MLC-MAC: A Multi-Layered Cluster-based MAC Protocol to Reduce Competition and Traffic in Wireless Sensor Networks

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ABSTRACT

Sensor nodes are broadcast in particular areas of the environment to identify events and establish wireless sensor networks. These sensor nodes have limitations such as power, memory and computational capability. Since medium Access Control sub-layer controls transmissions of the media and collisions, it has significant impact in reducing energy consumption and increasing the channel's efficiency. Therefore, the medium Access Control sub-layer plays an important role in wireless sensor networks. By allocating channel duty, media access control sub-layer can reduce collisions; these measures can reduce energy consumption and increase the productivity of the channel. In this paper, an improved medium access control protocol is proposed based on clustering technique. Using a multi-layered approach, this technique is intended to reduce competition and traffic in the network. The proposed algorithm consists of two steps including clustering and data transferring of each cluster. The proposed approach can significantly reduce collision, sleep-delay and idle listening. In order to evaluate the proposed algorithm computer simulation approach is used. The results of simulation show that the performance of the proposed protocol is more efficient than other existing protocols like ML-MAC in terms of the following features: number of successfully sent packets, number of collision, energy consumption and sleep-delay.

KEYWORDS

Collision, Delay, Medium Access Control, Wireless Sensor Network.

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are made of sensor nodes with limited capabilities which are distributed in specific areas and are used in many research fields such as industrial, military, environmental, health and home automation applications; WSNs can be used in these applications to collect data. These tiny sensors are also called "Nodes" which are able to sense and identify events and conditions of their environment in the nearby areas around themselves. The main goal of a WSN is to control the environment and identify the events. Each sensor node senses its surrounding events and then the processor of each node preprocesses data. Afterwards, the semi-processed data are sent through common media in multi-hops to the central node which is called sink. It should be noted that smaller hops known as multi-hops are considered to be more efficient than single-hops [Pesovic et al., 2010]. Also, the application of dense WSNs in large, remote and difficult-to-access areas requires keeping the size and cost of the sensor nodes as low as possible [Akyildiz et al., 2002].

Medium access control protocols manage the channel and determine which nodes at which time can be available in the channel. Wireless communication and broadcast feature between nodes of these protocols lead to collision occurrence in the system. Thus, sending and receiving data in sensor nodes, through the common media, result in the highest energy consumption. Controlling data transmission and data reception of a node in shared media is assumed to be the task of medium access control sub-layer. Therefore, medium access control (MAC) plays an important role in reducing energy consumption and consequently in increasing network life time. So, it can be argued that energy management is regarded as the most important responsibility of medium access control sub-layer [Akyildiz et al., 2002]. MAC sub-layer protocols in WSNs can be classified into wide varieties of classes based on, for example, how they access the medium, the number of available channels, etc [Brownfield, 2006]. With respect to channel assignment, medium access control protocols can be divided into two groups [Cordeiro et al., 2011].

- *Static channel allocation protocols: In these kind of protocols, certain channel capacity is already allocated to each node so that nodes can use the capacity exclusively. Three examples of these protocols include Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA) and Frequency Division Multiple Access (FDMA) [Brownfield, 2006]. Avoiding energy loss, reducing collision and idle listening are the main advantages of these types of protocols. However, lack of flexibility for different network conditions is the major disadvantage of these protocols; indeed, it would be much better if the Medium*

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Access Control protocol could apply a different method based on nodes traffic and different conditions. In fact, when there are fixed or small numbers of sensor nodes, these protocols work more efficiently [Cordeiro et al., 2011].

- *Dynamic channel allocation protocols: in the fixed allocation method, channel capacity is allocated uniformly to all nodes in the network regardless of the activity and traffic levels of the nodes. However, this method was based on the consideration of those nodes which were ready to transmit data and it was appropriate for node persistence to channel assignment [Cordeiro et al., 2011]. According to the evaluations of [Zhou et al., 2006], two major problems of this method is related to save energy and network life time.*

Energy, computational and memory resources of the sensor nodes are usually limited. Therefore, simplicity and low energy consumption are critical requirements and important features in the design of WSN protocols. With respect to such limitations of sensor nodes, fixed allocation and dynamic allocation protocols are inappropriate for wireless sensor networks. For instance, in the fixed allocation protocol the capacity of the channel is allocated uniformly to all the nodes of WSN without considering the state or the traffic parameters of the node. Therefore, MAC sub-layer protocols must be designed so that they can prevent and reduce the sources of energy waste. For instance, typical sources of energy loss in WSNs include idle listening, frame collisions, protocol overhead, and message overhearing [Cordeiro et al., 2011]. One of the significant reasons in WSNs energy loss is collision [Akyildiz et al., 2002].When two or more nodes simultaneously try to transmit data, collision occurs; hence, receivers may not be able to decode the packets correctly. Thus, by sending and receiving faulty packets, the limited energy sources of senders and receivers are wasted. In fact, this is the case with hidden stations because the sender nodes could not identify each other.

The next cause of energy loss in WSNs is idle listening [Jang et al., 2013]. Idle listening occurs when a station or node in the WSN listens to common medium while there is no packet in medium. Therefore, the sensor node will be idle for a long time and its energy will be wasted. Static sleep scheduling, dynamic sleep scheduling, preamble sampling, and off-line scheduling are some methods which have proposed to reduce idle listening.

Overhearing is known as another reason to energy loss [Kredo et al., 2007]. When a sensor node receives a packet which belongs to a different node, overhearing occurs which results in the extra energy consumption. Broadcasting features of WSNs is the main reason of overhearing.

Also, before data transmission in common media, nodes usually send control packets. Thus, high overhead is imposed on the network in case there is a heavy traffic and hence high levels of energy will be wasted [Cordeiro et al., 2011; Yadav et al., 2009].

With respect to computer networks, medium access control protocols with appropriate changes can be used in WSNs. Therefore, medium access control protocols for WSNs can be divided into the following three strategies [Cano et al., 2011]:

- *Common activity protocols: In these protocols, nodes have the same sleep/listen periods. A sensor node has to wait for the next wake-up period to send data. In case there is a hidden station, collision will occur. When a node is in common with two non-neighboring nodes, the common node is called hidden node. In such protocols, nodes need to have accurate time synchronization [Cano et al., 2011]. PAMAS [Raghavendra et al., 1999], SMAC [Ye et al., 2004], TMAC [Dam et al., 2003], BMAC [Polastre et al., 2004] and CL-MAC [Hefeida et al., 2013] algorithms are examples of these protocols.*
- *Schedule-based protocols: These protocols control media access through the use of scheduling. Sensor nodes are assigned to specific slots in a frame to transmit and receive data packets. Therefore, nodes have to wake up only in those slots; otherwise, they will sleep. Before sending data to a neighbor, a node should know the time slot in which a neighbor will be awake. Since nodes are not allowed to compete with each other, the probability of collision will be reduced. Most of these protocols are used from a variety of Time Division methods. High overhead is due to timeslot creation and their maintenance and synchronization is considered as short coming of these protocols [Cano et al., 2011]. SMACS [Sohrabi et al., 2000], TRAMA [Rajendran et al., 2003], LMAC [Van et al., 2004] and DMAC [Lu et al., 2004] are some examples of schedule-based protocols.*
- *Asynchronous protocols: This type of protocols does not require synchronization since nodes sleep and listen independently. These protocols perform different methods to ensure that they are awake. They can be divided into preamble sampling and receiver-initiated approaches. The advantages of this type of protocols are low cost and low complexity; these merits are attributed because these protocols do not require timing and its distribution. Also, energy consumption in these protocols is reduced due to low network traffic. However, high overhead, costly collisions, overhearing and incompatibility with new radios are regarded as main drawbacks of these*

protocols [Cano et al., 2011]. Wise MAC is an example of this type of protocols [Elhoiydi et al., 2004].

All the above-mentioned protocols and other similar protocols deal with problems with respect to save energy and network life time. Energy and life time are the most important constraints in WSN research field [5]. In this paper, in order to improve WSNs performance, two different but remarkable techniques have been used called clustering and layering. Competition reduction is the major advantage attributed to clustering [Abbasi et al., 2007]. Thus, using clustering method, an attempt will be made to reduce the density of nodes. Moreover, using layering technique node time within each cluster will be layered so that the density of nodes in each layer, collision and, consequently, energy consumption will be further reduced in contrast to other methods.

The remaining sections of this paper are organized as follows: the second section of the paper will describe new Medium Access Control protocols; then, in section three, the proposed approach will be explained; section four will explain the simulation and then the performance of the proposed algorithm will evaluated. Eventually, the conclusion to the study will be given in section five.

2. RELATED WORK

In this section, some recently proposed algorithms are described and reviewed. As a case in point, S-MAC protocol is one of common active-period protocols. It is used in several ways for reducing energy consumption, overhead and controlling delay. Also, it is used for periodic listening in which listening and sleeping durations are fixed. In this protocol, sensor nodes which are ready to transmit data wait until the active period starts. Due to periodic sleeping, delay will increase; therefore, adaptive listening is used in this protocol for resolving this problem. Furthermore, this protocol is used in message passing form for a better overhead reduction. Nodes freely determine their own listening and sleeping duration. Each node exchanges its schedule with those of neighboring nodes in the synchronization time. Protocols with common active-periods have a cost which is associated to the creation and maintenance of schedule. The main problems of S-MAC protocol are delay and fixed-duration listening [Ye et al., 2004].

T-MAC or Time-out MAC is based on the S-MAC protocol. This protocol introduces an adaptive listening/sleeping period and variable active-period to minimize idle listening and improve energy efficiency. In this protocol, a sensor will sleep if no activation event occurs for a while. Thus, reduction of idle listening and adaptation to traffic fluctuations are advantages of this protocol. Nevertheless, this protocol has a drawback called early-sleeping; Future request-to-send and take priority on full buffer are regarded as the solutions proposed by T-MAC protocol for these problems [Dam et al., 2003].

ML-MAC protocol is one of common active-period protocols. After the distribution of network nodes, each node randomly selects the layer. Nodes publish their schedule and store their neighbor schedules in their own timetables. Time is divided into several frames and each frame has listening and sleeping periods. Listening period is known as the duration of activity and is divided into L layer without overlapping. Short activity duration makes nodes spend more time in the sleeping period; therefore, this is regarded as a disadvantage for this protocol. Multi-layered active period and shorter duty cycle are solutions for reducing energy consumption and network traffic and increasing network lifetime as well [Jha et al., 2011].

R-MAC protocol introduced in [Tan et al., 2012] as a schedule-based protocol. Being receiver-driven is the main characteristic of this protocol. No collision occurs in the transmissions in this protocol and nodes do not need to publish control messages before sending data as well. Consequently, energy consumption is reduced. R-MAC protocol has three phases, i.e. neighbor discovery, timeslot allocation and scheduled data transmission. Also, the techniques of this protocol are Timeslot Stealing and Timeslot Reassignment. Timeslot stealing has been proposed for dealing with schedule-based protocols in which there are several timeslots in each frame for each node. Timeslot reassignment has been proposed to improve efficiency of the channel. After passing N frame, the receiver nodes redistribute timeslots considering the sender’s traffic load.

MC-LMAC protocol is a multi-channel MAC protocol without central scheduler that has been proposed in [Incel et al., 2011] to improve wireless sensor networks throughput. In this protocol transmissions are parallel and collision is improbable as well. Multi-channel Light-weight MAC protocol makes use of semi-dynamic channel allocation; In other words, the fixed channel is allocated to nodes but channel change is possible. Also, split-step is used in this protocol which includes control and data exchange phases. All nodes are switched to a common control channel and negotiate with their desirable receivers about channel possession during the control phase. Medium access in control phase is based on scheduling. In addition to clash problem, since nodes are frequently switched between channels, overhead probability increases. However, timeslot length is adequately large for switching time.

TDMA is a schedule-based protocol which proposed in [Pantazis et al., 2009]. This protocol aimed to establish a balance between energy consumption and end-to-end delay. Gateway node gathers connection information and creates the TDMA frame and then broadcasts it. Each node in this protocol executes the setup and energy storage stages. A Node is awake when it is sending a packet; then, it sends the wakeup message; all nodes will stay awake in the path until gateway receives this message and then the data exchange is completed. Therefore, end to end delay and power consumption are reduced.

AS-MAC is known as an energy efficient asynchronous protocol which makes use of duty cycle and low power listening. Nodes store neighbors' wakeup times in an uncoordinated manner. Control packet should be sent to each node at the awaking times which is considered as main disadvantage of AS-MAC protocol. AS-MAC protocol has initialization and listen/sleep periodic phases. When a new node is connected to the network, it makes a neighbors' table which stores the information of the neighbor nodes in it. Then, each node will determine the offset of periodic wakeup and broadcast it. Finally, node enters the listen/sleep periodic phase. AS-MAC reduces power consumption, idle listening, delay, and packet loss. Nevertheless, the need for a memory, in order to store neighbors' scheduling tables, and also publishing overhead are regarded as the disadvantages of AS-MAC [Jang et al., 2013].

In [Bhatia et al., 2013] A. Bhatia has proposed TRM-MAC protocol a TDMA-based reliable multicast MAC which is a framework for reliable multicast transmission in WSNs. It works on top of a Multicast Spanning Tree (MST) rooted at the base station. This protocol consists of Channel access mechanism for data transmission, ack/nack messages, MAC-frame structure establishment, ARQ mechanism to support link layer feedback, and retransmission and Sleep/wakeup schedule to save energy of nodes. TRM-MAC protocol has tried to improve the reliability performance of multicast communication while ensuring low access delay.

T. Dinh et al. in [Dinh et al., 2016] have proposed a wake-up time self-learning MAC (L-MAC) protocol. In this approach a receiver-initiated MAC protocol enable child nodes to coordinate their wakeup time with their parent node. This protocol does not require synchronization or exchanging schedule information, so that when a child node has data packets to send, it can send packets rapidly. The main advantages of this protocol are including: no extra transmission overhead, it resolves sleep latency problem, nodes can save more energy, and also packet delivery latency is reduced.

3. THE PROPOSED PROTOCOL

Broadcasting is in the nature of WSNs. Therefore, collision occurs while transferring data. As a result, medium accessibility in sensor nodes should be controlled. In the proposed approach, an attempt will be done to reduce competition between neighboring nodes to improve MAC efficiency. For this purpose, using cellular clustering, we have proposed an approach based on multi-layer control to reduce competitions and collisions. It is predicted that if sensor nodes are not in the same transmission layers, a significant improvement can be observed in network evaluation parameters such as energy consumption. Provided that non-adjacent nodes are in the same layer, collision will not occur in simultaneous transmissions; this is attributed to the fact that they are not in the same range. This protocol reduces power consumption by considering the number of sent packets and minimizing latency and collision. ML-MAC is a new MAC protocol which was described earlier in review of the related literature; however, it has some notable disadvantages. ML-MAC is a multi-layer MAC protocol in which nodes choose a layer randomly for transmitting data; consequently, reduced energy consumption, low average traffic and extended network life time are achieved. Nevertheless, the main disadvantage of this protocol is unable to separate adjacent and non-adjacent nodes and this is the main weak point of the protocol. So, it is possible that adjacent nodes would be in similar layers and non-adjacent nodes would be in different layers. Therefore, as soon as an event is detected in the region, all the adjacent nodes want to send data and a significant amount of exchanges in the same layers will occur and lead to collision. Thus, we intend to reduce the number of adjacent nodes which are working in the same layer. In the method proposed in this paper, network will be divided into some separate cells and hence, the competition between adjacent nodes will be reduced through adopting a local decision.

The proposed algorithm consists of two steps: clustering and data transferring of each cluster. Figure 1 shows a period of the proposed approach. Figure 2 illustrates the general procedure of the proposed approach. In the following sections, the two steps of the proposed algorithm will be explained in detail.

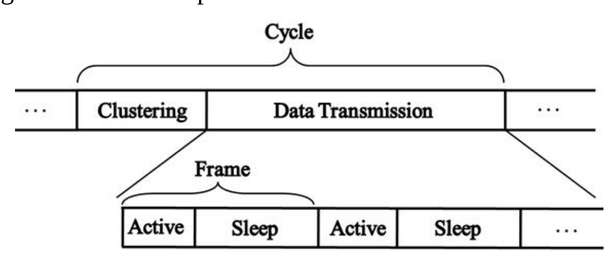

Figure 1. One phase in a cycle of the proposed approach

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Clustering and selecting a cluster-head for each cluster;
For all cluster Ci do  that 1≤ i ≤9
    For all nodes in cluster Ci do
        Node Nj selects a layer between 1 to L;
    EndFor
    For all nodes in cluster Ci do
        Investigate the neighborhood nodes' layer;
        If there are two nodes in a same layer then
           One of the nodes should change its layer;
        EndIf
    EndFor
EndFor
Data transferring by clusters;
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Figure 2. General procedure of the proposed approach.

3.1 Clustering Phase

Clustering is performed in three modes that include: when network topology is changed, when network is extended for the first time, and when a period of activity is completed. A simple cell clustering algorithm is used at this stage. Since power consumption in the transmission phase depends on the distance between the transmitter and receiver, so we preferred to use several parameters for selecting the proper cluster-head in order to reduce energy consumption while exchanging data between cluster-head and sink. Therefore, the considered parameters in selecting the cluster-head include: remaining energy, distance of the node from sink, and average distance between the candidate node and all other nodes. As Figure 3 shows, the first node in each cluster is awake until the members of each cluster are determined. Then, the node which has the shortest distance from the sink is selected as the cluster-head. The selected cluster-head's remaining energy should exceed the energy of the specified threshold. Next, cluster-heads publish their own unique CDMA code so that data transfer in each cluster does not collide with other clusters. Then, nodes within each cluster select a random layer between 1 and L. Nodes will exchange their selected layer with those of their neighbors within each cluster. Two adjacent nodes do not inform the cluster-head same events at the same time and do not compete with each other for sending data. Therefore, if two neighbor nodes select the same layer, one of them will change its layer. This is one of the advantages of the proposed protocol. That is, the same packets by two adjacent nodes at the same time will not collide with each other.

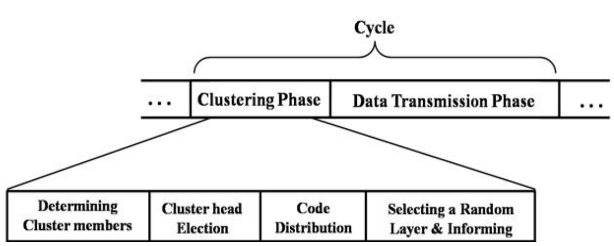

Figure 3. Clustering phase in the proposed algorithm

In order to improve ML-MAC protocol performance, in this paper we obtain T_f, t_1 and L parameters using (1), (2) and (3) equations which they have been mentioned in [21]. The number of layers (L) is obtained in three steps. During the First step, the frame duration (T_f) is calculated which is obtained through Eq. (1). In the equation, T_N denotes network life time, T_R stands for maximum response time delay, N_f refers to the number of frames, and t_1 represents the listening period for one layer. During the second step, the listening period per layer t_1 is calculated, that also Eq. (2) obtained at the end of this step. In Eq.(2), τ_p stands for propagation delay, τ_d is clock drift delay, W denotes maximum number of reservation slots, C refers to battery capacity and represents average output voltage of the battery, and ρ is node power consumption. Finally, the third step estimates the number of layers L. The result of this step is given by Eq. (3). Where λ_{avg} refers to the average traffic generated per frame in each layer, τ_t stands for packet transmission delay, T_f denotes frame duration and t_2 is guard time between layers. After the clustering phase, Network nodes enter the data transmission phase.

$$\frac{T_N}{T_R} \leq N_f < \frac{T_N}{t_1 \times L} \quad (1)$$

$$t_1 + \tau_\rho + 2\tau_d + W\tau_\rho < t_1 \leq \frac{C \times \nu}{p \times N_f} \quad (2)$$

$$\frac{\lambda_{avg} \times (\tau_t + \tau_p + 2\tau_d + (W/2)\tau_\rho)}{t_1} \leq L \leq \frac{T_f}{t_1 + t_2} \quad (3)$$

3.2 Data Transmission Phase

In the proposed protocol, competition is reduced due to the inherent properties of clustering; we predict that the proposed approach will increase the probability of successful transmissions. With this approach, all nodes randomly allocate their own layers. The Layer means a fixed time limit that each node allowed to do data transmission operation in the medium. When a new node joins the network, it chooses a layer randomly at its cluster and broadcasts its schedule to other nodes of the cluster. In order that any node in the network be aware of the listening time of other nodes that are working in different layers, each node maintains a schedule table which stores schedules of all other nodes. In order to improve network performance, we have tried to make the medium access control in each cluster become independent of the other clusters. Thus, control is performed parallelly and locally in this method; to achieve this goal, in the proposed approach, layer controlling was provided for each cluster. Therefore, network nodes are placed randomly in different layers during the set-up stage of the network and only the nodes in the same layer will compete with each other. Thus, the number of nodes in each layer decreases; there is little competition and when the number of layers is great, only one node may be present in each layer. As a result, packet collision rate decreases and in some cases it is close to zero. Figure 4 shows data transmission phases in each cluster and activity period layers. Time in the proposed method is divided into frames and each frame includes two periods: listening period and sleeping period. The active period is subdivided into L non-overlapping layers where the length of each layer is t_1. In this protocol, Nodes in each cluster wake up only in their assigned layer.

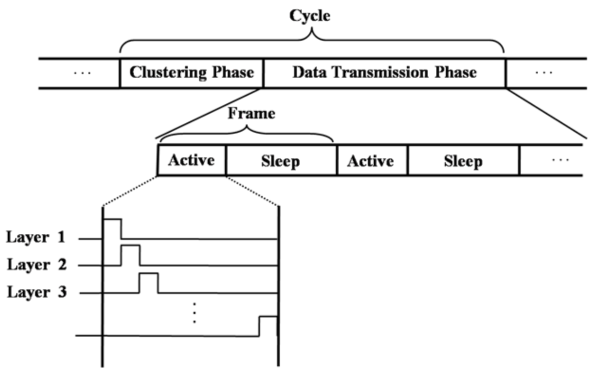

Figure 4. Data transmission phase in the proposed algorithm.

Cluster-head nodes stay awake while their members are transmitting and receiving their information. The cluster-head node starts sleep period if no activity occurs in the layers. Then, cluster-head nodes send their received data to the sink in a scheduled and single hop manner while the member nodes are in the sleep mode.

4. SIMULATION RESULTS

In order to evaluate the proposed algorithm's performance, we have used computer simulation method. The proposed protocol and ML-MAC protocols were simulated in Matlab software. In order to make accurate comparisons, all the assumptions mentioned in [Jha et al., 2011] have been considered in simulating the proposed protocol. Table 1 summarizes the values for the parameters chosen for the simulations.

Table 1. Values for the parameters chosen for the simulation

Parameter	value	unit
Average packet inter-arrival time (T)	2-11	S
Number of access layers (L)	1-10	
Number of nodes (n)	100	
Frame duration (T_f)	1000	Ms
Layer duration (t_1)	300/L	ms
Node transmitting power	24.75	mW
Node listening power	13.5	mW
Node sleeping power	15	μW
Simulation time	200	s
Nodes initial power	2	j

The simulation time was 200 seconds and the number of nodes was 100 for all the experiments. In the experiments, in case the length of each packet is 38 bytes, the inter-arrival time between two successive packets will be the random variable T which ranges from 2 to 11.

Simulation results presented in the following subsections are the average of thirty execution times and each execution is for different topologies. Figure 5 shows an example of a WSN which was simulated in Matlab environment. The position of sink was characterized by 150*150 dimensions and was fixed at the center of the environment. Sensor nodes were randomly distributed in the environment. There were nine fixed clusters. A node was chosen as the cluster-head if it was the nearest node to the sink in the cluster and its power was more than threshold level. Cluster-heads were marked with a black color in Figure 5.

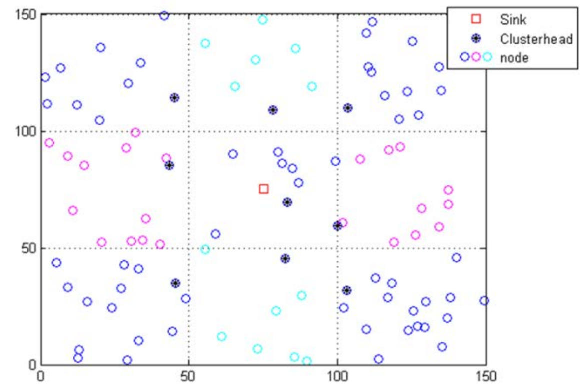

Figure 5. Simulated wireless sensor network

The main advantage of the proposed hierarchical and multi-layer protocol is that it covers all the events which occurred within the network. Therefore, the number of successfully transmitted packets in the proposed protocol is significantly high which will be discussed in the next subsection. In order to examine and verify the accuracy and efficiency of the operation of the proposed method, we compared it with ML-MAC approach with respect to several parameters. The parameters are including: number of sent packets, power consumption, delay, and collision.

4.1 Sent Packet Analysis

When the number of layers is limited and small, there will be more nodes in each layer of the ML-MAC protocol; therefore, due to high competition, fewer nodes will be able to send their packets. However, in a clustering-based approach, separate layers are assigned to sensor nodes of each cluster; thus, it is possible to assign one layer to each node in high number of layers. In this way, since there is no competition, more production packets will be sent and more nodes will successfully send their packets in the total simulation time. Figure 6 shows the number of successfully sent packets with a variable number of layers. Message inter-arrival time is fixed, λ=0.2. The amount of message inter-arrival time is gathered according to Eq. (4), T=5. Hence, the total number of generated packets during the simulation time is 40 packets for each node. Table 2 illustrates the significant difference in the number of sent packets in the both methods.

$$\lambda = 1/T \qquad (4)$$

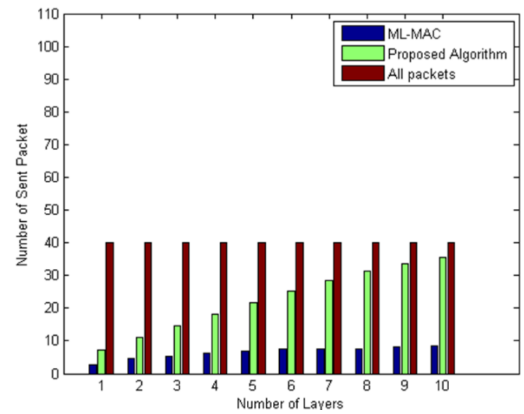

Figure 6. The average number of sent packets under fixed traffic, T=5.

Table 2. The number of sent packets in ML-MAC and the proposed methods.

Number of layers	1	2	3	4	5	6	7	8	9	10
all packets	40	40	40	40	40	40	40	40	40	40
ML-MAC	2.79	4.65	5.43	6.33	7.02	7.56	7.63	7.71	8.35	8.51
Proposed method	7.32	11.1	14.17	18.3	21.8	25.2	28.3	31.2	33.5	35.5

The number of successfully sent packets according to the message inter-arrival time is also depicted in Figure 7. The number of layers is considered to be constant and equal to three. The probability of collision increases as the traffic becomes high and heavy in both protocols. Therefore, fewer nodes will be able to send information. Also as the traffic increases, the number of collision decreases and the number of successfully sent packets increases as well. Nevertheless, we observed that the proposed method has better performance in contrast to the ML-MAC protocol; this higher performance is attributed to hierarchical method of the proposed approach. Table 3 presents detail values of the experiments.

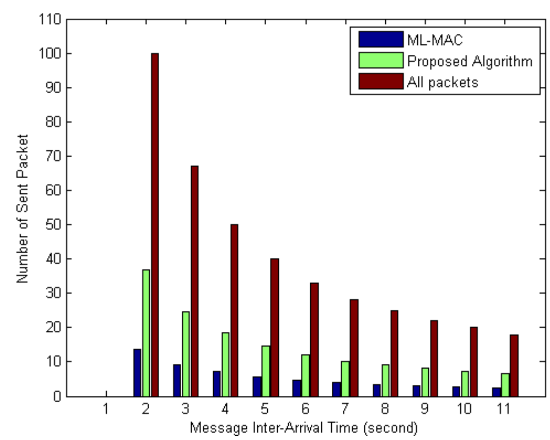

Figure 7. The average number of sent packets with fixed layer, L=3.

Table 3. The number of successfully sent packets according to various message inter-arrival times.

message interval time	2	3	4	5	6	7	8	9	10	11
all packets	100	67	50	40	33	28	25	22	20	18
ML-MAC	13.6	9.25	7.14	5.5	4.76	4.05	3.48	3.17	2.82	2.52
Proposed method	36.7	24.6	18.3	14.7	12.1	10.3	9.18	8.07	7.34	6.6

4.2 Analyzing Power Consumption

As shown in Figures 6 and 7, the number of successfully transmitted packets in the proposed protocol was more than ML-MAC protocol during 200 seconds of the simulation. Thus, it can be argued that the power consumption of the proposed method is higher. The total power consumption of each node is obtained by the sum of energy spent in listening mode, transmitting mode, and sleeping mode. Like the work has been done in [Jha et al., 2011], power consumption for the three modes were supposed to be 13.5mW, 24.75mW and 15μW respectively. Figure 8 compares the average energy consumed by a node for ML-MAC and the proposed protocols when L=3 and fixed traffic (T=5). As it can be seen, the energy consumption in the both methods are similar; it should be noted that, according to the section 4-1 results, considering the higher number of successful sent packets in the proposed method the energy consumption will be higher as well. In addition to the higher number of unsuccessfully sent packets in the ML-MAC protocol, it also spends more energy for listening and resending packets. Thus, generally in the proposed protocol more packets are transmitted with approximately equal consumption of energy. Fewer nodes in each layer, decreased competition, and delay are features of the proposed method. So, power would be stored for resending and controlling packets.

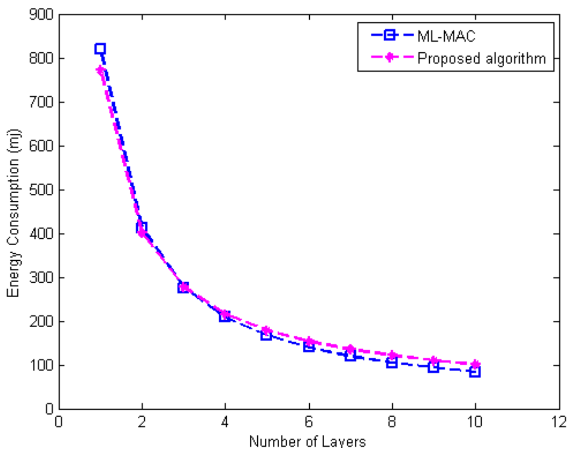

Figure 8. The average amount of energy consumption at fixed traffic, T=5.

Figure 9 illustrates the average energy consumption for each node with different message inter-arrival times. The number of layer in this experiment was intended to be three. Since it sent more packets at high traffic, energy consumption of the proposed algorithm was higher than the ML-MAC protocol. The energy consumption will decrease by reducing the traffic in the proposed protocol.

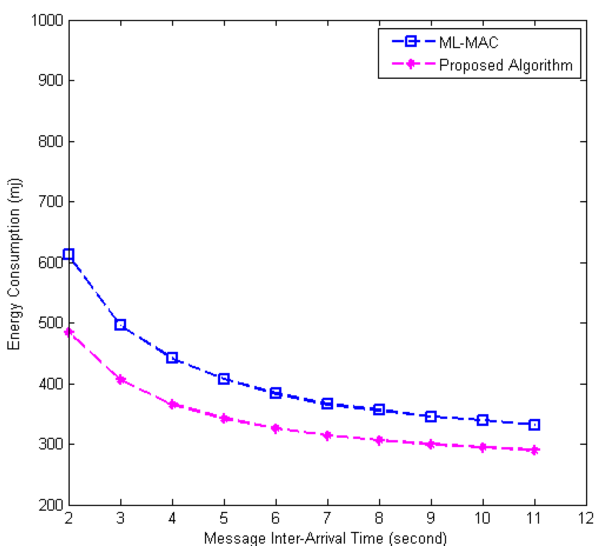

Figure 9. Average energy consumption for each node with fixed layer, L=3.

4.3 Delay Analysis

Delay refers to the latency which a packet may encounter since it is stored in the transmission buffer of node until it is sent successfully without a collision to its destination. Hence, in ML-MAC protocol, delay is caused by two factors: the first factor is related to Queuing delay that is a packet could be existent in the buffer of a sleeping node. The second factor is sending delay which it refers to the time that a node waits until its layer enables. It should be noted that the sending delay compared to the queuing delay is negligible. Packets are transmitted with less delay in lower layers. In contrast, packet latency increases by increasing the number of layers. Figures 10 and 11 demonstrate the average delay for the sent packets under fixed traffic with variable layers and fixed layer with variable traffic respectively. Sent packet delay increases as the number of sent packets increases. Thus, delay in the proposed protocol is higher than the ML-MAC protocol. As the number of sent packets is greater, the average queuing delay of them will become higher.

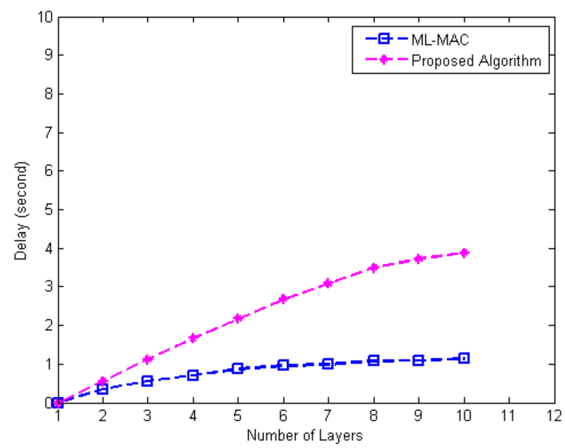

Figure 10. Average sent packets delay per node in fixed traffic, T=5.

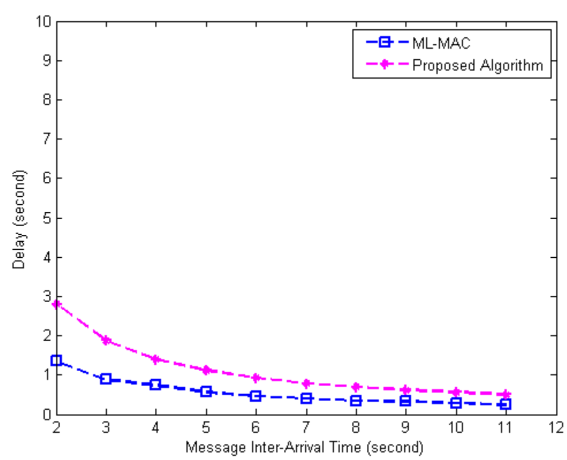

Figure 11. Average sent packet delay with fixed layer, L=3.

There is another definition for delay which refers to the wait time of packets for next frame since they could not be sent in the current frame (wait for next frame in order to retransmission). We have evaluated the proposed algorithm from this point of view as well.

Figures 12 and 13 demonstrate the waiting time in different layers and different traffic, respectively. As it can be seen, due to the more successful sending of packets, the amount of waiting time in the proposed method is less than ML-MAC.

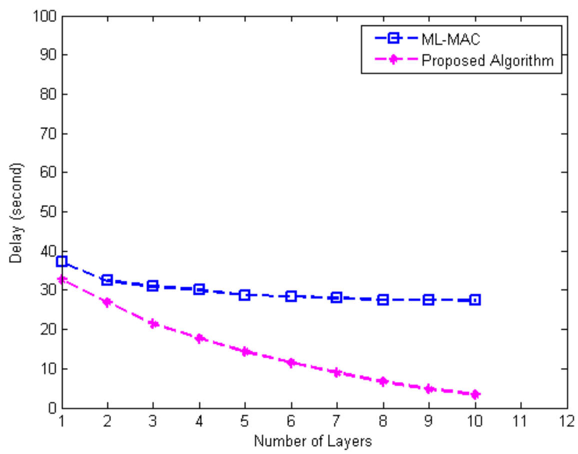

Figure 12. Average delay for retransmitting packets per node in fixed traffic, T=5.

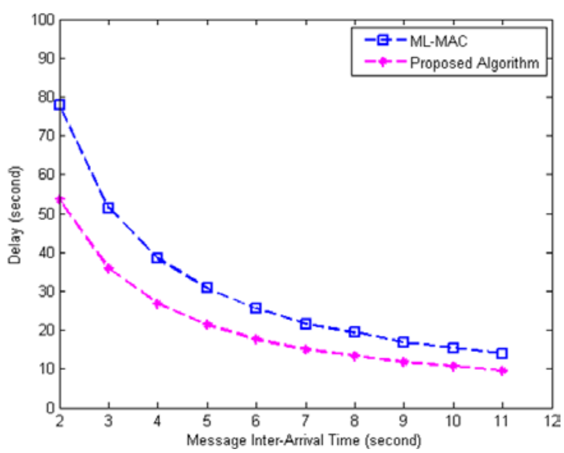

Figure 13. Average delay for retransmitting packets with fixed layer, L=3.

4.4 Clustering Phase

Collisions will occur when several nodes try to access a common medium at the same time. ML-MAC protocol reduces the number of nodes in each layer and hence the number of collisions will be reduced in comparison with the S-MAC protocol. With respect to the proposed method, since further number of competitive nodes is reduced within each layer and even sometimes there is no need to competition, the collision rate will decrease significantly. Figures 14 and 15 illustrate and compare the collision rate between two algorithms under two different situations. In the experiment related to figure 14, we have considered that the number of layers is fixed and equal to 3. As it can be seen in figure 14, in the proposed algorithm the number of collisions are fixed and near to zero. As shown in figure 15, after about 6 layers, the collision decrease will stop since request for packets is distributed among layers; as a result, the probability of collision for this type of traffic is reduced and near to zero.

In the two figures, the differences are remarkable. Because, in the ML-MAC protocol the competition is among further number of nodes while a much smaller number of nodes compete in the proposed protocol. As a result, in the proposed algorithm the number of packet collisions is significantly reduced and the number of successful sent packets is increased. Table 4 and table 5 show the detail values related to the figures 14 and 15 respectively.

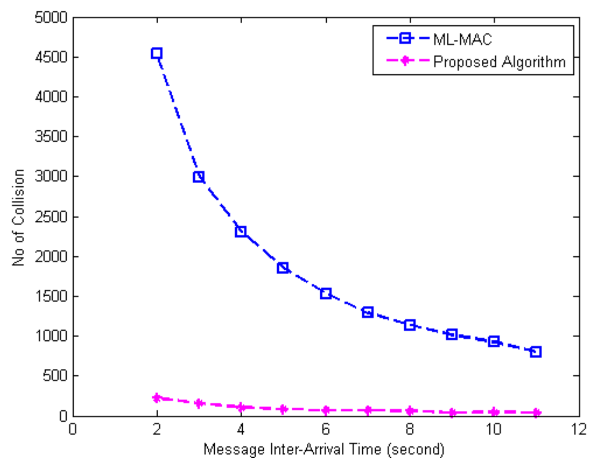

Figure 14. Number of collisions in fixed layer, L=3.

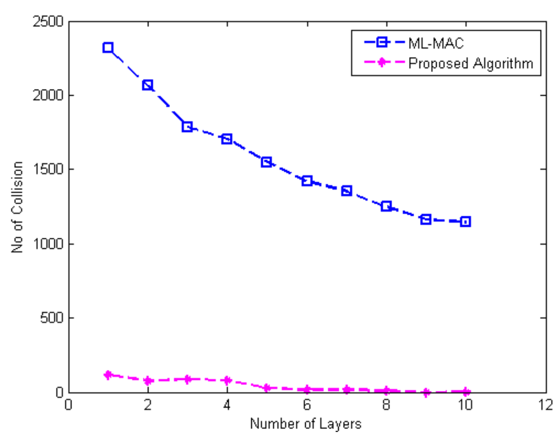

Figure 15. Number of collisions in fixed traffic, T=5.

Table 4. Number of collisions in fixed layer and various traffic loads.

message interval time	2	3	4	5	6	7	8	9	10	11
ML-MAC	4541	2994	2307	1852	1531	1287	1133	1014	925.4	800.1
Proposed method	219.5	156.8	103.8	84.17	72.9	68.47	58.63	43.07	47.9	38.47

Table 5. Number of collisions in fixed traffic and various number of layers.

Number of layers	1	2	3	4	5	6	7	8	9	10
ML-MAC	2315	2063	1788	1703	1547	1418	1352	1249	1161	1145
Proposed method	115.5	74.4	88.97	81.6	29.17	16.5	15.8	8.533	0	1.5

5. CONCLUSION

Sensor nodes in Wireless Sensor Networks (WSNs) have notable limitations such as power supply, processing and memory. Medium access control sub-layer manages node access to common medium. Thus, it is concluded that this sub-layer plays a significant role in saving energy. Indeed, researchers are trying to design energy-efficient protocols in order to increase the network lifetime. To resolve the problems of existing approaches, in this paper, we introduced a new algorithm for MAC sub-layer; this algorithm combines techniques of layering and clustering. Simulation results indicated that the proposed approach reduces delay and collision significantly. Also, the majority of occurred events in the network are sent to the sink. Whereas the power consumption of nodes in the proposed method is spent for sending packets, energy in the ML-MAC protocol is spent for resending packets and listening to channel.

In the proposed approach, multi-layered and clustering methods have been used. The clustering approach has a cellular and fixed structure. We can use smarter and adaptable clustering approaches to reduce energy consumption, collision and delay in future works.

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