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Design and Analysis of Energy Efficient MAC Protocol for Wireless Sensor Networks

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Abstract: For wireless sensor networks reducing the consumption of energy source has turn primary motivation for researcher. Energy efficient measures are essential at node level as well as process level in order to achieve fast transmission, minimum delay and least energy digestion. In wireless networks, radio operation is responsible for maximum energy breakdown. The MAC layer primarily handles channel and radio communications. The work carried in this paper, mainly proposes a novel scheme MD-SMAC (Modified Sensor MAC) at MAC layer that results in minimization of energy consumption in the wireless sensor networks. Our proposed scheme basically emphasize on sleep and listen schedules of the sensor nodes specially the periodic synchronization phase. Moreover, unlike SMAC, the nodes set aside in communication need to wake up less frequently allowing energy conservation in remaining sensor nodes. It results in preserving not only energy constraints but also packet delivery, throughput and delay. For simulation we have used NS2.35 tool and the experiment at ion results reveals the MD-SMAC scheme as effectively enhancing energy efficiency over S-MAC and demonstrate the enhancements by representing significant performance.

Keywords: MD-SMAC protocol, Energy Efficiency, SYNC Period, Wireless Sensor Network

I. INTRODUCTION

Due to hysterical transformation in technology as well as in low cost hardware accelerate the upcoming and growing application of wireless sensor networks practice as special-purpose networks. The remote area monitoring and tracking for the sake of data collection, security and observations leads the deployment of sensors in ad hoc manner co-operating together for sharing the common medium in the network. These networks are best suited to the applications requiring unattended deployment surviving on limited battery source in remote area for target tracking/ detecting.

The network foundation comprises collection of sensors along with a base station and radios are elementary body for communication between sensors in combination with base station. To accomplish data from the scenario, applications use the base station as a gateway of the sensors. The gateway (base station) is generally equipped withuninterrupted power supply on the other hand sensors are limitedpower-driven. A sensor node can work properly as long as power supply is available , if power run out happens then the coverage of sensor get lost and no communication is possible when node's energy drives down to zero.

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The sensor are deployed unattended consisting a limited power demands energy efficiency as primary constraint for nodes's operation. Power being a critical resource that act as foundation for other sources propose a functioning signals researcher exertions developing schemes for power conservation for long functioning of sensors in the target area because replacement or charging the battery source is not convenient and almost impossible in these networks.[1][2][6] As a result schemes for power saving lead towards low power hardware design, less power consuming topology design, low power schemes at MAC layer as well as at network layer. The basic working principle for a sensor node is to sense the target area, compute the data gathered followed by communication operations to supply data to the base station[2, 6, 4]. Out of all the activities performed by sensor node communication part consumes maximum part of energy source. Besides to sending or receiving, scanning the medium to check its availability can consume almost half amount of energy. So we can state that in wireless networks as compared to computation the communication phase results in more energy exhaustion. In order to achieve network performance key focus should be towards communication. Various schemes for energy managementcan be implemented at almost all layers, but most dominant results will be obtained at MAC layer because of its direct control on the radio[2, 5, 7]. In sensor networks, a MAC layer is primarily liable to decide effective and proficient allocation of shared medium and other resources of communication among all the nodes in a network . An efficient and power aware MAC protocol is expected to prolong the network lifetime by vigilant usage of power source and avoiding energy waste. In addition to energy efficiency, latency and throughput are also important features for consideration in MAC protocol design for sensor networks. IEEE 802.11DCF employed a power aware scheme by allowing the nodes in *idle listening* in order to save power in low traffic conditions. Even an idle listening state results in signification energy waste which makes 802.11 inappropriate for use in wireless sensor networks. The ordinary MAC protocols are designed with main concern for maximumthroughput, least possible latency along with good fairness whereas WSNs design issues focus mainly to minimize energy depletion with less throughput and more latency. Such networks are least bothered about fairness being part of a unaccompanied application working for a common goal[8,9]. This paper proposes modification by optimization of SMAC called MD-SMAC to achieve efficiency of energy resulting in prolonging the network life that adaptively determines the sleep-wake up schedules for a node based on its own traffic, and the traffic patterns of its neighbors.

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We experimentally show that our scheme is able to achieve a better throughput at high loads and conserve more energy at light loads than SMAC. We organize this paper as follows: The Sections II is about the work related to energy efficiency at MAC layer , section III describes the details of proposed work and modification in the basic SMAC protocol. In section IV qualitatively explains the methodology used in our simulation scenario along with analyzing the results of proposed work with the base work and in section V, we present the plots for our parameters along with the power savings by MD-SMAC over SMAC. Section VI presents the conclusion and future perspective.

II. RELATED WORK

For MAC layer energy efficiency various protocols aimed to accomplish low energy consumption for the transmission of packets around nodes with a common goal to achieve least packet loss and low delay. The main obligation of MAC layer is collision free access of the shared medium without any interference to all other's transmissions. The type of traffic depends upon application specifications like in case of monitoring applications the traffic occurs periodically and event based application generates busty traffic. So if we consider thetechniquefor power saving then a periodic duty cycling is the most basic mechanism simply following turning the radio off if case of no packet interactions. Our proposed approach, MD-SMAC implements optimization of theperiodic sleep/listen phases of duty cycle. This section represents a brief summary of existing energy efficient MAC protocols that implements duty- cycle scheme.

SMAC was specifically designed MAC layer protocol for energy effectiveness in wireless sensor networks. The main operational criterion is allowing sensor nodes to follow low duty cycle by switching to periodic sleep as an alternative of overhearing as well as idle listening. Sensor nodes also sleep during overhearing to save power. The time duration for sleep and listen collectively decides interval of duty cycle. The sleep period represents the least energy essential for triggering and no effective communication take place. is used but can only be carried out in the wake period. While listen period and idle listening both consume full energy whereas actual communication occurs in listening period. SMAC made successful improvement over traditional 802.11 standard but somehow it failed in adaptation to traffic change due to the concept of fixed duty cycle for every node. The tuning of duty cycle for low or high traffic result in inefficiency for opposite situation. To avoid the problem Timeout-MAC protocol was designed by employing adaptive duty cycle concept. It implements sleep state even if for a threshold time T, node reports no activity leading to adaptation according to network traffic. If the traffic load is constant then TMAC behaves exactly like SMAC, however in case of traffic variation saves more energy. TMAC may fallouts in quick node sleep thus accumulative more delay and lower throughput. Another drawback in both SMAC and TMAC is that, they group the communication during small periods of activity. As a result, the protocols collapse under high traffic loads [5,8].

S-MAC protocol is designed asa less energy consuming based on synchronization between nodes using RTS and CTS control signals implements aunhindered synchronization among all nodes to permit duty cycling for the sensor networks. The major operational functions are : a fixed and low duty cycling through periodic sleep, formation of clustering virtually to make schedule's communication comfortable and unambiguous and adaptive listening. All the nodes need to wake up periodically according to assigned schedule, transmit and receive available data then back to sleep state. As soon as the node wake up, it will exchange synchronization information along with all the schedule related information with all the neighbors on its neighbor list to check concurrently all neighbors are up. This process works only locally and decently accomplishes the need for system synchronization[9,11].

S-MAC achieved energy efficiency by fixing the duty cycle thereby resulting in wastage of energy for variation in traffic specially in low traffic. All nodes follows the assigned fixed schedule if no communication is on the channel. During traffic fluctuation, it has no mechanism to adjust the duty cycle adaptive to the network load. So, T-MAC focused to handle fixed active time changing it into adaptive (switching between active and sleep) to low as well as busty traffic without compromising further energy depletion. The idea worked by shortening the listen period in case of low traffic or channel is idle. Thus, T-MAC implements adaptive listening (listening for short period)after the synchronization phase, and allows the node back to sleep mode when no data exchange happens.The reason for no communication may be due to the following mentioned events and signals the closing time for radio. These events may be : if assigned frame length got time limit or required data received properly or data sent along with received acknowledgementor collision occurred due to other transmission, or all the nodes in neighborhood got successful data exchange. By implementing the concept of adaptive cycle TMAC manage the major issue of idle listening efficiently but sometime it results in early sleep state that consequencereduced throughput for the system. Both the protocols S-MAC as well as T-MAC enhanced the network life time by compromising latency over energy savings[10,13].

III. PROPOSED PROTOCOL MD-SMAC AND MODIFICATION IN S-MAC

In this section, we propose Modified Sensor- Medium Access Control(MD-SMAC) a modification over basic S-MAC. It uses the concept of duty cycle along with all the scheduling procedures to escape the energy fallout due to idle listening. It integrates the optimizations in the synchronization phase to reduce energy waste for advancement of over S-MAC at MAC layer. As we know, a major part of energy source got consumed in the periodic synchronization cycle as compared to the computation , transmissions and reception of data.

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It exploits the periodic nature of SYNC packet by allowing bypass the synchronization period allowing node to be in sleep state in SYNC period after successful exchange of SYNC packet until next SYNC period start.

For synchronization of nodes in the network, every S-MAC node is required exchanging of schedules using broadcast of a SYNC packet to all neighbors periodically. In Synchronization phase, exchange of SYNC packets takes place for transporting the schedule to neighbours. SYNC packets are broadcasted without any agreement between nodes using RTS and CTS handshaking mechanism. This period of exchanging the SYNC packet is called the *synchronization period*. In ns-2 default value of this period is 10 frames. SYNC packets get exchanged during SYNC period only. NS-2 defines following fields in the definition of SYNC packet frame.

Table 1: The SYNC frame

Type (Flag)	length	Src Addr	Sync Node	Sleep Time	State	CRC
SYNC packet	Fixed 9 Bytes	Sender's ID	Sender's Synchronization node	Sender's next sleep time	Indicates change of schedule	Cyclic Redundancy Check

MD-SMAC improves the energy consumption by accomplishing the manipulation of the periodicity of SYNC packets. In S-MAC, all the nodes need to maintain "neighbor_list" (a table containing ID entry for all neighbors of current node) in the neighbor list table. By adding a new field COUNT (a counter) in this neighbor list table, a nodes can be intelligent enough to make decision of either to sleep or wake up in the current SYNC period. All nodes will maintain separate counter corresponding to each neighbor. This counter is incremented by one after each cycle time. However, the counter is reset to zero when the node receives the

SYNC packet from the corresponding neighbor. In this way, the counter is used to calculate the number of cycles elapsed since the last SYNC packet received for each neighbor. Now the node X can realize whether it will receive the SYNC packet in the current SYNC period or not by examining thecounter value. If the node finds that any counter's value is equal or greater than synchronization period, then the node knows it will get a SYNC packet now. Thus, it will wake up in current SYNC periodotherwise it will go to sleep. For example: Suppose in a cluster of4 nodesprepared to send SYNC packets with interval of 10 cycles. Only the SYNC periods of 4 cycles are used to exchangethe SYNC packets, whereas 6 cycles remain in idle listening. This idle listening for 6 cycles in SYNC period happensin every synchronization period. This observation leads us topropose a new energy saving technique, MD-SMAC, which allows the nodes to be in sleep state in the SYNC period when theyrecognize that nobody has SYNC packet queued in the current SYNC period.

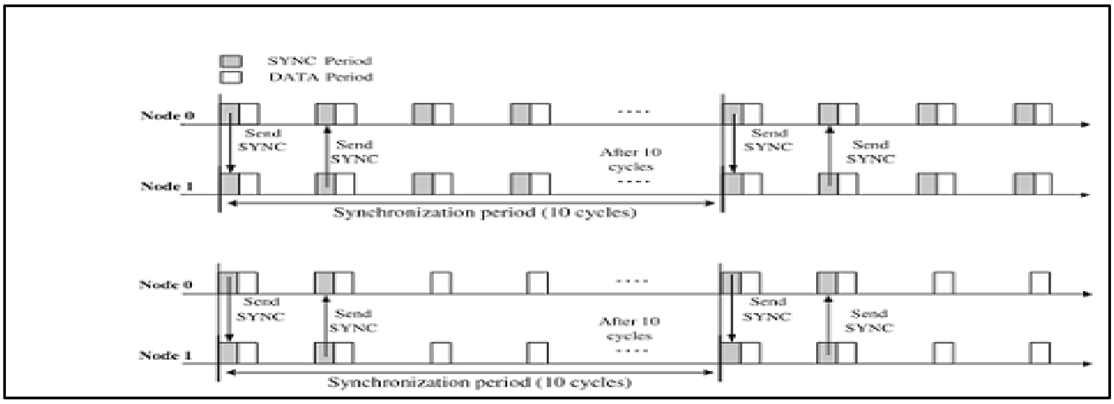

Figure1: Frame modification by MD-SMAC over SMAC frame

Updated Neighbor List in MD-SMAC:

Table 2: The Updated Neighbor List by MD-SMAC

	Field	nodeId	schedId	Active (Flag)	State (Flag)	Counter
SMAC	Remark	Node Id	Node's current schedule	Node is active	Node changed its current schedule	--------------
MD-SMAC	Remark	Node Id	Node's current schedule	Node is active	Node changed its current schedule	Cycles count since last SYNC received

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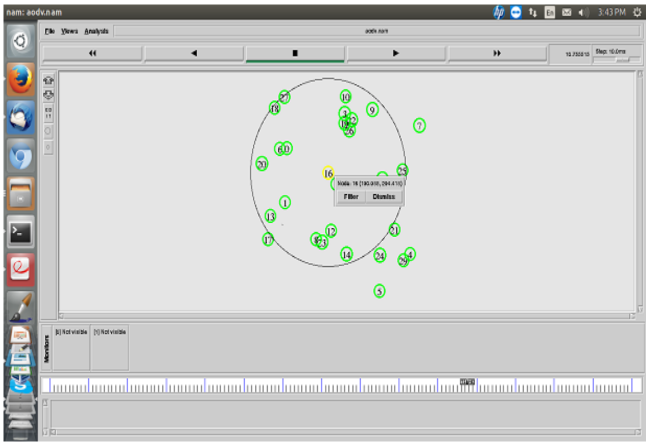
In MD-SMAC the synchronization period schedule updating is accomplished by sending a SYNC packet. The SYNC packet is very short, and includes the address of the sender and the time of its next sleep. The next sleep time is relative to the moment that the sender starts transmitting the SYNC packet. When a receiver gets the time from the SYNC packet, it subtracts the packet transmission time and use the new value to adjust its timer. This work is basically for improving the energy efficiency by managing the SYNC period only, the data period is not considered in this new protocol. Therefore, MD-SMAC doesnot degrade any performance metrics of our base protocol and can be adopted for the advanced energy conservation.

IV. METHODOLOGY USED AND SIMULATION SCENARIO

To evaluate the performance of our proposedwork the Network Simulator 2.35 is used under operating system – VM Ubuntu 14.04 LTS, RAM used– 4.0 GB, OS Type – 64 bit and NS package- ns-allinone-2.35. The experimental performance of MD-SMAC is evaluated considering consumed energy, remaining energy, throughput, packet delivery ratio and end to end delay as main performance metrices.For simulation the nodes taken are 30 with initial energy 100joule thereby resulting in 3000 joule total energy in the network at formation stage, mobility constraints are ignored to reduce the overhead and topology considered is random with the help of “setdest” function and area taken is 500*500 with simulation time of 100 seconds, pause time 2ms and packet size considered is 521kb. To enhancement the traffic load the packet inter-arrival time is changed from 1second to 20 second on the source node. The main parameters used for the implementation ofMD-SMAC protocolare listed in TABLE 3.

TABLE 3: Implementation parameters

Parameter Title	Values
Channel	Channel/Wireless Channel
Radio Propagation Mode	Propagation/Two Ray Ground
Network Interface	Physical/Wireless Phy
Interface Queue	Queue/Drop Tail/Pri Queue
Antenna	Antenna/Omni Antenna
Simulated Routing Protocol	AODV
Idle Power, Rx Power,Tx Power	0.1j, 0.1 j, 0.1 j
Duty cycle	10 %
Traffic Source	CBR/FTP



Snapshot 1: Topology and Simulation Scenario

V. RESULTS ANALYSIS AND DISCUSSION

The improved SMAC protocol i.e. MD-SMAC, enable optimized synchronous period along with a great relaxation for the nodes following multiple schedule. The network life is expected longer and for the analysis of results all the reflected parameters are plotted for both the protocols for a better comparison. The major parameters to evaluate the performance of MD-SMAC protocol are energy constrainted and for this the monitoring of changes in radio’s state is required. By Figure.11, we easily can state that at every interval of simulation time the consumed energy in SMAC ismore as compared to MD-SMAC. We have recorded the count forconsumed energy and remaining energy for both the protocols in the table 4. By the plots for both consumed energy as well as remaining energy we can easily conclude MD-SMAC outperforms SMAC in terms of average energy in the network. The energy efficiency for the network can be expressed as a relation of total consumed energy for the total number of bits transferred successfully. Inclusively our proposed protocol significantlysave energy and works efficiently

- Energy Consumption: It express the relationship among energy spent to the total data packets delivered by each node in the network.
- End-to-End Delay: A measure of the ratio between a sum of individual data packet delay such as carrier sense delay, back off delay in case of collision, transmission delay, processing delay, queuing delay for the entire number of successful data packets delivered.
- Packet Delivery Ratio (PDR): PDR represents the extent of overall successful delivered data packets from all the sent data packets.
- Throughput: It express the total count of data packets transported to sink node during the decided simulation time.

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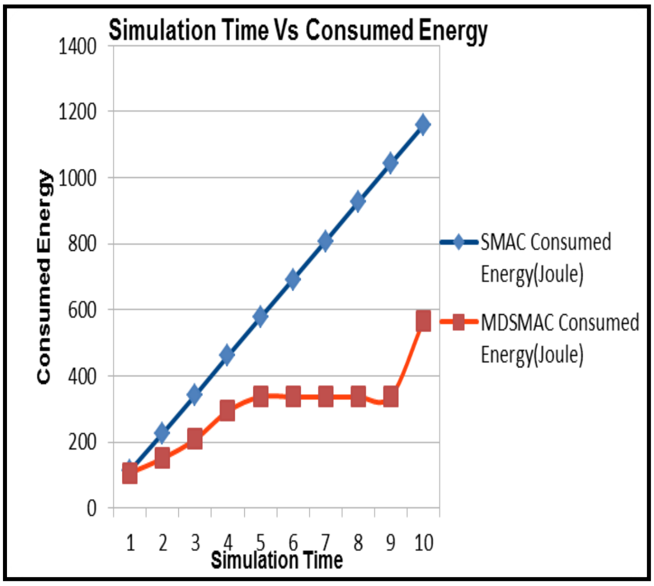

Figure 2: Plots Consumed energy for MD-SMAC and SMAC

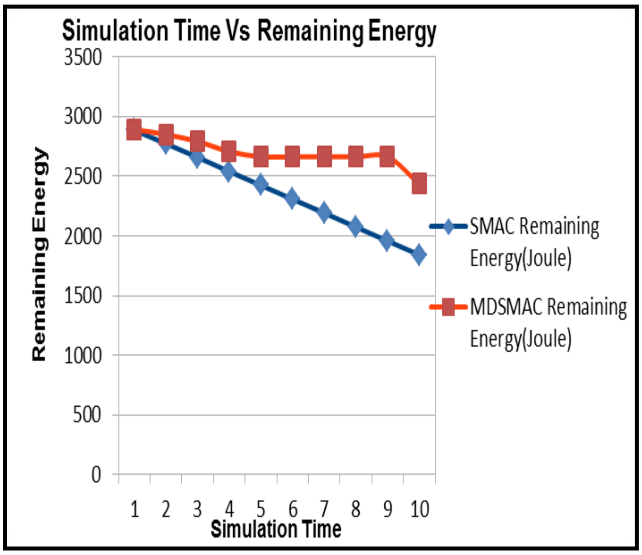

Figure 3: Plots Remaining energy for MD-SMAC and SMAC

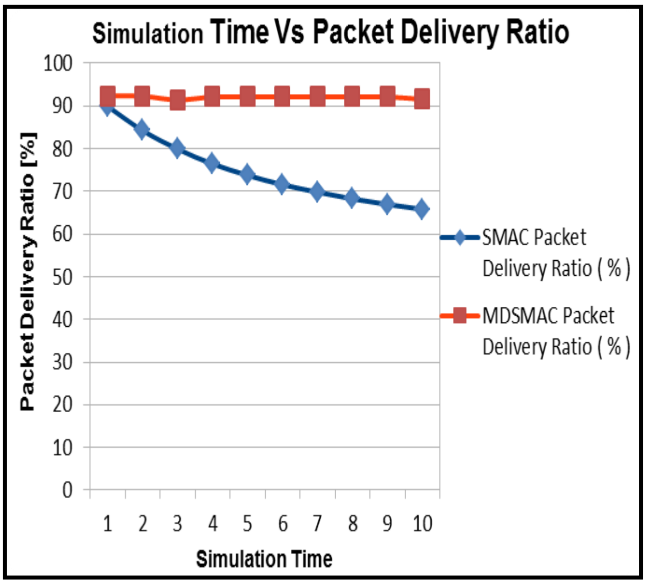

Figure 4: Plots PDR for MD-SMAC and SMAC

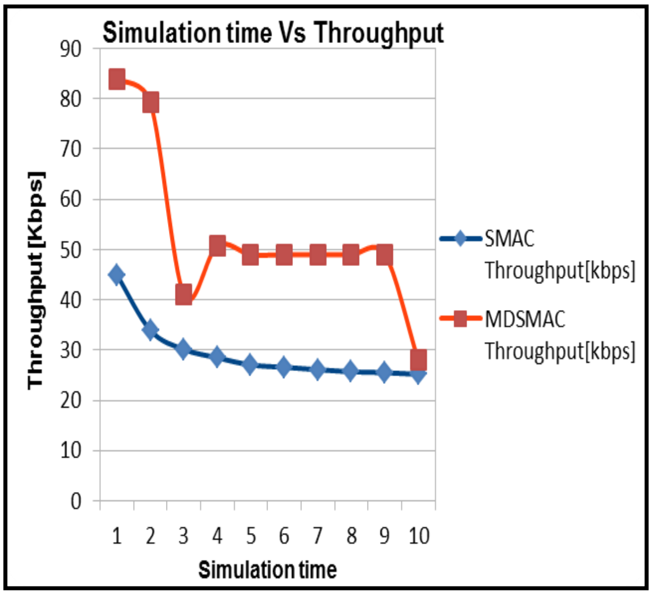

Figure 5: Plots Throughput for MD-SMAC and SMAC

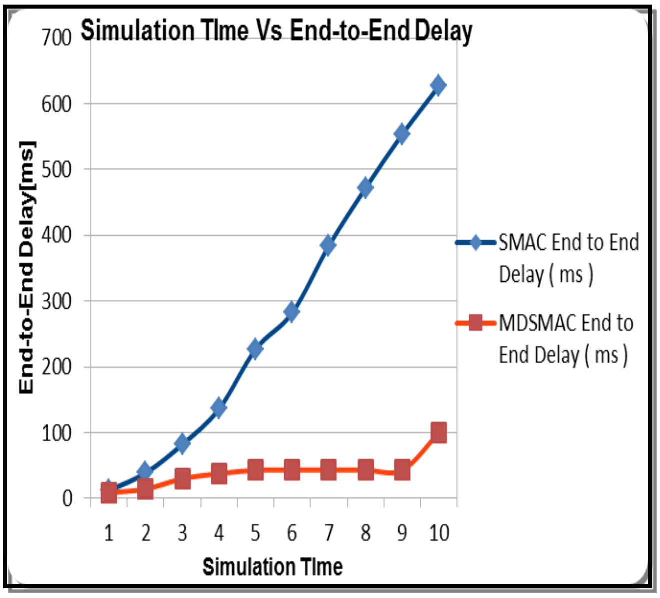

Figure 6: Plots End-to-End Delay for MD-SMAC and SMAC

Figure from 2 to figure 6 represents evidence indicating MD-SMAC has reduced the consumption of energy in the network over SMAC being packets in the synchronization phase are fewer relatively. The unnecessary SYNC packets are controlled by exploiting the periodic nature of SYNC packet thereby allowing to bypass the synchronization period, permitting node to be in sleep state in SYNC period after successful exchange of SYNC packet until next SYNC period start the consumed energy evaluation. The delay of proposed protocol is less comparatively due to optimized and adaptive SYNC phase resulting in more time and energy source for packet transmissions. The packet delivery ratio as well as throughput due to the adjustment of nodes to adaptive sync phase and duty cycle if the counter value manages greater than threshold times resulting in improved due to more energy available and more phases for data transmissions.

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Table 4: Illustrates various Simulation Parameters values

Simulation Time	Total Energy	Consumed Energy		Remaining Energy		Throughput		PDR		E-to-E Delay	
		MD-SMAC	SMAC	MD-SMAC	SMAC	MD-SMAC	SMAC	MD-SMAC	SMAC	MD-SMAC	SMAC
10 sec	3000	106.65	114.05	2893.35	2885.96	83.98	44.94	92.4	89.94	8	11.95
20 sec	3000	150.18	226.43	2849.82	2773.57	79.21	33.93	92.14	84.25	24	38.68
30 sec	3000	207.91	341.6	2792.09	2658.41	41.01	30.14	91.03	79.9	56	82.03
40 sec	3000	293.27	460.23	2706.73	2539.77	49	28.48	91.95	76.43	98	135.96
50 sec	3000	336.56	576.57	2663.44	2423.43	49	27.05	91.78	73.76	198	226.94
60 sec	3000	336.56	692.1	2663.44	2307.9	49	26.58	91.78	71.56	202	282.41
70 sec	3000	336.56	807.88	2663.44	2192.11	49	26.11	91.78	69.81	280	384.37
80 sec	3000	336.56	925.95	2663.44	2074.05	49	25.68	91.78	68.22	380	472.17
90 sec	3000	336.56	1042.56	2663.44	1957.44	49	25.52	91.78	66.93	420	553.67
100 sec	3000	564.85	1157.99	2435.14	1842.01	27.94	25.18	91.2	65.79	480	626.97

VI. CONCLUSION AND DISCUSSION

This work proposes design and investigation of a new energy efficient MAC layer protocol MD-SMAC Modified-Sensor MAC, which is basically an improvement of basic SMAC. Incorporation of proposed schemes allows improved energy efficiency for wireless sensor networks at medium access control layer. This approach, provides a mechanism to suppress the energy waste due to unnecessary periodical synchronization cycles and implementing it on requirement of the nodes whether it need to SYNC message in current cycle or not. The proposed schemes provide a way to allow adaptive synchronization instead of fixed schedule for synchronization. As a result of which it made possible to save resource as well as reduce the chances of collision. The simulation studyaccompanied with random topologydemonstrate that MD-SMAC accomplishes better performance over SMAC in terms of energy as well as other parameters. Furthermore, MD-SMAC also made possible to provide improved delay, packet delivery ratio and throughputcompared to SMAC. Future work may be carried out to further reduce energy consumption by finding optimal parameters.

Table 5: Simulation Parameters evaluation

Parameter	SMAC	MD-SMAC
Total Energy (Joule)	same	Same
Avg Energy(Joule)	low	Lower
Consumed Energy(Joule)	high	Low
Remaining Energy(Joule)	low	High
Throughput[kbps]	low	Higher
Packet Delivery Ratio (%)	low	High
End to End Delay (Sec)	high	Lower

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