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Single Inventory Cycled Data Population in LEACH-Cluster

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Abstract: Inside a cluster in LEACH based sensor network architecture, data from individual nodes are being populated by individual query or command governed by Cluster-head following TDMA slots. This conventional process can be further minimized with Cluster Energy consumption, Complexity and memory consumption aspects following the proposed architecture where a single inventory command populates all nodal data following the "*shortest close-loop energy path*" algorithm. The new protocol architecture has been simulated in MATLAB considering 3D domain with some basic consideration of localization and, simulation result with comparison study with some conventional topologies are presented in this paper.

Keywords: LEACH, Power Optimization, WSN, Sensor Node, Single Inventory Cycle, Complexity optimization, Memory Optimization, Optimized Shortest Energy/power Path, Optimized Shortest closed loop Energy/power Path

1. Introduction

LEACH (Low Energy Adaptive Clustering Hierarchy) is designed for sensor networks where an end-user wants to remotely monitor the environment. In such a situation, the data from the individual nodes must be sent to a central base station, often located far from the sensor network, through which the end-user can access the data.

Conventional network protocols, such as direct transmission, minimum transmission energy, multi-hop routing, and clustering all have drawbacks that don't allow them to achieve all the desirable properties. LEACH includes distributed cluster formation, local processing to reduce global communication, and randomized rotation of the cluster-heads. Together, these features allow LEACH to achieve the desired properties. Initial simulations show that LEACH is an energy-efficient protocol that extends system lifetime. The conventional algorithms are discussed in MECN [5] or SMECN [4]. In this paper, the simulation has been done in a defined three dimensional (3-D) area with randomly distributed nodes. Section 2 describes Conventional Energy optimization techniques which comprise Star topology with its power consumption and complexity, multi-hop Shortest Energy Path algorithm with its power consumption and complexity, Optimized multi-hop Shortest Energy algorithm with its power consumption and complexity. Section 3 describes proposed algorithm of Optimized Shortest Close Loop Energy Path with its power consumption and complexity. Section 4 does comparative study of all the architectures with respect to power consumption, power saving, complexity, memory, power consumption aspect. Section 5 provides conclusion and future scope.

2. Conventional Energy Optimization Techniques

2.1 Star Topology

The most conventional architecture in Wireless Sensor Network is the star topology where a peer to peer communication is being established between two nodes where the sink or cluster head or coordinator directly communicates to all other leaf nodes. It must be noticed that the power consumption in this architecture is not being optimized and hence, the total power consumption is relatively high to populate data from all the nodes.Fig.1 shows a typical network of five nodes where Node-1 is placed at (0, 0, 0) location and decided as cluster head. Following Star topology all the other nodes communicates with Node-1.

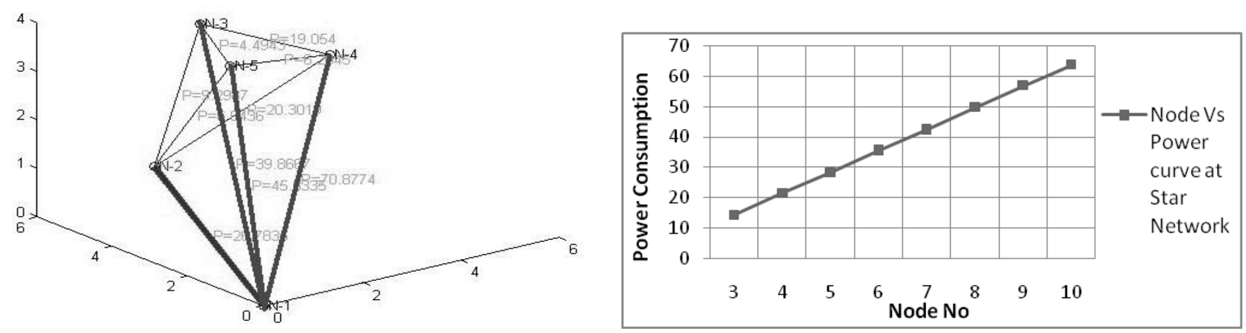


Figure 1. (a) Typical network of five nodes where Node-1 is place at (0, 0, 0) location and decided as cluster head. **(b)** Typical curve of "Node no vs. power consumption" in a network randomly distributed in an area of 1 to 2 units following star topology

If ith node is the cluster head, then total amount of power consumed by the network to populate all data in ith node will be Pi|star and it can be derived in following manner.

$$P_{i|star} = \sum_{j=1}^{n} P_{ij} + (n-1) \Big|_{i=1}^{n} \quad (1)$$

, where $P_{ij} = 0 \; \forall i = j$, all receiver power consumption $P_r = 1$

Fig.2 describes a typical curve of “Number of Nodes vs. power consumption” in a network randomly distributed in an area of 1 to 2 units following star topology.

It is also noticed that the minimum time complexity to populate all the data of a network of n nodes is

$$O(n-1) \quad (2)$$

2.2 Shortest Energy Path Multi –hop Topology

Shortest energy path topology which is also known as multi-hop topology [1, 2] has comparatively much higher efficiency than star topology. In this architecture the communication channel is being established through multi hop through in between nodes. The significant difference between “shortest path” and “shortest energy path” can be realized with following friis formula [EQ 3] and also COMPOW protocol [3].

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2 \quad (3)$$

Where Gt and Gr are the antenna gain of the transmitting and receiving antennas, respectively, λ is the wavelength, and R is the distance. By the equation (3) Pt can be termed as,

$$P_t = \frac{P_r}{G_t G_r} \left(\frac{4\pi R}{\lambda} \right)^2 \;\&\; \lambda = \frac{c}{f} \quad (4)$$

If Pr is assumed as unity and (Pr / (GtGr λ2)) = K then equation (4) becomes

$$P_t = K(R)^2 \quad (5)$$

Let us assume a typical small network as shown in Fig-3, where node-2 is placed at equal distance of R1from Node-1and Node-3.

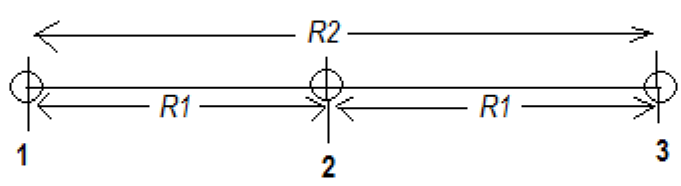


Figure 2. Typical small network where node-2 is placed at equal spaced of R1from Node-1and Node-3.

Say, Node-1 is the cluster head or sink which is intended to gather all the data from Node-2 and Node-3. To collect data from Node-3, Node-1 can directly communicate with Node-3 or it can communicate through Node-2. The two possible power consumptions are P13 or P12+P23. As per equation (5),

$$P_{13} = K\left(R_2\right)^2 = K\left(2R_1\right)^2 = 4K\left(R_1\right)^2 \qquad (6)$$

$$P_{12} + P_{23} = K\left(R_1\right)^2 + K\left(R_1\right)^2 = 2K\left(R_1\right)^2 \qquad (7)$$

From Equation (6) and equation (7), it is found,

$$P_{13} > P_{12} + P_{23} \qquad (8)$$

So, “shortest path” and “shortest energy path” may not be equal and also multi-hop has better power efficiency than single-hop communication. Following Fig.3, if star network is being followed, the total power consumption is Pstar =P12+P13, where, as per shortest energy path algorithm, total energy consumed by the system is PShortest Energy Path= P12+P123 where P123=P12+P23. And it is proved P123<P13, hence PShortest Energy Path< Pstar. Further study has been described where a series of randomly placed nodes has been simulated to estimate the power consumption in different topology.

Following the same random distribution as per Fig.1, if the Shortest Energy Path algorithm is being followed, the network communication architecture will be as per Fig.4.

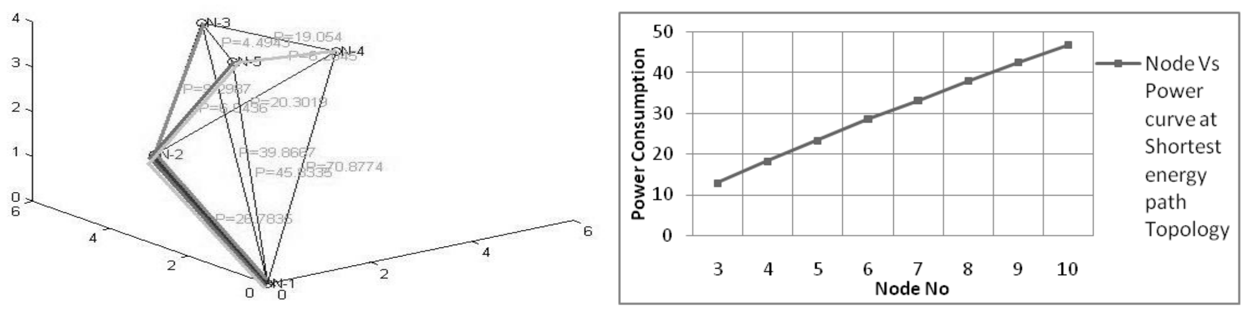


Figure 3. (a) Network communication architecture as per Shortest Energy Path algorithm. **(b)** “Node no vs. power consumption” following shortest path algorithm in a network randomly distributed in an area of 1 to 2 units.

For a wireless network of N no. of nodes, if ith node is the cluster head, then total amount of power consumed by the network to populate all data in ith node will be Pi|Shortest Path and it can be derived in following manner.

$$P_{i|\text{Shortest Energy Path}} = \sum_{j=1}^{n} \min[P_{ij}] + \left(n-1\right)^2 \Bigg|_{i=1}^{n} \qquad (9)$$

Where min[Pij] indicates the shortest energy path between Node-i and Node-j. And also min[Pij] < Pij. Fig.5 describes a typical curve of Node no. vs. power consumption” following shortest path algorithm in a network randomly distributed in an area of 1 to 2 units.

The shortest energy path algorithm has quite good power saving than conventional star-network and increases with no of nodes. The major issue in „shortest energy path’ algorithm is the complexity which is tremendously high and it has a minimum value of complexity,

$$O\left((n-1)\sum_{j=0}^{n-2}{}^{(n-2)}P_j\right) \tag{10}$$

2.3 Optimized Shortest Energy Path Multi – hop Topology

Optimized shortest energy path multi hop topology is the most sophisticated and advanced algorithm where the energy is further saved compared to conventional „shortest energy path' algorithm. The fundamental concept of this algorithm is avoidance of repeated path. For example, following the Fig.3, the sink or cluster head (Node-1) will follow single iteration from Node-1 to Node-3 through Node-2 and on that single iteration the path will collect all the data of nodes in the path. So, the power POptimisedShortestEnergyPath = P123 (=P12+P23) is enough to populate data of Node-2 and Node-3.It is to be noted, separate query is not needed to accumulate data of Node-2 which saves a power of P12 hence PShortestEnergyPath >POptimisedShortestEnergyPath.With the same random distribution of node position as per Fig.1 or Fig.4, if the communication is established by Optimized Shortest Energy Path algorithm, the network architecture will be as per Fig.6.

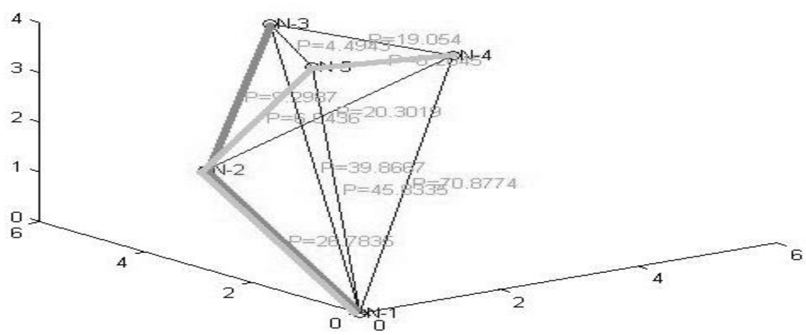


Figure 4. Network communication architecture as per Optimized Shortest Energy Path algorithm

$$P_{i|OptimizedShortestEnergyPath} = \sum_{j,k=1}^{n}\left(\min[P_{ij}]-\min[P_{ik}]\right)+\left(n-1\right)^2\Bigg|_{i=1}^{n} \tag{11}$$

The process complexity in the Optimized Shortest Energy Path algorithm increased from Shortest Energy Path algorithm and became:

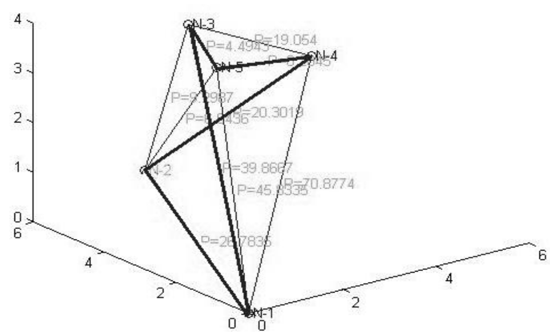
$$O\left(\left(n-1\right)\left(\sum_{j=0}^{n-2}{}^{(n-2)}P_j+\left(n-2\right)\right)\right) \tag{12}$$

However, the Optimized shortest energy path is more efficient than shortest energy path when data of entire nodes are being populated by cluster head, but if cluster head has interest to get data of a single node, the power consumptions are same in both the topology. And in practical implementation, the process complexity becomes so large that when node numbers are more than 10 or 11. It is almost impossible from CPU clock and memory aspect to find the optimum shortest path and vice versa the shortest energy path when the possible path combinations become around 98 lakhs.

3. Proposed Topology – Shortest Close Loop Energy Path

In the conventional architecture, the communication between source and destination are bidirectional that means, for a query based data population system which is more conventional, query propagates from source to destination (may be single or multi-hop) and the answer or reply comes back from destination to source and in this process, the total power consumption became just double as mentioned in equation (1), (9) and (11). However, in self-triggered TDMA based architecture, the data may propagate in a single direction and the total power consumption will be as per equations (1), (9) and (11). When the cluster head populates the data of entire nodes in the cluster assigning a query or a self-triggered node TDMA method, it has been realized that the Shortest Close Loop Energy Path may have the better energy efficiency than any other conventional topology. In the Shortest Close Loop Energy Path architecture, the cluster head tries to find the shortest path which covers entire numbers of nodes and the loop will be closed.

In case of Shortest Close Loop Energy Path algorithm, for same node distribution as per Fig.1, the network formation will be as per Fig.7. The path will be N1 ->N3 -> N5 -> N4 -> N2 ->N1 which is the calculated shortest close loop path.



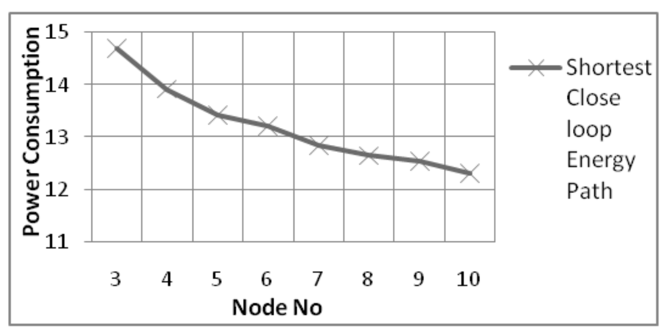


Figure 5. (a) Proposed network formation following Optimized Shortest Energy Path algorithm. **(b)** Node vs. Power consumption following shortest closed loop path algorithm in a network randomly distributed in an area of 1 to 2 units.

In the proposed Shortest Close Loop Energy Path architecture, the total power consumption in the system to collect all node data will be

$$P_{i|\text{Shortest close loop Energy Path}} = \min[P_{ii}] + n \qquad (13)$$

$$\text{, where } \text{PATH}\left(\min\left[P_{ii}\right]\right) = \{1,2,3,4,\ldots\ldots\ldots N\},\ P_r = 1$$

The simulation result of Shortest Close Loop Energy Path has been plotted in Fig.8where the nodes are randomly distributed in 1 to 2 unit area in three dimensional planes. The subsequent Figure also describes the variation of data for different area of distribution.

Another significant optimization can be observed in complexity which has reduced to a very low level. The process complexity of the Shortest Close Loop Energy Path algorithm becomes:

$$O((n-1)!) \tag{14}$$

The detail comparison study of process complexity is described in Section 5.

4. Comparative Study

4.1 Power Saving

It is to be noticed as per Fig.8, that the total network power consumption is decreasing with increase of number of nodes where as in other algorithm, the total power increases with increase in node numbers. The reason is very simple, with the increment of node number at a confined area, the network is becoming denser and as we know, at multi-hop process the total power consumption is less than single-hop. However, the negative slope becomes saturate at higher level which can be observed at Fig.8 and Fig.9. Fig.9 also describes the significant less power consumption with new proposed topology of Shortest Close Loop Energy Path than other conventional algorithms. In Fig.9, it is also observed that the energy consumption at Shortest Close Loop Energy Path algorithm is higher than Optimized Shortest Energy Path algorithm if node numbers are less than 5. It is also observed in Fig. 9 that if the area of random distribution of nodes is being increased, the crossing point of Shortest Close Loop Energy Path and Optimized Shortest Energy Path curve is increasing in "node no" axis that means if the area is increased, the proposed topology is more effective after a certain number of nodes. In Fig.10, the comparison of power saving has been plotted in reference of power consumption in Star connected Network and nodes are being randomly placed in 1 to 2 unit area.

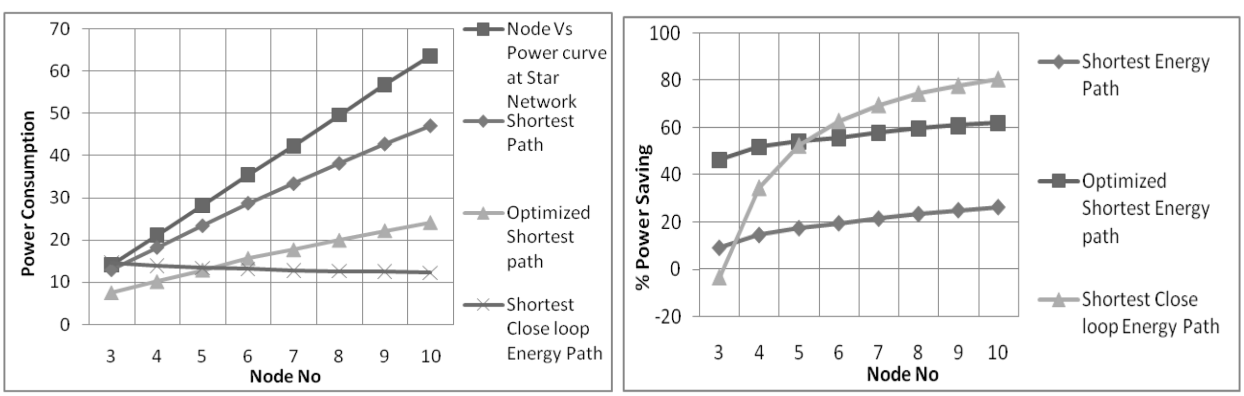


Figure 6. (a) Comparison results of Node vs Power consumption in different topology. **(b)** Comparison of power saving in reference of power consumption in Star connected Network. Nodes are being randomly placed in 1 to 2 unit area and data flow is unidirectional.

In the above study following Fig.10, the comparison has been done for unidirectional data flow i.e. sinks or co-coordinator or host will not send any query, but individual nodes will through their data on TDMA slots. And all the subsequent comparison has been done with this assumption except Fig 11 where the comparison has been done with bidirectional data flow i.e. the query based network and nodes are randomly distributed in the 1 to 2 unit area in three dimensional plane.

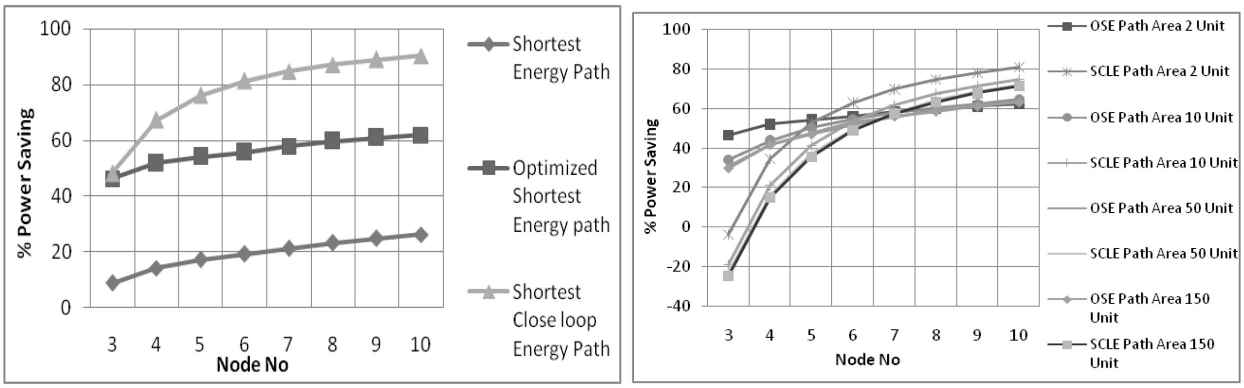


Figure 2. (a) Comparison of power saving in reference of power consumption in Star connected Network. Nodes are being randomly placed in 1 to 2 unit area and data flow is bidirectional. **(b)** Power Saving in Optimized Shortest Energy Path (OSE Path) and Shortest Close Loop Energy Path (SCLE Path) with varying distribution area and unidirectional communication.

Further study has been carried out to estimate the variation of power saving between Shortest Close Loop Energy Path (SCLE Path) algorithm and Optimized Shortest Energy Path (OSE Path) with unidirectional data flowandwith variation of random distribution area as per Fig.12.

Fig.12 clearly proves the statement “SCLE Path algorithm is more efficient than OSE Path algorithm after a certain higher numbers of nodes. It is found in the query based bidirectional communication system the efficiency of proposed algorithm is always high at any node numbers and area. The corresponding comparative chart follows Fig.13.The corresponding graph has been plotted in Fig.14 to estimate the efficiency of the proposed algorithm with variation of random distribution area.

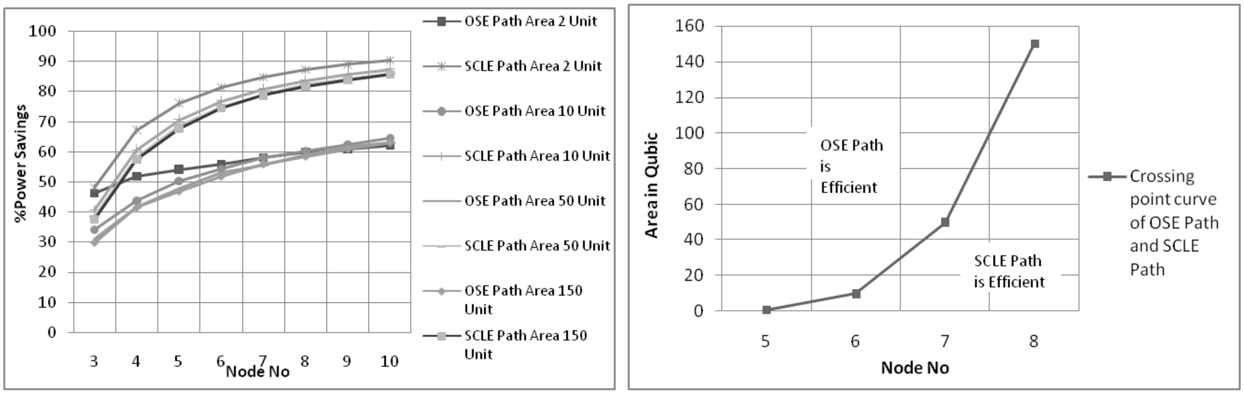


Figure 8. (a) 3 Power Saving in Optimized Shortest Energy Path (OSE Path) and Shortest Close Loop Energy Path (SCLE Path) with varying distribution area and bidirectional communication. **(b)** Algorithm selection curve for higher power saving efficiency for unidirectional data flow.

In the Fig.14, the curve has been plotted with crossing point values of SCLE Path and OSE Path at different area distribution from Fig. 12. The left side of the curve indicating the conventional OSE Path algorithm is better, and right side of the curve indicating the proposed SCLE Path algorithm is more efficient from energy saving aspect.

4.2 Complexity

The process complexity for different algorithm is as mentioned in Eq-10, 12, 14 are being plotted in Log scale in Fig.15

The comparative value of process complexity (Eq 14) in Shortest Close Loop Energy Path algorithm is much efficient than complexity (Eq 10) of Shortest Energy Path or complexity (Eq 12) of Optimized Shortest Energy Path, as a matter, it saves a significant amount of time complexity in CPU processing for analyze the routing algorithm. Although the theoretical complexity of conventional Optimized Shortest Energy Path algorithm is

$$O\left(\left(n-1\right)\left(\sum_{j=0}^{n-2} {}^{(n-2)}P_j + n - 2\right)\right) \tag{15}$$

But the practical implementation involves too many overheads which limits the computational software such as MATLAB to a certain no. of nodes and hence the simulation was only possible up to 10 no. of Nodes for Shortest Energy Path or Optimized Shortest Energy Path. The same simulation is expected to be solved in MATMETICA with high memory computational power. And also runtime optimization is required to free internal buffer of computational tool to achieve a fast result.

4.3 Memory

The memory consumption in different optimizations algorithm can be formulated as below:

Memory consumption in Shortest Energy Path algorithm:

$$\mathbf{O}\left((\mathbf{n}-1)(\mathbf{n}-2)\sum_{j=0}^{\mathbf{n}-2}\left({}^{(n-2)}P_j * (\mathbf{j}+2) \right) \right) \qquad (16)$$

Memory consumption in Optimized Shortest Energy Path algorithm:

$$\mathbf{O}\left(\mathbf{n} + \left((\mathbf{n}-1)(\mathbf{n}-1)\sum_{j=0}^{\mathbf{n}-2}\left({}^{(n-2)}\mathbf{P}_\mathbf{j} * (\mathbf{j}+2) \right) \right) \right) \qquad (17)$$

Memory consumption in Shortest Close Loop Energy Path algorithm:

$$\mathbf{O}\left((\mathbf{n}-1)!(\mathbf{n}+1) \right) \qquad (18)$$

The comparative result follows Fig.16 which shows the proposed algorithm consumes less memory if node no. is more than 3 which is almost obvious.

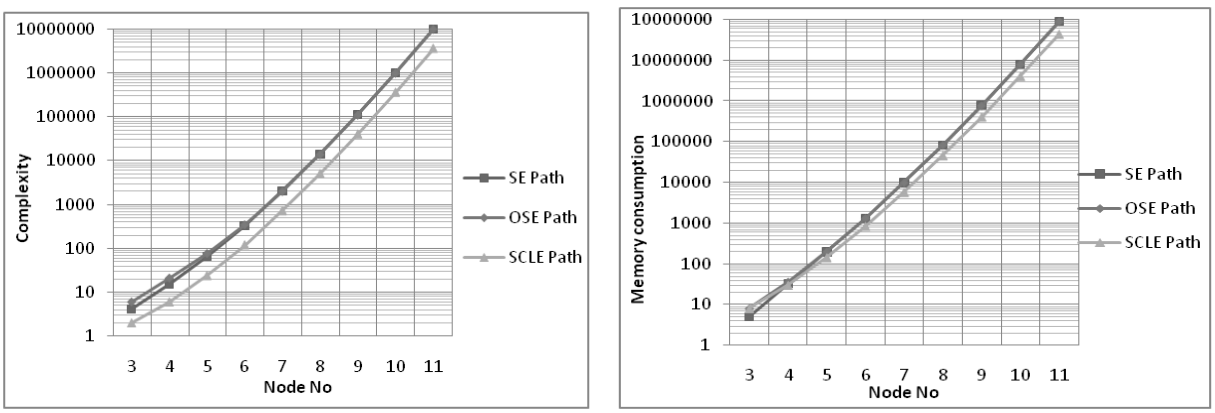


Figure 9. (a) Complexity curve for Shortest Energy Path (SE Path), Optimized Shortest Energy Path (OSE Path) and Shortest Closed Loop Energy Path (SCLE path) algorithm with variation of nodes. **(b)** Node No vs. Memory consumption in Shortest Energy Path (SE Path), Optimized Shortest Energy Path (OSE Path), Shortest Close Loop Energy Path (SCLE Path) algorithm.

5. Conclusions

A comparison has been made between Shortest Energy Path (SE), Optimised Shortest Energy Path (OSE) and the proposed one i.e. Shortest Closed Loop Energy Path (SCLE). After study it is found that SCLE Path algorithm is better in Energy Saving, Process Complexity & Memory Consumption aspects. The proposed algorithm can be studied further to implement in between cluster heads rather than a cluster. It will minimize the total power consumption and will provide better distribution of power thorough out the entire nodes to keep the total network active for a longer time period. It can be implemented in Cluster Head selection in LEACH to increase lifetime of network and equal power distribution among the nodes.

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