Optimum Cluster Size for Cluster-Based Communication in Wireless Sensor Network

Goutam Chakraborty
Dept. of Software & Information Science
Iwate Prefectural University, Takizawamura, Japan
Email: goutam@soft.iwate-pu.ac.jp

***Abstract*—Clustering of sensor nodes to reduce energy expense during data communication covers a large body of literature. Without clustering energy of sensor nodes near the sink drain fast, which in turn kills more rapidly nodes at further hop distances. Cluster-based routing protocol alleviates this problem. Yet, in cluster-based approaches too, for hop-by-hop communication, power of nodes nearer to the cluster head (CH) are drained more rapidly compared to those at the periphery, as they are more often used as hopping nodes. This is more so when the cluster is big. For too small cluster, there is no meaning in clustering. Uniform dissipation is achieved by reconfiguring the clusters at intervals, which is a big signalling overhead. Most of the previous works are on efficient cluster formation, and on using more than one CH to reduce SNR. In this work, we show that there is an optimum size of a cluster, for which the power dissipation at every node could be made uniform over a time, by transmitting packets at different energy levels. It is a co-operative approach for data transportation, where different portions of packets are forwarded to different nodes towards the CH. This way we can avoid frequent cluster reconfiguration. In this paper, the above goal is formally defined as a constrained optimization problem, for linear array of sensor nodes. It turns out to be a non-linear optimization problem, which is simplified to a linear optimization problem and solved. It is shown that the problem has a solution when the cluster diameter is 6 (in terms of hop count) or less. Cluster of bigger size has no solution. We also formulate the problem, when nodes are uniformly distributed over a plane.**

***Keywords*-Sensor nodes' power decay; Constrained optimization problem; Linear programming;**

I. INTRODUCTION

Regarding sensor network software, energy efficiency is the main motivation of all aspects of researches, ranging from OS [2], data acquisition[3], data dissemination/diffusion [4], query processing [5], media access control [6], communication protocol/routing [8] [7] [10] [11] to network topology [9]. In this work, our motivation is a novel energy-aware communication protocol.

Sensor network installations can be categorized into two classes according to the motivation of use

1) Individual sensor node and information it collects is important. Applications are like fire alarm, icy road condition, frosting of grape bunch (suitable for brewing ice-wine), surveillance camera, structural health of buildings and bridges, etc.. Here the sensor nodes' locations are usually fixed, though sometimes they may be moved in controlled direction remotely.
2) Individual sensor data is not important. Assembled data from a region or cluster is all that is to be delivered. The applications are mainly environmental monitoring for climate changes or like. Nodes may drift due to bad weather or flooding.

In scenario 1), it is obvious that the longevity of every sensor nodes is important. Even in scenario 2), we would like to see that most of the sensor nodes sustain for as long as possible, because information from all segments of the sensor network is equally important.

The main goal of communication protocol for wireless sensor networks (WSNs) should be (1) slower decrement of the average battery power with time, as well as (2) lower variation of the distribution of the remaining battery level. To our best of knowledge, all the works on energy aware communication protocols emphasize on item (1) above. But, in reality both (1) and (2) are important criteria.

A. Existing works and where wediffer

The WSN model used by almost all works is as shown in Fig. 2.

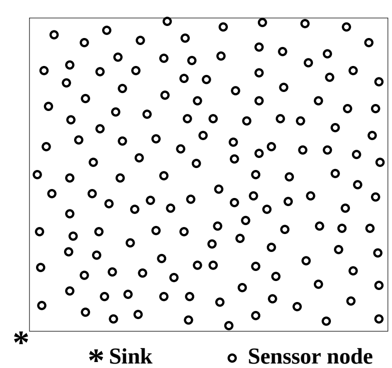

Figure 1. A WSN where sensor nodes are spread with uniform distribution, and the Sink is placed at a corner

We assume that nodes are able to transmit at different distances and control their transmission power accordingly. Assuming the power required to transmit to a distance d

is proportional to d^2, a direct transmission protocol will be very inefficient - considering that all nodes generate data packets at the same rate. Obviously, nodes at further distances from the "Sink" will die soon. There is the class of power aware protocols [1], where packets are routed through intermediate nodes - thus limiting the transmission range, thereby saving energy. Here, nodes near the sink will be overly loaded and die early, cascading the effect to next layers of nodes. The more conventional approach is clustering, where a cluster head (CH) collects packets from all members of the cluster, and transmits to sink through intermediate CHs. Here too, the nodes near to the CH are overloaded. LEACH protocol [10] first proposed to dynamically change the cluster configuration, so that the load is uniformly shared by nodes, over a long time. They showed much longer lifetimes for the sensor nodes.

But reconfiguring clusters is a power heavy task. In this work, we have shown that, if the nodes do not always send packets to their nearest nodes, but transmits different ratios of packets to different distances, towards the CH, the power depletion at different nodes could be made uniform. We have shown that this is possible for clusters of size up to 6 hops in diameter. We formulated this as a constrained optimization problem and solved the required ratios.

The rest of the paper is organized as follows. In Section II, we formally define our goal and corresponding optimization problem, for simple linear network. In Section III, we gave solutions to cluster of radius 2 and 3 hops. We also show that there is no solution for larger cluster that would satisfy the constraints of the problem. In Section IV, we extended the problem definition for WSN spread over a plane. Finally, discussion for further work and conclusion is in Section V.

II. Problem definition, Optimization criterion and constraints

A. Network model and assumptions

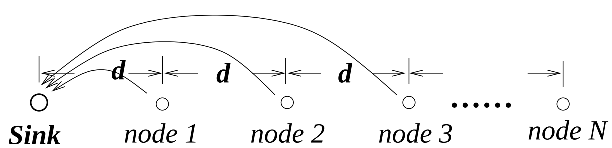

Figure 2. Simple linear node distribution

To simplify the problem, instead of a two dimensional distribution, we will start with a linear network of nodes on a straight line. We will further assume that N nodes are placed equidistant, as shown in Fig. 3. Let us consider the distance between two nodes be d. We assume that the nodes can adjust the transmission power to transmit packets to the target destination. Further, every node creates on an average same number of packets, say m, in a specific interval of time.

B. Defining the Constrained Optimization Problem

We have N-nodes at equal distances d. This includes the sink node, which is node-1. Every node generates m packets. Different proportion of these m packets are forwarded to different nodes towards the sink. In previous works, transmission is always one hop, causing overload of nodes near the CH.

Every node has to service (transmit packets to reach destination) - not only packets it generates, but also packets it receives from nodes further away from the CH. Nodes transmit different portions of its packets (own packets plus those received from behind) to different hop distances towards the sink. This is pictorially explained in Fig. 4.

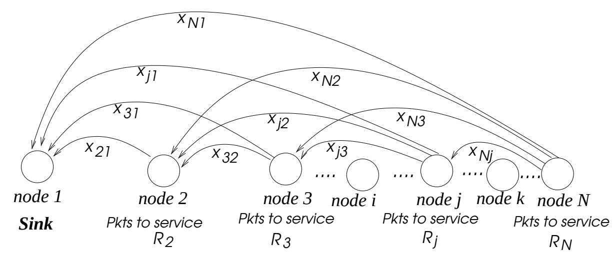

Figure 3. The linear network showing proportion of packets transmitted to different nodes towards the sink

The total number of packets the j^{th} node has to service is, say, R_j. R_j is the sum of packets it generates (i.e., m), plus all the packets it receives from nodes behind it. Thus, node-k has to service R_k packets. Out of that, it sends x_{kj} fraction directly to node-j, where $j < k$. We can write

$$\begin{aligned} R_j &= m + \sum_{k=j+1}^{N} R_k \, x_{kj} && (1) \\ &= m \times \big[1 + \{x_{(j+1)j}\} + \{x_{(j+2)(j+1)}\, x_{(j+1)j} \\ &\quad + x_{(j+2)j}\} + \{x_{(j+3)(j+2)}\, x_{(j+2)(j+1)}\, x_{(j+1)j} \\ &\quad + x_{(j+3)(j+2)}\, x_{(j+2)j} + x_{(j+3)(j+1)}\, x_{(j+1)j} \\ &\quad + x_{(j+3)j}\} \ldots\big] && (2) \end{aligned}$$

The cost of forwarding all those packets towards the sink is now considered. Say, C_j is the cost of transmitting packets at sensor node-j. Let us suppose that the power required to transmit a packet to a distance d is d^ν, where ν is somewhere between 2 and 3. We can write,

$$C_j = R_j \times \left[\sum_{i=j-1}^{1} x_{ji} \, \{(j-i) \times d\}^{\nu} \right] \qquad (3)$$

The problem is to find all x_{ji} s, where $i < j$. The optimization criterion is to minimize C_js. The constraints are as follows:

$$C_2 = C_3 = \ldots = C_i \ldots = C_N \qquad (4)$$

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$$0 \leq x_{ji} \leq 1 \text{ for all } i < j,\ i \geq 1,\ j > 1 \quad (5)$$

$$\sum_{i=(j-1)}^{1} x_{ji} = 1 \quad (6)$$

Eq. 4 says that the battery power of all nodes should drain equally. Eq. 5 says that the fraction of the packets forwarded to different nodes should lie between 0 to 1. Eq. 6 says that every node needs to transmit all the packets it is needed to service.

A general analytical solution for x_{ji} is not possible. We solved this problem for different values of N, namely for $N = 2, 3, 4, \ldots$. We will further show that there is no feasible solution for $N > 4$.

III. Solving the optimization Problem

We will solve specific problems, when cluster radius is 2, 3 and 4. We also will assume $\nu = 2$, which, though not always true, is accepted in general. For any other value of ν, the method will be the same, though the results would differ. Without any loss of generality, we assume the unit of cost function as $m \times d^2 = 1$ unit. This is only a multiplication factor and is done for making the equations look less cumbersome.

The case for $N = 2$ is trivial as all the packets are to be sent to the sink. Here, the unique solution is $x_{21} = 1$.

A. Case for N=3

Here, in addition to the sink node (i.e., node-1), we have two nodes, node-2 and node-3. Let us first see the total number of packets node-2 and node-3 have to service.

$$R_3 = m \quad (7)$$

$$R_2 = R_3.x_{32} + m = m \times (x_{32} + 1) \quad (8)$$

The optimization function, i.e., minimizing the cost of transmission for each node is expressed as:

$$\begin{aligned} C_3 &= R_3 \times (x_{32}\,(d)^{\nu} + x_{31}\,(2d)^{\nu}) = m\,d^2 \times (x_{32} + 4\,x_{31}) \\ C_2 &= R_2 \times \{x_{21}\,(d^{\nu})\} = m\,d^2 \times x_{21}\,(x_{32}+1) \\ &= m\,d^2 \times (x_{32}\,x_{21} + x_{21}) \end{aligned}$$

As already mentioned, we set $m\,d^2 = 1$. As, $x_{21} = 1$, we can further simplify the above two expressions as $C_3 = x_{32} + 4\,x_{31}$ and $C_2 = x_{32} + 1$.

The constraints are:

$$C_2 = C_3$$

$$x_{32} + x_{31} = 1$$

$$0 \leq x_{32} \leq 1;\ 0 \leq x_{31} \leq 1$$

Equating C_2 and C_3, we find that $4 \times x_{31} = 1$. So, the solution is unique, namely $x_{32} = 0.75,\ x_{31} = 0.25,$ and $x_{21} = 1$.

B. Case for N=4

Here, in addition to the sink node (i.e., node-1), we have three nodes, node-2, node-3 and node-4, as shown in Fig. 5. Let us first see the total number of packets every node has to service.

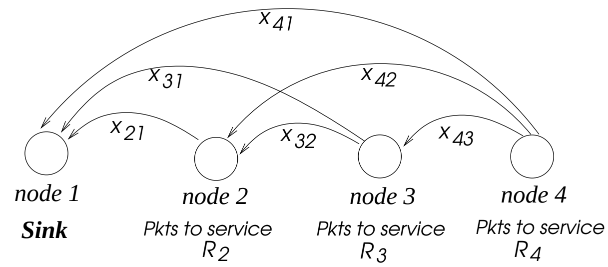

Figure 4. The transmission pattern of the network when N=4

Packets to service at node-4, node-3 and node2 are:

$$R_4 = m \quad (9)$$

$$R_3 = R_4.x_{43} + m = m\,(x_{43} + 1) \quad (10)$$

$$\begin{aligned} R_2 &= R_4.x_{42} + R_3.x_{32} + m \\ &= m.x_{42} + m.(x_{43}+1).x_{32} + m \\ &= m\,[x_{43}\,x_{32} + x_{42} + x_{32} + 1] \quad (11) \end{aligned}$$

The cost of transmission i.e., C_4, C_3 and C_2, for forwarding packets to nodes towards the sink are,

$$\begin{aligned} C_4 &= R_4 \times \{x_{43}\,(d)^{\nu} + x_{42}\,(2d)^{\nu} + x_{41}\,(3d)^{\nu}\} \\ &= m\,d^2 \times (x_{43} + 4\,x_{42} + 9\,x_{41}) \quad (12) \\ C_3 &= R_3 \times \{x_{32}\,(d)^{\nu} + x_{31}\,(2d)^{\nu}\} \\ &= m \times \{x_{43}+1)(x_{32}\,(d)^{\nu} + x_{31}\,(2d)^{\nu}\} \\ &= m\,d^2 \times (x_{43}\,x_{32} + 4\,x_{43}\,x_{31} + x_{32} + 4\,x_{31}) \quad (13) \\ C_2 &= R_2 \times \{x_{21}\,(d)^{\nu}\} \\ &= m\,d^2\,(x_{43}\,x_{32} + x_{42} + x_{32} + 1) \quad (14) \end{aligned}$$

We need to minimize C_2, C_3 and C_4. Here, we assume $\nu = 2$, and used the fact that $x_{21} = 1$. The cost equations, Eq. 13 and Eq. 14, are non-linear. To convert this non-linear problem to linear optimization problem, we replace the variable x_{43} with α, say a constant. As already mentioned, we also set $m\,d^2 = 1$. By that, Eq. 12 to Eq. 14 are modified to

$$\begin{aligned} C_4 &= 4\,x_{42} + 9\,x_{41} + \alpha \quad (15) \\ C_3 &= (1+\alpha)\,x_{32} + 4\,(1+\alpha)\,x_{31} \quad (16) \\ C_2 &= x_{42} + (1+\alpha)\,x_{32} + 1 \quad (17) \end{aligned}$$

As our motivation is to schedule the transmission so that all the nodes expend equal amount of energy, we made $C_4 =$

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$C_3 = C_2$. Combining Eq. 15 and Eq. 16, we get Eq. 18 and combining Eq. 15 and Eq. 17, we get Eq. 19, as follows.

$$4\,x_{42} + 9\,x_{41} - (1+\alpha)\,x_{32} - 4\,(1+\alpha)\,x_{31} = -\alpha \quad (18)$$
$$3\,x_{42} + 9\,x_{41} - (1+\alpha)\,x_{32} - 0\,(1+\alpha)\,x_{31} = 1-\alpha \quad (19)$$

From the constraint $\sum_{i=(j-1)}^{1} x_{ji} = 1$, we get

$$x_{43} + x_{42} + x_{41} = 1$$
$$x_{32} + x_{31} = 1$$

We rewrite the above, replacing x_{43} by α, as

$$1.\,x_{42} + 1.\,x_{41} + 0.\,x_{32} + 0.\,x_{31} = (1-\alpha) \quad (20)$$
$$0.\,x_{42} + 0.\,x_{41} + 1.\,x_{32} + 1.\,x_{31} = 1 \quad (21)$$

From the above we formulate our linear programming problem as follows. We need to find

$$X = [x_{42} \quad x_{41} \quad x_{32} \quad x_{31}]$$

that minimizes the transmission cost (Eq. 14)

$$f = 0.\,x_{42} + 0.\,x_{41} + (1+\alpha)\,x_{32} + 4(1+\alpha).\,x_{31}$$

subject to equality constraint (Copy of Eq. (20), (21), (18) and (19))

$$\begin{aligned} 1.\,x_{42} + 1.\,x_{41} + 0.\,x_{32} + 0.\,x_{31} &= (1-\alpha) \\ 0.\,x_{42} + 0.\,x_{41} + 1.\,x_{32} + 1.\,x_{31} &= 1 \\ 4.\,x_{42} + 9.\,x_{41} - (1+\alpha)\,x_{32} - 4\,(1+\alpha)\,x_{31} &= -\alpha \\ 3.\,x_{42} + 9\,x_{41} - (1+\alpha)\,x_{32} - 0\,(1+\alpha)\,x_{31} &= 1-\alpha \end{aligned}$$

The equality constraint can be written as

$$A_{eq}.\,X = b_{eq}$$

where,

$$A_{eq} = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 4 & 9 & -(1+\alpha) & -4(1+\alpha) \\ 3 & 9 & -(1+\alpha) & 0 \end{bmatrix}$$

and

$$b_{eq} = \begin{bmatrix} 1-\alpha \\ 1 \\ -\alpha \\ 1-\alpha \end{bmatrix}$$

In addition, we have upper bound and lower bound constraints for X-variables as follows:

$$0 \le x_{42} \le 1; \quad 0 \le x_{41} \le 1; \quad 0 \le x_{32} \le 1; \quad 0 \le x_{31} \le 1$$

We have assumed $X_{43} = \alpha$, which is again bound between 0 to 1. We changed the value of α from 0 to 1 in steps of 0.05 and solved the above linear programming problem.

Solutions of this linear programming problem exists when $0.47 \le x_{43} \le 0.80$. Corresponding to every value of x_{43}, we had unique solutions for $x_{42},\ x_{42},\ x_{32},\ x_{31}$. The whole set of solutions is shown in the following table. We presented only the important part, deleting rows of essentially similar results.

Table I
COST FUNCTION FOR DIFFERENT VALUES OF x_{ji}S

Flag	Cost	x_{43}	x_{42}	x_{41}	x_{32}	x_{31}
-2	2.6038	0.450	0.5385	negative	0.7347	0.2653
-2	2.6138	0.460	0.5385	negative	0.7366	0.2634
1	2.6139	0.470	0.5252	0.0048	0.7406	0.2594
1	2.6122	0.480	0.5096	0.0104	0.7450	0.2550
1	2.6104	0.490	0.4939	0.0161	0.7493	0.2507
1	2.6087	0.500	0.4783	0.0217	0.7536	0.2464
1	.	.	.	.	.	.
1	.	.	.	.	.	.
1	.	.	.	.	.	.
1	2.5583	0.790	0.0243	0.1857	0.8569	0.1431
1	2.5565	0.800	0.0087	0.1913	0.8599	0.1401
-2	2.5600	0.810	negative	0.1944	0.8619	0.1381
-2	2.5700	0.820	negative	0.1944	0.8626	0.1374

In Table. I, the first column, Flag, denotes whether there is a feasible solution or not. Here, '-2' indicates that the solution is not feasible, and '1' indicates that the solution is feasible. In row 1 and 2, x_{41} s' values are negative, and therefore are not feasible solutions. Similarly, for last two rows, x_{42} values are negative, making them infeasible solutions. The cost, for different values of x_{43} (=α), and corresponding values of other fractions, namely $x_{42},\ x_{41},\ x_{32},\ x_{31}$, are shown. Entries for α from 0.500 to 0.790 are omitted. As the cost function over the whole range of feasible solutions is minimum when $x_{43} = 0.8$, we can write our final solution as,

$$x_{43} = 0.800; \quad x_{42} = 0.009; \quad x_{41} = 0.191;$$
$$x_{32} = 0.860; \quad x_{31} = 0.140$$

Thus, to minimize the transmission cost and to share the load of transmitting packets so that power at all the nodes are equally drained:
Node-4 needs to transmit 80% of its packets to node-3, 1% to node-2, and 19% directly to the sink.
Node-3 needs to transmit 86% of its packets to node-2, 14% directly to the sink

C. *Case of* $N \ge 5$

In case the number of nodes is 5, to transform the transmission cost function to a linear one in terms of different x_{ji}s, we need to get rid of the three terms $x_{54},\ x_{53},\ x_{43}$ from transmission cost functions. As before, we assigned

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them values from 0 to 1, and changed in steps of 0.05. This time we could not get any feasible solution, with all fractions being positive. Thus, there is no solution for $N = 5$. The detail procedure, though not shown here, is exactly the same as in case of $N = 4$.

In case of $N = 5$ there is no feasible solution because, to maintain same transmission cost for all nodes some of the x_{ji} terms has to be negative. Intuitively, similar situation will arise for $N \geq 5$. We thus conclude that there is no solution for $N \geq 5$.

IV. Case when nodes are spread over a plane

In the previous section, we have shown that for a cluster, where sensor nodes are linearly spread, it is possible to transmit different portions of packets to different distances judiciously, so that all nodes dissipate power uniformly. In reality, the sensor nodes are spread over a plane. In this section, we will show that the analysis of the previous section can be extended nodes distributed on a plane.

Let us consider that the sensor nodes are uniformly spread as shown in Fig. IV.

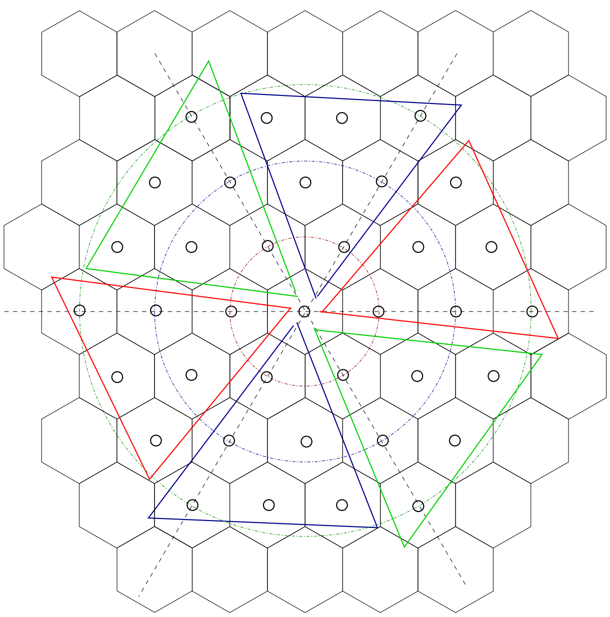

Figure 5. Sensor nodes spread uniformly over a plane

Nodes are put at the center of the imaginary equilateral hexagons. The node density is a function of the hexagon edge length, say a. For uniform distribution with any node density, we can represent the network as in Fig. IV, where with increasing node density the value of a is smaller. Here, CH is at the center. The whole cluster is divided into 6 triangular sections, which together forms the cluster, as shown in Fig. IV.

As in Section III, here too x_{ji} denotes the portion of packets node-j transmits directly to node-i. The ratios are

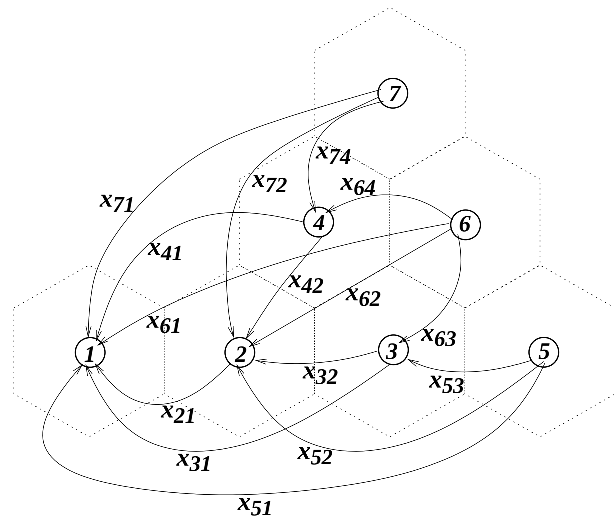

Figure 6. A triangular section showing one-sixth of the cluster

as shown in the following matrix. The columns are receiving node numbers, starting with 1, and the rows are transmitting node numbers, starting with node 2.

$$\mathbf{X} = \begin{array}{cc} \begin{bmatrix} x_{21} & 0 & 0 & 0 & 0 & 0 & 0 \\ x_{31} & x_{32} & 0 & 0 & 0 & 0 & 0 \\ x_{41} & x_{42} & 0 & 0 & 0 & 0 & 0 \\ x_{51} & x_{52} & x_{53} & 0 & 0 & 0 & 0 \\ x_{61} & x_{62} & x_{63} & x_{64} & 0 & 0 & 0 \\ x_{71} & x_{72} & 0 & x_{74} & 0 & 0 & 0 \end{bmatrix} & \begin{array}{l} node\ 2 \\ node\ 3 \\ node\ 4 \\ node\ 5 \\ node\ 6 \\ node\ 7 \end{array} \end{array}$$

Here, $x_{ji} = \frac{packets\ transmitted\ from\ node-j\ to\ node-i}{total\ packets\ transmitted\ from\ node-j}$. Corresponding distances of transmission are shown in the matrix **D** below, where entry d_{ji} is the distance from node-j to node-i. "NA" means the distance is not necessary to consider, because there is no transmission.

$$\mathbf{D} = \begin{bmatrix} \sqrt{3}a & NA & NA & NA & NA & NA & NA \\ 2\sqrt{3}a & \sqrt{3}a & NA & NA & NA & NA & NA \\ 3a & \sqrt{3}a & NA & NA & NA & NA & NA \\ 3\sqrt{3}a & 2\sqrt{3}a & \sqrt{3}a & NA & NA & NA & NA \\ \sqrt{21}a & 3a & \sqrt{3}a & \sqrt{3}a & NA & NA & NA \\ \sqrt{21}a & 2\sqrt{3}a & NA & \sqrt{3}a & NA & NA & NA \end{bmatrix}$$

As before, let us denote the total number of packets serviced (transmitted) by node-j by R_j, which includes both the packets generated at the node (i.e., m) plus those received from nodes further away from the the CH. Therefore,

$$R_7 = R_6 = R_5 = m \tag{22}$$

$$R_4 = m + \sum_{i=5,6,7} R_i \times x_{i4} \tag{23}$$

$$R_3 = m + \sum_{i=5,6,7} R_i \times x_{i3} \tag{24}$$

$$R_2 = m + \sum_{i=3,4} R_i \times x_{i2} + \sum_{i=5,6,7} R_i \times x_{i2} \tag{25}$$

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From distances in matrix **D**, we are able to calculate the amount of power the node dissipates for transmitting these packets. At this stage, we ignore (as is done in Section III) the energy required to receive packets, which is lower compared to what is required for transmission, though not zero. As before, we denote the power dissipated at node-j by C_j and make all C_js equal. Formaly, the problem is to find the elements of matrix **X**, where the optimization criterion is to minimize C_j subject to the following constraints:

$$\sum \vec{x_j} = 1 \tag{26}$$

$$C_2 = C_3 = \ldots = C_i \ldots = C_7 \tag{27}$$

$$0 \le x_{ji} \le 1 \quad \text{for all} \quad i < j,\ i \ge 1,\ j > 1 \tag{28}$$

Eq. 26 can further be expanded to get 6 simultaneous equations in x_{ij}. From Eq. 27, we get another 6 equations of expanded energy in terms of x_{ij}. By equating them, we get 5 more equations in x_{ij}s. From symmetry, we can assume that $x_{74} = x_{53}$ and $x_{64} = x_{63}$. Fixing values of two unknowns, x_{74} and x_{64}, in small steps, and using optimization criterion to minimize C_is, we can solve x_{ij}s.

the following set of equations:

$$x_{74} + x_{72} + x_{71} = \alpha + x_{72} + x_{71} = 1 \tag{29}$$

$$x_{64} + x_{63} + x_{62} + x_{61} = 2\,\beta + x_{62} + x_{61} = 1 \tag{30}$$

$$x_{53} + x_{52} + x_{51} = \alpha + x_{52} + x_{51} = 1 \tag{31}$$

$$x_{42} + x_{41} = 1 \tag{32}$$

$$x_{32} + x_{31} = 1 \tag{33}$$

$$x_{21} = 1 \tag{34}$$

where, we wrote $x_{74} = x_{53} = \alpha$, assuming $x_{74} = x_{53}$ due to symmetry, and α, a constant which we will vary manually in steps to find its optimum value. Similarly, we wrote $x_{64} = x_{63} = \beta$, assuming $x_{64} = x_{63}$ due to symmetry, and β, another constant which we will vary in steps. We now have 10 unknown x_{ij}s, and 5 equations, Eq. 29 to Eq. 33.

V. CONCLUSIONS

Cluster-based communication protocol in wireless sensor networks had to reconfigure at regular intervals for uniform power dissipation of different nodes. But, dismantling operating clusters and re-arranging a new set of clusters needs transmission of lots of signaling packets To avoid reconfiguration of clusters at regular intervals, we proposed that, the nodes within the cluster do not always transmit to its nearest neighbor, on the way to CH. Instead, they transmit packets to different distances towards the CH, with different pre-assigned ratios. We have shown that, we can then achieve uniform power dissipation for all the nodes within the cluster.

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