EH-MAC: Extensive Hybrid Medium Access Control Mechanism for Improving Network Lifetime and Communication Efficiency

Anitha K, Ramesh Shahabadkar

Abstract*: The domain of image signal processing, image compression is At Contribution of hybrid protocol has been gaining importance owing to more demands of energy efficiency among the communicating nodes in Wireless Sensor Network (WSN). Review of existing literatures shows that hybrid MAC protocols has been not been evaluated over heterogeneous environment in WSN with no much consideration of temporal factors connected to it. Hence, the proposed system introduces a novel extensive hybrid MAC protocol (EH-MAC). The system introduces a mechanism where time synchronization with respect to assigned dynamic slots are considered followed by inter-synchronization of network. Apart from this, a relay node selection process has been used uniquely considering the state of static and mobile sensor nodes in the analysis environment. The proposed system also introduces an unique selection of node unlike conventional MAC protocols which offers a capability to control any form of idle listening within WSN. The simulated outcome of the proposed system has been found to offer higher residual energy, faster response time, lower memory consumption, and optimal throughput delivery performance in comparison to standard existing hybrid MAC schemes in WSN.

Keywords*: Energy, Network Lifetime, Hybrid MAC, Wireless Sensor Network, Time factor.

I. INTRODUCTION

Wireless Sensor Network (WSN) is known for its cost effective remote communication system which are even unreachable to human. It also offers working in various environment hazardous conditions in order to facilitate various applications connected with monitoring physical attributes [1] [2]. At present, WSN is also one of the integral parts of the Internet-of-Things which calls for massively connected sensor devices [3]. A closer look into various application of WSN will show that it is basically formed by large number of distributed sensors that performs communication using either single-hop or multi-hop approach [4].

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Clustering is one of the common strategies to organize the process of data aggregation that directly contributes towards saving the unnecessary energy depletion [5]. At present, there are various strategies being evolved for saving the unnecessary energy depletion via routing using energy-efficiency techniques [6] [7]. However, MAC-based technique is primarily considered as the suitable technique for energy conservation [8] [9]. In order to evolve up with a good approach, it is essential to understand the problems connected with energy depletion. The prime factor of energy depletion is collision which occurs due to an event of re-transmission of data packets in case of failure of prior transmitted data packet to reach its destination for any reason. This event of re-transmission consumes much time, delay as well as energy. The secondary factor for energy consumption is overhearing where the data packets arrive to certain sensors which is actually not the destination node. Such problem occurs due to defective routing strategy. The third factor for energy consumption is overhead due to beacons. Although, the beacons are very less in size in comparison to the data packet but they too consume energy when attempted to be forwarded. Problem occurs when unnecessary data are also considered for data forwarding causing depletion of both transmitting and receiving beacons. Finally idle listening is another reason for energy drainage in WSN which happens when the node expends its energy to receive some data which is yet to be / not forwarded. All the above mentioned problems occur in large scale WSN application where the communication is quite distributed. Unfortunately, existing MAC schemes will do just the opposite as it allows the sensor to perform the listening operation over the communication channel that is needed to obtain the possible traffic information. Such MAC schemes are either CDMA or IEEE 802.11 and these scheme drains out nearly half of the residual energy of the sensor nodes. To design a good MAC protocol for the wireless sensor networks, we have considered the energy efficiency attribute. As the sensors are supported by the limited power supply, therefore, it is quite a difficult task to develop energy-efficient protocols. Apart from this, scalability and computational complexity is another factor that is required to be considered while evolving up with a new MAC scheme for energy efficiency. Finally, adoption of hybrid scheme and further investigation towards hybrid scheme will offer more insights towards the beneficial charecteristics that can be obtained by jointly using multiple approaches of MAC. This paper has reviewed the existing approaches of MAC and as addressed the existing research problem by introducing a novel framework of further extension to hybrid MAC system.

The complete implementation has been carried out over our prior research framework of hybrid MAC system where smart features are also incorporated for energy efficiency. The study outcome claims of achieving better energy efficiency performance for large scale of WSN environment.

The organization of the paper is as follows: Section ‘A’ discusses about the existing literatures where different techniques are discussed for detection schemes used in power transmission lines followed by discussion of research problems in Section ‘B’ and proposed solution in ‘C’. Section II discusses about algorithm implementation followed by discussion of result analysis in Section III. Finally, the conclusive remarks are provided in Section IV.

A. The Background

Our prior review has discussed various existing approaches of energy efficiency in WSN [10] and this section further upgrades the information about the MAC based approaches. Approach towards resisting the collision events was addressed in the recent work of Alfouzan et al. [11] where the authors have used MAC protocol on the basis of *depth layering* with a capability to schedule the transmission. Similar form of scheme was also considered in the study of Yang et al.[12] where a time-based waiting option was constructed for enhancing energy conservation. Xu et al. [13] have addressed the delay problem in WSN using *apaptive beaconing* process where the listening and transmission operation is discretely designed. Similar adaptive MAC protocol was also designed by Siddiqui et al. [14] where *Poisson arrival* has been used to enhance the quality of service in communication system of WSN. Pegatoquet et al. [15] has introduced an energy harvesting scheme that facilitates multi-hop communication system applicable for dual radio system. Most recently, the work of Liu et al. [16] have introduced an approach for delay minimization by using *quorum-based MAC protocol* for achieving further adaptiveness. Another adaptive based approach was carried out by Du et al.[17] where sampling scheme has been used for its supportability over access to opportunistic spectrum. The study contributes to conserve the energy of the cognitive sensors. Ha et al. [18] has presented a unique approach where harvesting operation is carried out first followed by transmission operation using *Markov modeling* and *probability theory*. Singh et al. [19] have discussed a cross-layer based approach for minimizing delay using contention-based MAC protocol that enables increase in the number of sensors that transmit data. Study towards contention-based MAC was also carried out by Agarwal et al. [20] using stochastic modeling approach along with renewal theory. Li et al. [21] have implemented a routing on the basis of the *depth-factor* considering underwater sensors. Aoudia et al. [22] have developed a model using *Markov Chain* with a focus on delay and energy reduction. Guimaraes et al. [23] have discussed a simulation based study for addressing the collision problem. Alvi et al. [24] have presented discussion about the adaptive approach emphasizing on using smaller time slots and knapsack algorithm for incorporating adaptive feature. Gouyong et al.[25] have investigated the influence of channel state information with artifacts which is used as a part of energy conservation scheme. Glaropoulos et al. [26] have used cognitive scheme of MAC using their analytical modeling. Le et al. [27] have discussed a solution where the power saving module has been created for minimizing the fluctuation of the wake-up schedule in WSN. Varga et al. [28] have developed a harvesting approach where specific beacon approach has been utilized for constructing MAC protocol with a capability to fine-tune the duty cycle associated with power saving sensor. Therefore, it can be seen that there are various approaches constructed in existing system for facilitating energy saving properties. However, these schemes are associated with specific limitation irrespective of the advantages claimed by the researchers. The next section outlines the research problem.

B. The Research Problem

The significant research problems are as follows:

- Applicability of MAC protocols over heterogeneous environment of sensory application is quite challenging to develop and complex to ensure design viability.
- Existing approaches do not offer any system model for asynchronous model of communication where temporal factor is slighlt ignored.
- There are less study towards inter-synchronized communication approach using hybrid MAC protocols.
- There are less standard models where hybrid MAC has been used extensively in multiple model of sensor node operation.

Therefore, the problem statement of the proposed study can be stated as “*Developing a cost-effective computational model for hybrid MAC protocol that can offer extensive facilitation of communication performance as well as energy saving*.” The next section highlights the solution to address this issue.

C. The Proposed Solution

The proposed study is an extention of our prior implementation of hybrid MAC protocol [29]. This part of the study considers analytical research methodology that mainly targets to address the issues related to low power listening. The technique also aims to permit any node to directly access the slot from owner node that is equivalent to TDMA scheduling. The design considers scenario of both static and mobility modeling of applications in sensor network. The study will consider that a cluster consists of three different types of nodes, i.e. cluster head, candidate member node and member node. The topology assumes that each cluster head are highly connected to each other using an IP network where each cluster head serves both data from both static and mobile application. The schematic diagram is as shown in Fig.1: Initially, a system model is build, which is nearly same as that of SF-HM, where the system uses asynchronous communication system in order to initiate discover of communication channel. A single hop communication is used by two sensors to establish connection. The technique will allow accessibility to owner slots by all the nodes and it uses CSMA to access other slots. The next step is to perform selection of one hop neighbor node followed by allocations of specific slots. This feature potentially assists in adjusting the proposed system with mobility.

The study will also use the concept of time synchronization to fine tune the problem of clock drift as it will be used for modeling purpose.

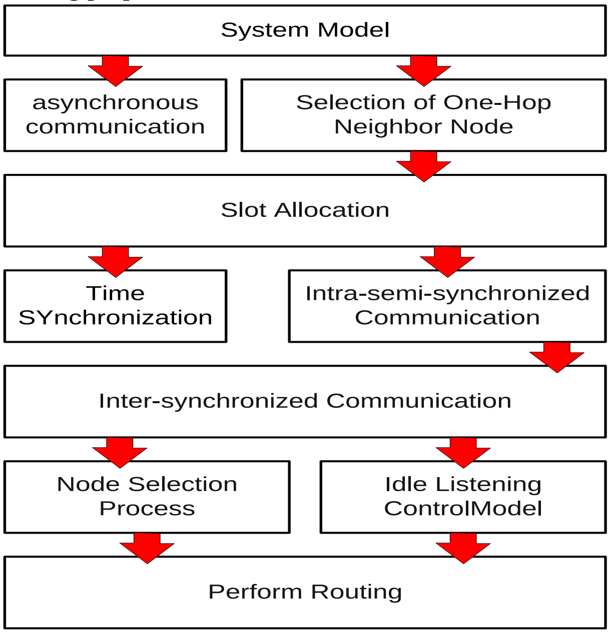


Fig.1 Schematic Diagram of EH-MAC

The next phases of communication perform intra and inter-communication that initiates with carrier sensing. A significant mathematical modeling is designed in order to model the hypothesis that shorter preamble can enhance the network lifetime of a sensor.

The final part of the modeling is to check for the power dissipation performance in idle mode. The core agenda in this final stage is to fine tune the modeling in order to make the idle time equivalent to off time of the nodes in order to resist the node to consume energy without doing any work. The routing is followed after all this to perform energy efficient communication.

II. SYSTEM IMPLEMENTATION

The core goal of the proposed system design is to evolve up with constructing a strategy towards development of an extensive hybrid MAC approach with an enhanced capability of communication efficiency considering different mode of communication in WSN. This section discusses about the assumptions and dependencies, design strategy, and execution flow for achieving the proposed system.

A. Assumptions and Dependencies

The *primary* assumption of the proposed system is that both the transmitting sensor as well as receiving sensor is assumed to consider depleting energy for each cycle of data aggregation.

The *secondary* assumption of the proposed system is that it introduces an auxiliary node which after obtaining the confirmation from the member node of onecluster, the auxiliary node assumes that request beacon is successfully transmitted. The *tertiary* assumption of the proposed system is that it uses both single and multihop where single hop is used only for capturing the environmental data while multihop is used for finishing the data aggregation cycle. The *fourth* assumption of proposed system design is to assume that there is aspontaneous degradation of energy even in idle mode. Owing to the adoption of the sleep scheduling approach, the study assumes the sensors to be working under active and passive state. Finally, the sensing capability of the sensor is assumed to be very smaller than the complete simulation area where the monitoring is carried out.

B. Design Strategy

The proposed system considers that there are three types of sensors viz. i) auxiliary node, ii) candidate auxiliary node, and iii) member node. All these three types of the nodes formulate a single domain of communication. A domain of communication is linked with application whereas all the nodes within its domain (except auxiliary node) are capable to sense different physical attribute within a single domain. For an example: consider that domain-1 is formed for industrial sensor where each member node can sense different environmental information. It will mean that all members as well as auxiliary candidate node are heterogeneous sensors. The auxiliary node is selected on the basis of maximum resource availability where they just fuse the data obtained from member node and forward it to either sink node or to next auxiliary node. All the sink nodes communicate via a cloud based IP network. Fig.2 gives the pictorial representation of the design implemented in proposed system.

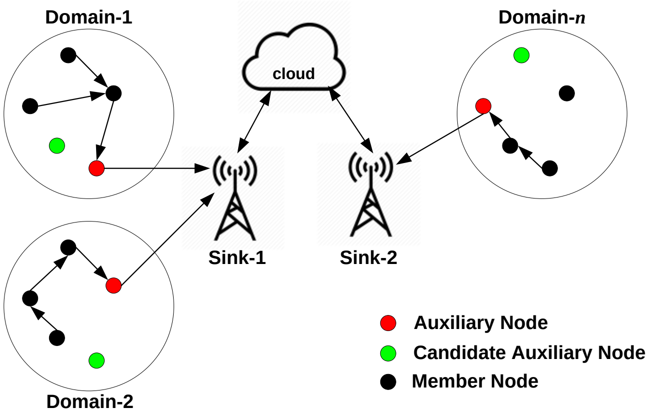


Fig.2 Adopted Design of Implementation

Fig.2 highlights that proposed system perform asynchronous communication system where one hop is mainly used for forwarding the fused data while multihop communication is faclitated between two domains. Inte-synchronization is carried out in same domain of communication while intra-communication takes place between two different domains. The process of node selection is carried out for electing auxiliary node while the energy modeling is carried out considering the energy factor during the idle mode too.

C. Execution Flow

The proposed system undergoes various set of process for constructing the extensive MAC approach towards leveraging energy efficiency in WSN. The complete execution process is constructed for minimizing consumption of energy and leveraging scalability. The first process is to perform selection of single hop in the proposed extended MAC approach where the selection of the relay node is carried out.

The steps of the algorithm are as follows:

Algorithm for Relay Node Selection

Input: *n* (number of sensors)

Output: r_{node} (confirmed relay node)

Start

1. **For** i=1: n
2. s_{node}→data(r_{node}) s_{node} is source node and r_{node} is relay node of one hop
3. r_{node}=update[c_{rel} s_{rel}]
4. **If** dis(c_{rel})>th
5. flag s_{rel} as c_{rel}
6. **If** dis(s_{rel})>th
7. find new s_{rel}
8. **If** dis(c_{rel} s_{rel})>th
9. flag msg to r_{node}
10. **End**
11. Select new r_{node}
12. **End**

End

The algorithm takes the input of *n* (number of sensors) which after processing yields an output of r_{node} (confirmed relay node). The algorithm considers that the entire node with single hop retains the information in the form of updates of the two discrete kinds of relay nodes that are within the reachability of one-hop neighbor node.The two types of nodes are core relay (C_{rel}) and support relay (s_{rel}). Basically, core relay or auxiliary node is used for transmitting as well as receiving the packets to the immediate node which is characterized by single hop only. Therefore, the algorithm considers all the node *n* (Line-1) and then chooses the source node s_{node} to forward data to its neighboring relay node r_{node} (Line-2). This relay node retains all the current information e.g. position of node, battery information, buffer, etc in the form of update associated with the core relay node and support relay node (Line-3). If the core relay node is found to exhibit displacement than it is required to ensure if this deplacement is significant enough to consider it as a movement. Therefore, the proposed system introduced a cut-off spatial distance *th* and if the displacement of core relay is found to be more than *th* (Line-4) than the system consider the support relay s_{rel} node as core relay c_{rel} node itself (Line-5). On the otherside, if the displacement of the support relay s_{rel} node is found to be more than cut-off *th* (Line-6) than the system looks for selection of new support relay s_{rel} node (Line-7). However, if the system finds both core relay c_{rel} and support relay s_{rel} node to be having higher displacement (or mobility) when compared with the cut-off value *th* than (Line-8) than a discrete message is flagged to relay node rnode (Line-9). This charecteristics of the algorithm offers better fine-tuning of the movement of the sensor nodes. A highly local slot of time is used in proposed system.

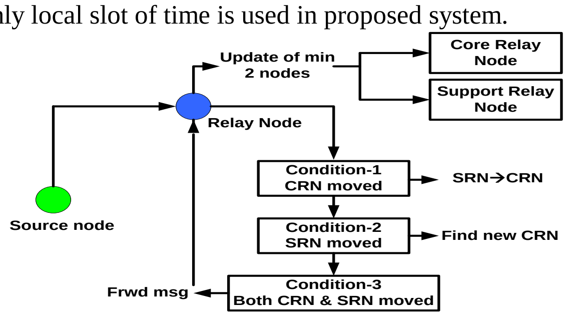


Fig.3 Algorithm Processing Steps

The next part of the implementation is connected with the communication over the similar domain of WSN. The complete lists of single-hop adjacent sensors are forwarded to sensors followed by transmission of message of shorter preamble in order to alert core relay c_{rel} node. However, if there is any form of failures of energy than the support relay s_{rel} node is required to forward the preamble message. The response is only forwarded to the transmitting node when it receives the preamble message of shorter length. This process is iterated until and unless the data is successfully forwarded to the support relay s_{rel} node with lesser extent of overhead. The novelty of this part of the study is that proposed system makes use of lower size of preamble message in compared to any existing MAC scheme that significantly causes issues of overhearing. Another interesting part of the proposed system is that contention windows with different time slots are used when a common neighboring sensor is corresponding with many sensors. This operation is carried out in order to manage traffic bottleneck problem. The selections of the slots of the sensors are carried out arbitrarly that significantly assists in communication without any collision. At the same time, there is no loss of data as sampling and randomization process is adopted while selecting similar time slots. The proposed system also has involuntary process of buffering data that contributes towards minimizing the time to wake up by the sensor while it also increases the network lifetime. In this buffering process, all the data ongoing is listened while a replica of the data is stored by the sensor that has been obtained irrespective of the actual receiver node and the process is continued until and unless the receiver node obtaines the acknowledgement of this data. The computation of the energy consumption is carried out with respect to three dependable parameters i.e. energy factor for carrier sensing, energy used for syncing destination and source node while attempting time synchronization, and drift factor of the computational clock in order to maintain track of time difference. The information about the rectified time is now received by core relay node (or support relay node too). Without a kind of usage of target address, the source node forwards a short preamble prior to forwarding the packet. The advantage of this implementation step is that it saves a higher degree of transmittance energy. The next phase of implementation is associated with the inter communication system where auxiliary node plays a prominent role.

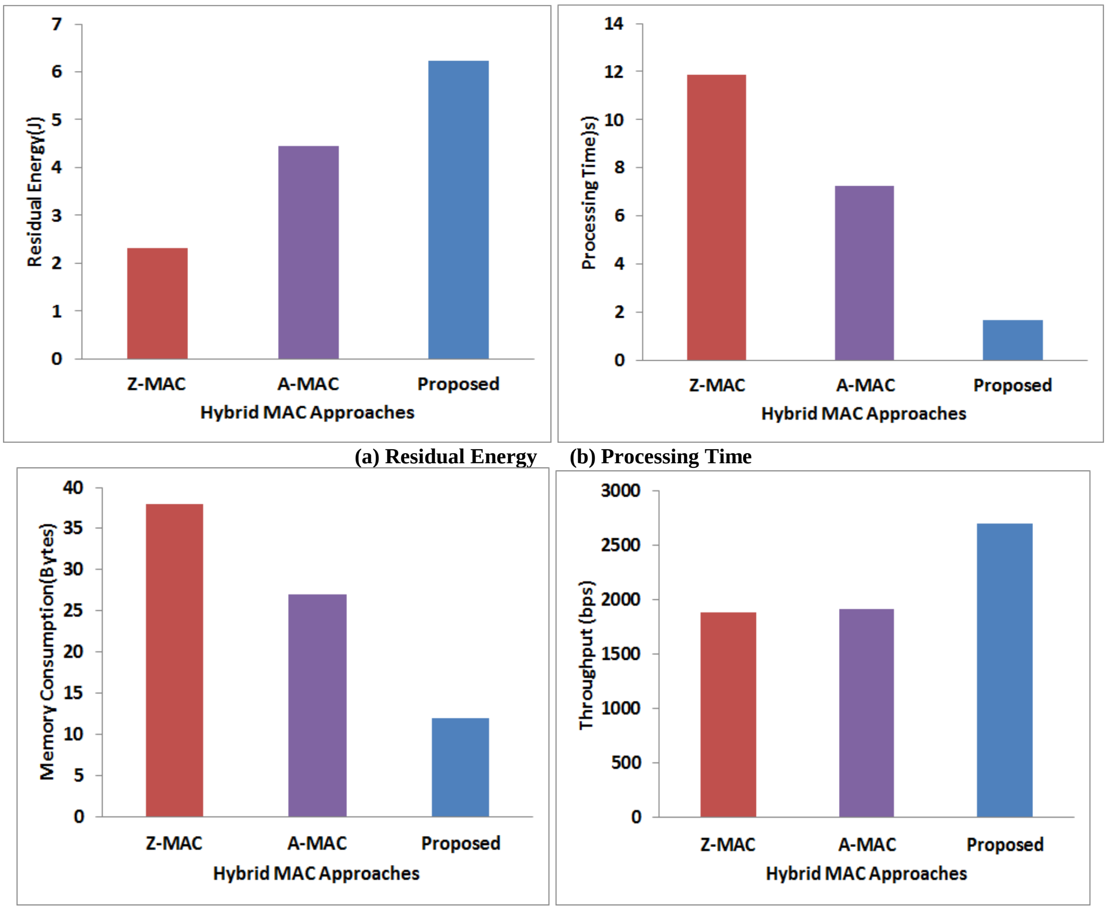
It is already known that auxiliary node is present in each domain of communicationwhere one auxiliary node in one domain communication with another auxiliary node in different domain in order to perform time synchronization. Basically, auxiliary node not only forwards the data that one of its node within the region has sensed (in single hop) but it also acts as relay node and forwards the information. Auxiliary node forwards a special beacon that has following information embedded within it viz. time for next data distribution, present time, consecutive aggregation time, and it also offers updated schedules for obtaining multiple data packets from the sensor within the domain. Now, after receiving theschedules from the auxiliary node, the member sensors are allowed to transmit as well as receive the sync message.

Once the transmission of the data from diferent domain is over, the sensors are permitted to transit to the state of sleep.One of the interesting part of the implementation is that the activeness of the sensor is ensured only during the transmission of the sync message from the auxiliary node because without it, the other member nodes will not be knowing the routines of sleep and awake state in proposed MAC protocol.

Essential information to be noted is that the selectionof the auxiliary node is carried out on the basis of the strength of signal, remnant energy, and allocation of buffer space within the member node. Any candidate member node that has higher value of it can be selected as an auxiliary node. The moment the remnant energyof the auxiliary node is touches the threshold energy, the system generates a flag message which selects the candidate auxialiry node located at a nearest distance of the existing auxiliary node. In order to effectivenly control the computational overhead for selection of next auxiliary node, the proposed system uses a decisive-based approach that chooses the new auxiliary node on the basis of above three parameters. The proposed system also assists in computing the instantaneous energy for the sensor nodes. The significant advantage of the proposed system is that it offers higher degree of flexibility where the member node can participate in the process of the election of auxiliary node. Initially, a preamble of shorter length is forwarded by the base station using broadcasting while as a part of response; the entire sensor performs computation of the spatial distance with respect to the base station on the basis of the strength of the signal. Only the sensor that obtains the preamble of shorter length and that transmission has been carried out over higher frequency of radio, that candidate member node becomes auxiliary node. Apart from this, the energy computation is carried out with respect to channel capacity, data packet length, transmission power, receive power, idle power, and sleep state. Therefore, a novel mechanism is introduced by the proposed system where an extended MAC protocol is implemented over WSN with a special emphasis over the energy efficiency.The algorithm is less iterative and more progressive in nature of its operation and therefore the algorithm offers less computational overhead.

III. RESULT ANALYSIS

The assessment of the study has been carried out in MATLAB considering 500 sensor nodes deployed randomly. All the sensors are initialized with 15J of energy which drains out in progression of communication. A test packet of 500 bytes has been used for analyzing the delivery performance while the memories of all the sensors are retained at 48 kilobyte. The outcome of the study is compared with existing hybrid MAC protocols e.g. Z-MAC [30] with respect to various performance parameters as shown in Fig.4



(a) Residual Energy (b) Processing Time

(c) Memory Consumption (d) Throughput

Fig.4 Comparative Analysis

A closer look into the existing system shows that proposed system offer better energy efficiency as well as communication performance at same time (Fig.4). The reason for optimal energy saving of the proposed system (Fig.4(a)) is that its unique scheduling technique allows the node to maintain a good sleep time without affecting the current communication system whereas Z-MAC includes increased number of energy monitoring activity resulting in overall drainage of energy after 1000 rounds. A-MAC offers better energy saving compared to Z-MAC due to its adaptive nature; however owing to its adaptive properties of its duty cycle. This is also the reason that proposed system offers faster processing owing to the use of shorter preamble as compared to Z-MAC and A-MAC (Fig.4(b)). The complete algorithm works on run-time and no intermediate information is saved resulting in lower memory consumption in contrast to exitsing hybrid MAC (Fig.4(c)).. The selection of the relay node is one essential contribution of proposed system and it offers a comprehensive route formation with a highly time synchronized sensors resulting in better throughput performance (Fig.4(d)). However, both A-MAC and Z-MAC offers nearly equivalent performance in data delivery as it only target the node with high residual energy for forwarding the data. The proposed system throughput is better as it formulates the routes and takes assistance of any sensors which satisfies the multiple criteria of staticness and mobility (discussed in prior section). Therefore, the proposed system can be claimed for offering cost effective hybrid protocol with a good balance over energy conservation performance as well as communication performance too.

IV. CONCLUSION

This proposed paper has presented a novel design of hybrid MAC protocol with a target that adoption of diverse form of sensors can be collaboratively used in WSN for cost effective and energy efficient data aggregation process. Different from existing approaches, the proposed system considers that a node could be either static or mobile and each cluster is formed with nodes with unique sensing towards different environmental attributes. The study also considers the presence of the entire base stations are connected via IP networks (cloud). The prime contribution of the proposed study is that i) it offers a unique relay node selection process unlike any existing system for energy efficient data forwarding scheme, ii) increased data throughput with energy efficiency,iii) higher supporability of mobility, iv) highly reduced computational efficiency.

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