# Enhancing the Energy Efficiencyin Wireless Sensor Network Using Extended S-MAC (ES-MAC) Protocol

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**Abstract**

Wireless Sensor Network applications deploy sensor nodes in large numbers in such manner to provide better results. All the sensor nodes are efficient sensing devices operating by the limited capacity of batteries. Most of the WSN applications belong to surveillance monitoring, like forest monitoring and environmental monitoring. Sensor nodes are organized in an Adhoc manner, and each node communicates individually with any other nodes for a long period without knowing its battery capacity. Due to the energy consumption, the sensor nodes suddenly become inactive or dead during the process. Thus, computing and electronics industries are joined together for reducing the overall energy spent by the sensors present in sensor network, i.e., to prolong their lifetime, they are focusing on configuring or designing MAC protocol to increase the energy efficiency. In earlier research different MAC protocols are implemented, but the efficiency varies based on the application and environment. Thus, it is important in designing a common MAC system to support a greater number of surveillance applications and also assists in improving the energy efficiency of the sensor in the network. To do that, this paper aimed to design and implement a novel Extended S-MAC routing protocol for enlightening energy efficiency. The Extended S-MAC is simulated in the Network Simulator tool, and the results are verified. The performance of the proposed Extended S-MAC is evaluated by comparing its results with the other state-of-the-art MAC protocols. Comparing with the existing MAC, the proposed MAC obtained 17% more energy and proved it is better.

**Keywords:** Wireless Sensor Networks, MAC Protocol, S-MAC, ES-MAC, Energy Efficiency, Surveillance Applications.

## Introduction

Nowadays, wireless is focused more than a wired network technology has grabbed researchers' attention too. The wireless sensor network is a widely used wireless technology which contains different types of sensors for different works and they are commonly connected to a base station [1]. A typical sensor consists of memory unit, an antenna for receiving signals, a processing unit and a battery with limited amount of energy. Generally wireless sensor networks are implemented in smart centres and industrial areas for surveillance purposes [2].

WSN is anadvanced application in a wireless network that comprises different actions such sensing an event, computing the data, and also has a communication protocol called as sensor nodes and sink. The sensor nodes help in data collection from different areas like temperature, pressure, humidity, etc [3]. The base station is a sink that receives all data from the sensor nodes. The sensor nodes work in good coordination to send data to base station and then the data is transmitted to the destination [4].

Nodes communicates among them using various protocols. In a wired network, the wires act as a medium to interact the sensor nodes coordinate with each other and send the data to the sink through a gateway is an interface between the sink and sensor nodes [5]. The sink analysis and processes the collected data. Based on this deployment, WSN is categorized [5] as follows.

- **Terrestrial WSN**: This type of network is usually placed on some denser areas and it is placed in ad-hoc manner.
- **Underground WSN:** This type of network usually placed below the surface level. This type requires a well planning for placement of sensor nodes.

- **UnderwaterWSN**: This sensor network is used to gather ocean related data and deployed inside a sea or ocean.
- **Multimedia WSN:** In this network, the sensor nodes are capable of retrieving and storing multimedia content from their surroundings.
- **Mobile WSN:** It is the same as a static sensor but is moveable.

Initially, WSN is used for military purposes. They are used in the military for monitoring, surveillance, and border monitoring, but now WSN is used widely in almost every field [6]. Some of the applications of WSN are, (1). **Agriculture, t**o increase production, crop production data are collected through sensors for monitoring climate, by deployed sensors under the ground or over the ground, (2). **Health care center,** WSN is used to monitor and diagnosis the disease of the patient by monitoring, (3). **Humidity,**sensor is deployed to measure temperature and the humidity data, which helps in forecasting the weather, (4). **Natural disaster prediction and prevention,** Natural disasters cannot be controlled but can be predicted WSN helps predict the change in the environment to reduce losses, (5). **Driverless vehicles,** WSN is used in collecting numerous data like velocity, speed, the distance between object or obstacles on road and vehicle, from various sensor and synthesis the data, and (5). **Weatherforecasting,** WSN helps collect data from the surrounding by the collected data scientist can forecast weather conditions.

As mentioned above, WSN helps in predicting all the spoken advantages. It also has some disadvantages such as energy limitation, aggregation in data, scalability, delay, and control overheads. These constraints can be addressed by introducing different media access control (MNC) protocols [6]. This paper focuses on:

- Short messages are used for overcoming the control overheads to enhance the energy efficiency.
- Introducing aES-MAC protocol to select cluster head so that the exiting algorithm is improved in terms of energy efficiency.
- Employing artificial neural network with backpropagation approach for improving the existing method in terms of throughput.

**IEEE 802.15.4**

The IEEE 802.15.4 standard defines two different types of Full Function Device (FFD) and Reduced Function Device (RFD). FFD supports the protocols of the wireless standard defined for WSN. Limited functionality with low cost and complexity id provided by RFD. Low data rate WPANs, with low complexity and stringent power consumption requirements, are the focus areas of IEEE 802.15.4 [7]. It is designed mainly for cost-effectiveness, low power consumption, and low interference technology. It can serve to a range of about 10 to 75 meters depending on the power it works on. The 802.15.4. standard defines two-layer, Data Link Layer (DLL) and physical layer (PHY). These layers support sensor devices withminimalpower consumption and limited area operations [8]. The two-layer effectively communicates between network nodes by avoiding a collision. DLL is of two sub-layer, medium access control and logical link layer, using acknowledged frame delivery MAC layer is responsible for frame validation. The channel can be accessed only if it free of activities. This can avoid collision and reduce energy consumption [9].

**Extended S-MAC Derived from S-MAC**

A modification over S-MAC is modified sensor-medium access control. The energy fallout due to idle listening is avoided by combining the scheduling process and duty cycle. **Extended S-MAC(ES –MAC)**reduces the energy waste at the MAC layer due to the advancement of S-MAC, by integrating the optimizations in synchronization phase. The energy consumed at different phases is compared and it is found that the highest amount of energy consumed is in synchronization phase. The next SYNC period starts once the SYNC packet is successfully exchanged. This enables the node in sleep mode even in SYNC period once the SYNC packet bypasses the synchronization phase.

Exchanging the schedules using the broadcast of a sync packet for an S-MAC node to neighbours periodically is required for phase exchange of synchronization of the node in the network. In the synchronization phase, an exchange of sync packets takes place for transporting the schedule to neighbours. RTS and CTS handshaking mechanism is used between nodes so that sync packet can be broadcasted without any agreement. The exchanging event of SYNC packet is called as synchronization period in which 0 frames is the default value of period ns-2. Only during the sync period, the sync packets get exchanged and the energy consumption is improved by **Extended S-MAC** by manipulating the SYNC packets based on the period required.

All the nodes in Extended S-MAC should maintain a 'neighbour list' in the neighbour list table. In the current sync period, a node can be intelligent enough to decide it is on by deciding either to stop or wake up. A new field is added called "COUNT", which acts as a counter corresponding to each neighbour all nodes maintains a separate neighbour. After each cycle time, the counter is increased by one when the node receives a sync packet from a corresponding neighbour, and the counter automatically resets to zero. By this, the counter can calculate the number of cycles elapsed since the last sync packet received for each neighbour by examining the counter value. Node **X** can realize whether it will receive the sync packet in the current sync period or not.

The node understands that it will get a sync packet now if the counter value and the synchronization period are equal.If the node receives a SYNC packet, then the node will wake up from the sleeping state. By this, we came to understand that **Extended S-MAC** allows nodes to be in a sleep state during the sync period while there is no sync packet queued in the sync period. The synchronization period schedule updating is accomplished by sending a sync packet in **Extended S-MAC**. The sync packet will be very short which includes the address of the sender and the time of its next sleep. The next sleep time is the moment the sender starts transmitting the sync packet. When the time is received by a receiver, it subtracts the packet transmission time and uses the new value to adjust its time. Thus SYNC period is managed for improving the energy efficiency. Extended S-MAC will not affect the system performance and it increases the chances of limiting the energy consumption.

**Lightweight medium access control for WSN**

In order to control the power consumption, a lightweight WSN MAC protocol and a fabricated ASIC-based controlled chip are used in this system [10]. The communication protocol of fabricated WSN has two modes: they are conservation and data transmission. The conservation mode is used for construction and data dismissing of data. An acknowledgement scheme is required by this conservation mode for maintaining the network security and reliability. The acknowledgement scheme is used based on the data and it is optional. A transition graph called DES is implemented for monitoring the changes in the proposed system [11]. The DES models and supervised control design are modelled using a graphical language named GRAFCET. Super node design is carried out in this method. Three different categories to handle the situation when more than one super node communicates in a data region are,

**PRIORITY DISTINCTIONS**

When multiple queries are sent from multiple super nodes the query with the most priority will take over a query with less priority.A sensor node is not converted into a super node by considering the number of queries it sends or by the time set. It is transformed with priority.If the variation value exceeds the maximum value, then the sensor nodes with the same level of priority is transformed into a super node.

**Existing S-MAC**

Usually, the sensor network is a group of smaller nodes which are arranged in an ad-hoc manner. This large number of the node can have a short-range, multi-hop communication. This will help conserve energy. Since the sensor network is mostly application performance. The application code is passed throughout the network layer and only activated whenever the situation demands it. The lifetime of the network is critical in some applications where they are vigilant for a long period, but largely inactive until something is detected. They can tolerate additional latencies.In such conditions, the proposed protocol reduces the listening time by letting the node go into periodic sleep mode. Every node after some sleep time wakes up and if any other nodes want to communicate within. During sleep time the radio of that particular node is turned off and an alarm is set to wake up the node after a particular time. A schedule table is maintained by each node so that it stores all the schedules of its neighbours.The following steps are been followed for choosing and establishing its schedule,

- A node listens for a certain amount of time if it does not receive any schedule, it chooses a time randomly to go to sleep and inform that time by broadcasting its schedule as a SYNC message. The schedule nodes are also called as "synchronizers" because the nodes select their own schedule on their own.
- When a node finds a schedule before choosing its schedule it tends to follow the schedule that it received. Such nodes are called followers. These schedules sleep at their sleep time and broadcast at the scheduled time to avoid collision between the rebroadcasting nodes.
- If a node finds a schedule after broadcasting its schedule, then it adopts both the schedule i.e., it wakes up at its schedule, and also the schedule it adopted from the neighbour and sleeps in the time in between.

**Proposed Extended S-MAC Protocol**

The proposed Extended S-MAC protocol is derived from the existing S-MAC protocol by extending additional features to reduce the energy consumption. Both the S-MAC and the Extended S-MAC protocols are explained below.

**Sensor-MAC Protocol Design**

The main goal of this paper is to maintain the energy consumption with a better scalability and avoiding collision. This protocol reduces the overall energy consumption by limiting the sources that causes energy wastage. For example; collision, idle listening, overhearing and control overhead. A new MAC protocol called **Extended S-MAC** protocol is developed for achieving such design. This **Extended S-MAC** protocol is constructed with three components such as (1) periodic listen and sleep, (2) overhearing and collision avoidance and (3) message passing.

**Network and Application Assumptions**

Sensor networks and traditional IP networks are different from each other. Sensor networks are usually composed of smaller nodes thus limiting the physical structure of the component and simplify the signal processing. Increasing in the number of nodes leads to short range, multi-hop communication for energy conservation [12]. Most of the communication is occurred between nodes which are deployed in a conventional ad hoc manner. Configuration of the nodes should be done more carefully.

A good sensor network should be implemented in applications with less collaborative nature. In this section, we will prioritize on increasing the performance of our proposed system. Processing a network is more crucial in maintaining the lifetime of a sensor network [13-14]. Application-specific code is distributed, because the sensor networks are implemented on different applications. This application specific code is activated whenever it is necessary. Data traffic in a network is reduced by aggregation techniques. The sensing quality is improved and the data traffic is reduced by implementing collaborative signal processing. Network processing shows that the data is processed as a whole message in storing and forwarding fashion. This results in increase in the latency. This sensor-MAC protocol will reduce the latency in the overall network. Applications of sensor networks such as surveillance and monitoring applications are remaining inactive until something is detected. For such surveillance networks, maintaining the network lifetime is crucial in such applications. Maintaining the latency is also difficult for such networks. For e.g.the object sensed must have latency in sensing because of the object's speed. Thus, the network and its applications strongly influence our proposed MAC design and thus motivate the differences of other previous protocols such as IEEE 802.11. [15]

**Periodic Listen and Sleep**

From the previous section, the nodes remain idle if there are no sensing events. Consider that the data spent during idle period is lesser than usual amount. Keeping the nodes as always active is not important. Our proposed protocol is capable of reducing the listening time of the sensor. For e.g. if the node sleep for half second in each second,then the energy consumed is reduced up to 50%.

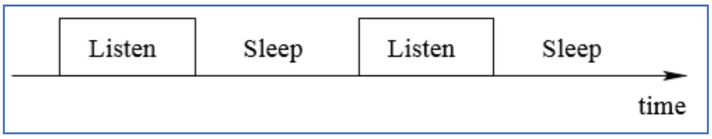


**Figure-1.** Sleep and Lister Time

**Fundamental Strategy**

The basic scheme is shown in fig-1. In this scheme, each node will go to sleep for some time until any activity needs to be done. At the time of sleep, the radio in the node gets turned-off and a periodic timer is set for automatic awakening. Based on the application scenarios, the time duration for sleeping and active session can be selected. The time durations is set equally for all nodes. Periodic synchronization is required by our proposed scheme to remedy their clock drift by the neighbour nodes. In this technique, two techniques are used to make the synchronization errors as robust in nature. Firstly, all the time stamps are exchanged. Secondly, the listening period should be set long than clock drift. On comparing with other TDMA schemes, our proposed system has lesser synchronization period. The listen and sleep schedules are chosen by the node itself. By synchronizing the neighbor nodes, the control overhead is abruptly reduced. It is essential to notice that all the synchronized neighbor nodes are available in a multi-hop network. For example; two neighboring nodes called A and B which have different schedules should synchronize with nodes C and D for reducing the control overhead and this is shown in Fig-2


**Figure-2.** Neighbour Nodes (A – B has different Schedule, C – D has synchronization)

Schedules of the nodes are exchanged to the neighbours. This exchanging process makes sure that all the neighbouring nodes are in contact with each other. Consider an example; from fig-2, if the node A wants to communicate to node B, node A needs to wait until node B is in listening state. In same case, if multiple nodes need to communicate, then they need to wait for the medium when the node is in listening state. This contention mechanism is same as IEEE 802.11. This IEEE mechanism is uses RTS and CTS packets for transmission and receiving packets. At first, the node first sends the RTS packets and the receiving nodes will reply with a CTS packet. Once the data transmission is started, the sleep schedule is not followed until the transmission is finished. Another important characteristic of our proposed scheme is that the nodes are formed into a flat topology. The neighbouring nodes are intended to talk to each other no matter what schedule they have. A special cluster called virtual cluster is formed by the synchronized nodes. Even though virtual cluster is formed, there occurred no clustering problems and interference problem. Our proposed scheme has the ability to adapt to different topology changes.

The drawback of our scheme is the increased latency because of the scheduled sleep period of each node. Moreover, each hop is accumulated by the delay in the nodes. The latency period is determined by the sleep time of the nodes.

**Schedule Maintenance and Schedule Choosing**

If a node tends to assign a sleep/work schedule, then it must choose a schedule with the respective neighbours. A schedule table is created by the nodes to store all the schedules. The below step shows how a schedule table is established;

1. At first, the node listens to some time. If they did not hear any schedule from the neighbor node, then it randomly selects a time and the node will go to sleep. The sleeping node will broadcast a SYNC message which denotes that the node will go to sleep after t-seconds. Such nodes are called as SYNCHRONIZER, because it selects the schedule on their own and the neighbor node will get synchronized based on the synchronizer node.

2. If any node receives a schedule from the neighbor before having its own schedule, then it follows the same schedule as the neighbor node. Such node is called as FOLLOWER. The follower node will wait for a delay ($t_d$). This delay schedule is broadcasted to its neighbors and it denotes the sleeping indication of the node in $t-t_d$ seconds. The main reason for scheduling a delay is to avoid data collision.
3. If a different schedule is received by any node, then the node will perform both schedules i.e. the nodes own schedule and arrived different schedule. The node then broadcasts its own schedule before the node go back to sleep. Such adoption of multiple schedules is rarely occurred. Because all the assigned nodes will follow the same schedule before selecting an independent schedule. There is also a possibility that the nodes will fail to broadcast the schedules. This is because of collision. In the subsequent listening period, the nodes will find out the schedule of other nodes.

Consider a sensor network in which all the nodes are in contact with their respective neighbour nodes.The synchronization of the neighbouring node will be based on the node timer and message broadcasting events. In case, two nodes have independent schedules tends to hear from each other, then the nodes will adopt those two schedules. Therefore, a node only needs to send once for a broadcasting packet. The main disadvantage of this packets is that the nodes have lesser time to sleep therefore it results in high energy consumption than the other nodes. The other option is that the node is programmed to adopt only one schedule. This result in simple pattern of periodic listens and avoids the wastage of energy, because the node will go to sleep like the other nodes.

**Synchronization Maintenance**

Maintaining the listen and sleep schedule requires synchronization between the neighbour nodes. A large clock drift is appeared for a node with long listen time. This is avoided by updating the neighbour node based on the schedule. The updating period is estimated around ten seconds and it is quite longer. Sending a SYNC packet will accomplish the updating schedules. The SYNC packet contains the sender address and the time of its next sleep period and it is very short. The next sleep time is relative to the time once the sender finishes transmitting the SYNC packet. Once the receiver receives the packet, the receiver nodes will adjust the timers and the node will go to sleep when the time comes.

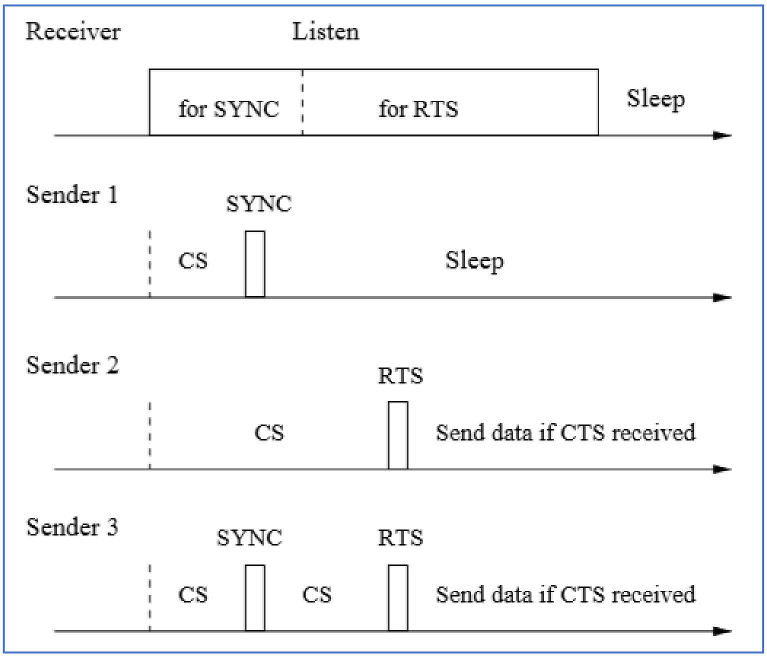


**Figure-3.** RTC-CTS – CS – SYNC Procedures

The interval of the listen state is divided into two parts in order to receive the SYNC packets and the data packets by a node. Receiving the SYNC packets and RTS packets is the primary task in this method which is shown in Fig-3. In order to perform the carrier sense, each part is again divided into multiple time slots for senders. From fig-3, it shows the timing relationship of the three possible situations. From the diagram, the only task of sender-1 and sender-2 is to sendSYNC packet anddata.But sender-3 sends both SYNC packet and RTS packet. In the next step, every node will broadcast a SYNC packet in a periodic manner to its neighbouring node.Even sender node contains zero followers. This will enable the new nodes to take part as a neighbour node in transmission. The same schedule is followed by the new node. The initial schedule should be long enough to learn and follow the existing schedules.

**Collision Avoidance and Overhearing Avoidance**

The primary problem in MAC-protocols is collision avoidance. Contention-based schemes are adopted by **Extended S-MAC** protocol. This scheme suggests that any packet which is transmitted by a node is received by all neighbour nodes, even the message is sent to one particular receiver node. Overhearing in contention-based protocol makes our proposed protocol as energy efficient protocol when comparing with other protocols such as TDMA protocols. Therefore, this should be neglected.

**Collision Avoidance**

A medium has a need to contend if multiple senders want to send and receive packets. Among all the contention protocols, 802.11done a great job in avoiding collision. Our proposed protocol also follows the same process which includes both virtual and physical carrier sense and also CTS/RTS exchange. RTS/CTS mechanism is adopted for addressing the hidden terminal problem [15]. In each transmitted packet, a duration field is presented which indicate the remaining transmission time. Therefore, the time to remain silent is known by the node. NAV (network allocation vector) is used to store the time value as an integer by the node [16]. It also sets a timer for it. The NAV value decrements the value, once the NAV fires the time value. The decrement continues until it reaches 0. When a node needs to send data it first looks at the NAV value. If the value is not 0, then the medium is considered as a busy medium and it is called as virtual carrier sense.

Physical carrier sense occurs once the physical layer is intended to listen to the channel for any transmissions. This randomized carrier sense time is crucial for avoiding any collisions. If both physical and virtual carrier sense is free, then the medium is free. Before initiating any transmission, all senders must perform carrier sense. If any node fails to reach the medium then the node will go to sleep and it wakes up after the receiver completes its job. Without the using of RTS/CTS packets, broadcast packets are sent to the receivers. Sequence of RTS/CTS/DATA/ACK is followed by the unicast packets.

**Overhearing Avoidance**

In order to perform an effective virtual carrier sense, all the nods must listen to all transmissions from its neighbours. This resulted in overhearing problem and it is seen mostly in 802.11. This will cause energy wastage. Our proposed protocol is constructed to avoid such overhearing issues by letting the interfering nodes to go to sleep. DATA packets are generally larger in size than the control packets and this prevents the neighbouring nodes to avoid overhearing issues.

A multi-hop network is formed by the nodes A, B, C, D, E and F in which every node will hear the transmission part only by its neighbours (fig-4). Collisions usually occur only on the receiving side. From the figure-4, we can see that Node-D will immediately falls into sleep state if any transmission interference occurs with Node-B. It is also seen that no transmission interference is produced by Node-E and node-F. Therefore it is not essential for node-E and node-F to go to sleep state. From the figure, we can clearly see that no interference is occurred between node-B and node-C, because C and B are far from each other. Therefore node-C will transmit the packets freely. Since node-C cannot get any reply from its neighbours, the energy used for transmission by node-C is considered as waste. From the diagram, we can conclude that all the immediate neighbours must sleep which includes both sender and receiver.

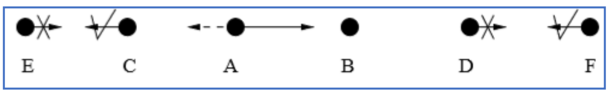


**Figure-4.** Nodes in Active and Sleep Mode

To indicate the activity in its neighbour, each node must maintain the NAV values. If any node receives a message wrongly, then the NAV value is updated by the duration field in the packet. A non-zero NAV value denotes an active transmission in its neighbourhood. Whenever NAV timer fires, the NAV value decrements every time. In case of avoiding overhearing issues, a node must sleep until the value becomes zero.

**Message Transmission**

In this section, we will see about the way to transmit signals efficiently in terms of energy and latency. A message could be either a long series or in a shorter packet. The receiver must obtain all parts of the message. The main disadvantage of sending a longer message is the cost of re-transmitting the same message. However, the long message is fragmented into smaller packets; a penalty of large control overhead must be paid to control the overhead delay. This is because of the usage of RTS and CTS packets. Our main goal is to segment the longer message into smaller packets. Only RTS and CTS message packets are used in this method for indicating the medium in which the packet is being transmitted. The sender should wait for a packet from the receiver called acknowledgement (ACK) packet. The transmission time is extended if no ACK packet is received.

All the packets have duration field. If any neighbouring node receive or hears about RTS/CTS packet, it will automatically go to sleep state. The sleep state will be continued till all the fragments are transmitted. It does not possible to switch the radio from sleep to active instantly. If the radio needs to be switch, then the frequency should be reduced. The hidden terminal problem is prevented by using ACK packet. There is a possibility that a neighbour node wakes up in the middle of the sleep or any new node joins the transmission. The node will not hear the data packets if the neighbour node is only a receiver. A node is mentioned as interfering node if the node does not send any ACK packet. If the node starts sending ACK, the current transmission will be corrupted.

Every data fragment and the ACK packet have duration field. If any node wakes up or any new node joins, then the node is forced to go to sleep if the neighbour node is either sender or receiver. Consider a sender transmits a RTS packet to the neighbour or a receiver sends CTS to the neighbour, then the node will enter into the sleep state during the entire time of transmission. If any node experiences any loss in fragments, then the sender will extend the transmission time based on the length of the message. It gets notified when it wakes up from the sleep. In IEEE 802.11, it has fragmentation support. In 802.11, the medium gets reserved by RTS and CTS for first ACK and first data fragment. Then the first fragment reserves the medium for second fragment and goes on. So each neighbour node knows that one more fragment needs to be transmitted. Therefore, all the nodes are in active state, till the transmission is completed. This results in high energy consumption. In 802.11, if the sender fails to transmit ACK, it should stop the transmission. This will cause delay in transmission. On the other hand, the message passing time will extend the transmission time and re-transmits only the failed fragment. This approach has small latency. A limit must be placed based on the number of extensions are made by the receiver. But in sensor networks, the main goal is to achieve application-level fairness.

**Latency VersusEnergy**

**This paper a**nalyses the compromission between the energy savings and the latency increase because of the sleep schedules. In this section, our proposed protocol is compared with the standard of IEEE-802.11.The analysation is carried for all the packets transmitted through two or more intermediate nodes. The following factors are calculated and analyzed.

**Carrier Sense Delay:** it is formed when the sender executesCS. The contention window determines the CS delay and its value.

**Back-off Delay:**It is a delay happen due to CS failure. The main reason for the CS failure is, the node finds another transmission due to collision.

**Transmission Delay:**Transmission delay is increased due to the data packet length, high bandwidth and coding methodology.

**Propagation Delay:**This delay is created due to the long distance between the source and the destination nodes.

**Processing Delay:** this delay happens on the computing power of the node and also determines the efficiency of the data processing algorithms.

**Queuing Delay:** this delay mainly depends on the traffic load. Queuing delay becomes an inevitable factor in heavy traffic situations.

The above-mentioned delays are appeared in a multi-hop network which uses contention-based MAC protocols. The delay factors are same for both S-MAC and 802.11. Periodic sleeping in the nodes will cause an extra delay in S-Mac. If any sender sends a packet for transmission, then the sender must wait until the receiver wakes up. This is called as Sleep Delay. The complete cycle of sleep and listen is called as frame. Consider a packet which is arrived at a sender with equal probability, and the corresponding delay is calculated using the formula as:

$$\mathbf{D_s} = \frac{\mathbf{T_{frame}}}{\mathbf{2}} \qquad (1)$$

Were

$$\mathbf{T_{frame}} = \mathbf{T_{listen}} + \mathbf{T_{sleep}} \qquad (2)$$

The protocol without any periodic sleep is compared to the respective energy reserves in S-MAC is calculated below;

$$\mathbf{E_s} = \frac{\mathbf{T_{sleep}}}{\mathbf{T_{frame}}} = \mathbf{1} - \frac{\mathbf{T_{listen}}}{\mathbf{T_{frame}}} \qquad (3)$$

The last equation shows how to obtain the duty cycle for each node in the network. It is essential to reduce the sleep and listen time. This will keep the average sleep delay shorter. The Extended S-MAC initialize the listen time is 250ms. The association between the energy saving and the delay is shown in fig-5. From the diagram, each node with the listen time is set as 250ms and 450ms. From the diagram, we can clearly see that there occurred a delay, even the sleep time is zero. This is because; the contention only starts at the beginning of each listen interval.

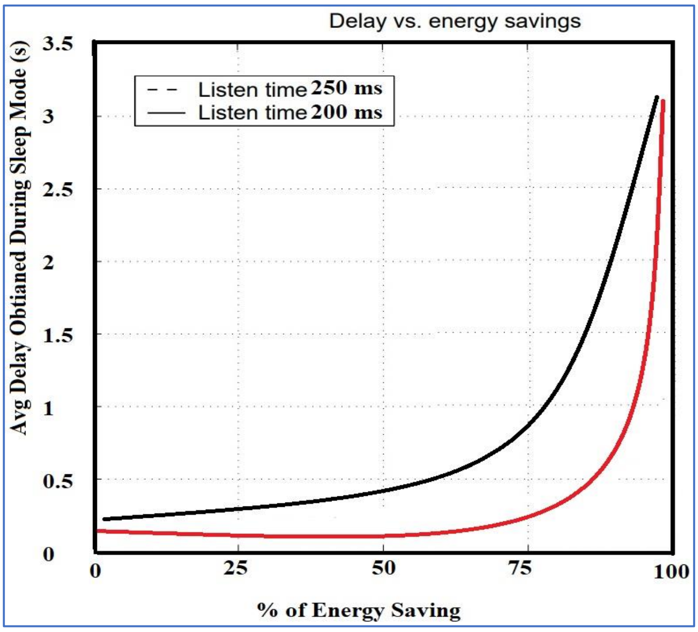


**Figure-5.** Energy VersusAvg. Sleep Delay

**MAC Protocol Implementation**

The logical modules of the MAC protocol are implemented in NS2 and investigated with IEEE 802.11 standard in terms of message transmission without overhearing. Also, the existing S-MAC rules are investigated in the simulation. In order to compare the performance analysis CS, back-off, retry, RTS-CTS, DATA-ACK and fragmentation results are verified.

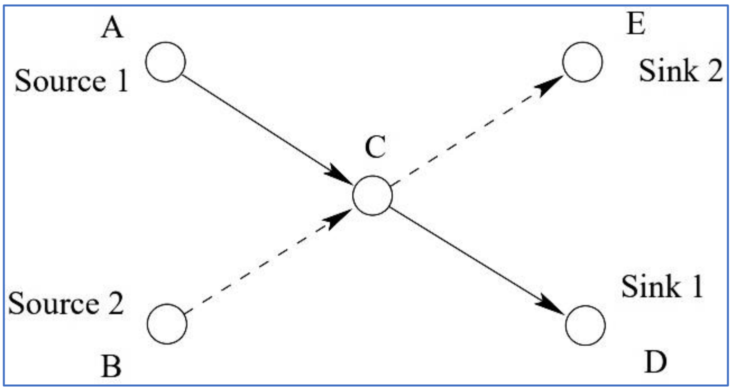


**Figure-6.** Network Topology used for Verifying Collision

The time taken by each CS is not constant in the contention window. This randomization task is highly important since it eliminates collision initially. Also, the size of the contention slot does not increase during the backoffs. There are no changes in the fragmentation support, where it similar to IEEE 802.x standards. In order to verify the above-said parameters, the topology of the proposed network is illustrated in Figure-6. In the module, the contention slot timing and the control overhead are reduced without affecting the listen time. Compared to IEEE-802.11 the sleep time is increased. After setting the listen and sleep time, the message transmission module is activated. The listen time of each node is 250ms and sleep mode is 450ms. Also, based on the node density the sleep time varies, and it frequently changes the duty cycle. In the simulation, we only focus on the sleep and listen time to save the energy. Because the sleep time of the microcontroller is very less and it consumes very less energy. The microcontroller turned to other mode by setting the watch-dog timer. If the microcontroller is in sleep mode, then it indicates the radio is in sleep mode and it does not require any amount of energy.

**Experimental Setup**

The topology of our proposed experiment is shown in fig-6. Our proposed system is a two-hop network each with two sources and two sinks. It is set that the data packets going to D from A should pass through C. Similarly, data packets from node B should pass though C and reach E. In Extended S-MAC, the network topology is created in simple manner with simplified rules. It does not have complication in its basic MAC behavior.

Generally, MAC protocols watch the energy consumption of the nodes. The utilized MAC protocols are executed with different traffic loads. The utilized two sources generate a sensing message periodically. The messages sensed by each node is partitioned into various segments in terms of small size. Similar to this, the IEEE 802.11 standard MACsegemented the messages and speedily transmit. For example, the RTS and CTS mechanism is enabled to diminish the collision before and during packets transmission. In this paper,it is notnecessary to calculate fragmentation process programmatically, because it allows fragmentation and each fragment is considered as an independent packet that uses CTS/RTS procedure. It is because; MAC generally consumes an additional energy when compared to the one with fragmentation. Therefore, the message transmitted in the form of burst.

The traffic load is changed by varying the messages based on inter-arrival period. For example; if the inter-arrival period of the message is 5 seconds, then for every 5 seconds, a message is generated. The range of inter-arrival period in this experiment varies from 1second to 10seconds. We have executed 10 different tests for each traffic pattern exists. This examination is used for calculating the energy consumed involving with MAC protocols. In each test, TinyOS is used for fragmenting the messages into smaller data packets. Each source will periodically generate 10 messages and each message is fragmented into 10 smaller data packets. Therefore, a huge number of data packets belongs to TinyOS are passed from thesources to sinks. The highest transmission rate is achieved at the inter-arrival time of 1second. Because of the lowest bandwidth, the wireless channel is fully utilized.

The total amount of time takes for sending the packets for each node is measured in terms of time spent on various modes likeTx, Rx, sleep and listen. The energy consumption can be calculated depends on various factors such as data size, time taken, and distance between the sender and the receiver. The power consumed from the data sheet is found as $13.5mW, 24.75mW\ and\ 15\mu W$for various modes. In this radio transceiver model, no difference is found between listening and receiving state.

In order to investigate the efficiency of the proposed MAC, it is necessary to set the values of the various parameter used in the simulation software. It helps to calculate the appropriate outputs based on the values set in the software. Parameters are mainly used for simulating the performance. The value of the simulation parameters are not fixed and vary for different works. The parameters and their values which are used in this work are shown in Table-1. The values assigned in the simulation parameters are as same as with the exisitng research wrokRakesh Kumar and Manju Gangwar, (2018). It gives the comparison ethics and accuracy in performance evaluation.

**Table-1.** Simulation Setting Parameters

| **Parameters** | **Values** |
|---|---|
| Width | 1000 |
| Height | 1000 |
| Total no. of rounds | 5 |
| Number of nodes in rounds I, II, III, IV and V | 50, 60, 70, 80 and 90 |
| Total packets | 100 |
| Location of BS | (500, 500) |
| $E_0$ (initial energy) | 0.5J |
| $E_{TX}$ (transmission energy) | 50*0.000000001 (J) |
| $E_{RX}$ (receiving energy) | 50*0.000000001 (J) |
| $E_{fx}$ (energy used in radio frequency) | 10*0.000000000001 (J) |
| $E_{mp}$ (amplification) | 0.0013*0.000000000001 (J) |
| EDA | 5*0.000000001 (J) |

**Performance Parameters**

In this work, energy and throughput are the two factors considered for evaluating the performance of the proposed MAC. Energy and throughput are chosen for improving the life span of the sensor networks and data transfer respectively. The performance parameters are listed below;

**Network Lifetime**

This factor is mainly used for evaluating the performance of the network system. It also results in improving the network lifetime in wireless sensor networks. It is important to conserve energy, because sensors are a tiny sensing device with a limited amount of power supply. The cost for replacing the battery is higher than replacing a complete node.

**Throughput**

This parameter also used in evaluating the system performance in a sensor network. This parameter is defined in terms of the amount of data packets transmitted in one unit of time.

**Transmission Delay**

Time taken to transmit a data packet from sender to receiver is called as delay.

**Results and Analysis**

The experiments are carried out on three different MAC modules. In the final graph, IEEE 802.11 DCF is simplified as IEEE 802.11. Any message with overhearing avoidance is mentioned as Overhearing Avoidance. Initially the Node A and Node B are considered in the experiment, the related energy consumption is calculated for the nodes and the obtained result is shown in Figure-7. When the inter-arrival time is less than 4seconds, the traffic is heavy. In such cases, the traditional MAC consumes energy as twice as our proposed S-MAC. Reducing the energy consumption is periodically measured for various modes. Avoiding overhearing results in energy saving and also results in transmit a long message more efficiently.

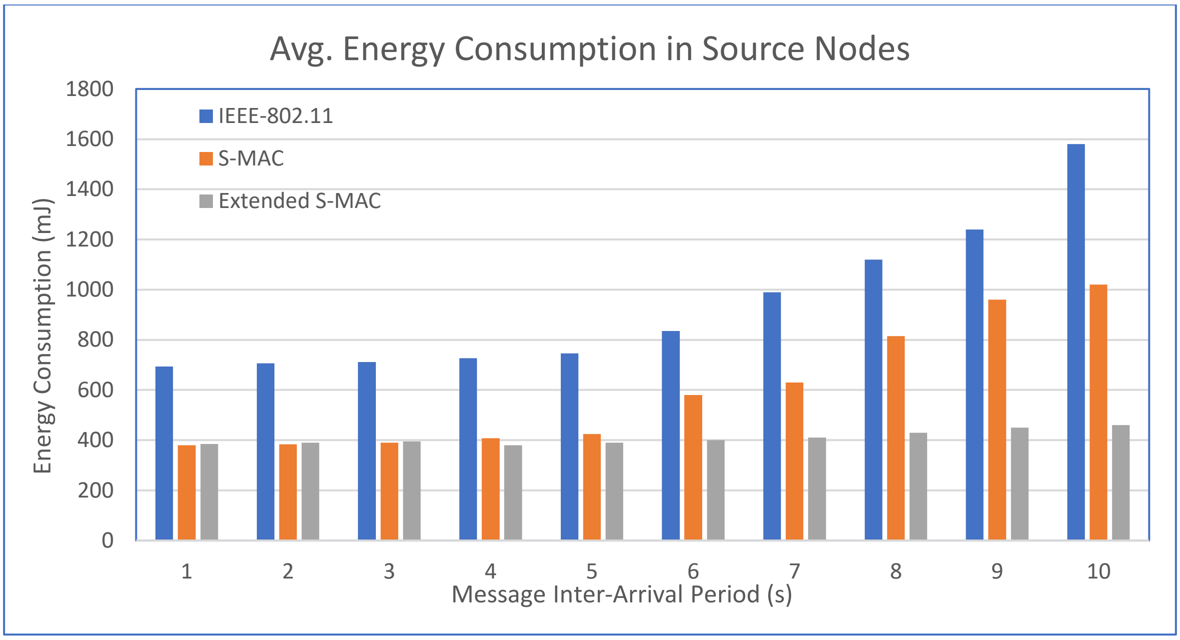


Figure-7. Energy Consumption Calculation On Source Nodes

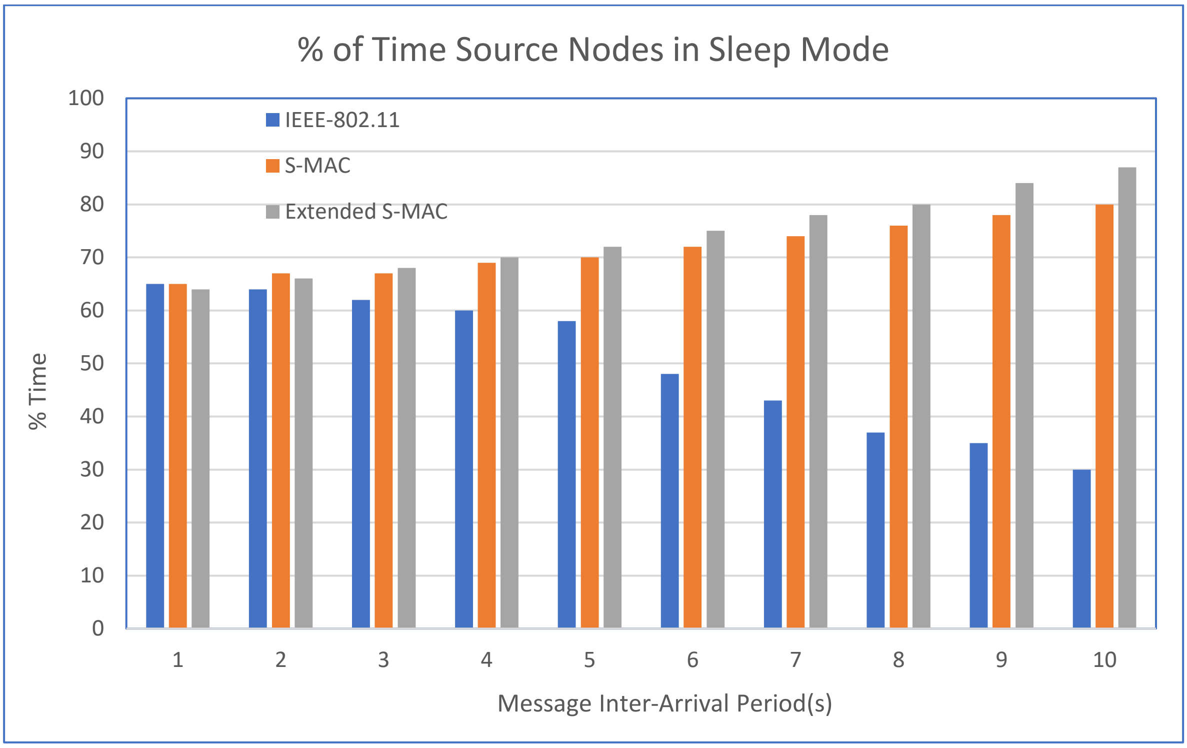

Figure-8. Time Calculation On Source Nodes

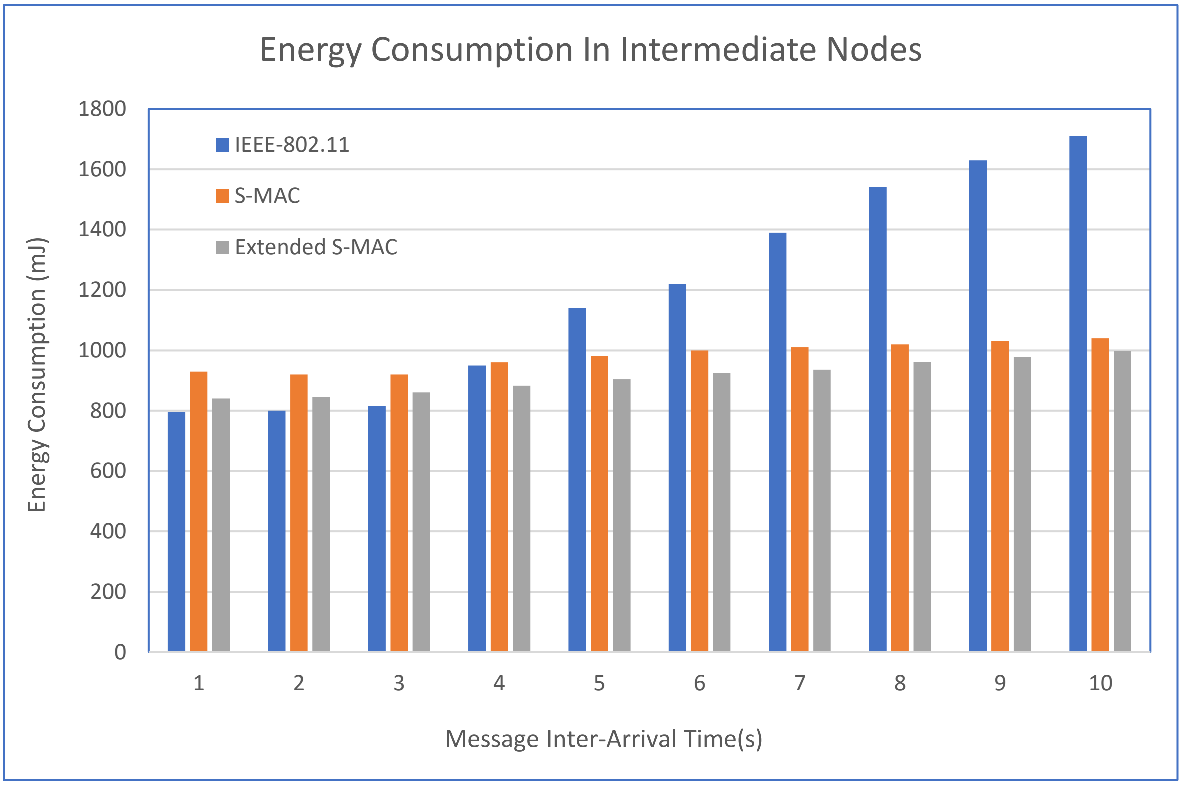


Figure-9. Energy Consumption Calculation on Intermediate Nodes

In case of the inter-arrival time is 4sec, then the network traffic is low. In such cases, our proposed S-MAC outperforms traditional 802.11 MAC in energy saving property. Compared to IEEE-802.11-MAC, the existing S-MAC outperforms regarding message transmission and overhearing. From the figure, it is shown that the idle listening almost dominates the total energy consumed. To save the energy, adjusting the sleep and listen time periodically gives more advantage. The amount of energy consumed by S-MAC and the traffic pattern are relatively independent to each other. It is examined in the simulation using A, B and C nodes are considered as neighbours. To obtain the better traffic, the data packet size is same for all the conditions.

The percentage of time in terms of sleep mode is shown in fig-8. Our proposed S-MAC has the capability to adjust the sleeping time of the nodes based on the traffic patterns. In the case of less traffic, then the node has more sleep time. Similarly, when the traffic increases, the sleeping time is very low. This feature is considered as a useful feature in sensor networks, because the traffic load tends to change with respect to time. The traffic is very light when there is no sensing activity. When some activity is detected by the nodes, it activates bigger sensor such as camera and this result in heavy traffic load. When the traffic load decreases, the nodes must spend more time in idle listening.

The overall energy consumed in the node C is shown as figure-10. As we can see, in lighter traffic load, the performance is greater than 802.11. If the traffic load is heavier, the energy consumed is slightly higher than IEEE-802.11. It is because of the S-MAC has synchronization overhead during data packet transmission. Another reason for higher energy consumption is because of more latency period. If the traffic is heavier than usual, then the node will not follow its usual sleep schedule. But it maintains the message passing and overhearing avoidance and results in energy savings, and it is shown in fig-9. This output is not similar to the node-C because all packet transmissions are involved in this node. Therefore, the energy consumed is same as 802.11 MAC.

**Comparison with the existing work [**Rakesh Kumar and Manju Gangwar, (2018)] For evaluating the performance of the proposed Extended S-MAC, the obtained results are compared with the existing MAC methods such as BEST-MAC (Rakesh Kumar and Manju Gangwar, (2018)), BMA-RR (Rakesh Kumar and Manju Gangwar, (2018)). The Extended S-MAC routing protocol is implemented in NS2 simulator using TCL and *.cc programming languages. Since NS2 is used for network simulation, it is easy to calculate various results which shows the real performance of the network. For example, the energy consumption is calculated and compared with the existing methods, is given in Table-2. From the comparison, it is noticed that the Extended S-MAC provides better performance in terms of energy consumption.

**Table.2. Comparison of Energy Consumption**

| Number of sessions | Energy consumed (J) | | | |
|---|---|---|---|---|
| | BEST-MAC | BMA-RR | FGF | Extended S-MAC |
| 1 | $0.0565*10^4$ | $0.18*10^4$ | 0.03 | $0.0021*10^4$ |
| 2 | $0.0954*10^4$ | $0.23*10^4$ | 0.04 | $0.0057*10^4$ |
| 3 | $0.2564*10^4$ | $0.35*10^4$ | 0.16 | $0.1362*10^4$ |
| 4 | $2.8500*10^4$ | $0.40*10^4$ | 4.6 | $2.4210*10^4$ |
| 5 | $2.7500*10^4$ | $0.52*10^4$ | 28.7 | $2.400*10^5$ |

Table-2 shows the comparative analysis between our proposed work and the existing system given in BEST-MAC (Rakesh Kumar and Manju Gangwar, (2018)), BMA-RR (Rakesh Kumar and Manju Gangwar, (2018)). From the Table-2, we can compare the energy efficiency. It is clearly seen that our proposed method has an advantage in terms of energy efficiency. This will also improve the network performance and also increases the network lifetime. This simulated method saves the energy about 3.085% of total energy. In Table-3, the values of throughput parameter for our proposed and existing method are shown. From the Table-3, it is shown that the throughput value is improved by 51.26% in our proposed work.

**Table.3. Comparison of Throughput**

| Number of sessions | Throughput*10(%) | | | |
|---|---|---|---|---|
| | BEST-MAC | BMA-RR | S-MAC | Extended S-MAC |
| 1 | 0.5 | 0.4 | 1.1 | 1.8 |
| 2 | 8 | 2 | 7.6 | 9.7 |
| 3 | 0.8 | 0.6 | 0.9 | 2.7 |
| 4 | 2.4 | 2.2 | 2.8 | 3.8 |
| 5 | 1 | 1 | 2 | 2.5 |

**Table.4. Transmission delay Comparison**

| Number of sessions | Transmission delay (ms) | | | |
|---|---|---|---|---|
| | BEST-MAC | BMA-RR | S-MAC | Extended S-MAC |
| 1 | 68 | 83 | 72 | 60 |
| 2 | 118 | 166 | 96 | 71 |
| 3 | 150 | 166 | 122 | 84 |
| 4 | 194 | 250 | 140 | 96 |
| 5 | 228 | 250 | 232 | 103 |

In Table-4, the transmission delay values are compared for both the proposed and existing method given in BEST-MAC (Rakesh Kumar and Manju Gangwar, (2018)), BMA-RR (Rakesh Kumar and Manju Gangwar, (2018)). From the table, it is clearly seen that our proposed work experienced only a minimum amount of transmission delay. Table-4 it proves that our proposed method is better than the existing method in terms of transmission delay.From the above figures and tables, it is proved that the proposed Extended S-MAC provides high energy saving protocol for WSN applications.

**Conclusion**

The main objective of this paper is to design and implement a novel MAC protocol for enhancing the energy efficiency in WSN. There are several MAC rules have been proposed in the earlier research works. But comparing with the other MAC rules, S-MAC proved its efficiency in terms of reducing the time delay. Reducing the delay can reduce the power consumption. Thus, this paper motivated to extend the S-MAC rules by integrating some additional features and implemented an Extended S-MAC routing protocol. It is implemented in NS2 simulation software and the results are verified. From the results it is proved that Extended S-MAC reduces the overall delay time and saves more energy in terms of individual nodes. Thus it increases the energy efficiency and improve the network life time. The proposed extended S-MAC saves 17% of energy than the existing MAC protocols.

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