A Cluster–based Approach for Minimizing Energy Consumption by Reducing Travel Time of Mobile Element in WSN

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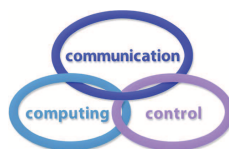
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Abstract: Envoy Node Identification (ENI) and Halting Location Identifier (HLI) algorithms have been developed to reduce the travel time of Mobile Element (ME) by determining Optimal Path(OP) in Wireless Sensor Networks. Data generated by cluster members will be aggregated at the Cluster Head (CH) identified by ENI for onward transmission to the ME and it likewise decides an ideal path for ME by interfacing all CH/Envoy Nodes (EN). In order to reduce the tour length (TL) further HLI determines finest number of Halting Locations that cover all ENs by taking transmission range of CH/ENs into consideration. Impact of ENI and HLI on energy consumption and travel time of ME have been examined through simulations.
Keywords: Envoy Nodes, Halting Locations, travel time, latency.

1 Introduction

Wireless Sensor Networks(WSN) are established by thousands of sensors distributed spatially over a specified geographical region for monitoring the changes in the environment. WSNs have wide range of applications like, health care monitoring, earth sciences, environmental sciences, military applications to detect intrusion of enemies disaster,tracking vehicular movement, etc. Sensor Nodes(SNs) are typically small electronic devices operated by battery with finite amount of energy. Each SN senses the environment and gathers the information about physical changes in the environment.Data generated by SN either periodically or continuously have to be submitted to the centralized processing unit called stationary Base Station (BS).

Contingent upon nature of the application, information detected by WSNs send either straightforwardly to a stationary BS or Mobile Element (ME). Usually BS location is fixed. In case if BS is located within the transmission range of a SN, then it will directly submit data to the BS. Otherwise, SN will send the data to its nearest neighbor, which will try to identify the shortest path and relay the data to the BS. There are few challenges associated with this traditional mechanism. Sometimes BS may be located far away from the area of interest, in such scenario SNs will not be able to communicate with the BS, apart from this, in large WSN considerable amount of energy will be spent for transmitting and receiving messages, this leads to high energy consumption and increased network traffic.

SNs nearest to BS have to allocate time slots for traffic coming from neighbor SNs, this result in traffic congestion. These nodes devour compared to other nodes. Such situation may prompt WSN's breakdown, as no information would reach BS if these nodes channel out the whole of their battery life.

The Above mentioned challenges can be addressed by employing a ME that travels along WSN space to gather data from SNs. The data gathered by the ME, is then submitted to BS [19]. How ever, it increases network latency. Latency can be minimized by identifying Envoy Nodes (EN), where EN is a node that ME must visit, in order to collect data. ME need not to visit exact geographical location of a EN, instead it can collect the data from any location within the transmission range of EN. Inspired by this ME's tour can be shortened further by identifying a set of locations in such a way that, ME will be able to collect data from all ENs by visiting these locations, these locations are referred to as Halting Locations (HL).

In literature various approaches makes use of heuristic approaches like Travelling Salesmen Problem (TSP) and Genetic Algorithms (GA) for defining ME's optimal tour [7, 12, 20].

In our previous work we have adopted a clustering method to minimize the energy consumption and decrease latency where every SN in a cluster is inside the transmission range of its Cluster Head (CH) [22]. As an extension to the previous work we try to investigate the effect of ME's TL on energy consumption. In this approach, Envoy Node Identification (ENI) algorithm has been developed to identify the number of ENs to be visited by the ME.

ME's tour consists of visit to all ENs. Optimal path(OP) that covers all ENs in WSN is identified using traditional TSP solver. Tour that has been given by TSP solver can further be reduced by visiting the HLs identified by Halting Location Identifier (HLI) algorithm. Adequacy of ENI and HLI have been evaluated in terms of optimizing the energy consumption and travel time of ME through simulation. An examination of simulation result shows that ENI, HLI outflank the COM and CSS.

Overview of research works related to clustering, energy issues and TL-optimization of ME discussed in Section 2. Section 3 presents an overview of proposed optimization approach. ENI and HLI algorithms described in Section 4. Section 5 showcases performance results through simulations carried out.

2   Related work

2.1   Minimizing the TL of mobile element

The problem of reducing TL of ME is addressed in [35]. First it carries out the cluster formation process as per [6], then the deployment region is partitioned into virtual grids and intersection points are identified. CHs have to choose one of these intersection points, so that ME can collect data from CHs by visiting these intersection points. Order of nodes to be visited is identified by a TSP solver.

A convex hull based method for reducing latency by considering amount of data to be collected is proposed in [36]. In this method a convex hull that covers all nodes is constructed. This process is applied progressively by eliminating nodes on previous layer of convex hull. This process is repeated until no nodes are left for further processing. All possible permutations for visiting nodes in layer - n and n-1are explored in order to identify an OP. This process is applied progressively until all the layers are covered. Optimal TL of ME is obtained by adjusting speed of ME.

Two different approaches are presented in [32, 34] for optimizing TL. The first approach enables ME to move unreservedly over the network deployment area, TL optimization depends on the requirement that information from SNs should reach BS in a given deadline. Second

approach pre-characterizes ME's path and TL is optimization will be achieved by identifying HLs along the pre-characterized path.

Optimal disc coverage is a technique which gives Centre and radius of the optimal disc that covers given set of points.

In [11], an attempt made to reduce ME's TL by using COM and CSS algorithms. An OP connecting all nodes has been identified by employing a TSP. In this approach the location to be visited by ME is referred as collection site. Optimal disc coverage technique [31] was employed by COM for identifying collection sites that must be included in ME's.

Location of two nodes will be given as input to decisional Welzl's algorithm, if Welzl's radius is less than or equal to transmission range then the two nodes will be replaced by Welzl's centre in ME's tour. CSS identifies the common intersection areas and establishes rendezvous points(RP) in it. The optimality of TL in these methodologies is restricted by the TSP solver. ENI and HLI made an attempt to overcome this limitation.

2.2 Clustering

In WSN, when clustering approaches are adopted,members of cluster submit the data to its CHs and CHs submits the data to the BS , in such networks, the CHs near the BS usually tend to become the conduit point for bulk data transmissions between the BS and far away clusters. As a consequence, the energy of CHs nearer to the BS may drain out quickly.

To maximize the lifetime of CHs nearer to BS variable size clustering has been proposed in [17, 19]. In both the approaches size of the clusters is defined by the distance of CH from BS. Since clusters nearer to BS will be of smaller size, the intra cluster communication and energy consumption for cluster routines is minimized so that the residual energy of CH can be utilized for relaying the incoming data to the BS.

Depending on the network topology it may happen that, some clusters accommodate more number of members. When a cluster has more number of cluster members, it leads to high energy consumption at cluster head and cluster head may drain out its energy very early. A clustering algorithm for addressing this problem is given in [27], size of the cluster and degree of a node are the two parameters that played key role in minimizing energy consumption.

A clustering algorithm based on common intersection area of SNs is proposed in [7], it groups the nodes having common intersection are in a cluster. Order of to be visited by ME is obtained by using GA. A genetic algorithm based cluster was proposed for reducing latency in [12].

Initially way points to be visited by ME are identified, then using weighing scheme nodes select one of the waypoint. These way points are optimized using genetic algorithms for minimizing ME's tour. An approach for determining optimized path from source to destination was proposed in [8].

As size of the cluster increases CH has to relay more number of packets and it leads to delayed transmission of data. This problem is address by exploiting nodes in common intersection area of clusters [9]. In this approach when waiting time of a packet at CH is more than the predefined threshold value, then node submits its data to neighbor CH through nodes in common intersection area. This phenomenon reduces packet loss and minimizes latency.

A protocol for minimizing the energy consumption by making use of beacon signal of ME is proposed in [23]. In this protocol a SN senses the environment periodically and goes to the sleep state, when a SN receive a Long Range beacon Signal from ME, it enters into active state. Node transmits data to ME when it receives Short Range beacon Signal and enters into sleep state.

Apart from latency and energy consumption fault tolerance is another issue associated with WSN. Even if the node detects fault and decides to reject the data, it takes considerable amount of time and energy. This problem is addressed by introducing Composite Interference Model

(CIM) in [4].

To determine Interference Fault-free Transmission (IFFT) schedule for all active links, a new approach Time Division Multiple Frequency (TDMF) is defined. Based on CIM and TDMF an algorithm for maximizing network throughput, Composite Interference-based Transmission Scheduling (CITS) is developed.

2.3   Energy issues

LEACH is one of the popular algorithm which has addressed the energy issues by adopting clustering mechanism [13]. An Energy Efficient Optimal Chain Protocol (EEOC) is proposed in [1].

EEOC has shown better performance than best known approaches in terms of first node die and last node alive. For extending the network lifetime and reducing data redundancy, a novel approach which is combination of chain based data transmission and clustering is proposed in [25].

A new clustering approach for achieving energy efficiency and reliability with the help of backup nodes is proposed in [26]. An attempt to achieve energy efficiency in delay sensitive applications is made in [24].

Raja et.al. tried to minimize the energy consumption by introducing multicasting mechanism and unequal size clustering [29].

Energy efficient and reliable routing is achieved using neural networks in [30].

Adoptive sectoring mechanism is used to prolong the network lifetime and reliable routing in [5]. A data collection strategy based on software defined network for enhancing network lifetime is proposed in [18].

A hybrid model of tree and cluster based approach is adopted for addressing hotspot issues, traffic congestion and energy issues in [15, 16, 21].

Shahinaz M. Al-Tabbakh adopted a tree based heuristic aggregation mechanism to enhance the network lifetime. A protocol for network lifetime improvisation is proposed in [10], it introduced a collection tree protocol to maintain dynamic routing table along with link state quality indicator.

Considerable amount of energy will be spent in WSN for data aggregation, this problem is addressed by using compressed sensing in [3].

3   Clustering approach to identify Envoy Nodes

Assuming a set of SNs S=s_0, s_1, ..., s_n have been deployed in an area where a set of phenomena are being monitored. Duty of ME is to collect data from all SNs in S. It minimizes multi hop communication and energy consumption, but it leads to increase in latency as ME needs to visit all nodes.

Latency can be reduced by identifying a set of Envoy Nodes SEN=en_0,en_1... en_n such that the sensed data of all nodes in the deployment region can be collected by ME by visiting all Envoy Nodes in SEN.The goal is to minimize the number of Envoy Nodes as many as possible.

In this paper we propose Cluster mechanism to further reduce the number of Envoy Nodes.

3.1   Cluster head selection

Geographical region that has to be monitored by WSN is divided into virtual square grids of side equivalent to 2 * T_r.

Partitioning process will be started from centre of the optimal disc given by Welzl's algorithm [31].

Making use of the following equation, assuming d_0, d_1 as the distance from node $s_0, s_1, ...$ to centre cen_i of each grid G_i select a cluster head ch_i.

$$Ch_i = s_j \mid d_j \text{ is min } \{d_0, \ d_1...\} \tag{1}$$

From (Eq.1) the node s_j that is nearer to cen_i will be ch_i for the grid G_i. Since length of each side of grid is $2*T_r$, locating CH nearby centre of the grid guaranties single hop communication with maximum number of nodes within the grid, also maximizes node coverage within the grid.

3.2 Cluster formation

After obtaining set of cluster heads CLH=ch_0, ch_1, ..., the nodes that are within one hop distance from a cluster head ch_i are made to join the cluster CL_i.

There is possibility that some CHs are closely located, it may lead to the situation that a CH becomes the member of other cluster. In order to avoid such situation cluster heads have to be excluded from cluster formation process as mentioned in (Eq. 2).

$$S' = S - CLH \tag{2}$$

A node s_j in S' joins the cluster CL_i if it belongs to the grid G_i and within the transmission range of CH ch_i.

$$S_j \epsilon CL_i \forall s_j \epsilon G_i \text{ if } dist(s_j, ch_i) < T_r \tag{3}$$

CH collects information from fellow cluster members and aggregates, this aggregated information will be transmitted to ME. Each node in CL_i submits it's data to ch_i. A node can join only one cluster. As soon as node joins a cluster it will be excluded from further clustering process . However, there is a possibility that few nodes may not fall into any cluster because of the reason that they are not within the transmission range of any of the cluster heads.

3.3 Envoy Node Identification

A node s_j in S is either a cluster member or a CH or a left over node. If s_j joins one of the clusters then it must belong to the set $CL_0, CL_1 ...$ U CL_m it's data is represented by the cluster head ch_i and ch_i belongs to cluster head set CLH.

The edge or corner SNs which have not joined any of clusters form a set of left over nodes L are identified as per the equation given below:

$$L = S - \{CLH \ U \ \{CL_0 \ U \ CL_1... \ CL_m\}\} \tag{4}$$

In addition to the cluster heads, set of envoy nodes SEN must also include the leftover nodes for ME's tour in order to ensure all nodes are visited.

$$SEN = CLH \ U \ L \tag{5}$$

ME can collect data from cluster members of CL_i by visiting it's cluster head ch_i i.e. ME covers all nodes in L_i by visiting ch_i. This altogether diminishes the quantity of ENs to be visited by the ME prompting significant reduction in the TL.

An optimised path for ME's tour covering all ENs in SEN is determined by using the best known TSP solver Lin-Kernighan [14].

Algorithm 1 Envey Node Identification - ENI

    Input:
1:    • Deployment Area WSN = s* s

      • Set of sensor nodes S= { s_0, s_1, ..., s_n, } where s_i represents (x_i, y_i) the coordinate of sensor

      • Set of cluster heads CHS $\leftarrow$ { ch_0, ch_1, ..., ch_m }

      • Transmission range T_r

    Output:
2:    • CLH - Set of Cluster heads

      • SEN - Set of Envoy Nodes

    Start:
3: $(C, R) \leftarrow Welzl(n, SNS)$ $\triangleright$ Determine Center C and radius R of Welzls circle
4: $CLH \leftarrow \{\phi\}$
5: Partition WSN Area into square grids G_i of side 2 * T_r with C as the Centre to the extent possible
6: Determine the grid center of each grid in GP where GP $\leftarrow \{G_0, G_1, ..., G_m\}$
7:
8: **for** $i = 0$ to m **do** $\triangleright$ where m i the number of grids
9:     Identify s_j closest to each G_i in Welzls circle
10:     $CLH \leftarrow CLH \cup s_j$
11: **end for**
12: $S' \leftarrow CLH \cup s_j$
13: **for** $j = 0$ to n **do**
14:     $CL_i \leftarrow \{\phi\}$
15:     **for** $i = 0$ to n **do**
16:         **if** $dist(s_i, ch_j) \leq T_r$ **then**
17:             $CL_j \leftarrow CL_j \cup s_i$
18:         **end if** *End if*
19:     **end for**
20:     $S' \leftarrow S' - CL_j$
21: **end for**
22: *End for*
23: $L \leftarrow CLH \cup S'$
24: SEN $\leftarrow L_i n$ - Kernighan(L)

Theorem 1. *Set of Envoy Nodes SEN=en_0,en_1, ..., en_k covers all nodes deployed in the network.*

Proof: Let S be a set of all nodes in the network.

Suppose s_j be a node in the network i.e $s_j \in$ S

Case i: s_j is a cluster head. Since s_j is a CH it will included in CLH, from (5) SEN covers all CHs, it implies s_j is covered by SEN.

Case ii: s_j is a member of cluster cl_i in the network. Since $s_j \in cl_i$, it is represented by its cluster head ch_i, and from (6) all cluster heads are covered by SEN, it implies that node s_j is covered by SEN.

Case iii: s_j is a left over node in the network. Since s_j is a left over node it must belong to L, from (5)SEN covers all nodes in L, it implies node s_j is covered by SEN. Let s_j does not belong to S. If $s_j \notin$ S it implies it does not belong to the network. Hence it need not be covered by SEN. From above it can be concluded that SEN covers all nodes in the network.   □

4   Halting location based path optimization

To further shorten the ME's path, Halting Locations are identified wherever possible, for each Envoy Nodes in SEN. The HLI optimizes the path determined by ENI by employing the HLIT technique introduced in this paper. TL of ME can be minimized by locating HLs along the tour given by TSP solver. Few ENs may have common intersection area or region, then ME can collect data by identifying a HL in the overlapping region.

Set of Halting Locations SHL= hl_0,hl_1..hl_k along ME's tour that covers all Envoy Nodes in SEN are established by HLI using HLIT technique. Each hl_i covers one or more Envoy Nodes in SEN. For identifying the HLs, we developed HL Identification Technique (HLIT), it identifies an optimal HLs to substitute some of the ENs along ME's path.

HLIT exploits the fact that the ENs can transmit their information to ME even if they are at a distance Tr from the ME. HLIT enables ME to collect the data of EN form a distance of T_r from the EN where T_r is transmission range of EN .HLIT identifies optimal HLs covering all ENs.

$$\sum_{j=1}^{j=k} |hl_j| = \sum_{i=1}^{i=m} |en_i| = |S| \tag{6}$$

$|hl_j|$ denotes number of SNs covered by Halting Location hl_j.

$|en_i|$ denotes number of SNs covered by en_i

$|S|$ denotes total number of SNs.

m and k represents total number of ENs and HLs respectively.

Fig.1. is an illustrative example of our approach. Our objective is to achieve (6) with optimal values of k and m for obtaining optimal TL of ME. Contingent upon the separations between the ENs, HLIT decides HL dependent on three criteria depicted underneath:

Criterion 1: Overlapped Unit disc regions of Envoy Nodes.

Let us consider a scenario where the node deployment and ME's tour is as shown in Fig.1.(a).In Fig.1.(b) it can be observed that distance between EN_1 , EN_2 is $< 2*T_r$ i.e. there is an overlap region between EN_1 and EN_2 , any location within the overlap region will be at a distance less than T_r from both the ENs, hence ME can collect data from both ENs by visiting any location within the overlap region.
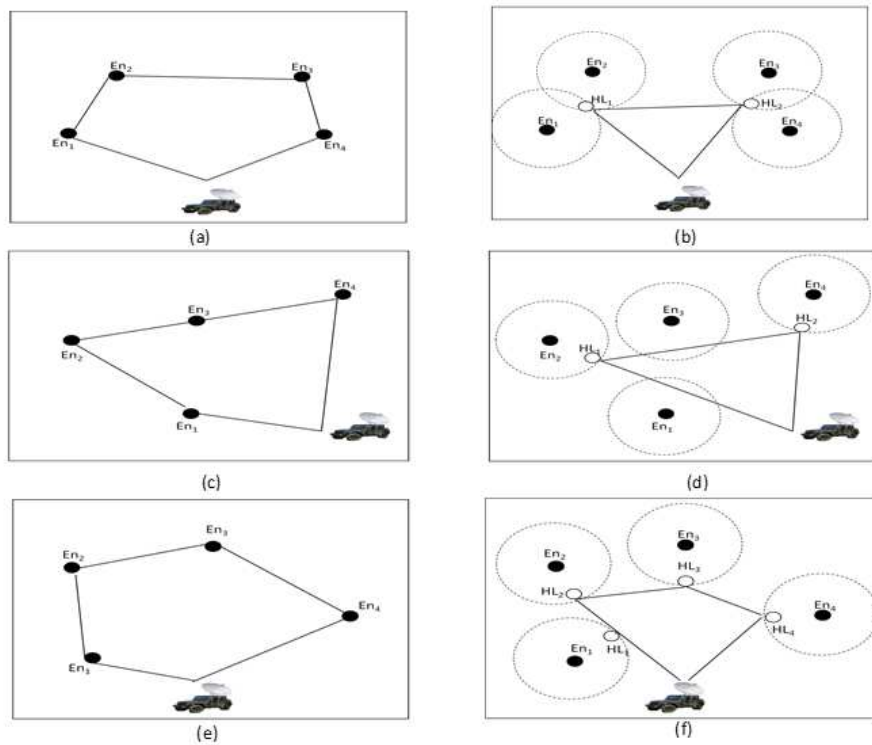
Figure 1: Illustrative example of Halting Location Identification Technique.(a),(c),(e) Actual tour of ME (b) HLIT based OP for Criterion 1. (d) Optimized HLIT based OP for Criterion 2. (f) HLIT based OP for Criterion 3
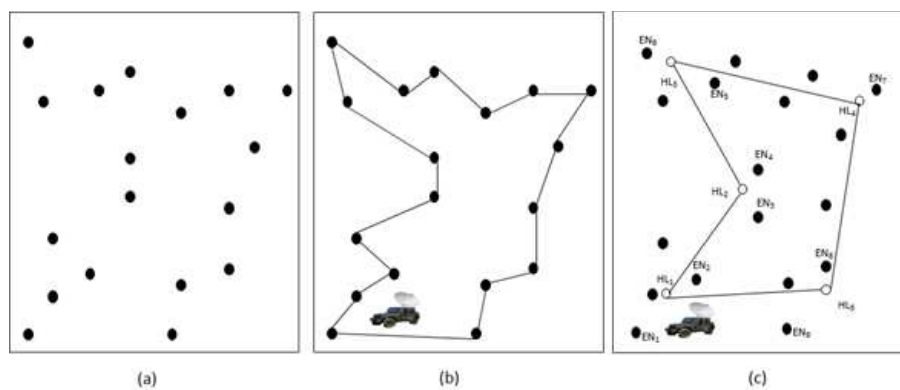

Figure 2: (a) Node Deployment (b) Tour given by TSP solver (c) Tour identified by HLI

HLIT determines a HL in the overlapping region of EN_1 and EN_2 , such that the distances from HL and either of two points is $\leq T_r$.

HLIT modifies SHL as per the equation given below:

$$SHL = SEN - \{en_{i+2}, en_{i+1}\} \cup \{hl_{i+1} \; if \; \ni \; en_{i+1}\} | dist(en_{i+2}, en_{i+1}) \leq 2 * T_r \qquad (7)$$

Halting Location hl_{i+1} in (7) is a location in the common intersection area nearest to ME's path from which ME will be able to receive data from both en_{i+1}, en_{i+2}. The ENs en_{i+1}, en_{i+2} are replaced by hl_{i+1} in SHL Since ME covers both en_{i+1}, en_{i+2} by visiting hl_{i+1}.

Criterion 2: en_{i+1} is at a distance $\leq T_r$ from the path en_i to en_{i+2}

Let us consider other node deployment scenario as shown in fig 1.(b). While ME is moving from its starting point to EN_2, the path is intersecting with the unit disc region of EN_1, that means distance from EN_1 to ME in the intersecting region is $\leq T_r$, hence ME can collect data form that EN while it is moving.

$$SHL = SEN - \{en_{i+1}\} if \exists \{en_{i+1} \; | pre\_dist(en_i, en_{i+1}, en_{i+2}) \leq T_r \qquad (8)$$

In fig.1(d) EN_1 is at a distance $\leq T_r$ from the path defined from starting point to EN_2, hence so ME can receive data from EN_1 when it is moving along the path from starting point to EN_2.

In this case neither ME has to visit the exact location of EN_1 nor there is a need of identifying HL for EN_1 since ME can collect the data while it is moving, hence HLIT modifies HLI based on this criterion as per (8).

Criterion 3: en_{i+1} is at a distance $> T_r$ from the path en_i to en_{i+2}

Let us assume the node deployment scenario as per Fig.1.(e).

In this case ENs neither have overlap region nor it is covered by ME's path as discussed in Criterion 2, then a HL within the unit disc region of EN has to be identified for covering each EN.

Following equation determines HL for this scenario:

$$SHL = SEN - en_{i+1} \cup hl_{i+1} \quad if \quad \exists \quad en_{i+1} | per\_dist(en_1, en_{i+1}, en_{i+2}) > T_r \qquad (9)$$

Perpendicular distance is the minimum distance from a point to the line, inspired by this as per (9) perpendicular distance from en_{i+1} to the path from en_i to en_{i+2} will be calculated, if it is more than the transmission range then HLIT determines an HL hl_{i+1} at a distance T_r from en_{i+1} along the direction perpendicular to path from en_i to en_{i+2} . Fig.1(f) is an illustrative example of this approach.

While ME is moving from its starting point, perpendicular distance from EN_1 to the path from starting point to EN_2 is more than the transmission range, hence HLI based on HLIT identifies a halting location HL_1 as shown in fig.1(e), fig.2 shows the impact of our approach on TL, for the node deployment given in fig.2(a) ME's tour is identified by a TSP solver, fig.2(b) represents ME's tour.

Finally, after applying HLI the tour of ME will be as shown in fig.2(c). Algorithm 3 represents HLIT based HLI algorithm to identify HLs.

Lemma 2. *If unit disc regions of each Envoy Nodes in SEN={en_i,en_{i+1}..en_l} with transmission range T_r have common intersection area then Halting Location hl_p located in the intersection area covers all the Envoy Nodes in SEN.*

Algorithm 2 Envey Node Identification - ENI

    Input:
1:    • Set of Envoy Nodes SEN = { en_1, en_2, ..., en_n }

        • Transmission range T_r

    Output:
2:    • Set of Halting Locations

    Start:
3: q=0
4: **for** $i = 0$ to $n - 2$ **do**
5:      k ← i+1
6:      **if** en_i and en_{i+1} have common intersection area **then**
7:         **while** envoy nodes en_i, ..., en_k have common intersection are **do**
8:            k ← k+1
9:         **end while**
10:        Find envoy nodes hl_q within the common intersection area of { en_i, ..., en_{k-1} } which is nearer to path from en_i to en_k
11:        SEN ← SEN- $\{en_i, ..., en_k - 1\} \cup hl_q$
12:      **else if** t **then**he path from en_i to $en_k + 1$ covers en_k
13:         **while** the path from en_i to en_{k+1} covers set of Envoy Nodes { $en_i + 1$, ..., en_k } **do**
14:            k ← k+1
15:         **end while**
16:        SEN ← SEN - { $en_i + 1$, ..., $en_k - 1$ }
17:      **else**
18:        hl_q ← point-to-point $en_i + 1$, $en_i + 2$, ..., T_r
19:        SEN ← SEN - $en_{i+1} \cup hl_{i+1}$
20:      **end if**
21:      q ← q+1
22: **end for**
23: SHL ← Lin - Kernighan(SEN)

Algorithm 3 Point_at_dist (P_1, P_2, T_r)

    Input:
1:    • Two points P_1 and P_2 | P_i ← (x_i, y_i)

        • Transmission range T_r

    Output:
2:    • Point P ar a distance T_r from P_1 along the line (P_1, P_2)

    Start:
3: d= dist (P_1, P_2)
4: x = x_1 + (x_2 - x_1) * (T_r / d)
5: y = y_1 + (y_2 - y_1) * (T_r /d)
6: P= (x,y)

Proof: Since hl_p is in common intersection area, distance from hl_p to any Envoy Nodes in SEN is less than or equal to T_r. Therefore hl_p covers all the ENs in SEN and hence Envoy Nodes in SEN can be replaced by $hl_p in$ SEN.

$\square$

Lemma 3. *The path from en_i to en_{i+2} covers Envoy Nodes en_{i+1} if the distance from Envoy Nodes to the path is less than or equal to transmission range T_r.*

Proof: From (7) if distance from a Envoy Nodes en_{i+1} to the path from en_i to en_{i+2} is less than or equal to T_r mobile element can collect data from the en_{i+1} in its journey. Therefore path from en_i to en_{i+2} covers en_{i+1} and hence en_{i+1} can be eliminated from SEN.

$\square$

Lemma 4. *Envoy Node en_{i+1} is covered by Halting Location hl_p if it is neither having common intersection area with any other Envoy Nodes nor it is covered by the path from en_i to en_{i+2}*

Proof: From (10) HLI establishes a Halting Location hl_p at a distance of T_r from en_{i+1} in a direction perpendicular to the path from en_i to en_{i+2} if en_{i+1} is neither having common intersection area with any other Envoy Nodes nor it is covered by the path from en_i to en_{i+2}. Distance from hl_p to en_{i+1} is equal to T_r. Therefore hl_p covers en_{i+1}. $\square$

Theorem 5. *Set of Halting Locations SHL={ $hl_0,hl_1..hl_m$ } covers all the nodes in S={$s_0,\ s_1,\ ...,\ s_n$ } deployed across the network.*

Proof: Let us assume that en_i be a Envoy Node in SEN.
Case i: Unit disc region of en_i with transmission range T_r as radius has common intersection area with a set of Envoy Nodes SEN.
From Lemma 2 Halting Location hl_p established by HLI covers all ENs in SEN. It implies SEN covers en_i.
Case ii: Distance from en_i to a point on the path from en_{i-1} to en_{i+1} is less than T_r.
From Lemma 3 path from en_{i-1} to en_{i+1} covers en_i. It implies SEN covers en_i.
Case iii: en_i is any EN in SEN, other than the one stated in case i and case ii.
From Lemma 4 HLI establishes a Halting Location hl_p within transmission range of en_i. It implies SEN covers en_i. In case i, ii and iii it has proven that SHL covers all ENs in SEN and from theorem 1 SEN covers all nodes in S, hence it can be concluded that SHL covers all nodes in S. $\square$

Lemma 6. *Number of elements in SHL is less than or equal to the number elements in SEN.*

Proof: Let m be the total number of Envoy Nodes in SEN.
Let SEN represents a set of Envoy Nodes having common intersection area and k be the total number of Envoy Nodes in SEN.
From Lemma 2 Halting Location hl_p established by HLI covers all ENs in SEN, so ENs in SEN can be replaced by in SHL, total number of elements in SEN are $m - k$. If $k = 0$ total number of elements in SHL are m.
Therefore it can be concluded that, number of elements in SHL is less than or equal to the number elements in SEN.

$\square$

Theorem 7. *TL of SHL is less than the TL of SEN.*

Proof: Let us assume t be the TL to cover all the ENs in SEN.

Case i: Let us assume that few of ENs in SEN have common intersection area.

From Lemma 2 Halting Locations in SHL established by HLI covers all ENs in SEN. Let us assume t_1 be the TL to cover all the HLs in SHL. Number of HLs in SHL is lesser than the number of ENs, hence $t_1 < t$. It implies TL of SHL is less than tour length of SEN. Reduced TL contributes to minimize the travel time of ME.

Case ii: Let k number of ENs are not having common intersection area with any of the ENs in SEN. From Lemma 4 HLI establishes Halting Location hl_p at a distance equal to T_r, the resultant TL will be less than or equal to t-k $* T_r$, it implies TL of SHL is less than the TL of SEN. □

5   Simulations and performance analysis

Simulations are carried out to examine the efficiency of proposed algorithms in terms of identifying ENs, minimizing TL and travel time of ME, minimizing latency and energy consumption by varying number of nodes, transmission ranges . This section details about the simulation model and analysis on efficiency of proposed approach.

5.1   Simulation model

WSN deployment area of size 500x500 m^2 have considered for implementing and evaluating the performance of the proposed algorithms ENI and HLI.

Homogeneous WSN environment is adopted, where all SNs nodes are equipped with equal transmission range. In order to evaluate the performance of ENI and HLI for higher node density, number of SNs in deployment region varied from 1000 to 5000. Identification of ENs and HLs have been carried out by ENI and HLI respectively.

It is assumed that ME requires halting time H_T to collect data from ENs. In the simulations value of H_T is considered as 2 sec. For calculating the energy consumption in the network values of two terms E_{elec} and $\varepsilon_a mp$ are taken as 50nJ /bit and 100pJ/ bit/ m^2, where E_{elec} is energy spent for running the electric circuitry, and ε_{amp} is energy spent for amplification [13], E_{Tx}, E_{rx} represents transmission and receiving energies respectively.

TSP solver Lin-Kernighan algorithm is employed for defining ME's optimal tour to cover given set of ENs or HLs. It is assumed that ME moves with a uniform velocity of 10m/sec. Results represented in each graph is mean of 50 simulations

Table 1: Simulation parameters

Parameter	Value
Field size	500x500 m^2
Node deployment	1000- 5000
Transmission range Tr	20m, 30m, 40m
Speed of ME	10 m/sec
Halting time HT	2 sec
Eelec	50 nJ/bits
εamp	100 pJ/bit/m2

5.2 Optimizing halting locations

In order to test the performance of ENI in terms of number of locations to be visited by ME, a new term Ratio of Halting Locations to the Total number of Nodes deployed (RHLTN) is introduced. RHLTN is calculated as follows:

$$RHLTN = 100 * \frac{Number of Halting Locations}{Total Number of Nodes Deployed} \qquad (10)$$

Value of RHLTN is inversely proportional to the efficiency of an algorithm, low value of RHLTN indicates that ME can collect the data of all SNs by visiting very few locations, it means algorithm efficiency is high. We have calculated the RHLTN value of HLI and CSS for different transmission ranges (20, 30 and 40) and total number of nodes varying from 1000 to 5000. The graph is plotted by taking number of nodes on X-axis and RHLTN value on Y-axis. In graphs HLI_20, HLI_30 and HLI_40 indicates the RHLTN values of HLI for transmission ranges 20, 30 and 40 respectively. From the fig.3 it can be predicted that, irrespective of transmission ranges HLI outperforms CSS. When total number of nodes is 5000, RHLTN value of HLI is 20. It means ME needs to visit only 20 percent of the nodes in order to complete its tour for collecting the data, whereas for CSS it has to visit 45-50 percent. This phenomenon will have adverse effect on Travel time of ME and energy consumption in the network.
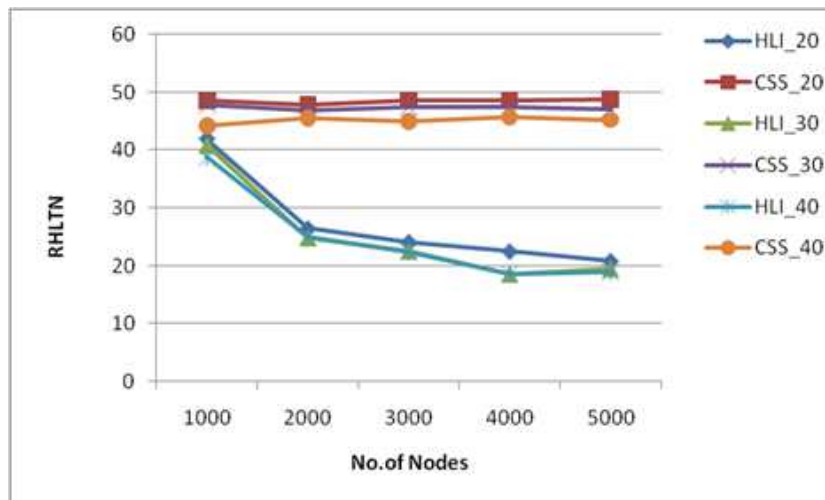

Figure 3: Ratio of halting locations to the total number of nodes

Minimizing travel time

TL refers to the total distance that has to be covered by ME for visiting a set of EN or HLs.Increase in number of ENs result in increased TL of ME. The TL has an immediate impact on the latency engaged with overhauling a query or a demand from a given SN. In order to obtain the OP covering set of ENs identified by ENI a TSP solver Lin-Kernighan algorithm [14] is employed. After obtaining the order of nodes to be visited, HLI establishes HLs using HLIT technique for minimizing the TL. A HL represents one or more ENs. Travel time of ME depends on number of ENs to be visited, speed of it and time taken for transferring data (halting time of ME) from EN to ME .

Assuming $d_{i,i+1}$ is the distance between Halting Locations HL_i and HL_{i+1} ; $v_{i,i+1}$ is the speed of ME while moving from HL_i to HL_{i+1}; and HT_i is the halting time of ME at HL_i, the

amount of time T required by ME to collect data from all Envoy Nodes is calculated as follows:

$$T = \sum_{i=1}^{n} \frac{d_{i,i+1}}{v_{i,i+1}} + HT_i \qquad (11)$$

If ME is moving with uniform speed v with a constant halting time HT then (11) becomes

$$T = \frac{\sum_{i=1}^{n} d_{i,i+1}}{v} + n * HT \qquad (12)$$

In our simulations total travelling time of ME is calculated as per (12). It is assumed that ME is moving with a constant speed of 10 m/sec and halting time at each EN is 2 sec. As ME's speed and halting time are fixed travelling time depends on number of HLs to be visited. Graphs are plotted between total number of nodes deployed and travelling time as shown in the fig.4, in order to study the efficiency of HLI in terms of travelling time of ME. With the help of simulations it is proven that criterions considered in HLIT resulted in reduced travel time of ME.

From the graph it can be concluded that latency of the network can be reduced considerably with HLI. Travelling time of ME is very low for different transmission ranges. Simulation results prove that HLI is more suitable for applications in which data is time critical i.e. data has to reach the base station with in the stipulated time interval otherwise the data becomes obsolete. It can be concluded that HLIT technique adopted for identifying HLs in HLI has shown its impact in reducing the travel time of ME considerably irrespective of transmission ranges and number of nodes deployed. ENI and HLI offer better QOS compared to COM and CSS in terms of travel time and energy consumption.
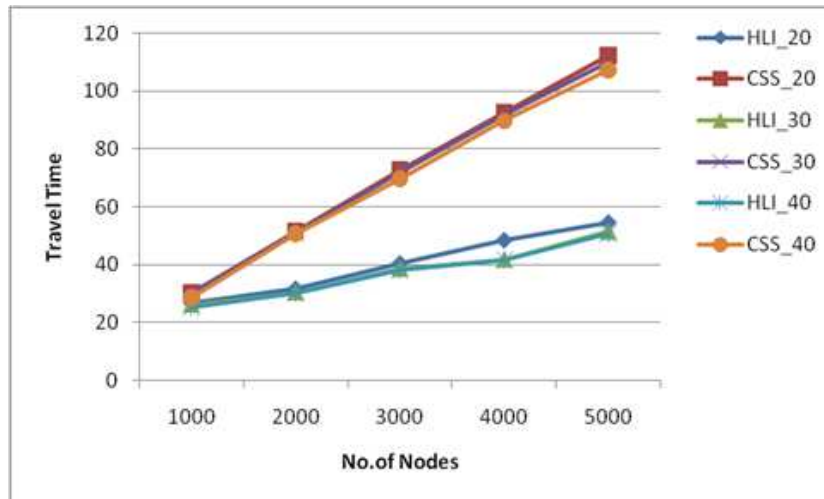

Figure 4: Travel Time .

5.3   Minimizing energy consumption

Every SN is equipped with finite amount of energy, this energy will be utilized for monitoring the targeted area, transmission and receiving of messages etc. For calculating energy consumption in the network the following equation is borrowed from [28].

$$E_{Tx} = E_{elec} * k + \varepsilon_{amp} * k * d^2 \qquad (13)$$

$$E_{Rx} = E_{elec} * k \tag{14}$$

$$E_{Total} = E_{Tx} + E_{Rx} \tag{15}$$

Where (13) gives the energy consumption occurred E_{Tx} for transmitting k number of bits over a distance d. Energy consumption for receiving k number of bits E_{Rx} is given by (14). Total energy consumption E_{Total} is given by (15). In the literature it is observed that energy spent to hold the data, till the data is transferred to ME is not taken into consideration. We have tried to identify the energy consumption at each ENs for transferring the data to ME. It is assumed that Amount of time taken by ME to reach halting location i from halting location 1 is Holding time T_{iHold} is the amount of time the Envoy Nodes i has to hold the data.

From (11) T_{iHold} can be calculated as follows:

$$T_{iHold} = \sum_{i=1}^{n} \frac{\sum_{i=1}^{n} d_{i,i+1}}{v} + i * HT \tag{16}$$

Here T_{iHold} is the time taken by ME to reach HL hl_i since from the starting point of it's tour, i represents the index of HL in SHL, $d_{j,j-1}$ is the distance from hl_j to $hl_{j-1}.v$ is the speed of ME. By taking holding time into consideration (13) is modified as follows:

$$E_i = 0.1 * E_{elec} * k * T_{iHold} + \epsilon_{amp} * k * d_i^2 \tag{17}$$

Total energy consumption in the network is calculated as follow:
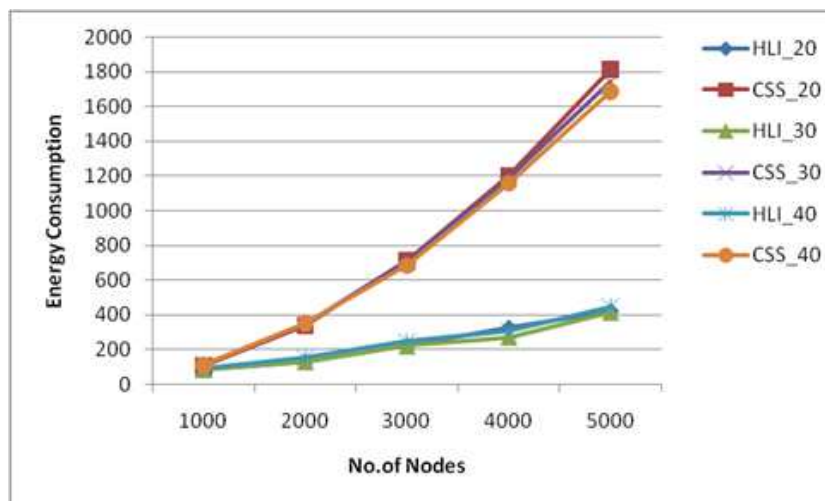
$$E_{Total} = \sum_{k=1}^{k=n} E_k \tag{18}$$

Figure 5: Ratio of Halting Locations to the Total number of Nodes.

Through the simulations we have tried to investigate the energy consumption of the network after applying HLI and compared it with CSS. In fig.5, initially there is not much difference whether it is HLI or CSS, but when total number of nodes is 5000, there is huge difference. We tried to diagnose the reason for this phenomenon, it is observed that travel time of ME is
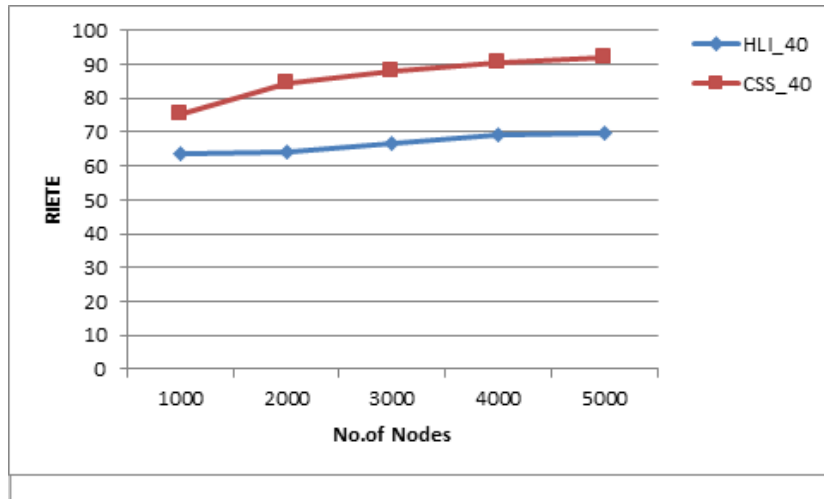
Figure 6: Ratio of Idle time Energy consumption to the Total Energy consumption .

influencing the energy consumption in the network, in order to substantiate this conclusion we have analyzed (17), in (17) all parameters are constants except T_{iHold} .

Hence energy consumption of a node E_{ik} α T_{ihold} . Increased travel time of ME results in high energy consumption in a node which shortens the network lifetime. In order to investigate the impact of waiting time on energy consumption of a node, we have introduced a term Ratio of Idle time Energy consumption to the Total Energy consumption (%):

$$RIETE = 100 * \frac{Idletime Energy consumption}{Total Energy consumption} \tag{19}$$

From the above equation RIETE α Idele time Energy it indicates that higher Idle time Energy consumption leads to the higher value of RIETE. The algorithm with lower RIETE value is more efficient.

Fig.6 indicates that more than the 60% of the energy spent by a node due to Idle time. From the graphs it is clear that T_{iHold} is the key factor influencing the energy consumption. Even for higher node densities energy consumption is low with HLI, the reason for this is T_{Hold} for HLI is low when compared to CSS.

6   Conclusion

ENI diminishes the TL of ME by limiting the ENs to be covered by ME. The TL so acquired by ENI is additionally abbreviated by deciding an ideal number of Halting Locations to supplant a portion of the ENs by utilizing the HLIT.

Simulations have demonstrated that ENI beats COM by a significant separation for all estimations of T_r and node density.

The HLI significantly decreases TL contrasted with best known algorithm, CSS. ENI, HLI offers desirable QOS in terms of latency and resource utilization.

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