MADM based Optimal Nodes Deployment for WSN with Optimal Coverage and Connectivity

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Abstract. It is the digital era that provides importance for the research in Wireless Sensor Network (WSN). Different issues with different solutions are suggested by many authors. The realistic deployment having restrictions for cost, area coverage, Cluster Head (CH) coverage, and sink connectivity for WSN that demands an estimation of total count of sensors for deployment with the conditions for CH coverage and sink connectivity. Area coverage means how much portion of total area is sensed by deployed sensors nodes. CH coverage means the sensor node is able to transfer the sensed data to its CH without amplification and sink connectivity means that the CHs are connected with the sink and able to send the data directly without amplification. AHP is a Multi Attribute Decision Making (MADM) method that is used for the selection of best choice having less cost and efficient coverage and connectivity.

1. Introduction
WSN is a group of small sensors that do sense the environment for particular reason and provide the information to sink. One node may have one or more sensors. As the applications increased, area of deployment is also maximized toward remote areas. This creates the un-reachability of humans frequently, so the replacement of battery is also not possible. This leads to the temporary network that works until the battery discharged. To maximize the data collection time, we need to optimize the energy in such a way so that data can be sensed and transferred for long period of time. Clustering provides comparative larger lifetime to network. CH coverage and connectivity plays an important role in clustering. Total count of nodes and area coverage are also considerable factors for cost efficiency and maximum area coverage respectively. So, here we are considering total four factors for network deployment. Our aim is to provide optimal solution for network deployment having 100\% area coverage with optimal count, optimal CH coverage, and optimal Sink connectivity. Optimal count helps to reduce the total cost of deployment and we need to put small amount of sensors. So this count should be minimized, due to this, cost is a non-beneficiary factor. Maximum CH coverage reduces the energy required for transferring the data from neighbour nodes to CH. So we need higher value for this factor, due to this, CH coverage is a beneficiary attribute. Finally, maximum BS connectivity helps CHs to transmit the data to the sink with minimum power requirement. So high value is needed for this factor, due to this, BS connectivity is a beneficiary factor. So finally among four factors, we need 100\% area coverage with minimum nodes having maximum CH coverage and sink connectivity. The layout of next sections are as follows: Section II represents the literature present on the WSN communication and layout. Section III illustrated our approach in detail, where as, the
results of simulation are provided and compared in section IV. Conclusion is illustrated in section V.

2. Related Work
As we discussed before that WSN is a lime light field in research. Many works are being carried out by many authors and delivered a lot of methods for optimal data collection and deployment in WSN. It can be represent in following manner:

LEACH [2] is the base for efficient protocols that is based on probability with TDMA method for forming the schedule for packet passing. It selects the CHs based on a threshold value and probability to select as a CH and use signal intensity to connect with other nodes. It also rotates the authority of CH among all nodes and assigns a time schedule to transmit the data. But it uses some randomness in the phases, due to this, unbalancing occurs during clustering and power consumption.

LEACH-C [2] reduces some limitations of LEACH and provides constrain on minimum energy. It verifies that the nodes are of high power, so that they may able to process the data. H-LEACH enhances the clusters by partitioning the network in optimal number and LEACH verifies the CH selection with rotation in each part. Aaditya et al. verified the optimal CH authority in each part of H-LEACH and verifies the optimal clusters.

HADCC is an approach to determine a path in clustering form suggested by Aslam [5]. In it, the nodes are placed in two levels: inner and outer. The inner level contains the circle form for advance sensors positions. Sink is having the responsibility of choosing the CHs. Many factors have been used for this like: Total and remaining power, distance etc. CSMA method assigns schedule for data transfer.

Another process uses the sink in the mid of the deployed area and the area is partitioned into optimal parts such that every part is having equal amount of energy [6]. After this, total 5% of total nodes are chosen as CHs. Probability and transmission power are used for clustering. Now the CHs communicate with other CHs with any partition restriction.

Another approach uses the concept of multi-hop [7], in which the maximum power nodes are placed near to sink and low power nodes placed far from the sink. This concept uses to reduce the effect of black hole problem since every packet pass through nearest nodes.

Subhasis et al. provided a hierarchy based node deployment in which each node has two parents except the root. This algorithm starts with finding the level for each node with its residual energy in next phase. After this, the nodes are divided into active node or inactive node. Active node finds two parents to connect and inactive node remains in sleep mode. Last phase is of data transmission.

Delaney et al. [9] proposed a metrics based route finding approach and balance the distance in routes. It uses and takes the support of routing matrices of nodes and find efficient route.

Halder et al. [10] provided routing and clustering process using the model of Archimedes spiral. This spiral is start from the center and make a view of turn till the end point. This spiral is used to calculate the distance between two nodes and also helps to maintain about equal distance among the nodes. Gujman et al. [11] provided ON/OFF capacity nodes for lifetime increment with low and high energy nodes.

Lee et al. [12] suggested an approach that uses semi-distribution method in which four levels are used as upper and lower. Upper level CHs are chosen in centralized manner, whereas, CHs are chose in distribution form in lower level. First sink is there then after grid head level 2, after it, level1 CHs are there and at last level 0 nodes are placed. Level 0 nodes sense the surroundings and transfer it to the level 1 and forwarded to sink via grid head.

Sanjay [13] proposed clustering for integrated network in which the area is partitioned into some regions with centralized sink. Now, CHs are chosen using its weight and also change the
responsibility in continuous fashion. PRRP method [14] is suggested by Zoman et al. in which the grid form is used for area division. Due to this, every node position got known and reduces the energy needed in searching process. Krishna et al. [15] provided two layered deployment approach in which they compared the two deployment approach. One is when inner deployment be in circular form and outer is in hexagonal form whereas in other the outer form is of pentagonal. Both the layers is having different CHs and hierarchical transmission takes place. Shubham et al. [16] suggested optimized clustering to this paper using divisional method. Some surveys [17], [18] are also performed regarding node deployment strategies. Many other authors also suggested many methods for efficient communication [19], [20], [21], [22], [23]. Some approaches by [24], [25], [26] also suggested intra cluster transmission using many efficient routes. Matrix method is also proposed by [27] to select best population for next generation. Many conflicting attributes are also suggested and applied with MADM approaches for load balance by [28] and for energy balanced by [29]. But these techniques can be applied with high computational sensor networks. Some algorithms for low computation network with lower attributes and simple calculations are also suggested by [30], [31], [32], [33], [34], [35], [36], [37], [38]. Neetu et. al [39] provides efficient communication to supervise the gas pipeline using clustering. Fuzzy tool can also be a option taken by [40], [41], [42], [43] for selection of optimal CHs that are able to perform data transfer with minimum use of energy. Here, we have proposed a method that uses AHP protocol that chose best alternative solution for node deployment with 100% area coverage, low cost, higher CH coverage and higher sink connectivity. The approach is explained in detail in next section.

3. Proposed Approach

We have proposed an AHP based method that provides a way to chose best node deployment with maximum area coverage, connectivity and less cost among many options. The Figure ?? shows the working of proposed algorithm in step by step process as a flow chart of complete procedure.

Table 1 shows the parameters to generate network and deploy the nodes.

Here, first we see whether the network is covering whole area or not. For this, first we calculate

\[
\text{Cover}_{\text{percent}} = \frac{\sum_{x=0}^{x_{\text{max}}} \sum_{y=0}^{y_{\text{max}}} SC(x,y)}{x_{\text{max}} \cdot y_{\text{max}}} \cdot 100
\]

Table 1. Factor Values for network deployment

| Factor                  | Values   |
|------------------------|----------|
| Size                   | 200m x 200m |
| Sensor Position        | Variable |
| Prime Power of sensor  | 1J       |
| Sensor Nodes           | Variable |
and

\[
SC(x_1, y_1) = \begin{cases} 
1 & \text{if } \exists \ p \in (1..N), \quad D(x_p,y_p),(x_1,y_1) \leq R_{\text{Sense}} \\
0 & \text{otherwise} 
\end{cases}
\]

where \(SC(x_1,y_1)\) - supervise condition of point \((x_1,y_1)\)

We find the alternatives with different count and position of nodes. Now, our aim is to chose the best alternative having minimum cost with maximum CH coverage and sink connectivity. For this we have used AHP algorithm that ranks the alternatives and provides best solution among them that would satisfy all the constraints with better conditions. Per unit cost contains sensor cost, LIPO battery cost, and GPS device cost for each sensor node, so when we calculate the cost of sensor, it comes around 7350 Rs. per unit. There are following steps that can determine the complete approach.

**Step I:** Generate the alternatives and calculate the values of factors-

| S.No. | Nodes | Cost    | Area Cover | CH Cover | BS Connect |
|-------|-------|---------|------------|----------|------------|
| 1     | 100   | 735000  | 98.2       | 100      | 50         |
| 2     | 100   | 735000  | 98.2       | 95       | 90         |
| 3     | 100   | 735000  | 100        | 95       | 80         |
| 4     | 100   | 735000  | 100        | 92       | 60         |
| 5     | 100   | 735000  | 100        | 94       | 50         |
| 6     | 100   | 735000  | 100        | 92       | 50         |
| 7     | 100   | 735000  | 100        | 95       | 80         |
| 8     | 100   | 735000  | 100        | 97       | 80         |
| 9     | 120   | 882000  | 100        | 100      | 40         |
| 10    | 120   | 882000  | 100        | 97.5     | 60         |
| 11    | 120   | 882000  | 100        | 100      | 50         |
| 12    | 120   | 882000  | 100        | 97.5     | 60         |
| 13    | 130   | 955500  | 100        | 100      | 50         |
| 14    | 130   | 955500  | 100        | 99.23076923 | 60         |
| 15    | 130   | 955500  | 100        | 99       | 80         |
| 16    | 130   | 955500  | 100        | 98.46153846 | 70         |
| 17    | 130   | 955500  | 100        | 100      | 60         |
| 18    | 150   | 1102500 | 100        | 100      | 50         |
| 19    | 150   | 1102500 | 100        | 100      | 80         |
| 20    | 150   | 1102500 | 100        | 99.33333333 | 80         |

Table 2 shows the values for different alternatives having different node count with the cost, area coverage, CH coverage and sink connectivity. Now we will apply the AHP algorithm and rank the alternatives, finally we will select the best alternative and the corresponding CHs for the final transmission of data. The next step explains the complete AHP process.

**Step II:** Apply MADM Approaches for rank the solutions:

3.1. **Apply AHP method to rank the solutions**

**Step A.a:** **Normalization**- Normalized matrix (NM) is calculated as:

For beneficiary factors:

\[
\text{Norm\_value}_i = \frac{\text{Value\_Factor}_i}{\text{Max\_value\_Factor\_in\_All\_CH}}
\]  

(2)
For Non-beneficiary factors:

\[ \text{Norm}_{\text{value}}{i} = \frac{\text{Min}_{\text{value,Factor in All CHs}}}{\text{Value}_{\text{Factor},i}} \]  \hspace{1cm} (3)

**Step A.b: Compute Relative Importance Matrix RW** - It shows the relative importance of the factors with each other. In our proposed method, it is formed as:

|           | cost  | coverage | connectivity |
|-----------|-------|----------|--------------|
| cost      | 1     | 1.7      | 1.3          |
| coverage  | 0.59  | 1.00     | 0.91         |
| connectivity| 0.77  | 1.10     | 1.00         |

**Table 3. RW Matrix for attributes**

**Step A.c: Compute Geometric Mean** - It is calculated as row wise and is calculated as:

\[ G_{\text{Mean}k} = \left( \prod_{k=1}^{N} \text{RW}_{pq} \right)^{1/N}, p = 1, 2, \ldots, m \quad \text{and} \quad q = 1, 2, \ldots, m \]  \hspace{1cm} (4)

where \( \text{RW} \) is the relative weight importance matrix and \( m \) is the number of factors.

**Step A.d: Enumerate Weights in Matrix Form** - Matrix contains weight of all factors is enumerated as:

\[ \text{Weight}_{Mk} = \frac{G_{\text{Mean}k}}{\sum_{j=1}^{N} G_{\text{Mean}j}} \]  \hspace{1cm} (5)

It should verify that \( \sum_{k=1}^{N} \text{Weight}_{Mk} = 1 \)

**Table 4. Weight\(_{M3 \times 1}\) Matrix for attributes**

|           |
|-----------|
| 0.425661937 |
| 0.265248859 |
| 0.309089204 |

**Step A.e: Consistency Verification of Weights** - Following steps are used to verify the consistency of our calculated weights:

Step A.e.1: Enumerate Consistency Matrix1 as:

\[(CM1)_{N \times 1} = (RW)_{n \times n} \ast (G_{\text{Mean}})_{n \times 1} \]  \hspace{1cm} (6)

Step A.e.2: Enumerate Consistency Matrix2 as:
\[(CM_2)_{N*1} = \frac{(CM_1)_{N*1}}{(Weight_M)_{N*1}} \]  

(7)

Enumerated consistency matrix 2 for proposed approach is:

| \( CM_{2,3} \) Matrix for attributes |
|--------------------------------------|
| 3.00324589                           |
| 3.007364497                           |
| 3.004310686                           |

Step A.e.3: Enumerate \( \lambda_{max} \)

\[ \lambda_{max} = \frac{\sum_{p=1}^{N} (CM_2)_p}{N} \]  

(8)

Enumerated \( \lambda_{max} \) for proposed approach is: 3.004999924

Step A.e.4: Enumerate Consistency Index-

\[ Cont\_Index = \frac{\lambda_{max} - N}{N-1} \]  

(9)

Enumerated Consistency Index for proposed approach is: 0.002499962

Step A.e.5: Enumerate Consistency Ratio-

\[ Const\_Ratio = \frac{Cont\_Index}{RI} \]  

(10)

where \( RI \) = Random Index.

\( Const\_Ratio \) should be less than 0.1 for error less than 10%.

Enumerated Consistency Ratio for proposed approach is: 0.00480762. Means total error is 0.48%.

Since it is less than 0.1, so our enumerated weights are acceptable.

Step A.f: Enumerate Efficiency Value for Each Alternative- Following two methods are used to enumerate efficiency value for each alternative. Simple Additive Weighting (SAW) or Weighted Product Method (WPM) uses these weights to compute the values of \( P_i \).

1) SAW Method: It is known as Simple Additive Weighting method. It enumerates efficiency value for alternative as:

\[ EV_k = \sum_{k=1}^{N} (Weight_M)_k \ast (NM)_{jk}, j = 1, 2, .., m \]  

(11)

2) WPM Method: It is known as Weighted Product Method. It enumerates efficiency value for alternative as:
\[ EV_k = \prod_{k=1}^{N} (\text{Weight}_M)_k \ast (NM)_{jk}, j = 1, 2, \ldots, m \] (12)

In proposed approach, we have used SAW method to enumerate efficiency value.

**Step A.g: Rank the Solutions using Efficiency Value** - After ranking the final rank for each solution or alternative in proposed approach is shown in Table 6:

| Pop Num | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| Rank    | 8 | 1 | 3 | 6 | 9 | 10| 4 | 2 | 18| 14 | 16 | 12| 5 | 17 | 15 | 7 | 11 | 19 | 20 | 13 |

3.2. **TOPSIS method to rank the solutions**

Rank the patients as higher value of condition \( C_{\text{worst}} \) using TOPSIS is shown in Table 7.

| Pop Num | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| Rank    | 12| 1 | 3 | 9 | 13| 14| 4 | 2 | 20| 11 | 18 | 10 | 5 | 19 | 15 | 6 | 8 | 16 | 17 | 7  |

3.3. **PROMETHEE method to rank the solutions**

Rank the patients using PROMETHEE is shown in Table 8.

| Pop Num | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| Rank    | 5 | 1 | 3 | 8 | 14| 16| 4 | 2 | 11| 13 | 10 | 6 | 7 | 19 | 17 | 9 | 15 | 18 | 20 | 12 |

4. **Results and Analysis**

We have simulated our approach on WSN modeled by using MATLAB tool that gives realistic support to perfect vision of data transfer and energy consumption with death of nodes. We have applied our approach on homogeneous network having equal amount of prime power with equal characteristics of nodes for energy depletion. A node is known to be dead of the energy becomes less than the threshold value this threshold value is equal to the energy required to send the packet to a distance where no amplification is needed for packet transmission. We have compared among Proposed algorithm, Base Algorithm [16], SNPCM [15], and LEACH [2].

Case 1: Sensors=500; Sink=0,0
Case 2: Sensors=500; Sink=150,50

| Pop Num | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| Rank    | 12| 1 | 3 | 9 | 13| 14| 4 | 2 | 20| 11 | 18 | 10 | 5 | 19 | 15 | 6 | 8 | 16 | 17 | 7  |

| Pop Num | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|
| Rank    | 5 | 1 | 3 | 8 | 14| 16| 4 | 2 | 11| 13 | 10 | 6 | 7 | 19 | 17 | 9 | 15 | 18 | 20 | 12 |

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5. Conclusion
 Proposed algorithm provided efficient deployment of sensor in the field in such a way that the whole area can be sensed by at least one sensor means 100% area coverage must be provided to the network. It also gave the possible smallest amount of nodes for the coverage, that minimizes the cost with the constraint of effective data collection. The effectiveness of data collection is confirmed by the maximum CH coverage and sink connectivity. Maximization of CH coverage confirms the minimization of the distance to CHs from all the respective nodes that minimized the power consumption from nodes to CHs. Whereas, the maximization of sink connectivity confirms the minimization of distance from CHs to the sink that reduces the power consumption for data transfer from CHs to the sink. Finally, the results also support the effectiveness of the proposed approach.

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**Acknowledgment**

This work would not have been possible without the financial support of TEQIP-III, Rajkiya Engineering College, Ambedkar Nagar.