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INPMAC: An Improved Node Power based MAC protocol with Adaptive Listening period

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Abstract— Wireless Sensor Networks comprises of a number of elementary devices called motes that are also equipped with some capabilities of sensing, computing and communications that works simultaneously to sense data and send the information at the sink. WSNs are always expected to be operational for a long period of time because the battery is non-replaceable and also non-rechargeable. For this MAC protocols are used as these are energy efficient protocols. These protocols reduces the Energy consumption, idle listening, delay, collisions. In that order the concept of Duty Cycle is taken into consideration. Lesser the Duty cycle, lesser the energy consumption and hence improved lifetime. In this paper, INPMAC protocol is proposed that uses the concept of multi-layering. When the active duration of frame duration is divided into a number of layers and thereby further the active and sleep modes are defined that do not overlap among layers, this technique of reducing the duty cycle is called multi-layering. In this paper, we have used Modified Logarithmic Backoff Algorithm. In simulation results, it is found that the energy consumption per node in case of proposed INPMAC reduces to 25.95% than NPMAC with improvement in Sleeptime, Average Packet Delay, Probability of Collision than NPMAC as 5.8%, 8.4% and 12.2%.

Keywords— Wireless Sensor Network; MAC; Adaptive node power; network lifetime

I. INTRODUCTION

With the advancements in technology the application field of Wireless Sensor Network has been broadening over the last decade which is mainly due to the tiny size and low cost of sensor nodes. The number of applications[1] includes event detection and reporting like intruder detection, hazard detection, pollution testing of soil and water. So the WSNs may be placed in some cumbersome and hazardous geographical area where human intervention is rarely possible.

Also, the sensor nodes have limited and irreplaceable power source which has led to the need of an efficient use of battery power especially where there is a need of using WSNs for long duration. This has prompted the use of protocols that controls the power consumption of Radio transceiver in typical sensor node [2].

MAC protocols in Wireless Sensor Networks must have built-in power consumption mechanism, mobility management and failure recovery system. These protocols are thus responsible of prolonged lifetime as the energy consumption directly effects the lifetime of a network. There are some major reasons of energy wastage: collision, idle listening, overhearing, control packet overhead [3]. One of the class of MAC protocols that is contention based MAC protocols uses the Duty cycle technique to save the energy consumption by radio by turning it off periodically [4]. Duty cycle is defined as the ratio of active time to the Frame duration. Lower duty cycle contributes to low energy consumption. Different protocols have been proposed to lower the duty cycle to reduce the energy wastage and hence to improve the lifetime like SMAC [5], TMAC [6], MLMAC [19].

In this paper a new INPMAC protocol has been proposed that attempts to lowers the duty cycle beyond the SMAC, TMAC, MLMAC, NPMAC protocols by using the more number of layers and targetting other sources of energy wastage like idle listening and collisions also. This is a distributed contention based MAC protocols that is self-organizing in which central node is not the head. Also, the proposed protocol INPMAC uses an efficient modified Logarithmic Backoff Algorithm that efficiently reduces the collisions that is one of the major stumbling block in energy saving.

II. Related work

The primary attributes to analyse the performance of a Wireless Sensor Network are Network lifetime, scalability and adaptability. The lifetime of a sensor network is mainly dominated by energy efficiency that can be achieved by avoiding collisions and idle listening. Many MAC protocols have been proposed in this regard that improves these attributes.

Based on the method to access the channel, MAC protocols are divided into three major categories: Reservation based MAC protocols, Contention based MAC protocol and Hybrid protocols. In Reservation based MAC protocol, the nodes have already reserved channel for them that too for a reserved time this is in the form of slots that allocated to each node. In this way collisions are avoided and it is the main advantage of using this type of protocols. Other advantages includes reduced energy consumption by avoiding idle listening and overhearing too.

But, these protocols have disadvantages of difficulty in allocation and maintaining of slots, Clock synchronization and lack of scalability. Examples of this type of MAC protocols are TRAMA and ERMAC.

In Contention based MAC protocols, nodes get access to the shared channel by sensing and then competing to get access. In this energy of node is wasted more than in reservation based MAC protocol. To solve this limitation of Contention based MAC protocol many researches have been done, first a CSMA/CA that is Carrier Sense Multiple Access with Collision avoidance technique is used in IEEE 802.11 which is known for its simplicity and reliability but it is mostly used for adhoc networks and not in WSNs because Power consumption is still a limitation. Then a protocol SMAC was proposed that considered the concept of Duty Cycle in which energy is saved by turning the radio ON and OFF for duration of half the Frame time that is called the Active mode and Sleep mode respectively. At the time of transmission activities by other nodes, radio is at sleep mode. This protocol avoids overhearing and adjust the sleep time according to traffic patterns.

S-MAC donot use clustering to reduce the interference and communication between the clusters. This is achieved at the expense of making the listening period long. To join a network in this protocol, a node waits for its schedule from another node which is then followed by that particular node. But if it does not get that schedule it forwards its own schedule to other nodes. In this way other nodes also forward their schedule but in a periodic manner by using a Control packet SYNC bearing the time of next frame cycle. This has the limitation that as the traffic varies so the SMAC is not able to reduce idle listening completely. **Dam et al. in [3]** discussed TMAC protocol which is an improved version of SMAC protocol. After the synchronization phase the node istens to a channel only for a small duration otherwise it gets in a sleep mode that is why it is called timeout MAC protocol. **Polastre et al.** in [4] advised BMAC protocol which is an asynchronous MAC protocol. It reduces idle listening. This protocol also uses an extended preamble and uses low power listening mechanism. This protocol is tested on the basis of throughput and latency also.

Buettner et al. in [5] proposed XMAC protocol in which a shorter preamble is used on the basis of early acknowledgement. This protocol has reduced per hop latency and it outperforms many protocols that uses long preamble. **Sun et al.** in [6] proposed an important synchronous MAC protocol called DWMAC protocol. This is specially designed protocol for heavy traffic. It reduces the latency by the help of scheduling. These nodes enable the nodes to wake at a particular demand.

Ren and Liang in [7] proposed ASCEMAC protocol (Asynchronous Energy- efficient MAC protocol). Free running scheme and schedule broadcast is utilized for phase switch schedules. In this protocol the need for time synchronization is removed by using rescheduling method. It uses the Time slot allocation method. **Tang et al.** in [9] advised PW-MAC (Predictive – Wakeup MAC protocol) A prediction-based retransmission mechanism and on demand error correction mechanism is used. Average sender duty cycle is very less that is 11% when compared with other protocols. Packet delivery ratio of 100%. The chances of idle listening increase due to prediction and collisions. **Berder et al.** in [10] proposed TDAMAC (Traffic – aware dynamic MAC protocol) Wake-up interval is adapted dynamically based on traffic status register bank so that interval may converge to a steady state in variable or fixed traffic. Lifetime was found to increase 3-6 times the other protocols. Other factors like packet delivery ratio, collisions are not discussed.

Lim et al. in [11] suggested ASMAC (Asynchronous Scheduled MAC protocol) in which Wakeup time of neighbouring nodes is scheduled periodically and asynchronously. The advantage includes reduced energy consumption and delay. Limitation of this protocol includes the Overhead for broadcast and need to store one hop neighbour table.

III. **Proposed MAC protocol**

A. **Improved Node Power based MAC protocol for Adaptive Listening Period (INPMAC):**

To study the performance of INPMAC, we need to analyze the network that is designed by considering following parameters:

B. **Design procedure of INPMAC:**

For this protocol some changes have been introduced in NPMAC so that to make it more energy efficient and for this two major changes in NPMAC have been done.

1. It has been proved for MLMAC protocol that the protocol shows improvement till five number of layers. So, in this research work five layers have been used in proposed INPMAC protocols.

a) Low power nodes
b) Lower- medium power nodes
c) Upper- medium power nodes
d) Lower- high power nodes
e) Upper- high power nodes

In both MLMAC and NPMAC protocols Binary exponential backoff algorithm has been used which has two disadvantages:

a) Fairness: Binary exponential Backoff algorithm allocates new channel by preferring last contention winner and new contenting nodes. The process involves selection of a random backoff value from a contention window (CW) which has a smaller size for new contending nodes and contention winner. This behavior causes " Channel capture effect" in the network.

b) **Stability:** BEB algorithm is not stable for larger number of nodes. So, in INPMAC protocol, to reduce the capture effect of BEB algorithm the size of contention window is increased using the modified Backoff logarithmic algorithm in which next Backoff is calculated as :

$$(BO)_{NEW} = (\log(BO)_{OLD})*(BO)_{OLD}*\text{one slot time}$$

Table 2. List of parameters with values

Parameter	**Value**
Average packet inter-arrival time	2-11s
Number of Frames	2000
Simulation time	2000s
Number of Layers	5
Number of nodes	100
Frame duration	1s
Listen time for SMAC	0.3s
Sub-layer duration for MLMAC	0.3/3s
Low power node sublayer time	$0.05T_{listen}$
Lower-Medium power node sublayer time	$0.08\ T_{listen}$
Upper-Medium power node sublayer time	$0.12\ T_{listen}$
Lower-High power node sublayer time	$0.25\ T_{listen}$
Upper-High power node sublayer time	$0.5\ T_{listen}$
Node sleeping Power	15µW
Node transmitting Power	13.5Mw
Node listening Power	24.75Mw
Number of initial reservation slots,W	8
Node transmission data rates	19.2kbps
Average packet length	38Bytes

IV. Performance Analysis of proposed INPMAC protocol

The INPMAC protocol - Improved Node Power based MAC protocol for adaptive listening, proposed in the theory is simulated and validated. Here proposed INPMAC protocol improves the network lifetime by reducing the energy consumption of low power, medium power and high power nodes of NPMAC protocol.

MATLAB is a tool for mathematical computations and so the simulations of INPMAC protocols are performed on this tool so that performance metrics of the MAC protocols can be analysed. For simulations some hypothesis are taken:

a) Nature of Sensor unit is static.
b) Messages follow Poisson distribution.
c) A frame duration is further divided into sleep and active duration.
d) A node performs only operations that are transmission, listen or otherwise they are in sleep mode.
e) Buffer size of transmitting and receiving nodes is infinite.
f) MAC procedures are according to IEEE802.11
g) Wireless channel is perfect.
h) Radio unit is TR1000 from RF monolithic.

For simpler simulations firstly the traffic is generated for all nodes of the network. Then each packet generated is stored in transmit buffer and three flags are assigned to it namely arrival time, receiving node address and appointed slot address. After that time and energy required to send the message to its transmission are calculated. Other simulations are carried out by considering parameters given in the table.

V. Simulation results

The simulations are performed on MATLAB considering the parameters given in the table with their respective values. The INPMAC protocol is a multi layered protocol with number of layers equal to five. So performance metrics of MAC protocols are evaluated in the form of graph.

a) Average percentage time of sleep state:

As the number of layers have been increased from three in NPMAC protocol to five in INPMAC protocol. So the sleep time of low power, medium power and high power nodes have been increased as now they are active for comparatively lower time period in INPMAC protocol. Also it is proved from the graph obtained from simulations.

I. Average packet delay:

Delay is given by the difference of packet receiving time and packet generation time. This is denoted by D_i and the average packet delay is the average of all the delay of individual packets. INPMAC protocols shows reduced value of delay from the graph obtained through simulations.

II. Probability of collision:

Collision occurs when two nodes that is sending and receiving nodes send data at the same time and the packet becomes corrupt and is retransmitted. Probability of collision is defined as the ratio of total number of collisions to the total number of transmission attempts.

The INPMAC protocol has lower probability of collision which can be attributed to the modified logarithmic backoff algorithm in this protocol which has reduced number of collisions as compared to binary exponential backoff algorithm.

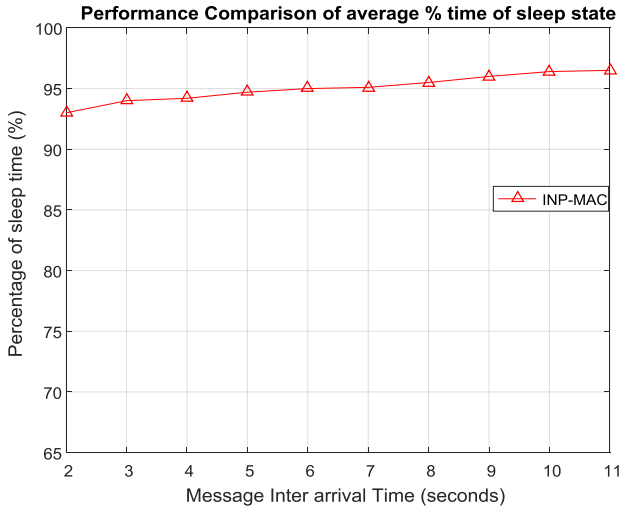

Fig 1. Graph of percentage of Sleep time versus Message Inter arrival Time for INPMAC

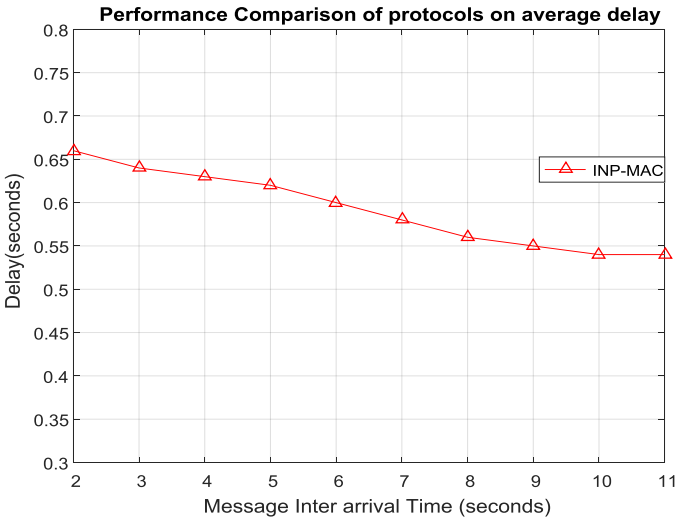

Fig. 2 Graph of Delay versus Message Inter arrival Time for INPMAC

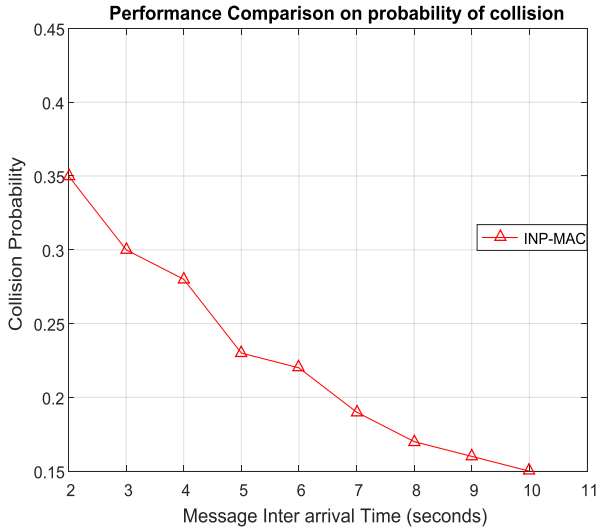

Fig. 3 Graph of Collision probability versus Message Inter arrival Time for INPMAC

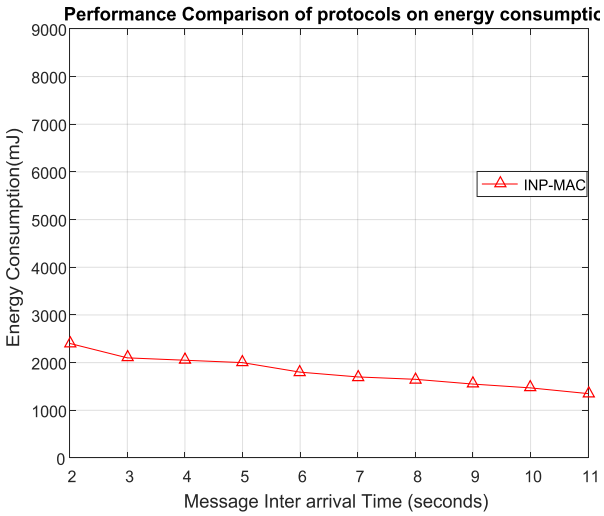

Fig. 4 Graph of Energy consumption versus Message Inter arrival Time for INPMAC

III. Comparison of SMAC, MLMAC, NPMAC And INPMAC Protocols:

The most important performance metric for MAC protocol is the Energy Efficiency. The concept of layering is done to reduce the energy consumption so that lifetime of individual nodes can be increased. As there were three types of nodes in NPMAC protocol that are low power nodes, medium power nodes and high power nodes based on certain threshold, there arises a need to reduce the energy consumption per nodes so that overall the lifetime of the network can be more.

The proposed INPMAC protocol has five layers:

a) Low power nodes
b) Lower- medium power nodes
c) Upper- medium power nodes
d) Lower- high power nodes
e) Upper- high power nodes

IV. Average energy consumption per node:

Average energy consumption per node is compared for all the nodes of SMAC, MLMAC, NPMAC and INPMAC. It can be clearly seen that the proposed INPMAC protocol has outperformed the other existing protocols and the individual lifetime of the node has been increased which has contributed to the overall increase of the lifetime.

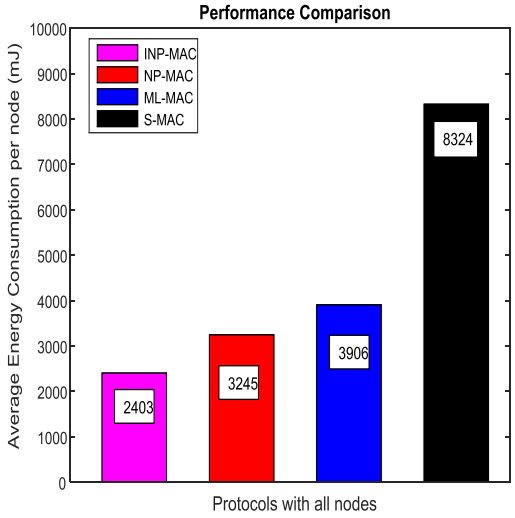

Fig. 5 Graph showing comparison of proposed INPMAC with existing MAC protocols.

V. Conclusion

The proposed INPMAC protocol shows an improvement of 71.11% as compared to NPMAC protocol as it consumes an average energy of 2403mJ over 3245 mJ of NPMAC protocol. The sleep time of the proposed protocol is also increased due to the lesser active duration of the proposed protocol. Average packet delay has been reduced to 8.4% with reduction in probability of collision of 12.2%.

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