

Optimizing Performance Parameters in Wireless Sensor Network using Hybrid Medium Access Control

Anitha K^{1,*}, Ananda Babu J²

¹Research Scholar, VTU, Department of Information Science & Engineering, Malnad College of Engineering, Hassan, India.

²Associate Professor, Department of Information Science & Engineering, Malnad College of Engineering, Hassan, India.

abj@mcehassan.ac.in

Abstract

To carry out an efficient data aggregation operation, it is essential to retain the optimal number of nodes for an extensive sensing period in wireless sensor networks. Hybrid Medium Access Control (MAC) uses its contention and scheduling options to offer this feature by facilitating access over the shared resources and offering better energy efficiency. However, a review of existing approaches highlights that there is still a large scope for improvement. Therefore, the proposed system introduces a model for hybrid MAC that facilitates optimal routine management of states of nodes and offers a dual optimization model by ensuring extensive participation of intermediate nodes. The proposed scheme Simulated in MATLAB, the study outcome shows that it offers a good balance between energy efficiency and communication performance in comparison to existing hybrid MAC schemes.

Keywords: Hybrid MAC, Network Lifetime, Energy, Slot management, Wireless Sensor Network, Clustering techniques.

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*Corresponding author. Email:anitharesearchvtu@gmail.com

1. Introduction

With the increase in automation proliferation, there is an increasing demand for using sensors to obtain surrounding information. The extracted information is forwarded to the user via data fusion and data aggregation after clustering. In this entire process of capturing and forwarding the data, a significant amount of energy is drained. There is still some extent of data collision in the large and distributed environment of deployment. Various studies are associated with data quality and energy efficiency, where various forms of approaches have been present to date. Out of all the approaches, the Medium Access Control (MAC) scheme offers more capability to deal with this situation. For the sensors to work effectively, it is required that their life be extended as MAC protocols always target to enhance energy efficiency.

MAC protocols also improve delay performance, fairness, channel capacity, and data transmission performance along with energy efficiency. However, this operation also leads to idle listening, which causes excessive drainage of energy. Conventionally using MAC protocol lets the sensor node to be more in their sleep state to conserve their energy. Once the sleep and awake time is configured, a lower duty cycle is allocated for the nodes to operate to conserve the maximum amount of energy. Therefore, the network life can be extended. At present, there is a certain sensory application that demands the usage of priority-based data communication. An example to cite this operation is to detect the smoke/fire within the building premises via sensors. In such a case, the sensor will identify the threat level and produce a true alarm about the vulnerable environmental condition. MAC protocol's prime responsibility is to decide on a favorable condition for accessing the shared medium for resisting the possibility of a collision while performing data aggregation. This is essential as a sensor node doesn't have a higher degree of processing

capability nor has extensive resource availability. Hence, a better performance form can only be ensured if they operate by accessing the sharing medium. As per theory and deployment, there are various forms of MAC protocols viz. i) contention-based and ii) schedule-based. This implementation's prime plan is to evolve with an integrated framework with a special emphasis on balancing energy conservation and data aggregation performance. Following are the contribution of this paper:

- 1) The proposed system performs exploration of the neighboring nodes, followed by the formation of group-based communication. This operation stage leads to forming a list with single and multiple hops, followed by synchronization by exchanging the synchronization message.
- 2) A unique management of time-slot is carried out with a uniform size of period of synchronization. It also formulates the logic of forming the duty cycle followed by the construction of logic for ensuring better scalability while performing slot management by the nodes.
- 3) The proposed system also explores the optimal number of the data transmission links that are resistive towards collision and leads to effective data transmission.
- 4) The proposed hybrid MAC protocol assists in data transmission, considering the ownership of the slots. This process lets multiple numbers of nodes to perform communication in the presence of a defined time allocation.
- 5) Finally, the proposed Hybrid MAC scheme is scripted in MATLAB and evaluated concerning throughput, energy, processing time, and memory compared to the existing approach.

The proposed paper's organization is as follows: Section 1 discusses the existing literature where different hybrid MAC scheme techniques over various test environments are discussed for detection schemes used in data aggregation for sensory application. A discussion of research problems and the proposed solution is carried out in Section 3. Section 4 discusses algorithm implementation where the primary and secondary hybrid MAC scheme is discussed and elaborated, followed by a discussion of result analysis with more detailing about comparison in Section 5. Finally, the conclusive remarks are provided in Section 6.

2. Related Work

At present, there are various hybrid MAC approaches used in a wireless sensor network and are discussed in our work [1]. Existing studies have witnessed the implementation of MAC protocol with a communication scheme to improve routing performance. The work carried out by Kam, and Schurgers [2] have presented a scheme where a routing protocol is integrated with MAC

protocol considering a smaller deployment scale. The existing system has also witnessed swarm optimization usage for improving the scheduling process in the MAC algorithm. The model developed by Wang et al. [3] has a hybrid protocol that uses simulated annealing and particle swarm optimization to develop the scheduling process, thereby allocating time slots in the sensor network. The adoption of spatial correlation is also reported to improve MAC protocol performance, as seen in Zhao et al. [4]. The idea uses different MAC in different deployment regions, which lets certain sensors go in sleep mode. The implementation shows that system to be energy efficient with the least delay. The works carried out by Chen et al. [5] have developed a MAC protocol by considering a case study of underwater transmission. This mechanism makes use of a handshaking mechanism to introduce reliability factors within it. The study outcome was found to offer an effective utilization of channel as well as it also offers lower consumption of energy in comparison with other MAC protocols. Ruan et al. [6] have performed a comparative study for different network forms to assess the efficiency of the hybrid MAC protocol. The recent work carried out by Al-Janabi et al. [7] has discussed a stochastic model for hybrid MAC using the Markov model, where the energy performance is improved significantly. Existing studies have also seen various case studies where a hybrid MAC approach has been used. A unique study carried out by Madi and Al-Qamzi [8] has presented a MAC approach for a hybrid network system considering mobility factor.

In contrast, Zhang et al. [9] have considered underwater sensory applications where slot management is carried out based on traffic load. The discussion presented by Saboor et al. [10] has disclosed certain open-end research issues associated with using hybrid MAC in the special case of application. Ammar et al. [11] have presented a cooperative scheme with a single relay in a distributed manner to minimize energy consumption and assured the quality of service. Haqbeen et al. [12] have used dynamic scheduling for resisting delay, mainly while applying a hybrid MAC approach. A study towards the optimization of network performance has been studied by Hu et al. [13]. A different form of wireless network has been studied to find that it offers maximum data transmission capacity. A case study of industrial application has been taken by Meinyk et al. [14], where the study found different hybrid MAC applicable over the resource-constrained wireless transmission. Saad et al. [15] have offered an optimized scheme focusing on machine-to-machine communication using a hybrid MAC system where Monte-Carlo simulation has been used. Apart from this, there are various other approaches, e.g., Yang et al. [16], Deng et al. [17], Ma et al. [18], Jeon et al. [19], Cao et al. [20], Alam and Kim [21], Nguyen et al. [22], Yang et al. [23], Liu et al. [24], Hu et al. [25]. Therefore, it can be seen that there has been extensive work carried out towards the hybrid MAC approach considering different use cases where the majority of the work has focused on energy problems in wireless

networks [30-32]. The above-discussed work has its advantages claimed in the papers itself; however, its identified issues after reviewing the existing approaches are briefed in the next section.

3. Proposed Methodology

With the continuation of our prior work [26][27], the proposed system's main goal is to design and develop a novel hybrid MAC approach that could offer optimal data aggregation in wireless sensor networks. The identified issues from the existing system are as follows i) There is less number of hybrid MAC scheme which balances energy efficiency along with data transmission performance in wireless sensor network, ii) Inclusion of more involvement of slots in developing hybrid MAC scheme incurs extensive resource usage which degrades the communication performance over a long run, iii) Although scheduling is carried out in the existing system, they are not found to offer supportability of collision avoidance and interference, and iv) Existing approaches has not assessed the applicability of hybrid MAC over the variable traffic load scenario which renders them non-applicable over real-time traffic system.

The proposed methodology's discussion is carried out considering a specific case study as pictorially exhibited in Figure 1. The study assumes various sensor nodes groups where cluster heads carry out the communication in respective groups. The exchange of the synchronization message is carried out in intra-clustering and inter-clustering mode. During inter-clustering, all member nodes forward their slot information to the cluster head, selected based on maximum residual energy—the cluster head, after receiving the synchronization message, fine-tunes slots for all member nodes uniformly. During inter-clustering, the two communicating nodes will only exchange their slot information to propagate using a multi-hop approach. This form of exchange takes place via the gateway node. This use case is designed considering the practical aspect of integrating sensor nodes to advance technologies (like IoT) further.

Therefore, the proposed framework design will require a new form of beacon to support this novel topology. The new form of data packet consists of two classified regions in one slot. Part of the slot is allocated for an active communication period, while other slot parts are used for the idle communication period. The slot's active part has further synchronization messages and beacons to forward and receive the data packet. The idle (or sleep) part of the slot bears the field for data packet and acknowledgment. As the proposed study targets deploying in a practical scenario, it is essential to consider incoming data streams with variable bit rates. In such cases, there could be events when certain essential data are pushed back or delayed owing to a higher number of traffic towards the gateway node. This challenge is addressed by letting the user decide the data's importance by adding a bit of information with the data packets. The normal data packet

will only have a header and data field. The prioritized packet frame will consist of a header, data, and an additional single bit to show that this data packet is required to be transmitted. This form of transmission is done by migrating the resource allocation for normal data transmission to prioritized data.

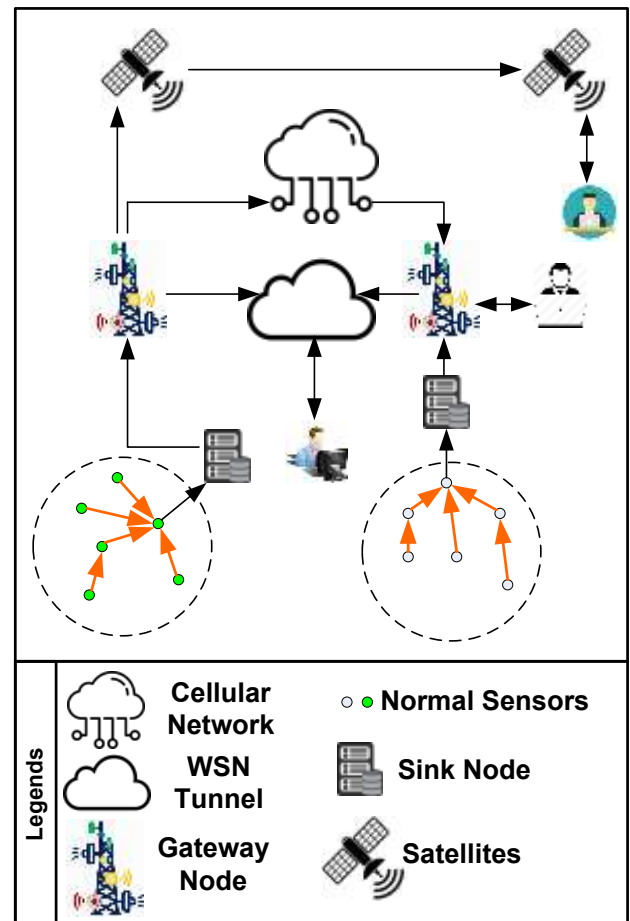


Figure 1. Adopted Case Study showing two heterogeneous sample groups of sensors connected via the sink node and gateway node to WSN tunnel and inter-satellite links. The proposed hybrid MAC scheme is used for both resource management and improving data transmission. The exchange of the slot information is carried out by communicating a cluster head via gateway nodes.

The proposed system formulates an architecture of the hybrid MAC protocol by adopting the case mentioned earlier. Figure 2 highlights the proposed system's implementation scheme. It can be seen that it initiates from a neighborhood discovery of the sensor nodes followed by a unique and simplified clustering operation, unlike any existing system. This operation is further followed by a synchronization process about managing effective time slots suitable in a dynamic order. This operation is essentially meant for resisting an event of a collision while performing the routine operation. The next part of the proposed design planning consists of selecting

intermediate sensors where the preference is given for the nodes in a single hop, which is considered to possess information about location, energy, and buffer. A simplified energy modeling is a design, which ensures to restrict and fine-tune the transmittance energy as per the current data forward demanding. Finally, a logical condition is formulated, which ensures that the selection process of intermediate nodes.

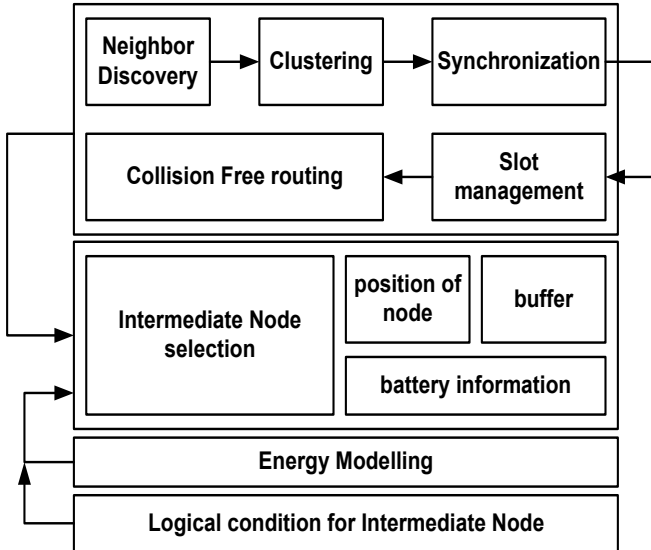


Figure 2. Proposed Schematic Architecture. The neighbor Discovery block initiates the communication process for sensor nodes where the data aggregation is carried out using the clustering block of operation. The synchronization block performs the SYNC message formation, which further interacts with dynamic slot management to ensure collision-free routing. The routing process occurs between two communicating nodes in the presence of an intermediate node considering node position, buffer, and battery information. A logical condition is set for intermediate nodes based on these parameters. Energy modeling is carried out, which finetune the allocated energy during the scheduling process.

4. Algorithm Implementation

The proposed system's complete implementation is carried out in two implementation stages: the primary and secondary hybrid MAC scheme. The primary hybrid MAC scheme focuses on achieving energy-efficient data transmission while the secondary hybrid MAC scheme focuses on achieving more optimized data transmission. The complete algorithm emphasizes offering an effective scheduling approach considering the defined framework of timeslots with both scheduled accessibility (idle mode) and arbitrary accessibility (active mode). The algorithm's complete focus is to offer a good balance between communication performances and energy control while

performing data aggregation in wireless sensor networks. The descriptions of the algorithms are as follows:

4.1 Algorithm for Primary Hybrid MAC Scheme

This primary scheme's core responsibility is to offer better sleep and awake management for the sensor node to carry out enhanced hybrid MAC scheduling. The algorithm takes the input of the number of nodes n in the presence of a single base station that can be placed over the simulation area. Unlike any clustering approaches in the existing system, the algorithm performs clustering based on the number of cluster n_c . The operation leads to a yield of data to be transmitted $data$ and energy e . The steps of the algorithms are as follows:

Algorithm for Primary Hybrid MAC scheme

Input: n (nodes), n_c (number of cluster)
Output: $data$ (transmitted data), e (energy)

Start

1. **For** $i=1:n$
2. **If** $d < r$
3. $C_{mat}=[(i, n+1), (n+1, i)]=1$
4. $[c, p]=f_1(C_{mat}, xy,)$
5. **End**
6. **If** $h_{1n} \neq (n+1)$
7. $h_{2n}=h_1(h_{1n})$
8. **If** $j < n_c$
9. $c_{id}=f_2(j, n/n_c)$
10. **If** $j=1:n_c$
11. **For** $k=1: \text{length}(\text{idx})$
12. forward syn_{msg}
13. **End**
14. **For** $l=1: pr$
15. $m(c_{idx}(pr(l))) = m$
16. **End**
17. Apply $e=f_3(c_{idx})$
18. Forward $data$
19. **End**
20. **End**

The algorithm took the n number of nodes and dispersed them randomly in the simulation area. The algorithm then computes the distance d among each node (Line-2). A condition is formulated to check if the nodes come within the transmission range r for each other using Euclidean distance (Line-2). This operation is followed by upgrading the C_{mat} matrix to unity values. The C_{mat} matrix stores all the nodes within the transmission range of each other (Line-3) as well as it also computes the distance xy between all nodes in its new position with the base station. This operation is followed by applying an explicit function $f_1(x)$, which acts as a new transmission scheme considering input arguments of matrix C_{mat} and distance xy (Line-4). This function formulates a communication vector based on the shortest path between two nodes with an outcome of cost c and path p (Line-4). The next part of

the algorithm is to search for double hops h_{2n} from the single-hop h_{1n} considering a matrix h_1 with all information of single-hop nodes (Line-6 and Line-7). This process is followed by assigning a cluster identity where a function $f_2(x)$ is formed, assigning the random numbers to the communicating nodes considering the number of nodes n and number of clusters (Line-9). The consecutive process is to consider all the clusters n_c (Line-10), and it extracts all the identity of the nodes which are part of clusters. It considers the length of that identity (Line-11) followed by forwarding the sync message syn_{msg} (Line-12). The proposed system also considers different levels of priority and selects the node for participating in the data forwarding process based on priority level (Line-15). Another function, $f_3(x)$, is formulated for energy control for all the nodes inside cluster cid_x (Line-17). The next algorithm implements a secondary hybrid MAC scheme as its continuation part of this algorithm.

4.2 Algorithm for Secondary Hybrid MAC Scheme

The primary algorithm discussed mainly the slot management, thereby reviewing a new form of hybrid MAC protocol considering hop wise communication; however, it is essential to ensure the participation of an intermediate sensor in order to prevent collision in the proposed system. The hybrid nature of the MAC protocol in the prior algorithm is required to ensure extensive participation of all the sensors where intermediate sensors are very important in the data forwarding process. Therefore, this algorithm is responsible for optimizing the primary hybrid MAC protocol concerning energy efficiency. The core idea is to enhance the scalability, too, while performing communication. The algorithm essentially chooses an intermediate sensor to ensure that their communication successfully takes place. The algorithm input nodes and data to be forwarded after processing yields n_r finally selected intermediate node. The steps of the algorithm are as follows:

Algorithm for Secondary Hybrid MAC Scheme

Input: n (nodes), $data$ (data to be forwarded)

Output: n_r (final relay sensor)

Start

1. **For** $i=1: n$
2. $n_s \text{forward } data(n_r)$
3. $n_f \text{forwardsu}(\phi_1 \phi_2)$
4. **If** $\tau(\phi_1) > \phi$
5. $\text{declare } \phi_2 \text{ as } \phi_1$
6. **If** $\tau(\phi_2) > \phi$
7. $\text{search new } \phi_2$
8. **If** $\tau(\phi_1 \phi_2) > \phi$
9. $\text{declare } msg \rightarrow n_r$
10. **End**
11. $\text{Select new } n_r$
12. **End**

End

The proposed algorithm's execution considers a similar number of sensors that offer an outcome of several intermediate nodes n_r to facilitate a robust transmission of the data packet among the sensor node. The proposed system performs an essential consideration that every single hop sensor possesses the discrete information about the intermediate sensors that come under another sensor's proximity with a single hop. For this purpose, two definitive roles are given to a sensor, i.e., a main intermediate node ϕ_1 and support intermediate sensor ϕ_2 . The main intermediate sensor is responsible for forwarding and obtaining the data packets to and from the intermediate sensors. The intermediate sensor node should be under a single-hop connection. Considering all the sensors (Line-1), the proposed system entails the transmitting node n_s to transmit the data packet to its proximity intermediate node n_r (Line-2). An intermediate sensor accesses essential information, e.g., energy, memory, and location of the sensors, in the form of updated information connected with both support and main intermediate sensors (Line-3). A simplified logic of movement is considered in the proposed system, where the distance between two nodes is computed. If that distance is more than a certain limit, the system considers that the node has moved from an old to a new position within the simulation area (Line-4). It will eventually mean that if the distance between the main intermediate sensors is greater than the cut-off value of ϕ (Line-4), the algorithm declares the support intermediate node n_s as main intermediate node n_r (Line-5). However, the new support intermediate sensor n_s is selected if the difference between the intermediate support sensor's distance is more than the cut-off ϕ (Line-6 and Line-7).

On the other hand, if the main intermediate node n_r and supports intermediate node n_s to exhibit maximized mobility degree compared to the cut-off value (Line-8), the system declares a notification to a main intermediate node (Line-9). This is one of the sensor's explicit characteristics to fine-tune the mobility aspect of the sensors in any form of application. In the complete process, a discrete-time slot system is maintained and managed for better optimization. Therefore, the primary hybrid MAC algorithm introduces a novel scheduling practice in wireless sensor network when exposed to a dynamic traffic condition. In contrast, the secondary hybrid MAC algorithm incorporates more communication efficiency in the form of reliability in data transmission. This is carried out by ensuring that data, once forwarded, will always reach its destination irrespective of any traffic challenges and energy-efficient manner.

The proposed system computes energy E using the following expression:

$$E = E_1 + E_2 + E_3 \quad (1)$$

In the above expression (1), the variable E_1 represents receiving/transmittance energy and time to synchronize. The variable E_2 represents receiving/transmitting energy and time to receive / forward data, while the variable E_3

represents the product of receiving/transmitting energy with time to receive the acknowledgment. Therefore, it should be noted that this expression is used for computing both transmittance and receiving energy. To compute data delivery performance concerning throughput, it is necessary to compute frequencies of transmission or receiving of the data σ for obtaining the rate. This is done by following the expression,

$$\sigma = \chi \cdot d_{sim} \quad (2)$$

In the above expression, the variable χ represents the arrival rate of transmission and receiving based on the Poisson rule and duration of simulation d_{sim} . It should also be noted that the proposed study's processing time also considers duration consumed by a node from conversion to active mode to idle mode and vice-versa. This duration is computed by,

$$d = n \cdot d_{conv} \quad (3)$$

In the above expression, the d_{conv} represents the duration required to convert from idle to active mode. This parameter is used as a prime role in computing algorithm processing time. The next section discusses the simulated outcomes obtained from the proposed implementation.

5. Result and Discussion

This section briefs about the simulated outcome of the proposed system that has been scripted in MATLAB. The simulation environment is as follows: the simulation consists of 500 sensors dispersed randomly over $1100 \times 1100 \text{ m}^2$ considering the initial time for message interval as 1 second, which is progressively increased to 10 seconds for assessment. The study considers the threshold for the proposed system's buffer to be 4 data packets with a length of 20 bits and a channel capacity of 20 kilobits per second. As the proposed system is an essentially MAC approach, it is compared with the existing hybrid MAC protocols, e.g., Z-MAC [28] and A-MAC [29]. Performance parameters selected are remaining energy, delay, energy consumption, and algorithm processing time. Considering a similar simulation parameter, the assessment is carried out for the performance mentioned above parameters, and the largest scale is constructed on each MAC method's respective scores in WSN.

The first performance parameter is processing time, as it can directly state the level of energy efficiency in the proposed hybrid MAC scheme. Considering the random topology, the residual energy is computed. Figure 3 highlights that the proposed system offers better energy efficiency in contrast to existing hybrid MAC protocols. The prime reason behind this is that the proposed system emphasizes energy saving and offers data transmission based on the dynamic slot management, which ensures optimal sleep time of the node, which is missing in existing hybrid MAC protocols.

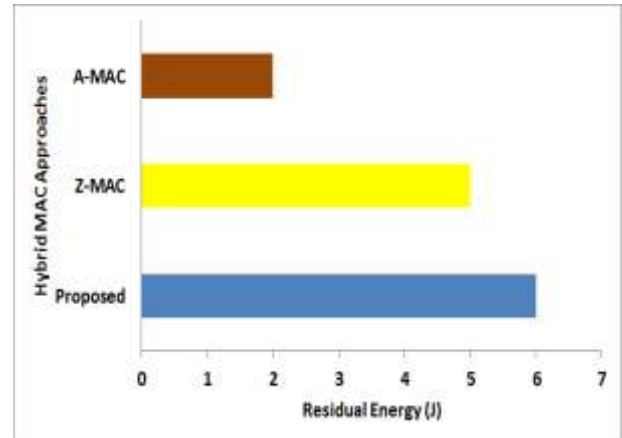


Figure 3. Comparative Analysis of Residual Energy. Observation carried out over maximum Residual Energy of 7 Joules. The proposed scheme conserves 6J, A-MAC conserves 2J, and Z-MAC conserves 5J on a scale of 0-7J of residual energy computed.

Hybrid MAC protocols are also known for their effective scheduling, which significantly affects the data transmission performance. This fact can be assessed by observing the throughput as a performance factor. Similarly, Figure 4 highlights that the proposed system offers better throughput, too, which can be justified by the availability of many sensors as it works on the dynamic scheduling process. Moreover, the secondary hybrid MAC approach offers better participation of the intermediate nodes, ensuring better throughput than the existing system.

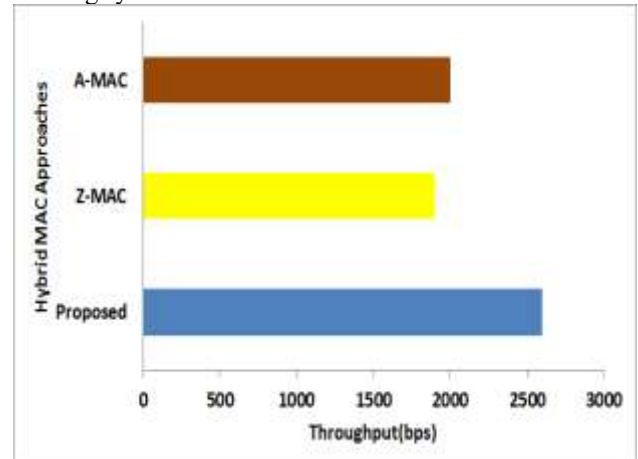


Figure 4. Comparative Analysis of Throughput. Observation carried for a maximum of 3000 bps throughput. The proposed scheme possesses 2500 bps, the A-MAC scheme offers 2000 bps, while the Z-MAC scheme offers 1950 bps of throughput on a scale of 0-3000 bps.

The proposed hybrid MAC's effectivity can also be justified if they offer reduced memory dependency and faster execution. Figure 5 and Figure 6 show that the proposed system offers highly reduced memory consumption and processing time compared to frequently used standard hybrid MAC protocols. The prime reasons behind lower memory consumptions are i) the only optimal number of nodes assists in the data forwarding process as per secondary hybrid MAC approach, which results in lesser involvement of saturated nodes, and ii) the complete operation is based on run time, and no intermediate information is stored. However, it is not the case with existing protocols where information about slot management is stored in every node. There is a lack of frequent updating operations resulting in a saturation state leading to higher memory consumption.

Similarly, the processing time of the proposed system is very much less due to similar reasons. The proposed system offers no iterative operation in forming a communication vector; neither offers a typical clustering system like existing clustering approaches with many criteria. This saves abundant time to formulate a network and carry out data aggregation. Hence, the complete mechanism of route discovery and management becomes much easier and faster.

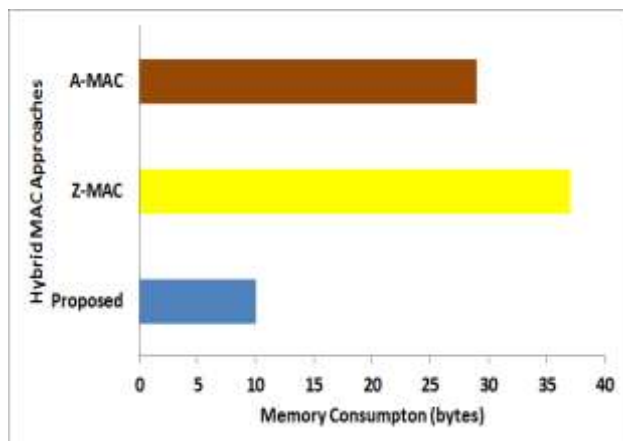


Figure 5. Comparative Analysis of memory Consumption. The proposed scheme consumes memory till 10 bytes; the A-MAC scheme consumes 30 bytes, while the Z-MAC scheme consumes 36 bytes of memory on a scale of 0-40 bytes.

Owing to this result, it can be said that the proposed system could offer supportability to the sensory application, which is required to be operated in dynamic conditions as it can sustain for a longer duration without affecting any data transmission performance. As it offers faster processing duration, it can be used for any time-bound operation with wide ranges of the application running over its variable traffic condition.

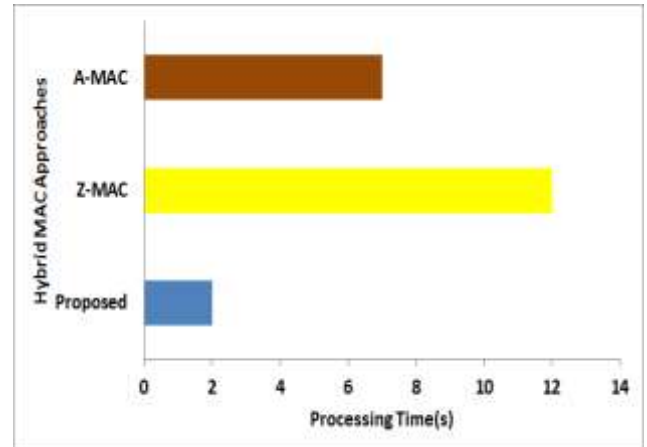


Figure 6. Comparative Analysis of Processing Time. The proposed scheme takes only 2 seconds; the A-MAC scheme takes 7 seconds, while the Z-MAC scheme takes 12 seconds of algorithm processing time on a scale of 0-14 seconds.

The proposed system develops a unique mathematical approach to compute the energy (expression-1) used for computing for all the other A-MAC and Z-MAC approaches. The analysis doesn't use the conventional approach used in A-MAC and Z-MAC to compute energy outcomes. Similar consideration goes for assessing other performance parameters too. Hence, the proposed system's outcomes are mathematically correct and applicable for assessing any environmental situation of WSN.

6. Conclusion

From the discussion of this concept, it is essential to state that energy is one significant resource required for proper operation over a long time in a wireless sensor network, and hybrid MAC is an appropriate option. The proposed concept essentially brings out the contribution by incorporating better energy-saving towards the complete set of sensors in variable/dynamic traffic conditions. This implementation's distributed nature can be executed over a large geographical deployment zone with limited power consumption without affecting the data transmission. The significant study contributions of the proposed system are

- i) The model offers good mobility-based supportability. The proposed system is considered a use case where there could be either static or mobile sensors in each group. The proposed system registration of a new node joining the group or old node leaves the group and implements the entire algorithm as its flow to ensure a wide range of supportability.
- ii) It ensures participation of the best intermediate node with significant information from its hop, ensuring the least search time. The proposed modeling

considers temporal factors associated with the transition of states of the node during synchronization. This increases the capability of a faster route discovery process with the latest updates. It will mean that the proposed hybrid MAC offers a reliable exploration of routes linking to the destination node.

iii) Along with energy efficiency, it also offers efficient throughput showing a healthy balance between data transmission and energy efficiency performance. This is one of the essential characteristics of any hybrid MAC scheme in WSN, which has resource-constrained nodes. Hence, this balance both energy demands and data transmission efficiency.

iv) It is computationally efficient, as observed from its least processing time. This is reflected in lower memory consumption and faster processing speed.

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