Performance Analysis of MAC protocols in Energy Consumption of Wireless Sensor Networks

Prof Mrs. Urmila A. Patil[1], Ms. Suma B. J[2], Ms. Smita. V Modi[3]

Electronics and Telecommunication DYPIET, Pune University

Pune, Maharashtra, India

[1]urmilaapatil76@gmail.com

[2]suma.dupalli@gmail.com

[3]Smita.modi3@gmail.com

***Abstract*- Recent advancement wireless communications and electronics have enabled the development of low-cost sensor networks. This sensor networks consist wireless sensor nodes. These sensor nodes majorly depend on batteries for energy, which get reduced at a faster rate because of the computation and communication operations. For such wireless communication few efficient routing protocols and MAC protocols can be designed for significant benefits to wireless sensor networks. In this article we had compared the performance of some routing and MAC protocols and the simulation results were analyzed by graphical manner. A network simulator-2 (NS-2) called MobiREAL simulator has been designed and developed for performance evaluation for these protocols.**

Keyword: AODV, DSDV, SMAC, Simple, NS-2.

I. INTRODUCTION

A Wireless sensor network (WSN) is collection of nodes organized into a cooperative network. Each node consists of processing capability, may contain multiple types of memory, have a Power source, and accommodate various sensors and actuators. A wireless sensor network consists of a large number of distributed nodes with sensing, data processing, and communication capabilities. Those nodes are self- organized into a multi-hop wireless network and collaborate to accomplish a common task [1].As sensor nodes are usually battery-powered, and they should be able to operate without attendance for a relatively long period of time, energy efficiency is of critical importance in the design of wireless sensor networks.

WSNs offer unique benefits and versatility with respect to low-power and low-cost rapid deployment for many applications that do not need human supervision. Some of these applications include disaster recovery, military surveillance, health administration, environmental & habitat monitoring, target-tracking etc. Due to the large numbers of nodes
Involved in the WSN deployment new benefits to the afore-mentioned sensing applications including:

• **Extended range of sensing:** WSNs enable large numbers of nodes to be physically separated; while nodes located close to each other will have correlated data (e.g., these nodes will be collecting data about the same event), nodes that are farther apart will be able to extract information about different events.
• **Robustness and fault-tolerance:** Ensuring that several nodes are located close to each other and hence having correlated data makes these systems much more robust in terms of data sensing (even though it involves redundancy). In case of WSNs even if a small number of sensor nodes from a network fail, there is enough redundancy in the data from different nodes that the system may still produce acceptable quality information.
• **Improved accuracy** - While an individual sensor's data might be less accurate than another independent sensor's data (both sensor nodes are assumed to be in close proximity to the detected event) in the WSN, combining the data from nodes increases the accuracy of the sensed data. Since nodes located close to each other are gathering information about the same event, aggregating their data enhances the common signal and reduces the uncorrelated noise as well.
• **Lower cost** - Due to reduced size, reliability, and accuracy constraints on sensor nodes, these nodes are much cheaper than their high-accuracy high- complexity sensor counterparts.

However to be able to realize all the discussed specifications we need to design protocols that can provide appropriate support and allow the wide-spread use of WSNs.

Sensors are small nodes which are capable of data processing and communication. The sensor node measures ambient conditions from environment, transform it into electrical signals and sends via radio transceiver to a sink and then this aggregated information is sent back to a base station through a gateway [1]. Sensor networks are distributed sensors to monitor conditions like temperature, sound, vibration, pressure and pollutants etc. WSN links physical world and digital data network and provide a distributed network having the constraint of scalability, lifetime and energy efficiency.

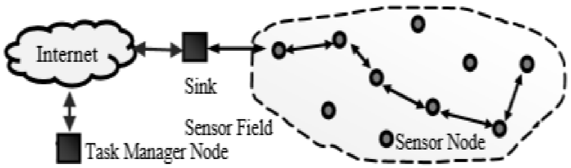

Figure1. A Wireless Sensor Network

System Architecture and Design Issues Since routing protocols are application specific so the performance of routing protocol is dependent upon the system architecture. The following issues are generally encountered [2]

• **Network Dynamics:** Since the sensed event can be either static or dynamic so the most challenging task is to route the message among the nodes. Route stability becomes an important optimization factor, in addition to energy and bandwidth.

• **Node Deployment:** The performance of the routing protocol is application dependent and it can be either deterministic or randomized.

• **Data Aggregation:** The elimination of duplicate data collected from different sensors is called data aggregation. Every node should have the capability of data aggregation because computation is less energy consuming than communication.

• **Node Capability:** A sink is more powerful than normal sensors in terms of energy and bandwidth. Some application requires cluster-heads with normal sensors for computation or aggregation.

• **Data Delivery:** The aggregated data through the sensors is delivered to the sink; this delivery can be continuous, query driven or hybrid. • Direct Vs Multi-hop: When all the nodes are close to the sink, direct routing is preferred. Since the transmission power is proportional to the square of the distance covered by data so in that case multi-hop routing is preferable.

II. WSN Background:

The devices are typically equipped with a processor, memory, sensors and communication deviceswith radio systems. All these functions can be put together in one microchip. Wireless devices are very flexible as long as the power supply, usually a battery, provides enough energy. But chargingor replacing a battery can be very expensive and complicated. That is why energy saving is soimportant. Usually the sensor nodes don't need to stay active continuously, they only transmit dataperiodically. Especially wireless communication consumes a lot of energy by amplifying receivedsignals or sending data. The radio units have generally three states: Transmitting signals costsmost energy. Receiving signal doesn't need the same amount of energy, but it also needs a lot.

The Idle state needs (nearly) no power. To be reliable for network peers the devices have tointerpret the received radio signal even if there is nothing transmitted. Based on these Information'sthe idea is to put the devices to sleep when they are not used and let them periodically wake up.

That is not as easy as it sounds. To realize this idea the communication partners have to besynchronized at least for each single transmission. The wireless extension is managed by a mediaaccess control protocol. The task of this protocol is to transport local data to a target peer over thephysical layer, the networking hardware.

III. Requirements for Wireless Network MAC Protocols

A Wireless Medium is a shared medium. This means one instance in the signal range is allowed tosend data at most. This data can be received by one or more attendees. The MAC Protocol has totransmit given information frames over this shared medium to a network peer. To do so it isrequired that every network peer has an identifier. This is usually called a MAC address and has tobe unique for the current network. It is even better if the address is global unique because addingor exchanging sensors in different networks might be possible. How this MAC address looks like ispart of the MAC protocol definition. There should be a large range of addresses because thenumber of participants in the network may increase fast. The network size should be scalable; asmall fixed limit of peers is not useful in general. Autonomy should be guaranteed. It would be toocomplicated if a human has to set up a lot of single parameters on the mac layer. It is alsoexpected that the network is self-organizing. Possibly new peers appear, others might disappear orthe topology will be changed. A network has to be reliable. It is not useful if a user has nowarranties for successful participation. These are basic properties which should be fulfilled by aMAC protocol.

IV. Problem statement:

In this paper our main aim is to present practical investigation of MAC protocols and routing protocols in terms of various network conditions in terms of energy efficient in different protocols of routing and MAC protocols.

In this paper, the behavior of routing protocols and MAC protocols are compared with each of the routing protocols and final simulation is represented which specifies which routing protocols are efficient in terms of energy efficient for wireless sensor networks.

V. Objective:

- To present MAC protocols such as SMAC and Simple.
- To evaluate the performances of above said MAC protocols under different routing protocols like AODV and DSDV with varying number of sensor nodes.
- To present the comparative analysis for average energy consumption, total energy consumption and residual energy.

- To present the conclusion based on above simulation results.

VI. Presentation of Mac Protocols

S-MAC:

This Protocol is based on the adaptive listening concept. Nodes are in sleep mode and listenperiodically if there is a data transmission announced. In that way the virtual carrier sense can beused and the radio can remain turned off until the transmission of the neighbours is done. Forsynchronization nodes listen to and send routinely SYNC packets via broadcast. Because of thedistributed ad-hoc structure there are nodes which can reach each other directly and nodes whichcan't. The groups of nodes which can reach each other are called virtual clusters. Nodes in thesame virtual cluster synchronize each other. Nodes at borders of two clusters may have two wakeup schedules. The clock drift between the peers is very small in comparison to the wakeup period.But to ensure a received message is complete nodes wait a short time value before sending. Toavoid overhearing the transmission time is part of the announcement. There is no central accesspoint, network peers communicate with each other. It follows that no instance configures thenetwork, so every node has to detect its communication peers. Neighbours detection is expensive. Anode with no neighbours performs the detection more often than a node with one or manyneighbours. There is no fairness guarantee. To prevent starvation the carrier sense time israndomized in a certain time window. It is possible that sources can't reach the destination directly.

S-MAC [4] is a low power RTC-CTS based MAC protocol that makes use of loose synchronization between nodes to allow for duty cycling in sensor networks. The protocol uses three techniques to achieve low power duty cycling: periodic sleep, virtual clustering, and adaptive listening. The nodes in the network periodically wake up, receive and transmit data, and return to sleep. At the beginning of the awake period, a node exchanges synchronization and schedule information with its neighbors to assure that the node and its neighbors wake up concurrently. This schedule is only adhered to locally, resulting in a virtual cluster, which mitigates the need for system wide synchronization. Nodes that lie on the border of two virtual clusters adhere to the schedules of both clusters, which maintain connectivity across the network. After the synchronization information is exchanged, the nodes transmit packets using RTS-CTS until the end of the awake period and the nodes then enter sleep mode.

In many wireless sensor network applications, nodes are in an idle state for a longtime if no sensing event occurs. Given the fact that the sampling rate is very low, itis not necessary to keep nodes listening all the time. Therefore, in order to reduce thetime for idle listening, duty cycle is introduced in the recent contention-based MAC protocols. Instead of listening to the medium all the time, each node periodically cycles between an awake and a sleep states. Standard MAC protocols developed for duty-cycled wireless sensor networks are categorized into synchronous and asynchronousapproaches, along with hybrid combinations. Synchronous MAC protocols define a lowduty cycle and synchronize the listening and sleeping schedules for all the nodes (such as S-MAC and T-MAC)).

For example, in SMAC, each listen phase is dividedinto two parts. The first part is used for schedule synchronization. This is accomplishedvia a periodically transmitted SYNC packet. An SYNC packet is very short, includingthe address of the transmitting node and the time for its next sleep. Once a nodeenters a wireless sensor network, it first listens to the channel for a period of time. Ifit hears a SYNC packet from one of its neighbors during this time, it will adjust itsown schedule according to it and goes to the sleep state as soon as the timer fires.

If no SYNC packet is received, the node will randomly and independently choose aschedule and sends its corresponding SYNC packet in a broadcast mode. If the nodereceives a different schedule after it selects its own one, it will accept both schedules.This makes a node at the border of a network listening for a longer time. The secondpart is used for data communication by applying the message passing mechanism.Instead of sending a data packet each time, SMAC divides the long message into manysmall fragments and transmits them in burst. This optimization highly reduces theretransmission cost if only a few bits have been corrupted during the data transmission.In addition, the control packet of RTS and CTS prevents the neighbor overhearingproblem. The working mechanism of SMAC is described in Figure 2

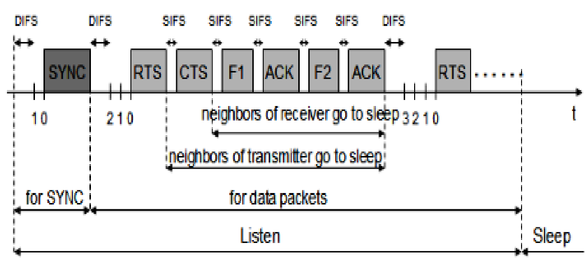

Figure 2: Working Procedure of SMAC

An important feature of S-MAC is the concept of message-passing where long messages are divided into frames and sent in a burst. With this technique, one may achieve energy savings by minimizing communication overhead at the expense of unfairness in medium access. Periodic sleep may result in high latency especially for multi-hop routing algorithms, since all immediate nodes have their own sleep schedules. The latency caused by periodic sleeping is called sleep delay in [5]. Adaptive listening technique is proposed to improve the sleep delay, and thus the overall latency. In that technique, the node who overhears its neighbor's transmissions wakes up for a short time at the end of the transmission. Hence, if the node is the next-hop node, its neighbor could pass data immediately. The end of the transmissions is known by the duration field of RTS/CTS packets.

VII. Simple Mac (B-Mac/X-MAC)

Even though the synchronous MAC protocols greatly reduce the time of node idlelistening, the required schedule synchronization brings extra communication overheadand increases design complexity. In order to address these issues, the asynchronousMAC protocols are proposed by decoupling time schedules of nodes (such as B-MAC, WiseMAC, X-MAC and RI-MAC). Instead of using the controlpacket of RTS and CTS, the asynchronous MAC protocols use either preamble orbeacon to reserve the medium.

For example, B-MAC utilizes an extended preamble toachieve low power communication. If a node wishes to transmit, it precedes the datapacket with a preamble that is set longer than a node's sleep period. This guarantees thedetection of preamble by a receiver no matter when it wakes up. Since the target addressis embedded in the header of each data packet, a node can only figure out whether itis the intended receiver after it overhears the entire preamble. In order to minimize thetime for overhearing, X-MAC is developed. Instead of sending a long preamble, seriesof short strobed preambles are transmitted, each including the target address. In thisway, once a receiver wakes up and detects a short preamble, it will either reply withan early ACK packet if it is the intended receiver or directly go to sleep otherwise. Asillustrated in Figure 3, the asynchronous approaches save much energy and time.

VIII. X-MAC Protocol Design

The design goals of the X-MAC protocol for duty-cycled WSNs are:

• Energy-efficiency

• Simple, low-overhead, distributed implementation • low latency for data

• High throughput for data

• Adaptively to offered data load

• Applicability across all types of packetizing and bit stream digital radios

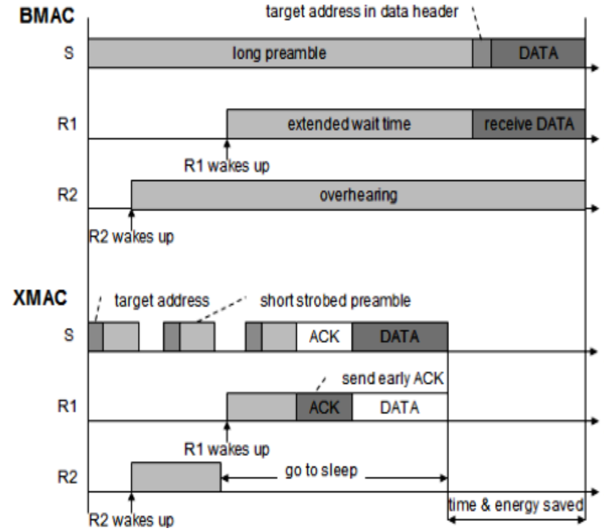

Figure 3: the working mechanism of B-MAC and X-MAC

IX. Asynchronous Duty Cycling

A visual representation of asynchronous low power listening (LPL) duty cycling is summarized in the top section of Figure 3. When a node has data to send, it first transmits an extended preamble, and then sends the data packet. All other nodes maintain their own unsynchronized sleep schedules. When the receiver awakens, it samples the medium. If a preamble is detected, the receiver remains awake for the remainder of the long preamble, then determines if it is the target. After receiving the full preamble, if the receiver is not the target, then it goes back to sleep.

In X-MAC, we ameliorate the overhearingproblem by di- viding the one long preamble into a series of short preamble packets, each containing the ID of the target node, as indi- cated in Figure 3. The stream of short preamble packets ef- fectively constitutes a a single long preamble. When a node wakes up and receives a short preamble packet, it looks at the target node ID that is included in the packet. If the node is not the intended recipient, the node returns to sleep imme- diately and continues its duty cycling as if the medium had been idle. If the node is the intended recipient, it remains awake for the subsequent data packet. As seen in the figure, a node can quickly return to sleep, thus avoiding the over- hearing problem.

X. ANALYTIC RESULT

In this section, we will compare the simulation and analytic results to show the accuracy of our proposed model. We also shows how the model can be used to help sensor application design. Finally, we present some observations of S-MAC and SIMPLE MAC based on the proposed model using two routing protocols AODV and DSDV.

XI. SIMULATION ENVIORNMENT:

NS2 is stand of the Network Simulator Version 2 which is targeted specially for the networks simulations. NS2 is nothing but the discrete event simulator for the researches in the area of networking. NS2 provides the simulation and research supports for the wired networks, wireless networks by using TCP, and UDP, IP, and CBR patterns of the communications. NS2 is made of two parts basically such as NS means network simulator and other one is NAM means network animator. NS is used to simulate all the protocols like commonly used IP protocols over the wireless as well as wired networks.
There also some other features of the ns-2 which increases our interests of using the ns2 simulator for the simulation of our network applications such as:

- NS2 provides the network simulation environment for both wired, wireless means MANET networks.
- Provides the modules for the wireless channel such as 802.11, 802.16 etc.
- Provides the number of routing protocols for choice in which the routing is done along multiple paths.
- Simulations of the cellular networks possible as the mobile hosts are simulated as well.

Scenarios:

<u>Mac protocols</u>

1) Simple

2) SMAC

<u>Scenarios</u>

1) 25 nodes

2) 50 nodes

3) 75 nodes

<u>Routing Protocols</u>

1) AODV

2) DSDV

Number of Nodes	25
Traffic Patterns	CBR(Constant Bit Rate)
Network Size	500 x 500 (X x Y)
Max Speed	10 m/s
Simulation Time	15s
Transmission Packet Rate Time	10 m/s
Pause Time	2.0s
Routing Protocol	AODV/DSDV
MAC Protocol	Simple/SMAC

Number of Nodes	50
Traffic Patterns	CBR (Constant Bit Rate)
Network Size	1000 x 1000 (X x Y)
Max Speed	10 m/s
Simulation Time	20s
Transmission Packet Rate Time	10 m/s
Pause Time	2.0s
Routing Protocol	AODV/DSDV
MAC Protocol	Simple/SMAC

Number of Nodes	75
Traffic Patterns	CBR (Constant Bit Rate)
Network Size	1000 x 1000 (X x Y)
Max Speed	10 m/s
Simulation Time	25s
Transmission Packet Rate Time	10 m/s
Pause Time	2.0s
Routing Protocol	AODV/DSDV
MAC Protocol	Simple/SMAC

XII. Results:

As per the discussions, here we are presenting the calculations and results obtained from simulation work done over estimated two MAC protocols and Two Routing protocols.

We have recorded the metrics such as average energy consumption, total energy consumption and residual energy consumption for all MAC protocols and routing protocols. Below is the comparative analysis graphs based on practical readings.

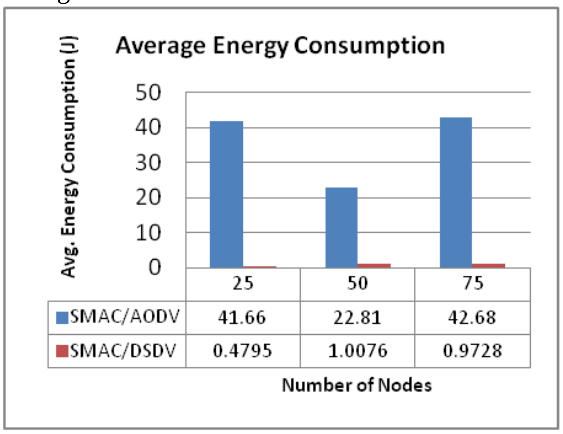

Figure 4: SMAC Average Energy

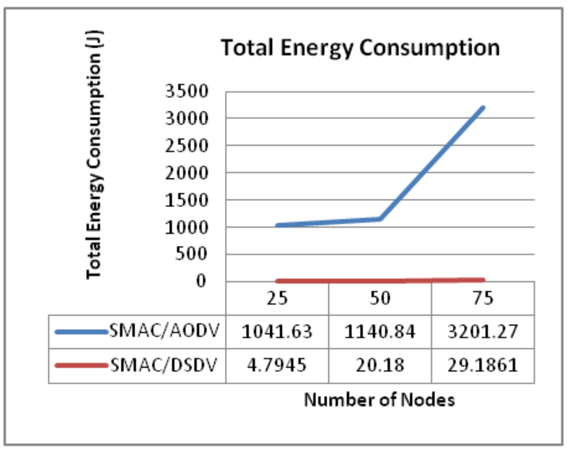

Figure 5: SMAC Total Energy Consumption

From the graphs showing in figure 4, 5, 6 for SMAC protocol, it shows that energy consumption in case of AODV in all scenarios is still more compared to DSDV

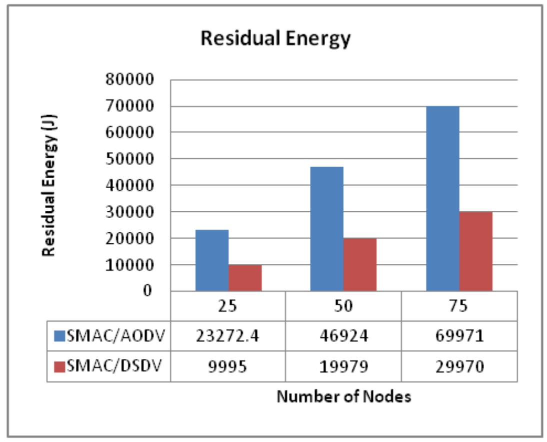

Figure 6: SMAC Residual Energy

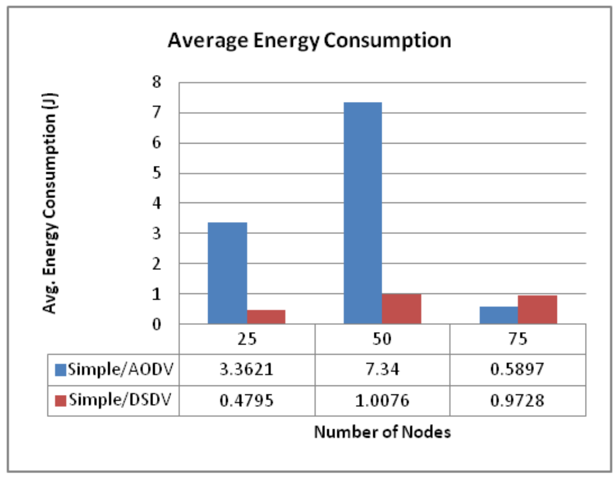

Figure 7: Simple Average Energy consumption

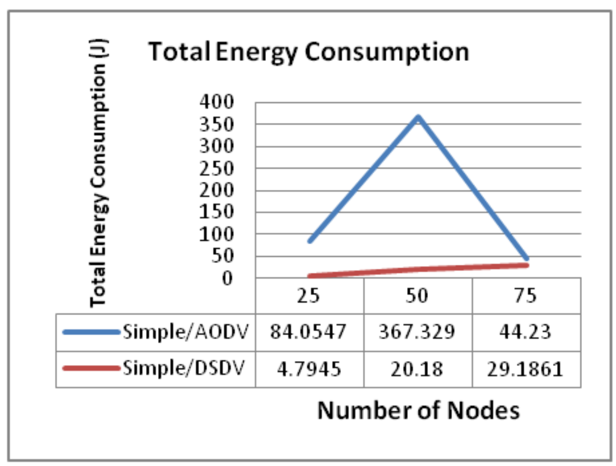

Figure 8: Total Energy Consumption

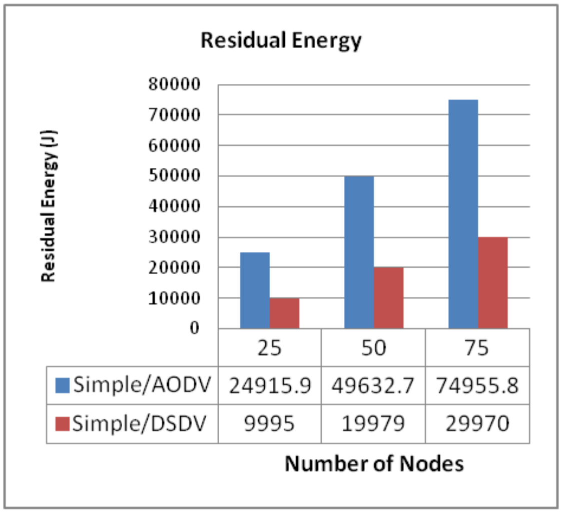

Figure 9: Residual Energy

From this final graphs figure 7, 8 and 9 showing above for Simple MAC protocol, it shows that energy consumption of AODV for 25 and 50 nodes more as compared to DSDV, while for 75 nodes its less as compared to DSDV. As per the consideration of MAC, Simple Mac having less energy consumption SMAC.

XIII. Conclusion

As sensor nodes are typically considered to be small, inexpensive, and low processing power devices, energy-efficiency has been perceived as the primary metric of concern in WSNs. At the heart of research, medium access control is an intriguing topic, since it directly controls the radio transceiver operation that is considered to be the most energy-consuming operation of a sensor network node. As a consequence, there have been numerous MAC protocol proposals in the scientific community, as well as industrial and institutional standards for wireless sensor and personal area networks. The proposed MAC protocols can be categorized in multiple ways according to their type of operation, topology, layers involved, etc. to group the nuances of different proposals and perceive the scope.

We have observed for that SMAC is better for WSN by considering the average performances, whereas for low energy consumption, Simple MAC is better option.

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