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VTA-SMAC: Variable Traffic-Adaptive Duty Cycled Sensor MAC Protocol to Enhance Overall QoS of S-MAC Protocol

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ABSTRACT Sensing and monitoring the physical conditions are basic purposes of Wireless Sensor Networks (WSN). Sensor nodes are the building blocks of WSN and they are battery operated. Battery charging or changing is impossible in harsh areas of deployment, so battery life needs to be maximized by improving the MAC protocol. If the Duty Cycle is selected wisely, it may reduce energy utilizations of a wireless sensor network, but it may impact other factors of WSN as well. Optimum duty cycle for a specific data traffic may not be optimal for other levels of data traffic and it may negatively affect the performance of a wireless sensor network. An adaptive duty cycle algorithm, VTA-SMAC (Variable Traffic-Adaptive Duty Cycle Sensor MAC) is proposed to reduce the problem of idle listening or collisions and to reduce energy consumption of traditional S-MAC protocol. VTA-SMAC algorithm was simulated in Network Simulator NS-2 and simulation results were evaluated to assess the impact of duty cycle variation on performance of S-MAC, particularly energy conservation with condition of varying data traffic. Impact of duty cycle variation in accordance with data traffic were also evaluated on various factors like latency, throughput, collisions, delay, jitter, and packet delivery ratio etc. Trade-off between energy consumption and latency was also studied. Simulation results show that VTA-SMAC improves energy conservation by 19.9 %, 14.4 % and 20.2 % at low, medium, and high traffic, respectively. Latency is also decreased by 10.2 %, 7.5 % and 18.9 % at low, medium, and high traffic, respectively.

INDEX TERMS Adaptive duty cycle, energy conservation, MAC (medium access control), S-MAC (sensor-MAC), variable data traffic.

I. INTRODUCTION

Wireless Sensor Network is a web of sensing nodes that are dispersed at specific distances to communicate with other networks and to monitor and sense various conditions of the environment like humidity, temperature, pressure, movement, sound etc. The four basic functions of these wireless sensor networks are data sensing, data processing, data storing and communication. WSN have been widely used in almost all the important fields such as medicine, fire control, military, enemy detection, structural health monitoring, traffic control, and smart homes etc. WSN's are generally used to remotely access the data and monitor various events. Wireless nature of WSN's makes them low cost and easy to establish. The communication can occur either via radio waves, or infrared or some other wireless medium [1].

Being wireless, no doubt is a very useful aspect of the wireless sensor networks, but on the other hand, it comes with the energy challenge as most of the WSN nodes are equipped with batteries. Another challenge is the usually small size of these nodes, which limits the size and capacity of the batteries, eventually making them more critical for energy efficiency. Owing to the applications of WSNs, it is a very crucial and threatening problem, because nodes transmit very useful data and any loss or delay is intolerable. WSN nodes are placed mostly at some hard to access positions,

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such as, various hard to access places of buildings, jungles, far off mountainous areas, underwater, bridges, vehicles etc. [2][3]. WSN's are also installed for military detections by the militaries on various critical positions [4].

In such scenarios, no failure is acceptable because of any dead node in the network. There must be uninterruptible transmissions for the smooth communication and environmental sensing by the WSNs. Changing the nodal battery again and again is also not feasible due to the hard to access positions of the nodes. Common transmission problems like collisions, sleep cycles, idle listening, etc. can also drastically increase the amount of required energy [5]. Thus, a WSN must be as much energy efficient as possible.

Data-link Layer in OSI model controls and manages the data transmissions and makes sure that the flow of data is smooth. Data layer has two sub-layers; Logical Link Control (LLC) and Medium Access Control (MAC) [6]. MAC regulates the access to the medium that is shared. In fact, it controls the hardware that deals with the communication medium. This medium may be wired, optical or wireless.

The main functions of the MAC layer include Delimiting and recognizing the frame, addressing of targeted stations, accurate data transfer of LLC, avoiding errors, and control of access to the physical transmission medium [7]. Owing to such important characteristics of the MAC layer, WSN's should be highly energy efficient and scalable in accordance with the network size. It should be adaptable to variable network loads caused by addition of new nodes or any dead nodes. Energy efficiency can be ensured by different techniques, such as Dynamic Power Management (DPM) and Periodic Traffic Models (PTM) [7]. In DPM, the mode of operation can be set as Active, Idle and Sleep mode [8]. Whereas PTM is a modification of DPM, in which the device is put into sleep mode to consume less power and a sensing node is kept active for a fraction of time [7].

Duty cycle or Power cycle is a period fraction in which a system is active and completes one cycle. It can be determined as a ratio or a percentage [9]. In the field of electronics, it may be defined as the ratio of the width of pulse to the total period of the wave [10]. In MAC protocols, duty cycles are used by nodes for listen/sleep cycles i.e., turning radios on and off periodically. The main advantage of duty cycling is the avoidance of idle listening and energy conservation as well. Some MAC protocols were designed initially with fixed duty cycles, but they resulted in more energy consumption and lesser lifetime of nodes. Because in fixed duty cycles, the nodes remain active in specific time periods even if there is no data to be received or transmitted at all [7].

MAC protocols are not only concerned with energy efficiency, but also with the processing and memory capacities. Adaptability is an ability to adjust to the new situations and conditions. The MAC protocol should be flexible and able to adapt itself according to the topology variations, altering network size, changes in density and traffic [11], [12]. Dynamic protocols effectively adapt to such changes without significant overheads, whereas the fixed assignment protocols are vulnerable to the large overheads and all nodes of the network may get affected by them.

In WSNs, there are certain latency deadlines within which all the data must be gathered and delivered. The delay can be calculated based upon the choice of MAC protocol [13]. In contention-based protocols, although the wireless medium is reachable to the nodes at an early stage, yet they are more vulnerable to collisions and the resulting retransmissions are ultimately delayed. Reliability, is another factor that is affected by the MAC protocol architecture. Such architecture must be selected that ensures maximum avoidance of errors during transmission and helps in detecting collisions. Moreover, it must be capable of recovering the losses during transmissions.

There are certain challenging problems for the MAC protocols that create hurdles during the transmissions like idle listening, collision, overhearing, overhead, and over-emitting [14]. The consequences of these problems are data loss, extra energy consumption and taking more time to reach the target nodes. Quality of Service (QoS) is a measure of total efficiency of a network and can be measured by many aspects such as bit rate, throughput, packet loss, collision avoidance, transmission delay, jitter, etc. QoS is measured to select the application depending upon users' needs [15], [16].

Energy conservation which is one of the main aspects of overall QoS in WSN is the main concern of the latest research. In WSN nodes, majority of energy is used by transmission radios and these hardware's are controlled through MAC protocols. Most feasible way to improve battery life of WSN nodes is to improve the MAC protocol and make it more energy efficient [17]. In traditional MAC protocols, a big amount of energy is wasted by many factors such as idle listening, latency, overhearing, collision etc. that reduce the average nodal lifespan to devastating levels. Duty cycle selection for periodic sleep/wake of these radio transmission hardware is essential for energy conservation. Researchers are doing a lot of research in this aspect, but every solution has its own drawbacks as well. The main objective of this research work is to purpose an algorithm for MAC protocol which can efficiently select and automatically update duty cycle according to traffic load and other aspects of the network. Main contributions of this research include development of a MAC protocol algorithm, which is capable to calculate traffic load adaptive duty cycle. It decreases the energy consumption and simultaneously improves or at least maintains other aspects of QoS such as delay, throughput, packet loss, and collisions etc.

In section II classifications of MAC protocols are discussed briefly, and section III covers some latest available literature of same research area. Through analysis of section II and section III a MAC protocol (S-MAC) with maximum potential is selected for improvisation. Basic mechanism of S-MAC protocol is discussed briefly in Section IV. Section IV also includes problem statement. Proposed solution and algorithms are covered in section V. Section VI describes the simulation details and results of the simulation. Finally, the article is concluded in section VII.

II. CLASSIFICATION OF MAC PROTOCOLS

The two fundamental classifications of MAC protocols are Contention based and Contention free. There is another category named as Hybrid which depicts features of both the basic categories [7].

A. CONTENTION FREE MAC PROTOCOLS

In Contention free protocols, only one node is permitted to connect through the channel at a given time. It helps a lot in avoiding collisions and retransmissions, thereby becoming energy efficient. Fixed slot allocations cause delays in upper bounds and it is difficult to set schedules for big networks. These protocols cannot handle varying topology and traffics as effectively as is required. There are many types of contention free MAC protocols such as TRAMA, Y-MAC, DESYNC-TDMA, LEACH, LMAC etc. [7].

B. CONTENTION BASED MAC PROTOCOLS

For the Contention based protocols, no transmission schedules are needed, but alternative methods are used by for smooth transmissions. The best feature of these protocols is their simplicity in comparison to the contention free protocols. These protocols are effectively adaptable to fluctuating network topologies and traffic densities but still they face issues of idle listening and fairness. There are many types of contention free MAC protocols such as PAMAS, S-MAC, T-MAC and P-MAC, Data Gathering MAC, and Wise-MAC etc. [7].

C. HYBRID MAC PROTOCOLS

Hybrid protocols exhibit characteristics of both the contention free and contention-based protocols [7]. By relying on contention free protocols scheme, hybrid protocols reduce their collisions. While they exhibit low complexity and flexibility like contention-based protocols. There are two most widely used hybrid protocols, Z-MAC and Mobility Adaptive MAC [7].

III. LITERATURE REVIEW

There have been many efforts done to improve MAC protocols to enhance overall QoS and Energy Consumption.

Morshed *et al.* in [18] proposed an adaptive duty cycle based on traffic rate for a MAC protocol. They aimed at increased throughput, decreased latency and ultimately less use of energy. The proposed design is said to be capable to cope sudden increase in data traffic efficiently. Two approaches have been proposed in a combination i.e., a Burst packet transfer that is request based, and Duty cycle adaptation that is based on traffic rate. The proposed protocol has also been compared with the X-MAC and Wise-MAC protocol for throughput and delay per packet and claimed to have better performance. Energy efficiency has also been reported to be maintained but proposed solution is not scalable for large networks.

Evaluation on asynchronous X-MAC protocol for vehicle-base sensor networks has been done by Hasan and Turjman in [19]. The effects of hidden terminal have been investigated by simulations. A Markov model has been suggested for analysis of quality of service (QoS) parameters that include delay, throughput and finally the energy consumption. The authors claim that the proposed model is very efficient under varying conditions of the network. It comes with problems like hidden terminals, especially on varying number of vehicles. The increased node density results in increased wake up time that ultimately causes more energy consumption due to the collisions.

An improved mission critical MAC protocol with adaptive duty cycle has been suggested by Sakya and Sharma in [20]. The duty cycle is based on regression approach. The performance of S-MAC protocol has been taken into consideration for energy conservation, overall throughput, and rate of packet delivery. It has been claimed that it saves 20 % energy of the nodes compared to S-MAC, thus, increases the lifespan of the network. This protocol has been claimed to be a better option for some overcritical situations in which sudden change in the traffic loads is very common. The total number of nodes in the suggested network is eleven, one of them is sink and one is source node. Thus, the proposed solution is not evaluated for its performance with higher network densities and different topologies.

Saini *et al.* in [21] presented an improved S-MAC protocol in terms of energy efficiency by changing the duty cycle lengths. Its effects on data transmission rate were also analyzed. Different duty cycle lengths have been analyzed and most energy efficient cycle has been chosen as the best. Moreover, throughput and the end-to-end delay has also been studied for different duty cycles and a comparison has been presented. It has been reported in the conclusion that the S-MAC with 10 % duty cycle may save 459.735 more joules of energy than the traditional protocol. In this research, traffic variation is not considered for performance evaluation.

The effects of duty cycling on wireless sensor networks have been presented by Udoh and Getov in [22]. Three duty cycled protocols that have been compared including Sensor-MAC, Timeout-MAC and Tunable-MAC. Energy consumption and throughput has been compared through simulation and presented in graphical form by varying duty cycles. The test application is done for a bridge to check for its health. It has been revealed in results that SMAC and TMAC are better than Tunable-MAC regarding energy consumption, but Tunable-MAC is better regarding throughput. In this research, the impact of protocol on the network is not considered for final results.

Donghong and Ke in [23] aimed at detecting the duty cycle in S-MAC protocol. A duty cycle that is adaptive has been presented along with back-off algorithm. The duty cycle is changed dynamically by the nodes in accordance with the buffer queue length. The micro-cycle scheduling scheme has been suggested that divides the total listen/sleep time into smaller listen/sleep cycles, called micro-cycles. It has been claimed that the suggested protocol reduces energy consumption and latency as compared to S-MAC protocol, particularly in case of crowded data traffic and greater number of nodes. Processing and memory requirements for the proposed mechanism cost energy.

An algorithm to reduce the problem of Energy Consumption, Latency and Collison's in SMAC protocol was proposed by Ahmed [24]. The proposed algorithm can vary contention window according to data traffic and it is capable to handle variable traffic. Sensing the carrier is basic mechanism to calculate the traffic and vary contention window. Authors claimed that the proposed algorithm consumed less energy as compared to other MAC protocols and reduced latency as well as collisions. The simulation time is only 10 seconds, which is obviously not enough to get more reliable results.

Energy conservation is the major goal of recent research work on WSN, whereas throughput and delivery success rate are already achieved goals. It is a proved fact that duty cycle cannot be fix for all kinds of applications and traffic loads. There are two approaches for duty cycle selection one of which is optimum static duty cycling according to application of WSN and other one is dynamic or adaptive duty cycling for WSN protocols. Static duty cycle is fixed pre calculated value of duty cycle which is obviously main cause of energy wastage through idle listening, overhearing and collisions. Dynamic values are not constant and can be modified. Adaptive value is a dynamic value, which is automatically change according to some other values of scenarios. In this scenario, the objective of VTA-SMAC is to adapt duty cycle according to data traffic or other aspects of the network and implement them on regular intervals. Adaptive duty cyclizing is preferred because data traffic of a WSN cannot be fixed as it is always changing and static duty cycle waste huge amount of energy and introduce large delays or collisions in network. Literature review proves that most of recent research work is focused on adaptive mechanisms to enhance the energy conservation and other aspects of QoS in WSN.

IV. SENSOR-MAC

S-MAC protocol has periodic listen/sleep mechanism and forms virtual clusters for synchronizing and sleep schedules. Unlike PAMAS, it uses in-channel signaling mechanisms and also consumes less energy in low traffic, which makes it robust and adaptive. Some basic Features of S-MAC protocol are discussed here briefly.

A. SLEEP AND AWAKE CYCLE

During very low traffic loads, the nodes remain inactive for larger time intervals. Fifty percent of the energy can be saved for 50 percent duty cycle, if a node remains inactive for half a second and listens for the other half second. Figure. 1 depicts active and sleep slots if time cycle.

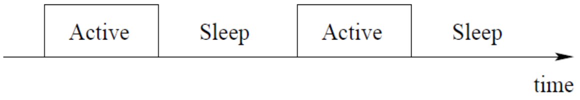

FIGURE 1. Active and sleep slots of duty cycle.

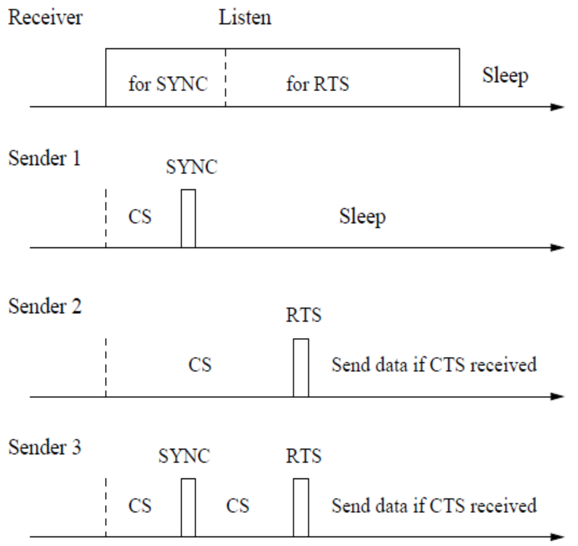

FIGURE 2. Synchronization and carrier sense.

B. SLEEP AWAKE PATTERN

In the absence of a signal, the node becomes inactive. After some time, it again senses for the presence of a signal, and if no signal is detected, it goes to sleep again, and radio is turned off. An awake timer is set before turning off the radio. The ratio of sleep-awake intervals is called duty cycle.

C. SCHEDULING

Since a node has to transmit its schedule to its neighboring nodes; it must keep a table of schedule having schedules of all the adjacent nodes. At first, a node must sense for any signal in the medium It turns ON its sleep interval if there is no signal received at all. Before going to sleep, it shares its SYNC message to the surroundings. This type of node is then called a synchronizer and other nodes have to synchronize in accordance with its schedule.

D. SYNCHRONIZATION

There is always a need of synchronization between nodes to avoid clock drift to maximum extent. Thus, periodic update is required for the nodes according to the schedules. A long update interval may be required i.e., in order of tens of seconds. At first, a short SYNC signal including the sender address and its next sleep schedule is sent. The receiving node sets its schedule according to the SYNC signal. The listening period can be divided into two portions; one for receiving RTS and the other for SYNC packets as shown in Figure. 2.

E. COLLISION REFRAINING

Usually, more than one node wants to broadcast its packets simultaneously. To avoid collisions, they must claim for the medium. The hidden terminal problem is resolved by RTS and CTS technique. A node on receiving an irrelevant packet which is targeted to some other node, estimates for how long it should remain silent. It is termed as virtual carrier sense.

F. OVERHEARING REFRAINING

Since a node listens to all the signals from the adjacent nodes for virtual carrier sensing, it increases the problem of overhearing. The nodes that are not being targeted are made to go to sleep after hearing RTS/CTS. These control packets are much shorter than the data packets, thus the non-targeted nodes do not have to listen for long intervals.

G. MESSAGE PASSING

The message is composed of some units of data that are related to each other. When a long message is sent in form of several smaller packets, it may cost more energy and results in more delay due to multiple RTS/CTS packets. The sender would have to re-claim for the medium and start the transmission from the very first packet if even a single packet is lost. To overcome this problem, all small packets of a long message are released as burst. RTS/CTS packets are required only once and the whole message can be transmitted completely.

H. VIRTUAL CLUSTERING

The technique of virtual clustering is introduced to make the protocol more energy efficient. In SMAC, only those nodes keep their radio ON that need to transmit data packets, whereas other nodes remain sleeping. Though it saves a lot of energy, but it may create problems in case network comprises of large number of nodes. Greater the number of virtual clusters, a greater number of nodes will remain active and use more energy. Hence, optimal number of virtual clusters for a network should be calculated. It may be determined by adjusting the transmission power of nodes.

S-MAC performs good with low data traffic, but fails to handle heavy traffic loads. In addition, idle listening and long listening intervals reduce nodal lifespan drastically making it expensive [25]. QoS of S-MAC protocol needs to be improved to increase its energy efficiency by reducing the problem of idle listening, latency, and collisions by applying adaptive duty cycles that varies according to the variable traffic load.

SMAC is proved to be a protocol, based on duty cycle with most potential, but it does not perform well when traffic loads vary. Applying some modification on SMAC and making it capable to tackle all kinds of traffic loads with maximum possible QoS can be a major enhancement and addition to MAC protocols.

V. VTA-SMAC

Variable Traffic Adaptive S-MAC is proposed to improve energy efficiency and throughout at optimal duty cycle for all the different types of traffic load. Delays and collisions are also trade-off factors of this process, which cannot be ignored. VTA-S-MAC is analyzed for variable traffic applications for throughput, available nodal energy, and effects of duty cycles on the protocol performance.

Algorithm 1 Virtual Clustering Algorithm

Require: Node Location & Node Energy Levels.

```
Begin
Broadcast locations of nodes to the Sink node.
Send remaining energy information of every node to BS.
  If selected node has highest remaining energy, then
    Choose node as synchronizer.
    Unicast information to followers.
  Else
    Choose nodes as follower.
  Endif
Send data of nodes to synchronizer.
  If current time < node transmission time than
    Turn off the radio of each follower node.
  Else
   Aggregate the data at Synchronizer.
   Send Aggregated data to Base Station.
   Decrease ordered arrays according to energy level.
     If residual energy < threshold value then
       Run new round for selecting Synchronizer.
     Endif
  Endif
End
```

Algorithm 2 Dynamic Sleep Algorithm

Require: Node Locations and Energy Levels.

```
Begin
Check packet information, its type and energy.
Save information with coordinates and energy.
Check for sleep duty processing
  If routing queue length is zero then
    Set node to sleep.
    Repeat for next node
  Endif
Check Current Time
  If last data duration + Interval < Current Time then
    Set node to sleep
    Repeat for next node
  Endif
End
```

VTA-SMAC consists of multiple algorithms to perform its desired task. The first algorithm (algorithm 1) is a virtual

Algorithm 3 Adaptive Duty Cycle Algorithm

Require: Transmission Time, Receiving Time and Idle time.

1. **Begin**
2. **Set** L = 0, No of Packets = 0
3. **Calculate** S & L_{avg}
4. **If** $S > S_{high}$ and duty cycle $< D_{max}$ **then**
5. **Set** duty cycle = duty cycle + ***m***
6. **Else**
7. **If** $S > S_{low}$ and duty cycle $< D_{min}$ **then**
8. For $L_{avg} < L_{max}$ then
9. Set duty cycle = duty cycle – ***m***
10. **Endif**
11. **Endif**
12. **Set** $L = L + L_p$
13. **Set** No of Packets = No of Packets +1
14. **End**

clustering algorithm to form virtual clusters in WSN. In this algorithm, locations and remaining energy information of all nodes are sent to the sink node known as base station. If selected sensor node has highest remaining energy, then the node is selected as synchronizer. It then unicasts the required information to its followers to develop synchronization and virtual cluster. If the node has low energy level, then it becomes follower and follows another node. Synchronizer aggregates the data and forwards it to the base station. If synchronizer energy gets low, a new synchronizer is selected by running another round of virtual clustering.

The number of border nodes which follow more than one schedule, increase directly with the increasing number of virtual clusters. Greater the number of virtual clusters, a greater number of nodes will remain active and use more energy. Hence, optimal number of virtual clusters for a network should be limited. Whole network cannot consist of only one or few virtual clusters as it will increase energy consumption of synchronizer nodes drastically. Optimal number of virtual clusters can be controlled by changing the radio range of nodes. For current scenarios, radio range is kept minimum, as maximum number of nodes are 50. So total numbers of virtual clusters will not be zero but limited to few.

Dynamic sleep is provided with VTA-SMAC to conserve energy in the case of very low data traffic. For this, a dynamic sleep algorithm is provided. It checks if there is no data in queue, then it makes the node sleep and checks all nodes one by one. It further checks last data duration and adds it to the data time. In case it is smaller than current time, it will make the node sleep and conserve energy.

Dynamic sleep algorithm consumes energy during checking of data queue at each node, so it needs to be activated in the networks, which have enough zero activity periods to conserve energy. This algorithm enables user to enable or disable dynamic sleep accordingly.

Adaptive duty cycling has been proposed in VTA-SMAC to improve traditional SMAC. In VTA-SMAC, the nodes can determine their duty cycles on their own and different nodes can be assigned different duty cycles. To overcome problems of fixed duty cycle and latency, an algorithm is proposed here. The algorithm determines the value of activity factor S at first nodes. Expressions for finding activity factor S and average sleep time L_{avg} are given by eq. (1) and (2).

$$S = \frac{Tr + Tt}{Tr + Tt + Ti} \tag{1}$$

$$Lavg = \frac{L}{No\ of\ Packets} \tag{2}$$

Greater traffic load leads to higher value of activity S_{high} and consequently duty cycle is increased according to the allowed modification factor *m* percentage value. Nodes adapt themselves according to the value of *m* and traffic loads; hence duty cycle values are changed in small steps instead of sudden higher changes. Value of Maximum allowed duty cycle D_{max} is also considered and duty cycle is not allowed to be greater than this value. If the traffic is low, as activity factor is below S_{low}, then the duty cycle is decreased as per *m* percentage value.

In such case, duty cycle is not decreased than Minimum allowed duty cycle D_{min}. Similarly, the highest bearable sleep interval L_{max} is also calculated. Sleep interval does not increase further after L_{max} is reached, keeping latency within allowed limits.

After the completion of a packet transmission, the total sleep interval L is refreshed. L_p is extracted from data packet and added to L. Number of packets received is also updated at arrival of every packet. The parallelism between the value of latency and energy requirements are hereby found. The traffic density can be calculated with the help of the values of average sleep time and activity factor and hence, duty cycle is set accordingly. Description of variables used in adaptive duty cycle algorithm is provided in table 1.

VI. SIMULATION AND RESULTS

An advantage of VTA-SMAC is that its performance can be compared with traditional SMAC in the absence of any real hardware by the Network Simulator. The analysis is done for different duty cycles at low, medium, and high rates of traffic and remaining amount of energy is compared for traditional SMAC and VTA-SMAC.

A. SIMULATION ENVIRONMENT

Network Simulator 2.35 is used to write TCL script under Cygwin environment. The trace file is stored in a new format and used to get results. The latest energy model of the NS-2 is used and various network conditions are examined. Area of 2000 × 2000 meter is used in simulation. Omni type antenna is considered with drop tail type queue. In this simulation experiment, three different size networks are simulated which consists of 10 nodes with random deployment, 26 nodes

TABLE 1. Variables for adaptive duty cycle algorithm symbols.

Legends	Description
No of Packets	Number of packets transmitted.
m	Modification factor in percentage.
T_r	Time spent in receding the packet.
T_t	Time spent in sending the packet.
T_i	Time for which node is idle.
S	Activity Factor.
S_{high}	High Activity Factor.
S_{low}	Low Activity Factor.
duty cycle	Duty cycle of the protocol.
D_{max}	Highest Possible duty cycle.
D_{min}	Lease possible duty cycle.
L	Total Sleep Time.
L_{avg}	Average sleep time.
L_{max}	Maximum allowed sleep time.
L_p	Sleep Time between packet arrival & RTS.

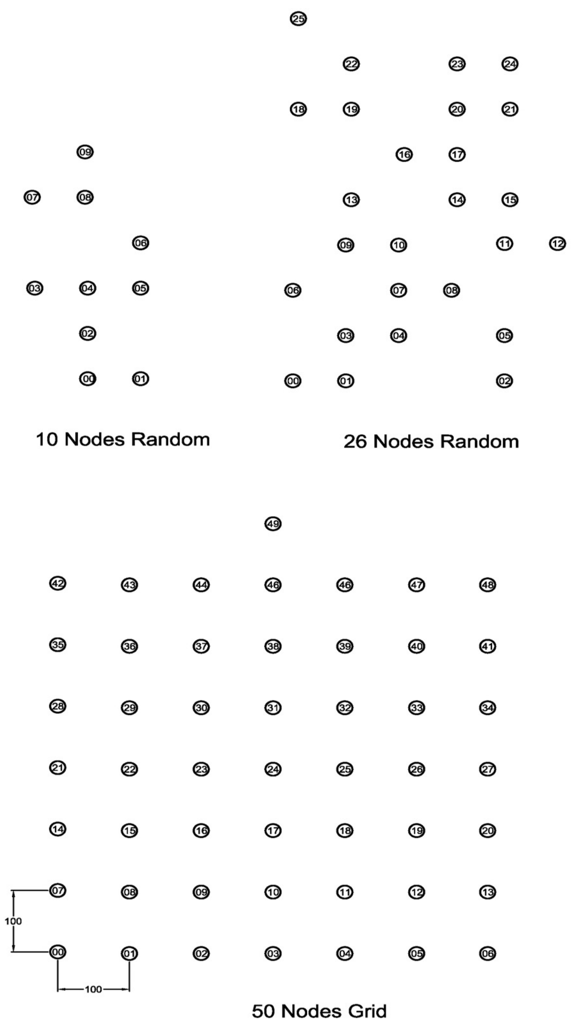

FIGURE 3. Node deployment scheme.

with random deployment and 50 nodes with 7 × 7 grid of deployment sensors.

The maximum distance between adjacent nodes is 100m from all sides. Figure. 3 shows the node deployment scheme. The dependence of cluster size on the transmission power of nodes has been studied. Traffic load has been set at constant bit rate from first node to the last. End to end delay and overall energy usage are then calculated. Star, Mesh and Star/Mesh mix topologies are used in this study. Three different size of networks are simulated to evaluate the response of VTA-SMAC under different sizes of networks such as 10, 26 and 50 nodes. These nodes are provided with UDP agents and linked to CBR traffic. SMAC scenario is created in NS-2 using a Wireless Channel with propagation of Two Ray Ground and Physical Layer of Wireless type.

Multi-hop network is assumed, because it is very practical topology for the large sensor network. Modified DSR routing is used at network layer along with the Direct Diffusion to simulate SMAC.

B. SIMULATION PARAMETERS

The smallest arriving interval between data packets for this study is 0.01 seconds, whereas in case of lowest traffic loads, the arriving interval may increase up-to 50 seconds. Simulation software NS-2 is capable to change the traffic load randomly within the given limits, thus making it variable during the simulation. For analysis of network under a specific traffic load, the traffic load is kept static through initial parameter settings of NS-2.

The range of varying duty cycle is from 1 to 50 percent and duty cycle is calculated through adaptive duty cycle algorithm. Fixed duty cycles are simulated for analysis of conventional S-MAC protocol by disabling the adaptive duty cycle algorithm and inputting the static duty cycle values one by one. Maximum number of data packets in this simulation is 1000, for which the beginning energy is up-to 100 joules. Simulation is carried out for 500 seconds. For desired synchronization, all the nodes begin to transmit after 50 seconds. Table 2 shows the list of input parameters.

C. PERFORMANCE PARAMETERS

Basic performance parameters considered are latency and remaining energy on the nodes for varying packet arriving time interval and varying duty cycles. Major performance paraments are:

1) AVERAGE ENERGY

To calculate the average energy used by nodes after simulation, an updated energy model is used for new format of trace file. Energy calculation is done in joules for all the nodes after every event.

2) LATENCY

Average time for the packets to reach their destination is termed as latency. It is calculated for each packet to determine the network performance in milliseconds.

3) TRAFFIC LOAD

Varying traffic load is the key feature in this analysis. It is desired to check the response of network, if each and every factor of network remains same and only traffic load is varied.

TABLE 2. Input parameters of simulation.

Parameter	Value
Communication Channel	Wireless type Channel
Radio Propagation Model	Two Ray Ground
Physical Layer	Wireless Physical Layer
Medium Access Control	SMAC
Queue Management	Drop Tail / Priority Queue
Antenna Type	Omnidirectional Antenna
X	2000 meters
Y	2000 meters
Starting Time	50 seconds
Stop Time	500 seconds
Seed	1
Nodes	10, 26, 50
Node Energy at Boot-Up	100
Energy Consumption to Receive	0.3682 joules
Energy Consumption to Transmit	0.3862 joules
Energy Consumption in Idle State	0.3442 joules
Energy Consumption in Sleep State	5.00E-05 Joules
NS-2 Version	2.35
Application	CBR

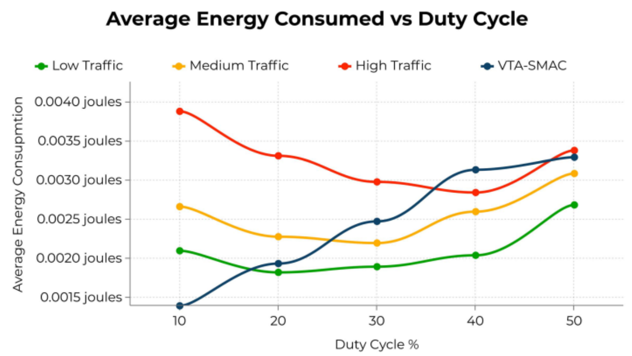

FIGURE 4. Average energy consumption comparison for VTA-SMAC vs traditional SMAC at different traffic loads.

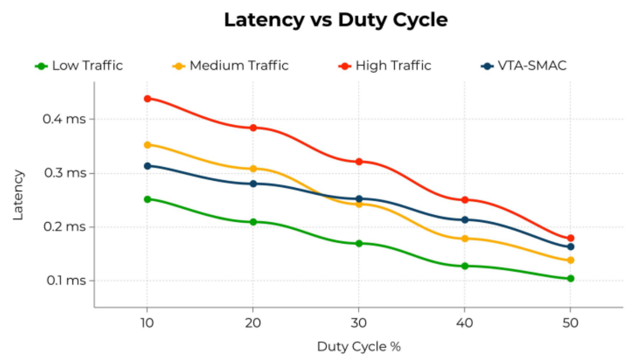

FIGURE 5. Latency comparison for VTA-SMAC vs Traditional SMAC at different traffic loads.

Each different values of duty cycles simulation are executed minimum three times for three different traffic loads i.e., Low, Medium, and High. To get smooth meaningful simulation results, each simulation is executed for several iteration and average of the performance is considered to prepare graphs.

D. SIMULATION GRAPHS

Simulation results show that data transmission was almost null for the duty cycle value of 1 and 10 percent. So, results accumulated for the duty cycle range from 10 to 50 percent. Data Traffic is 1, 2 and 3 Mb for low, medium, and high traffic loads, respectively. For every different traffic load and duty cycle in the given range Average Energy Consumption, Latency, and Collision are calculated and compared for traditional SMAC and VTA-SMAC.

The simulation results graphs show that the impact of duty cycle variation is greater for the higher traffic loads as compared to the low traffic loads but not ignorable. Similarly, the impact of duty cycle variation is greater for the larger networks as compared to small networks but not ignorable. If duty cycle is reduced to a very low value, minimum possible energy consumption cannot be achieved. It is due to the increase in latency and collisions, which requires more energy consumption caused by retransmission of packets or long buffering queues. Increasing duty cycle decreases the energy consumption, as the delays and collisions decreases as well as shown in Simulation Graph in Figure. 4.

Simulation results prove that VTA-SMAC performed consistently with different sizes of networks (10, 26 and 50 nodes) and different topologies. As smaller networks already face the less energy consumption and latency, still VTA-SMAC outperformed conventional S-MAC by decreasing energy consumption and latency to more lower values. Unlike other protocols, VTA-SMAC performed efficiently under large network scenarios, where most of the other MAC protocols collapse. Handling large networks uniformly was the one of the main objectives of this research, which is achieved as proved by simulation results.

If the duty cycle is above these MEDC values, the active period energy consumption is higher as compared to energy consumption caused by collisions and delays. This is because, these values were decreasing when duty cycle was increased. VTA-SMAC effectively calculates and implements the quite close values to optimum duty cycle values for varying traffic loads, as indicated in Figure. 4. VTA-SMAC is tracking MEDC points quite efficiently and which results in low energy consumption for varying data traffic, as shown in Figure. 4. VTA-SMAC keeps the duty cycle within the allowed limits as indicated in simulation graphs in Figure. 4,5 & 6.

Latency and collisions decrease until minimum possible values are achieved as the duty cycle is increased, even after

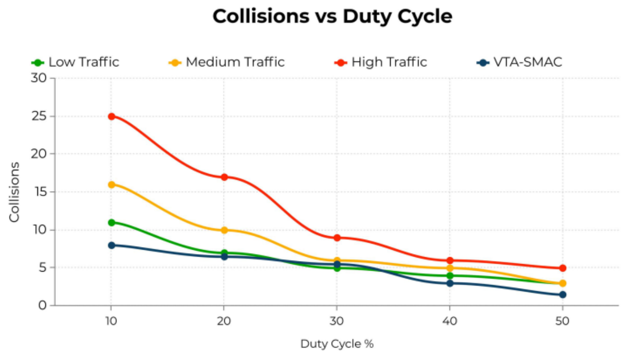

FIGURE 6. Collisions comparison for VTA-SMAC vs Traditional SMAC at different traffic loads.

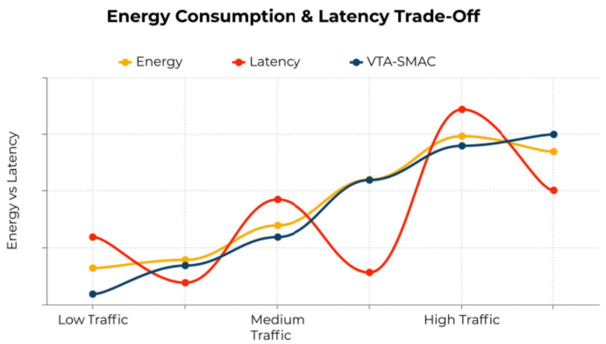

FIGURE 7. Average energy consumed vs latency at low traffic.

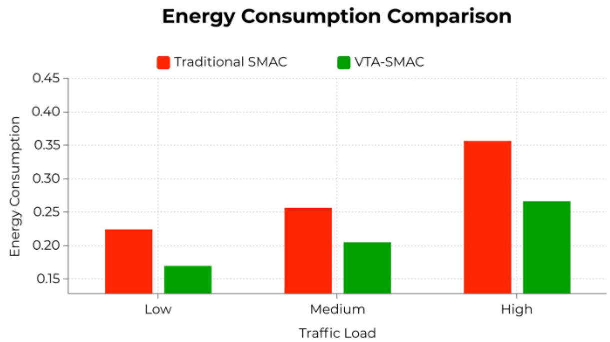

FIGURE 8. Energy consumption comparison for traditional SMAC vs VTA-SMAC.

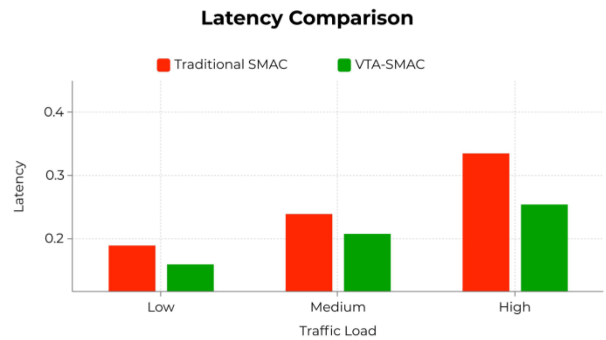

FIGURE 9. Latency comparison for traditional SMAC vs VTA-SMAC.

crossing MEDC points. Relationship of latency and collisions with duty cycle is almost inverse, as indicated in Simulation Graphs in Figure. 5 & 6. It is notable that latency and collisions are very high for the higher traffic loads on similar duty cycle as compared to the low traffic loads. VTA-SMAC helps the nodes to achieve the minimum possible values of latency and collisions while maintaining the low energy consumption by implementing optimal duty cycle values as indicated in in Figure. 5 & 6. It is impossible to ignore any performance factor while achieving minimum value for the other performance factor.

E. ENERGY, LATENCY TRADE-OFF ANALYSIS

The second most important factor after energy consumption is latency, which cannot be completely ignored to achieve minimum energy consumption. It is necessary to analyze the trade-off between average consumed energy per packet and average latency. While analyzing this trade-off, it was found that the intersection points of both parameters are not same for different types of traffic loads as shown in Figure. 7. The intersection point of these values are different for all different types of traffic loads. Following intersection points do not achieve minimum possible values of energy consumption or latency, so it is important to decide the trade-off factor for different applications before selecting duty cycle.

In case of extreme low traffic, VTA-SMAC make nodes, sleep using the factor of traffic probability calculated from recent events. In this way, higher energy conservation is achieved in the applications where long time periods of zero activity and periods with high activity are expected. VTA-SMAC algorithm is simple and calculates optimum duty cycle very efficiently. Time interval for the recalculation of duty cycle according to the recent traffic load and maximum allowed latency can be adjusted as required.

Simulation results prove that VTA-SMAC improved overall QoS of S-MAC protocol. Simulations results show that for low traffic, the VTA-SMAC decreased energy consumption by 19.9 % and latency by 10.2 %, as compared to traditional S-MAC protocol. At medium traffic, the VTA-SMAC decreased energy consumption by 14.4 % and latency by 7.5 % as compared to traditional S-MAC protocol, as shown in Figure. 8. For high traffic. Simulation results indicate that the VTA-SMAC decreased energy consumption by 20.2 % and latency by 18.9 % as compared to traditional S-MAC protocol, as shown in Figure. 9.

VTA-SMAC performed uniformly for all types of traffic loads. Optimum duty cycle calculation is very fast and the simulation output results are close to the manual calculation results. Simulation is further extended to the other levels of traffic and with extremely low traffic load, in which VTA-SMAC conserved energy up-to 23.6 % as compared to fix duty cycle with traditional S-MAC protocol.

VII. CONCLUSION

In this paper, the effects of duty cycle on energy consumption in WSN network were analyzed with traditional S-MAC protocol with different variations of traffic. Remaining energy on the nodes is not always inversely proportional to the duty cycle values. An optimum duty cycle value should be opted in accordance with the traffic loads to get maximum possible energy conservation, maintaining other QoS. Optimum duty cycle values to achieve minimum Energy Consumption are different for every different traffic load. Experiments show that there is a trade-off between average consumed energy and latency. Intersection points of both parameters are not same for different types of traffic loads and these points do not achieve minimum possible values of energy consumption or latency. Simulation results proved that VTA-SMAC reduces the energy consumption and decreases latency and collisions, while maintain other QoS by calculating optimum duty cycle efficiently. Simulation results show that VTA-SMAC performed equally good with all types of traffic loads and decreased energy consumption by 19.9 % for low traffic, 14.4 % for medium traffic, 20.2 % for high traffic. VTA-SMAC decreased latency by 10.2 % for low traffic, 7.5 % for medium traffic, 18.9 % for high traffic. Results show that VTA-SMAC is capable to handle large size of networks as efficiently as small size networks. Compiling the results show that VTA-SMAC provides overall 18.2 % reduction in energy consumption and 12.3 % decrease in latency for all types of traffic loads as compared to traditional SMAC protocol. For deployments with long inactivity periodic VTA-SMAC provides up to reduction in 23.6 % energy consumption.

FUTURE SCOPE

Pre-Calculated optimum duty cycle values through VTA-SMAC algorithm can be stored in node memory to avoid repetitive calculation of duty cycle. Nodes may simply select optimum duty cycle from the given values according to traffic load and maximum energy can be conserved. QoS of other duty cycle-based protocols may also be improved by implementing same algorithm.

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