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ENERGY AND DELAY REDUCTION ALGORITHM FOR CLUSTER BASED CONGESTION CONTROL IN WIRELESS SENSOR NETWORKS

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ABSTRACT

In Wireless Sensor Networks (WSN), delay has be reduced in delay sensitive applications at cost of increased energy consumption, since there is a tradeoff between delay and energy consumption in WSN. But most of works in WSN focus on reducing the energy rather than the delay. Hence the main aim of this work is to reduce both the delay and energy consumption in delay sensitive applications of WSN. In this paper, an efficient energy and delay reduction technique for cluster based congestion control model is proposed. In this technique, the cluster head (CH) is elected based on the energy level of the node. Each cluster member transmit the data and its remaining energy information to the corresponding cluster head as per the given time slot schedule. The delay in data transmission can be reduced by adaptively adjusting the active mode of the node based on the congestion status and distance of node. By simulation results, we show that the proposed technique reduces the energy consumption and delay of highly loaded sensor nodes.

Keywords: *WSN, Energy, Congestion, Cluster, Delay Reduction*

1. Introduction

A collection of small sensor nodes communicating among themselves is known as Wireless Sensor Network (WSN). WSN is organized in large scale from tens to thousands for various applications which includes monitoring of physical phenomena like temperature, humidity, air pollution and seismic events alarm detection, and target classification and detection [1]. It provides solutions potentially in low-cost for the issues of military and civilian applications which counting battlefield surveillance, environmental and health care monitoring, target tracking, wildfire detection, and traffic regulation [2]. Each sensor node in a WSN has a limited power and computation capability and WSN s strictly energy-constrained systems [3]

In WSN, the main aim of delay sensitive applications is to reduce the queuing delay by optimizing the queuing time and number of hops. But reducing delay would require sacrifices on energy efficiency since there is a tradeoff between delay and energy consumption in WSN. But most of works in WSN focus on reducing the energy consumption alone thereby leaving the delay [4]. In most of the WSN sleep/wake protocols, energy awareness is considered as a key design issue to maximize the network lifetime at the cost of delay. [5].

In this paper, an efficient energy and delay reduction technique is proposed for the cluster based congestion control model in WSN. The main contribution of the work is energy efficient cluster head selection and adaptive adjustment of duty cycle by the cluster heads for reducing the delay.

2. Related Works

Babar Nazir et al [5] have presented a sleep/wake schedule scheme for minimizing end-to-end delay for event driven multi-hop wireless sensor networks. In this scheme, nodes adaptively adjust their sleep/wake schedule based on traffic loads.

It considers three important factors: distance of the node from the sink, the node's location and proximity from the event. Their scheduling scheme reduces end-to-end delay, minimizes the congestion at nodes and improves the throughput. Though this scheme reduces the delay, the energy consumption increases due to the multi hop transmission.

Liqi Shi et al [6] have created a nonlinear cross-layer optimization model for reducing the average energy consumption. They have proposed an algorithm for generating the TDMA schedules and provided optimized TDMA schedules with reduced delay. The algorithm utilizes the slot reuse concept to achieve minimum TDMA frame length. But it does reduce the delay involved in the sleep/wakeup scheduling.

Trong Thua Huynh et al [7] have performed a comparative study on balancing energy efficiency and delay in WSN. Their presentation includes analysis of the current state-of-the-art of routing techniques for optimizing energy-efficiency along with latency factor.

Ali Chodari Khosrowshahi1 et al [8] have enhanced the multi-channel medium access (MCSMAC) protocol. MCSMAC is a contention based MAC protocol based on the S-MAC protocol. The primary purpose of the enhanced MCSMAC protocol was to reduce the energy consumption and the delay during data transmission. In the enhanced MCSMAC protocol, the bandwidths of channels are dynamic as opposed to the standard MCSMAC protocol. But the delay due to the sleep scheduling is not resolved.

E. Srie Vidhya Janani and P. Ganesh Kumar [9] have proposed an Energy Efficient Cluster Based Scheduling Scheme for WSN that balances the network lifetime and energy efficiency. In the first phase of this scheme, the network is clustered by means of topology discovery and the cluster heads are selected based on the residual energy. In the second phase, scheduling algorithm is proposed to allocate the time slots for the cluster members. In the third phase, an energy consumption model is proposed to maintain the maximum energy level in the network. But since the sleep wakeup interval is not updated based on the traffic load, the delay will be increased.

From the above review of literature, it can be observed that there is a need for techniques which aim to provide energy efficient data transmission along with adaptive duty cycle periods in WSN.

3. Energy and Delay Reduction Algorithm

3.1 Overview

In this paper, we propose an efficient energy and delay reduction technique for the cluster based congestion control model in WSN. In this technique, the cluster head (CH) is elected based on the energy level of the node. Each cluster member transmits the data and its remaining energy information to the corresponding cluster head as per the given time slot schedule. The delay in data transmission can be reduced by adaptively adjusting the active mode of the node based on the congestion status and distance of node.

3.2 Fuzzy Based Congestion Detection

We detect the congestion status of the node using fuzzy logic technique. The parameters number of contenders, buffer occupancy percentage of parent nodes and traffic load are taken as input for the fuzzy member ship functions. These inputs are fuzzified and processed by interference system to provide congestion status of the node as output which is then de-fuzzified. The outputs are aggregated and form new fuzzy sets.
The steps that determine the fuzzy rule based interference are as follows.

- **Fuzzification:** This involves obtaining the crisp inputs from the selected input variables and estimating the degree to which the inputs belong to each of the suitable fuzzy set.
    - **Number of Contenders:** It is estimated using the RTS or CTS packets which are generated by the neighbor nodes. If there are too many contenders, collision probability is higher.
    - **Buffer Occupancy Percentage:** If the buffer occupancy percentage of the node is high, the congestion probability will also be high.
    - **Traffic Load:** It is defined as the ratio of the incoming packets to the outgoing packets

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- **Rule Evaluation:** The fuzzified inputs are taken and applied to the antecedents of the fuzzy rules. It is then applied to the consequent membership function.

- **Aggregation of the rule outputs:** This involves merging of the output of all rules.

- **Defuzzification:** The merged output of the aggregate output fuzzy set is the input for the defuzzification process and a single crisp number is obtained as output.

The fuzzy inference system is illustrated using Figure-3.

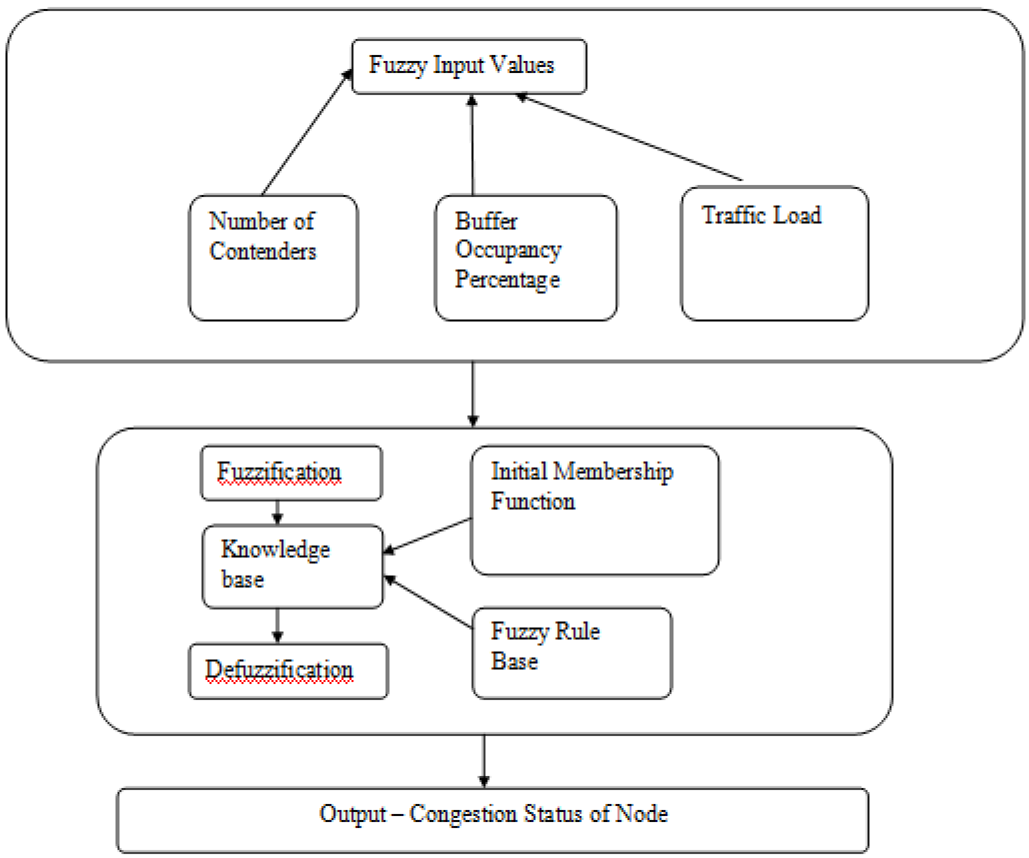

Figure-3 Fuzzy Inference System

Fuzzification

This involves fuzzification of input variables such as number of contenders (C), buffer occupancy percentage (B), and traffic load (T) and these inputs are given a degree to appropriate fuzzy sets. The crisp inputs are combination of C, B and T. We take the possibilities, high, medium and low for C, B and T.

Figure 4, 5, 6, 7 shows the membership function for the input and output variables. Due to the computational efficiency and uncomplicated formulas, the triangulation functions are utilized which are widely utilized in real-time applications. Also a positive impact is offered by this design of membership function.

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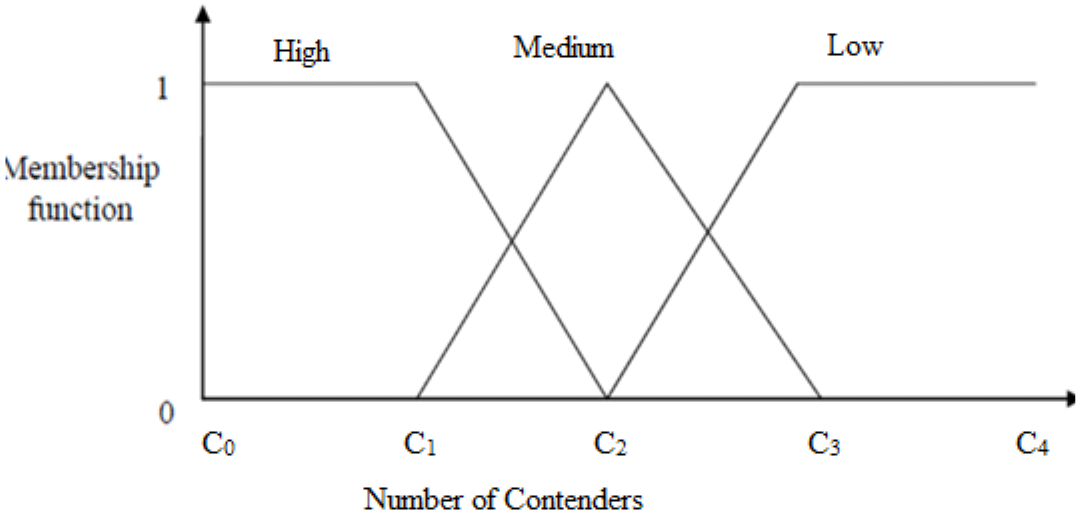

Figure 4 Membership Function of Number of Contenders

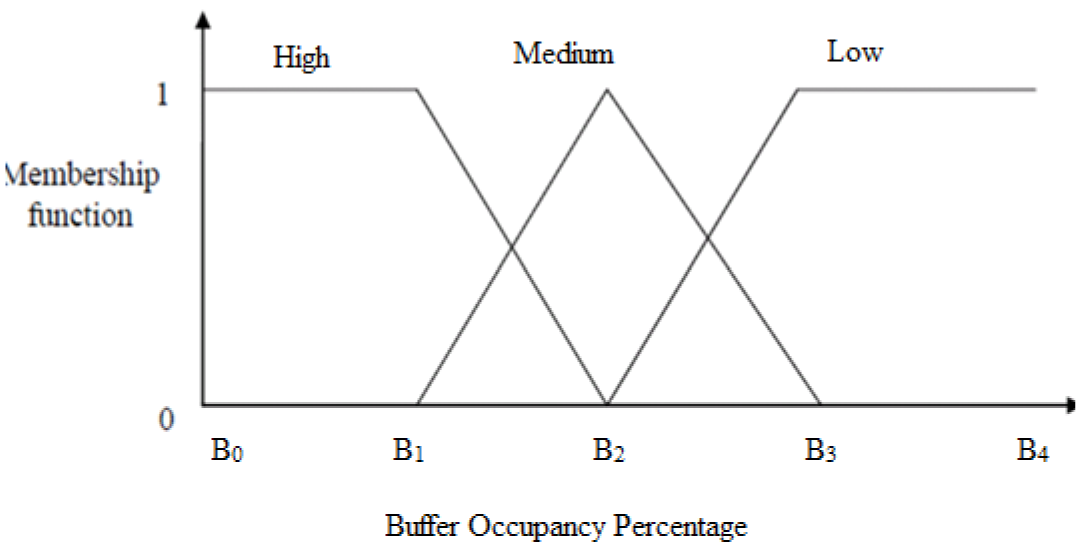

Figure 5 Membership Function of Buffer Occupancy Percentage

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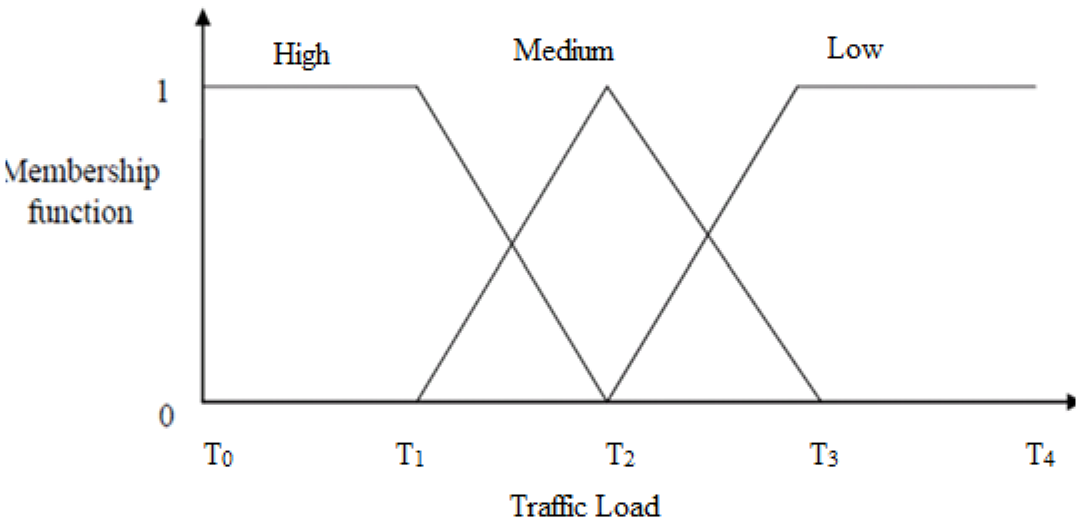

Figure 6 Membership Function Of Traffic Load

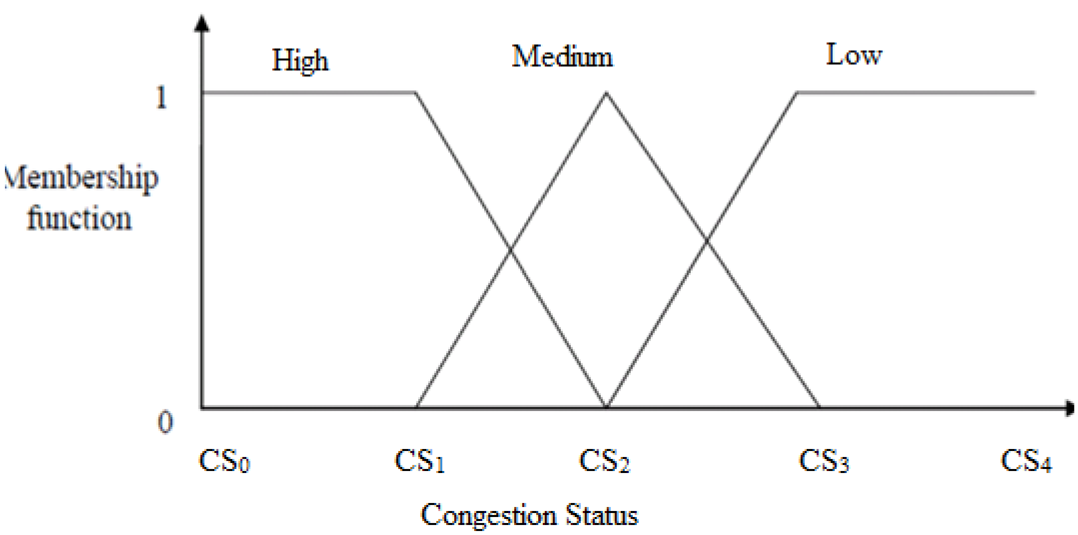

Figure 7 Membership Function Of Congestion Status

In table C, B and T are given as inputs and the output represents the Congestion Status (CS). The fuzzy sets are defined with the combinations presented in Table-1.

Table-1 Fuzzy Rule Base

S.No	C	B	T	CS
1	Low	Low	Low	Low
2	Low	Low	Medium	Low

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S.No	C	B	T	CS
3	Low	Low	High	Medium
4	Low	Medium	Low	Low
5	Low	Medium	Medium	Medium
6	Low	Medium	High	Medium
7	Low	High	Low	Low
8	Low	High	Medium	Medium
9	Low	High	High	Medium
10	Medium	Low	Medium	Medium
11	Medium	Low	High	Medium
12	Medium	Medium	Low	Low
13	Medium	Medium	Medium	Medium
14	Medium	Medium	High	Medium
15	Medium	High	Low	Medium
16	Medium	High	Medium	Medium
17	Medium	High	High	Medium
18	Medium	Low	Low	Low
19	High	Low	Medium	Medium
20	High	Low	High	Medium
21	High	Medium	Low	Medium
22	High	Medium	Medium	High
23	High	Medium	High	High
24	High	High	Low	High
25	High	High	Medium	High
26	High	High	High	High

Table-1 demonstrates the designed fuzzy inference system. This illustrates the function of the inference engine and method by which the outputs of each rule are combined to generate the fuzzy decision.

For example

Let us consider Rule 26.

If (C, B, T = high)

Then

CS = high

End if

This reveals that the selected node is subject to congestion.

Defuzzification

Defuzzification is used for extracting a crisp value from a fuzzy set as a representation value. We consider the centroid of area strategy for defuzzification.

$$F_{QoS} = \frac{\int_f \eta_{agg}(F)_{fdf}}{\eta_{agg}(F)_{df}} \quad (1)$$

Where $\eta_{agg}(F)$ = aggregated output of membership function

3.3 Distance from Sink to Node

The distance (d_{ij}) among the sender node (N_i) and receiver node (N_j) can be estimated based on free space propagation model. It considers the wavelength utilized for transmission and reception.

The Free-space propagation model is defined using the following equation

$$P_{rx} = P_{tx} * \left(\frac{\eta}{4\pi d_{ij}}\right)^2 * \alpha * \beta \quad (2)$$

where P_{rx} = reception power
P_{tx} = transmission power
η = wavelength
α = transmitter gain
β = receiver gain

3.4 Estimating Scheduling Interval of the Cluster Member

The waiting time of the sensor node required for data transmission is computed based on its active or sleep mode.

The time for which the node remains active is estimated using the following Eq (3):

$$T_{ac} = \frac{t_{\min}}{R_{\max}} \quad (3)$$

t_{min} = minimum time for the sensor node to reach the coverage area
R_{max} = maximum sensing range of the node

The time for which the node remains in sleep mode is estimated using the following Eq(4):

$$T_{sl} = \min\left\{\frac{t_{\max}}{R_{\min}} t_{\exp}\right\} \quad (4)$$

where t_{max} = maximum time for the sensor node to reach the coverage area
R_{min} = minimum sensing range of the node

The waiting time for the sensor node is estimated using the modes of the node (active or sleep)

$$T_w = \begin{cases} \dfrac{a_1}{z_i^{a_2} LT(E_i, R_i)^{a_3}} Q + \lambda, & (E_i - E_t) \\ Q, & otherwise \end{cases} \quad (5)$$

where a_1, a_2 and a_3 = constants
E_t = threshold energy level
λ = random number between [0, T_{ac}]
$LT(E_i, R_i)$ = lifetime of the cluster group in terms of current energy and sensing range.

3.5 Cluster Formation and Data Transmission

Let CM_i and CH_i be the cluster member and cluster head respectively.
Let RREQ be the route request message

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Cluster Head Election

The steps involved in selecting the cluster head are as follows:

1. Each sensor node randomly generates a energy probability (EP(t)) and computes the threshold value (Th(w)) using the following equation:

Th(z) =

$$\begin{cases} \dfrac{EP_t}{1-EP_t(q.\text{mod}(1/EP_t))}.\dfrac{E_{res}}{E\max}, w \in N \\ 0 \qquad\qquad\qquad\qquad\qquad , Otherwise \end{cases} \quad (6)$$

where N = set of clusters
E_{res} = residual energy
E_{max} = maximum energy of the node
EP_t = energy probability
q = current round number

2. If $E<EP_t$, then the relevant node is selected as CH.

3. CH_i transmits the E_{max} of all its CM_i to its another CH_i before the expiry of last round of transmission.

4. Each CH_i collects all E_{max} value and identifies the maximum value

5. The identified Emax is broadcasted to its CM_i.

6. CM_i then stores the E_{max} for future computation of Th(w).

Data Transmission

If the cluster member wants to transmit the data to its destined node, it performs the following process:

1. The selected CH broadcasts the data packets to neighboring CM_i.

2. CM_i gathers the data during t and transmits the 'RREQ' message to nearest $CH_{i.}$

3. CH_i upon receiving the RREQ constructs the route table (RT) and time slot (TS) based on the Time division multiple access (TDMA) schedule interval.

The time slot refers to the time taken by the CM_i to transmit their data and energy details to the relevant CH_i

Table -1 Routing Table

Source Cluster ID	Destination Cluster ID	Scheduling Status	Network Lifetime	Total Energy Level	Sequence Number

4. CH_i then broadcasts the generated timeslots to the neighboring $CM_{i.}$

5. CM_i upon receiving the timeslot updates its route table to perform data transmission.

6. Following CH_i selection, each CM_i transmit the data and its residual energy to its relevant CH as per TS schedule.

7. CH_i maintains the residual energy details of each CM_i.

3.6 Adjusting the Active Mode of the Node

In order to reduce the delay, the active mode (AM) is adaptively updated based on the congestion status (estimated in section 3.2) and distance from sink of each node (estimated in section 3.3.) (ie)

$$AM \propto \frac{CS}{D} \quad (7)$$

AM is directly proportional to the congestion status and inversely proportional to the distance of the node the sink.

Thus, the node with high congestion or shortest distance to the sink is updated with increased active time interval whereas nodes with least congestion and longer distance to sink are updated with reduced active interval.

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That is, the nodes near to the sink node have greater traffic load when compared to the nodes away from the sink node and are assigned longer active time intervals.

4. Simulation Results

4.1 Simulation Parameters

We use NS2 to simulate our proposed Energy and Delay Reduction Algorithm for Cluster based Congestion Control (EDRA) protocol. We use the IEEE 802.11 for wireless sensor networks as the MAC layer protocol. It has the functionality to notify the network layer about link breakage. In our simulation, the number of transmission rate is varied as 50, 75,100,125 and 150 Kb. The area size is 1000 meter x 1000 meter square region for 50 seconds simulation time. The simulated traffic is Constant Bit Rate (CBR).

Our simulation settings and parameters are summarized in table 2

Table 2: Simulation parameters

No. of Nodes	100
Area	1000 X 1000
MAC	802.11
Simulation Time	50 sec
Traffic Source	CBR
Rate	50,75,100,125 and 150Kb
Propagation	TwoRayGround
Antenna	OmniAntenna
Initial Energy	8.5J
Transmission Power	0.3
Receiving Power	0.3

4.2 Performance Metrics

We evaluate performance of the new protocol mainly according to the following parameters. We compare the Sleep Wakeup Scheduling SSS [5] scheme with our proposed EDRA protocol. In addition to the main metrics delay and energy consumption, the packet drop and packet delivery ratio metrics are also considered for evaluation, in order to measure the reliability of delivered data.

4.3 Results & Analysis

In order to evaluate the effect of traffic load on the performance metrics, the data transmission rate as is varied from 50 to 150Kb.

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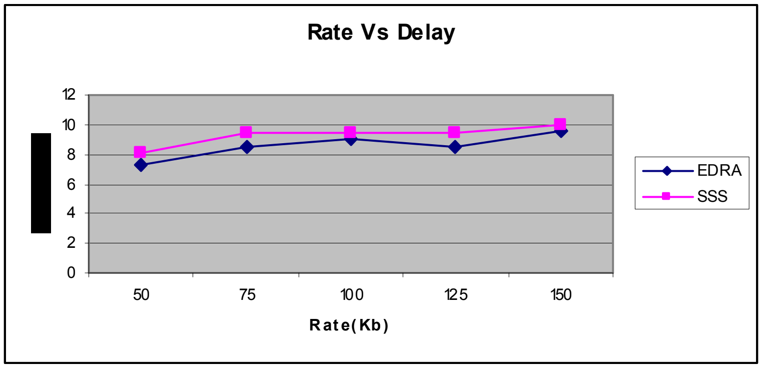

Fig 8: Rate Vs Delay

Figure 8 shows the delay measured for EDRA and SSS when the rate is varied. When the rate is increased from 50Kb to 150Kb, as we can see from the figure, the delay of EDRA increases from 7.29 to 9.60 and the delay of SSS increases from 8.08 to 9.99. Due to the adaptive adjustment of active duty cycle, the delay of EDRA is 7% less, when compared to SSS.

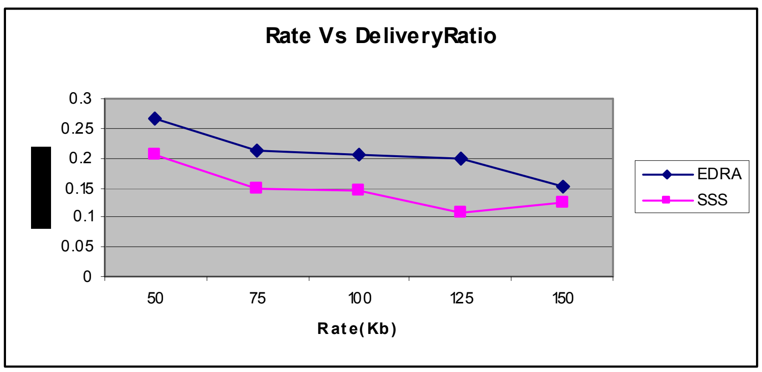

Fig 9: Rate Vs Delivery Ratio

Figure 9 shows the delivery ratio measured for EDRA and SSS when the rate is varied. When the rate is increased from 50Kb to 150Kb, there will be more congestion. As we can see from the figure, the delivery ratio of EDRA decreases from 0.26 to 0.15 and the delivery ratio of SSS decreases from 0.20 to 0.15. Since EDRA resolves the congestion, the delivery ratio of EDRA is 29% of higher than SSS.

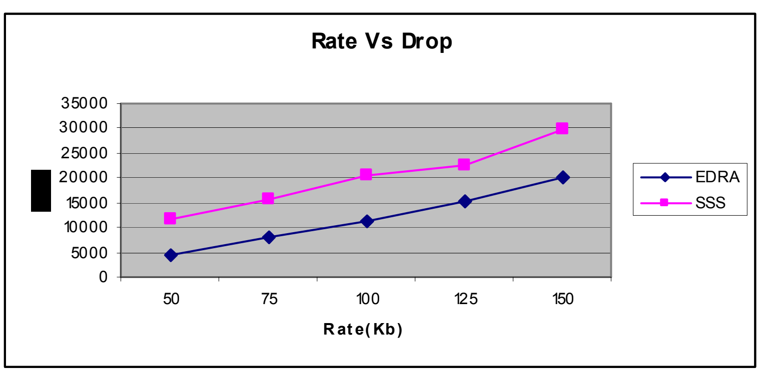

Fig 10: Rate Vs Drop

Figure 10 shows the packet drop measured for EDRA and SSS when the rate is varied. When the rate is increased from 50Kb to 150Kb, there will be more congestion, leading to increase in packet drop. As we can see from the figure, the packet drop of EDRA increases from 4225 to

20159 and the packet drop of SSS increases from 11515 to 29866. However, since EDRA resolves the congestion, the packet drop of EDRA is 44% of less when compared to SSS.

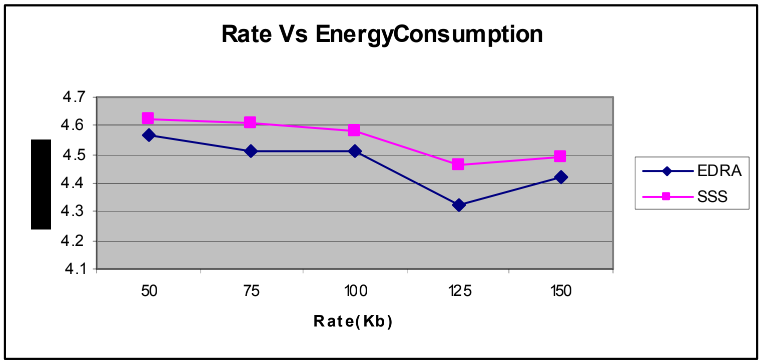

Fig 11: Rate Vs Energy Consumption

Figure 11 shows the energy consumption measured for EDRA and SSS when the rate is varied. When the rate is increased from 50Kb to 150Kb, as we can see from the figure, the energy consumption of EDRA decreases from 4.56 to 4.42 and the energy consumption of SSS increases from 4.62 to 4.49. Since EDRA uses energy efficient cluster heads, the energy consumption of EDRA is 2% lesser than SSS.

5. CONCLUSION

In this paper, an efficient energy and delay reduction algorithm (EDRA) has been proposed for cluster based WSN. In this technique, the cluster head (CH) is elected based on the energy level of the node. Each cluster member transmits the data and its remaining energy information to the corresponding cluster head as per the given time slot schedule. The delay in data transmission can be reduced by adaptively adjusting the active mode of the node based on the congestion status and distance of node. Due to the energy efficient CH election, the proposed technique reduces the average energy consumption by 2%. Due to the adaptive adjustment of active duty cycle, the delay was reduced by 8%. Thus the proposed EDRA achieves both the objectives of the research work. The future work concretes on providing more reliability to the cluster heads and reducing their overhead.

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