

# Random-based Routing Enhanced MAC protocol for Transmission Delay and Energy Consumption Reduction in Wireless Sensor Network

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**ABSTRACT:** In Wireless Sensor networks (WSN), energy consumption is the primary and most important issue. Each node in a wireless sensor network is only supplied by a battery that it has a limited energy reserve. Each node in a wireless sensor network is also scattered on the sensor field that the random-based MAC protocol scheme in WSN should be able to establish a communication link to transfer data. The proposed protocol focused on analysing the amount of energy consumption required for S-MAC protocol, T-MAC protocol and RR-MAC protocol.

The simulation results show that the random-based MAC protocol which can save energy or use low energy consumption is RR-MAC protocol. Its ability to save energy is better than that of the S-MAC protocol and T-MAC protocol. Its ability can be even better when compared with the 802.11 MAC protocol. If we use the duty cycle as a variable which affects the energy consumption, the RR-MAC protocol can save energy consumption more than the rest protocol can.

**KEYWORDS:** Wireless Sensor Network, S-MAC, T-MAC, RR-MAC and MAC 802.11

## I. INTRODUCTION

A sensor network consists of many sensing, computing, and communicating elements within a network which help an administrator to observe, react, and compute an event in a specific environment. These sensor networks can be used in a wide variety of applications in different fields like civil, commercial, and industrial. Sensor technology has evolved in recent years and has taken a central place within a wide variety of applications. Sensor technology can be used for collection of data, monitoring of data, surveillance of data, and other applications. Sensing devices can also be used in controlling devices by means of automation in sensing environments. The terms sensor node, wireless node (WN), Smart Dust, mote, and COTS (commercial off-the-shelf) mote are used somewhat interchangeably in the industry; the most general terms used here are sensor node and WN.

In the scheme of S-MAC protocol, T-MAC protocol and RR-MAC protocol, the nodes are in two states, namely, sleep and listen. When the nodes are in a sleep state, they turn off the radio to save energy. The nodes will turn on the radio or turn into listening period when they will send or receive packets. This differs from the mechanism of the 802.11 MAC protocol, where nodes are always in a state that is idle listening. In this case, the S-MAC and T-MAC protocol will become the material that is being studied to address the major issues in Wireless Sensor Network [1].

In this research, the energy consumption of the S-MAC, T-MAC protocol, and RR-MAC protocol in wireless sensor networks are analyzed with some limitations. First, research is conducted on a static wireless network.

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Second, it is assumed that the sensor nodes are homogeneous. Third, it cannot convert its own energy. This network topology research in WSN is expected to produce simulation results that can be accurately analyzed and can obtain significant results in overcoming the main problems that exist in wireless sensor networks.

## II. WIRELESS SENSOR NETWORK AND ENERGY CONSUMPTION

### A. Wireless Sensor Network

While many sensors connect to controllers and processing stations directly (e.g., using local area networks), an increasing number of sensors communicate the collected data wirelessly to a centralized processing station. This is important since many network applications require hundreds or thousands of sensor nodes, often deployed in remote and inaccessible areas. Therefore, a wireless sensor has not only a sensing component, but also on-board processing, communication, and storage capabilities. With these enhancements, a sensor node is often not only responsible for data collection, but also for in-network analysis, correlation, and fusion of its own sensor data and data from other sensor nodes.

When many sensors cooperatively monitor large physical environments, they form a wireless sensor network (WSN). Sensor nodes communicate not only with each other but also with a base station (BS) using their wireless radios, allowing them to disseminate their sensor data to remote processing, visualization, analysis, and storage systems. For example, Figure 1.3 shows two sensor fields monitoring two different geographic regions and connecting to the Internet using their base stations [1].

A set of sensor nodes forms a network called Sensor Field, while the item that connects a Sensor Field to the internet is a Sink as shown in Figure 1 above. Thus the user can perform the work in accordance with the direct application needs to access the Internet easily.

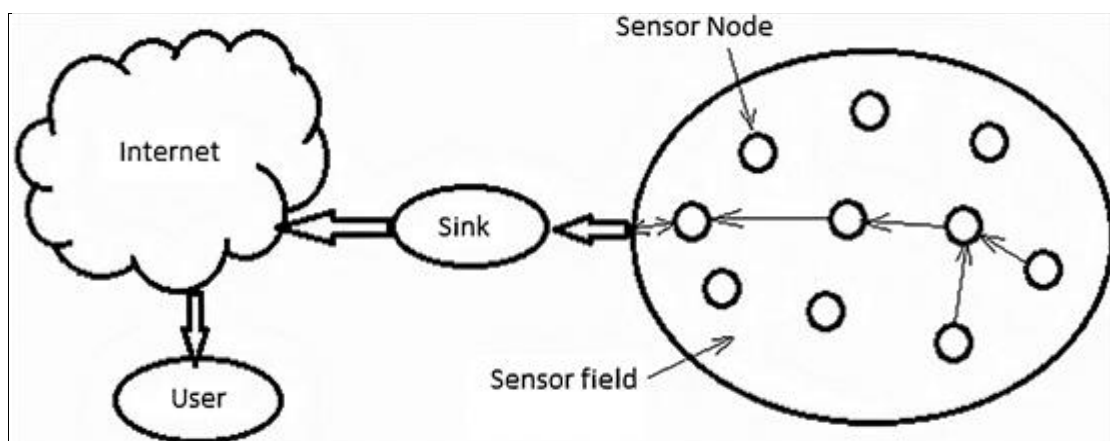


Figure 1. Wireless Sensor Network Architecture

The protocol stack that is used on the sink and sensor nodes consists of physical layer, data link layer, network layer, transport layer, and application layer. The areas of protocol stack include power management plane, mobility management plane, and task management plane. The tasks of the protocol stack are to combine power and routing, to integrate the data with the protocol, to communicate energy efficiency through the wireless medium, and to coordinate sensor nodes in order to be cooperative [1].

### B. S-MAC Protocol

The goal of the sensor MAC (S-MAC) protocol is to reduce unnecessary energy consumption, while providing good scalability and collision avoidance. S-MAC adopts a duty-cycle approach, that is, nodes periodically

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transition between a listen state and a sleep state. Each node chooses its own schedule, though it is preferred when nodes synchronize their schedules such that they listen or sleep at the same time. In this case, nodes using the same schedule are considered to belong to the same virtual cluster, but no real clustering takes place and all nodes are free to communicate with nodes outside their clusters. Nodes periodically exchange their schedules with their neighbors using SYNC messages, that is, every node knows when any of its neighbors will be awake. If node A wants to communicate with a neighbor B that uses a different schedule, A waits until B is listening and then initiates the data transfer. Contention for the medium is resolved using the RTS/CTS scheme.

In the S-MAC protocol, there is a node that divides common listen period. Using common listen period requires the establishment of synchronization and maintenance among nodes. In this protocol, listen period or the radio on is divided into two sub periods, one is for exchanging SYNC packets and the other one is for exchanging data packets as shown in Figure.2. Each sub-period is divided into mini-slots. In both sub-periods, the node forms a carrier sense first and then transmits it to the mini-slot if the channel is idle.

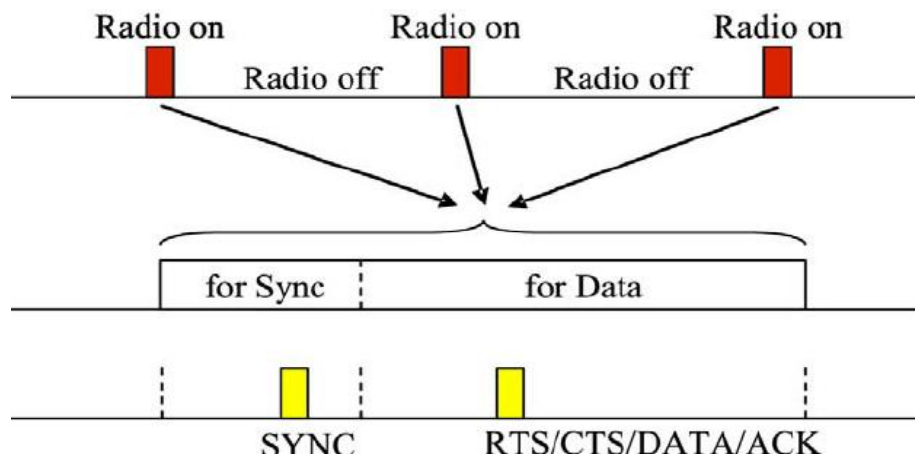


Figure 2. SMAC in radio on and radio off condition

In the S-MAC protocol, scheduling the radio on or off becomes very important. Each node continuously listens to the channel for at least one listen period plus a sleep period. If the nodes receive SYNC package, then they adopt a schedule carried by the packet. If they do not receive SYNC package, nodes choose their own schedule and follow it. Once a node has a schedule, it will broadcast SYNC packets throughout the whole network. Neighboring nodes will receive SYNC package by adopting a schedule and then continue the deployment of the schedule to the entire network [3,4].

To save energy, each node is usually in a state of sleep period. The channel seizure may occur in listen period. Node is implicitly synchronized at the beginning of listen period. There is a chance that nodes simultaneously access the channel at the beginning of listen period.

S-MAC protocol makes serious efforts to avoid collision by having a node backoff for the random duration before transmission. It uses traditional mechanism such as the exchange of RTS / CTS and virtual listening by NAV (Network Allocation Vector). NAV contains a value that tells the node if there is an ongoing transmission and when it will end. NAV sets this value by listening to the header of the RTS, CTS, and data frames because there is information in this header about the duration of the transmission. The time frame period between nodes can be seen in Figure 3 below [3,4].

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## S-MAC period listen and sleep modes of operations

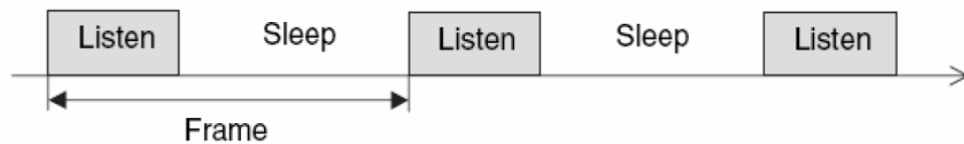


Figure 3. S-MAC Time Frame Period

### C. Energy Consumption

In the S-MAC protocol, each node follows the schedule of listen and sleep to reduce the energy consumption. One cycle of the listen period and the sleep period is called a frame. During the sleep period, the node will turn off the radio device and turn it back on at the listen period. In the S-MAC protocol, there is a duty cycle which is the ratio between the listen period and the frame length. In the S-MAC protocol with a fixed frame length, listen period value will depend on the parameters of the physical layer and MAC layer. To set the sleep time period, the user can set the value of duty cycle.

Energy saving (Es) in S-MAC is as follows:

$$Es = T_{\text{sleep}} T_{\text{frame}} \tag{1}$$

Here,

$$T_{\text{frame}} = T_{\text{listen}} + T_{\text{sleep}}$$

$$\text{Duty Cycle} = T_{\text{listen}} T_{\text{frame}} \tag{2}$$

With the equation above, it can be concluded that the energy saving depends on the duty cycle value. The larger the duty cycle value gets, the bigger the energy used and the smaller the energy saving becomes. Therefore, in the implementation, the maximum value of duty cycle is 10% [3,5].

### D. T-MAC Protocol

The listening period of S-MAC is of fixed duration, that is, if there is only little traffic, this can actually waste energy. On the other hand, if traffic is heavy, the fixed duration may not be large enough. Therefore, the Timeout MAC (T-MAC) protocol is a variation of S-MAC that uses an active period that adapts to traffic density. Nodes wake up during the beginning of a slot to listen very briefly for activity and return to sleep mode when no communication has been observed. When a node transmits, receives, or overhears a message, it remains awake for a brief period of time after completion of the message transfer to see if more traffic can be observed. This brief timeout interval allows a node to return to sleep mode as quickly as possible. The end effect is that a node's awake times will increase with the heavier traffic and will be very brief if traffic is light.

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The purpose of the T-MAC protocol is to reduce idle listening by sending all the messages on the burst with different package lengths and by the existence of sleep among bursts. To maintain the active time that is based on the variable load, we dynamically determine the length of the active time(TA). The active time is terminated by intuition: designing a timeout if it does not hear anything. Figure 4 shows the basic scheme for the T-MAC protocol with flexible TA [6].

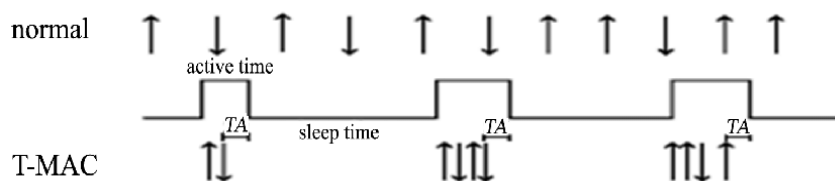


Figure 4. Basic scheme of T-MAC protocol with adaptive active time

Each node is periodically active to communicate with the neighboring nodes and back to sleep after the next frame. Meanwhile, if there is a new message, it will go into the queue. Each node communicates with other nodes using Request-To- Send (RTS), Clear-To-Send (CTS), data, and acknowledgment (ACK) scheme to avoid collision in transmission and to make the communication reliable. This scheme is very popular and frequently used, for example in the IEEE 802.11 standard.

In the T-MAC protocol, a node will keep listening and has the potential to transmit the transmission signal as long as the node is in the active period. The active period will end if there is no activation event that occurs during the TA time. The meanings of activation event are [6,7] :

- a. Capturing the frame regularly.
- b. Acceptance of any data on the signal.
- c. Sensor Communication on the signal.
- d. Transmit ACK for every received node.
- e. Node, unexpectedly receives prior RTS and CTS packets that the data exchange in a neighbor node has been completed.

In general, a node will sleep when it is not in active period. Therefore the timeout (TA) estimates the minimum amount of time for idle listening per frame. Timeout schematic depiction basically moves all communication towards burst at the start of the frame, and the message between the active time must be in the buffer. The buffer capacity determines the maximum number of frames that can be accommodated.

### E. RR-MAC protocol

Random-based routing enhanced MAC (RR-MAC) protocol [8] is another example of a protocol that exploits duty cycles to preserve energy. Compared to S-MAC, it attempts to improve upon end-to-end latency and contention avoidance. The key idea behind RMAC is to align the sleep/wake periods of nodes along the path of sensor data such that a packet can be forwarded to the destination within a single operational cycle. It achieves this by sending a control frame along the route to inform nodes of the upcoming packet, allowing them to learn when to be awake to receive and forward this packet. RMAC partitions an operational cycle into three components: the SYNC period, the DATA period, and the SLEEP period (Figure 5).

During the SYNC phase, nodes synchronize their clocks to ensure that they maintain sufficient precision. The DATA period is used to announce and initiate the packet transmission process along the packet's route to the destination. The DATA period is contention-based and the sender waits for a randomly chosen period of time plus an additional DIFS period, during which it senses the medium. If no activity is detected, the sender transmits a Pioneer Control Frame (PION), containing the addresses of the sender, destination, and next hop; the duration of the transmission, and the number of hops the PION has travelled so far (which is set to zero at the sender).

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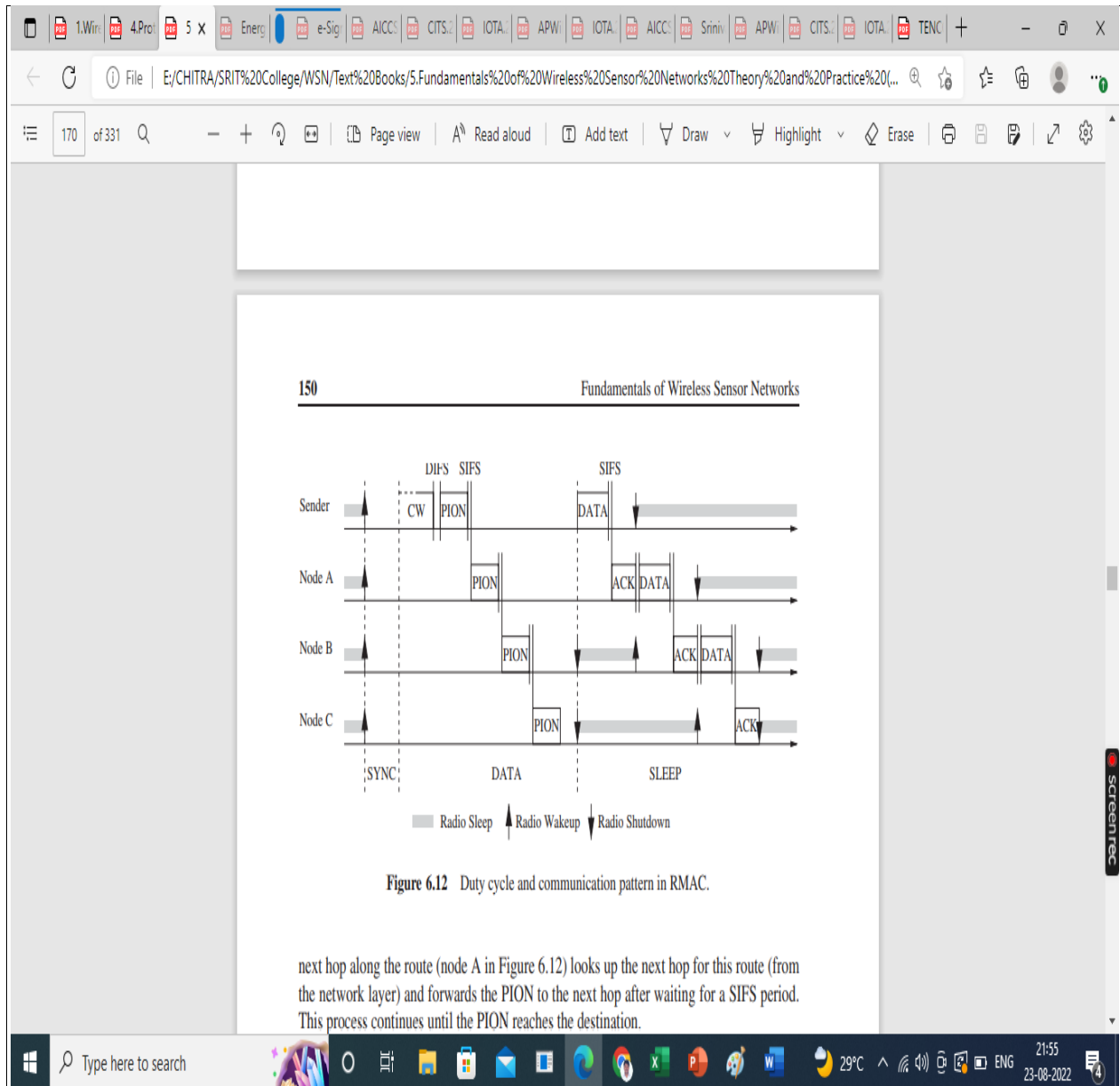


Figure 5: Duty cycle and communication pattern in RR-MAC

The next hop along the route (node A in Figure 5) looks up the next hop for this route (from the network layer) and forwards the PION to the next hop after waiting for a SIFS period. This process continues until the PION reaches its destination. Actual data transmission takes place during the SLEEP period of the protocol. In Figure 5, node A stays awake to receive the data packet from the sender and after successful transmission, A returns an acknowledgment (ACK). Similar to the PION schedule during the DATA period, all data and ACK packets are separated by a SIFS period. After receiving the ACK from node A, the sender has completed its part and can return its radio into the sleep mode. Node A relays the received packet to the next hop, node B, and also returns its radio to sleep mode once B has acknowledged the data packet. This process continues until the data packet has been received

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and acknowledged by the destination. In this example, the sender and node A stay awake after the DATA period to immediately begin the transmission of the data packet over the first hop. All other nodes along the route can turn off their radios after the DATA period has been completed to further preserve energy. Each node wakes up at the right time to receive the data packet from the upstream node. This time to wake up can be computed by node  $i$  as:

$$T_{\text{wakeup}}(i) = (i - 1) \times (\text{size}(\text{DATA}) + \text{size}(\text{ACK}) + 2 \times \text{SIFS}) \quad (3)$$

where  $\text{size}(\text{DATA})$  and  $\text{size}(\text{ACK})$  are the times required to send a single data and ACK frame, respectively.

### III. SIMULATION AND SCENARIO

The network simulation is carried out by using NS-. The default parameters used are:

- There are 500 nodes.
- The initial energy is 1500 joules.
- The duty cycle is 15%
- The type of traffic is CBR with random delivery

### IV. RESULTS AND ANALYSIS

#### A. Energy Consumption

Energy consumption at each node of S-MAC, T-MAC protocol and RR-MAC protocol are different. Both protocols have the same sleep periods and listen periods. Both protocols also maintain listen period. It means if the node does not receive or send data, the node will immediately go back to sleep period. In the simulation results as shown in Figure 6, at the beginning of the simulation duration that is at the duration of 500 seconds, the energy consumption of RR-MAC protocol is less and reasonable when compared with rest of the protocols.

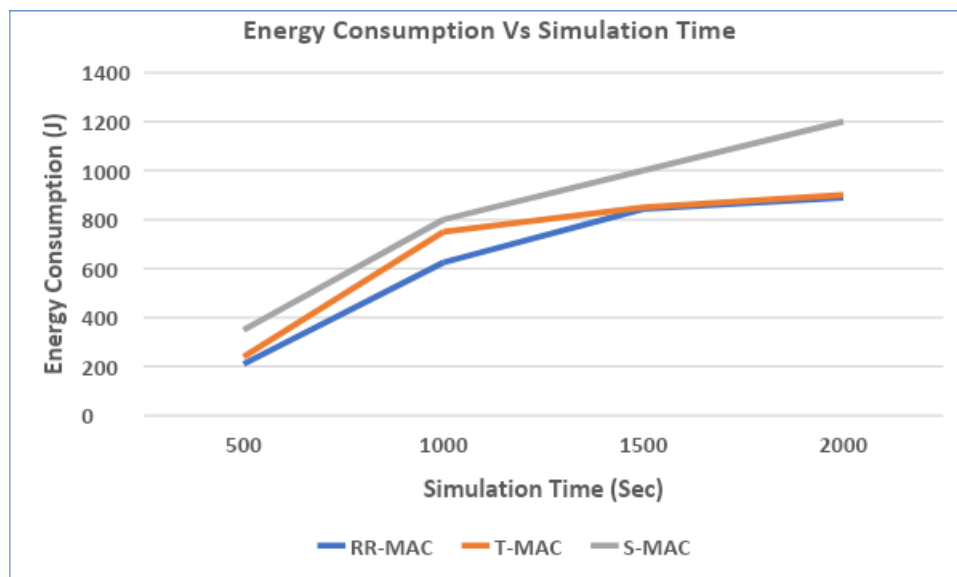


Figure 6. Energy Consumption of S-MAC protocol and T- MAC protocol

#### B. Effect of Duty Cycle on Energy Consumption

The energy consumption based on various duty cycle values of 5% to 15% for the RR-MAC protocol is much larger, on average around 10%, than the energy consumption of S-MAC as well as T- MAC protocol as shown in Figure 7. The purpose of managing the value of the duty cycle in MAC protocol is to save the use of energy in

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accordance with equation (2), where the listen period to the frame period ratio becomes smaller if it requires greater energy saving.

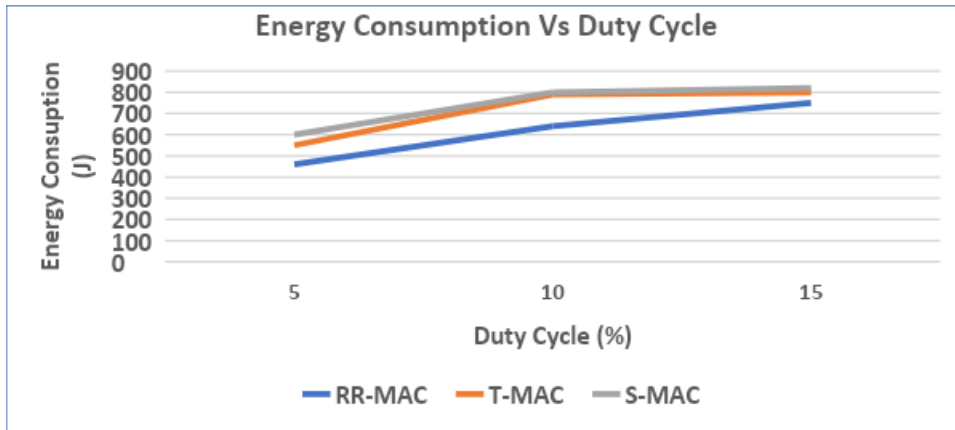


Figure 7. Effect of Duty Cycle on Energy Consumption

### C. Energy Consumption Comparison of MAC Protocols

In the case of 802.11 MAC protocol, the Consumption of energy used by all nodes is equal, while S-MAC, T-MAC, and RR-MAC protocols use different energy consumption for each node. The 802.11 MAC protocol has idle listening when the current node does not perform any activity, the node remains in a listen period state. This differs from the S-MAC, T-MAC and RR-MAC protocol which has to listen period and sleep period. It means, that when the node does not perform any activity, the node is located on sleep period condition. The simulation result as shown in Figure 8 exhibits that the 802.11 MAC protocol consumes energy more than the rest of the protocols do.

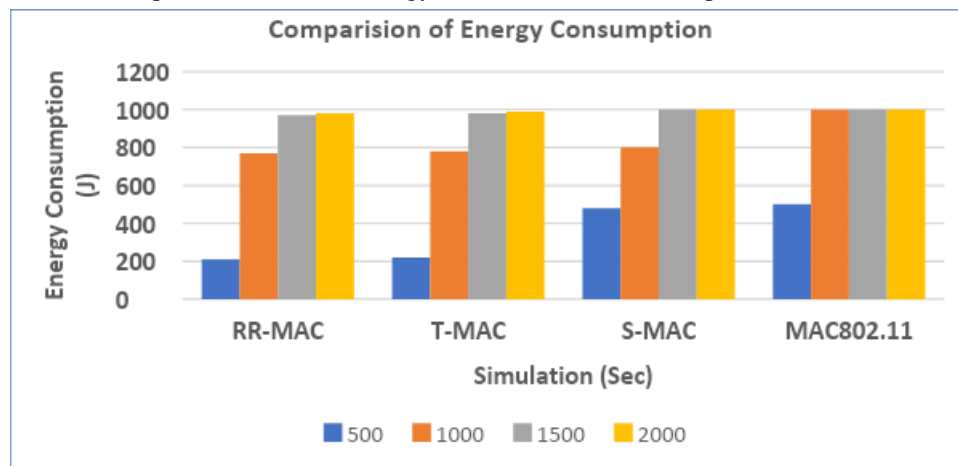


Figure 8. Energy Consumption Comparison of MAC Protocols



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## V. CONCLUSION AND FUTURE WORK

We proposed a random-based routing enhanced MAC (RR-MAC) protocol in terms of energy consumption used by the sensor network that is represented by the limited number of nodes. RR-MAC optimizes the retransmission period to maximize the number of data packets that the source node can forward through its scheduled flow. In addition to this, RR-MAC uses a small size control packet to send the request for data transmission which increases the length of the flow and reduces the energy consumption in overhearing. Simulation results suggest that RR-MAC would be a better choice for monitoring delay-sensitive events in unsafe regions.

Based on various duty cycle values, the energy consumption of RR-MAC protocol is more efficient than S-MAC protocol as well as T-MAC protocol. For further study, the research is suggested to use contention-based protocol types such as B-MAC and X- MAC with a little a greater number of nodes in a wider sensor area. This is to find out whether we can obtain more efficient energy consumption or perhaps less.

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