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Prolong Stability Period in Node Pairing Protocol for Wireless Sensor Networks

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P A P E R   I N F O

A B S T R A C T

Wireless sensor networks are efficient way to monitor important parameters in various fields of science and engineering. These sensors are battery operated and in each round of transmission some energy is used. Therefore, over the period of time battery drains, and thus effect the stability period of the networks. To conserve battery nodes are divided as normal and advance nodes. The energy of the advanced nodes is higher than normal nodes. Further clustering mechanism is used to reduce energy dissipation. This paper proposes a mechanism by which stability period, network lifetime and throughput can be increased significantly. The proposed mechanism considers S-SEP protocol and nodes are coupled to form pairs, then number of clusters and radius of the clusters are optimized such that isolated nodes are zero. It is found that using proposed mechanism stability period can be improved by 17% in comparison to recently proposed work.

1. INTRODUCTION

Recently, we have witnessed a lot of advancement in the field of Wireless sensor networks (WSNs) [1]. The transmission using sensor nodes is reliable and secures [2]. The data collected by these nodes is further transmitted to the BS either directly or with the help of cluster heads (CHs) [3]. The source of energy of these nodes is batteries, which are not replaceable. Hence, it is quite important to have a long lifetime of these nodes for the efficient transmission system. As soon as the first node dies out, the network becomes unstable [4]. Thus, the major issue with the WSNs is to enhance the lifetime and reduce the energy consumption of the nodes [5]. A number of techniques are proposed to reduce the consumption of energy of the SNs [6-8] like energy-aware medium access control and power-aware storage protocols [8]. To some extent, these protocols have upgraded the lifetime and battery replacement time of WSNs, but failed to provide sufficient energy for the proper functioning of the system. The positioning of the nodes also plays an important role in reducing energy

consumption. The nodes must be deployed in such a way that they must cover the main area which is to be focused concentrated to have proper and precise collection of data [5]. In this work we are analyzing the effect of number of clusters, radius of the clusters and distance of the nodes in the optimization of stability period. We would like to increase the radius of the clusters such that no isolated node remain, but under the condition that the pairing of node will only be done for the nodes which follows free space model. The free space model demands smaller radius of the cluster circle while to avoid isolate node radius of the clusters should be large enough to accommodate distant nodes. Two requirements are inverse to each other. Therefore, optimization of radius of the clusters is necessary to maximize stability period.

2. RELATED WORKS

A new protocol, stable election protocol (SEP) is proposed for improving the lifetime of the nodes. In this protocol, we have two kinds of nodes: advanced and

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normal nodes. The selection of cluster head is based on the residual energy in each node. Many researchers have proposed various heterogeneous protocols similar to SEP using some improvement mechanism. In the other clustering protocol named as zonal-stable election protocol [9], the basic concept of working is based on the zonal division. Further modification is done where considered area is divided into sectors (S-SEP) [10].

Each node in a WSN network collects and transmits data, which causes some consumption of energy. In the case of uneven distribution of nodes in a WSN, some nodes left as isolated as shown in Figure 1. The consumption of energy by isolated nodes is a major problem in a WSN network. This problem can be solved by deciding whether the isolated nodes will send the data to a CH node or to sink on the basis of the distance between the isolated nodes and the sink. Recently,we proposed modified Sectorial SEP protocol; here field is divided into sectors, and as shown in Figure 2 [11], nodes away from sink node are advanced nodes and have more energy as compared to normal nodes and they follow clustering mechanism and a group of nodes lie within a
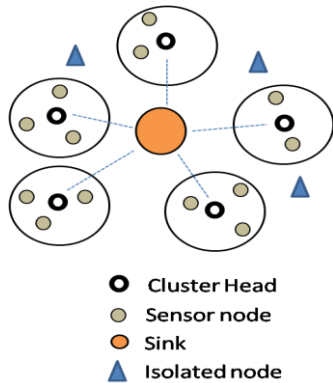

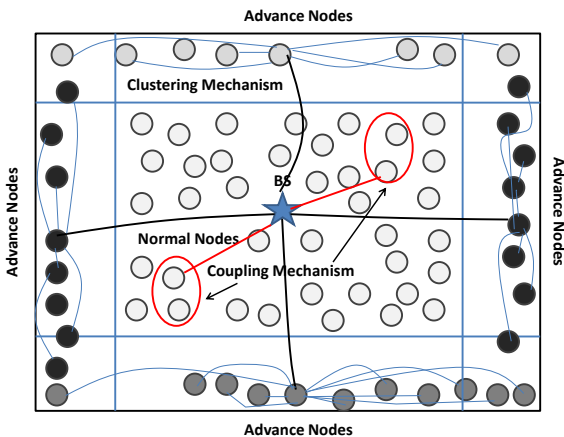**Figure 1.**Schematic of isolated nodes

Figure 2. Node deployment in $(2X+Y)\times(2X+Y)$ m^2 square field

cluster elect cluster head among themselves. However, the normal nodes also follows clustering mechanism and within a cluster each node do not transmit to cluster head but two nearby nodes combine using node coupling mechanism and in each round one node awake and transmit to cluster head and other node goes to sleep mode after transferring its data to its coupledpartner. Initially all the nodes are active and they broadcast their positions, node_ids and type of applications they run. On the basis of message received from other nodes each node maintain a table and select pairing node which is closet to neighbouring nodes and run same application. Let initial energy of each node is $2E_0$ but due to neighbour formation some of the energy is lost therefore we assume that initial energy of each node is $E_0(1+U)$ where U is uniform random number between 0 and 1. It is also noticeable that in n number of nodes forms clusters, without node pairing because node pairing will not be beneficial as distance between the nodes is larger. We define this region as 1. Let 'p_1' is the probability of a node to become cluster head, then the average number of clusters would be np_1. Similarly, m nodes forms paring of nodes, and further let that isolated nodes are denoted by$I$, therefore number of pairing active nodes in a particular round would be $A = [m/2 – I]$, and we define this area as region 2. Let 'p_2' is the probability of a node to become cluster head, then the average number of clusters would be $C=Ap_2$. In regions 1 and 2, the average number of nodes in each cluster except cluster head are $(1/ p_1-1)$ and $(1/ p_2-1)$, respectively.

In region 2, the cluster head selection is done using Equation (1), in the equation R denotes the round.

$$Th(n) = \begin{cases} \dfrac{p_2}{1 - p_2\left(R \times \text{mod } \dfrac{1}{p_2} \right)} \times \dfrac{E_r(i)}{E_0(1+U)} & if \ n \in (A_L) \\ 0 & otherwise \end{cases} \quad (1)$$

3. ENERGY CALCULATION

For the description and simulation of proposed protocol first order, radio model is used and list of symbols used and their descriptions are detailed in Table 1. For the packet size of 'S' bits and distance between transmitter and receiver as 'd' the transmission energy will be given by:

$$E_{TX} = \begin{cases} SE_{el} + SE_{fs}d^2 & d \leq d_0 \\ SE_{el} + SE_{mp}d^4 & d > d_0 \end{cases} \quad (2)$$

where, $d_0 = \sqrt{\dfrac{E_{fs}}{E_{mp}}}$.

And the receiver energy is:

$$E_{RX} = SE_{el} \qquad (3)$$

Region 1:
In a single round, energy dissipated at node cluster head (CH) is:

$$E_{CH} = SE_{el}\left(\frac{1}{p_1}-1\right) + SE_{DA}\frac{1}{p_1} + SE_{el} + SE_{fs}d^2_{CH-BS} \qquad (4)$$

Or

$$E_{CH} = SE_{el}\left(\frac{1}{p_1}-1\right) + SE_{DA}\frac{1}{p_1} + SE_{el} + SE_{mp}d^4_{CH-BS} \qquad (5)$$

where, $d^{2,4}_{CH-BS}$ is the distance of cluster head to base station. Energy dissipation in non-cluster head (N-CH) is:

$$E_{N-CH} = SE_{el} + SE_{fs}d^2_{CN-CH} \qquad (6)$$

where, d^2_{CN-CH} is the distance of cluster nodes to cluster heads. Total energy dissipated in a cluster in a round is:

$$E^T_{CH} = E_{CH} + \frac{1}{p_1}E_{N-CH} \qquad (7)$$

Region 2:
In a single round, energy dissipated at non- cluster head node is:

$$E_{CH} = \left(\frac{1}{p_2}-1\right)(E_{ei} \times S + E_{amp} \times S \times d^2_{CN-CH}) \qquad (8)$$

Energy dissipation in data receiving is:

$$E_{Rc} = SE_{RX}\left(\frac{1}{p_2}-1\right) \qquad (9)$$

Data aggregation energy is:

$$E_{AG} = SE_{AD}\frac{1}{p_2} \qquad (10)$$

Energy dissipated by cluster to transmitaggregated data to BS is (by following Equation (2))

$$E_T = S \times E_{el} + E_{amp} \times S \times d^2_{CH-BS} \qquad (11)$$

Or

$$E_T = S \times E_{el} + E_{amp} \times S \times d^4_{CH-BS} \qquad (12)$$

Total energy dissipated in a cluster in a round is

$$E^T_{CH} = E_{Rc} + E_{AG} + E_T \qquad (13)$$

Therefore, in both the regions dissipated energy is different; distance among the nodes is more in region 1 as compared to region 2. Therefore different packet transfer schemes are adopted.

In the proposed method, we aim to minimize isolated nodes. For mathematical point of view, we consider, the area of the field is $L \times L$, and let 'n' numbers of nodes are uniformly distributed over the given area, the clusters are circular in shape and each cluster has same size and area (Figure 3). Let initially there are m numbers of nodes, the numbers of coupled nodes are c, and numbers of isolated nodes are I.

$$m = c + I \qquad (14)$$

Therefore, numbers of alive nodes in a round are

$$A_L = \frac{c}{2} + I \qquad (15)$$

Therefore, numbers of clusters are:

$$C = \left(\frac{c}{2} + I\right)p_2\gamma \qquad (16)$$

As in each round the isolate will transfer packets to sink node directly; therefore energy depletion will be fast and further if distance of isolated node from sink is larger then energy depletion problem becomes two folds. We aim to increase the radius of the clusters to bring isolated nodes to zero, i.e., and the maximum number of clusters will be

$$C_{max} = \left(\frac{m}{2}\right)p_2\gamma \qquad (17)$$

The covered area can be represented as:

$$\left(\frac{m}{2}\right)p_2\gamma \times \pi r^2 = L^2 \qquad (18)$$

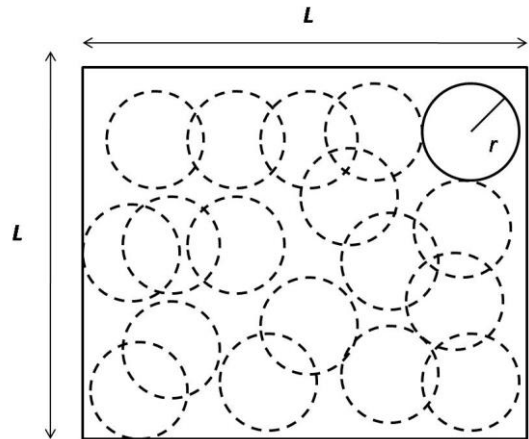or

$$r = \sqrt{\frac{2L^2}{\pi m p_2 \gamma}} \qquad (19)$$

Figure 3. Schematic of cluster area coverage

The maximum radius can be evaluated as:

$$r_{max} = \sqrt{\frac{2L^2}{\pi m p_2^{min} \gamma}} \qquad (20)$$

Referring Figure 3, it can be seen that if overlapping clusters are chosen such that each node is covered by four adjacent clusters than isolated nodes can be set to zero. But the number of clusters cannot be chosen arbitrarily; therefore we should increase the radius of the clusters to get k node coverage. But radius cannot be increased beyond a limit which is set as:

$$r_{max} = \frac{d}{2} = \frac{\sqrt{E_{fs}/E_{mp}}}{2} = 43.85m \qquad (21)$$

Node Coupling Mechanism
ID=0;
fori=1:1:n
for j=1:1:n
if(j~=i)
$d_{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$ (distance between the nodes)
if($d_{i,j} <= d_o$ (coupling distance))
if($d_{i,j} < d_{i,j}(n)$ (neighbour distance))
$d_{i,j}(n) = d_{i,j}$;
                        ID=j;
end
end
end
end
 end
if (ID>0)
          pair nodes
x=x+1;
else
          isolated nodes
y=y+1;
$d_{i,j}^{CH} = \sqrt{(x_i - x_j^{CH})^2 + (y_i - y_j^{CH})^2}$ (distance between cluster head and   isolated nodes)
$\min\left[d_{i,j}^{CH} \right]$, (select cluster head j for data forwarding)
end

Referring to Figure 4, and coupled nodes are marked as 1 and 2, respectively. We know that using wireless channel model if distance between nodes is less than thresholds ($d \leq d_0$) then the power loss is proportional to d^2 and known as free space and when thresholds ($d \geq d_0$) then the power loss is proportional to d^4 and known as multi-path propagation. Let us first consider that node 2 transmit to sink node. Therefore, we have:
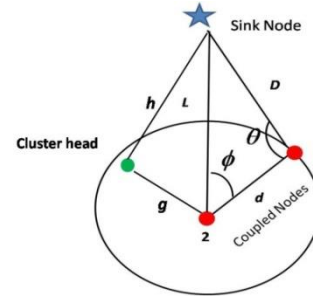
$$L^2 = D^2 - d^2 + 2Dd\cos\phi \qquad (22)$$

Figure 4. Schematic of cosine rules between nodes, cluster head and sink

We have four cases
Case 1: If distance between the coupling nodes is small i.e., ($d \leq d_0$) the energy loss will be proportional to d^2 and distance between node 2 and sink node is small then energy loss will also be proportional to L^2. Therefore, total energy loss will be proportional to $L^2 + d^2$.
Case 2: If distance between the coupling nodes is large and distance between node 2 and sink node is small then the total energy loss will be proportional to $L^2 + d^4$.
Case 3: If distance between the coupling nodes is small and distance between node 2 and sink node is large then the total energy loss will be proportional to $L^4 + d^2$
Case 4: Again if distance between the coupling nodes is large and distance between node 2 and sink node is large then the total energy loss will be proportional to $L^4 + d^4$

Case 1 is applicable for the nodes which are close to sink node. Case 2 will lead to unfeasible solution, case 3, is applicable for the nodes which are moderate distance from sink, and finally case 4, is applicable for nodes which are away from the sink nodes. In our proposed method optimum numbers of clusters with radius which satisfies Equation (21) are chosen such that, d, g and h are less than d_0. Referring Figure 4, Equations (5) and (12) are modified as:

$$E_{CH} = \left(\frac{1}{p_2} - 1\right)(E_{ei} \times S + E_{amp} \times S \times g^2) \qquad (23)$$

$$E_T = S \times E_{el} + E_{amp} \times S \times h^2 \qquad (24)$$

Problem Constraints
The objective is to maximize the stability period and can be written as

$$\max \sum_r S_p \qquad \forall r \in R \qquad (25)$$

Subjected to
$$A_{is} = \begin{cases} 1 & \text{if } i \text{ establishes a link with } s \\ 0 & \text{otherwise} \end{cases}$$

$$A_{fs} = \begin{cases} 1 & \text{if } f \text{ establishes a link with } s \\ 0 & \text{otherwise} \end{cases}$$

A_{is} represents the connectivity between i and s. similarly A_{fs} is the connectivity between f and s. therefore all the links establish connection is given by:

$$A_{is} = A_{fs} = 1 \qquad \forall i, \quad f \in N \qquad (26)$$

No packet drops at the cluster head is given by

$$P_{ic} - P_{cs} = 0 \qquad \forall (i \in N, c \in C_H) \qquad (27)$$

Node having energy less than minimum energy will stop transmission:

$$E_i \leq E_{\min} \qquad \forall i \in N \qquad (28)$$

$$\sum_i \lambda_i t \geq cb_i \qquad \forall i \in N \qquad (29)$$

says that the data generation rate of a given node i during a time period t should not exceed its buffer capacity cb_i. To achieve above objective we should have:

$$\min \sum_r I \qquad \forall r_n \in R_n \qquad (30)$$

$$\max \sum_{r_n} r \leq \mathbf{r}_{\max} \qquad \forall r_n \in R_n \qquad (31)$$

where I are isolated nodes.

5. SIMULATION RESULTS

In this section simulation results are presented. In simulation various results are detailed using graphs. The parametric values are detailed in Table 1 which is also used in Monte Carlo simulation. 100 nodes are considered with a radius of 10m and 25m in Figures 5 and 6, respectively. Referring Figure 5 in case of smaller radius it is not possible to cover entire field, and some of the nodes remain as isolated nodes (marked in dotted red colour); however in case of larger radius it is possible to cover entire field, and isolated nodes can be bring down zero. Referring case 1 above and Equation (19), radius cannot be increased beyond set limit. Avery large radius
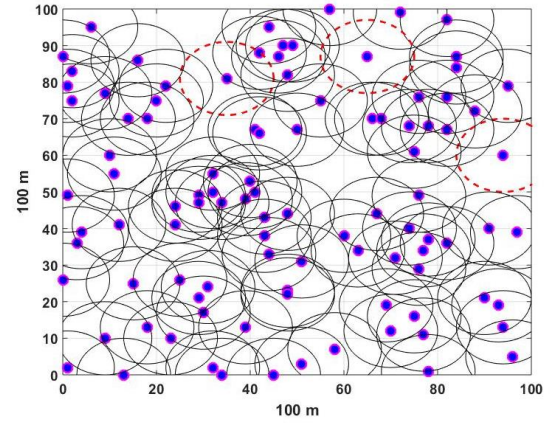
TABLE 1. Simulation Parameters [10]

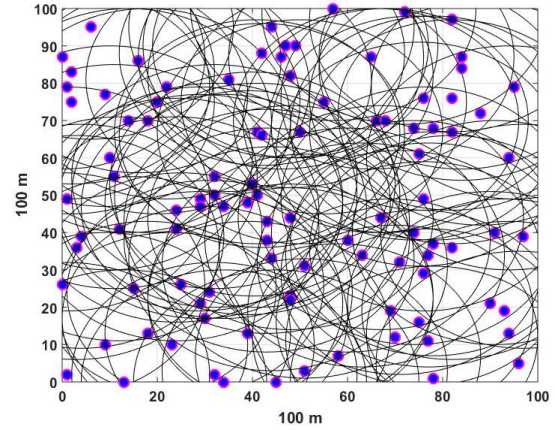| Parameters	Value
Initial Energy E_0	0.5 J
Energy for data aggregation E_{DA}	5 nj/bit
Transmission and Receiving energy	5 nj/bit
Amplification energy for short distance E_{fs}	10 pj/bit/m^2
Amplification energy for long distance E_{amp}	0.013 pj/bit/m^4
Probability P_1	0.3
Probability P_2	0.4

Figure 5. Cluster coverage 10 m

Figure 6. Cluster coverage 25 m

will not bring any further improvement as a node will be covered by a large number of clusters which will not affect node coverage.

In Figure 7, $\gamma = \dfrac{E_r(i)}{E_0(1+U)}$ normalized residual energy is plotted for round number 10 when all the nodes are alive and 6000 rounds when nearly 40% nodes are dead. Initially all 80 nodes are alive and energies values lie between 0.5 and 1, and as the round progresses the value of γ falls and after 6000 round its value is around 0.1 only. As the value of $A_L p_2 \gamma$ goes less than 1, the cluster formation stops and the leftover nodes, directly transmit data to base station.

In Figure 8, radius vs. $p_2\gamma$ for 10%, 50% and 100% alive nodes are presented. When all the nodes are alive for $p_2\gamma = 0.05$ radius is 40m for $p_2\gamma = 0.5$ the radius is 12.62m, similarly, when 50% nodes are alive for $p_2\gamma = 0.05$ radius is 56.42 m for $p_2\gamma = 0.5$ the radius is 17.84. Finally, when 10% nodes are alive for $p_2\gamma = 0.2$ radius is 63.08 m for $p_2\gamma = 0.4$ the radius is 44.6. In Figure 9, radius vs. alive nodes is presented *for $p_2\gamma$* for 0.2, 0.3, 0.4 and 0.5. for $p_2\gamma = 0.2$ the clustering mechanism will break
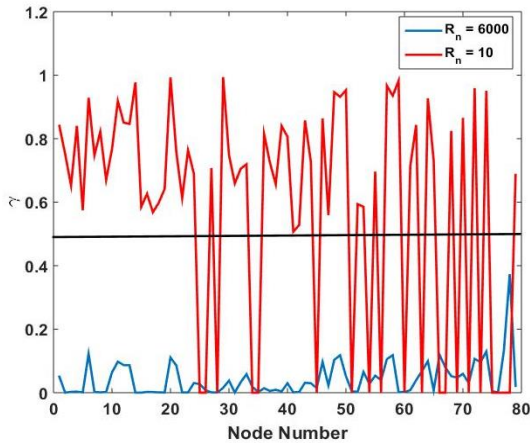
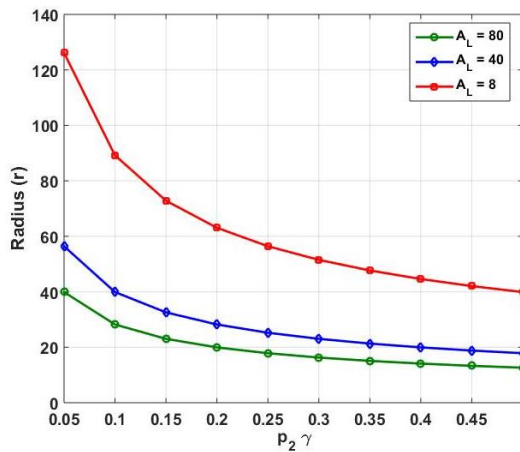**Figure 7.** The value of γ for all 80 nodes

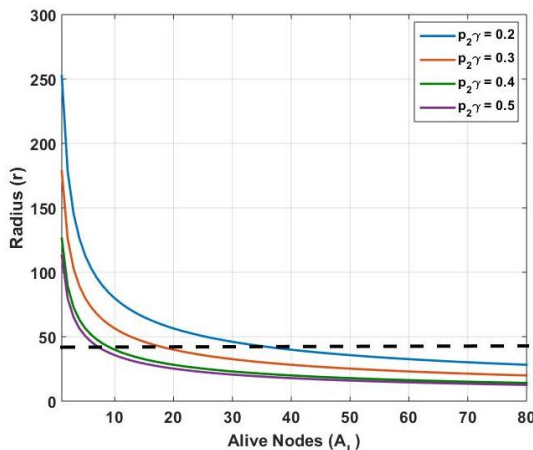**Figure 8.** Radius vs. $p_2\gamma$ for 10%, 50% and 100% alive nodes

Figure 9. Radius vs. alive nodes for various values of $p_2\gamma$

when alive nodes are nearly 35, and lower value of $p_2\gamma$ also means less number of clusters. Similarly if we choose $p_2\gamma$ = 0.5, clustering mechanism will break when alive nodes are nearly 6, but initially the value of $mp_2\gamma$ is

40, therefore all the alive nodes will transfer data to base station and there will not any advantage of clustering mechanism. If we consider, $p_2\gamma$ = 0.4, clustering mechanism will break when alive nodes are nearly 10, and clustering will become effective from round 1 of the simulation. Therefore in our simulation we have considered $p_2\gamma$ = 0.4.

Next we have simulated effect of coupling distance on the number of coupled nodes and detailed are shown in Figure 10. The cluster diameter is considered to be twice of coupling distance. For small diameter 2m the numbers of coupled nodes are 4 and isolated nodes are 76. While increasing diameter from 2m to 15 m the numbers of coupled nodes becomes 70 and isolated nodes are 10. For diameter range from 25 m to 55m the numbers of coupled nodes are 78 and isolated nodes are 2, and from diameter of 60 m onwards the numbers of coupled nodes are 80 and isolated nodes are none. Considering Equation (14) and Equation (15), we conclude that the optimal coupling distance is around 30-35 m and cluster diameter is around 60-70 m. The optimal distances are also depends on the distribution of the nodes therefore while evaluating parameters like stability period, network life time and throughput optimal distance may differ slightly.

In Figure 11, stability period vs. cluster diameter is shown, for lower value of cluster diameter stability period is very less due to the reason as stated above (more umber of isolated nodes). For cluster diameter of 10 m stability period is 2437, which increases to 2729 for cluster diameter of 20 m. If we compare results with recently proposed work [11] the stability period is 2185, 2471 for cluster diameter of 10 m and 20 m respectively. For cluster diameter of 60 m the stability period for yadav et. al. [11], work is 2862, and for proposed work stability period is 2854. For the proposed work, the stability period reaches its maximum value 2888 for cluster diameter of 65 m. It is important to note that for diameter more than 60m the number of isolate nodes are zero.
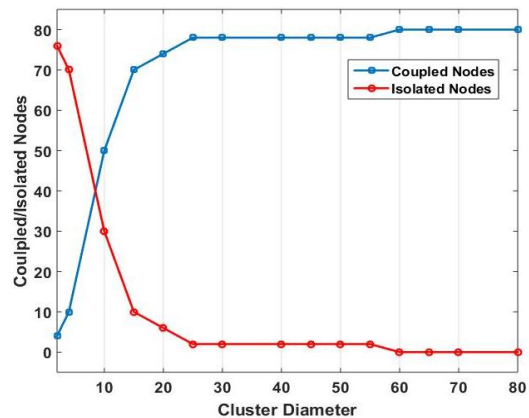

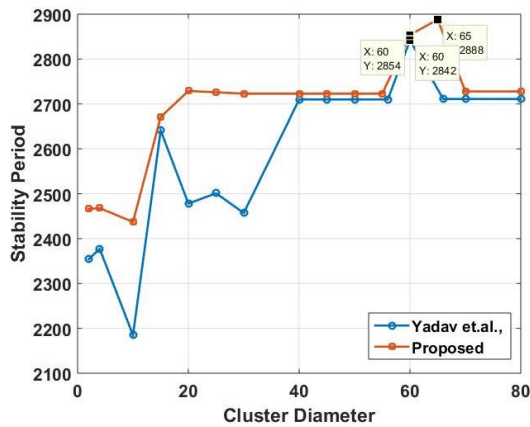**Figure 10.** Numbers of coupled/Isolated nodes vs. Cluster Diameter

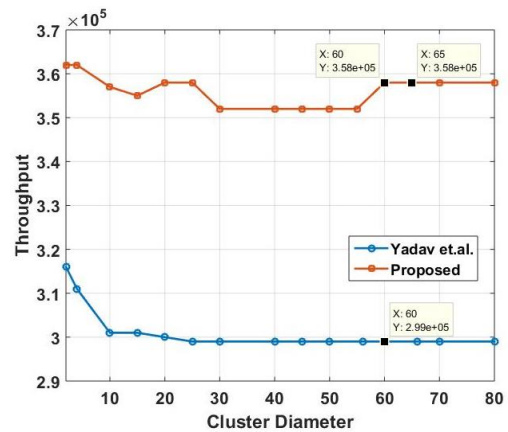**Figure 11.** Stability Period vs. Cluster Diameter

Figure 13. Throughput vs. Cluster Diameter

However, as diameter increases as nodes are covered by more than one cluster and a few nodes change their cluster heads and lead to the better stability period.

In Figure 12, network lifetime vs. cluster diameter is shown. For cluster diameter of 10 m network lifetime is 7582 and remains nearly same for any cluster diameter. If we compare Yadav et. al. [11], works with proposed work network lifetime at the cluster diameter of 60 m is 7248 and 7616 rounds respectively. It is further to note that network life time does not change with rise in cluster diameter as energy dissipation remain proportional to d^2 but as diameter increases a few nodes change their cluster heads therefore distance from cluster heads also alters, and it has been found that this reorganization of nodes does not bring any significant change in energy dissipation in fact it increases slightly for diameter of above 60m. The network life time is maximum for diameter of 60 m.

In Figure 13, Throughput vs. cluster diameter is shown. For cluster diameter of 10 m throughput is 3.62×10^5 and remains nearly same for any cluster diameter. If we compare Yadav et. al.,[11] works with
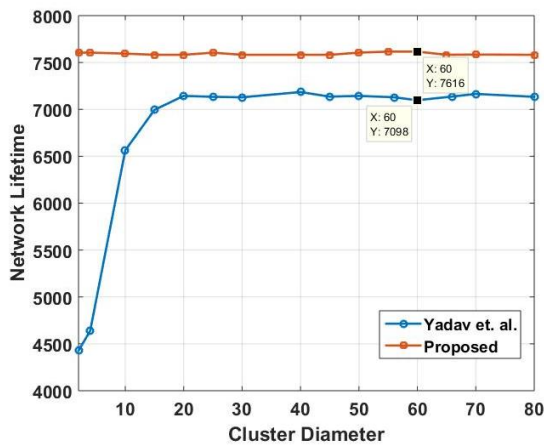
proposed work network lifetime at the cluster diameter of 60 m is 2.99×10^5 and 3.58×10^5 rounds, respectively. Again it is noticeable that that network throughput does not changes with rise in cluster diameter as energy dissipation is does not changes and it remain proportional to d^2, but as diameter increases as discussed above a few nodes change their cluster heads therefore distance from cluster heads also alters, and it has been found that this reorganization of nodes does not bring any significant change in energy dissipation, thus throughput remains nearly same. The throughput is maximum for diameter of 60 m.

6. COMPARISON WITH RECENT NOTABLE SCHEMES

In Table 2, results of the recently proposed protocol are detailed. It can be seen that for LEACH, SEP, Z-SEP, EECP-EI, DDEEC, DEEC and MAHEE stability period

Figure 12. Network Lifetime vs. Cluster Diameter

TABLE 2. Comparison with notable schemes

Protocol	Stability Period (Rounds)	Network Lifetime (Rounds)	Throughput (Packets)
LEACH [12]	1018	4685	1.99×10^4
SEP [13]	2471	3005	3.43×10^4
Z-SEP [9]	1089	3791	2.16×10^5
S-SEP [10]	1422	3824	2.32×10^5
EECP-EI [14]	1763	5143	1.51×10^5
DDEEC [15]	1433	3399	6.89×10^4
DEEC [16]	1233	3166	4.61×10^4
MAHEE [17]	1333	3690	1.84×10^5
Yadav et al. [11]	1455	7248	2.99×10^5
PROPOSED	2888 (d=65 m)	7616 (d=60 m)	3.58×10^5 (d=60m)

is less than 1500 rounds. For SEP stability period is 1763 rounds, and in Yadav et al. [11] work stability period is 2471 rounds. However in the proposed work stability period is around 2888 rounds which is 16.87% better than Yadav et al. [11] work. Similarly improvements are also observed in network lifetime and throughput. In comparison to S-SEP improvement is around 100%, therefore it can be concluded that in S-SEP using node coupling mechanism and optimization of parameters such that isolated nodes are zero a significant improvement is possible. It is further to note that stability period is maximum for diameter of 65 m, while network lifetime and throughput is maximum for diameter of 60 m.

7. CONCLUSIONS

This paper presents a wireless sensor network based protocol. The main objective considered in the work is the improvement in the stability period. We have optimized the relevant parameters in such a way that the numbers of isolated nodes can bring down to zero. A detailed mathematical as well simulation results are discussed for the optimization done. It is found that cluster diameter of 65 m produces best stability period results. It is also found that both network lifetime and throughput also improves significantly. Results are also compared with recently proposed protocol and it is found that all three parameters stability period, network lifetime and throughput improves significantly.

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Persian Abstract

چکیده

شبکه های حسگر بی سیم راهی کارآمد برای نظارت بر پارامترهای مهم در زمینه های مختلف علوم و مهندسی هستند. این سنسورها با باتری کار می کنند و در هر دور انتقال مقداری انرژی استفاده می شود. بنابراین ، با گذشت زمان ، باتری تخلیه می شود و بنابراین دوره پایداری شبکه ها را تحت تأثیر قرار می دهد. برای حفظ گره های باتری به گره های معمولی و پیشرفته تقسیم می شوند. انرژی گره های پیشرفته بیشتر از گره های معمولی است. مکانیسم خوشه بندی بیشتر برای کاهش اتلاف انرژی استفاده می شود. این مقاله مکانیزمی را پیشنهاد می کند که به موجب آن می توان دوره ثبات ، طول عمر و توان شبکه را به میزان قابل توجهی افزایش داد. مکانیسم پیشنهادی پروتکل S-SEP را در نظر می گیرد و گره ها به هم متصل می شوند تا جفت شوند ، سپس تعداد خوشه ها و شعاع خوشه ها به گونه ای بهینه می شود که گره های جدا شده صفر باشند. مشخص شده است که با استفاده از مکانیسم پیشنهادی دوره پایداری می تواند در مقایسه با کارهای اخیراً ۱۷ درصد بهبود یابد.