An Efficient Energy Harvesting Assisted Clustering Scheme for Wireless Sensor Networks

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Abstract:- One of the prominent challenges in Wireless sensor networks (WSNs) is the energy conservation of sensor nodes irrespective of the nature of the sensor applications due to the tiny, limited batteries of the nodes.One promising solution to preserve energy is the clustering phenomenon and this mechanism also requires adequate stress on overall overhead of the network. Various clustering solutions have been addressed to extricate the power constraints of the sensor networks and they fluctuate in their boundaries owing to the multifaceted nature of this problem. In a typical clustering process in a WSN, energy is consumed in three phases: data sensing, data forwarding and data aggregation. A potential green, untrammeled replacement towards the conventional clustered sensor networks is the harvesting and utilization of energy from an ambient power resource. Unlike many other solutions, this approach overcomes the customary trade-offs but hosts economic and application-specific constraints. Our proposed Efficient Energy Harvestingassisted Clustering (EEHC) scheme contributes the idea of forming effective clusters that are free of residual nodes and overlapping. In this environment each sensor node is equipped with the energy harvesting device.The cluster head effectively balances the load in a cluster based on energy budgeting and nearly reduces the need for reclustering. Our approach is compared against the conventional and modern clustering algorithms for WSNs and yields significant improvement in the scope of lifetime from the pecuniary perspective.

Keywords:*Wireless Sensor networks, energy harvesting, residual nodes, network lifetime, multi-hop relay.*

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I.INTRODUCTION

Today wireless sensor networks are employed in wide variety of application fields ranging from battlefield to hospitals [1]. These sensor networks are equipped with sensor nodes to sense, collect and forward the data to one or multiple sinks. Since traditional sensor nodes deployed are provided with batteries of limited energy resources, efficient utilization and preservation of energy becomes a crucial and inexorable issue in prolonging the lifetime of these sensor networks. Extensive researches have been carried out to handle this issue and many solutions have been proposed so far. Clustering the sensor network is one among them which includes its advantages and limitations from the viewpoints of efficiency, overhead and delivery ratio [2]. A typical sensor cluster comprises of a cluster head that collects data from a set of cluster members, aggregates and transmits to the sinkeither in single-hop or multi-hop scenario. Eventhough many clustering solutions have been proposed to prolong the lifetime of a sensor network with carefully chosen scenarios, sensor nodes deplete their energy and stop functioning.

As an alternative to this solution, the idea of harvesting energy from boundless, green power resources is adopted by the recent research works. The inheritance of this mechanism requires special tiny hardware devices like solar cells, thermal energy harvesters, etc., and introduces the economic concerns in the existing environment. A thumb rule of energy harvesting is that the energy consumed must be compensated by the energy harvested at any time slice which necessitates accurate, flawless prediction techniques. The implementation of this rule protects the sensor nodes from getting drained in energy and ensures that sensor nodes continue their functioning. Meanwhile, such prediction techniques arises a prerequisite of awareness and control on functional behavior of the network. Energy harvesting complements the on-board batteries but falls to occupy the prominent role in lifetime enhancement due to the cost factor. An eternal solution is theoretically feasible but arises many questions on pragmatic application fields.Consequently, the limited capacity of the batterystorage marks an upper threshold on harvesting and conservation of energy.

The remainder of this paper is organized as follows. Section 2 reviews the related works in the literature and analyzes their shortcomings. Section 3 presents the proposed system model. Section 4 provides experimental results. Section 5 concludes the work and presents the future scope of extensions.

II. RELATED WORK

Energy harvesting assisted clustering approaches has been selectively studied to explore the evolution and drawbacks of the ancestor works. Eventhough these approaches attain the goals in some environments, they expose their fall in majority of the emerging sensor applications owing to the arrival of new requirements, lack of compatibility, deployment complexity and inherent tradeoff among the performance parameters. Several attempts are made to handle the aforementioned issues but seldom have they achieved a justifiable scope of enactment across the performance goals. A complete and generalized solution still becomes an ideal scenario due to the dynamic behavior of sensor applications and unpredicted scenarios. This work indents to improve energy optimization in a clustered sensor network by adopting and integrating the merits of the existing works.

As a conventional protocol, Low Energy Adaptive Clustering Hierarchy (LEACH) [3] occupies a benchmarking position over the clustering protocols in which each sensor node has certain probability of being a cluster head and cluster head position is rotated among the nodes across rounds. LEACH adheres to an environment which demands that communication between a cluster head and the BS is always done on single-hop fashion. This makesclustering based on LEACH infeasible in many pragmatic scenarios. Hybrid Energy Efficient Distributed Clustering (HEED) [4] broadens the limits of LEACH to a multi-hop intercluster communication model. Despite of its triumph on extension of communication ranges, HEED leaves many energy holes in clusters near the BS. Lack of energy balancing makes a substantial impact over the implementation of HEED in many sensor applications.

Researches rode on the path of unequal clustering approaches to solve this hot-spot scenario in WSN applications. The very idea of this approach is to make the clusters near to the BS smaller in their sizes and hence the intra-cluster traffic could be reduced against the raise in inter-cluster traffic. UCS [5] becomes the first protocol that inherited the concept of unequal clustering but becomes impractical since it necessitates cognitive CHs and planned deployment of CHs. Energy Efficient Clustering Scheme (EECS) [6] and Energy-Driven Unequal Clustering protocol (EDUC)[7] form unequal clusters but they rely on single-hop communication relay between BS and cluster heads. For the past one decade, many such unequal clustering algorithms have been introduced and they make a detour in energy distribution and balancing among the fluctuating, dynamic nature of sensor networking applications.

As time getting advanced, researches tend to harvest the benefits of emerging technologies. As observed in the literature, the knot of the problem lies in the limited, size-constrained, non-renewable energy resources of the sensor networks. Irrespective of the cognitive ideas and specially equipped hardware embedded in solutions, the sensor nodes have to get drained off over certain period. None of these solutions can offer the infinite lifetime for sensor nodes and they all become insufficient to satisfy the power thirst of emerging applications. Research works incline their view towards adding supplementary energy resources to the sensor nodes to prolong their lifetime. Eventhough this idea attracts many of the researchers, it arises questions over economic feasibility and compatibility to the existing setup.The secondary level energy resources can be allotted either to the entire network or to a set of nodes based on their requirements.

. A variant of LEACH, named S-LEACH was proposed by Voigt et al. [15] which gives room for both conventional and solar batteries. A portion of the sensor environment is equipped with solar energy cells and cluster heads are always elected from these sensor nodes only. This can balance the load across the capacity of sensor nodes. This mechanism neither makes a smart energy budgeting nor it supports multi-hop traffic. Moreover, this approach lacks of scalability across sensor population. The works in [8] and [9] represent typical harvesting techniques in sensor applications and they encounter major issues in estimating the energy consumption of nodes. The principal claim of these works point to the avoidance or long postponement of reclustering. Since the consumed energy is harvested in stipulated time period, cluster heads withstand the traffic and postpone their expiry time.To optimize energy consumption against coverage area and spectrum utilization, cognitive multihop transmission protocols were introduced [12,13,14]. These approaches exhibit significant boostage in performance but lead to increased quantum of overhead and lack of energy estimation under dynamic environments. Zhang and Yin propose an energy harvesting protocol namely, Energy Harvesting and Information TransmissionProtocol (EHITP) [11] which estimates the energy to be harvested based on the outage probability.

The crucial focus of the research in these solutions finger the need for a well-estimated, self-trained and automated energy budgeting model against the complex demands.The presence of overlapping nodes in cluster and scattering of residual nodes tend to collapse the energy budget estimation and hence makes a road to reclustering. Scalability of the existing solutions becomes another challenging issue and hence the proposed solution has to be tested across various sizes of the sensor network. Our scope of the research work is confined to optimize the cluster formation across the sensor environment with respect to these identified challenges. Our research work also moves towards a solution that introduces neither additional overhead nor the need for specially equipped hardware platforms.

III. SYSTEM MODEL

3.1. System Environment

A wireless sensor network is randomly deployed. The location of the BS is known to all the sensor nodes. The BS is assumed to be a node having no energy constraints and connected to all the sensor nodes either direct transmission or on multi-hop routing. The distance between the nodes is estimated by sending the beacon signals and measuring the received signal strength. The energy model of Heinzelman et al. is adopted here. The energy is consumed during transmission, reception and idle states for all the sensor nodes.

There are ‘k’ cluster heads are chosen in the sensor networks randomly subject to the condition that each of these nodes should atleast have a distance that is more than or equal to the threshold‘d_0’ to all remaining cluster heads. In the subsequent steps, clusters are formed by associating the nearby nodes to the set of cluster heads. The clustering phenomenon proposed in this approach adheres to two major constraints to improve the energy utilization: (i) Overlapping of nodes in clustering is prohibited. (ii) There are no residual nodes produced as an outcome of this clustering process. The clustering process is iterated till both of these constraints are satisfied.

Fig.1 describes a scenario where residual nodes are formed as an outcome of the conventional clustering process. Fig.2 shows the scenario where these residual nodes are associated to the nearby clusters. After the cluster formation, the primary cluster head measures the overall energy dissipated in the cluster. The cluster head consumes energy due to data reception, aggregation and transmission processes. The cluster members dissipate energy during sensing the data and forwarding it to the cluster head. The energy dissipated by every sensor node is estimated and harvested on periodic intervals. This mechanism leads to computation overhead but effectively handles the energy balancing among the sensor nodes and hence aids in prolonging the lifetime of the sensor network as a whole. The need forreclustering is evaded by setting an appropriate energy budget for sensor nodes and cluster head.

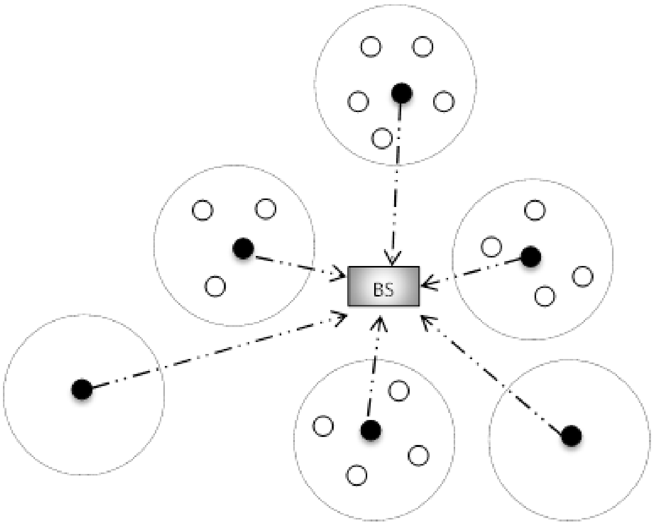

Fig.1. Clustering with Residual Nodes

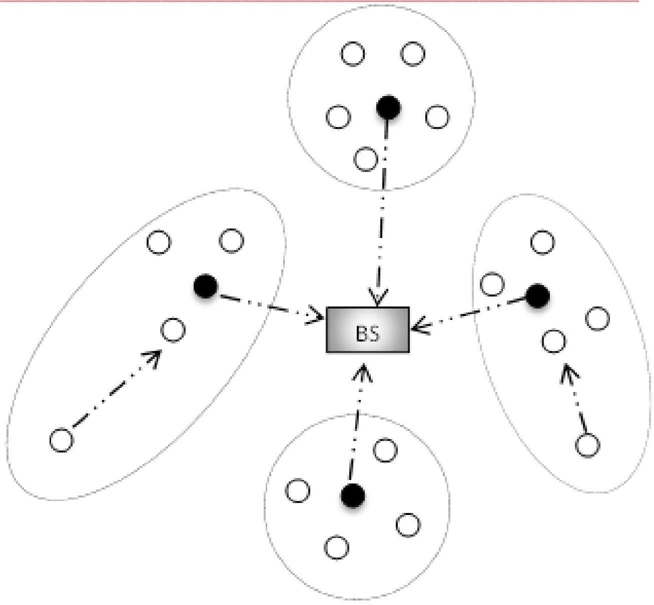

Fig. 2.Associating residual nodes to nearby clusters

3.2. Efficient Energy Harvesting assisted Clustering (EEHC) scheme

Algorithm 1: Cluster formation

```
N← number of sensor nodes
SN← array of sensor nodes
r←radius of the sensing region


1.    foreach sensor node SN_i do
          a. NodeID (SN_i)←NodeID for this sensor node
          b. NodeDistBS (SN_i) ← Distance from SN_i to BS
          c. NodeRole(SN_i)← Cluster_Memeber

// cluster head selection

2.    x=0
3.    do
          a. RandomSelect (CH[k]) from SN // Randomly select k sensor nodes
          b. foreach node CH_i in CH[1,2,…k]
             foreach node CH_j in CH[i+1,…,k]
                 i.   dist=CalculateDistance(CH_i, CH_j)
                 ii.  if (Dist< d_0)then
                 iii.     x=1
      repeat step 3until x=0
4.    foreach sensor node SN_i∈ CH[1,2,…k]do
          NodeRole(SN_p) ← Cluster_Head

// cluster formation

5.    foreach sensor node SN_i∈ CH [1,2,…,k]
      a.      neighbour[i][]=all sensor nodes (SN_i, r)
```

```
        // list of neighbours in the sensing region of Cluster
                Head $SN_i$
        b.      create_stack($c_i$)
        c.      foreach sensor node $SN_z \in$ neighbour[i][]
                    i.   member[z]←'false' // a boolean variable
                         // avoid overlapping in membership
                    ii.  if (neighbour[i][q] $\notin$CH) then
                         foreach cluster $c_j$ in ($c_{i+1,...}c_k$)
                         if (neighbor[i][q] $\notin c_j$)then
                             member[z]←'true'
                    iii. if (member[z]←'true')then
                         add (neighbour[i][q],$c_i$)
6.  if (size ($C_i$) ← 1) then
     // if a cluster head $SN_i$ contains no other nodes except
    itself, it becomes a residual node
      member [i] ←'false'

7.    // clustering of residual nodes
        foreach sensor node $SN_i$
            a.  if (member[i] ←'false') then // not a member of any cluster
                    i.   foreach $SN_k \in$ CH
                dist[k]=CalculateDistance($SN_i$, $SN_k$)
                    ii.  foreach $SN_k \in$ CH
                         foreach $SN_m \in$ CH
                             if(dist[k]≤dist[m])
                                 min←k
                    iii. add ($SN_i$, $C_k$) // add the residual node to the nearest cluster
                    iv.  foreach sensor node $SN_p \in C_k$
                         dist[p]=CalculateDistance($SN_i$, $SN_p$)
                    v.   select $SN_{min}$ |dist($SN_{min}$) ← min(dist($SN_1$), dist($SN_2$),...in cluster $C_k$)
 // nearest node of $SN_i$ in cluster $C_k$
                    vi.  assign_node($SN_i$, $SN_{min}$)
```

3.3. Energy Conservation

A sensor node consumes energy during sensing the data and forwarding the data to the cluster head. A cluster head consumes the data during the reception, data aggregation and forwarding of the aggregated data.

The energy consumption of a cluster member to sense and transmit 1-bit of information to the cluster head is estimated in Equation (1):

$$E_{SN}=E_{sensing} + E_{tx} \quad (1)$$

Assuming a sensing rate of 'x', the total data sensed and transmitted by 'n' cluster members in a time period 't' is estimated as given in Equation (2).

$$E_{CM} = (n.x.t).E_{SN} \quad (2)$$

Since the maximum number of cluster members are located at 1-hop distance to the cluster head, it is assumed that the data sensed at time 't' is transmitted to the cluster head within the same interval.

Suppose a cluster head collects L-bit length of data at time 't', (ie., L= x.t.n) then the total energy conservation for data reception, aggregation and forwarding in that CH across time period 't' is estimated as given in Equation (3).

$$E_{CH} = n.x.t.E_{rx} + n.x.t.E_{DA} + \frac{n.x.t}{\alpha}.E_{txr} \quad (3)$$

Here α stands for aggregation ratio.

The total energy consumed in time 't' for a cluster is given in Equation (4).

$$E_c = E_{CH} + E_{CM} \quad (4)$$

For a time slot't', the entire cluster, ie, all the cluster nodes including the cluster head should harvest the energy equal to that of the estimated energy. Suppose there are 'n' cluster members and a cluster head, then the energy that is required to be harvested by a sensor node/ a cluster head is given by the Equation (5).

$$E_h = \frac{E_c}{n+1} \quad (5)$$

Obviously, the energy consumed at a cluster head is more than the cluster members. Hence for a CH, more energy should be harvested to balance the energy constraints of the network. This model does not impose on any special mechanism to track and deal the energy harvesting resources of a CH. Although this mechanism simplifies the constraints, a new cluster head is selected whenever the energy level of a CH goes below certain threshold E_{th}.

3.4. Energy harvesting

Energy of the node n at

$$t_1 = E_{t1}(n) \quad (6)$$

Energy of the node n at

$$t_1 + T = E_{t+T}(n) + \tau \int_{t_1}^{t_1+T} E_h(n,t)\,dt - \int_{t_1}^{t_1+T} E_l(n,t)\,dt \quad (7)$$

For every time interval 'T' between time 't_1' and 't_1+T', the harvested energy is calculated. In Equation (7), the three components represent the energy of the node at starting time 't_1', energy harvested at time interval 'T' and energy leakage during this interval. The factor 'τ' represents charging efficiency. All the sensor nodes are provided with the storage buffers to store energy harvested.

3.5. Energy Budget

The energy consumed must be compensated by the energy harvested within the boundary of a cluster across any time slot. ie, the energy budget should harvest more energy than that of the energy consumed in every cluster periodically.

In a typical unattended sensor network, it is pragmatically difficult to set different energy harvesting levels for various sensor nodes. Hence, an efficient energy budget should ensure that the energy consumption should not be increased than the energy harvested across any time slice. In general, this kind of situation may arise in cluster heads and this seldom happens in cluster members. As it is learned from the survey, dominant factor of energy consumption lies on transmission and reception phases and sensing makes a minor and even negligible occupation here. A cluster head is forced to shut down when its energy level goes below certain threshold.

IV. PERFORMANCE EVALUATION

4.1. Simulation

The simulations are performed using MATLAB. Extensive studies are carried out to study the performance of the proposed EEHC against classical and modern clustering algorithms. The set of simulation parameters are present in Table 2.

Table 2. Simulation Parameters

Parameter	Value
Network Area	200 x 200 m^2
Sink Location	(100 m, 100 m)
Number of sensor nodes	100,200
Initial energy level of sensor nodes	1 J
Control Packet Size	40 bytes
Data packet size	1000 bytes
Transmission range of sensor nodes	5m, 10 m, 15 m, 20 m, 25 m
Harvesting buffer capacity per node	1 J
Aggregation ratio	0.1
Cluster Head sustainability threshold	1 J
Energy consumption during amplification	100 pJ/bit/m2
Energy consumption during transmission and reception	50 nJ/bit

4.2. Results

The performance of the proposed EEHC algorithm is evaluated against a classical protocol, namely, LEACH and a modern harvesting aided clustering protocol, EHITP [11]. There are three scenarios taken for experimentation and the scalability of the proposed solution is monitored over the size of the sensor network.

4.2.1. Scenario 1:

100 Sensor nodes are deployed in simulation. For LEACH, nodes are clustered in such a way that all the cluster members are at 1-hop distance to the cluster head. Residual nodes are permitted in this scenario. All the nodes are allotted with energy harvesters and they produce energy based on energy budgets. The rest of the parameters including aggregation ratio and deployment area are set as given in Table 1.

Experimental results indicate the efficiency of the proposed EEHC protocol over LEACH and EHITP as shown in Fig. 3 and Fig. 4. Basically, LEACH shows the poorest of the three approachesin terms of energy consumption since it adheres to single-hop communication in transmitting the data to the BS. EHITP supports multi-hop relay but suffers from the lack of energy budgeting. This constraint limits the performance of EHITP. EEHC shows the best energy characteristics of the three since it avoids residual nodes and overlapping of clusters. The scalability is tested by varying the transmission range of sensor nodes in the WSN. By increasing the transmission range, the number of clusters is reduced. This, in turn, reduces the inter-cluster traffic significantly. Hence, there is a fall in the total energy consumption with respect to these three protocols. The proposed approach outperforms the existing algorithms across increase in transmission range.

Due to its simple mechanism, LEACH reveals a low overhead and reduced number of control message packets. EHITP models the outage probability in clusters but imposes on remarkable increase in the overall overhead of the network. This makes more number of control packets are produced in EHITP when compared to LEACH. EEHC reveals better load distribution to other two approaches and this approach logically reduces the number of clusters and communication complexity. Besides, EEHC decides the transmission of data based on the quantum of data harvested. This feature can effectively help the unattended sensor environments in load balancing and energy optimization.

The time taken for cluster head reelection across the time slots is recorded as shown in Fig. 5. As observed, a cluster head loses its position when its energy level goes below certain threshold. Every time slot here is set as 60 seconds and simulation is run for 100 timeslots to study the cluster head sustainability of the network. Accumulated

Cluster head Failure Count is a metric used here to measure the stability of a cluster head. This is calculated by considering the failure of cluster heads from various clusters and accumulated over the subsequent timeslots. Due to the planned structure and local energy budgeting of clusters, EEHC balances the load among its members and resists the role change of cluster heads. The results demonstrate the efficiency of EEHC with respect to EHITP and LEACH.

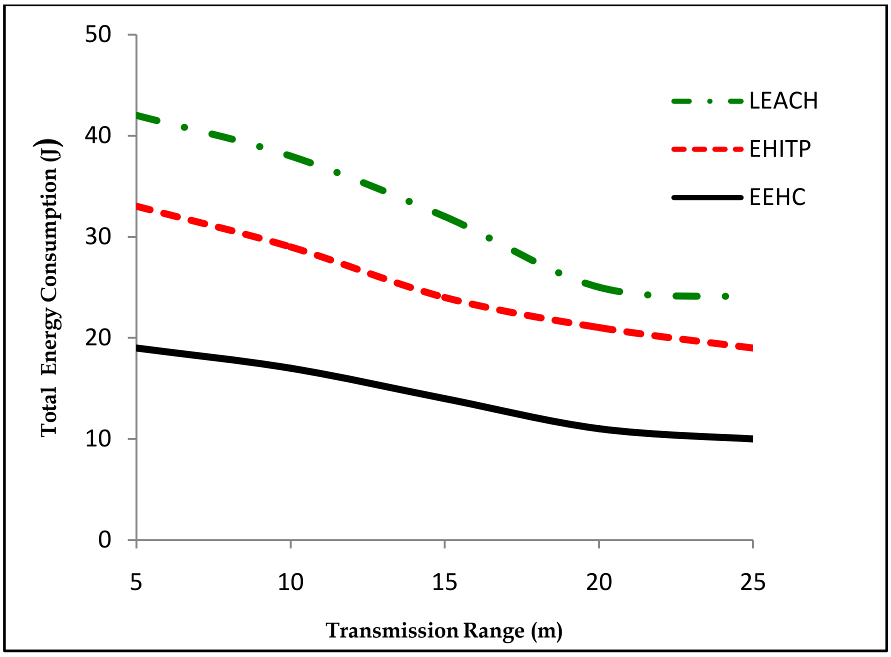

Fig.3. Energy Consumption in Scenario 1

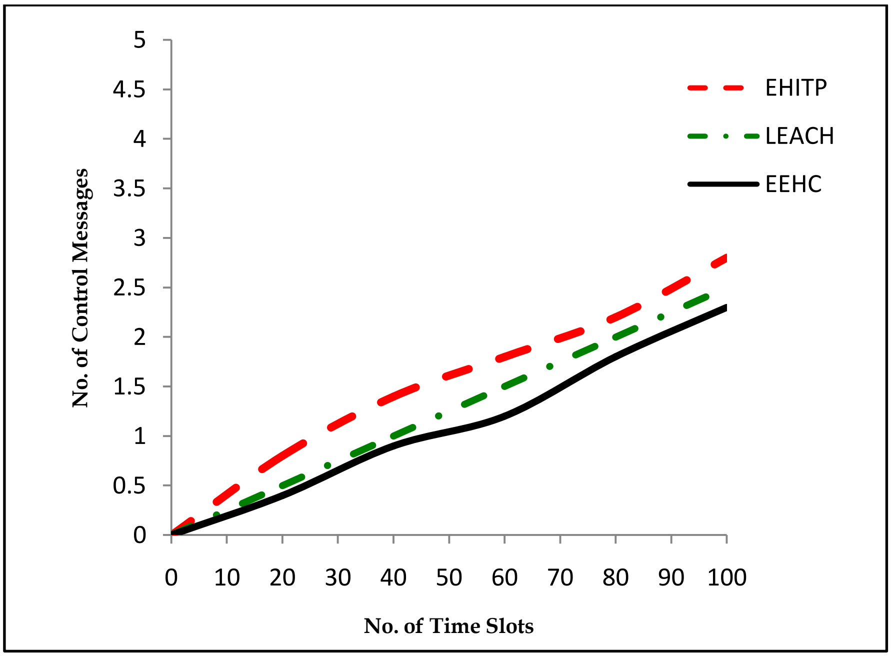

Fig.4. Control message overhead in Scenario 1

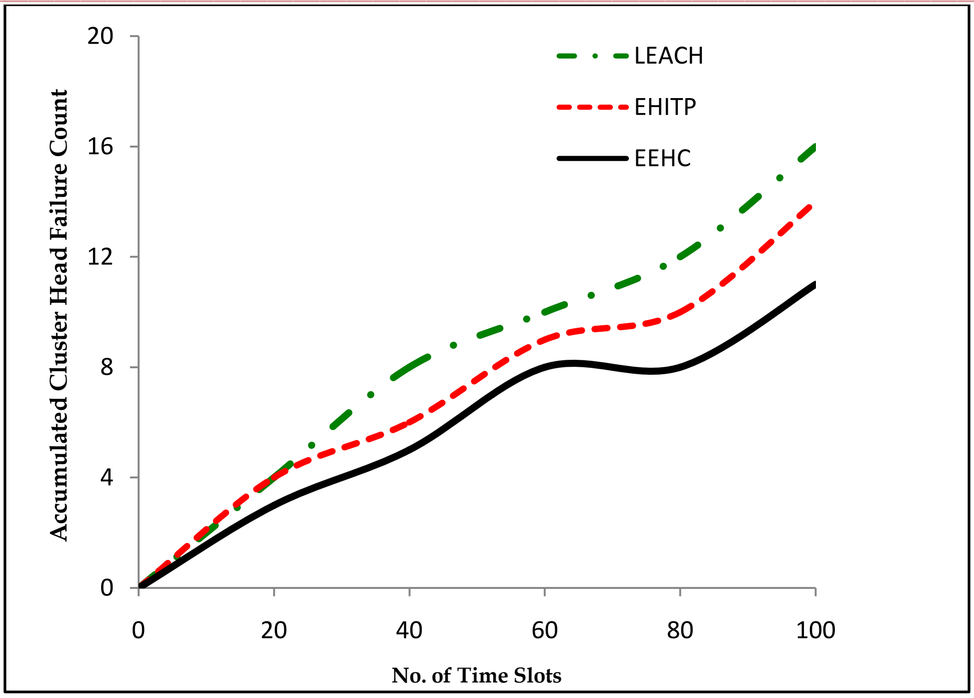

Fig.5. Cluster Head Sustainability in Scenario 1

4.2.2 Scenario 2:

The scalability of the proposed solution is tested in this scenario by deploying 200 nodes in the same area as in sceario1, which doubles the density of sensor node population. The remaining parameters are inherited from sceario1.

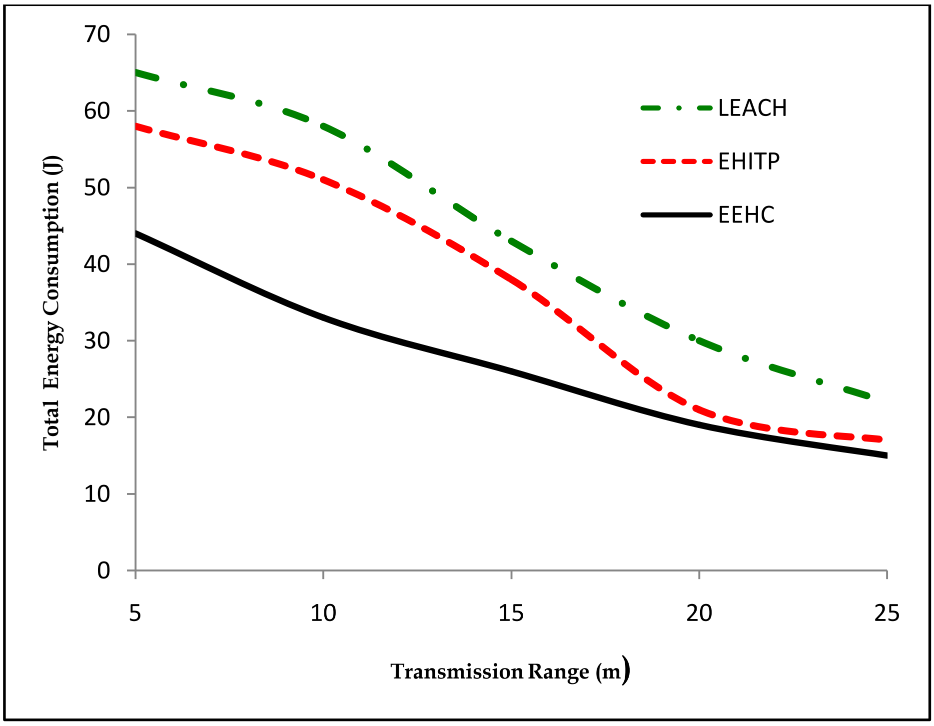

Fig.6. Energy Consumption in Scenario 2

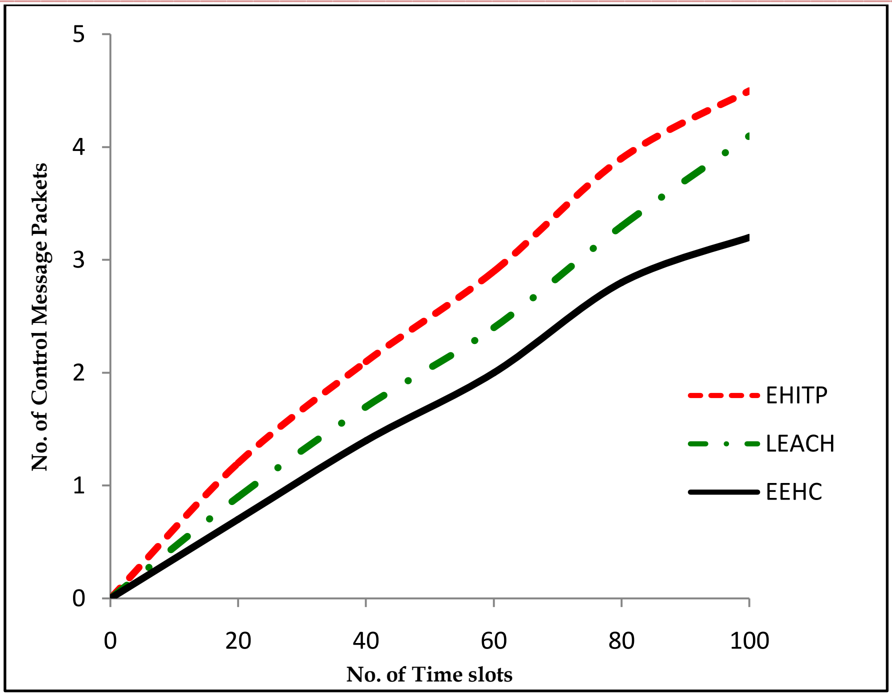

Fig.7. Control message overhead in Scenario 2

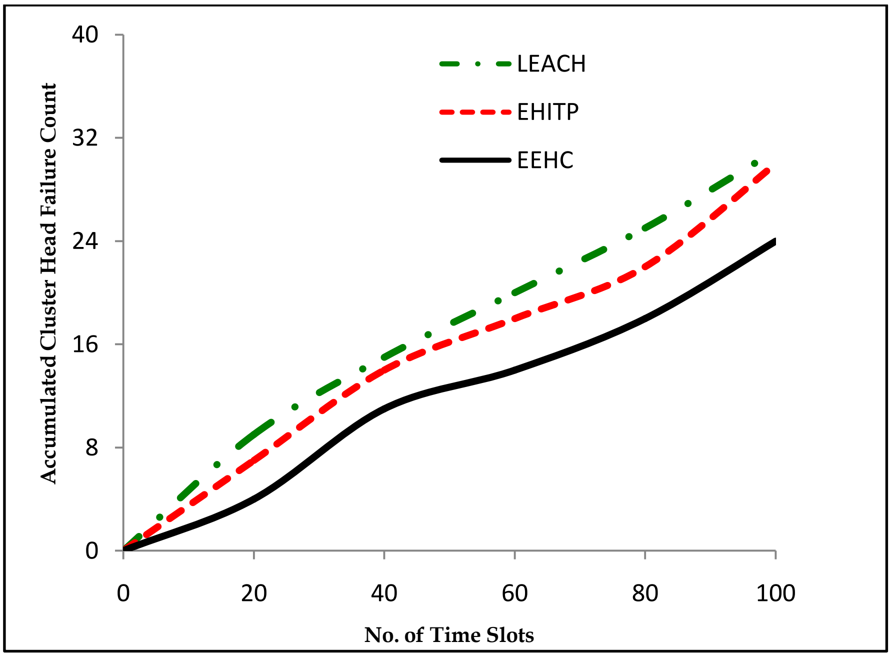

Fig. 8.Cluster Head Sustainability in Scenario 2

As shown in Fig. 6**,** proposed EEHC shows betterment in terms of energy consumption and overhead comparing to LEACH and EHITP. While the transmission range increases, EHITP shows a closer performance to EEHC. As discussed in the previous scenario, an increase in transmission range leads to reduction in number of clusters. Hence, energy consumption is reduced in this direction and proposed EEHC promises its scalability across transmission ranges.

Since the sensor population is doubled, more control message packets are produced and this can be observed from the Fig.7. that records the relationship between the control overhead and transmission range. Since LEACH operates on unpretentious administration, it produces less number of control messages with respect to EHITP. Despite its simplicity, LEACH suffers from increased intra-cluster traffic due to single-hop cluster-BS transmission. EEHC limits the control messages compared to LEACH since it effectively manages and preserves its cluster heads.

Fig. 8.depicts the sustainability of cluster heads in scenario 2. Cluster head Failure Count is calculated across time slots for each cluster and is accumulated.

4.2.3 Scenario 3:

Here 200n sensor nodes are deployed and the area is doubled (200 x 400 m^2). The rest of the parameters are adopted from scenario 1.

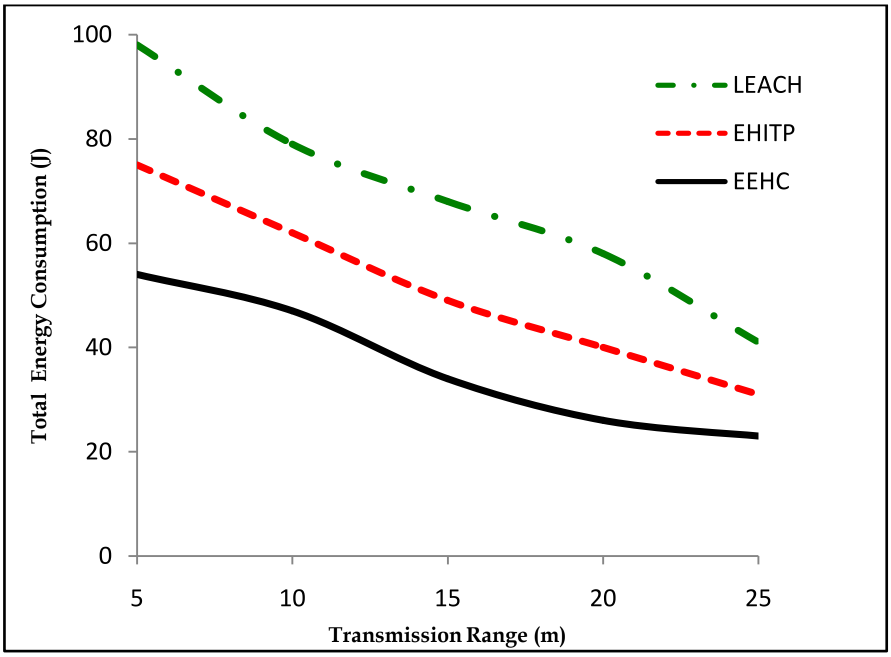

Fig.9. Energy Consumption in Scenario 3

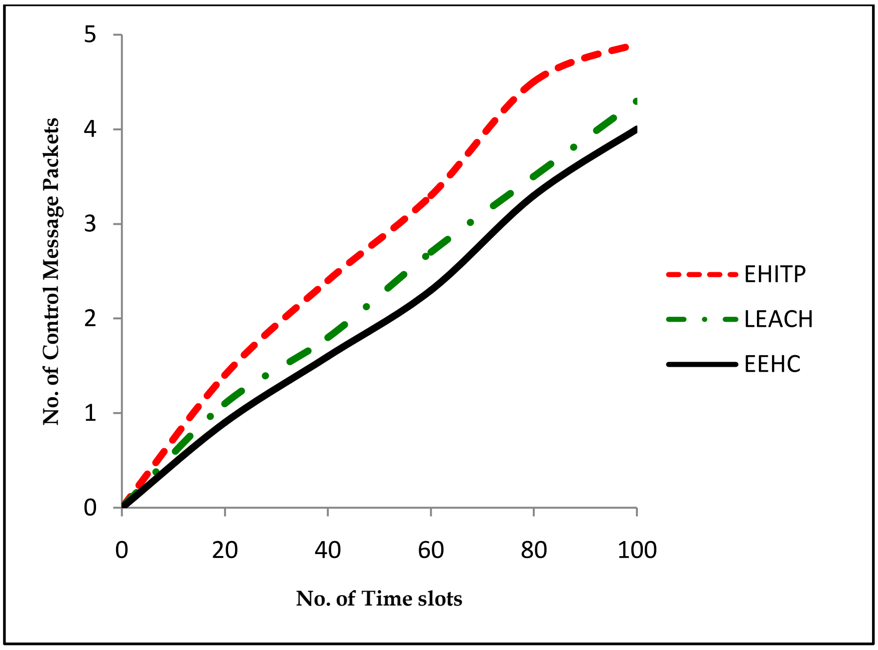

Fig.10. Control message overhead in Scenario 3

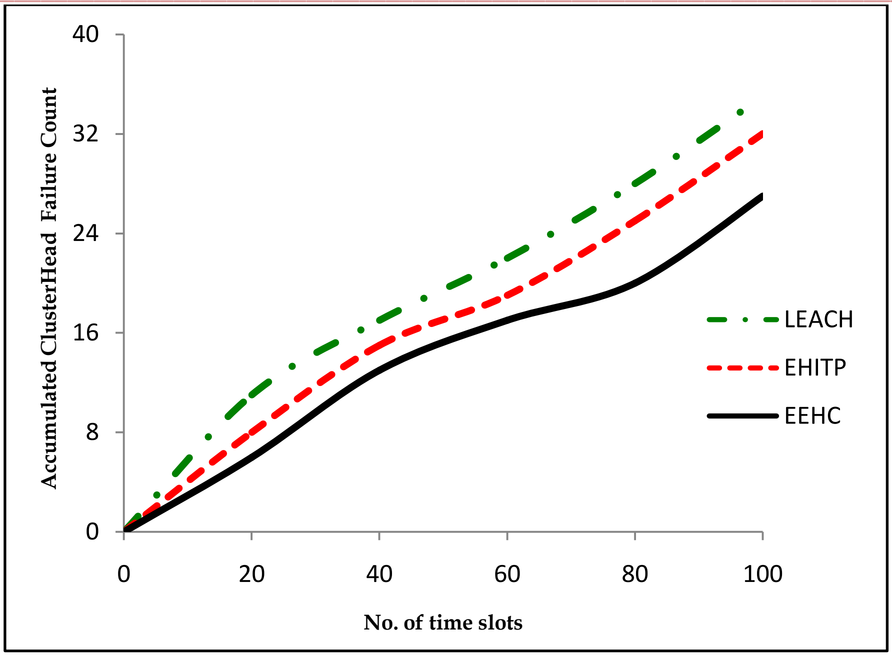

Fig.11. Cluster Head Sustainability in Scenario 3

Fig. 9 and Fig. 10 illustrate the energy and control overhead characteristics of scenario 3, respectively. Fig. 11.exhibits cluster head sustainability across clusters. Here, the density of the network is reduced to half of its earlier scenarios since the area is doubled here. EEHC shows consistent improvement in comparing against LEACH and EHITP. The distributed nature of the proposed approach guarantees the cluster head sustainability and hence the cluster stability.This endorses the distributed nature of the proposed approach and normalizes the energy performance of the networks.

V. CONCLUSION

This work presents anenergyconservation/ harvesting estimation model to prolong the lifetime of a sensor network with respect to limited harvesting. The simulation results of the research work demonstrate the efficiency of the proposed solution in terms of cluster head re-election process. A closer observation of the results exhibits the scalability of the proposed solution across different scenarios.The proposed solution relays on the aggregated mean values of energy conservation and hence is confined to the application environments where the production changes are admitted and absorbed in a gradual manner. The scope of the research can be tuned by mapping the characteristics of power harvesters such as solar cells in the energy budgeting since they are kept idle during considerable duration of a day.

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