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Effect of Increasing Node Population on the Performance of Cluster Based Energy-Efficient Routing Protocols in Wireless Sensor Network

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ABSTRACT

A wireless sensor network (WSN) is a network consisting of miniaturized smart sensors communicating the information gathered or collected from a monitored environment via a wireless link. The sensors are capable of sensing the events within their environment, process the data, and transmit the data to the base station (BS). The entire processing of data and subsequent transmission to BS requires high energy consumption. The operation of WSN is limited by repeated dead nodes, which results in energy depletion. Hence, to prolong the life-span of the network, several routing protocols have been developed. However, the effectiveness of these protocols has not been well examined in terms of increasing node population for a given WSN field or area. Therefore, in this work the effect of increasing node density on cluster based energy-efficient routing protocols in wireless sensor network was analysed. The implemented routing protocols were Low Energy Adaptive Clustering Hierarchy LEACH, stable election protocol (SEP), and zone-SEP (Z-SEP). The dimension of the WSN was 100 × 100 square metre area with varying number of sensor nodes: 50, 60, 70, 80, 90, and 100. The results of the simulation conducted in MATLAB revealed that increasing node density resulted in increased alive node and throughput (measures in terms of transmitted number of packets). On the contrary, the protocol with the best performance was ZSEP.

Keywords - **LEACH, Node population, SEP, ZSEP, WSN**

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I. INTRODUCTION

In the study of WSN, different routing algorithms have been proposed to minimize the energy consumed so as to extend the lifespan of the network. The routing techniques used for this purpose can be categorized into three broad energy efficient protocols namely hierarchical or clustering based protocols, data centric protocols, and location based or geographical protocols. Three famous techniques have emerged from these three categories. Data centric routing techniques uses a model that is query driven to reduce the amount of transmitted data and are also capable of collecting data while conveying it to the sink. Directed Diffusion and Adaptive Protocols for Information Dissemination in WSNs (Sensor Protocol for Information via Negotiation known as SPIN) are the dominant data centric protocols [1]. Low Energy Adaptive Clustering Hierarchy (LEACH) is best among the hierarchical or clustering based protocols. These three techniques have become common performance baselines, with most of energy efficient routing study focused on improving their performance.

In the deployment of WSN, selecting the best routing protocols to optimize energy consumption of sensor nodes in the network is a critical issue because of the available limited resources. Several factors must be taken into consideration for packets to be successfully delivered from source node to destination node [2]. Thus in routing protocols and algorithms design, there are exceptional factors that need to be considered and one of these is scalability. Despite the fact that routing algorithms have been famously implemented in many studies regarding WSN, the effect of increasing number of nodes for a given network field or area where this routing protocol is implemented has not been given adequate attention. Therefore, this paper will examine the effectiveness of different routing protocols including LEACH, stable election protocol (SEP), and zone-SEP (Z-SEP) in the performance of WSN in terms scalability.

II. NETWORK AND ENERGY CONSUMPTION MODEL

With respect to radio energy dissipation model shown in Figure 1, energy consumption in transmitting k-bit message over a distance d in a WSN can be mathematically defined as follows.

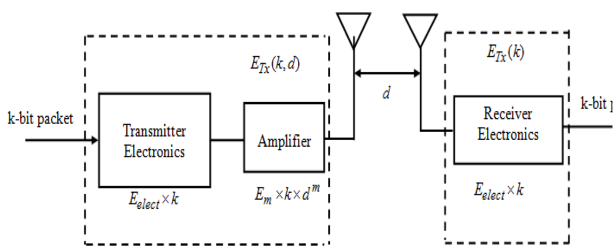

Figure 1 Radio energy consumption model of WSN

The energy dissipated by sensor is given by Smaragdakis et al. [3]:

$$E_{Tx}(k,d) = \begin{cases} k.E_{elec} + k.\in f_s.d^2 & \text{if } d \le d_0 \\ k.E_{elec} + k.\in_{mp}.d^4 & \text{if } d > d_0 \end{cases} \quad (1)$$

where E_{elec} is the energy consumed per bit to run the transmitter or receiver circuit, $\in f_s$ and $\in_{mp}$ depend on transmitter amplifier model, d is the distance between transmitter and receiver. Equating d = d_0 gives:

$$d_0 = \sqrt{\frac{\in f_s}{\in_{mp}}} \quad (2)$$

The energy expended to receive k-bit message by the sensor is given by:

$$E_{Rx} = k.E_{elect} \quad (3)$$

Assume an area $A = N \times N$ square metres over which n sensor nodes are uniformly distributed to form a WSN field. Now for simplicity purpose, the sink is assumed to be located at the centre of the field such that the distance of each node to its CH or the sink is $\le d_0$.

Therefore, the energy consumed in the CH node for each round is defined by Smaragdakis et al. [3]:

$$E_{CH} = \left(\frac{n}{l} - 1\right) k \times E_{elec} + \frac{n}{l} k \times E_{DA} + k \times E_{elec} + k \times \in f_s d_{BS}^2 \quad \text{..... (4)}$$

where l is the number of clusters, E_{DA} is the processing (data aggregation) cost of a bit per report to the sink, d_{BS} is the average distance between the CH and the sink. The energy dissipated in a non-CH node is given by Smaragdakis et al. [3]:

$$E_{nonCH} = k \times E_{elec} + k \times \in f_s \times d_{CH}^2 \quad (5)$$

where d_{CH} is the average distance between a cluster member (CM) and its CH. Assuming uniformly distributed nodes, the average distance between a cluster member (CM) and its CH is given by Smaragdakis et al. [3]:

$$d_{CH}^2 = \int_{x=0}^{x=x_{max}} \int_{y=0}^{y=y_{max}} (x^2 + y^2) p(x,y) dxdy = \frac{N^2}{2\pi\pi} \quad (6)$$

where $p(x,y)$ is the node distribution.

The energy dissipated in a cluster per round is defined by:

$$E_{cluster} \approx E_{CH} + \frac{n}{l} E_{nonCH} \quad (7)$$

The total energy dissipated in the network is given by:

$$E_{tot} = k\,(2nE_{elec} + nE_{DA} + \in f_s (l d_{BS}^2 + n d_{CH}^2)) \quad (8)$$

Differentiating E_{tot} with respect to l and equating to zero, the optimal number of constructed clusters can be determined by Smaragdakis et al. [3]:

$$l_{opt} = \sqrt{\frac{n}{2\pi}} \frac{N}{d_{BS}} = \sqrt{\frac{n}{2\pi}} \frac{2}{0.765} \quad (9)$$

Equation (10) is the average distance from a CH to the sink and is given by Smaragdakis et al. [3]:

$$d_{BS} = \int_A \sqrt{x^2 + y^2} \frac{1}{A} dA = 0.765 \frac{M}{2} \quad (10)$$

If the distance of a significant percentage of nodes to the sink is greater than d_0, then following the same analysis as in Smaragdakis et al. [3] gives:

$$l_{opt} = \sqrt{\frac{n}{2\pi}} \sqrt{\frac{\in f_s}{\in_{mp}}} \frac{N}{d_{BS}^2} \quad (11)$$

The optimal probability of a node to become a CH is computed as follows Smaragdakis et al. [3]:

$$p_{opt} = \frac{l_{opt}}{n} \quad (12)$$

III. WIRELESS SENSOR NETWORK PROTOCOL

The different routing protocols considered in this paper are presented in this section as follows.

3.1 LEACH PROTOCOL

The LEACH routing protocol operation is well-ordered by rounds that consists of two phases: set-up phase and steady phase. The formation of clusters and the selection of cluster head (CH) for each cluster takes place during set-up phase. On the other hand, the data detection, aggregation, compression and transmission to the base station (BS) occurs in the steady phase.

The stages of the set-up phase involving cluster formation, CH election and schedule formations are briefly discussed.

- Cluster Head Election

When the network is installed, each sensor in the WSN may choose to become a CH with an assigned probability *p*. There is no optimal number of CHs for a WSN. The clustering process for each topology must ensure that no nodes become isolated and that the number of clusters formed is not more than required since excessive clusters reduces the energy savings produced from clustering.

The processing of electing or choosing to become a CH is not undergone by the sink node, which is the BS. The nearest CH is simply searched by the sink node so as to join as a cluster member. The sink node is served by a CH called sink node CH. The mathematical descriptions of the clustering and the CH election are as follows.

The threshold value T_n for ith sensor node SN(i) to belong to a cluster is defined by:

$$T_n = \frac{p}{1 - p \times (\mathrm{mod}\ (\mathrm{rnd}, 1/p))}, \quad \text{otherwise}\ T_n = 0 \qquad (13)$$

where *p* is the expected percentage or fraction of CH, and rnd is the current round number.

Note E_I is the energy of ith sensor node SN(i) during the current operation, $\overline{E}$ is the average energy calculated for each round (rnd) and is given by:

$$\overline{E}(\mathrm{rnd}) = E_o\left[1 + s(q + s_o r)\right]\left(1 - \frac{\mathrm{rnd}}{R}\right) \qquad (14)$$

and

$$R = \frac{E_{tot}}{E_{rnd}} = \frac{N \times E_o\left[1 + s(q + s_o r)\right]}{E_{rnd}} \qquad (15)$$

where r is the current number of round energy dissipated by ith sensor node SN(i) when transmitting data to CH is given by:

$$E_i = E_{elec} \times k + E_{amp} \times k \times SN(i) \times d_{CH}^2 \qquad (16)$$

where d_{CH} is the distance between the ith sensor node SN(i) in a cluster transmitting data to the CH and is given by:

$$d_{CH} = \sqrt{(d_{CHx} \quad d_{SN(i)x})^2 \quad (d_{CHy} \quad d_{SN(i)y})^2} \qquad (17)$$

The energy dissipated by CH node while transmitting data to sink node with respect to SN(i) is given by:

$$E_{i\text{-}CH} = (E_{elec} + E_{DA}) \times k + E_{amp} \times k \times SN(i) \times d_{BS}^2 \qquad (18)$$

where x and y means the horizontal and vertical coordinates of the WSN.

$$E_{RX} = (E_{elect} + E_{DA}) \times k \qquad (19)$$

The summation of energy dissipated E_{rnd} is the total energy dissipated by ith sensor node SN(i) in the network during transmission and reception.

- Cluster Formation

In the formation of cluster, the equation describing the process is given by Chandanse et al [4]:

$$E(CH) = E(CH^j) \quad \{[(E_{tx} + E_{agg}) \times pCH] + (\in f_s \times pCH \times d_{BS}^2) + pnE_{rx} rnd(n/numClust)]\} \qquad \text{... (20)}$$

where E(CH) is the updated energy of CH, E(CH) is the energy of CH in simultaneous round (rnd), p(CH) is the packet size for CH per round (bits), pn is the packet size for normal node per round (bits),), E_{tx} is the energy for transmitting one bit, E_{rx} is the energy for receiving one bit, $\in f_S$ is the energy of free space model amplifier, E_{agg} is the data aggregation energy, and numClust is the number of clusters in particular round.

- Schedule Creation

Time slot is generated for all nodes by the CH. Data can be transmitted to the CH by nodes only in the time slot. The total number of nodes in the network is the basis for schedule creation. Time Division Multiple Access (TDMA) determines when data is transmitted to the CH by the node [5].

3.2 STABLE ELECTION PROTOCOL

In this subsection, the SEP which is designed to improve the stable region of the clustering hierarchy process employing the characteristics parameters of heterogeneity is presented. These characteristic parameters of heterogeneity are: advanced nodes fraction (m) and additional energy factor between normal and advanced nodes α.

Mathematically, given that E_0 is the initial energy of each normal sensor, the energy of each advanced node is given by Smaragdakis et al. [3]:

$$E_{adv} = E_o(1 + \alpha) \qquad (21)$$

The total (initial) energy of the heterogeneous setting is given by:

$$n \times (1 \quad m).E_o + n \times m \times E_o(1 + \alpha) = n \times E_o \times (1 + \alpha \times m)$$
$$E_{tot} = n \times E_o(1 + \alpha \times m) \qquad \text{... (22)}$$

Looking at (22), there almost $n \times (1 + \alpha \times m)$ nodes with energy equal to the normal node initial energy. The weighted probabilities for normal and advanced nodes are respectively defined by Smaragdakis et al. [3]:

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$$p_{nrm} = \frac{p_{opt}}{1 + \alpha \times m} \quad (23)$$

$$p_{nrm} = \frac{p_{opt}}{1 + \alpha \times m} \quad (24)$$

where p_{opt} is the optimal probability. The threshold (probability) employed in electing the CH in every round for both normal and advanced nodes is expressed by Smaragdakis et al. [3]:

$$T(s_{nrm}) = \begin{cases} \frac{p_{nrm}}{1 \quad p_{nrm} \times (r \bmod \frac{1}{p_{nrm}})} & \text{if } s_{nrm} \in G' \\ 0 & \text{otherwise} \end{cases} \quad (25)$$

$$T(s_{adv}) = \begin{cases} \frac{p_{adv}}{1 \quad p_{adv} \times (r \bmod \frac{1}{p_{adv}})} & \text{if } s_{adv} \in G'' \\ 0 & \text{otherwise} \end{cases} \quad (26)$$

where G' and G'' are the set of normal and advanced nodes that have not become CHs within the last $1/p_{nrm}$ and $1/p_{adv}$ rounds of the epoch respectively.

Thus, the average total number of CHs per round/heterogeneous epoch is defined by Smaragdakis et al. [3]:

$$n \times (1 \quad m) \times p_{nrm} + n \times m \times p_{adv} = n \times p_{opt} \quad (27)$$

And this represents the expected number of CHs/rnd/epoch Smaragdakis et al. [3].

3.3 ZONE-STABLE ELECTION PROTOCOL

Two techniques are employed in the ZSEP I transmitting data to BS. These are direct communication and transmission through CH. In the direct communication, the nodes in zone 0 directly transmit their data to BS. Data are directly sent to BS by Normal nodes, which sense their environment and gather data of interest.

The ZSEP is modification of SEP in which nodes are sectored into zones. Data is transmitted to BS through clustering scheme from nodes in Head 1 and Head zone 2 via CH transmission. That is in this technique, CH is elected among nodes in Head zone and Head zone 2. Generally, the ZSEP maintains the same algorithm but nodes are zoned.

3.4 SIMULATION PARAMETERS

In this paper, the various protocols are simulated in a WSN field with dimension 100 m × 100 m and with number of nodes varied from 50, 60, 70, 80, 90, and 100. Table 1 shows the simulation parameters of a WSN implemented in MATLAB.

Table 1: Simulation parameters [6]

Parameters	Value
Initial energy E_o	0.5 J
Initial energy of advance nodes	$E_o(1+\alpha)$
Energy for data aggregation E_{DA}	5 nJ/bit/signal
Transmitting and receiving energy E_{elec}	5 nJ/bit
Amplification energy for short distance $\in f_s$	10 pJ/bit/m^2
Amplification energy for long distance E_{amp}	0.013 pJ/bit/m^4
Probability p_{opt}	0.1

IV. SIMULATION RESULTS

The performances of different cluster based routing protocols simulated in MATLAB simulation environment are presented in this section. For the purpose of simulation, the parameters in Table 3.1 and various number of nodes 50, 60, 70, 80, 90, and 100 and network area 10000 m^2 was used to evaluate the performance of the WSN. The BS (or sink) was considered to be placed at the centre of the network field. The effects of changing the number of increasing node density was analyzed for the clustering protocols LEACH, SEP, and ZSEP in terms of dead nodes, alive nodes, and transmission of packets to BS against number of rounds. Also, the computational complexity of the system was also determined in terms of the simulation time (duration) for computer evaluation of the network for at any given number of nodes. Hence, the results are presented in terms of the performance parameters as follows.

Dead nodes are nodes that died until last round. Figure 2 shows the number of dead nodes recorded in the network for each of LEACH, SEP, and ZSEP protocols for the various number of nodes considered. The numerical performance is shown in Table 2.

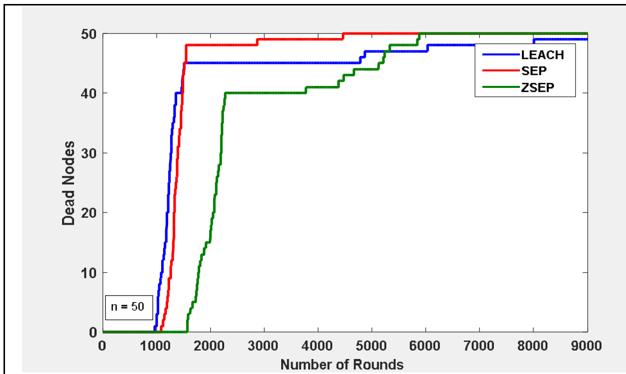

Figure 2a Dead nodes against rounds (n =50)

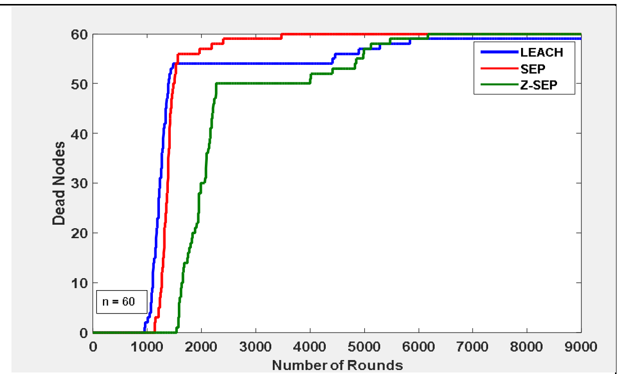

Figure 2b Dead nodes against rounds (n =60)

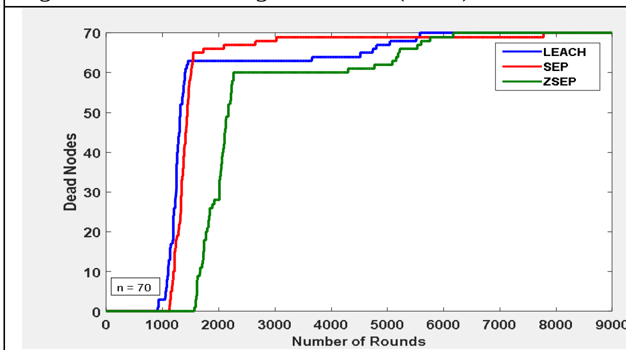

Figure 2c Dead nodes against rounds (n =70)

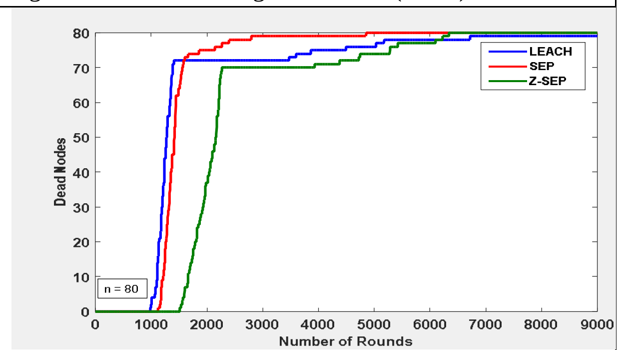

Figure 2d Dead nodes against rounds (n =80

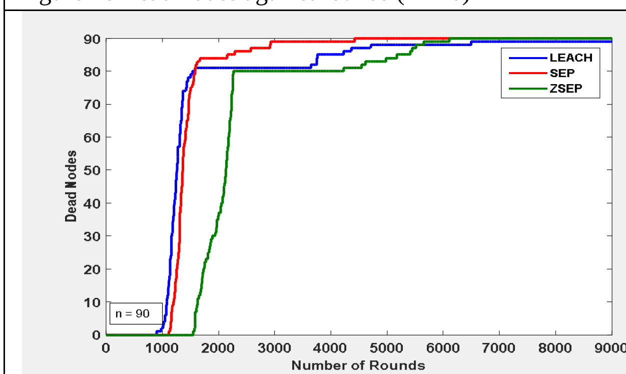

Figure 2e Dead nodes against rounds (n =90)

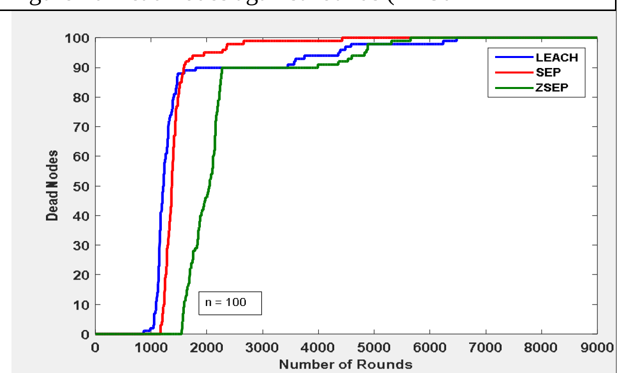

Figure 2f Dead nodes against rounds (n =100)

Figure 2 Dead nodes against number of rounds

Protocols	**Number of dead nodes at 3000 rounds**					
	50	60	70	80	90	100
LEACH	45	54	63	72	81	90
SEP	49	58	68	78	88	98
ZSEP	40	50	60	70	80	90

Figure 2 shows the simulation curves of the performance of LEACH, SEP, and ZSEP routing protocols in terms of dead nodes per number of rounds for varying number of node population in WSN. Looking at Table 2 it can be seen that increasing number of nodes prolongs the life of WSN. It is obvious from Table 2 that more nodes die with SEP compared to ZSEP LEACH and ZSEP algorithms. Generally, ZSEP provided better performance in terms of energy conservation since it ensures lesser number of dead nodes in WSN. For example for n = 50, number of dead nodes at 3000 rounds for LEACH was 45, for SEP was 49, while for ZSEP was 40. Therefore, ZSEP can be seen to have provided better network performance since with the protocol, minimum dead nodes was recorded.

Alive nodes are nodes that exist until last round. Figure 3 shows the number of alive nodes recorded in the network for each of LEACH, SEP, and ZSEP protocols for the various number of nodes considered. The numerical performance is shown in Table 3

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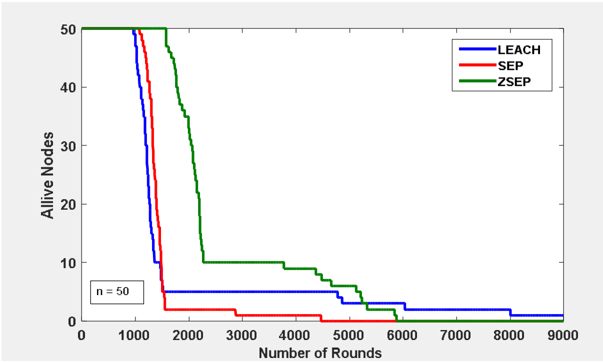

Figure 3a Alive nodes against rounds (n =50)

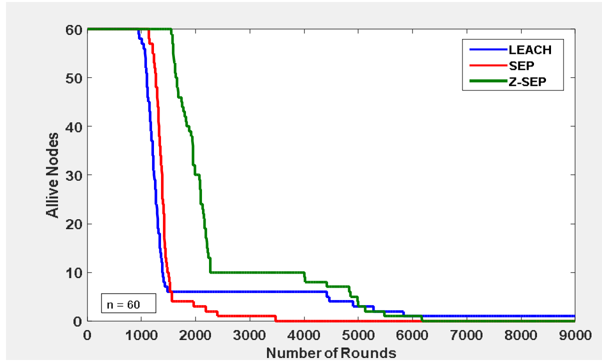

Figure 3b Alive nodes against rounds (n =60)

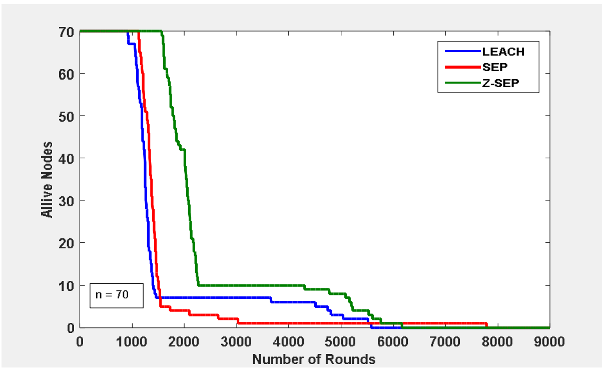

Figure 3c Alive nodes against rounds (n =70)

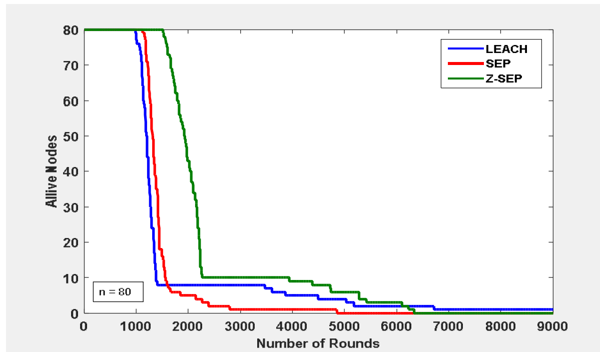

Figure 3d Alive nodes against rounds (n =80)

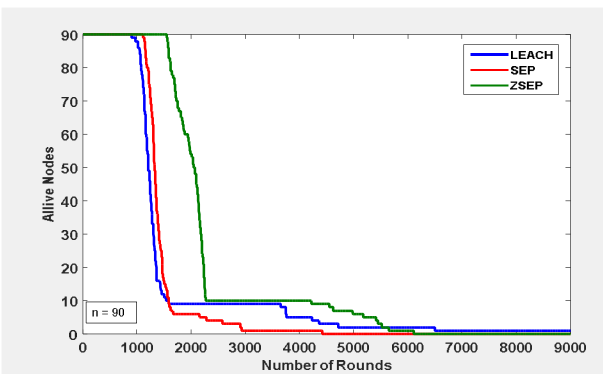

Figure 3e Alive nodes against rounds (n =90)

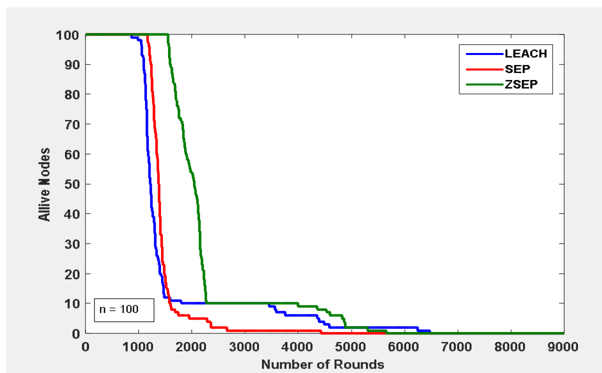

Figure 3f Alive nodes against rounds (n =100)

Figure 3 Alive nodes against number of rounds

Table 3 Numerical performance in terms of alive nodes against number of rounds

Protocols	**Number of alive nodes at 3000 rounds**					
	50	60	70	80	90	100
LEACH	5	6	7	8	9	10
SEP	1	2	2	2	2	2
ZSEP	10	10	10	10	10	10

The simulation curves for performance of LEACH, SEP, and ZSEP routing protocols in terms of alive nodes per number of rounds for varying number of senor node population in WSN is shown in Figure 3. It can be seen in Table 3 that increasing number of nodes ensures that more nodes remain alive and thereby increasing the network life span. This is even more obvious with LEACH protocol as shown in Table 3, wherein only 5 nodes where alive at 3000 rounds but for n = 50 and increased to 10 for n = 100.

However, with SEP and ZSEP algorithms, no obvious increase was observed in number of alive nodes with respect to growing node population in the network. Conversely, ZSEP protocol ensures that more nodes are alive during the operation of the WSN. This means that with ZSEP, less energy is consumed by the nodes compared to LEACH and SEP. Thus, ZSEP can be seen to have provided better network performance since with the protocol, maximum alive nodes was recorded

Data packets transmitted to base station (BS) indicates the quantity of packets received by BS for per round. Figure 4 shows the number of packets to BS recorded in the network for each of LEACH, SEP, and ZSEP protocols for the various number of nodes considered.

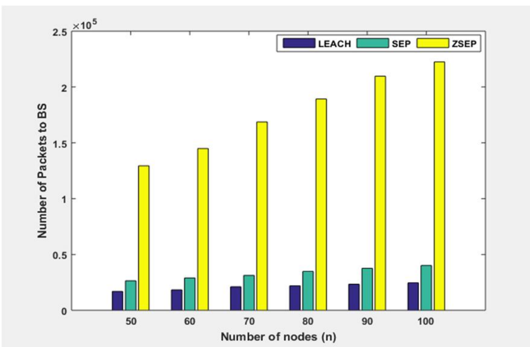

Figure 4 Simulation plots of packets to BS against number of nodes

The performances of LEACH, SEP, and ZSEP cluster based routing algorithms in WSN are evaluated in terms of packets sent to BS for each round as shown in Figure 4.3. It can be seen in Table 3 that more data are sent to BS with increase in node population in the network. That is the number of packets sent to the BS increases as the number of nodes in increases. Also, ZSEP seems to offer the most efficient performance in terms of routing collected that from nodes to BS. However, the LEACH algorithm gives the least performance in this regard.

Generally, this section presents the summary of the simulation results. The numerical analysis of the results obtained from the simulation revealed that as the number of nodes increases there are chances of more nodes being alive as shown in Table 3. The life of the network is prolonged as the number of nodes increases. However, the algorithm that offered least performance in terms of dead nodes and alive nodes is the SEP protocols as can be seen that when the number of nodes was 50, at 3000 rounds, 49 nodes were dead already while only a node was alive. On the other hand, the ZSEP protocols provided the most promising performance in terms of dead nodes and alive nodes. As can be seen with number of nodes equal 50, while 45 dead nodes were recorded for LEACH protocols, 40 was observed for ZSEP at 3000 rounds. Also, the equivalent alive nodes were 5 and 10 for L EACH and ZSEP respectively. In the case of the number of packets sent to BS, increasing number of nodes influenced the packets transmitted. All the protocols showed promising performance in this regard, but the LEACH algorithm provided the least packets to BS performance. Conversely, ZSEP outperformed the LEACH and SEP protocols as it offered the highest number of transmitted packets to BS.

V. CONCLUSION

This paper examined the effect of increasing node density on cluster based energy-efficient routing protocols in wireless sensor network (WSN). The LEACH, SEP, and ZSEP were considered as cluster based routing protocols and with simulations carried out in MATLAB to analyze the performance of each algorithm in WSN under increasing number of sensor nodes population. It was observed that by increasing the number of nodes the number of dead nodes decreases, while the number of alive nodes increases which was obviously seen with the LEACH protocol. Also, the data traffic (packets sent to BS) in the network was seen to increase as the number of nodes increases. However, it was also shown from the simulations that increasing number of nodes resulted in increased computational time, which was used to determine the computational complexity of the routing protocols in the network. Generally, it is remarkable to know that increasing node density (or changing number of nodes) clearly affects the performance of heterogeneous cluster based protocols in WSN.

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