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Energy Efficient Inter-Cluster Routing Using PSO for WSN

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Abstract: To design an energy efficient routing algorithm is a hot topic in the research of wireless sensor networks. Energy (battery) of the sensor node is considered as the scarcest resource in Wireless Sensor Network (WSN), hence a communication protocol that efficiently uses the limited energy must be developed. Cluster Heads (CHs) form the backbone of the crucial inter-cluster communication for Wireless Sensor Network (WSN). Due to relaying high data traffic, some of these nodes quickly exhaust their precious energy and increase the risk of node failure. In conjunction with the node failure, data packet loss also occurs in a CH due to congestion and poor link quality. For the problem present of energy efficient inter-cluster routing for WSN, this study is giving a three phased solution. In the first phase derived link quality and congestion metrics using bit error rate and packet loss rate due to congestion respectively. The bit rate and error rate detection is followed by to select cluster heads, cooperative particles of swarm were initialized in PSO. In the final stage of the proposed method fitness function is calculated based on the three metrics namely energy cost, bit error rate and packet loss rate due to congestion so as to determine the optimal path.. The proposed protocol of REC is effective in prolonging the network lifetime, as well as supporting for scalable network. This study's technique achieves substantial energy savings and improved reliability over the contemporary cluster based routing techniques. The effectiveness of the routing algorithm presented in this study considerably increasing the efficiency of routing.

Key words: Partial swarm optimization, energy efficient routing, cluster head, contemporary, India

INTRODUCTION

WSN: A wireless Sensor Network (WSN) consists of spatially distributed autonomous devices called nodes utilizing one or more sensors to monitor physical or environmental conditions. These nodes in conjunction with routers and a gateway create a typical WSN system. Each node is equipped with processing capability (one or more microcontrollers, CPUs or DSP chips), sometimes multiple types of memory (program, data and flash memories), a RF transceiver (generally with a single omni-directional antenna), a power source (e.g., batteries and solar cells) and with various sensors and actuators. The sensors in a node observe thermal, optic, acoustic, seismic and acceleration events which are then analyzed by the processing and other components and formulate answers to specific user requests. The nodes enable wireless communication wirelessly and often self-organize after being deployed in an ad hoc fashion so as to carry the sensed data towards the sink. WSN has its application in environmental monitoring, disaster recovery, etc., (Joshi and Jayswal, 2012; Alkhatib and Baicher, 2012).

However, WSN face many challenges such as energy constraints, latency, data delivery, self-configuration, self-organization, etc. Also, WSN is susceptible to collision, overhearing, idle listening and these results in wastage of energy. As sensor nodes are battery powered and non-rechargeable, WSN has limited energy (Alkhatib and Baicher, 2012; Atto and Guy, 2012; Li *et al*., 2013a).

Energy efficient inter cluster routing: Large scale networks divide nodes into a number of small groups, called clusters and cluster heads sense the data and also collect data packets from cluster members and relay data to base station via gateways in either single hop or multi-hop mode thus aggregating data by efficient network organization (Mao *et al*., 2011; Yun *et al*., 2010; Chen, 2012). Sensor nodes coordinate together and collect the brief data from sensing area and send it to sink yet

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they consume much energy for data transmission. Hence, multi hop inter cluster routing can reduce the problem of expensive energy consumption and limited transmission range. Moreover, the many-to-one traffic pattern raises the hot spot problem, i.e., area near to the sink become a hot spot as the cluster heads in this area are burdened with heavy relay traffic where sensor nodes may drain their energy and die much faster than other nodes causing node failure in WSN causing coverage reduction or network partition (Chen and Chen, 2010). Data packet loss also occurs in CH along with node failure to congestion and poor link quality (Sadat and Karmakar, 2010). An efficient clustering scheme can achieve energy efficiency as well as reduce packet collisions between nodes for better network throughput under high load conditions (Yun *et al*., 2010).

The WSN clustering leads to several issues, such as ensuring connectivity and scheduling inter-cluster communications (Yun *et al*., 2010; Arthi and Ranjan, 2013). Traditional routing algorithms prefer minimum hop count or merely energy efficient paths for data forwarding towards the Base Station (BS) however, the reliability (data loss) was ignored in the route selection process for a WSN (Sadat and Karmakar, 2010).

Considering the problem of energy efficient inter-cluster routing for WSN this study is giving a three phased solution. In the first phase to select cluster heads, to derive estimated link quality and congestion metrics using bit error rate and packet loss rate due to congestion respectively. The energy cost function is calculated based on distance between cluster heads and sensing range of sensors. The above method is followed by cooperative particles of swarm were initialized in PSO. In the last stage of the proposed method fitness function is calculated based on the three metrics namely energy cost, bit error rate and packet loss rate due to congestion, so as to determine the optimal path. To prevent hotspot problem near base station, we divide the whole network into three regions based on communication range.

To make a structured study, the current study is giving an introduction at first of the study in the first section. To find a suitable solution and from the exiting work some literature has done in the second section. The third section gives the proposed method with the problem definition. At last a suitable conclusion is given in section four.

Literature review: Chen and Chen (2010) proposed a novel cluster-based energy efficient routing algorithm to solve the hot spot problem involved in inter-cluster routing and optimize network lifetime. Particle Swarm Optimization algorithm was deployed to search optimal inter-cluster routing path for the optimization of network lifetime. However, energy consumption is not reduced much.

Sadat and Karmakar (2010) proposed an inter-cluster route selection framework offering a trade-off between reliability and energy consumption by formulating a cost function. Link quality and congestion at CH node were defined as path metrics with respect to reliability. The scheme achieved substantial energy savings and improved reliability over the contemporary cluster based routing techniques.

Hasbullah and Nazir (2010) presented Region-based Energy-aware Clustering (REC) scheme to optimize the energy usage in which clustering has been identified as an effective data forwarding technique in WSN. Energy efficient cluster formation, cluster head selection and inter cluster communication algorithms were proposed using this scheme. However delay per packet was increasing.

Han (2010) proposed an energy efficient cluster head election protocol (LEACH-HPR) and the minimum spanning tree algorithm was deployed to construct an inter-cluster routing. LEACH-HPR can efficiently reduce and balance energy consumption and hence prolong the lifetime of WSN. However, the network was overloaded.

Li *et al*. (2013b) presented an energy-efficient routing protocol based on particle swarm clustering algorithm and inter-cluster routing algorithm for WSN regarding energy saving, stable transmission and load balancing. However, throughput reduces with increasing rounds as well as nodes.

Zhang *et al*. (2012) proposed an energy efficient Unequal-Clustering Routing Algorithm (UCRA) for WSNs, comprising of an Unequal-Clustering Algorithm (UCA) and a multi-hop routing algorithm considering residual energy and degree of a sensor node while grouping the sensor nodes into unequal clusters. Minimum Energy Consumption (MEC) multi-hop routing algorithm was deployed for inter-cluster communication and also sensor nodes' location information to determine a MEC routing path. However it consumes much time.

Ganesh and Amutha (2013) developed a hybrid efficient and secure routing protocol through SNR-based dynamic clustering mechanisms (ESRPSDC) by combining SNR based dynamic clustering and routing pattern based security mechanisms. Inter cluster routing enable error recovery to avoid end-to-end error recovery. However, packet delivery ratio was decreased.

Mantri *et al*. (2013) proposed Bandwidth efficient Heterogeneity aware Cluster based Data Aggregation (BHCDA) algorithm for the effective data gathering with in-network aggregation by considering heterogeneous nodes in terms of energy and mobile sink to aggregate the data packets. The correlation of data within the packet was deployed for applying the aggregation function on data generated by nodes. However, it has less packet delivery ratio.

MATERIALS AND METHODS

Problem identification and solution

Problem identification: The existing works on inter cluster routing with energy efficiency has few drawbacks as unable to reduce much energy (Chen and Chen, 2010), increased delay per packet (Hasbullah and Nazir, 2010), overloading of network (Han, 2010), time delay (Zhang *et al*., 2012), reduced throughput (Li *et al*., 2013a, b), less packet delivery ratio (Ganesh and Amutha, 2103; Mantri *et al*., 2013).

Hence, this study's objective is to propose an energy efficient inter-cluster routing scheme with reduced energy consumption, reduced time delay, overloading prevention, increased throughput, high packet delivery ratio (Fig. 1).

In our previous research, an adaptive clustering using fuzzy decision model in WSN is proposed. In the proposed technique, first the optimal number of nodes in the cluster is found based on energy level of each node and transmission range is found. Also, the size of cluster is found to determine the density of the network. Finally, selection of CH is done using the fuzzy decision model which includes the parameter such as energy level, quality of link, distance of node to sink, data rate and degree of heterogeneity. The advantage of proposed technique is that it provides network with most reliable CH for transmission of the packet.

Proposed solution: As an extension to this research, this study wishes to provide energy efficient inter-cluster routing for WSN.

According to the selected cluster heads, cooperative particles of swarm were initialized in PSO (Chen and Chen, 2010). The energy cost function is calculated based on distance between cluster heads and sensing range of sensors. This study estimated link quality and congestion metrics using bit error rate and packet loss rate due to congestion respectively. Then, fitness function is calculated based on the three metrics namely energy cost, bit error rate and packet loss rate due to congestion so, as to determine the optimal path. To prevent hotspot problem near base station, this study divide the whole network into three regions based on communication range. The responsibility of forwarding data to base station is given alternatively to different clusters. The base station send signal with different transmission powers and on receiving the signals, the regions determine its region and utilize this region information to alternatively assign data forwarding to sink.

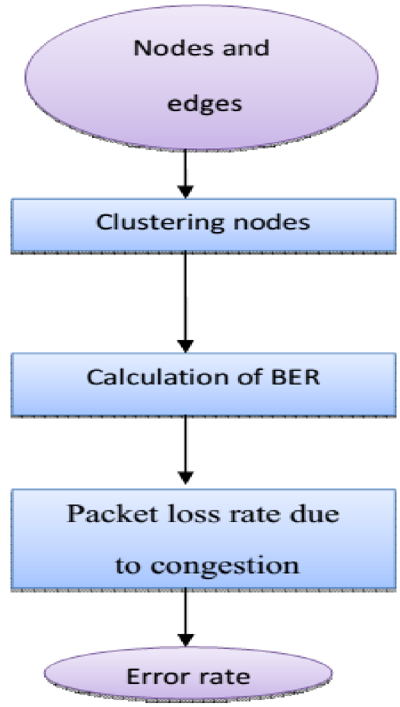

Fig. 1: The architecture diagram

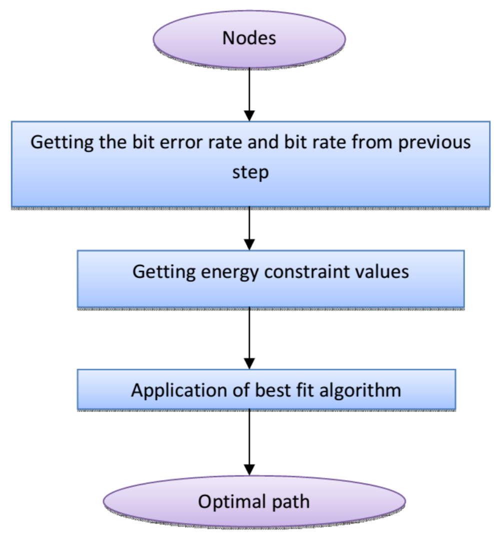

Fig. 2: Modular diagram for link quality and congestion metrics

Link quality and congestion metrics

Cluster formation: In this study, this study describes link quality and congestion metrics for inter-cluster communication path selection. This study's metrics selection and algorithm focus to avoid poor quality links and congested CH. Interference in a particular transmission link is the result of transmissions of other nearby nodes which is accounted as noise (Fig. 2).

Bit error rate calculation: Bit Error Rate (BER) assesses the full end-to-end performance of a system including the transmitter, receiver and the wireless medium between these two. Jiejie derived the following expression to calculate BER:

$$\text{BER} = 0.5 \times \text{erfc}\left(\sqrt{\frac{\text{Pr} \times \text{W}}{\text{Pn} \times \text{TB}}}\right) \quad (1)$$

Where:
Pr = The received power
W = The channel bandwidth
Pn = The noise power
TB = The transmission bit rate and erfc is the complementary error function

If the packet size is known, it is easy to calculate Packet Loss Rate (PLR) from BER. Signal-to-Noise Ratio (SNR) is calculated using BER. In this study, this study used PLR to define the link quality between each CH-CH and CH-BS link of the network. Let, Lij(t) represents the link quality between CHi and CHj at time t. at this stage the link quality is expressed in terms of PLR. The value of Lij(t) = 0 interprets the ideal case where there is no packet loss, while Lij(t) = 1 indicates that no link exists between CHi and CHj . All CH again experiences data loss due to congestion, buffer of which reflects this status. On the condition of buffer of a CH is full, it will be unable to forward its traffic to the next CH or BS and drop packets. In this way, congestion at the CH node causes packet loss and congestion at multiple intermediate CHs of a route decreases performance significantly.

Packet loss rate due to congestion calculation: Let, Bin and Bout denote the rates of incoming packet in the buffer and outgoing packet from the buffer of a CH, respectively. Then, the number of packet drop due to congestion at a CH at time duration of TR is {(Bin-Bout)×TR-Bsize} when (Bin-Bout)×TR should be more than Bsize (Bin-Bout)×TR>Bsize. Here, Bsize is the buffer size of the CH node. In case of the packets are dropped, the packet loss rate due to congestion at time t can be defined as:

$$\text{B}(t) = \frac{\text{Bsize} - (\text{Bin} - \text{Bout}) \times \text{TR}}{\text{Bin} \times \text{TR}} \quad (2)$$

The negative value of B(t) indicates the packet drop rate due to buffer overflow at the CH node. Thus, to increase reliability by minimizing data loss, a routing path must carefully exclude congested CH nodes for relaying multi-hop data.

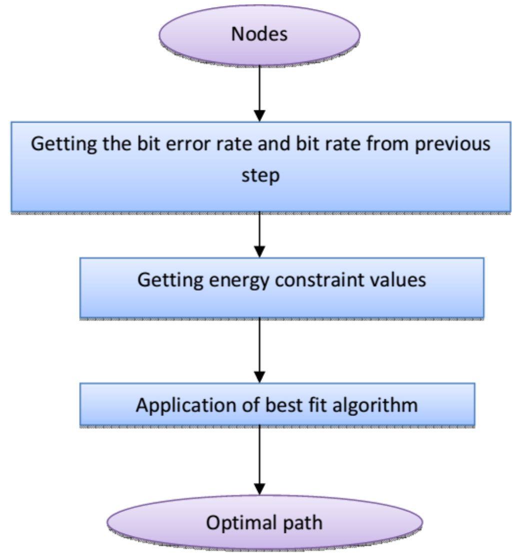

Fig. 3: Modular diagram for Cooperative particles of swarm

Algorithm for link quality and congestion metrics phase:
Step-1: Put all the Nodes and edges in a specific 2D matrix.
Step-2: Divide the nodes into clusters.
Derive the cluster head
Step-3: Bit error rate is calculated as for the Eq. 1.
Step-4: The packet loss rate due to congestion at time is calculated as or Eq. 2.
Step-5: Proceed to the next phase.

Cooperative particles of Swarm Optimization algorithm

Divide the network with clusters: The network is partitioned into clusters; sensor nodes will transmit data to the sink in a time period. Data transmission is classified into two stages, intra-cluster and inter-cluster communication. Intra-cluster communication represents the phase of data transmission between cluster heads and sensor nodes in their clusters. Inter-cluster communication represents the phase of data transmission that cluster heads send the data to the sink through inter-cluster routing (Fig. 3).

Consider the nodes into inter-cluster and intra-cluster: In the stage of inter-cluster communication, a cluster head have to choose a neighbor cluster-head for data forwarding. The selection of an appropriate next-hop cluster head from the neighbor area to forward data with minimum energy consumption is a critical issue for achieving energy efficiency and energy balance in the whole network. In this study's routing algorithm, this optimization problem is solved by applying PSO (Particle Swarm Optimization) algorithm. PSO utilizes a cooperative swarm of particles where each particle represents a candidate (feasible) solution, to explore the space of

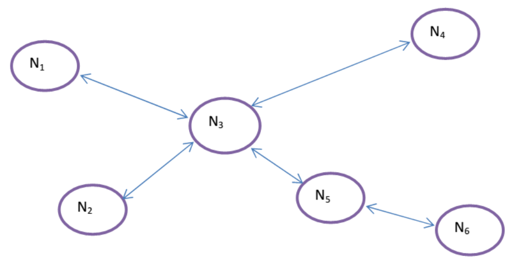

Fig. 4: Nodes applicable for PSO

possible solutions to the optimization problem and has been proved effective for solving combinational optimization problems (Fig. 4).

Practical swarm optimization: The PSO is relatively simple to implement and has excellent performance in convergence speed. The details of the inter-cluster routing scheme using PSO is shown below.

The topological relationship between cluster heads and the sink is modeled by a connected graph G(V, E) , where V = {S, H1, H2,…,Hm}(m is the number of cluster) denotes the set of cluster heads and the sink and E_{ij}∈E represents the communication cost from Hi to Hj. The aim is to achieve optimal energy cost when cluster heads transmit data to a sink.

Dis(x,y) defines the distance between the cluster head x and y. R is the sensing range of sensor. Definition2: Next (i) is the set of cluster heads that are in the sensing range of the I'th cluster head and also closer to the sink than the ith cluster head. According to definition, E_{ij} can be depicted by Eq. 3:

$$E_{ij} = \begin{cases} \infty & j \notin Next(i) \\ C(i.j) & otherwise \end{cases} \quad (3)$$

Where, C(i, j) is the energy cost for transmitting k-bit message at a distance d using the radio propagation model described. The radio dissipates the elec E and amp ϵ = 100 pJ/bit/m:

$$E_T(k,d) = E_{elec} \times k + \in_{amp} \times k \times d \quad (4)$$

$$E_R(k) = E_{elec} \times k \quad (5)$$

Best fit function: The PSO algorithm uses the objective of minimizing the total energy consumption of all cluster heads when sending data to the sink as the evaluation function directly. Evaluation function can be fined as follows:

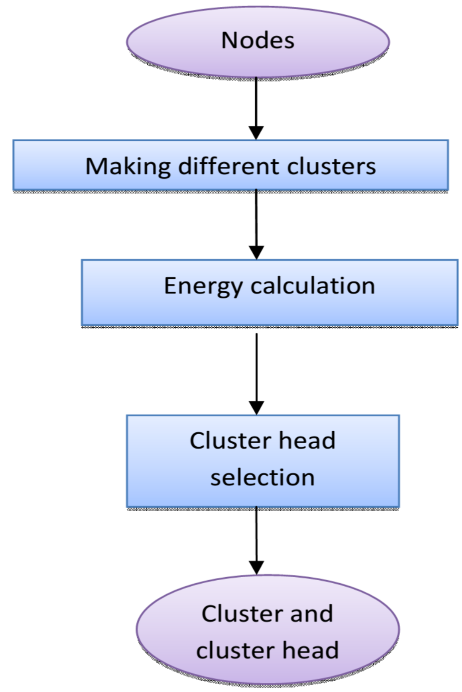

Fig. 5: Modular diagram for Division into regions based on communication range

$$it = \sum_{i=1}^{K} \sum_{j \in Next(i)} (E_r(k) + B(t) + BER) \quad (6)$$

Where, K is the number of cluster heads.

Algorithm for cooperative particles of swarm algorithm:

Step-1-: The collection of the nodes are represented in a 2D matrix.
Step-2: The parameters error rate and bit rate is collected from the previous step.
Step-3: Energy constraint is calculated as for the formula 4 and 5.
Step-4: Best fit algorithm is applied.
Step-5: Optimal path is choosen.

Division into regions based on communication range: The selection algorithm to find the CH was based on single metric of residual energy, number of linked nodes or distance from BS. In REC, both residual energy and coverage area are used together as a combined metric for the selection of CH. When a node has more battery power but it is the only node covering a particular part of the sensing area then the balance between these two parameters must be computed. In this case, to avoid coverage hole (hotspot), it is better to select a node that has less battery power but is less critical in terms of coverage area. This coverage area is having one or more sensor nodes that they are overlapping and covering the same part of sensing area (Fig. 5 and 6). In the case of any of these nodes die, there are some other nodes to cover

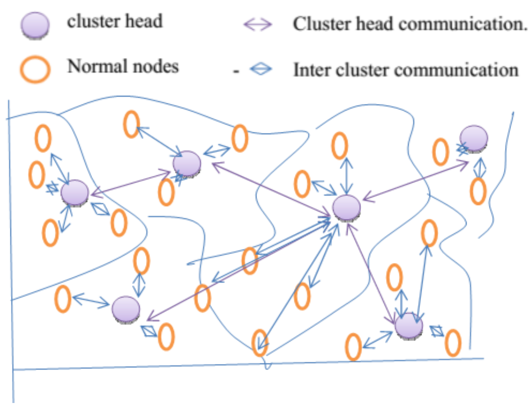

Fig. 6: The clusters with the cluster head and other nodes with residual power

the same sensing area. For the above reason, REC uses residual energy and coverage area as CH selection decision. Additional benefit is that it may improve the life time of the network.

Algorithm for Division into regions based on communication range

Parameter considered:

T_{sen} time period based on sensing range i.e. half of transmission range
Ti time period based on cluster head selection metric
Tj time period based on communication delay
Tk Ti time period based on double communication delay
CH Cluster Head
CHann Cluster Head Announcement
CHreq Cluster Head Announcement
CHack Cluster Head Acknowledgment
BBSack Bridge to Base Station Acknowledgment
SNn Sensor Node Normal
SNc Sensor Node Critical

Algorithm applied

Step-1: Every node send message using half the transmission power (as sensing range is half the transmission range).
It calculate the time period 'Ts' based on its transmission power
Step-2: Wait for time period 'Ts'.
Step-3: When (receive response from the any sensor node).{
Calculate
Overlap Coverage Percentage (OCp) of sensing area with the receiver node(s).
IF (OCp > 70%) {
Mark itself as Normal Sensor Node SNn;
later consider it as having normal sleeping interval as its sensing range is pre-dominantly overlapped by other sensor node(s) as well.
}
ELSE
{
Mark itself as critical sensor node SNc;
Consider it for longer sleeping interval as it is the only node to cover its sensing area (. no other node is covering the same sensing area.)
Step-4: IF (node status == critical sensor node SNc)
Set the timer for communication delay 'Tk'
IF (message == CHann && cluster affiliation == NULL)
Send CHreq message to that node
ELSE
IF (message ==CHack AND cluster affiliation ==NULL)
Change cluster affiliation status

Overall algorithm

Step-1: Collect the nodes in a specific region of 2D matrix.
Step-2: Get the Link quality and congestion metrics as given in the section 3.2.1
packet loss rate due to congestion is calculated
Step-3: Apply PSO as given in the study
Apply best fit formula.
Step-4: Go for
Division into regions based on communication range
Step-5: Energy efficient data transmission.

RESULTS AND DISCUSSION

Simulation model and parameters: The Network Simulator (NS2) is used to simulate the proposed architecture. In the simulation, the mobile nodes move in a 500×500 meter region for 50 sec of simulation time. All nodes have the same transmission range of 250 m. The simulated traffic is Constant Bit Rate (CBR) (Table 1).

Performance metrics

The proposed Energy Efficient Inter-Cluster Routing using PSO (EEICR) is compared with the SCH-LEACH technique [ ]. The performance is evaluated mainly, according to the following metrics.

Packet delivery ratio: It is the ratio between the number of packets received and the number of packets sent.

Packet drop: It refers the average number of packets dropped during the transmission

Energy consumption: It is the amount of energy consumed by the nodes to transmit the data packets to the receiver.

Delay: It is the amount of time taken by the nodes to transmit the data packets.

Based on nodes: In our first experiment we vary the number of nodes as 25, 50, 75 and 100.

Figure 7 shows the delay of EEICR and SCH-LEACH techniques for different number of nodes scenario. We can conclude that the delay of our proposed EEICR approach has 27% of less than SCH-LEACH approach.

Figure 8 shows the deliver ratio of EEICR and SCH-LEACH techniques for different number of nodes scenario. We can conclude that the delivery ratio of our proposed EEICR approach has 15% of higher than SCH-LEACH approach.

Figure 9 shows the drop of EEICR and SCH-LEACH techniques for different number of nodes scenario. We

Table 1: The simulation settings and parameters are summarized

No. of Nodes	25,50,75 and 100
Area size	500×500
Mac	IEEE 802.11
Transmission range	250m
Simulation time	50 sec
Traffic source	CBR
Packet size	512
Initial energy	10.3J
Receiving power	0.395
Transmission power	0.660
Rate	50,100,150,200 and 250 Kb

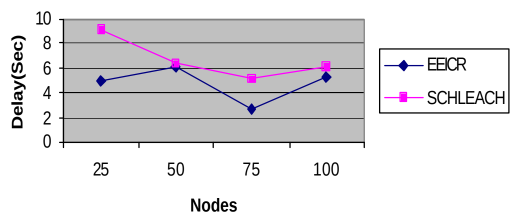

Fig. 7: Nodes vs delay

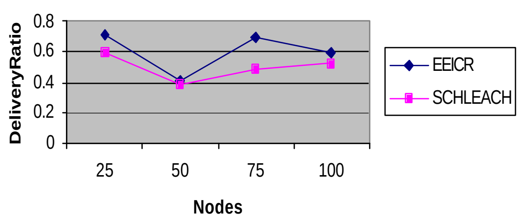

Fig. 8: Nodes vs delivery ratio

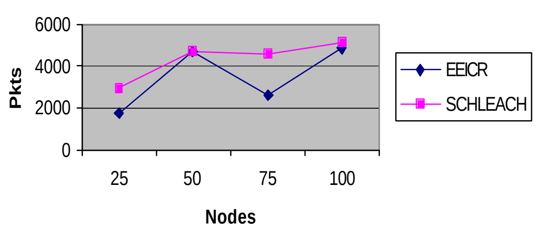

Fig. 9: Nodes vs drop

can conclude that the drop of our proposed EEICR approach has 23% of less than SCH-LEACH approach.

Figure 10 shows the energy consumption of EEICR and SCH-LEACH techniques for different number of nodes scenario. We can conclude that the energy consumption of our proposed EEICR approach has 3% of less than SCH-LEACH approach.

Figure 11 overhead the delay of EEICR and SCH-LEACH techniques for different number of nodes scenario. We can conclude that the overhead of our proposed EEICR approach has 5% of less than SCH-LEACH approach.

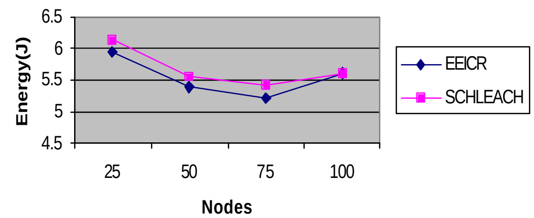

Fig. 10: Nodes vs energy consumption

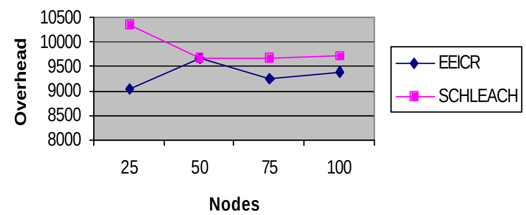

Fig 11: Nodes vs overhead

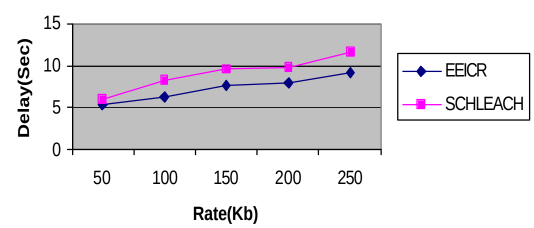

Fig. 12: Rate vs delay

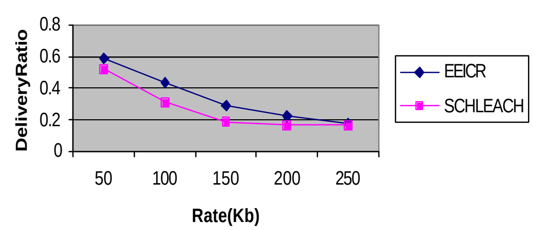

Fig. 13: Rate vs delivery ratio

Based on rate: In our second experiment we vary the transmission rate as 50,100,150,200 and 250 Kb.

Figure 12 shows the delay of EEICR and SCH-LEACH techniques for different rate scenario. We can conclude that the delay of our proposed EEICR approach has 19% of less than SCH-LEACH approach.

Figure 13 shows the deliver ratio of EEICR and SCH-LEACH techniques for different rate scenario. We can conclude that the delivery ratio of our proposed EEICR approach has 21% of higher than SCH-LEACH approach.

Figure 14 shows the drop of EEICR and SCH-LEACH techniques for different rate scenario. We can conclude that the drop of our proposed EEICR approach has 13% of less than SCH-LEACH approach.

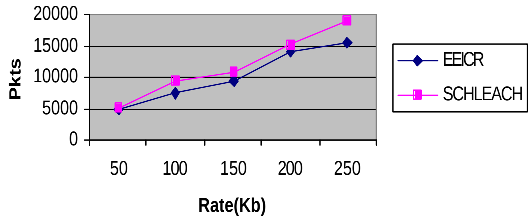

Fig. 14: Rate vs drop

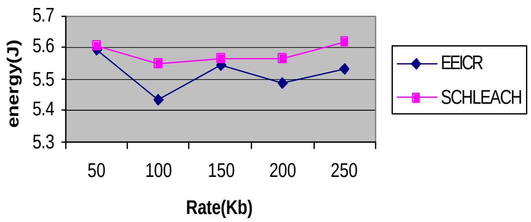

Fig. 15: Rate vs energy consumption

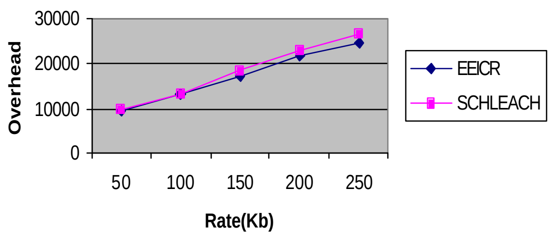

Fig. 16: Rate vs overhead

Figure 15 shows the energy consumption of EEICR and SCH-LEACH techniques for different rate scenario. We can conclude that the energy consumption of our proposed EEICR approach has 2% of less than SCH-LEACH approach.

Figure 16 shows the overhead delay of EEICR and SCH-LEACH techniques for different rate scenario. We can conclude that the overhead of our proposed EEICR approach has 5% of less than SCH-LEACH approach.

CONCLUSION

To make a structured study, the current study is giving an introduction at first of the study in the first section. To find a suitable solution and from the exiting work some literature has done in the second section. The third section gives the proposed method with the problem definition. At last, a suitable conclusion is given in section four. Considering the problem of energy efficient inter-cluster routing for WSN this study is giving a estimated link quality and congestion metrics using bit error rate and packet loss rate due to congestion respectively. The energy cost function is calculated based on distance between cluster heads and sensing range of sensors. The above method is followed by a three phased solution.in the first phase to select cluster heads, cooperative particles of swarm were initialized in PSO. In the last stage of the proposed method fitness function is calculated based on the three metrics namely energy cost, bit error rate and packet loss rate due to congestion so as to determine the optimal path. To prevent hotspot problem near base station, we divide the whole network into three regions based on communication range.

The proposed protocol of REC is effective in prolonging the network lifetime, as well as supporting for scalable network. This study's technique achieves substantial energy savings and improved reliability over the contemporary cluster based routing techniques. The effectiveness of the routing algorithm proposed in this study considerably increasing the efficiency of routing.

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