Fuzzy Based Enhanced Medium Access Control protocol for Wireless Sensor Networks

N. Tamilarasi, S. G. Santhi

Abstract: Wireless Sensor Networks (WSNs) have increased huge consideration because of their wide scope of utilizations. In these networks, the sensor hubs gather various kinds of information from the general condition. During the transmission of collected data packets, some of them will be dropped due to the collision of packets. So, collide packets are retransmitted which may lead the network to high energy consumption. As Medium Access Control (MAC) protocol has responsible for reliable communication in WSN, an enhanced MAC protocol has to be proposed for improving energy efficiency of the network. By considering this solution, Fuzzy Based Enhanced Medium Access Control protocol (Fuzzy-MAC) is proposed in this paper. Before transmission, data packets are prioritized using the Fuzzy system. Then the packets are transmitted in light of the need of the parcels. Simulation results show that the exhibition of the proposed Fuzzy-MAC beats that of existing MAC protocols as far as energy utilization, delivery ratio and throughput.

Keyword: Wireless Sensor Networks (WSNs), Medium Access Control (MAC) protocol, Fuzzy system, Fuzzy-MAC

I. INTRODUCTION

WSNs comprise of an extensive number of remote sensor nodes that have detecting, information handling and correspondence functionalities [1] [2]. WSNs are regularly used to monitor a field important to recognize development, temperature changes, precipitation and so forth. The nodes are ordinarily outfits with power-compelled batteries, which are frequently troublesome, costly and even difficult to be supplanted once the nodes are conveyed. Time efficiency and energy efficiency are two noteworthy contemplations for sensor information accumulation in WSN. Energy concerns the measure of energy spent in information accumulation. Since sensor nodes are regularly controlled by batteries, it is basic to preserve energy however much as could reasonably be expected to broaden the lifetime of a sensor network. Time effectiveness, then again, alludes to the latency of gathering information from sensors nodes to a base station. Sensor information is frequently required to be immediately assembled data and exchange effectively to the goal [3-5].

As medium access is the significant customer of sensor energy in WSN, Medium Access Control (MAC) assumes imperative job to guarantee the successful task of WSNs. A MAC protocol chooses while contending hubs could get to the common medium and attempts to guarantee that no collisions happen while hubs' transmission [6]. MAC protocol straightforwardly controls the action of hubs radio and chooses when the contending hubs may get to the mutual medium to transmit the information.

In this way, MAC protocols must be energy efficient to accomplish longer system lifetime [7]. When running a MAC protocol on a sensor wireless arrange, much energy is squandered because of idle listening of sensors, collisions between the packets, Overhearing, Protocol overhead and Traffic vacillations. To tackle these issues, numerous MAC conventions had been displayed, for example, dispute based MAC protocol [8], Channel Polling Based MAC Protocol [9], Scheduling Based MAC Protocol [10] and Hybrid MAC protocol [11]. However, energy consumption and communication overhead of WSN are further to be reduced. To attain these goals, MAC layer of WSN is to be improved so that priority based MAC protocol is presented in this paper.

Commitments of this paper are described as follows:

- Sensor nodes validate the collected data packets based on its Residual Delay (RD_{Pkts}) and Buffer Occupancy (BO_{Pkts}). These calculated values of the data packets are forwarded to the Base Station (BS).
- The BS prioritizes packets using Fuzzy system. Then the information parcels are transmitted based on their preferences.
- The exhibition of this proposed approach is assessed as far as energy utilization, communication postponement and system lifetime.

Rest of this paper is sorted out as follows. Section 2 surveys some past literatures which centered research on MAC protocol in WSN. Section 3 proposes Fuzzy Based Enhanced MAC protocol for WSN. Outcomes of this proposed approach are talked about in segment 4. At long last, this paper is finished up by segment 5.

II. RELATED WORKS

In this section, some past literatures which centered research on MAC protocol in WSN. Due to the collision of data packets, the transmitted packet will be dropped. To overcome this, the dropped packets will be retransmitted but it leads to high energy consumption. So, to save energy in WSN, several MAC protocol had been presented. Such, Ashutosh Bhatia and R.C. Hansdah [12] had proposed a system for efficient multicast transmission in WSNs. The authors aimed to manage the collision and to attain reliable multicast. They had achieved their aim by presenting TDMA-based channel access in MAC layer. This proposed channel access was performed on the high of a Multicast Spanning Tree (MST) rooted at BS. Because of the proposed approach, they had attained better tradeoff between reliability and latency. Peyman Teymoori *et al* [13] had proposed an proficient MAC protocol for Unmanned Aerial Vehicle (UAV) based WSN. Aim of the literature was to increase throughput and productivity of WSN-UAV.

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To accomplish these goals, the authors had presented Advanced Prioritized MAC protocol which was abbreviated as AP-MAC. By presenting the AP-MAC protocol, they had achieved better higher throughput and higher efficiency.

Sohail Sarang *et al* [14] had illustrated a QoS aware MAC protocol in energy harvesting WSN. The authors aimed to minimize the delay for data transmission. To accomplish their goal, they had introduced a QoS MAC protocol for Prioritized information. This proposed technique, supported multi-priority of data packets. Since of this proposed approach, the creators had shortened the delay by dropping the sitting tight clock for the most priority information parcels.. Jaeho Lee and Seungku Kim [15] had presented an improved MAC protocol for various sorts of traffic in WSNs. The aim of the literature was to reduce energy consumption that was happened due to retransmission and duplicated transmission of packets. To attain this goal, the authors had presented an improved receiver-initiated MAC protocol which was abbreviated as EnRI-MAC protocol. This protocol had reduced duplicated transmission of packets by considering a rendezvous time. By presenting this enhanced protocol, the authors had achieved better delivery latency and duty-cycle ratio.

Ananda Kumar Subramanian and Ilango Paramasivam [16] had proposed energy proficient MAC convention based on priority for WSNs varying the sample inter-arrival time. The authors goal to increase the energy efficiency of the network. To accomplish their aim, they had introduced PRIority in Node based innovative QoS MAC protocol. By presenting this proposed approach, they had developed energy productivity of the network. M. K. Kirubakaran and N. Sankarram [17] had presented power efficient MAC protocol for WSNs. The aim of this approach was to enhance energy productivity by reducing the control packets adoption. To attain this goal, the authors had proposed an invite and wait MAC protocol which was abbreviated as IWMAC. Due to this proposed technique, the creators had improved delivery ratio and energy productivity of the network.

Ripudaman Singh, Brijesh K. Rai, and Sanjay K. Bose [18] had presented transmission delay aware improved MAC protocol for Multi-Hop WSN. The authors aimed to decrease transmission delay and to improve energy efficiency. To achieve their aim, they had presented dispute based steering improved MAC protocol which was abbreviated as CR-MAC. Because of this proposed approach, the authors had decreased transmission delay and energy consumption. Sohail Sarang, Micheal Drieberg and Azlan Awang [19] had illustrated QoS aware MAC protocol for WSNs. The aim of the literature was to reduce consumption energy and delay in the network. To attain this goal, the authors had proposed Multi-Priority based QoS MAC Protocol which was abbreviated as MPQ-MAC. By introducing this protocol, they had accomplished better energy efficiency and delay.

III. FUZZY BASED ENHANCED MEDIUM ACCESS CONTROL PROTOCOL

A. System model

Figure 1 shows the framework model of the traffic aware WSN. As appeared in the figure, the network incorporates number of sensor nodes (S1-S9) and one base station (BS). Each sensor node collects or senses information from the environment and forwards the gathered data to the BS. The BS also acts as a coordinator which coordinates all sensor hubs in the network. The sensor nodes transmit the data bundles with the support of MAC protocol which manages traffic congestion of information bundles in the network. The collected information packet in the sensors is assumed with a lifetime limit. Before this limit expires, the collected data packet is to be forwarded to the BS. Otherwise, it will be dropped. For WSN, MAC protocol performs based on the structure of super frame which is shown in **Figure 2**.

This structure includes five interval periods that are Beacon message period, Contention Access Period (CAP), Notification Period (NP), Contention Free Period (CFP) and Inactive Period (IP). This structure has 128 slots among them 20 slots fixed for CAP. Length of CFP is dynamic i.e., based on the traffic it may vary. The rest of the length of the structure is inactive. In this structure, the beacon message contains the information about the BS and remaining nodes in the network. In the period of CAP, Data Transfer (DT) allocation requests are forwarded to the BS. After the completion of CAP, the BS allocates the DT slots to the packets and this allocation status will be notified to the nodes in the period of notification. After the allocation of DT, the data packets will be transmitted in the period of CFP. Then the rest of the period is considered as latent period. In this period, the nodes are inactive but can listen to the environment by using low power.

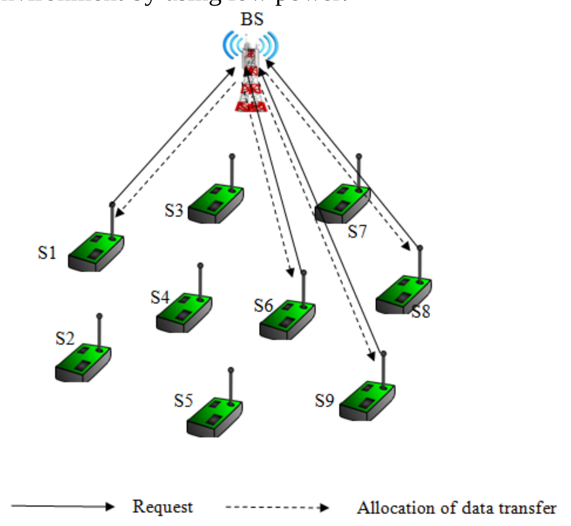

Figure 1: System model

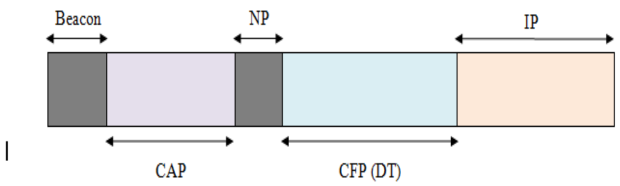

Figure 2: Structure of super frame

B. Overview

At a time period, number of sensor hubs sense the information from the environment and forward it to the BS.

This may cause collision between the data packets. So, collide packets are retransmitted which may lead the network to high energy consumption. Thus, traffic congestion of data packets in WSN is to be solved by improving the performance of MAC protocol. In this approach, MAC protocol is improved by presenting Fuzzy system. Using this Fuzzy system, received packets are prioritized debend on the buffer occupancy and residual delay of the hubs in BS. Depends on the need of data bundles DT is allocated and the packets are transmitted in the period of CFP. **Figure 3** shows the workflow of this approach.

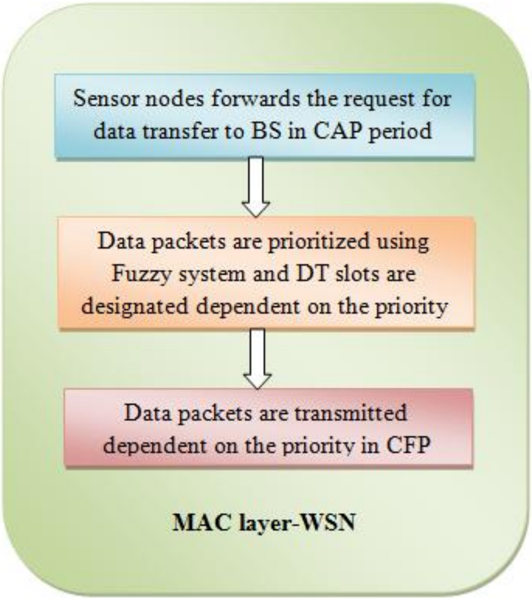

Figure 3: Workflow of the proposed approach

C. Packet prioritization using Fuzzy system

In the period of CAP, sensor node forwards the DT slots allocation requests for the data packets to the BS. After receiving the requests, BS prioritizes the data packets using the Fuzzy system. By prioritizing the packet before transmission, MAC protocol can save energy efficiency of the network. For packet prioritization, Mamdani Fuzzy Logic model is presented. **Figure 4** appeared the proposed fuzzy logic model. This method prioritizes the packet by performing the four levels such as generation of the fuzzy rule base, Fuzzification, fuzzy inference framework, and defuzzification. In this model, Residual Delay (RD_{Pkts}) and Buffer Occupancy (BO_{Pkts}) of the packets are given as input to the model.. Residual Delay (RD_{Pkts}) is defined as the difference between cumulative delay of the packet and maximum tolerable delay of the packet. For the collected data packets, RD_{Pkts} at time t is calculated as follows,

$$RD_{Pkts}(t) = d_{Max} - d^{i}_{cum}(t) \qquad (1)$$

Where, dMax represents the maximum tolerable delay of the packet and $d^{i}_{cum}(t)$ represents the cumulative delay from the ith sensor node to the BS.

Buffer Occupancy (BO_{Pkts}) of the collected packets is characterized as the proportion between the size of the packets and the total buffer size and is calculated as follows

$$BO_{Pkts}(t) = \frac{S^{i}_{Pkts}(t)}{S^{i}_{Buff}} \qquad (2)$$

Where, $S^{i}_{Pkts}(t)$ represents the size of the packets from the ith sensor node at time t and S^{i}_{Buff} represents the total buffer size of ith sensor node.

These calculated input variables are given as input to the fuzzy logic model and this model converts these input crisp values into fuzzy variables.

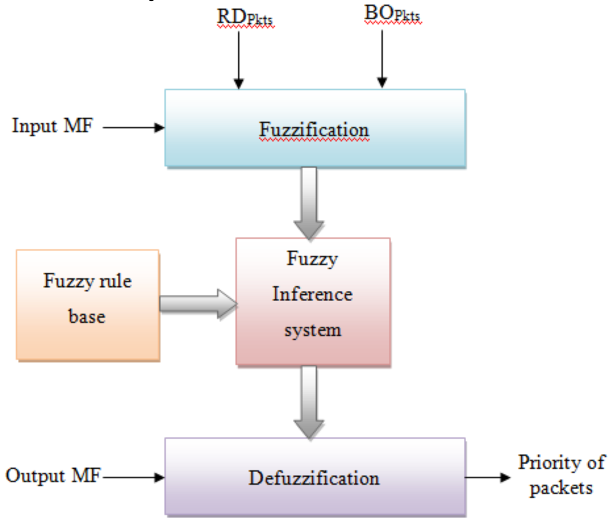

Figure 4: The proposed fuzzy logic model

Fuzzification: Input crisp estimations of RD_{Pkts} and BO_{Pkts} changed over into fuzzy factors. At that point, for every fuzzy variable, participation work is resolved. The yield parameter of this model is the packets priority. Fuzzy variables of RD_{Pkts} are defined as Low (L), Medium (M) and High (H) in the range [0, 100secs]. Also fuzzy variables of BO_{Pkts} are defined as L, M and H in the extend [0, 1]. Fuzzy factors of the yield Packet Priority (PP) are High (H), Average (AV) and Low (L) as appeared in **Table 1**. For acquiring the optimum outcomes, trapezoidal and triangular enrollment capacities are used right now. These trapezoidal and triangular participation capacities are utilized for a limit and middle of the road factors. Trapezoidal enrollment work a d triangular participation work for the info esteem 'y' are characterized as following eruations (3) and (4) separately. Figure 5 and 6 show the essential structure of trapezoidal capacity and triangular capacity. **Figure 7 and 8** appeared the membership capacity of fuzzy variables for the input variables RD_{Pkts} and BO_{Pkts} separately. **Figure 9** appeared the membership function of the yield variable to prioritize the packets.

$$\mu_A(y) = \begin{cases} 0, & y \le p_1 \\ \dfrac{y - p_1}{q_1 - p_1}, & p_1 \le y \le q_1 \\ 1, & q_1 \le y \le r_1 \\ \dfrac{s_1 - y}{s_1 - r_1}, & r_1 \le y \le s_1 \\ 0, & s_1 \le y \end{cases}$$

(3)

$$\mu_A(y)=\begin{cases}0, & y\le p_2\\ \dfrac{y-p_2}{q_2-p_2}, & p_2\le y\le q_2\\ \dfrac{r_2-y}{r_2-q_2}, & q_2\le y\le r_2\\ 0, & r_2\le y\end{cases} \qquad (4)$$

At that point these trapezoidal enrollment work and triangular participation work are applied to all phonetic worth or fuzzy factors of a standard utilizing the capacities (5) and (6) separately

$$f(y\ ;p_1,q_1,r_1,s_1)=\max\left(\min\left(\frac{y-p_1}{q_1-p_1},1,\frac{s_1-y}{s_1-r_1}\right),0\right) \qquad (5)$$

$$f(y\ ;p_2,q_2,r_2)=\max\left(\min\left(\frac{y-p_2}{q_2-p_2},\frac{r_2-y}{r_2-q_1}\right),0\right) \qquad (6)$$

If - then rules: If-then rule is applied to the fuzzy factors to accomplish the fuzzy set out. These standards have different information sources and the fuzzy administrator (AND). Utilizing this administrator, insignificant of three enrollment esteems is chosen for each standard. For a model, If-then guideline is taken from the table and portrayed as

If *RD_{Pkts} is Low***AND** *BO_{Pkts} is High* **Then** *output PP is High*

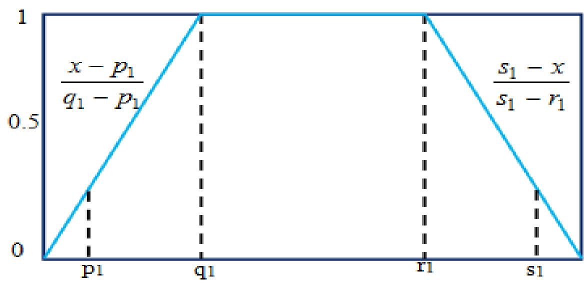

Figure 5: Basic structure of trapezoidal function

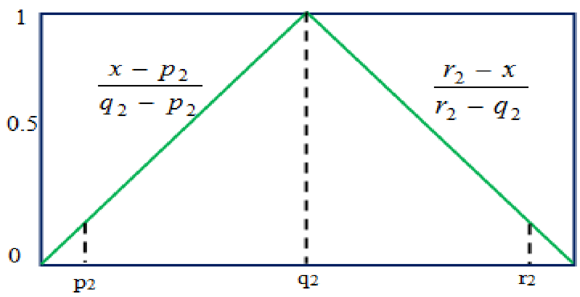

Figure 6: Basic structure of triangular function

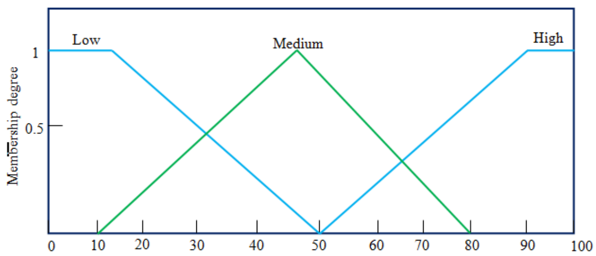

Figure 7: Membership function of Residual delay

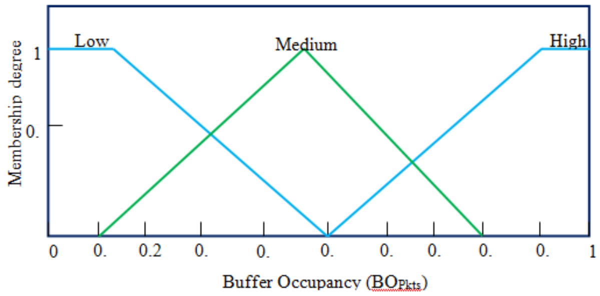

Figure 8: Membership function of Buffer occupancy

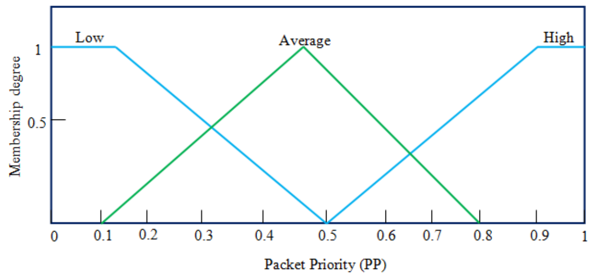

Figure 9: Membership function of Output (Packet Priority)

Table 1: Fuzzy rule

RD_{Pkts}	BO_{Pkts}	PP (O/P)
H	H	AV
M	H	AV
L	H	H
H	M	AV
M	M	H
L	M	H
H	L	L
M	L	L
L	L	L

Defuzzification: For defuzzification, Center of Gravity strategy is utilized. Utilizing this technique, we get the single crisp incentive as yield from the contribution of fuzzy sets.

$$COG=\frac{\sum_{i=1}^{l} S_i\times C_i}{\sum_{i=1}^{l} S_i} \qquad (7)$$

Where, Ci indicates the inside purpose of yield fuzzy variable on the x-axis that crossing point with MF. S_i represents the firing strength of yield fuzzy variables of every rule and is estimated utilizing the fuzzy operator (OR). This firing strength of the output of i^{th} rule is calculated as follows:

$$S_i=\sqrt{\sum_{j=1}^{l}\sum_{i=1}^{m} Degree_{ij}^{\,2}} \qquad (8)$$

Where, $Degree_{ij}$ denotes the enrollment level of j^{th} variable in the i^{th} rule.

The greatest fuzzy yield is given as input to COG for defuzzification. After the defuzzification, crisp values of Packet priority are attained as output. Then these attained crisp values sorted based on their priority. Then, depend on the priority DT slots are allocated to the packets.

Algorithm 1: Procedure for Packet prioritization using Fuzzy system

1. For collected packets, the parameters RD_{Pkts} and BO_{Pkts} are calculated.
2. Crisp values of these parameters are given as contributionto the Fuzzy logic framework.
3. The input crisp values are converted into fuzzy variables.
4. *If_Then_* fuzzy rules are defined for input fuzzy variables.
5. Firing strength is calculated for output fuzzy variables using equation (8).
6. The maximum fuzzy yield is given as input to COG for defuzzification.
7. Using COG defined in equation (7), a value of packet priority is calculated.
8. Based on the priority values, DT slots are allocated to the packets.
9. This allocation status is notified in NP period.
10. Finally, data packets are transmitted based on its priority in CFP period.

D. Operation of Enhanced MAC protocol

The operation of Fuzzy based enhanced MAC protocol in WSN is described as follows:

- In WSN, sensor nodes transmit the sensed data to other nodes or BS through the wireless medium with the support of MAC protocol.
- In this approach, performance of the MAC protocol is enhanced by presenting Fuzzy based packet prioritization.
- By following the super frame structure of WSN, beacon message is forward by BS to all nodes in the network.
- In CAP period, sensors send DT allocation requests for data packets to the BS. After receiving the requests, the BS calculates the priority of data packets using Fuzzy system. In this system, RD_{Pkts} and BO_{Pkts} are given as input to estimate the packet priority.
- Based on the packet priority, DT slots are allocated to the data packets and it is notified in the period of NP.
- In CFP period, the data parcels are transmitted dependent on its priority.
- In IP period, the hubs are inactive but can listen to the environment by using low power.

IV. RESULTS AND DISCUSSION

The proposed Fuzzy-MAC (Fuzzy based enhanced MAC convention) is actualized in arrange test system NS2. Right now, sensor hubs are acted in the locale 1000m×1000m. Every sensor hub in the locale is executed with the transmission intensity of 0.66W and furthermore the accepting intensity of 0.395W. Transmission scope of every sensor hub is 250m. AOMDV steering protocol is utilized right now. Every sensor hub is incorporated with omnidirectional recieving wire transmits radio wave power consistently every which way. Additionally, two beam ground radio engendering model is considered, which utilized to anticipate the got signal intensity of every bundle. Table 1 appeared the simulation parameter and its estimation of our proposed approach. In this simulation, packets from sensor nodes are prioritized using the proposed Fuzzy system. For fuzzy system, Residual Delay (RD_{Pkts}) and Buffer Occupancy (BO_{Pkts}) of packets are given as input to prioritize the packets. Then, based on the priorities, sensor nodes transmit the packets to the BS.

Table 1: Simulation setting

Parameter	Value
Area size	1000m×1000m
Routing protocol	AODV
MAC	802_11
Antenna	Omni Antenna
Radio propagation model	Two Ray Ground
Packet size	512bytes
Initial transmitting power	0.660W
Initial receiving power	0.395W
Initial energy	10.3J
Simulation time	100secs
Rate	500kb

A. Performance metrics

Execution of our proposed approach is assessed utilizing the accompanying metrics.

Throughput: It is the quantity of information that can be sent from the sources to the goal every second. Unit of this parameter is Mbps.

$$Throughput = \frac{Amount\ of\ transmitted\ data(kb)}{Transmitted\ time(s)} \quad (9)$$

Delivery ratio: It is the ratio of the quantity of parcels got effectively and the aggregate sum of bundles transmitted.

$$Delivery\ ratio = \frac{Amount\ of\ packets\ received}{Amount\ of\ packets\ transmitted} \quad \mathbf{(10)}$$

Energy consumption: Measure of energy devoured by every hub during the ***transmission***. Likewise, it is characterized as the contrast between the present energy and starting energy of a hub. Unit of this parameter is Joule(J).

$$Energy\ consumption = Initial\ energy - current\ energy \quad (11)$$

Packet drop: It is the quantity of parcels dropped during the information transmission.

Packet delay: The deferral of the system portrays to what extent the system takes to transmit a piece to the goal. Unit of this parameter milliseconds (ms).

B. Performance based on nodes

Performance measurements of our proposed approach Fuzzy-MAC are assessed for differing hubs 100, 200, 300, 400 and 500 hubs. Figures 10-14 appeared the correlation of the performance measurements of Fuzzy-MAC with the past work QPPD-MAC and TRM-MAC. Figure 10 portrays the examination of delivery ratio of Fuzzy-MAC with QPPD-MAC and TRM-MAC for varying hubs. Because of prioritization of packets using Fuzzy system, collision between the packets has been reduced. So, delivery ratio of Fuzzy-MAC is expanded 66% and 93% than that of existing QPPD-MAC and TRM-MAC individually.

Figure 11 delineates the correlation of bundle drop of Fuzzy-MAC with QPPD-MAC and TRM-MAC for varying hubs. As the packets are prioritized, they will be transmitted in the period of allocated DT slots so that packet drop is reduced during transmissions. So, compared with QPPD-MAC and TRM-MAC, bundled drop of Fuzzy-MAC is reduced to 15% and 33% individually. Examination of start to finish delay of Fuzzy-MAC with QPPD-MAC and TRM-MAC for varying hubs is appeared in figure 12. Since the enhanced MAC protocol based on Fuzzy system, the transmitted data packet from the sensors is arrived at the goal inside the timespan. Along these lines, bundle deferral of Fuzzy-MAC is decreased to 19% and 34% than that of existing QPPD-MAC and TRM-MAC individually.

Figure 13 shows the correlation of throughput of Fuzzy-MAC with QPPD-MAC and TRM-MAC for fluctuating hubs. As shown in the figure, throughput of the network is decreased when the quantity of hubs increments. In any case, due to the effective transmission of packets by prioritizing those using the Fuzzy system, throughput of Fuzzy-MAC is increased to 20% and 45% than that of QPPD-MAC and TRM-MAC respectively. As the bundles are transmitted based on their priority in the proposed approach, collision between the packets is reduced so that retransmission of collide packets has been lessen. Thus, consumption energy of the Fuzzy-MAC is decreased to 92% and 94% than that of the QPPD-MAC and TRM-MAC individually as shown in figure 14.

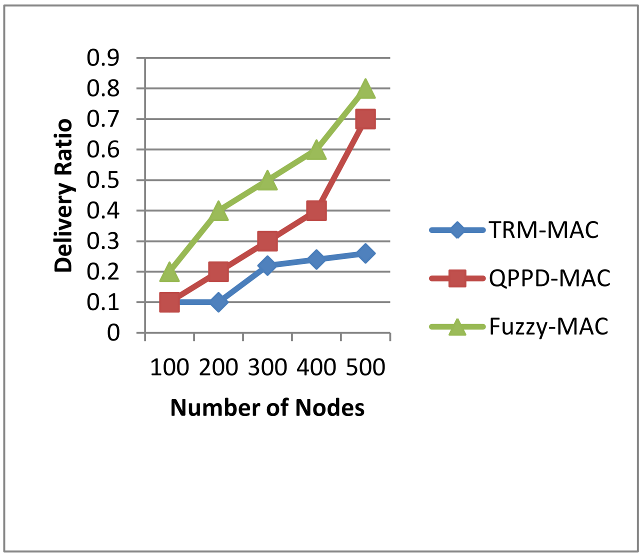

Figure 10: Number of nodes Vs Delivery ratio

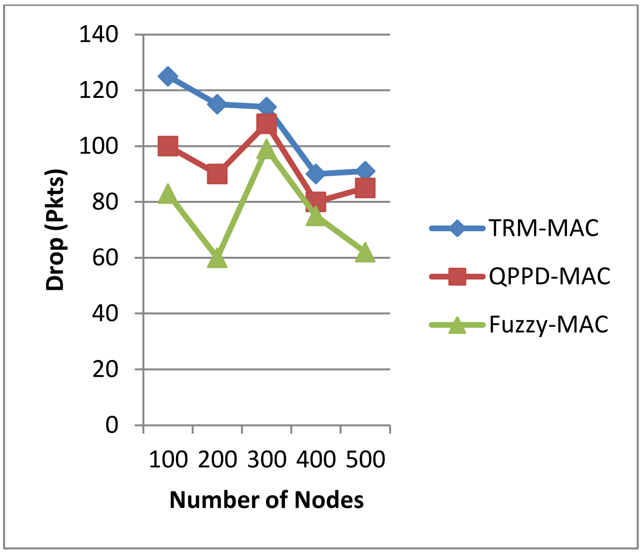

Figure 11: Number of nodes Vs Delivery ratio

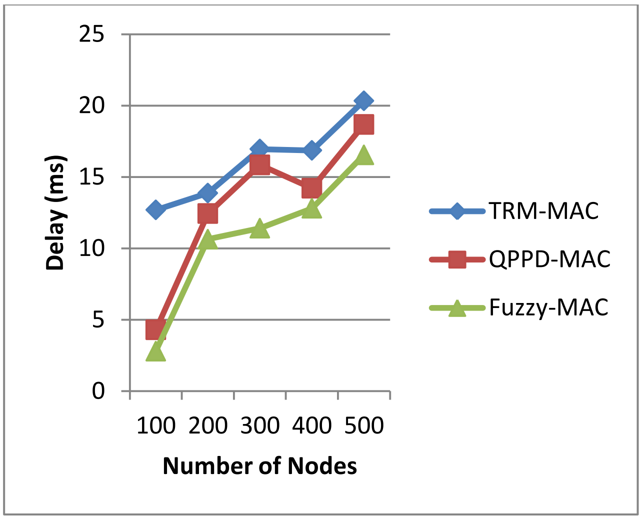

Figure 12: Number of nodes Vs Delay

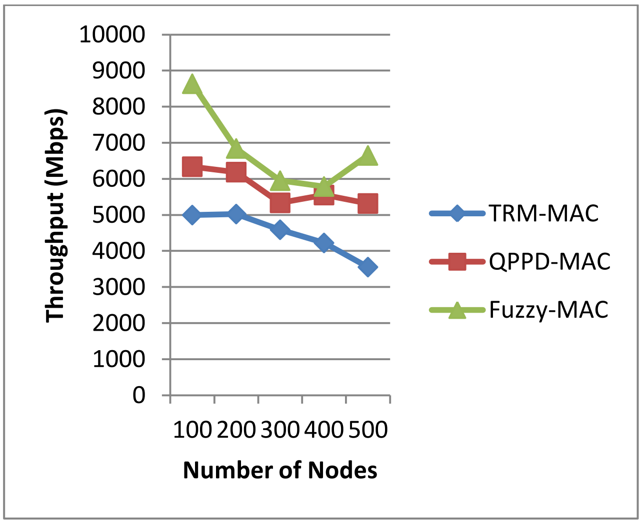

Figure 13: Number of nodes Vs Throughput

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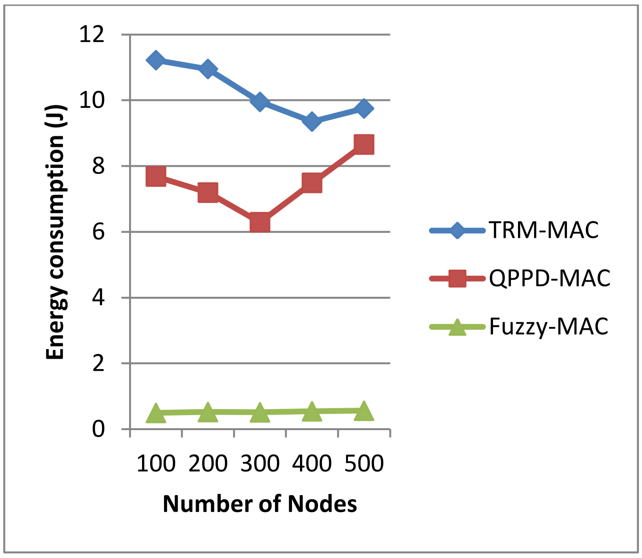

Figure 14: Number of nodes Vs Energy consumption

V. CONCLUSION

Energy effectiveness of the system has been improved by displaying Fuzzy Based Enhanced Medium Access Control protocol (Fuzzy-MAC). Using the proposed Fuzzy system, data packets from the sensors are prioritized. Then the sensors forwarded the data packets to the BS based on the priority of the packets. This process has reduced retransmission of collide packets in the system so that energy efficiency of the network has been developed. The performance of the proposed Fuzzy-MAC is compared with that of existing QPPD-MAC and TRM-MAC approaches. Simulation outcomes showed that the proposed Fuzzy-MAC beated existing approaches in wording energy consumption, delivery ratio and throughput.

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