# A Dynamic Contention MAC Protocol for Wireless Sensor Networks

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## ABSTRACT
Research in the area of Wireless Sensor Networks has taken tremendous growth due to its wide applications spanning from health monitoring, environmental monitoring and tactical systems. The tiny nodes equipped with low batter power and computation power collaborate to sense the parameters and communicate to the base station. The contention in the channel demands the design of efficient MAC protocols that can save the battery power and reduce the data loss during transmission while are used in various fields. Medium Access Control (MAC) Protocols, are at the lower layers of WSNs' protocol stack. They have a greater influence on performance and energy consumption of the network. Sensor MAC (SMAC) is one of the oldest and most widely used MAC protocol for WSN. There exists few variations of SMAC, but still the research is going on to modify this protocol in order to support real time traffic while making it more energy efficient. The current work plans to find the drawbacks of SMAC and to make it more energy efficient.

## Keywords
Wireless Sensor Networks; Medium Access Control; Contention Window; SMAC

## 1. INTRODUCTION
Research in Wireless Sensor Networks (WSNs) has become very popular due to its wide application in the domains like military surveillance, agriculture, disaster relief, health care, environments, Intelligence, emergency, forensic etc. [4]. Data traffic in WSN follows a particular pattern, and the data is sensed by tiny nodes (mainly source nodes) and are transferred to sink node. These tiny nodes are resource constrained, i.e. they scarce in battery power, computation power, storage etc. In order to use these resource constrained nodes efficiently, it is required to design the hardware and software accordingly [5]. It is practically impossible to recharge the batteries. Since the sensor nodes operate independently with small batteries for a few months or years, the researchers mostly aim to design the energy efficient protocols for MAC and routing layers. Along with energy efficiency, the other parameters like end to end latency and throughput in transmission are also considered to enhance the reliability in data transmission.

In WSN, the major power consuming components remain the MAC layer as it has its control over the radio of sensor nodes. MAC protocols decide how the nodes share the wireless medium and when the node can start releasing the data to the medium. An energy efficient MAC protocol can not only increase the energy efficiency of sensor nodes but also can reduce collisions and provide better throughput and lesser transmission delay.

Nowadays, various MAC protocols are proposed for less power consumption and less end-to-end delay in the network. MAC protocols are classified into contention based, reservation based and scheduling based [14]. The Schedule-based protocols usually divide the time into several time slots with the TDMA (Time Division Multiple access) approach. These time slots are then divided amongst different sensor nodes for communication. In this way, each node uses the channel during the allotted time slots. During the idle time slots, the nodes sleep and save their battery power. This requires strict time synchronization and is some-times complicated to implement. The contention based protocols allow users to use the channel when required. For example, the node should compete for the shared channel before sending the data [1]. This might increase the power consumption.

In recent years' researchers have tried to develop MAC protocols that are more energy efficient [15]. Various protocols like SMAC, TMAC has been proposed. SMAC is considered to be more energy efficient [15]. Some tried to make duty cycle dynamic that resulted in better energy efficiency [2]. The contention window was also changed by the authors [3]. This showed that contention window has a significant influence on the performance of MAC protocols.

In this paper, we have proposed Dynamic Contention Window (DCW) MAC protocol that is energy efficient and outperforms the SMAC protocol in terms of low latency. The DCW-MAC is based on SMAC, which is a contention-based MAC protocol. The size of the current contention window is decided considering the status of the channel with previous CW size. Unlike SMAC protocol that has a fixed contention window, we propose a dynamic contention window for our protocol. We ensure that the contention window is not drastically changed. The DCW-MAC ensures that the nodes choose a correct contention window before sending the Data and thus avoid collision.

The rest of this paper is organized as follows. Section II discusses about the related work in this area followed by Section III where the basics of the proposed protocol is explained in detail. The simulation and analysis are discussed in section IV.

Finally, section V concludes the paper.

## 2. LITERATURE SURVEY

IEEE 802.11 is the standard protocol for the MAC and PHY layer of wireless LAN. Sensor-MAC (SMAC) is a popular energy efficient contention based MAC protocol [9,10]. It is developed in a special way to reduce power consumption. The most important technique used in SMAC protocol is periodic sleep and listen. The nodes sleep for a certain time and then wake up for transmission. Here, the complete cycle is divided into listen period and sleep period as in Figure 1.

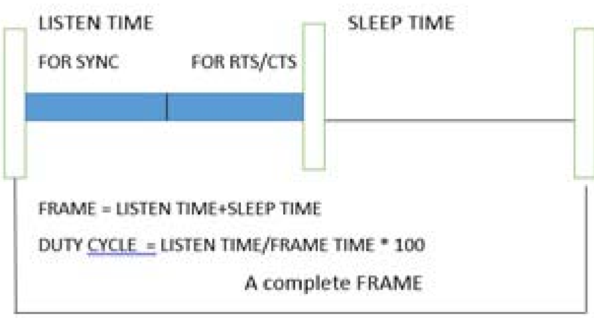


**Figure 1: SMAC periodic Sleep/Listen**

SMAC employs both virtual and physical carrier sense and RTS/CTS exchange. Each transmitted packet contains a field called duration field. Duration field tells how long the transmission takes place. When a node receives a data packet that is destined to another node, it uses the duration field of the packet and sets the timer to sleep. During the transmission, all the immediate neighbors of sender and receiver go to sleep on hearing the RTS/CTS packet till the transmission ends. Here, the node after defining the medium free for a DIFS or EIFS period calculates a random back-off time before transmission. If the node finds the medium to be free when the timer declines to zero, the node transmits. If it finds the medium busy, it continues to carrier sense for more than a DIFS period. The back-off time is calculated by,

$$\text{Backoff time} = \text{Random}\,(0, \text{CW}\,) \times \text{SlotTime}$$

Though SMAC is better for WSN, still there is some deficiency. We can see that SMAC uses random back off mechanism. The contention window which is used to calculate back-off time is fixed. The traffic in sensor network changes regularly. This creates a problem when the traffic is light; a high contention window may cause an unnecessary wait. This increases the delay as well as energy consumption. Moreover, the node needs to calculate the deferral time once again when the medium is busy. For the above reasons, it can say SMAC can't adapt to dynamic traffic. This may result in increased delay and higher power consumption.

Different works are done to modify the SMAC protocol. In [11] the contention window of the SMAC protocol is changed. It uses an adaptive contention window by using the node's way to contend for the medium and then using neighbor nodes competition. The RTS packet consists of the information regarding the competition faced by the sender node. The receiver node then uses the information to change its contention window. But in case the sender is source node it can never get any information from its neighborhood.

A DSMAC protocol is proposed by the authors in [8]. It changes the duty cycle as well as contention window. In the beginning, the node calculates a value that uses the number of packets in the queue. In case there are more packets in the queue the contention window is reduced so that the nodes can access the channel in a lesser time. It is a priority based access to the channel by the nodes having a higher number of packets. The duty cycle of the protocol is also changed by using the number of packets in the queue.

TMAC [7] dynamically defines the sleep time as listen time. If there is no transmission, the node goes to sleep. TMAC protocol has better latency in comparison to SMAC. Its main disadvantage is the early sleeping problem. Here the nodes may sleep as per their activation time and data may get lost when long messages are transmitted. An SMAC based proportional fair-ness scheme is used to evaluate the contention window. A shadow price is used to calculate the contention window. The shadow price depends on the number of nodes that are contending for the medium. But it does not provide more energy efficiency as SMAC.

WiseMAC performs better than one of the S-MAC variants [12]. Besides, its dynamic preamble length adjustment results in better performance under variable traffic conditions. In addition, clock drifts are handled in the protocol definition which mitigates the external time synchronization requirement. However, the main drawback of WiseMAC is that decentralized sleep-listen scheduling results in different sleep and wake-up times for each neighbor of a node. This is especially an important problem for broadcast type of communication, since broadcasted packet will be buffered for neighbors in sleep mode and delivered many times as each neighbor wakes up. However, this redundant transmission will result in higher latency and power consumption. In addition, the hidden terminal problem comes along with WiseMAC model as in the Spatial TDMA and CSMA with Preamble Sampling algorithm.

DMAC [13] achieves very good latency compared to other sleep/listen period assignment methods. The latency of the network is crucial for certain scenarios, in which DMAC could be a strong candidate. Disadvantages: Collision avoidance methods are not utilized, hence when a number of nodes that has the same schedule (same level in the tree) try to send to the same node, collisions will occur. This is a possible scenario in event-triggered sensor networks. Besides, the data transmission paths may not be known in advance, which precludes the formation of the data gathering tree.

However, from the energy efficiency point of view, SMAC still predominates as a better and simple algorithm. Thus we propose a protocol that modifies SMAC by choosing a dynamic contention window mechanism.

## 3. PROPOSED DCW-MAC PROTOCOL

We make two aspects of modifications in original SMAC protocol. The calculation of the contention window is done dynamically based on a formula,

$$CW = 0{:}5\ \ CW_1 + 0{:}5\ \ CW_2 \qquad (2)$$

It is ensured that the value of contention window is not changed drastically as well as it adapts with the network. The value of contention window varies within the range of $CW_{min}$ and $CW_{max}$. We de ne a parameter called TRANSMIT; if a packet is successfully transmitted it is set to 1 and 0 otherwise.

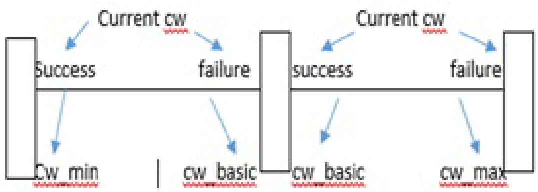


**Figure 2: Calculation of CW1**

## 3.1 The Algorithm for $CW_1$

In the proposed work, a new parameter $CW_{basic}$ is introduced. The value of $CW_{basic}$ is considered as same as the contention window of SMAC. It is used to have an information about the current traffic level in the network. If the value of current contention window is greater than $CW_{basic}$, heavy traffic in the network is assumed. Based on the level of network traffic the algorithm changes the value of the contention window $CW_1$ adaptively. It also considers the status of the last transmission attempt. If the last packet is successfully transmitted, then the $CW_1$ is minimized otherwise it would be increased. Here the boundary values are $CW_{min}$, $CW_{basic}$, and $CW_{max}$. As shown in figure 2, when the current contention window lies between $CW_{min}$ and $CW_{basic}$, on a success $CW_1$ is set to $CW_{min}$ and on a failure, $CW_1$ is set to $CW_{basic}$. Similarly, if the contention window lies between the $CW_{basic}$ and $CW_{max}$, the failure results in increasing the value of $CW_1$ to $CW_{max}$ and $CW_1$ is decreased to $CW_{basic}$ if the last transmission attempt was a success. Table 1 clearly depicts how the values are changed.

**Table 1: Working of $CW_1$**

| Value | Explanation |
|---|---|
| $CW_1 = CW_{basic}$ | Failed Previous time and current $CW < CW_{basic}$ |
| $CW_1 = CW_{max}$ | Failed Previous time and current $CW \geq CW_{basic}$ |
| $CW_1 = CW_{min}$ | Success Previous time and current $CW < CW_{basic}$ |
| $CW_1 = CW_{basic}$ | Success Previous time and current $CW \geq CW_{basic}$ |

## 3.2 The Algorithm for $CW_2$

$CW_2$ is modified according to two different formulae on the success and the failure of the transmission. For that, a new variable called $CW_{count}$ is introduced here that keeps track of the number of failures in the transmission of the data packet. $CW_2$ is initialized with $CW_{min}$. Each time a collision occurs the value of $CW_{count}$ is increased. The count can reach a maximum value of the threshold. After that, it is reassigned to zero. The formula for calculating $CW_2$ in case of a failure is calculated as:

$$CW_2 = CWmin \times \prod_{i=0}^{CW_{count}-1} \left(1 + \frac{\theta - 1}{\theta}\right)$$

Where θ is the threshold. Here it is trying to ensure that the contention window doesn't change drastically but changes smoothly. Similarly, in case of a success the contention window is given as:

$$CW_2 = CW_2 \times \left(\frac{CW_{count}}{\theta}\right)$$

The value of the threshold is set such that $CW_2$ should have a maximum value near to the $CW_{max}$. The above-mentioned two methods are used to calculate the contention window and both $CW_1$ and $CW_2$ carries equal weightage. $CW_1$ provides good range for the contention window and $CW_2$ ensures that it does not change drastically. In this way, contention window is calculated dynamically. This helps to provide a required waiting time depending on the traffic in the network.

# 4. SIMULATION RESULTS AND DISCUSSION

This section demonstrates the postulates of the proposed DCW-MAC and evaluates the performance by comparing it with SMAC. The simulation is carried out in NS-2. Three metrics are considered: throughput, delay and energy consumption for evaluation, first by changing the packet interval and then the number of nodes in the network. The simulation was carried when the nodes are considered to be static. The simulation parameters are given in Table 2.

**Table 2: Simulation Parameters**

| Parameter | Value |
|---|---|
| CWmin | 15 |
| CWmax | 127 |
| CWbasic | 63 |
| CBR packet Size | 200 (bytes) |
| CBR maxpkts | 1000 |
| Routing protocol | AODV |
| Initial Energy | 1000(J) |
| Transmit Power | 0.386(W) |
| Receive Power | 0.368(W) |
| Idle Power | 0.344(W) |
| Sleep Power | 5.0e-5(W) |

Two source - sink topology scenario is used for the comparison by changing the packet interval. The packets are transmitted from each source node at the 50th second after the start of the simulation. The simulation runs for 500 seconds. The traffic load is changed by changing the packet interval. Packet interval refers to the time gap between two successive packets from a source. The packet interval changes from 1 second to 10 seconds. Small packet interval causes higher traffic in the network. For accuracy each simulation is done for five times and the average is taken.

## 4.1 Comparison by changing the packet interval

By introducing the concept of the dynamic contention window, we can see that the performance of DCW-MAC is better than SMAC in the whole simulation. The nodes in DCW-MAC update the contention window as per requirement that ensures fewer collisions in the network. The graphs show the performance comparison of DCW-MAC and SMAC. Initially, when the traffic is high, i.e., the application packet interval varies from 1 to 4 second the throughput in SMAC is near about 50% less than that of DCW-MAC. Gradually when the packet interval is increased from 6 to 10 sec, the throughput in both the protocols decreases. The decline in throughput is greater in DCW- MAC, but still, it is higher than SMAC. The Throughput in SMAC is 25% lesser than that of DCW-MAC. This happens because data transmission occurs faster in the case of DCW-MAC than that of SMAC.

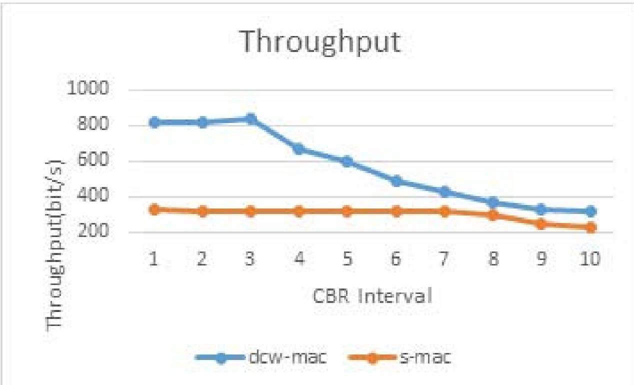


**Figure 3: Throughput v/s Packet Interval**

Figure 4 depicts the average end-to-end delay between the source and destination. Since DCW-MAC has the network traffic adaptive dynamic contention window, the end-to-end delay for the data packets is lesser than in the case of SMAC. At higher traffic, delay in SMAC is longer than that of DCW-MAC. The delay then further contracts and stabilizes in DCW-MAC. This would be because of the lesser number of collisions.

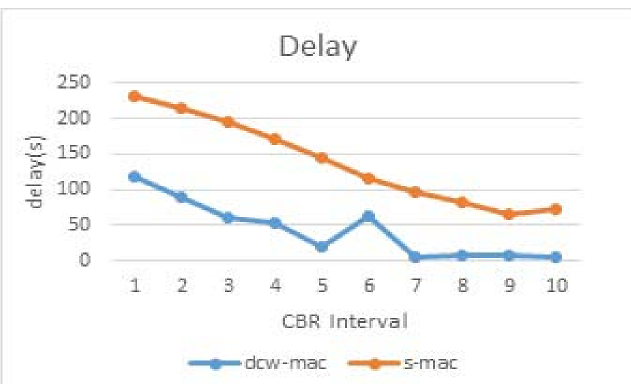


**Figure 4: End-to-End Delay v/s Packet Interval**

Energy consumption per bit is the amount of energy required to transfer a bit from the source to the destination. It is calculated as the ratio of total energy consumed to total bits transferred. The lower the value, the better is the energy efficiency. The energy consumed per bit in DCW-MAC is initially small, but gradually it increases. But when com-pared to SMAC it is lower. When the traffic is high (1 to 5 sec) the average energy consumed to transfer a bit is 40% lesser in DCW-MAC than SMAC. But gradually the energy consumption in DCW-MAC increases but still it is lesser than SMAC. In low traffic conditions, the energy consumed in DCW-MAC is 17% lesser than SMAC.

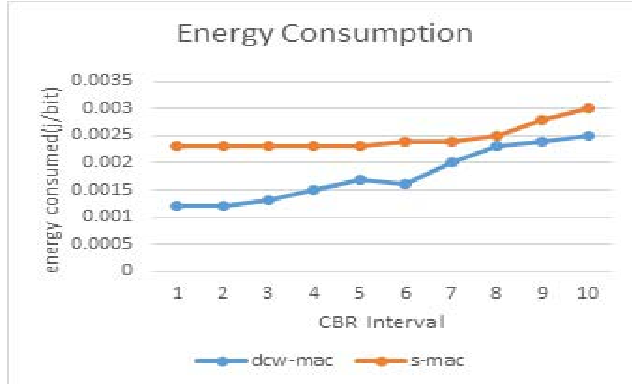


**Figure 5: Energy Consumption v/s Packet Interval**

## 4.2 Comparison by changing number of nodes

Here, evaluating the performance of both the protocols with different the number of node in the network. We number nodes were varied from 20 to 80 in the simulation. The CBR packets are sent at an interval of 2 seconds.

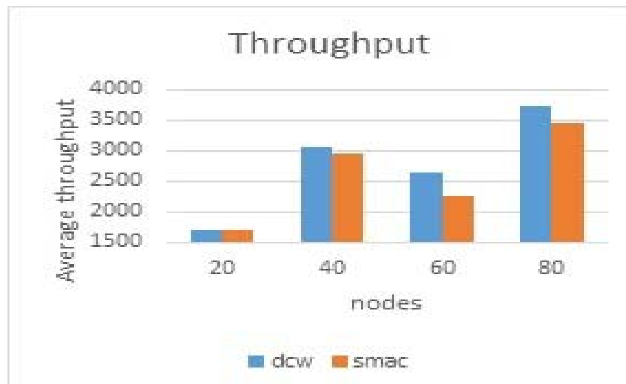


**Figure 6: Throughput v/s Number of nodes**

The total simulation time was 150 seconds. The other parameters remain same. When the number of nodes was fixed to be 20, throughput in case DCW-MAC was almost equal to that of SMAC. As the nodes were gradually increased the difference in throughput gradually increased, the percentage change in throughput is near about 10%. Similarly, in case of average end-to-end delay SMAC has more delay than DCW-MAC. When there are more nodes in the network, the difference in delay is also high.

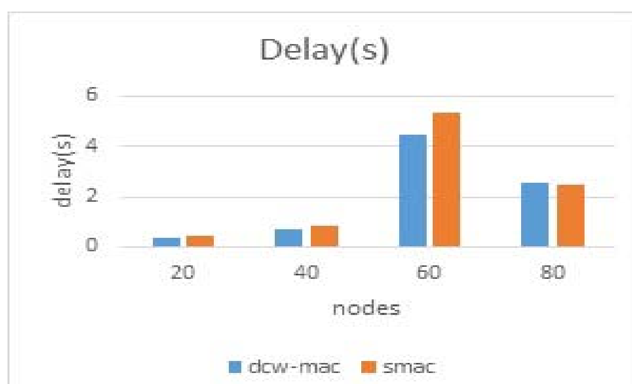

**Figure 7: End-to-End Delay v/s Number of nodes**

DCW-MAC has lesser energy consumption compared to SMAC. When the nodes were less than 40 the energy consumption per bit in case of SMAC was 5% more than DCW-MAC. But gradually when the number of nodes was in-creased to 80 energy consumption in the case of SMAC is increased up to 10% more than DCW-MAC. So DCW-MAC can consider being more energy efficient.

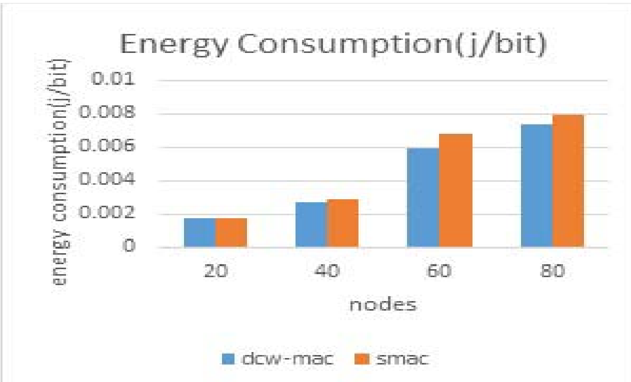


Figure 8: Energy Consumption v/s Number of nodes

## 5. CONCLUSION

In this paper, we put forward a new dynamic contention window based sensor MAC protocol DCW-MAC that changes the contention window as per the requirement in the network. This protocol was evaluated at different traffic level and for various topologies. Simulation results show that DCW-MAC performs better regarding throughput, delay and energy consumption. This variation of SMAC can be compared with other existing protocols for the parameters like throughput and latency.

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