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RESEARCH ARTICLE

Performance Analysis and Enhancement of Contention-Based Sensors Medium Access Control Protocol in Wireless Sensor Networks

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Abstract – Wireless Sensor Networks (WSN) are recently attracting significant research and commercial interest. Since data dissemination is different from traditional Ad Hoc sensor networks, WSN results in a new challenge. Basically, the challenges are the outcome of limited energy, communication, and processing capacity of wireless sensor nodes. Those challenges can be mitigated by the effective use of the medium access layer of wireless sensors network. Basically, there are three types of medium access control (contention-based, contention-free, and hybrid) in wireless sensors networks. The contention-based MAC layer scheduling technique consumes sensor nodes' energy due to idle listening and overhearing. Sensor medium access control is one of the contention-based protocols that have a strong reputation. The fixed duty cycle and fixed contention window size pose a challenge in Sensor medium access control (SMAC). As the network traffic increase fixed contention window of SMAC deteriorate throughput of the network and data transmission delay. The fixed duty cycle of SMAC reduces energy efficiency as a sensor node energy deplete due to using the same idle listening period for high remaining energy node and low remaining energy node. In this article, enhancement is made to SMAC protocol by introducing network load and remaining energy of nodes to adjust contention window as well as duty-cycle dynamically. Performance evaluation was performed on Network Simulator-2 (NS2).

Index Terms – Wireless Sensor Network (WSN), Medium Access Control (MAC), Contention-Based MAC, Network Load, Remaining Energy, Contention Window Adaptation, Duty-Cycle Adaptation.

1. INTRODUCTION

In this recent era of networking, it is possible to monitor remote environments due to the existence of low-power devices with minimum cost and infrastructure-less communications [1, 2]. Wireless sensor networks are characterized as tiny, low-powered, energy-constrained sensor nodes with sensing, data processing, and wireless communication components. Sensor nodes in WSNs are small battery-powered devices with limited energy, and non-rechargeable batteries once the sensor nodes become deployed [5, 11].

However, there is challenge in optimizing the energy efficiency, communication latency and reliability in wireless sensors Network.

The most effective mechanism of optimizing the limited capacity of wireless sensors network is through Medium Access Control. Medium access control deals with scheduling channel access of wireless sensor nodes. Medium access control scheduling algorithms can be categorized as contention-based and contention-free [6, 7]. Contention-free MAC scheduling algorithms enable sensor nodes to reserve channels with prior coordination. The contention-free protocols suffer from dynamic channel access problems since nodes should wait until their channel access time. The contention based medium access control protocols allow

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multiple sensor nodes to use the same radio channel without prior coordination (without prior channel reservation).

1.1. Objective of the Article

The aim of this article is to:

- Assess existing contention-based MAC protocol in perspective of energy efficiency, delivery latency and throughput.
- Design a version of Sensors medium access control (SMAC) protocol that takes into consideration network load and remaining energy of sensors node to adopt the contention window and duty cycle.

The sensors medium access control (SMAC) protocol is one of contention-based protocol designed for wireless sensor network to reduce energy consumption due to idle listen. However, the luck of considering dynamic change in network like network load and sensor node energy makes sensors medium access control (SMAC) protocol in efficient as competition between sensors node increase and sensors node energy deplete.

In this article, the survey of existing contention based medium access control protocol is made and we enhance sensors medium access control (SMAC) protocol.

2. LITERATURE REVIEW

Sensor Medium access control (SMAC) [12] introduces periodic sleep wake-ups. The basic idea behind periodic sleep listen is letting sensor nodes sleep during their sleep time, but listening to the channel and transmission will be performed during the listening time. The Periodic sleep or listen of SMAC can reduce the predominant energy-consuming factor known as idle listening in wireless sensor networks for light network load. Sensor nodes in a network turnoff their radio to save energy during sleep period. Sensors medium access control (SMAC) protocol follows a duty cycle to put the nodes to sleep as well as listen to phase. Duty cycle is computed as the ratio of the listening period to complete cycle time. SMAC defines a complete synchronization mechanism using broadcasting synchronization packets (SYNC packet), periodic neighbor discovery, and neighbor list maintenance.

The duty cycle is adjustable by the user based on the application requirement. The duty cycle is computed from a ratio of listening period to frame length. Frame length (cycle period) is fixed for all nodes in a network but listen period may vary. Listen period consist of two parts synchronization (SYNC) period and DATA period. The synchronization (SYNC) period is the moment of transmitting broadcast packets to solve the synchronization problem among neighboring nodes. DATA period is time for sending or receiving data packets. The schedule timer controls each node's sleep or wake-up period, and reschedule when the current schedule expires. Every node must have at least one schedule. Each frame in SMAC has an expiration period which is called a checking point. At each checking point, SMAC will decide what to do for the next period. There are other features of SMAC like overhearing avoidance and message passing. Overhearing occurs when nodes overhear the packets not destined for them. To avoid over-hearing, SMAC leads neighbor nodes of sender and receiver nodes to sleep. Message forwarding takes place as fragments or single packets. SMAC sends a long message of 8 fragments and transmits it in the burst, but only one Request to Send (RTS) or Clear to send (CTS) packet is transmitted/received to send those eight fragments of a message. But ACK (Acknowledgement) packets should be sent by the receiver each time it receives those fragments. If there is a packet loss sender extends its transmission time.

The short duty cycle reduces sensor node energy consumption but it reduces throughput and increases latency. Whenever a node receives a data packet from its source node, it will not send that packet until the next listening period of the next-hop nodes. Waiting for the next listening time incurs delay when there is a multi-hop communication network. Another drawback of SMAC is the fixed duty cycle used by each node in a network [13]. During light network traffic small duty cycle performs better for saving sensor nodes energy, while during high traffic load maximum duty cycle performs better [3][4]. In a wireless sensor network, fixed traffic type is rare since traffic load may change over time. To solve this problem, researchers attempted to adapt the duty cycle to network load. In the next section, we review some of the methods developed to overcome the stated problem.

Adaptive duty cycle mechanism [14] replaced fixed duty cycle of SMAC with priority discriminant function to enable nodes with more packets to get access to the channel before the nodes with fewer packets. The basic idea behind the dynamic duty cycle is while network traffic is relatively high duty cycle becomes doubled to enables nodes to listen more time. Enabling nodes to listen more time reduces the loss of packets. While network traffic is smaller than the original the duty cycle will be reduced by half of the original duty cycle. The authors prove the proportionality between duty cycle and frame length through the mathematical model. The frame length is the sum of the listening period and sleep period. Reducing the duty cycle increase the T_{frame} value that in turn incurs additional delay. The duty cycle is computed by equation 1.

$$\text{Duty cycle} = \frac{T\ listen}{T\ frame} \quad \ldots\ldots\ldots (1)$$

The authors point out that SMAC uses a fixed sleep scheduling scheme without considering traffic load in a network. In wireless sensor networks, network traffic changes frequently that may result in collision and loss of a packet.

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DC-SMAC dynamically change the duty cycle by predicting network traffic. The duty cycle of DC-SMAC is changed based on the number of packets in a queue and transmission time required to send each packet. The assumption behind DC-SMAC is the minimum transmission interval is 3d where d is the sum of time required for carrier sensing and time required for transmitting the packet ($d = t_{cs} + t_{ts}$).

With this assumption, DC-SMAC adjusts the duty cycle in three cases based on average transmission delay calculated from the sum of transmission delay of each packet in a queue divided to a total number of packets:

Case 1: If the average transmission delay is less than 3d the duty cycle is set to half of the initial duty cycle, assuming that the traffic load is small.

Case 2: If the average transmission delay is between 3d and T frame, the initial duty cycle was assumed to have a moderate traffic load.

Case 3: If the average transmission delay is greater than the T frame, the duty cycle becomes doubled by assuming high network traffic.

Using average transmission delay, DC-SMAC can evaluate the network load to decide a better duty cycle that considers the current network condition. Authors evaluate DC-SMAC in star topology containing four nodes. As per the evaluation result, DC-SMAC has better performance in energy consumption, throughput, and end-to-end delay.

Timeout Medium access control (T-MAC) [15] was designed to overcome the shortcoming of S-MAC in varying traffic load. A node following T-MAC ends their listen period when no activation event occurs among neighbor nodes within time threshold TA. T-MAC considers variable load in the network. The activation events are periodic frame timer, completion packet or acknowledgment transmission, reception data on radio, overhearing of CTS or RTS. The time threshold (TA) defines a shortest amount time required for idle listening per frame. Sensor node will not go to sleep in T-MAC while there is a communication among neighboring nodes since it may be the receiver of successive messages. Every node transmits its queued message in a burst. The sending node waits for answer until time threshold TA before going to sleep. This situation may happen since the first frame transmission may reduce the throughput. If the node does not receive any answer, it should re-send the RTS. The node will go to sleep if it doesn't receive anything within two subsequent trails. The value of TA is larger than the summation of contention interval, length of request to send packet, short time between the ending of Request to send packet, and beginning of clear to send packet (turnaround time). The main aim of TMAC design is to reduce the time of idle listening in which nodes may listen to the idle channel. In addition to idle listening, other factors have been taken into consideration while designing the TMAC protocol. Those factors are:

Collision: Packet transmission from nodes in a network can collide with neighboring node data. To retransmit dropped packets due to collision sensor nodes requires extra energy.

Protocol Overhead: since control packets exchanged in most of the protocols do not contain any application data T-MAC considers the energy to send and receive those control messages as overhead.

Overhearing: the communication through the air takes place in a shared medium. So, through this communicating node may receive packets that are not sent to it. Avoiding overhearing reduces the energy wasted to receive packets not destined to the current node.

However, the predominant waste of energy occurs during idle listening than other factors that are above. TMAC reduces the energy required for idle listening by introducing the activation factor TA.

The shortcoming of TMAC is it suffers from the early sleeping problem. The early sleeping problem of T-MAC makes it vulnerable for lower throughput of the protocol than earlier SMAC protocol [9][10].

Adaptive contention window medium access control (ACW-MAC) [16] change the contention window size based on the past history of successful transmission. Contention window determining when and how long to transmit packets. During light traffic load, a high contention window can result in an unnecessary wait and increase energy consumption. In high traffic load, a smaller contention window size may cause intensified competition. The sensors medium access control protocol cannot adapt to dynamic network traffic. The luck of considering dynamic situations results in delay and high-power consumption in SMAC.

Considering the deficiency of SMAC back-off mechanism ACW-MAC modifies RTS frame as well as contention window, ACW-MAC proposes a back-off algorithm that uses adjustable contention window rather than fixed contention window.

In the SMAC every node calculates the random back-off time before transmission and sets the back-off timer. The node starts to transmit when the timer becomes declined to 0. Random back of time proposed for collision avoidance. ACW-MAC introduces two parameters known as CWinit and CWbasic. CWinit is the initial contention window that is obtained by dividing the minimum contention window and maximum contention window sum by two. Then the value of the initial contention window becomes assigned to CW.

$$CW_{init} = \frac{CWmin+CWmax}{2} \quad \ldots\ldots (2)$$

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Contention window basic is obtained by dividing the contention window into two intervals.

ACW-MAC also introduces another parameter called ACCESS which will be set to 1 if the node accesses the channel and transmits the packet successfully last time. If the node fails to send the packets successfully last time ACCESS becomes set to 0. The current network traffic load is determined by comparing the current contention window with the contention window basic. Then current contention situation is announced to neighbor nodes through the newly added RTS packet field called CONTENT. Authors evaluate the performance of SMAC and ACW-MAC through five nodes start topology. As a routing protocol, Ad Hoc On Demand Distance Vector (AODV) is used to evaluate performance. ACW-MAC performs better in terms of average energy efficiency, end-to-end delay and throughput by varying CBR intervals.

The fixed contention window of SMAC cannot achieve better performance as traffic load changes since it requires either waiting more time to transmit packets or intensify the competition for the channel under varying network traffic. Existing literature in contention-based protocol specifically none of SMAC modification takes into consideration network load while adjusting contention window and remaining energy while adjusting duty-cycle. We enhance the performance of the SMAC protocol by considering those two parameters. We also illustrate the effect of network load on the performance of SMAC, while the number of nodes kept the constant increase in network load degrades the performance of the protocol. In this article, we use packet inter arrival time to determine network load and adopt a contention window.

Dynamic Sensor Medium Access Control (DMAC) [17] authors propose a communication protocol based on converge cast. In wireless sensors network coverage cast communication pattern is the most observed method of communication. The unidirectional path from source nodes to the sink forms a data gathering tree. DMAC was designed to achieve very low latency while being energy efficient. DMAC is an enhanced Slotted Aloha algorithm where sets of sensor nodes are allotted slots based on data gather tree. The child node in data gathering tree can transmit during receive period of a node. To achieve low latency DMAC allocates consecutive slots to successive nodes in the data transmission path. Through implementing this technique DMAC achieves minimum latency compared to other medium access control scheduling algorithms. DMAC is preferable for scenarios that need low latency.

The drawback of DMAC is it does not consider collision avoidance methods. In addition, the luck of prior knowledge of data transmission paths may prevent formation of data gathering tree [5].

Demand-Wakeup Medium Access Control (DW-MAC) [18] demand wake-up medium access control was designed to wake up nodes during their sleep period. In a wireless sensor network, most of the time Duty cycle is used to reduce energy consumption due to idle listening, however, the duty cycle similarly introduces extra latency in packet delivery. Schemes proposed to minimize latency due to duty cycle works for light traffic condition. But, due to broadcast or converge-cast traffic wireless sensors network could often experience high network traffic. The authors present Demand Wakeup MAC (DW-MAC) protocol that wakes up sensor nodes during sleep period with low overhead. This protocol also enables nodes to make sure that data transmissions do not collide at the receiver node. DW-MAC increasing effective channel capacity with change in traffic load. DW-MAC achieves small delivery latency in broadcast and unicast communication under varying network traffic. The authors compare performance of demand wakeup medium access control protocol with Sensors medium access control protocol (SMAC) and RMAC using ns-2. The result of the simulation shows that DW-MAC outperforms SMAC and RMAC protocols as traffic load increase.

Receiver Initiated Medium Access Control protocol (RI-MAC) [19] is designed to increase network throughput, reduce power consumption and increase packet delivery ratio through receiver-initiated mechanism of data transmission. The sender node in Receiver Initiated Medium Access Control waits in active mode until the receiver node is ready to receive data. Whenever the receiver node wake-up it broadcast the beacon to notify neighboring node data transmission. Upon reception of beacon neighbor node which has data to transmit will send data since the receiver is awake. Beacons in RI-MAC are used for two purposes one for initiation of the connection and the other for continuation of the current connection. After receiving the current transmission data successfully receiver again broadcasts a beacon, which is used for two purposes: as an acknowledgment to currently received data and to announce the continuation of connection to the sender. The beacon frame format of RI-MAC contains frame check sequence, source address, hardware preamble, back-off window, frame control field, Destination address. The back-off window and destination address are the optional field in the beacon frame field. The beacon frame length is stored in the size of the beacon field.

Any node transmitting the beacon adds its address as a source address to enable the receiving node in identifying the sender of a beacon. Each node in RI-MAC has its own duty cycle.

RI-MAC reduces the data period in the duty cycle and reduces the energy consumption of nodes since the receiver node will not listen to the idle channel while there is no transmission. In addition, to increase the lifetime of nodes RI-MAC uses

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receiver-initiated transmission that reduces collision that may happen due to transmission of packets from different source sensor nodes at the same time.

Randomized adaptive medium access control protocol (RASS) [20] is based on clustering and adjusting the sleep schedule based on the data rate of a node. At the beginning node in a network become clustered based on the clustering algorithm. Each cluster contains one cluster head and one or more cluster members. Cluster head polls the cluster members to send the sensed data packet by broadcasting request. The cluster members start to send sensed data upon reception of the request. Then cluster head calculates the sending rate of each node and sorts them based on the initial threshold of the data sending rate. Nodes with a minimum data sending rate are supposed to be slow senders. Slow senders become in sleep mode by turning off their radios to avoid sensing and processing in the current time slot to save energy. But nodes with higher data rates are considered as faster senders and they become active nodes. Cluster head generates the schedule based on members sending rate. After the generating schedule, the cluster head is responsible to broadcast the schedule information to all clusters.

The scheduling is performed by following two steps:

Initially, nodes in each cluster with minimum data sending rate are set randomly to sleep mode in each slot. The schedule is generated based on two key cases. If, some **k** nodes in the cluster have a data sending rate lower than the minimum threshold rate, then ‘n’ nodes are set to sleep mode. If, all **k** nodes in the cluster can send the data with a rate larger than the minimum threshold, then ‘n/2’ nodes are set to sleep mode randomly.

The second step is in case of the minimum data sending rate of all the nodes in the cluster, at the particular time slot, the time slot is divided into tiny slots that are equal in size. Then round-robin scheduling is used to set at least one node in active mode to avoid the absence of the cluster. RASS becomes energy efficient since it puts some nodes to sleep to reduce energy wastage.

Pattern medium access control (PMAC) [21] protocol is designed to overcome frequent sleep wakeup of SMAC and T-MAC at the beginning of each cycle whether there is traffic or not. This frequent sleep wakes up consumes energy since they need to turn on and off their radio to sleep or wake up. To overcome this problem PMAC proposes a pattern generation scheme based on nodes' traffic and neighbor nodes' traffic. The pattern of nodes determines when to sleep and wake up. For instance, the pattern of 001 indicates the sensor node plan to sleep in next two successive time slots and wakeup in the third slot. At the end of the current period newly generated pattern for the subsequent period is broadcasted by a node. To achieve the exchange of pattern period is divided into supper time frames (STF) that has two sub-frames. STF has two sub-frames called pattern exchange time frame (PETF) and pattern repeat time frame (PRTF). In pattern repeat time frame (PRTF) every node repeats their recent pattern. PRTF has a period in which all nodes stay awake for listening to the channel. If a node receives any packet during this period from the downstream node it will set its pattern to one. Setting the pattern to one allow a node to be awake swiftly next time since it is more likely to receive a packet. The generated pattern is exchanged during the pattern exchange time frame (PETF). The pattern generated for the last time during PRTF decides the schedule for the next packet repeat time frame. The performance of PMAC has been evaluated against SMAC protocol with total energy consumption, total throughput, and power efficiency.

Division Multiple access medium access control protocol (MDA-MAC) [23] stated that SMAC nodes can access channel only during the scheduling and listening periods. This scenario creates data latency and high conflict. MDA-MAC introduce splitting duty cycle into multiple micro duties and two backoff mechanisms. The backoff mechanisms use fast binary exponential backoff and conflict avoid binary exponential backoff to reduce chance of collision in packet transmission. The proposed model is evaluated against Sensors medium access control using network simulator-2 (NS-2) by using effective throughput, latency and residual energy as a parameter.

The combined effort of backoff algorithms and micro duties enable Division Multiple Access Medium Access Control (MDA-MAC) to achieve less latency, high effective throughput and better residual energy than the Sensors Medium Access Control (SMAC) Protocol. However, MDA-MAC takes the decision of backoff or computing adoptive duty cycle based on success or failure of packet transmission.

In this article we propose assessing the network condition based on the packet inter arrival time and remaining energy of sensors node to set contention window size and duty cycle. Taking the decision of duty cycle adaptation after the collision occur can result in better performance compared to fixed duty cycle but it requires some time to readjust the duty cycle as well as contention window size. In frequently changing environment these mechanisms can result in performance deterioration due to less recognition of network condition before collision actually occurs.

The comparison in Table-1 suggests high delay can be due to small duty cycle, high traffic load, low remaining energy of sensors node and small contention window size. Most of the MAC layer protocols make a use of random sleep, scheduled sleep, sleeping sensors with low data sending rate and sleeping idle nodes. Comparison of Contention based MAC protocols in wireless sensor networks is shown in Table 1.

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MAC protocol	Delivery latency	Energy efficiency	Reliability
DW-MAC [18]	Less delay in high traffic load	Less energy consumption in high traffic load	Better reliability than SMAC in high traffic condition
SMAC [12]	Low duty-cycle increase data delivery latency	Reduce energy consumption through overhearing avoidance	High duty-cycle increase throughput and reduce data delivery latency
RASS [20]	Increase delay as a sensor node in a cluster drain their energy	It is energy efficient since sensor nodes with low sending rate become sleep.	Frequent Cluster formation reduces reliability of a network.
ACW-MAC [16]	The average end-to-end delay of ACW-MAC is smaller than SMAC Protocol	The average energy consumption ACW-MAC is lower than SMAC protocol.	ACW-MAC has high throughput than SMAC Protocol.
TMAC [15]	High delay since it increases percentage sleep time.	Save energy by sleeping idle nodes.	Low throughput due to early sleeping of node in a network

Table 1 Contention Based Medium Access Control Protocols Comparison

However, in the above-mentioned methods they use a single factor to decide on reducing energy consumption that may affect other parameters such as throughput and end to end delay. The network throughput is affected by early sleeping, frequent clustering, traffic condition, size of duty cycle and contention window.

3. ENHANCED SENSOR MEDIUM ACCESS CONTROL (ESMAC) PROTOCOL

ESMAC enhances SMAC protocol by taking the traffic condition and remaining of energy of node. We introduce the adoptive contention window to traffic condition and any application area based on demand. The design of ESMAC is based on the Figure 1 flow chart.

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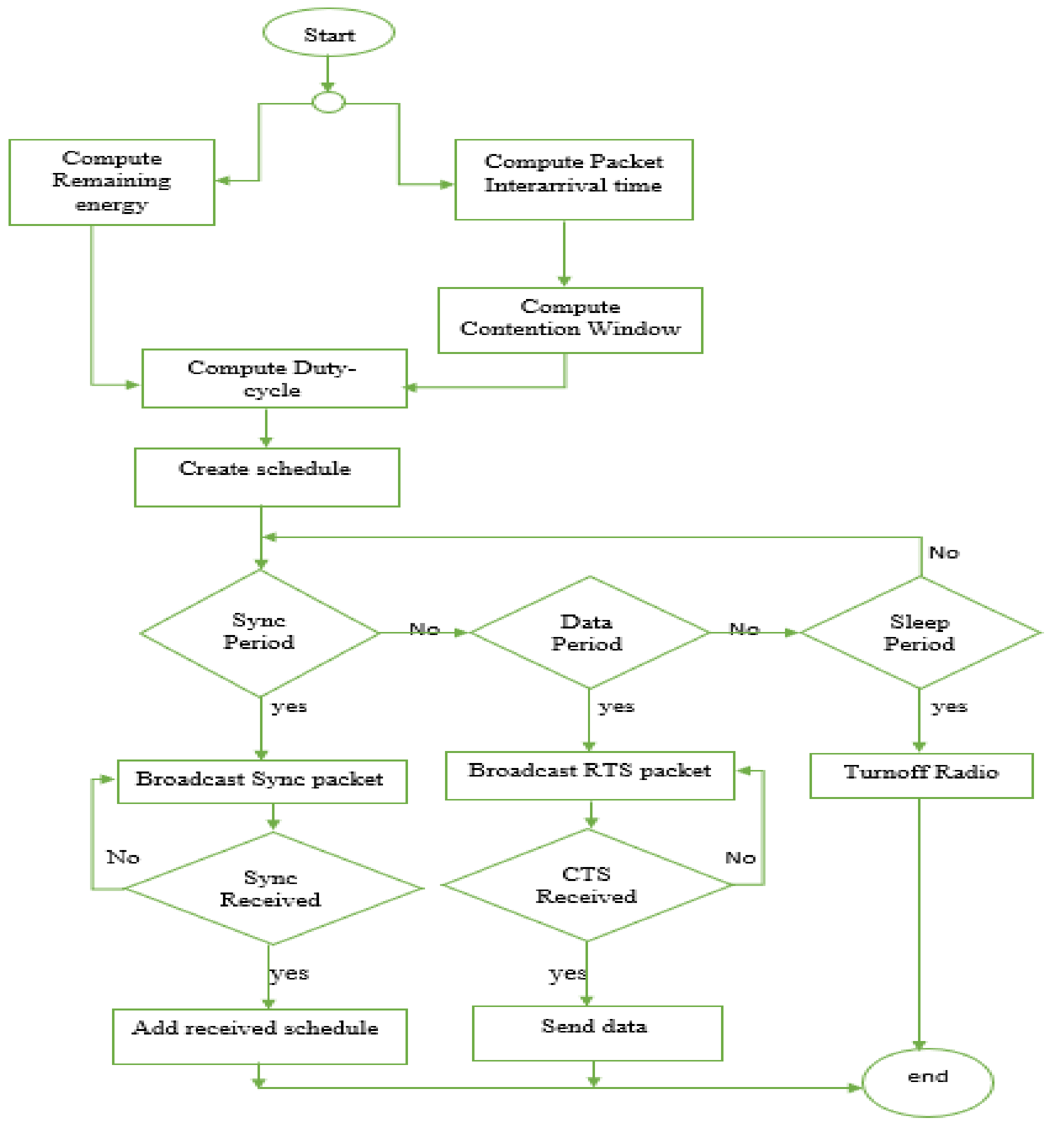

Figure 1 Flow Chart of Enhanced Sensor Medium Access Control Protocol

3.1. Determining Contention Window

At the initial stage, every node in the network determines its contention window-based network load. We perform various simulations to see the effect of the network load contention window.

The simulation result of a varying network load enables us to determine the relationship between the contention window and network load. Based on the simulations packet interarrival time affects the contention window. In ESMAC contention window is determined using:

$PIT_{recent} = ((P_n - P_{n-1}) + (P_{n-1} - P_{n-2}) + (P_{n-2} - P_{n-3}) + \ldots + (P_{n0+1} - P_{n0})) / (n-1)$ ……. (3)

$CW = (PIT_{previous} / PIT_{recent}) * CW_{previous}$ …… (4)

Where CW in Equation (4) stands for contention window, n is total number of packets received in current contention window. We assumed that there will be high network load for small value of packet inter arrival time (PIT) based on Equation (3). As a network load increase the contention window size will increase in our scheme. Every node in the network computes their contention window using the above equation. By using simulation experiment on ns-2 we are able to get the optimal contention window that increase throughput and minimize end-to-end delay.

3.2. Determining Remaining Energy of Nodes

Nodes in a network evaluate their remaining energy against specified thresholds. When the energy of sensor nodes drops below the specified thresholds sensor nodes re-adjust their duty cycles. Sensor node becomes active for less time when their energy becomes less than a certain stated threshold. By reducing duty cycle the sleep period of the nodes become larger and sensor nodes save more energy.

$$Dutycycle = \frac{listen\ time}{frame\ length} \quad ..... (5)$$

Frame length in Equation (5) is fixed according to some physical layer parameters. So, for a given duty cycle the listen time can be given as Equation (6):

$$Listen_{time} = dutycycle * framelength \quad ......\text{Equation (6)}$$

Sleep time will be determined using the following Equation (7):

$$Sleep_{time} = cycle_{time} - listen_{time} \quad ....\text{ Equation (7)}$$

The proposed scheme has more sleep time than SMAC protocol. By sleeping nodes for longer time when sensor nodes energy drops below specified thresholds (i.e 0.75, 0.5, 0.25) of its initial energy, ESMAC is able to save wireless sensor nodes energy.

3.3. The Algorithm of Proposed ESMAC Protocol

Determine the remaining energy of node

Determine CW that fits to current network load

Generate primary schedule

Create synchronization (SYNC) packet

Broadcast SYNC packet

If receive SYNC packet **then**

Check the schedule against primary schedule

If schedule match **then**

Follow the current schedule

Else if schedule does not match **then**

Insert current schedule to schedule table

Else if no schedule exists **then**

Create the new schedule

Else if data exist **then**

Send Request to Send (RTS)

If receive clear to send (CTS) **then**

Send data

Else

Wait for CTS timeout

Rebroadcast RTS

Algorithm 1 The Algorithm of Proposed ESMAC Protocol

Get initial value of duty-cycle

Get remaining energy of sensor node

If remaining energy > 0.75 * initial energy **then**

Dutycycle = dutycycle

Else if remaining energy < 0.75 * initial energy **then**

Dutycycle = dutycycle * 0.75

Else if remaining energy < 0.5 * initial energy **then**

Dutycycle = dutycycle * 0.5

Else

Dutycycle = 0.25 * dutycycle

Algorithm 2 Algorithm for Adjusting Duty-Cycle According to Predefined Energy Threshold

3.4. Simulation Environment

We implement the design of the proposed enhancement to SMAC on network simulator NS-2.34. Network simulator-2 is an open-source simulator tool that implements various protocols. We evaluated the performance of the proposed work considering two factors:

- Effect of network load on contention window as in Algorithm 1.
- The consequence of the duty cycle on an energy level as in Algorithm 2.

The design of a power-efficient medium access protocol can prolong the lifetime of the network. In addition to energy-efficient design, a transmission delay and throughput are necessary features considered in performance evaluation.

3.5. Simulation Scenario

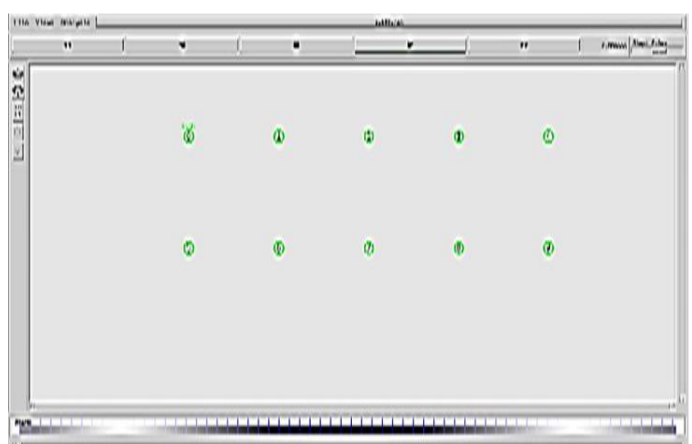

Figure 2 Simulation Scenario

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We used the grid topology of 10 nodes, where node 0 sink node as indicated in Figure 2. The sink node receives the packet sent from source nodes and processes packets.

3.6. Simulation Parameters

Parameters	Description (value)
MAC protocol	ESMAC/SMAC
Agent	UDP
Routing protocol	AODV
Initial energy	1000J
Network area	801x500
Number of nodes	10
Duty cycle	20,30,40,50,60,70,80,90,100
Idle power	1.0
txpower	1.0
rxpower	1.0
Sleep power	0.0001
Transmission power	0.2
Interface queue length	50
Simulation-time	500 s

Table 2 Simulation Parameters

Table 2 lists out the various parameters used for simulation.

4. RESULT AND DISCUSSION

We made a performance evaluation of SMAC and ESMAC in two conditions based on Table-1 parameters:

Scenario-1: performance evaluation with change in duty cycle.

This scenario demonstrates performance gain and loss in accordance with change in duty cycle. The theoretical critics from the related work comparison part the effect of duty-cycle on energy efficiency, throughput and end-to-end delay are demonstrated in this scenario.

Scenario-2: Performance evaluation with change in network size.

This scenario demonstrates the effect of channel competition on contention window. Since the intense competition degrade performance of SMAC due to fixed contention window size.

4.1. ESMAC and SMAC Protocol Average Throughput Comparison

In case, of sensors medium access control (SMAC) protocol using fixed duty cycle size can end the listen period of sensors nodes even while there is high traffic load in a network. This scenario reduces the average number of bits received per second. Considering the packet interarrival time to decide duty cycle and contention window size increase throughput of ESMAC as indicated in Figure 3.

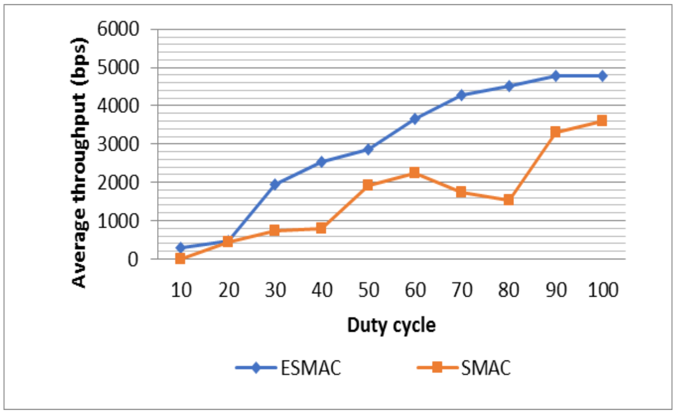

Figure 3 Average Throughput with Change in Duty-Cycle

As a number of nodes in a network increase there will be intensive competition to get channel access. Using small contention window size results in intense competition for large number of nodes and large contention window size results in unnecessary wait for small number of sensor nodes. In both case SMAC results in low throughput.

4.2. ESMAC and SMAC Protocol Average Throughput Comparison with Change in Network Size

As Figure 4 indicates the throughput of enhanced sensors medium access control increase the throughput due to assessing the network load before setting the contention window size.

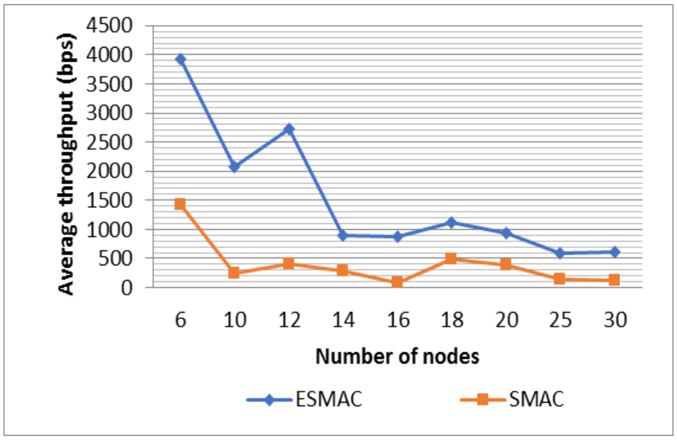

Figure 4 ESMAC and SMAC Protocol Average Throughput Comparison with Change in Network Size

4.3. ESMAC Average End-to-End Delay Comparison

The average end-to-end delay as indicated by Figure 5 and Figure 6 is reduced in ESMAC than SMAC due to adopting

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the sleep schedule as well as contention window size of sensor nodes based on the network condition. Adopting the duty cycle to existing network traffic makes sensor nodes to stay awake in intense traffic situation which in-turn reduce time required by source to wait for transmitting its packets.

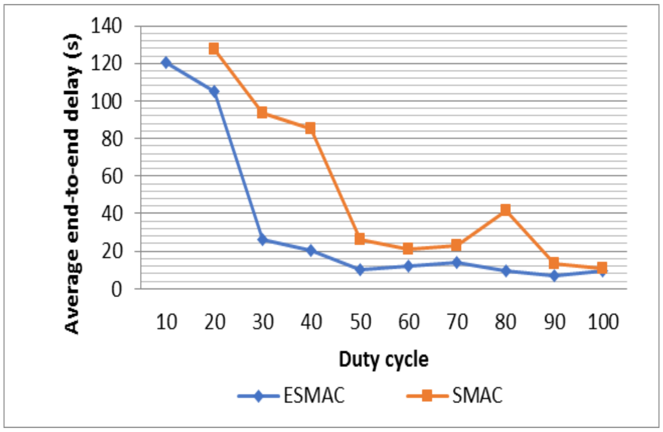

Figure 5 Average End-to-End Delay with Change in Duty-Cycle

4.4. ESMAC and SMAC Average End-to-End Delay Comparison of with Change in Network Size

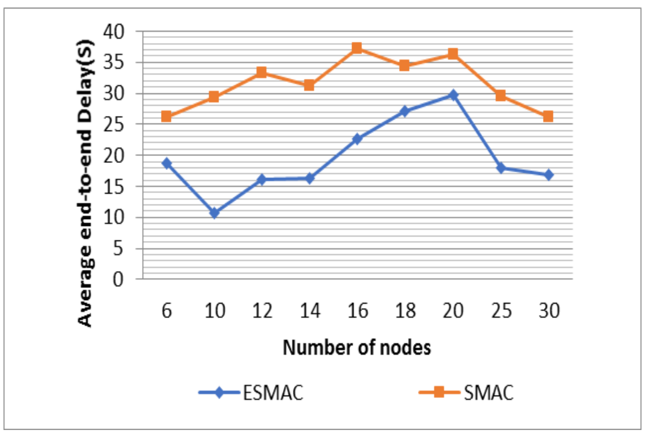

Figure 6 Average End-to-End Delay with Change in Network Size

4.5. Power Efficiency Performance Evaluation of ESMAC and SMAC

As a result, from Figure 7 and Figure 8 show ESMAC is more power-efficient than SMAC with all duty cycles that we used to measure the performance of SMAC and ESMAC. As the duty cycle rise, the power efficiency of ESMAC become higher.

The average energy consumption is reduced as an increase in duty-cycle in the case of ESMAC as a result of adjustment of duty-cycle based on a node residual energy. As the residual energy of the node drops below 0.75, 0.5, and 0.25 of initial energy ESMAC adjusts the duty cycle to 0.75, 0.5, and 0.25 of initial duty cycle. Since duty cycle is the fraction of listening period to frame length when duty-cycle is minimized nodes will have more sleep time than listen time. During sleep time sensor nodes turnoff, the radio to reduce energy consumption due to idle listening.

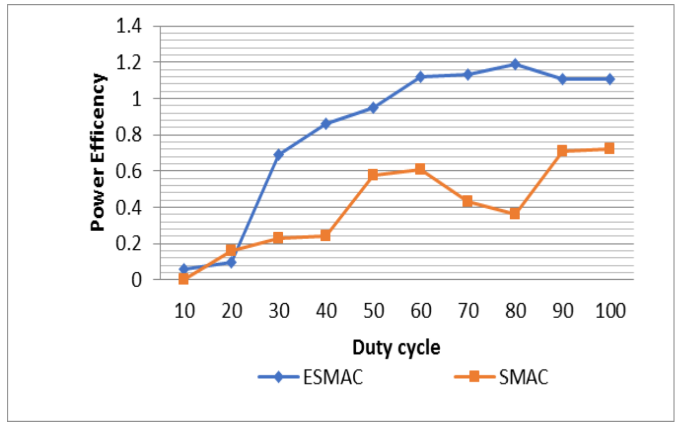

Figure 7 Power Efficiency Performance Evaluation of ESMAC and SMAC

4.6. Power Efficiency Performance Evaluation of ESMAC and SMAC

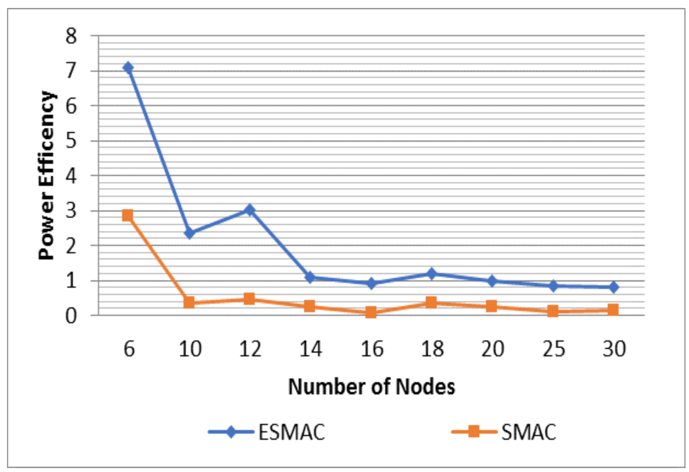

Figure 8 Power Efficiency Performance Evaluation of ESMAC and SMAC with Change in Network Size

5. CONCLUSION

The SMAC protocol is well known contention based medium access control protocol. However, it has shortcoming related to fixed duty cycle and fixed contention window size that results in short life time of a sensor nodes as sensors node energy deplete and poor quality of service (QoS) for changing network condition. We propose dynamic contention window and duty cycle adjustment-based network traffic (packet inter arrival time) and remaining energy of sensor nodes. Taking

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those factors into consideration in essential for preventing the network congestion (intense competition) for accessing the channel before it actually happens. Residual energy of sensors node enables as to preserve sensor nodes energy in light traffic condition by increasing the sleep period of sensors nodes with less remaining energy. The result of proposed work is evaluated with sensors medium access control (SMAC) and there is performance gain in terms of Power efficiency, average throughput and average end-to-end delay.

As our future research direction, we aimed at designing priority-based scheduling scheme with ESMAC for an application that requires mixed data types and cross layer design between medium access control and routing layer of wireless sensors network.

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