Journal of Information & Computational Science 9: 7 (2012) 1795–1805
Available at http://www.joics.com

Power Efficient Dynamic MAC Protocol (D-MAC) for Wireless Sensor Networks

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Abstract

In the wireless sensor network there are several patterns of data forwarding interruption problems from the source to sink nodes in multi-hop path. In this paper, we propose a Dynamic MAC (D-MAC), energy efficient and low latency MAC for data gathering in wireless sensor networks. DMAC is designed to solve the interruption problem by giving the sleep schedule of a node an offset that depends upon its depth on the novel methods. DMAC also adjusts the duty cycles adaptively according to the traffic load in the network. We previously propose paper D-MAC protocol design methodology and presently the results is projected at self-learning, traffic adaptive algorithm for the WSNs. The design incorporates contention based on CSMA/CA mechanism based timing for energy-aware sensing network to overcome this control overhead and latency. This protocol is simulated in Matlab and performance evaluated. Our simulation in Matlab shows that DMAC provides significant energy savings and latency reduction while ensuring high data reliability.

Keywords: Energy Conservation; MAC Protocols; Wireless Sensor Networks; Survey; Protocol Design; Traffic Adaptive Wakeup; Latency

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1 Introduction

Wireless Sensor Networks (WSNs) have become very popular in this current decade due to their wide range of applications in domestic, defense and industrial applications. Some of these appli-

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1548–7741 /
July 2012

cations of WSNs can be used for different purposes such as target tracking, intrusion detection, wildlife habitat monitoring, climate control and disaster management [12]. The sensor node in the WSN consists of a sensor, embedded processor, moderate amount of memory and transmitter/receiver circuitry. They are normally battery powered and coordinate among themselves to perform a common task. The radio on a sensor node is usually the component that uses most energy. Not only transmitting costs energy; receiving, or merely scanning the ether for communication, can use up to half as much, depending on the type of radio [23]. Medium Access Control (MAC) layer is described by a MAC protocol takes care to ensure that no two nodes are interfering with each other's transmissions by setting sensor nodes functions. While traditional MAC protocols are designed to maximize packet throughput, minimize latency and provide fairness, protocol design for wireless sensor networks focuses on minimizing energy consumption. The fairness is the secondary. Recent advances in energy efficiency in the wireless sensor networks have led to many new protocols specifically designed for sensor networks where energy wakefulness is an essential consideration [3].

To design a good MAC protocol for the wireless sensor networks, the following attributes are to be considered [14] energy efficiency, latency, throughput and fairness. Prolonging network battery lifetime for these nodes is a critical issue. Another important attribute is the scalability to the change in network size, node density and dynamic topology [15]. There is several attraction drawing considerable researchers into this fields of engineering.

Major sources of energy waste in wireless sensor network are basically of four types [24] such as collision, packet overhead, idle listening and overhearing. In order to evaluate and compare the performance of energy conscious MAC protocols, the following matrices of research areas are: energy consumption per bit, average delivery ratio, average network throughput, and average packet latency.

1.1 Motivation

Conventional MAC protocols have been optimized for maximum throughput and minimum delay. Because of the target, they are not suitable for wireless sensor networks. X-MAC uses less energy for all sleep periods and generation rates, and is less sensitive to network density. But in our adaptive D-MAC energy efficient MAC protocol dynamically selects the preamble periods and turns off the nodes to conserve the energy.

1.2 Contributions

D-MAC protocol design methodology and results projected at self-learning, traffic adaptive algorithm for varying traffic conditions inherent to the WSNs. For this design the preamble periods to place the sensor node into power saving mode [20] and optimizing the traffic rhythm that tends the sleep duration to maximize the energy saving and minimizing power mode transition.

The rest of the paper is organized as follows. Section II summarized the related work of existing protocol. Section III illustrates the proposed design principle. Section IV analyzes the D-MAC protocol algorithm that is adaptive energy efficient protocol. Implementation methodology of protocol Section discussed in section V. This is followed by the experimental setup and results are discussed in the Section VI. Finally section VII concludes the paper with future scope.

2 Related Work

Reference to the previous published paper the further work is towards the implementation and result performance evaluation. The research areas of medium access control is a widely accepted topic that have gone very far and dept of research works as proposed in [4], [7], [13], [17]. Reducing energy consumption becomes the prime focus in the recent research of wireless sensor network. To solve the control over wasteful energy Sensor-MAC (SMAC) protocol [14] introduce an active-sleep cycle in the presence of random access channel. SMAC implements Neighbor Information Variables (NAV) for its collision avoidance technique. However the X-MAC protocol may be able to mitigate the hot -spot problem in wireless sensor networks. This is the scale of research. The Light Weight Medium Access Control (LMAC) protocol was developed based on EMAC protocol [1]. The clustered nodes communication architecture as shown in Fig. 1 of Wireless Sensor Network (WSN) [5] is largely reflected in various papers. Network clustering is recommended due to scalability requirements and to avoid overloading the gateways, network through the involvement of multiple gateways. Clusters gateway is located within the communication range use long-haul communication to send reports fused from its cluster sensor data to other gateways, and eventually to the command node. Clustering, Inter-gateway communication, data fusion and task allocation are beyond the scope of this paper.

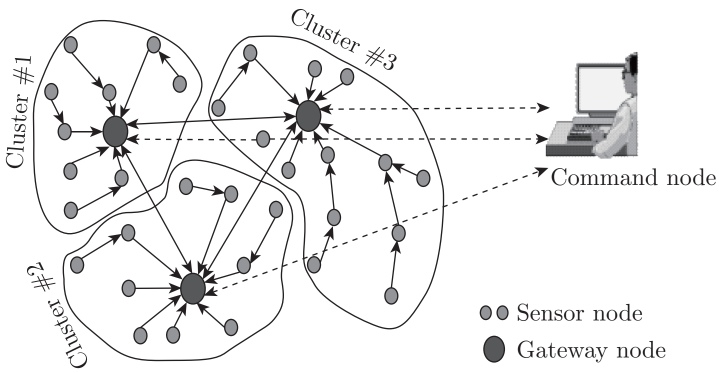

Fig. 1: The clustered architecture of wireless sensor networks

There are different reasons for the energy waste [9] [17]. The X-MAC protocol an approach employs a short preamble to low power listening to reduce energy consumption and latency. The first idea is to embed address information of the target in the preamble so that non -target receivers can quickly go back to sleep. This address reduces the overhearing problem [2]. The second logic is to use a strobe preamble to allow the target receiver to interrupt the long preamble as soon as it wakes up and determines that it is the target receiver. This short strobe preamble approach reduces the time and energy wasted waiting for the entire preamble to complete. The new D-MAC protocol considers all these concepts to design a new algorithm for the energy efficient in the varying non stationary active nodes.

3 Proposed D-MAC Protocol Design

The medium access control protocols for the wireless sensor networks can be classified broadly into two categories: Contention based and Schedule based. The schedule based protocol can avoid collisions, overhearing and idle listening by scheduling transmit & listen periods but have strict time synchronization requirements. The contention based protocols on the other hand relax time synchronization and adjust to the topology changes depend on join and dying of nodes. These protocols are based on Carrier Sense Multiple Access (CSMA) technique and have higher costs for message collisions, overhearing and idle listening.

The D-MAC protocol algorithms of the proposed model consist of two techniques that are introduced in the following subsections.

3.1 Dynamic Short Preamble Periods

The clumsy MAC usually suffers from long and inefficient preambles. X-MAC uses less energy for all sleep periods and generation rates, and is less sensitive to network density. Senders' duty cycle is 7.0% for X -MAC versus 9.3% for LPL, accounting for 32.5% increase in energy lifetime [2]. But in our D-MAC protocol the new logic consider the limitation of the X-MAC preamble in Fig. 2 and its duty cycle is tabulated in Table 1.

Table 1: Parameters of duty cycle different MAC

Figure no.	Duty cycle
Figure X1	12.16%
Figure X2	10.98%
Figure X3	10.07%
Figure X4	9.31%
Figure X5	7.0%
Figure X6	6.88%

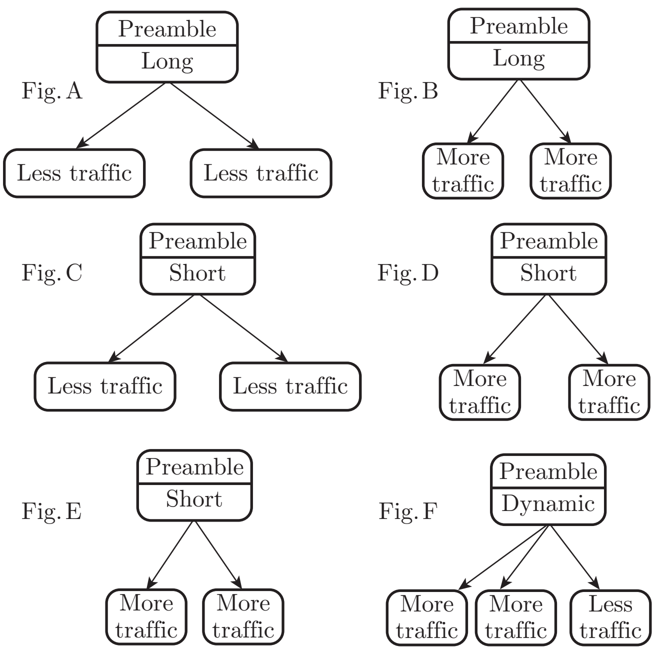

Fig. 2: The preamble period vs. traffic levels of sireless sensor

3.2 Adaptive Back off Probability Algorithm

To avoid this type of energy waste, must guarantee a period of turning on the radio and running NR algorithm. Therefore, the length of the entire preamble is defined as

$$\mathrm{L_{preamble}} \times \mathrm{T_{txbyte}} \geq \mathrm{T_{interval}} + \alpha \tag{1}$$

where, Lpreamble is the length of the entire preamble, Ttxbyte and Tinterval are the time of sending one byte and the check interval time respectively, and α is the minimum recognition time [5]. From this we can calculate the suitable length of the entire preamble. However this will not meet the requirements as the preamble requirements to dynamically change as per the traffic density. The Equation (2) shows energy used by a node consists of the energy consumed by receiving, transmitting, listening of messages on the radio channel, and sleeping [8].

$$\mathrm{E} = \mathrm{E_{tx}} + \mathrm{E_{rx}} + \mathrm{E_{listen}} + \mathrm{E_{sleep}} \tag{2}$$

According to the proposition, if the transmission probability is optimal then the ratio of idle time to the delay between two consecutive successful packet transmissions is ΓR(L). If the transmission probability if higher than the optimal value then the ratio is lower than ΓR(L) and vice versa [16]. The correlation between energy consumed per frame with the time slot length is checked by the Equation (3)

$$\mathrm{D - MAC} = (\mathrm{N_{ts}})\mathrm{P_{rx \times t\,listen}} + \mathrm{P_{rx \times t\,listen}} + \mathrm{P_{rx}}(\mathrm{t\,slot} - \mathrm{t\,bcn}) \tag{3}$$

Increasing the network life time leads to shortening the numbers of time slots.

4 Proposed Algorithm

The D-MAC protocol flowchart in Fig. 3 shows that when a transmission of each packet between each node is requested from its upper application layer the node checks for the pending packet.

Furthermore, as indicated below in Fig. 4, the energy stare diagram of Beacon and Back -off counter.

This has a typical station three states: Initial/idle node, Reserved/wait node, and Contentious/active node. For the power efficient frame we start out by leaving the nodes in idle state allow the nodes to enter the shutdown state when not active.

Stations in the reserved group do not have much collision because of dynamic back off timing which avoids using conflicted back off counters [18]. The 3 back off slots (960 μs) is considered. Every node back off for a random number of back off slots before sensing the channel that in turn on the radio. A good choice of selection of probability factor is considered for the calculation [6].

The Fig. 5 illustrates the timing diagram structure of frame. Each node in the network owns a timeslot. Nodes that are not needed for communication turn to power down mode.

The protocol timing schedules as shown in Fig. 6, is accomplished by sending an ASYNC packet of very short duration, and includes the address of the sender and the time of its next sleep. The duration of the wake-up preamble must be computed as per the nodes traffic. If the traffic is high, the interval L between transmissions will be small, and so the wake -up preamble is small and vice versa. This important property makes the D-MAC protocol adaptive to the traffic thereby the per-packet overhead decreases in high traffic conditions.

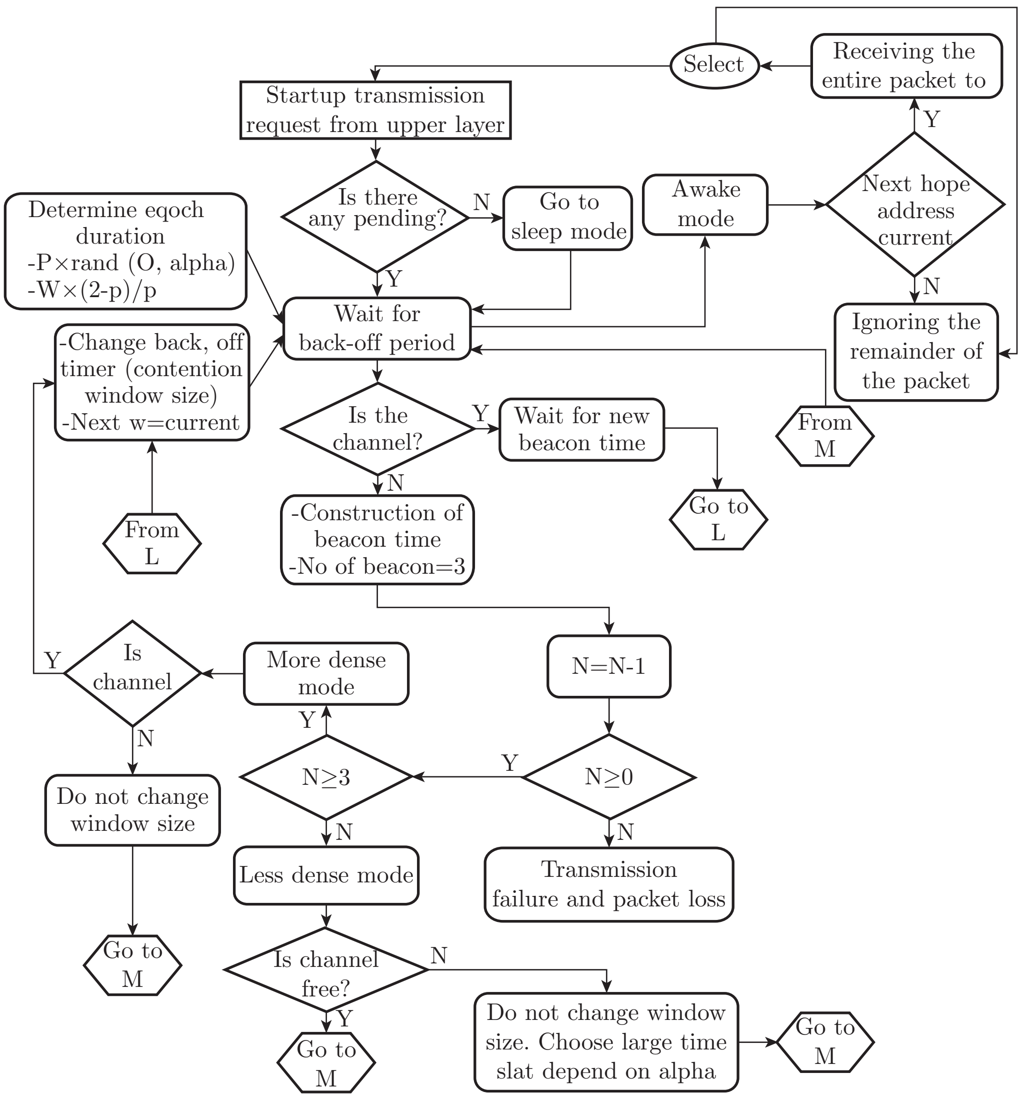

Fig. 3: The flow chart of proposed model

5 Implementation

D-MAC protocol using simulations, we implemented most of the protocol on the CC2420 wireless sensor node [19] as shown in Fig. 7. We did not implement all features. To test the effectiveness of the, a large-scale experiment is needed, involving a lot of nodes. We have also not implemented the possibility to keep multiple schedules yet. Although this is fairly easy to implement, we have only tested D-MAC with single-cluster configurations.

The Table 2 lists the primitive operation by a low power sensor.

The performance is evaluated in terms of throughput and energy efficiency using Matlab simulations for maximum of 3 nodes. Each sensor nodes choose a random movement for receiving packets from neighbors. In this implementation routing issue is not considered, hence we assumed simple AODV routing model.

This model node built in a network of fixed node in star topology placed at a minimum distance of 7 meters radio range. For the simulation purposes we use the parameters in Table 1 for the

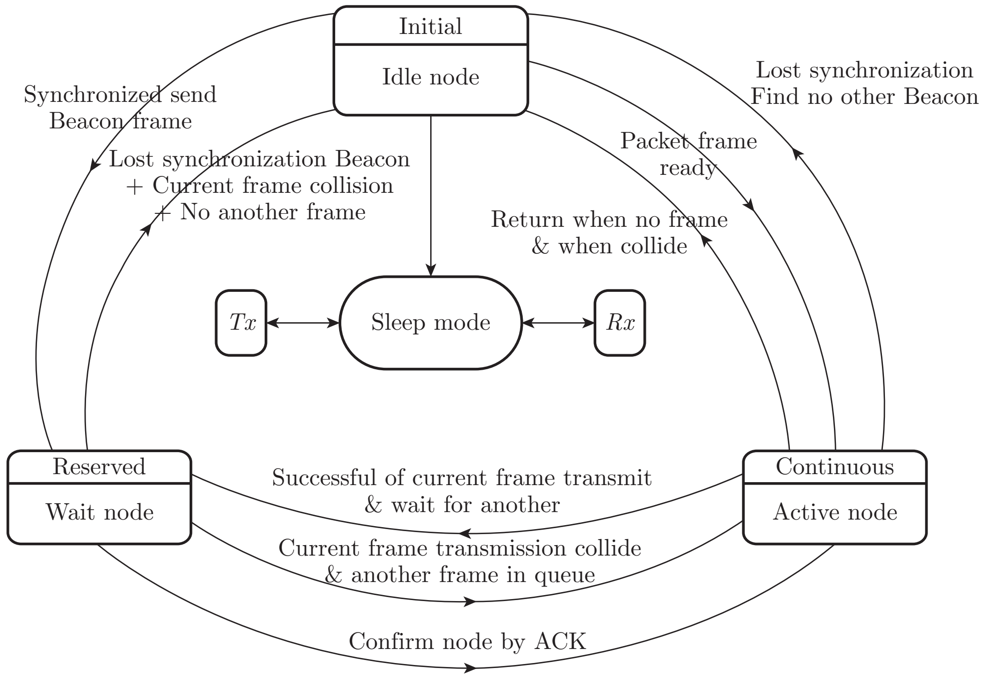

Fig. 4: Energy state and transition

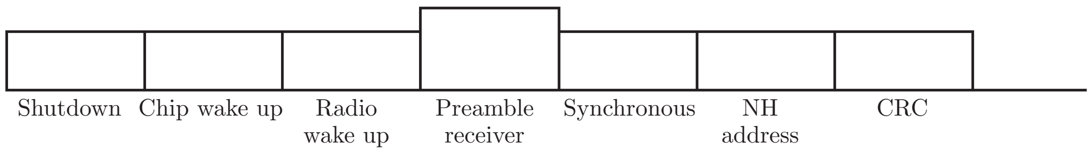

Fig. 5: The structure of D-MAC frame

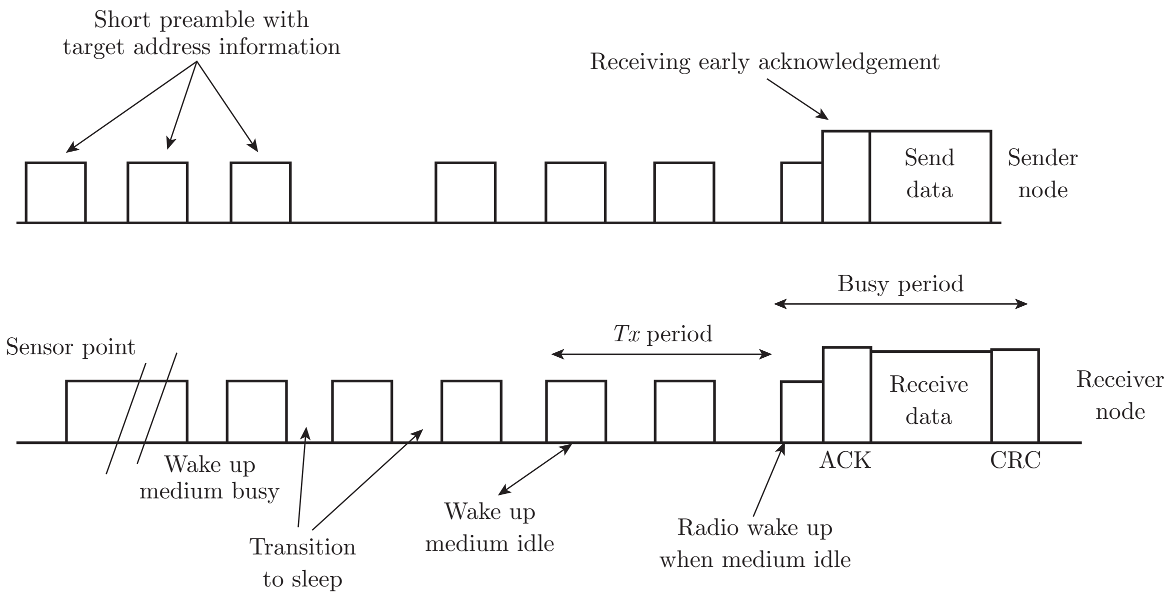

Fig. 6: Timing diagrams of energy states

radio transmitter and receiver.

Fig. 7: CC2420 radio interface board

Table 2: Parameters used during simulation

	Testing Parameter	Value
1.	Transmission power	0.45 mW
2.	Receiving power	0.5 W
3.	Packet transmission time	115 ms
4.	Discount factor	0.63
5.	Frame length	3.124 sec
6.	Buffer size	21
7.	Radio transmission rate	28 kbps
8.	EIDLE (Energy used in idle listening)	0.001 mW
9.	ETX (Energy required for transmitting a bit) E	25.0 mW
10.	ERX (Energy required for receiving a transmit bit) E	0.014 mW
11.	ESLEEP (Energy used in sleep mode of radio)	0.015 mW
12.	Energy expended during Transition of state (Sleep-Receive)	0.04 mW
13.	Energy expended during Transition of state (Transmit-sleep)	0.025 mW

6 Result Discussion

In our experiments, we compared three protocols: X-MAC, E-MAC and D-MAC.

Fig. 8 (a) represents the simulation result of sensor hops & latency. It reveals that D-MAC latency is less compared other two MAC by the adaptive listening technique.

Fig. 8 (b) represents the simulation result based on energy consumption against packet sent shows reduction in overhearing that caused by several check intervals and the increase in sleep mode of the numbers of neighboring nodes.

D-MAC shows the observation cost is lower for the nearly higher sleeping probability in Fig. 8 (c). Compared to other two protocols X-MAC and E-MAC the D-MAC shows improvement that observed in the number of packets received efficiency, reduction in end to end delay of the packet transfer thereby the throughput improved. The energy consumption is optimized to 9.83% in the modified D-MAC protocol [16]. For D-MAC the average gain in collision over the other two protocols is 32.7%. In other words, adaptive form of preamble concept leads the Z -MAC protocol performs better than the X-MAC and E-MAC.

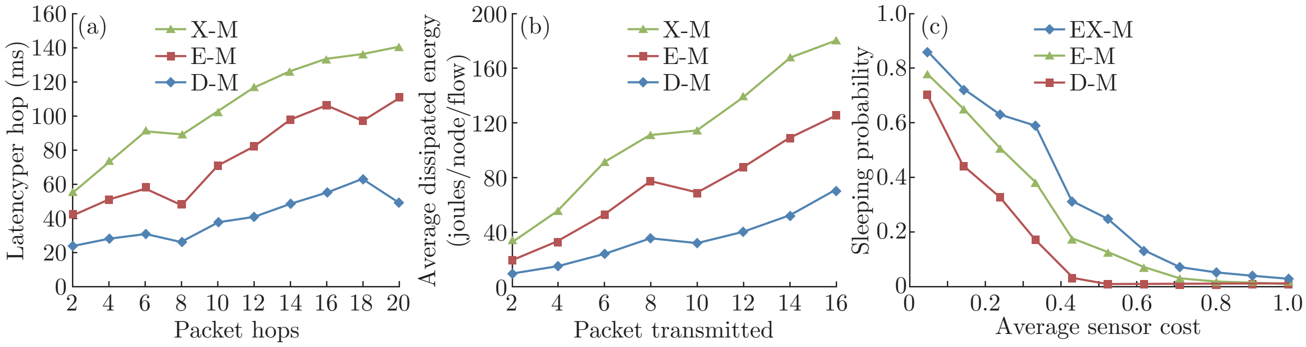

Fig. 8: (a) Latency study with hop numbers; (b) Energy consumption with packet wakeup; (c) Optimal sleeping probability for average power consumption

The result analysis is observes are stated below Table 3.

Table 3: Result analysis

	X-MAC	E-MAC	D-MAC
Packet receive	90%	78.3%	90.62%
Average sleep (ms)	292.88	145.64	387.23
Duty cycle	7.1% sleep, 4.3% active	5.6 sleep, 7.2% active	8.6% sleep, 3.9% active
Energy saving	10% less	23% less	9% less
Throughput	26%	14%	37%

7 Conclusion

We have simulated the performance of the proposed MAC protocol is based upon energy consumption and latency. In the simulation, no mobility is assumed. In our experimental simulation we performed test based on flow chart as illustrated in Fig. 3. We vary the traffic load by changing the packet inter-arrival time on the source node. In our simulations we evaluate the performance of our scheme and compared it with the standard gives 37% throughput & 9% less energy saving.

The simulation results point up that the energy consumption has been optimized significantly when compared with X-MAC & E-MAC protocol. It is worth to note, that D-MAC conserves an appropriate latency property under very large nodes. A collision and control packet under large heterogeneous network provides argument in D-MAC protocol performance. Results assessment indicates that the D-MAC provides around 61% improvement where it has 46% better energy saving than X-MAC & E-MAC protocol. Overall, the combination of these two methods fortifies our model and makes it far suitable for sensor networks in random traffic situation.

Further study is to be devoted to the random D-MAC protocol Model to minimize the overhearing design for improving the energy efficiency. However the D-MAC protocol gives the efficient result for the reduction in dusty cycle, amount of packet received rate more than 90.62%. But still there is a room for future research works. Our future plan includes D-MAC protocol by combining with topology types to provide an energy efficient node.

Acknowledgment

The author would like to thank the Mr. Ranjit Patro-Project Team coordinator of R&D-Samsong India and Dr. K. Tangavelu, Professor, Periyar University, Salem, India for their valuable support. Also would like to thank the anonymous and efficient reviewer for the constructive feedback and valuable input to shape this paper for the research product. This works was carried towards the academic research of Anna University Coimbatore.

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