Dynamic Clustering in Wireless Sensor Networks Based on the Data Traffic Flow and the Node Residual Battery Life Computation

Sachin Sharma
Department of Computer Science and Engineering
Suresh Gyan Vihar University, Jagatpura

Professor (Dr.) K C Roy
Department of Electronics and Communication Engineering
Suresh Gyan Vihar University, Jagatpura

Professor (Dr.) Dinesh Goyal
Department of Computer Science and Engineering
Suresh Gyan Vihar University, Jagatpura

Abstract

Wireless Sensor Networks forms the core of the infrastructural facilities and amenities that constitutes a major part of modern living. Wireless Sensor Networks founds tremendous applications in domains such as theft alarms, wildlife monitoring, radiation/pressure/light/heat sensor networks and the list is endless. It constitutes the core part of the modern Internet of Things (IoT) that will revolutionize the modern living. The Iot specifies a scenario in which the devices can communicate with each other using the internet over a flexible framework and can be programmed to perform specific actions based on the programming customization made by the users. For example, a refrigerator is runs out of milk or bread can email the requirement to the dairy that can entertain the mail and ship a delivery of the same to the location of the refrigerator. As sensor nodes are battery powered, there is a critical aspect to same battery power. This is possible only by avoiding the in-network communication as much as possible. A fraction of communication overhead can be reduced through clustering. In this paper, an approach for dynamic clustering is proposed based on the varying traffic loads to various PAN coordinators so as to maximize the battery life and therefore the network lifetime.

Keywords: Wireless sensor network, Clustering Protocols, Battery Life etc.

I. CLUSTERING IN WIRELESS SENSOR NETWORKS

Clustering forms, the backbone towards the persistence of sensor nodes towards sensing data in such a way that a single lithium ion battery can work even for one and a half year continuously. This is because of the reduction in in-network communication to the central node through the creation of clusters in such a way that all the node in the cluster transmit the data to the cluster head and the cluster head is responsible to transmit the data to the central node. The senario is expressed in the following figures.

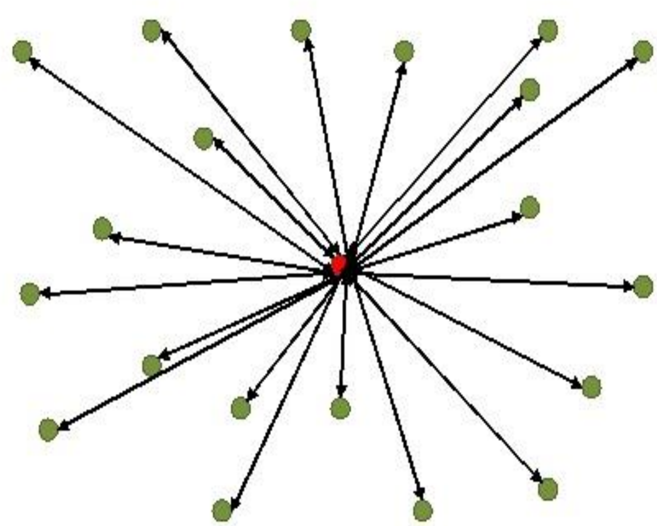

Fig. 1: Wireless Sensor Network without clustering

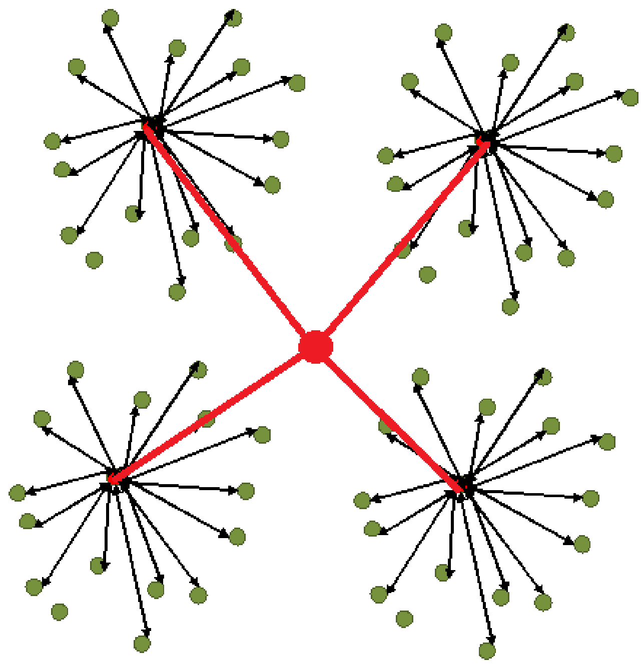

Fig. 2: Wireless Sensor Network with clustering and Data Aggregation

The individual collections shown in figure 1.2 are known as clusters and the nodes that belongs to a particular cluster sends the data only to the cluster head. Thus, reducing the data transmission over long distance from the individual nodes to the central computer. In the clustered approach, the nodes transmit the data to the cluster head over a relatively very short distance, thus, conserving the battery life and enhancing the network lifetime.

II. Dynamic Clustering over the Wireless Sensor Network

Consider a network of N nodes and a static number set initially k as the total number of cluster over the network. Thus, on an average, there are N/k in each cluster. Also, consider a rectangular plane of dimension aXa over which the sensor nodes are (approximately evenly) speeded.

As state previously, there are k clusters each having (N/k)-1 nodes as ordinary sensing nodes and a Cluster head that hold the responsibility of aggregating data from each of the (N/k)-1 nodes. Also assume that each packet senses the medium and sends the data packet to the cluster head in specified TDMA frame.

Considering the first order radio energy dissipation model, let the energy consumption per bit in the transmission circuitry be E_t and the energy consumption per bit in the processing circuitry be E_p. Let there be B bits in a TDMA packet. Considering the initial energy level in the battery be E, one can approximate the residual battery life after N rounds.

Let Me be the number of rounds after which the leader election takes place and a message is broadcasted to all the other nodes in the cluster regarding the node which is elected as the leader so that all the nodes may transmit the data to the specific node. The specified node then aggregates the data from all the nodes in its cluster and transmit the data to the central computer.

It is important to note that the leader election process is an overhead and is incurred only to manage the network traffic. Rapidly electing new heads and consequently broadcasting the message to all other nodes in the network induce an overhead which is to be avoided. On the other hand, it is also important to note that the node which is elected as the cluster head depletes its energy very frequently as it has to perform all the data aggregation processing all be itself for all the nodes in the network. Thus, frequent leader election leads to an evenly consumption of battery power in all the nodes of the cluster. If no election of leader takes place, then the node which handles the task of leader will soon run out of the battery.

In addition to the depltion of the battery in the normal rounds during the data gathering, the leader will deplete the energy

$$E = E_{broad}*n*[(N/k)-1]$$

in view of broadcasting the message, where n is the number of bits in the broadcasted message, and all the nodes depletes an amount of energy equals to

$$E = n*E_p$$

in view of the reception of the message regarding the leader of the cluster.

Let p be the average number of packets that are transmitted by any node and let the length of each packet be l. For implementation, the case study of Zigbee radio sensors is considered in which the underlying operating system is tiny OS having packet size of l=114 bytes.

The important points to analyze in the scenario is:

1) The optimal number 'k' of clusters in the network.

2) The optimal number of rounds M after which the leader election takes place provided the parameters for packet size and energy consumption per bit in the transmission and processing circuitry.

III. PERFORMANCE MODELING OF DYNAMIC CLUSTER OVER VARIOUS NETWORK PARAMETERS

Consider the following parameter values for the network as specified, in the previous sections.

Nodes N	*100*
clusters k	*10*
Et	*0.005*
Ep	*0.001*
Initial Battery	*300*
Ebraod	*0.09*
Data Packet Size	*912*
Broadcast Size	*8*

Table - 1
Residual Battery Life Of The Cluster Head As A Function Of The Number Of Rounds

Round	*Residual Energy in Cluster Head*
1	*291.792*
2	*283.584*
3	*275.376*
4	*267.168*
5	*258.96*
6	*250.752*
7	*242.544*
8	*234.336*
9	*226.128*
10	*217.92*
11	*209.712*
12	*201.504*
13	*193.296*
14	*185.088*
15	*176.88*
16	*168.672*
17	*160.464*
18	*152.256*
19	*144.048*
20	*135.84*
21	*127.632*
22	*119.424*
23	*111.216*
24	*103.008*
25	*94.8*
26	*86.592*
27	*78.384*
28	*70.176*

29	*61.968*
30	*53.76*
31	*45.552*
32	*37.344*
33	*29.136*
34	*20.928*
35	*12.72*
36	*4.512*

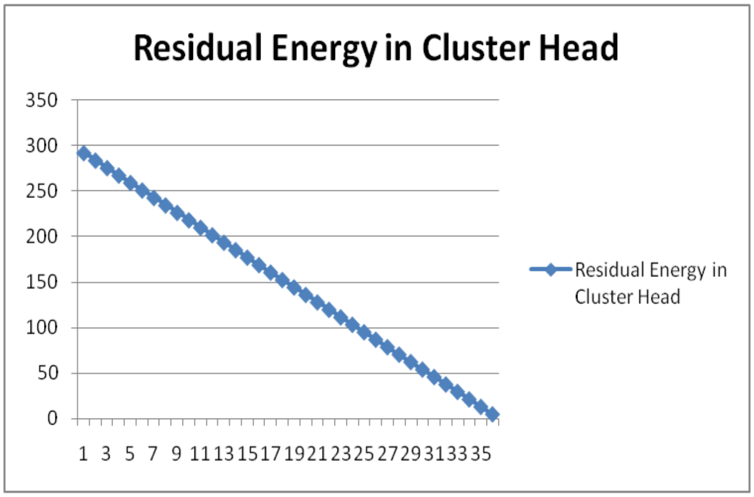

Fig. 1: Residual Battery life as a function of number of rounds. The Horizontal axis shows the number of rounds and the vertical axis shows the residual battery life at the end of rounds

Table - 2
Residual Battery Life of the Cluster Nodes as A Function of the Number of Rounds

Round	*Residual Energy in Nodes*
1	*295.44*
2	*290.88*
3	*286.32*
4	*281.76*
5	*277.2*
6	*272.64*
7	*268.08*
8	*263.52*
9	*258.96*
10	*254.4*
11	*249.84*
12	*245.28*
13	*240.72*
14	*236.16*
15	*231.6*
16	*227.04*
17	*222.48*
18	*217.92*
19	*213.36*

20	*208.8*
21	*204.24*
22	*199.68*
23	*195.12*
24	*190.56*
25	*186*
26	*181.44*
27	*176.88*
28	*172.32*
29	*167.76*
30	*163.2*
31	*158.64*
32	*154.08*
33	*149.52*
34	*144.96*
35	*140.4*
36	*135.84*
37	*131.28*
38	*126.72*
39	*122.16*
40	*117.6*
41	*113.04*
42	*108.48*
43	*103.92*
44	*99.36*
45	*94.8*
46	*90.24*
47	*85.68*
48	*81.12*
49	*76.56*
50	*72*
51	*67.44*
52	*62.88*
53	*58.32*
54	*53.76*
55	*49.2*
56	*44.64*
57	*40.08*
58	*35.52*
59	*30.96*
60	*26.4*
61	*21.84*
62	*17.28*
63	*12.72*

64	8.16
65	3.6

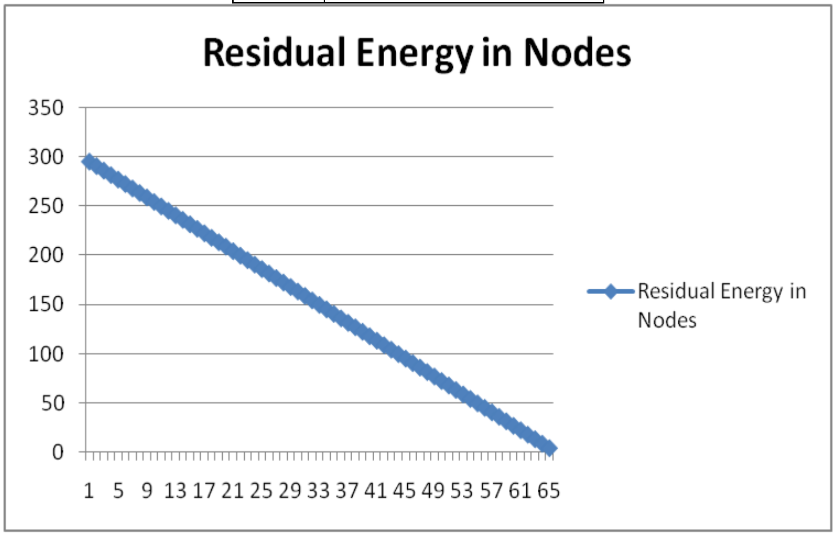

Fig. 2: Residual Battery life of nodes as a function of number of rounds. The Horizontal axis shows the number of rounds and the vertical axis shows the residual battery life at the end of rounds

It is clearly evident from figure 1 and 2 that it took 36 rounds for the cluster head to run out of battery and fail whereas under similar settings, it took about 65 rounds for an ordinary node belonging to a cluster to run out of battery. Thus, it is critical to employ leader election so that there might be and evenly consumption of battery in all the constituent nodes of the network.

The variation in the residual energy with the variation of number of nodes in the network is tabulated in the table 3 below.

Table - 3
Residual Battery Life in Cluster Head as A Function of Number of Nodes in The Network

Round	Residual Energy in Cluster Head (N=100)	Residual Energy in Cluster Head (N=110)	Residual Energy in Cluster Head (N=120)
1	291.792	290.88	289.968
2	283.584	281.76	279.936
3	275.376	272.64	269.904
4	267.168	263.52	259.872
5	258.96	254.4	249.84
6	250.752	245.28	239.808
7	242.544	236.16	229.776
8	234.336	227.04	219.744
9	226.128	217.92	209.712
10	217.92	208.8	199.68
11	209.712	199.68	189.648
12	201.504	190.56	179.616
13	193.296	181.44	169.584
14	185.088	172.32	159.552
15	176.88	163.2	149.52
16	168.672	154.08	139.488
17	160.464	144.96	129.456
18	152.256	135.84	119.424
19	144.048	126.72	109.392
20	135.84	117.6	99.36
21	127.632	108.48	89.328
22	119.424	99.36	79.296

23	111.216	90.24	69.264
24	103.008	81.12	59.232
25	94.8	72	49.2
26	86.592	62.88	39.168
27	78.384	53.76	29.136
28	70.176	44.64	19.104
29	61.968	35.52	9.072
30	53.76	26.4	-0.96
31	45.552	17.28	-10.992
32	37.344	8.16	-21.024
33	29.136	-0.96	-31.056
34	20.928	-10.08	-41.088
35	12.72	-19.2	-51.12
36	4.512	-28.32	-61.152
37	-3.696	-37.44	-71.184
38	-11.904	-46.56	-81.216
39	-20.112	-55.68	-91.248
40	-28.32	-64.8	-101.28

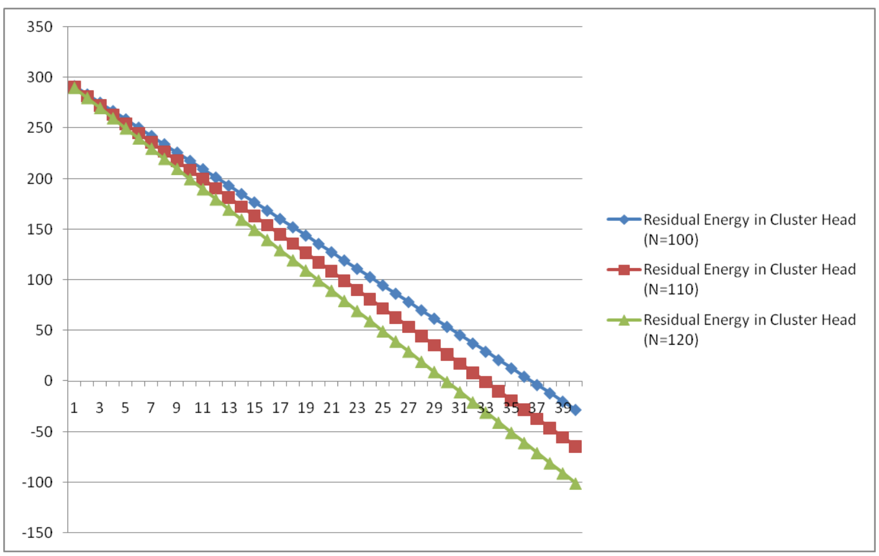

Fig. 3: Residual battery life of the cluster head as a function of the number of nodes in the network.

The horizontal axis shows the number of rounds and the vertical axis shows the residual energy. The portion of the curve at which it touches the horizontal axis shows the number of round at which the cluster head completely runs out of the battery. The part below it is only for analytical viewpoint.

Table - 4
Residual Energy in Cluster Head as A Function of the Number Of Cluster Heads

Round	Residual Energy in Cluster Head (k=10)	Residual Energy in Cluster Head (k=8)	Residual Energy in Cluster Head (k=6)
1	291.792	289.512	285.712
2	283.584	279.024	271.424
3	275.376	268.536	257.136
4	267.168	258.048	242.848
5	258.96	247.56	228.56

6	250.752	237.072	214.272
7	242.544	226.584	199.984
8	234.336	216.096	185.696
9	226.128	205.608	171.408
10	217.92	195.12	157.12
11	209.712	184.632	142.832
12	201.504	174.144	128.544
13	193.296	163.656	114.256
14	185.088	153.168	99.968
15	176.88	142.68	85.68
16	168.672	132.192	71.392
17	160.464	121.704	57.104
18	152.256	111.216	42.816
19	144.048	100.728	28.528
20	135.84	90.24	14.24
21	127.632	79.752	-0.048
22	119.424	69.264	-14.336
23	111.216	58.776	-28.624
24	103.008	48.288	-42.912
25	94.8	37.8	-57.2
26	86.592	27.312	-71.488
27	78.384	16.824	-85.776
28	70.176	6.336	-100.064
29	61.968	-4.152	-114.352
30	53.76	-14.64	-128.64
31	45.552	-25.128	-142.928
32	37.344	-35.616	-157.216
33	29.136	-46.104	-171.504
34	20.928	-56.592	-185.792
35	12.72	-67.08	-200.08
36	4.512	-77.568	-214.368

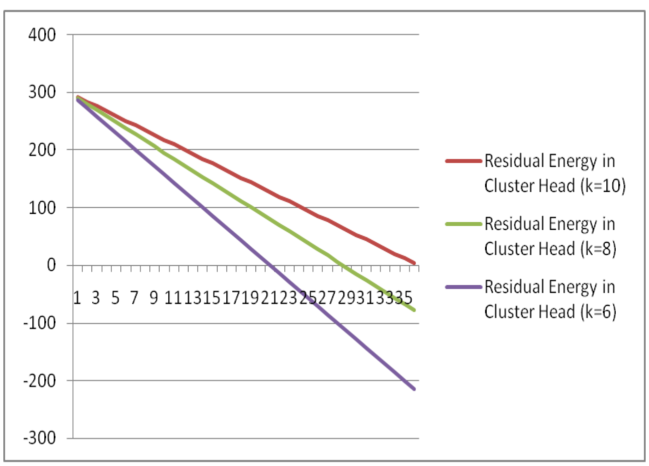

Fig. 4: Residual Energy of cluster head as a function of number of clusters, given the total number of nodes is 100. The Horizontal axis shows the number of rounds and the vertical axis shows the residual energy.

IV. CONCLUSION

It is evident from the above results that the optimal number of rounds after which the leader election should takes place depends on various parameters including the mean number of packets transferred, the average size of the packet, the size of the packet of the broadcast signal, the number of clusters in the network and the initial power of the battery. Also, as the number of nodes actively participating in the transmission of data is variable, it can be stated subjectively that the leader election takes place at most after the cluster head runs out its one third of the battery it has at the time it was elected as the cluster head.

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