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EVALUATION OF WIRELESS SENSOR NETWORK CLUSTER HEAD SELECTION FOR DIFFERENT PROPAGATION ENVIRONMENTS BASED ON LEE PATH LOSS MODEL AND K-MEANS ALGORITHM

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Abstract— In this paper, the evaluation of wireless sensor network (WSN) cluster head selection for different propagation environments based on Lee path loss model and K-means algorithm is presented. A set of 50 WSN nodes distributed randomly over an area of 3000 m by 3000 m with the base station located in the middle of the area , at the coordinate of x = 1500 m and y = 1500 m. The X and y coordinates of each of the 50 WSN nodes were generated using Matlab software random number generators function. The coordinate geometry formula for distance, d between two points with coordinates, (x_1, y_1) and (x_2, y_2) is used to compute the distance from each of the nodes to the base station and then the distances were used to compute the path loss and hence the received signal strength (RSS) for each of the nodes. The computation was conducted for the three different propagation environments, as specified in the Lee model, namely, the urban , the suburban and the rural or open area. Based on RSS (-60 dBm ≤ RSS ≤ -90 dBm), candidate cluster heads were selected for the urban , the suburban and the rural or open area. Afterwards, the K-means clustering algorithm was used to select the cluster heads from the candidate cluster heads. The results show that for the urban area, only 4 nodes were selected as cluster heads ; the node with a received signal strength of -60.8 dBm had the highest number of 17 slave nodes clustered around it whereas, the node with a received signal strength of -91.7 dBm had the lowest number of 10 slave nodes clustered around it. Also, for the open or rural area, 12 nodes were selected as cluster heads; the node with a received signal strength of -60.1 dBm had the highest number of 13 slave nodes clustered around it whereas, the several cluster head nodes with received signal strength lower than -60.1dBm had the lowest number of 2 slave nodes clustered around them. In all, the results showed that the urban area had the highest path loss, the lowest RSS value and the lowest number of cluster heads selected by the K-means algorithm. On the other hand, the open or rural area had the lowest path loss, the highest RSS value and the l highest number of cluster heads selected by the K-means algorithm.

Keywords— K-means algorithm, Lee path loss model, wireless sensor network, sensor device, propagation loss, received signal strength.

1.0 Introduction

Wireless sensor networks (WSNs) are very useful technology for smart city and other contemporary applications [1,2,3,4,5,6,7,8]. In WSNs, resource limited sensor devices are used to collect data from the environment and to transmit the data to remote locations. [9,10,11,12,13,14]. One of the key challenges of WSN is the power limitations of the sensor devices which tends to lime the WSN lifetime [15,16,17,18,19,20]. As such, effort is always made in WSN to adopt energy efficient approaches that will enhance WSN life time. One of such energy efficient approach is device-to-device communication which utilizes clustering mechanism to select appropriate set of WSN nodes as cluster head heads which aggregates the data from the other nodes in the network and relay them through the base station or gateway to their respective destination [21,22,23,24,25,26,27,28,29,30,31].

In any case, the transmission energy demand depends among other things on the distance [32,33,34,35,36] of the nodes from the base station as well as path loss [37,38, 39,40,41,42,43,44] which depends on the environmental factors. Accordingly, in this paper, the effect of propagation environment on the cluster head selection by K-means algorithm is studied [45,46,47,48]. The study is based on the received signal strength (RSS) computed using Lee path loss model [49,50] and link budget formula. The computation was carried out for three different propagation environments, as specified in the Lee model. A common RSS range of values were used for cluster head selection in the three propagation environment. The actual computation was conducted using the Matlab tools for K-means algorithm. Key analytical expression are presented along with requisite data and discussion of findings.

2. Methodology

The papers presents a study of cluster head selection in a wireless sensor network for different propagation environment based on Lee path loss model K-means clustering algorithm. The study considers a set of 50 sensor network nodes distributed randomly over an area of 3000 m by 3000 m. The Base station in the network is located in the middle of the area and it has the coordinate of x = 1500 m and y = 1500 m. The X and y coordinates of each of the 50 WSN nodes are generated using Matlab software random number generators function and they are shown in Figure 1.

The coordinate geometry formula for distance, d between two points with coordinates, (x_1, y_1) and (x_2, y_2) is used to compute the distance from each of the nodes to the base station, where;

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \qquad (1)$$

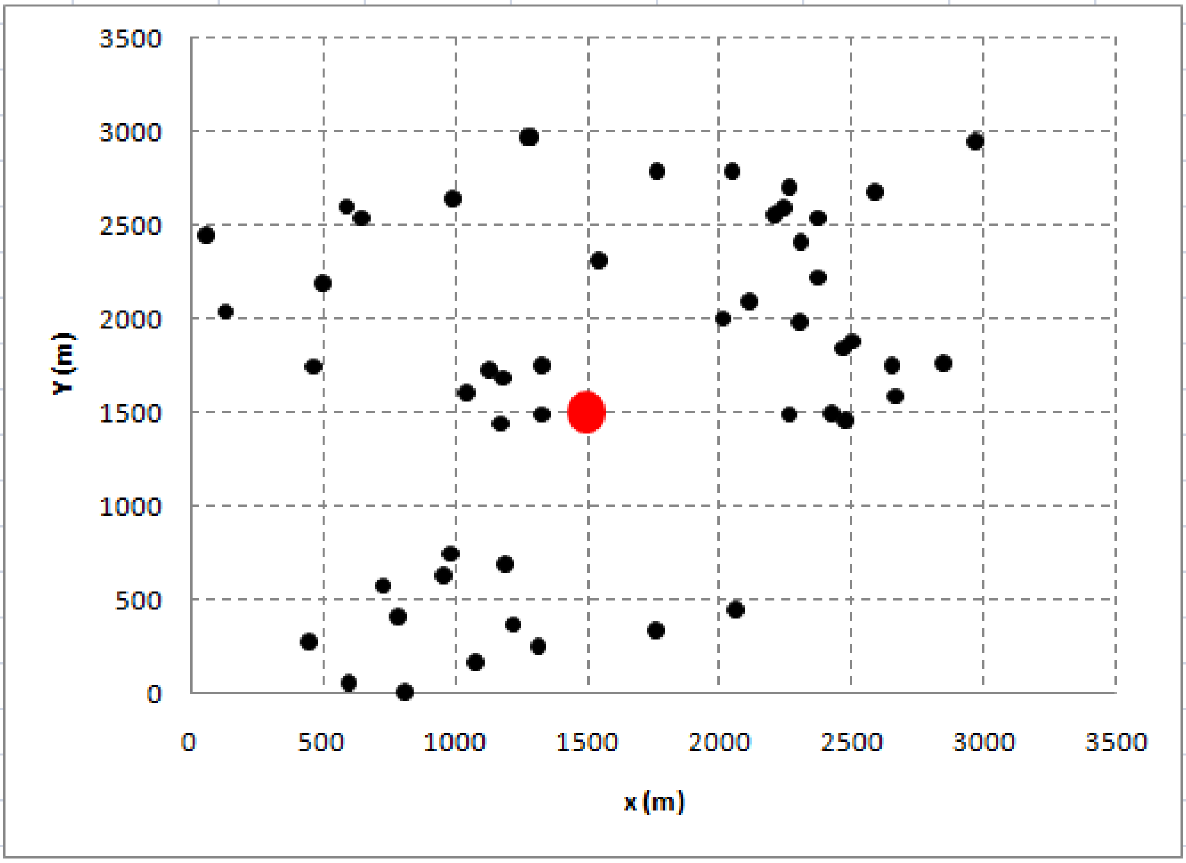

Figure 1; Coordinate positions of the 50 WSN nodes and the base station at the center (1500 m, 1500 m)

The received signal strength (RSS) at each of the nodes is estimated using link budget formula where the path loss was estimated using Lee path loss model for three different propagation environments, namely, the urban area, the suburban area and rural area. The propagation loss according to Lee path loss model is given as follows;

$$LP_{LEE(dB)} = (10n)\log_{10}(d) - (20)\log_{10}(h_b) - (P_0) - (10)\log_{10}(h_m) + 29 \qquad (2)$$

Where

f is the centre frequency f in MHz;

d = path length in km;

h_b= antenna height of the base station;

h_m = antenna height of the mobile station;

The values of n and Po for the Lee path loss model are given in Table 1 for the various propagation environments.

Table 1 The value of n and Po for the Lee path loss model

Environment	P_o	n
Free space	80	2.0
Open Area	89	4.35
North American Suburban	101.7	3.85
North American Urban	110	3.68

The RSS is dBm according to link budget formula is given as;

$$RSS = P_T + G_T + G_R - LP_{LEE(dB)} \qquad (3)$$

Where P_T = transmitter power, G_T = transmitter antenna gain and G_R = receiver antenna gain. Based on Lee model and the values of Po and n in Table 1, the RSS was computed for the open rural area, the suburban area and the urban area. The RSS values obtained were then used in Matlab for K-means based cluster head selection from the 50 WSN nodes. The cluster head selection was first based on a set rang of RSS values for the candidate nodes that can be eligible to serve as cluster heads. Specifically, in this paper, the receiver sensitivity is assumed to be -110 dBm and the range of values of RSS for used nodes for selecting candidate cluster heads is -60 dBm ≤ RSS ≤ -90 dBm. The same range of values of RSS was used for the three different propagation environments, namely, the open rural area, the suburban area and the urban area.

3. Simulation and Results

The results of the devices or nodes selected as candidate cluster heads for the urban area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm) are given in Table 2 and Figure 2. Similar results of the devices or nodes selected as candidate cluster heads for the suburban is shown in Table 3 and Figure 3 while the results for the open or rural area is shown in Table 4 and Figure 3. In all, based on the selected range of values for RSS, there are 12 candidate nodes in the urban area, 19 candidate nodes in the suburban area and 39 candidate nodes in the open or rural area.

Table 2 The results of the devices or nodes selected as candidate cluster heads for the urban area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm).

S/N	Device Number	x-coordinate (m)	y-coordinate (m)	d (km)	Lee Path Loss For Urban (dB)	RSSI For Urban (dB)
1	1	1043.1	1602.2	1.2287	101.7	-91.7
2	2	449.99	269.85	0.2355	70.8	-60.8
3	4	786.44	408.88	0.3006	75.4	-65.4
4	7	728.36	569.13	0.2386	71.1	-61.1
5	10	1077.7	164.92	0.6678	90.3	-80.3
6	19	810.81	1.5671	0.5874	87.9	-77.9
7	26	1190.4	683.53	0.7144	91.6	-81.6
8	33	982.7	740.2	0.5392	86.3	-76.3
9	35	1315.9	250.45	0.8532	94.9	-84.9
10	45	599.59	50.949	0.46	83.3	-73.3
11	46	1220.9	362.58	0.7339	92.1	-82.1
12	50	955.57	628.22	0.4733	83.9	-73.9

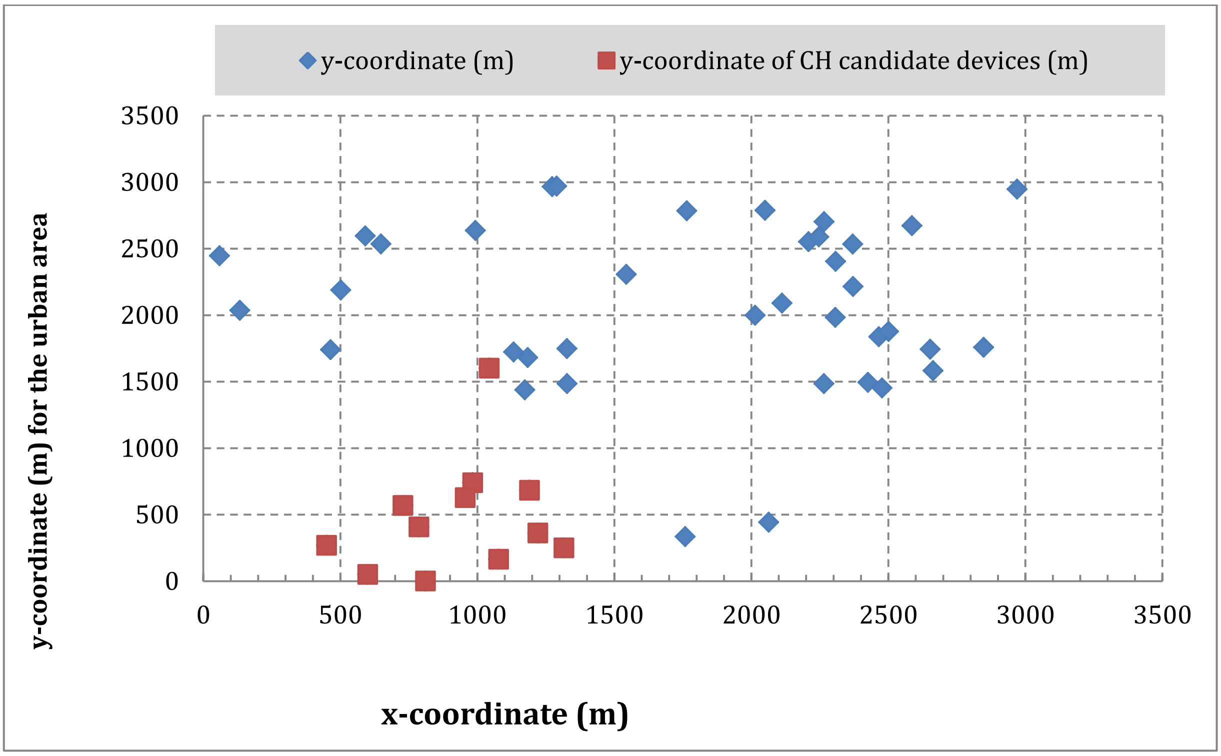

Figure 2 The results of the devices or nodes selected as candidate cluster heads (red square dots) for the urban area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm).

Table 3 The results of the devices or nodes selected as candidate cluster heads for the suburban area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm).

S/N	Device Number	x-coordinate (m)	y-coordinate (m)	d (km)	Lee Path Loss For Suburban (dB)	RSSI For Suburban (dB)
1	1	1043.1	1602.2	1.2287	98.3	-83.3
2	3	1758.3	335.12	1.2691	98.9	-83.9
3	5	133.36	2036	1.5792	102.5	-87.5
4	8	1327.2	1485	1.2863	99.1	-84.1
5	9	2063.4	442.82	1.5644	102.4	-87.4
6	10	1077.7	164.92	0.6678	88.1	-73.1
7	12	1184.1	1681.7	1.3654	100.1	-85.1
8	15	1326.9	1748.4	1.4974	101.6	-86.6
9	19	810.81	1.5671	0.5874	86	-71
10	24	1173.5	1438.6	1.1552	97.3	-82.3
11	26	1190.4	683.53	0.7144	89.3	-74.3
12	29	1132.2	1724	1.3776	100.2	-85.2
13	33	982.7	740.2	0.5392	84.6	-69.6
14	35	1315.9	250.45	0.8532	92.2	-77.2
15	38	501.76	2189.3	1.6893	103.6	-88.6
16	44	464.26	1740.3	1.2408	98.5	-83.5
17	45	599.59	50.949	0.46	81.9	-66.9
18	46	1220.9	362.58	0.7339	89.7	-74.7
19	50	955.57	628.22	0.4733	82.4	-67.4

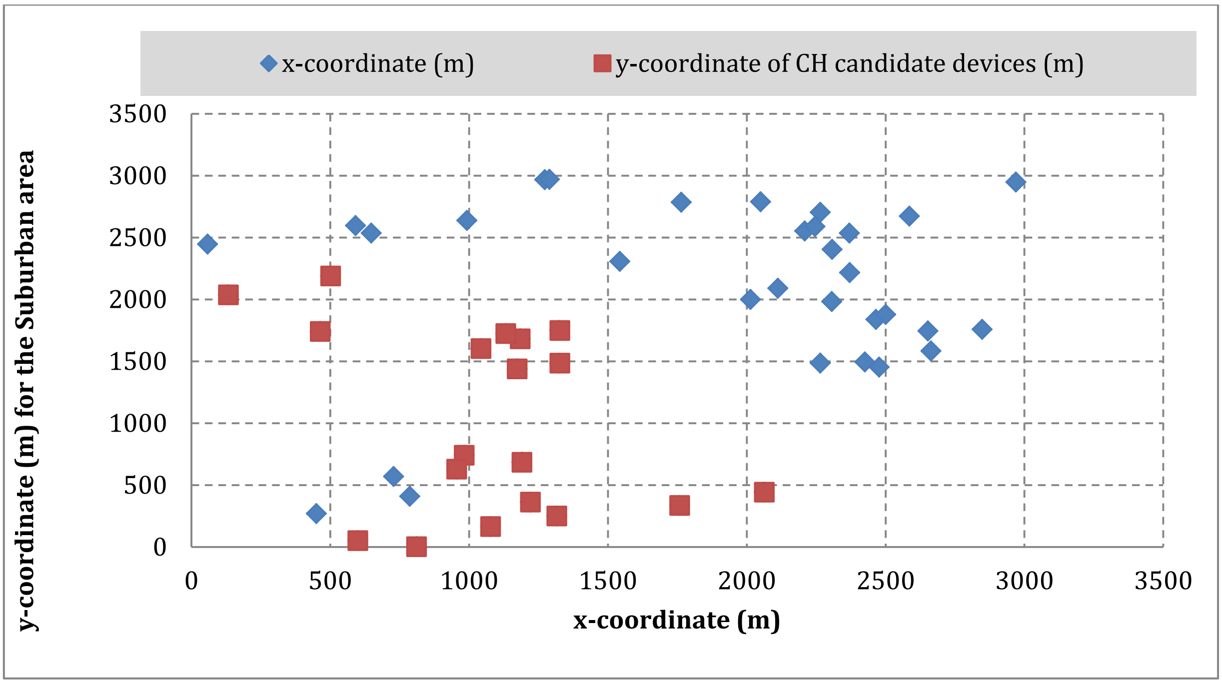

Figure 3 The results of the devices or nodes selected as candidate cluster heads (red square dots) for the suburban area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm).

Table 4 The results of the devices or nodes selected as candidate cluster heads for the open or rural area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm).

S/N	Device Number	x-coordinate (m)	y-coordinate (m)	d (km)	Lee Path Loss For Rural/Open (dB)	RSSI For Rural/Open (dB)
1	1	1043.1	1602.2	1.2287	75.7	-60.7
2	3	1758.3	335.12	1.2691	76	-61
3	5	133.36	2036	1.5792	77.8	-62.8
4	6	2264.8	1485.5	2.0213	80	-65
5	8	1327.2	1485	1.2863	76.1	-61.1
6	9	2063.4	442.82	1.5644	77.8	-62.8
7	11	2209	2552.1	2.6705	82.4	-67.4
8	12	1184.1	1681.7	1.3654	76.6	-61.6
9	13	2050.2	2788.8	2.7644	82.7	-67.7
10	14	2112.1	2090	2.2643	81	-66
11	15	1326.9	1748.4	1.4974	77.4	-62.4
12	16	58.733	2446.2	1.9956	79.9	-64.9
13	17	992.57	2637	2.193	80.7	-65.7
14	18	1272.9	2966.7	2.585	82.1	-67.1
15	20	591.16	2596.3	2.0983	80.3	-65.3
16	21	2465.2	1837.7	2.3773	81.4	-66.4
17	22	1289.8	2969.9	2.5931	82.2	-67.2
18	23	2663.3	1583	2.4192	81.6	-66.6
19	24	1173.5	1438.6	1.1552	75.1	-60.1
20	25	2307.3	2404	2.6252	82.3	-67.3
21	27	2425.5	1494.3	2.1671	80.6	-65.6
22	28	2265.2	2702.6	2.8227	82.9	-67.9
23	29	1132.2	1724	1.3776	76.7	-61.7
24	30	648.06	2535.5	2.0409	80.1	-65.1
25	31	2371.2	2215.9	2.5388	82	-67
26	32	2847.9	1758	2.6637	82.4	-67.4
27	34	2013.8	1999.2	2.1305	80.5	-65.5
28	36	2500.5	1877.9	2.4291	81.6	-66.6
29	37	2306.6	1982.8	2.3372	81.3	-66.3
30	38	501.76	2189.3	1.6893	78.4	-63.4
31	39	2585.9	2672.3	3.0116	83.5	-68.5
32	40	2969.6	2946.9	3.4765	84.7	-69.7

33	41	1543.3	2307.1	2.0866	80.3	-65.3
34	42	2652.8	1744.3	2.4865	81.8	-66.8
35	43	1764.1	2784.9	2.6113	82.2	-67.2
36	44	464.26	1740.3	1.2408	75.8	-60.8
37	47	2246.1	2588.1	2.722	82.6	-67.6
38	48	2476.8	1452.9	2.1945	80.7	-65.7
39	49	2369.9	2534.6	2.7634	82.7	-67.7

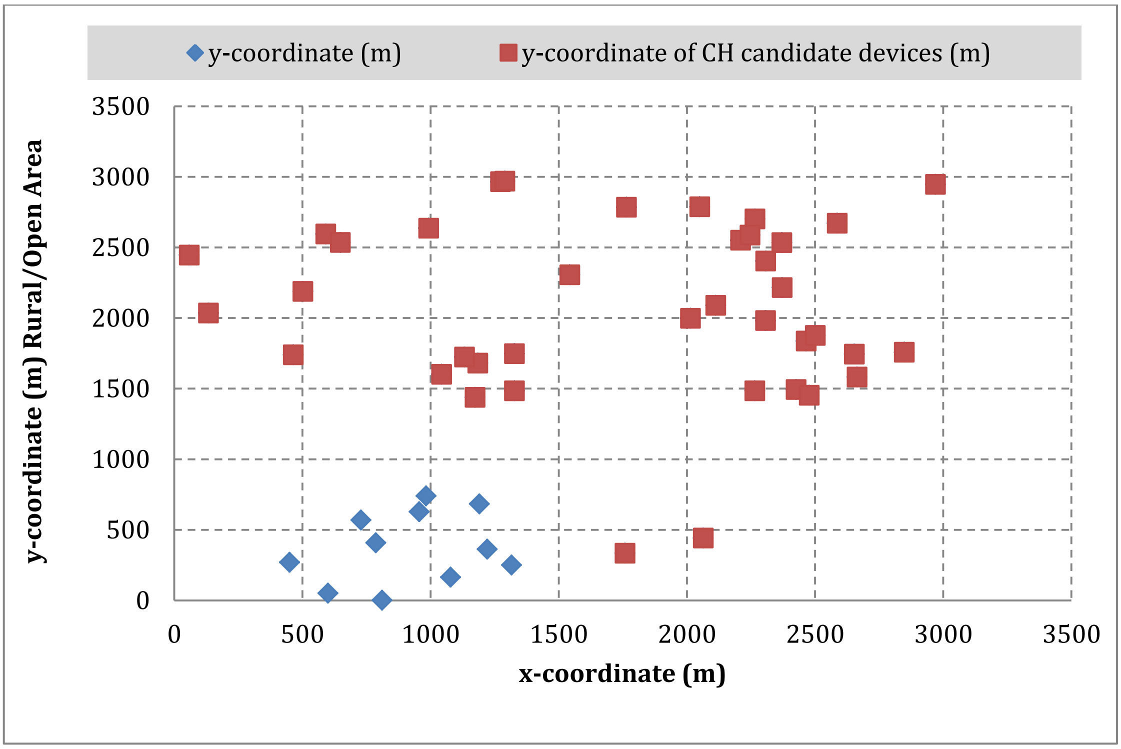

Figure 4 The results of the devices or nodes selected as candidate cluster heads (red square dots) for the open or rural area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm).

The results of the nodes selected as cluster heads by the K-means algorithm for the urban area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm) are shown in Table 5. Table 5 shows that only 4 nodes are selected as cluster heads in the urban propagation environment and the node with a received signal strength of -60.8 dBm had the highest number of 17 slave nodes clustered around it whereas, the node with a received signal strength of -91.7 dBm had the lowest number of 10 slave nodes clustered around it.

Again, the results of the nodes selected as cluster heads by the K-means algorithm for the suburban area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm) are shown in Table 6. Table 6 shows that 7 nodes are selected as cluster heads in the urban propagation environment and the node with a received signal strength of -66.9 dBm had the highest number of 13 slave nodes clustered around it whereas, the node with a received signal strength of -87.4 dBm had the lowest number of 2 slave nodes clustered around it.

Furthermore, the results of the nodes selected as cluster heads by the K-means algorithm for the open or rural area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm) are shown in Table 7. Table 7 shows that 12 nodes are selected as cluster heads in the open or rural propagation environment and the node with a received signal strength of -60.1 dBm had the highest number of 13 slave nodes clustered around it whereas, the several cluster head nodes with a received signal strength lower than -60.1dBm had the lowest number of 2 slave nodes clustered around them. The bar chart showing the comparison of the number of selected candidate cluster heads based on RSS (-60 dBm ≤ RSS ≤ -90 dBm) and the number of K-means selected cluster heads for the three different propagation environments is shown in Figure 5. The results show that the urban area had the highest path loss, the lowest RSS value and the lowest number of cluster heads selected by the K-means algorithm. On the other hand, the open or rural area had the lowest path loss, the highest RSS value and the highest number of cluster heads selected by the K-means algorithm.

Table 5 The results of the nodes selected as cluster heads by the K-means algorithm for the urban area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm)

Device Number	x-coordinate (m)	y-coordinate (m)	d (km)	Lee Path Loss For Urban (dB)	RSSI For Urban (dB)	Number of Slave Nodes to the cluster head
1	1043.1	1602.2	1.2287	101.7	-91.7	10
2	449.99	269.85	0.2355	70.8	-60.8	17
3	982.7	740.2	0.5392	-76.3	-76.3	12
4	1315.9	250.45	0.8532	-84.9	-84.9	7

Table 6 The results of the nodes selected as cluster heads by the K-means algorithm for the suburban area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm)

S/N	Device Number	x-coordinate (m)	y-coordinate (m)	d (km)	Lee Path Loss For Suburban (dB)	RSSI For Suburban (dB)	Number of Slave Nodes to the cluster head
1	5	133.36	2036	1.5792	102.5	-87.5	6
2	9	2063.4	442.82	1.5644	102.4	-87.4	2
3	15	1326.9	1748.4	1.4974	101.6	-86.6	4
4	26	1190.4	683.53	0.7144	89.3	-74.3	8
5	38	501.76	2189.3	1.6893	103.6	-88.6	3
6	44	464.26	1740.3	1.2408	98.5	-83.5	7
7	45	599.59	50.949	0.46	81.9	-66.9	13

Table 7 The results of the nodes selected as cluster heads by the K-means algorithm for the open or rural area based on the set range of value for RSS (-60 dBm ≤ RSS ≤ -90 dBm)

S/N	Device Number	x-coordinate (m)	y-coordinate (m)	d (km)	Lee Path Loss For Rural/Open (dB)	RSSI For Rural/Open (dB)	Number of Slave Nodes to the cluster head
1	3	1758.3	335.12	1.2691	76	-61	5
2	9	2063.4	442.82	1.5644	77.8	-62.8	3
3	13	2050.2	2788.8	2.7644	82.7	-67.7	2
4	14	2112.1	2090	2.2643	81	-66	3
5	21	2465.2	1837.7	2.3773	81.4	-66.4	2
6	24	1173.5	1438.6	1.1552	75.1	-60.1	6
7	30	648.06	2535.5	2.0409	80.1	-65.1	3
8	37	2306.6	1982.8	2.3372	81.3	-66.3	2
9	38	501.76	2189.3	1.6893	78.4	-63.4	3
10	39	2585.9	2672.3	3.0116	83.5	-68.5	2

11	41	1543.3	2307.1	2.0866	80.3	-65.3	3
12	44	464.26	1740.3	1.2408	75.8	-60.8	4

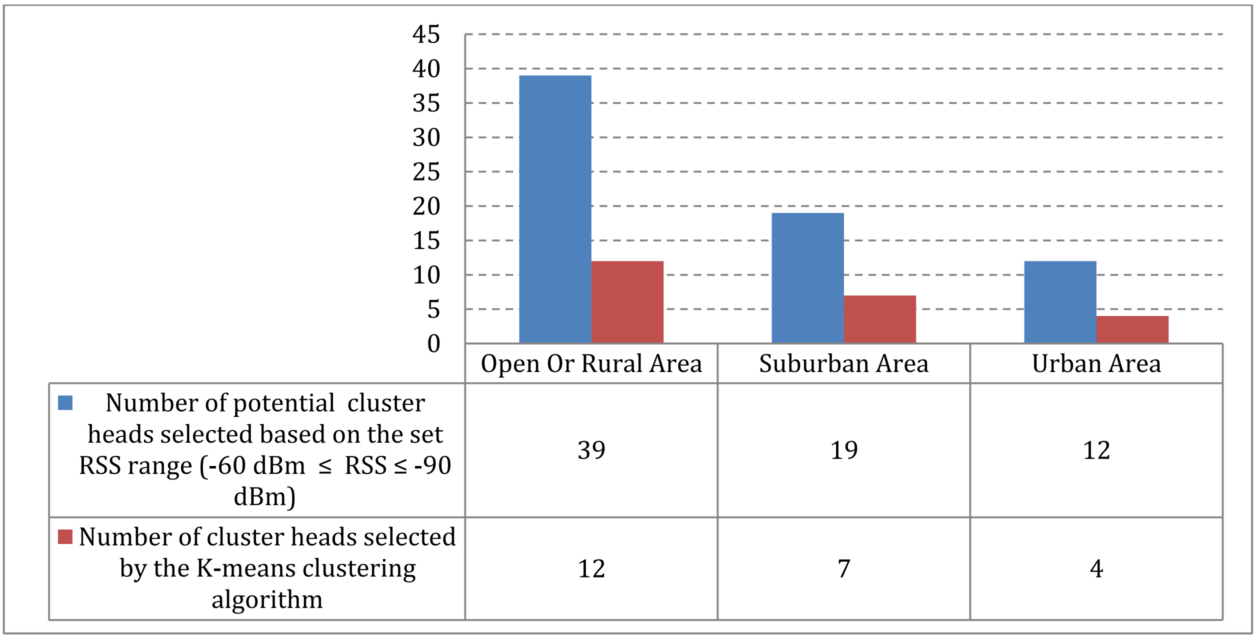

Figure 5 The bar chart of the number of selected as candidate cluster heads based on RSS (-60 dBm ≤ RSS ≤ -90 dBm) and the number of K-means selected cluster heads for the three different propagation environments

4. Conclusions

The ability of K-means clustering algorithm to select cluster heads from a set of wireless sensor network nodes is studies. The key parameter used for the cluster head selection is the received signal strength which was calculated suing Lee propagation loss model and link budget expression. The computation was conducted for the three different propagation environments, as specified in the Lee model, namely, the urban , the suburban and the rural or open area. The results show that the urban area had the highest path loss, the lowest RSS value and the lowest number of cluster heads selected by the K-means algorithm. On the other hand, the open or rural area had the lowest path loss, the highest RSS value and the l highest number of cluster heads selected by the K-means algorithm.

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