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CLUSTERING OF WIRELESS SENSOR NODES WITH SELF-ORGANIZING MAP (SOM) ALGORITHM

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***Abstract*— In this paper, clustering of wireless sensor nodes with self-organizing map (SOM) algorithm is presented. A wireless sensor network with 120 sensor nodes was considered. The sensor nodes were randomly located within a 1200 m by 1200 m square region with the base station at the center of the region (1200 m by 1200 m). The SOM clustering algorithm used the hardware capacity of the sensor nodes along with the x-y coordinates of the sensor nodes in the clustering process. Particularly, the received signal strength at the location of each of the sensor nodes was estimated using link budget and path loss computed using Hata model-based propagation loss. The SOM algorithm was simulated in MATLAB 2015a. The selection of cluster heads was based on the nodes with hardware capacity greater than 4.0 and above. The results show that 25 sensor nodes were selected as cluster heads from the 1200 sensor nodes. In all, the results show that all the cluster heads have hardware capacity that is above 4.0. Also, one cluster head has the maximum number of eight (8) slave nodes to a cluster head while two cluster heads have the lowest of one (1) slave node to a cluster head.**

***Keywords*— Clustering, Wireless Sensor Nodes, Self-Organizing Map (SOM), Clustering Algorithm, Link Budget, Hata Model, Cluster Heads**

I. INTRODUCTION

In recent years, advances in electronics and wireless communication technologies have facilitated wider applications and adoption of the technologies across the globe [1,2,3,4,5]. The notable adoption of tiny wireless sensors in precision agriculture, smart city technologies and other technological needs of the society has placed more demand on the capacity and capabilities of such resource-constrained sensor devices [6,7,8,9]. As such, there is growing researches on how to cope with the increasing demand on the quality of service (QoS) of wireless sensor networks (WSNs). In the early years of wireless communication technologies, the focus of researchers was on accurate prediction of the propagation loss [10,11,12,13,14], expected fade mechanisms and maximum fade depths [15,16,17], coverage area of the network or maximum path length or optimal path length [18,19,20,21], efficient call admission and handoff schemes [22,23,24,25,26,27,28], etc. In recent years, energy-aware and location-aware technologies are increasingly being used to improve on the QoS of wireless networks.

One particular area of importance is the device-to-device (D2D) communication technique which enables sensor devices to conserve transmission energy by transmitting to nearby device with sufficient hardware capacity and received signal strength which in turn will transmit the collected data to the end device through the base station [29,30,31,32,33,34,35,36,37]. In D2D communication, cluster head selection is essential and the clustering of the slave nodes to the cluster head is also required on a regular basis. As such, in this paper, the use of self-organizing map (SOM) algorithm for cluster head selection in a sensor network [38,39,40,41,42,43] is presented. The SOM algorithm is also used to cluster the sensor slave nodes to the cluster head nodes. The clustering algorithm in this paper utilized the hardware capacity of the sensor nodes and their estimated received signal strength to select the cluster heads from a set of sensor nodes. The sensor nodes that are not selected as cluster heads are then clustered around the cluster head nodes. The SOM cluster head selection and clustering process were simulated in MATLAB 2015a.

II. METHODOLOGY

A. The Case Study Data

In this paper, a network with 120 sensor nodes was considered. The sensor nodes were located within a 1200 m by 1200 m square region with the base station at the center of the region. The x-y position of the base station is 600 m by 600 m.

In the communication industry, the range of values for hardware capacity of sensor devices is from 0 to 5 which is defined by the following composite function [44];

$$\left.\begin{array}{ll} 4 < a \leq 5; & \text{very strong capacity.} \\ 3 < a \leq 4; & \text{strong capacity} \\ 2 < a \leq 3; & \text{fairly strong hardware capability} \\ 1 < a \leq 2; & \text{poor capability} \\ a \leq 1; & \text{very poor capability} \end{array}\right\} \quad (1)$$

where 'a' is the hardware capacity value of the sensor nodes. The hardware capacity (denoted as 'a') of each of the sensor nodes was generated in Matlab software using the random distribution function ($randnd$) as follows;

$$randnd = la + (ua - la) \times rand(120,1) \quad (2)$$

where ua indicates the maximum value of the device hardware capacity (which is 5) and la indicates the minimum value of the device hardware capacity (which is 0). Similarly, the x-y position of each of the 120 sensor nodes were generated in Matlab software using the random distribution function ($randnd$) as follows;

$$randnd = lb + (ub - lb) \times rand(120,1) \quad (3)$$

where ub indicates the maximum distance of the device from the base station (600m) and lb indicates the minimum point of the location of the devices from the base station

(0m). Table 1 shows the generated x-y coordinates of the sensor nodes and their hardware capacity .

Table 1; The hardware capacity and location (x-y) coordinates of the sensor nodes at 1200 m by 1200 m region

Device number	Hardware Capacity	x-coordinate (m)	y-coordinate (m)
1	4.0736	127.98	102.62
2	4.529	1154.3	314.98
3	0.63493	5.5611	961.22
4	4.5669	929.89	35.064
5	3.1618	980.76	1114.6
6	0.4877	1042.4	876.4
7	1.3925	101.32	586.33
8	2.7344	479.74	694.23
9	4.7875	311.84	284.74
10	4.8244	960.08	550.62
11	0.78807	517.7	1155.7
12	4.853	1092.8	656.17
13	4.7858	218.22	625.36
14	2.4269	316.56	277.91
15	4.0014	174.65	586.68
16	0.70943	163.28	748.87
17	2.1088	1043.2	814.96
18	4.5787	695.65	474.62
19	3.961	659.83	440.92
20	4.7975	173.95	1185.6
21	3.2787	1023.6	45.287
22	0.17856	746.47	1062.2
23	4.2456	421.14	1095.9
24	4.67	615.9	955.42
25	3.3937	482.17	118.45
26	3.7887	91.16	314.25
27	3.7157	287.9	402.43
28	1.9611	147.98	815.67
29	3.2774	220.69	163.86
30	0.85593	287.94	865.47
31	3.5302	500.72	128.11
32	0.15916	59.585	784.51
33	1.3846	1083.3	593.01
34	0.23086	1133.7	934.86
35	0.48566	589.04	858.04
36	4.1173	587.1	1084.5
37	3.4741	405.26	1069.1
38	1.5855	1080.1	401
39	4.7511	443.1	838.49
40	0.17223	133.44	237.37
41	2.1937	936.3	36.649
42	1.9078	467.69	892.89
43	3.8276	290.03	600.03
44	3.976	484.69	575.91
45	0.93436	115.75	1085.7
46	2.4488	158.37	731.84
47	2.2279	1130.5	741.2
48	3.2316	1147.4	1031.3
49	3.5468	690.25	966.59
50	3.7734	71.735	692.07
51	1.3801	281.74	219.51
52	3.3985	423.79	287.92
53	3.2755	985.43	1063.8
54	0.81306	18.484	34.409
55	0.59499	51.629	587.88
56	2.4918	202.79	201.51
57	4.7987	778.94	1174.4
58	1.7019	878.07	855.23
59	2.9263	777.3	600.57
60	1.1191	541.11	565.31
61	3.7563	656.41	71.543
62	1.2755	355.58	818.37
63	2.5298	893.63	50.917
64	3.4954	226.75	85.735
65	4.4545	824.13	625.98
66	4.7965	220.21	116.08
67	2.7361	442.18	981.78
68	0.69312	750.74	981.06
69	0.74647	936.27	866.93
70	1.2875	97.351	179.84
71	4.2036	1115.3	791.53
72	1.2714	930.86	622.31
73	4.0714	584.15	1167.6
74	1.2176	523.03	778.79
75	4.6463	536.14	960.4
76	1.7499	367.62	544.56
77	0.98298	610.21	518.87
78	1.2554	612.93	990.38
79	3.0802	981.15	100.16
80	2.3664	953.8	159.81
81	1.7583	773.18	208.07
82	4.1541	454.33	469.13
83	2.9263	973.9	997.66
84	2.7486	639.39	964.04
85	4.586	420.87	72.565
86	1.4292	1126.8	479.11
87	3.786	1051.1	632.25
88	3.7686	660.19	500.16
89	1.9022	746.97	788.23
90	2.8391	704.45	753.57
91	0.37927	249.29	350.38
92	0.26975	361.5	517.98
93	2.654	565.11	18.585
94	3.8958	276.59	1180.9
95	4.6701	1013.2	200.6
96	0.64953	233.72	127.46
97	2.8441	271.11	446.89
98	2.347	204.85	237.74
99	0.05951	273.2	587.63
100	1.6856	522.84	407.39
101	0.81091	373.32	1142
102	3.9714	1108.1	1104.4
103	1.5561	516.25	63.212
104	2.6427	221.78	885.43
105	0.82824	1085.9	322.94
106	3.0099	1175.7	507.4
107	1.3149	526.64	657.45
108	3.2704	133.34	1131.3
109	3.4461	309.68	501.29
110	3.7408	490.46	1179.7
111	2.2527	713.88	361.75
112	0.41911	314.65	841.32
113	1.1449	723.41	799.61
114	4.5667	853.46	646.95
115	0.76189	266.1	837.73
116	4.1291	140.9	799.83
117	2.6917	356.01	213.76
118	2.9807	382.53	153.62
119	0.39088	509	1198.9
120	2.2134	609.43	205.35

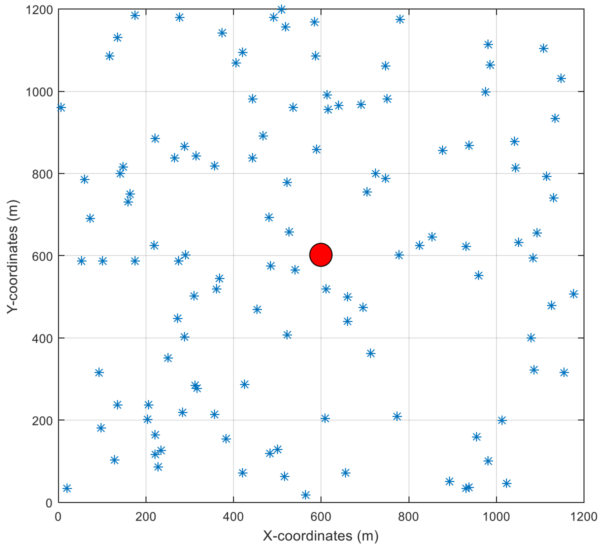

Figure 1; The x-y position of the WSN nodes and the base station.

The base station is located at x,y coordinates of 0,0 hence, the x and y coordinates of the sensor nodes indicates their horizontal and vertical distance from the base station. Accordingly, with the x-y coordinates, the Pythagoras formula was used to compute the distance of each of the nodes from the base station as follows;

$$d = \sqrt[2]{x^2 + y^2} \quad (4)$$

Next, the received signal strength (P_R) of each sensor node was calculated using link budget equation as follows;

$$P_R = P_T + (G_T + G_R) - PL \quad (5)$$

where;

P_R = Received Signal Power (dBm)

P_T = Transmitter Power Output (dBm)

G_T = Transmitter Antenna Gain (dBi)

G_R = Receiver Antenna Gain (dBi)

PL = Path Loss (dB) which in this paper is based on Hata path loss model. Also, in the paper, the parameter values are PT = 45 dBm, GT = 18.0 dBi, GR = 0 dBi . In this paper, the path loss is based on Hata model for urban area which is given as follows;

$$LP_{HATA(urban)} = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) + (44.9 - 6.55 * \log_{10}(h_b)) \log_{10}(d) \quad (6)$$

$$a(h_m) = [1.1 * \log_{10}(f) - 0.7] * h_m - [1.56 * \log_{10}(f) - 0.8] \quad (7)$$

$$a(h_m) = 8.28 * [\log_{10}(1.54 * h_m)]^2 - 1.1 \quad for\ large\ city\ \ f \leq 200\text{MHz} \quad (8)$$

$$a(h_m) = 3.2 * [\log_{10}(11.75 * h_m)]^2 - 4.97 \quad for\ large\ city\ \ f \geq 400\text{MHz} \quad (9)$$

Where the centre frequency, f is in MHz and the link distance , d is in km;

III. RESULTS AND DISCUSSION

The SOM algorithm was simulated in MATLAB 2015a. The simulation of the SOM-based cluster head selection was based on the data in Table 1 and further SOM-based clustering of the slave sensor nodes to the cluster heads. The selection of cluster heads was based on the nodes with hardware capacity greater than 4.0. The results show that 25 sensor nodes were selected as cluster heads from the 1200 sensor nodes which are shown in Table 2. Also, the cluster head position in terms of x-y coordinates is shown in Figure 2. The cluster head and the number of clustered slave sensor nodes to each of the cluster heads is shown in Figure 3. In all, the results show that all the cluster heads have hardware capacity that is above 4.0. Also, one cluster head has the maximum number of eight (8) slave nodes to a cluster head while two cluster heads have the lowest of one (1) slave node to a cluster head.

Table 2; Cluster head and their location coordinates and hardware capacity

CH number (device number)	x-coordinates (m)	y-coordinates (m)	Hardware Capacity
1(1)	127.98	102.62	4.0736
2(2)	1154.3	314.98	4.529
3(4)	929.89	35.064	4.5669
4(9)	311.84	284.74	4.7875
5(10)	960.08	550.62	4.8244
6(12)	1092.8	656.17	4.853
7(13)	218.22	625.36	4.7858
8(15)	174.65	586.68	4.0014
9(18)	695.65	474.62	4.5787
10(20)	173.95	1185.6	4.7975
11(23)	421.14	1095.9	4.2456
12(24)	615.9	955.42	4.67
13(36)	587.1	1084.5	4.1173
14(39)	443.1	838.49	4.7511
15(57)	778.94	1174.4	4.7987
16(64)	824.13	625.98	4.4545
17(66)	220.21	116.08	4.7965
18(71)	1115.3	791.53	4.2036
19(73)	584.15	1167.6	4.0714
20(75)	536.14	960.4	4.6463
21(82)	454.33	469.13	4.1541
22(85)	420.87	72.565	4.586
23(95)	1013.2	200.6	4.6701
24(114)	853.46	646.95	4.5667
25(116)	140.9	799.83	4.1291

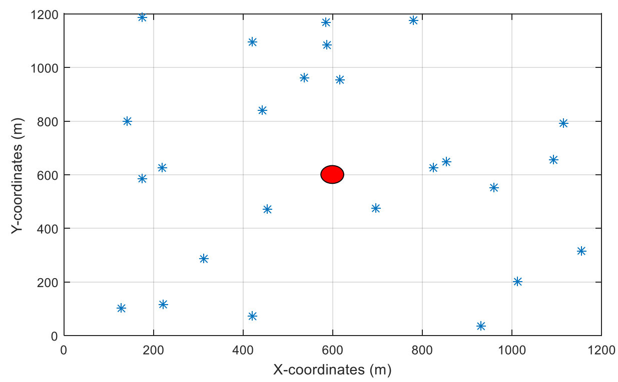

Figure 2; Location of cluster heads in the 1200 m by 1200m region

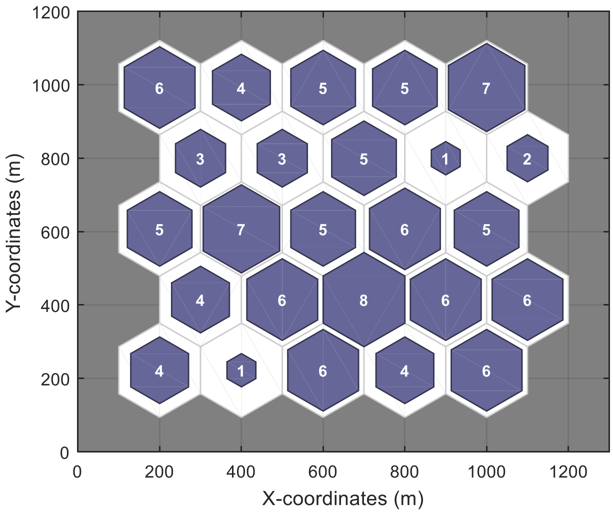

Figure 3: The cluster head and the number of clustered slave sensor nodes to each of the cluster heads

IV. CONCLUSION

Self-organizing map (SOM) algorithm-based cluster head selection and clustering of slave sensor nodes to the selected cluster head is presented for a case study sensor network. The clustering algorithm used the hardware capacity of the sensor nodes along with the x-y coordinates of the sensor nodes. From the location coordinates, the received signal strength was estimated using link budget equation and the Hata path loss model was used to determine the propagation loss in the area where the sensor nodes were located. In all, the SOM algorithm was able to select a good number of cluster heads from the set of 120 sensor nodes and also cluster the slave nodes to the selected cluster sensor nodes.

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