 237-240

Bian, K. and Leung, V.C.M. 2018. A survey of MAC protocols for mission-critical applications in wireless sensor networks. Wireless communications and mobile computing, 10(2), 155-170

Chang, Y.T., Chen, H.C. and Hsiao, H.I. 2023. Improving energy efficiency in wireless sensor networks via adaptive Aloha protocol. IEEE transactions on mobile computing, 22(1), 1-1

Chen, Q., Mao, S. and Leng, S. 2023. An adaptive channel allocation scheme based on the CSMA/CA mechanism foe cognitive radio sensor networks. International journal of distributed sensor networks, 19(1), 15501477221087819

Choi, B.Y., Kim, D.H. and Lee, C.S. 2022. An energy-efficient TDMA CSMA/CA hybrid MAC protocol for cluster-based wireless sensor networks. IEEE access, 10, 24598-24610

Choudhary, V., and Sharma, N. 2016. A review paper on performance analysis of improved mobility adaptive slotted CSMA/CA MAC protocol with adaptive backoff exponent algorithm for mobile IEEE 802.15.4 wireless sensor networks. International Journal of Engineering Research & Technology (IJERT), Volume 4, Issue 32, pp. 1-4

Chukwuka, E. and Arshad, K. 2023. Energy efficient mac protocols for wireless sensor network: A survey. School of Engineering, University of Greenwich Chatham Maritime ME4 4TB United Kingdom, pp. 1-16

Djimli, A., Merniz, S. and Harous, S. 2019. Energy-efficient MAC protocols for wireless sensor networks: A survey. TELKOMNIKA, Vol.17, No.5, pp.2301~2312

Evangelakos, E. A., Kandris, D., Rountos, D., Tselikis, G., Kandris, D., Rountos, D., and Tselikis, G. 2022. Energy Sustainability in Wireless Sensor Networks : An Energy Sustainability in Wireless Sensor Networks : An Analytical Survey Analytical Survey.

Huang, P., Xiao, L., Soltani, S., Mutka, M. W. and Xi, N. 2013. The Evolution of MAC Protocols in Wireless Sensor Networks: A Survey, IEEE Communications Surveys and Tutorials, Vol. 15, No. 1,

Kabara, J. and Calle, M. 2012. MAC Protocols Used by Wireless Sensor Networks and a General Method of Performance Evaluation. Hindawi Publishing Corporation International Journal of Distributed Sensor Networks. Article ID 834784, 11 pages doi:10.1155/2012/834784

Kang, D.Y., Kim, T.H. and Choi, B.Y. 2021. A QoS-aware CSMA/CA MAC protocol for IEEE 802.11ax WLANs. IEEE transactions on vehicular technology, 70(10), 10110-10124

Križanović, V., Grgić, K., Spišić, J., and Žagar, D. 2023. An Advanced Energy-Efficient Environmental Monitoring in Precision Agriculture Using Lora-Based Wireless Sensor Net- works. June. https://doi.org/10.20944/preprints202306.1057.v1

Lee, H., Hwang, J., & Yoe, H. 2010. Energy Efficient MAC Protocol for Ubiquitous Agriculture 2 Background of Research. 4(3), 15–26.

Liu, K., Zhang, Y. and Gao, Q. 2024. Performance analysis and optimization of an energy-efficient MAC protocol for wireless sensor networks with UAV mobile sink. IEEE transactions on vehicular technology, 73(3), 1527-1539

Medjahed, A., Mehadheb, R. and Khoukhi, L. 2022. A new adaptive backoff algorithm for RFID Aloha protocol. IEEE internet of things journal, 9(1), 806-816

Meong-hun Lee, Chang-sun Shin, Yong-yoon Jo, Hyun Yoe, 2009. " Implementation of Green House Integrated Management System in Ubiquitous Forestry Environments", Journal of KIISE, Vol.27 No. 6, pp. 21-26.

Rachedi, A. and Yassein, M.B. 2010. MAC protocols for wireless sensor networks: A survey. IEEE communications surveys and tutorials, 12(2), 222-248

Yick, J., Mukherjee, B. and Ghosal, D. 2008. Wireless sensor network survey. Computer networks, 52(12), 2292-2330

Zhang, Y., Yan, Y. and Wang, K. 2023. Energy-efficient transmit power control for slotted Aloha-based NB-IoT networks. IEEE internet of things journal, 10(2), 1533-1544

Zhu, Q., Afsar, S., and Tahir, S. 2019. An Energy Efficient: Media Access Control Layer Protocols Based on Contention and Channel Polling in Wireless Sensor Network (WSN). 0958.