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Modified X-MAC/CA Protocol to Improve Throughput and Energy Efficiency in Wireless Sensor Networks

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Abstract*:* The aim of research is to introduce the Modified X-MAC/CA protocol, which is an Extension of combining X-MAC protocol with the CA (Collision Avoidance) algorithm to maximize transmission randomization in congested networks. The X-MAC protocol, among the most often asynchronous MAC protocols for wireless sensor networks (WSNs), is characterized by delivering a series of brief acknowledgement is received. This allows all nodes to autonomously and sporadically sleep. By enabling the receiver to let the sender know when it is awake, this quality is intended to use less energy. The Modified X-MAC/CA protocol is meant for reducing collisions, particularly when several nodes in densely packed WSNs provide data at once after sensing some events to report. This work also expands a traditional analytical model for Modified X-MAC protocol to incorporate the addition of Collision Avoidance algorithm for its precise assessment. The simulation has been carried out using OMNet++ along with Mixim Library.According to the extended model, the Modified X-MAC/CA protocol can increase X-MAC/CA's throughput in 60 -nodes network by up to 40%.

Keywords: *X-MAC, X-MAC/CA, S-MAC, B-MAC, CA, CW, OMNet++,Mixim.*

1. Introduction

Duty-cycled Medium-Access Control (MAC) protocols are used in wireless sensor networks (WSNs) to conserve energy and minimize network energy usage and wireless channel collisions. These protocols include S-MAC [1] (Sensor MAC), T-MAC [2] (Time-based MAC), and AMAC [3] (Adaptive MAC). They provide a number of advantages, like as reduced energy usage, collision avoidance, and scalability.

Asynchronous MAC protocols, like B-MAC [4], require broadcasting a preamble immediately due to lack of schedule information. The X-MAC protocol, an improved variant of B-MAC, combines two features to reduce the time it takes to deliver preambles: shortening the length of the lengthy preamble and allowing the receiver to indicate readiness to accept. This approach reduces the time it takes to deliver preambles by breaking up a large preamble into a series of brief poll messages.

However, X-MAC [5] possibility for experiencing severe performance deterioration in overloaded networks due to spatially correlated contention, where nearby nodes competing for control of the wireless channel. This may lead to excess frames collisions, significantly reducing throughput and energy efficiency.

A MAC protocol called X-MAC/CA [11] combines the advantages of X-MAC with the features of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) for use in WSNs. X-MAC enables nodes to sleep most of the time and only wake up to send or receive data. The contention-based MAC protocol CSMA/CA uses a backoff technique to prevent collisions. X-MAC/CA operates by having nodes transmit a series of brief preambles first, with the receiver responding with an acknowledgement When awake. The sender backs off and attempts later if the recipient is not awake. This approach helps to lessen collisions very high densities in WSNs.

Here we are Modifying X-MAC/CA using addition of Double Contention Window, this study suggests the Modified X-MAC/CA protocol as a solution, which enhances the collision avoidance algorithm by randomizing Period it takes for information to be sent. The Modeling and Simulation of this work has been carried out using OMNet++ Testbed along with Mixim Library. Methods and Implementation section presents the suggested performing models for the Modifications of X-MAC/CA protocol, and compares the protocols' in Result Section. The final conclusions and further work are recorded in Discussion and Conclusion Section.

2. Materials and Methods

This section presents the suggested performing models for the Modifications of X-MAC/CA protocol.Figure1 shows the sender's X-MAC/CA [6] compliance. It was eliminated since the X-MAC/CA protocol receiver is identical to the X-MAC. Figure.1 shows that a sensor node does a

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preliminary backoff when it wakes and already has data in its queue. Unlike IEEE 802.11, it randomly selects the integer i from (1, W_{MAX}) then listens over i backoff slots for deciding the channel state. After waiting, it performs a CCA (Clear Channel Analysis) to confirm the channel is open before transmission. Until the initial acknowledgement, it transmits small preambles. It sends one data frame before sleeping after receiving the early acknowledgment.

It will wait for the message to arrive before going to sleep if the channel being used is busy and the brief preamble has the very same destination's address as the sender [7]. Like preamble backoff, data backoff chooses time spent waiting at random to broadcast after transmission. The data packet is sent without preface after this arbitrary timeout. The receiver must be vigilant while awaiting the a follow-up communication to the first one [8].

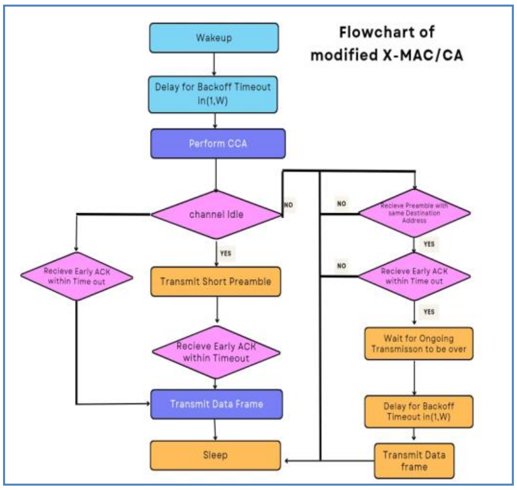

Fig. 1. Modified XMAC/CA Protocol Flowchart

Next, [9] presents the X-MAC/CA protocol performance model,displays a snapshot from the X-MAC/CA protocol throughout a cycle T, where a node begins delivering time period frames that was observed of t. In contrast, n_i additional nodes awake When i time slots prior to t, wherein A positive integer i that ranges from 1 and W_{MAX}. A cycle Two periods separate t. $T_{affected}$ and $T_{unaffected}$ if woken nodes cause collisions. Time slot T in one cycle is equal to each backoff windows tick, and [10] shortens the period synchronize broadcasts, etc. X-MAC/CA slots last 20 s and 1 ms, respectively [10].Parameters for the equations are shown in TABLE 1.

In Equation (1), the symbols N, 0, also P_{Succ} It depicts the total number of nodes in a frame, the probability that a particular node has no buffering packets to share, and the probability that that particular node can communicate with a particular frame

$$THR = \frac{N.(1-\pi 0).Psucc.S}{T} \tag{1}$$

2.1. Chance of a Successful Transmission

According to the Equation (2), the Possibility of a transmission successfully is the result of the production of P_s, which represents potential that just one node will come out on top contention at any given time, and P_{FrCh}, which shows potential that an open channel is going to be available[12-14].

$P_{FrCh} = P_{Succ}$ (2)

Equation (3) calculates the average odds Ps by counting all scenarios at t time with no a collision and shifting the three-distribution variable the j, ni, and N_2 appropriate directions,and proper boundaries. inside of the equation (3), which are the precise sum of the three probabilities P_{N2}, P_{ni}, and P_s, represent the usual situation when the data frame is sent at time t is successful. To prevent interrupting the transfer of information at t, the backoff timing of j nodes has to end subsequent to N2, as well as n_i nodes, wake up while $T_{affected,}$ as well as j nodes among n_i nodes, store particular queued information at the i^{th} slot[15-16].

$$\sum_{t=1}^{T}\frac{1}{T}\prod_{i=1}^{W_0}\left(\sum_{N3=0}^{N3}\sum_{n_i=0}^{N_2}\sum_{N_2=0}^{N-1}\sum_{n_i=0}^{N_2}\sum_{j=0}^{n_i}P_{N_2}P_{N_2}P_{n_i}P_{s_i}\right)$$

(3)

Equation (4) illustrates the chance P_{N2} that N_3 nodes awaken during the $T_{unaffected}$ period (W_0) and which remain (N1-N3) nodes awaken during the $T_{una3ted}$ interval (T-W_0).

$$P_{N_3} = \binom{N-1}{N_3}\left(\frac{W_0}{T}\right)^{N_3}\left(\frac{T-W_0}{T}\right)^{N-1-N_3}$$

(4)

Equation (5) demonstrates division of the chance P_{ni} where ni nodes awaken at the i^{th} contention_ window W_0 where the other (N2-ni) nodes awaken in other cases contention window slots.

$$P_{n_i} = \binom{N_3}{n_i}\left(\frac{1}{W_0}\right)^{n_i}\left(\frac{W_0-1}{W_0}\right)^{N_3-n_i} \tag{5}$$

Equation (6) illustrates the chances that, even if nodes (n_i - j) do not have data to broadcast, nodes j out of $_i$ do possess data, but only if their backoff timers terminate after t to guarantee they do not obstruct data the transmission occurred at t.

$$P_{s_i} = \binom{n_i}{j}\pi_0^{n_i-j}(1-\pi_0)^j\left(\frac{t_i-1}{W_0}\right)^j$$

(6)

2.2. Collision Possibility

To compute the collision Possibility $P_{Coll,}$ expression (7) mixes the open channel Possibility P_{FrCh} with the Possibility Pf that multiple nodes will transmission statistics at moment t.

$P_{Coll} = P_{FrCh} = P_f$

(7)

Equation (8) computes the mean Possibility Pf, which measures every possible instance with collisions at time t, utilizing the same three distributed variants j,N_2, and ni as Equation (3). The internal portion among the equation (8) [17-20] provides the Possibility of when the back-off timings of many nodes will run out at time t, considering all conceivable outcomes. It is precisely the outcome of the three probabilities $N_{2,}$ P, P_{ni}, and i ,P_s.

$$P_f = \sum_{i=1}^{T} \frac{1}{T} \sum_{i=1}^{W_0} \left(\sum_{N3=0}^{N3} \sum_{N_2=1}^{N-1} \sum_{n_i=1}^{N_2} \sum_{j=1}^{n_i} P_{N_2} P_{n_i} P_{f_i} \right)$$

(8)

A minimum of during this time, a single N_2 node and a single N_I node became active. $T_{affected}$, causing a collision at moment t. Equation (9) determines the Possibility that j nodes are included among the ni nodes contains data and that have backoff timings expire at period t, results in those j nodes collision at that time.

$$P_{f_i} = \binom{n_i}{j} \pi_0^{n_i - j} (1 - \pi_0)^j \left(\frac{W_0 - t_i + 1}{W_0} \right)^j$$

(9)

2.3 Possibility of the channel being unpaid

The typical range for the number of free transmission chances that or P_{FrCh} a weighted average of time is a weighted average duration of a free channel to the total length of the channel. These terms are defined by Equations (10), in which E_{free} and E_{Busy} represent the average periods that the communication the channel is available for transmission with a collision or successful transmission, respectively [21-22].

$$P_{FrCh} = \frac{E_{free}}{E_{free} + E_{busy}} \qquad (10)$$

Before we can compute E_{free}, we must first evaluate the likelihood that an event will occur when a transmitting terminates and a space between transmission channel begins. The span of a of a free channel is n_{T+t} cycles, and the Possibility of this happening is P_{free} if that channel remains free for an additional t periods and n cycles. In the lack of a backoff mechanisms, Equation (11) demonstrates that k of the j nodes are simultaneously competing for the Environment. During this situation, the likelihood of a catastrophe is significant. Utilizing the backoff process, it is feasible to calculate the Possibility P_{free} based on potential that a single node is going to transmit data, which is expressed by equation (13).

$$P_{free} = \pi_0^{\;Nn} \sum_{N3=0}^{N3} \sum_{i=0}^{N-1} \sum_{j=1}^{N-i} \sum_{k=1}^{j} \binom{N}{i} \left(\frac{t}{T}\right)^i \pi_0^{\;i} \binom{N-i}{j} \left(\frac{1}{T}\right)^j$$
$$\binom{j}{k} (1 - \pi_0)^k \cdot P_{sk} \cdot \pi_0^{j-k} \left(\frac{T-t-1}{T}\right)^{N-i-j}$$

(11)

The Possibility of achieving contention when k or more nodes compete for a medium is represented by the equation (12).

$$\mathrm{P_k} = \sum_{\mathrm{l}=1}^{\mathrm{W_0}} \frac{1}{\mathrm{W_0}} \left(\frac{\mathrm{W_0} - \mathrm{l} + 1}{\mathrm{W_0}} \right)^{\mathrm{k}} \qquad (12)$$

This information is provided by (13), which provides potential that a single node broadcasts data while competing connect to k additional nodes for the same channel.

$$\mathrm{P_{sk}} = \sum_{\mathrm{l}=1}^{\mathrm{W_0}} \sum_{\mathrm{N3}=0}^{\mathrm{N3}} \frac{1}{\mathrm{W_0}} \left(\frac{\mathrm{W_0} - \mathrm{l}}{\mathrm{W_0}} \right)^{\mathrm{k}} \qquad (13)$$

To the contrary, using equation (14), the average vacant channels time between the two broadcasts can be calculated.

$$E_{free} = \sum_{n=0}^{\infty} \sum_{t=0}^{T-1} \sum_{N3=0}^{N3} (nT + t) \cdot P_{free}$$

(14)

Using the chance of an event taking place Whenever the signal is sent occurs successfully within two free channel periods and the chance of an event taking place in the presence of a collision among two free channel-related intervals, we are able to determine average The amount time that that the channels remains between a pair free channels intervals, or E_{Busy}. Equation (15) represents the chance that the channels will be occupied as a result of a successful broadcast within two channel no cost periods.

$$P_{busy}^{sucs} = \pi_0^{\;Nn} \sum_{N3=0}^{N3} \sum_{i=0}^{N-1} \sum_{j=1}^{N-i} \binom{N}{i} \left(\frac{t}{T}\right)^i \pi_0^{\;i} \binom{N-i}{j} \left(\frac{1}{T}\right)^j$$
$$\binom{j}{1} (1 - \pi_0) \pi_0^{\;j-1} \left(\frac{T-t-1}{T}\right)^{N-i-j} \qquad (15)$$

Equation (16) calculates the Possibility of a busy channel arising from short preamble collisions among two free channel periods. When there is lack of backoff mechanisms, k and j units that a simultaneous competition for a medium will collide. Identical steps as in Equations (11), except in this instance using 'P_k' while no fewer than two each of the 'k' node awaken up simultaneously [23-25].

$$P_{\text{busy}}^{\text{coll}} = \pi_0^{Nn} \sum_{i=0}^{N-2} \sum_{j=2}^{N-i} \sum_{k=2}^{j} \binom{N}{i} \left(\frac{t}{T}\right)^i \pi_0{}^{i} \binom{N-i}{j} \left(\frac{1}{T}\right)^j \binom{j}{k} (1-\pi_0)^k \cdot P_k \cdot \pi_0{}^{j-k} \left(\frac{T-t-1}{T}\right)^{N-i-j} \tag{16}$$

The mean busy channels time during two clear channel periods is derived by taking an average throughout the time period of the successful data transmission (T/2+t_{Data}) with the amount of busy channel time brought on by collisions of shorter preambles (T). Equation (17) may be used to get the average time difference between the two free channel periods.

$$\mathrm{E_{busy}} = \sum_{n=0}^{\infty} \mathrm{P_{busy}^{sucs}} \sum_{t=0}^{T-1} \left(\frac{T}{2} + t_{\text{Data}}\right) \cdot \mathrm{P_{busy}^{succ}} + T \cdot \mathrm{P_{busy}^{coll}}$$
(17)

3. Implementation

3.1 OMNeT++ Testbed

We are using Objective Modular Network Testbed in C++(OMNeT++) [19] for simulating and modeling networks. Many Researchers turn to OMNeT++, an open-source, discrete-event simulation toolkit. Complicated systems and networks may be simulated so that their behavior and performance under different situations can be studied and understood. Regarding networks of computers, mobile communication, and distributed systems, OMNeT++ [27] is where it's at. Maintaining the Integrity of the Specifications.

3.2 Mixim Library

We are using MIXIM [19] (Mixed-Mode Simulation of Wireless Networks) which is, a library for OMNeT++ that aims to make it easier to simulate wireless communication networks. MIXIM is a suite of modules, models, and tools for simulating and analysing wireless protocols and technologies that helps academics and developers. Some of MIXIM's most notable features are, Prebuilt models for IEEE 802.11 (Wi-Fi), wireless technologies, and other IEEE 802.15.4 (ZigBee) are available in MIXIM. Different channel models are available in MIXIM, each simulating the effects of wireless communication conditions including interference and fading. Important for researching ad hoc networks for mobile devices and vehicular communication, the library provides mobility models to replicate the movements of nodes in a network that is wireless. Analyzing the power efficacy of wireless networks and devices requires energy consumption modelling, which is supported by MIXIM. Multiple wireless protocols may be tested and analysed thanks to the protocol implementations provided by this tool. Integration with OMNeT++'s visualization and analysis tools simplifies the examination and interpretation of simulation data generated by MIXIM. Academics and developers widely use MIXIM in the discipline of wireless networking since it considerably improves upon OMNeT++'s capabilities in this area.

	Meaning
N	Total count of the network's nodes
N_2	Number of In the course of T_{affected}
T	Length of one cycle
Q	Queue length of a node
S	Frame size
λ	Data MAC layer frame arrival rate
W_{MAX}(W_O)	Maximum time unit for contention window size of slot
τ	One contestable position of window
π_0	Stationary Possibility of no waiting list state
P	Possibility of transmission $P = P_{\text{Succ}} + P_{\text{Coll}}$
P_{succ}	Possibility that a node has been established sends data $P_{\text{Succ}}=P_S P_{\text{FrCh}}$
P_{Coll}	Possibility a node has a collision while sending data" $P_{\text{Coll}}=P_f P_{\text{FrCh}}$
Ps	Possibility that At any given moment, only one node may claim victory in a network
P_f	Possibility that, at any one moment, contention is won by more than one node
P_{N2}	Possibility where nodes N2 both the impacted and unaffected nodes awaken at "unaffected
P_{N3}	Possibility that nodes N3 both the afflicted and unaffected nodes awaken.
P_{Ni}	Possibility that ni nodes awaken at i^{th} slot of W_0 and the remaining nodes awaken "at different contention window slots.
P_{si}	Possibility that n_i Other nodes wakeup at various contention window times at t.
Pfi	Possibility that ni Nodes hinder communication at t.
P_{FrCh}	Possibility of Once a node wakes up, a free channel.
P_{free}	Possibility of between two broadcasts, a free channel.
$P_{\text{busy}}^{\text{sucs}}$	Possibility the successful broadcast has caused the channel to be congested.
$P_{\text{busy}}^{\text{coll}}$	Possibility that collisions have made the channel congested.

E_{free}	Average interval between two free channel segments"
E_{busy}	Average interval of two transmissions.
P_k	Possibility of winning a media battle when a node competes with k other node.
P_{sk}	Possibility that When competing for space with another node, one node provides data k other nodes.

Table 1. The Symbols and their ExplanationSymbol

4. Results and Discussion

This part of section provides a concise summary of the information presented the analytical results that demonstrate how the t_{sum} of all those involved nodes, cycle duration, and at last contention window size all affect the demonstration of the X-MAC/CA protocol. The system parameters are $W_0 = 64$, 1 frame/s, S = 50 bytes, Time= 20 s, and Q = 10. Maintains the listening time t_{Listen}, the time required it takes to send single shortest preamble ($t_{Preamble}$), that first ACK (t_{ACK}), and the data_frame (t_{Data}). The standards have been established to 15 ms, 5 ms, 3 ms, and 1 ms, respectively.

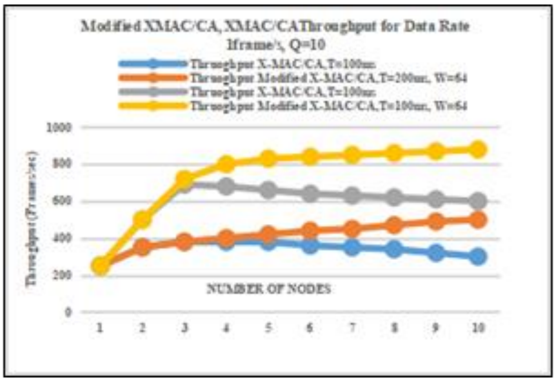

Fig. 3. Comparing simulation results in Modified XMAC/CA and XMAC/CA Throughput for Data Rate=1frame/s, Q=10.

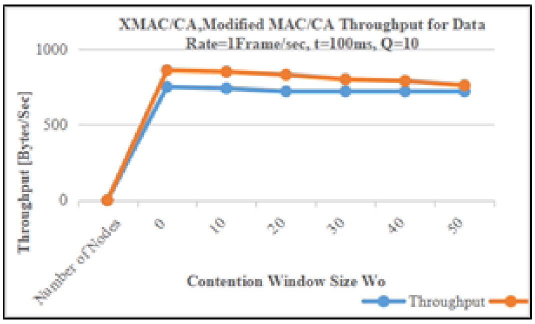

Fig.4. Comparing simulation results in Modified XMAC/CA and XMAC/CA Throughput Vs. Cycle Length for Data Rate=1Frame/sec, N=40, Q=10, CW=64.

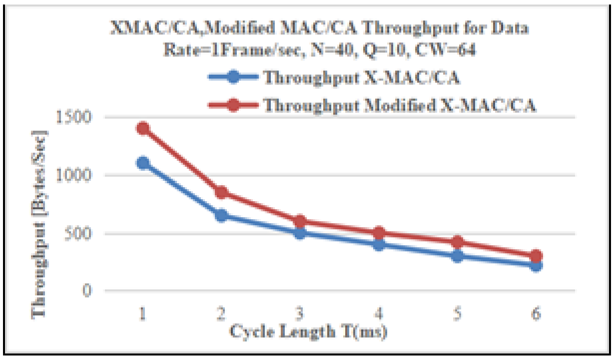

Fig. 5. Comparing simulation results in Modified XMAC/CA, XMAC/CA Throughput Vs Contention Window Size for Data Rate=1Frame/sec, t=100ms, Q=10.

Modified XMAC/CA grows as more networks compete within fewer cycles. It accomplishes 40% higher throughput than Traditional X-MAC/CA in a 40-nodes network when T equals 100 m it's been mentioned in Fig. 3. Fig. 4 Depicts that the distinction between both of these approaches grows as cycle_length T decreases, which suggests that collision_rate is increasing.It illustrates the CA algorithm's effectiveness as network density and cycle duration rise. Fig. 5. Shows that Modified X-MAC/CA obtains improved performance when CW (Contention_Window) and the sum total of nodes rise with width and size. This is brought about by a stronger CW effect that lessens the result of collisions. The more excellent the CW, however, the longer the waiting time, therefore the rate of throughput of CW tends to decrease once it surpasses a certain threshold.

5. Conclusion

To decrease the consequences of collisions, this research offered its model of performance and recommended combining the CA algorithm along with the XMAC protocol. According to the model, results of XMAC/CA will be improved by the Modification in X-MAC/CA protocol, particularly in congested WSNs. In the following years, our study will use the two simulations and their mathematics foundation to investigate the many aspects of the Modified X-MAC/CA protocol, such as energy usage and latency. The extension of the performance model will also include bit errors and the acknowledgment of the data frame. Finally, we want to transform Modified X-MAC/CA into a dynamical X-MAC/CA that can fluidly shift the size of its contention_window historical considerations of the collision rate. Extended model, the Modified X-MAC/CA protocol can increase X-MAC/CA's throughput in 60 nodes network by up to 40%.

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Author contributions

Harish Joshi: Conceptualization, Methodology, Software, Field study,Writing-Original draft preparation, Investigation, **Mohammed Bakhar:** Data curation, Software, Validation., Field study.

Ravindra Eklarker: Visualization, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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