Optimizing Power through Geometrical Shapes Consideration for Sensor Network

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***Abstract*-- The deployment of sensor node in network can either be deterministic or self organizing. In a self organizing system the nodes are scattered all throughout the area of interest. The sensor network topologies, where the nodes arrange themselves in different geometrical shapes, in different conditions, power consumption factor is to be considered and the communication cost is to be minimized as much as we can. In this paper, localization problem is addressed. We have considered a network where the nodes are scattered all over the area of interest, thus arranging themselves in various geometrical shapes. The base station while forming the cluster configures the network in the best possible 'Geometric shape' based on the information gathered through the members of its network. Through extensive simulations on such self arranged nodes, we show that our technique results in an improvement over other techniques where the base station doesn't make intelligent decision on selecting the cluster head and randomly selects the cluster head .Our technique also fulfills the challenge of providing flexible, configurable, self organizing architecture capable of catering to the dynamics of the network The performance of the proposed technique is analyzed in terms of different system metrics – topological robustness and reliability, system cost and network exposure due to failure conditions. The network model considered is a hierarchical cluster based sensor network for data aggregation, where the sensor nodes are mobile while the base station is stationary.**

***Index Terms*-- Sensor Network, Sensor Node, Data Aggregation, Topology, Hierarchical Clustering, Cluster Head.**

I. Introduction

IN a self organizing network the nodes organize them in an ad-hoc basis. It is very difficult to predict the energy requirement of the network as a whole. The sensor nodes have constraints regarding their life as they are operated on battery [4]. Therefore, it becomes essential to have an updated knowledge about where the sensor node is deployed. We present a network model with mobile sensor node that are scattered in the network, thus directly or indirectly fitting themselves in various geometrical shapes. We consider a dynamic topology where the nodes change their locations after each session as we're considering mobile nodes. It becomes necessary for the base station to have an updated knowledge on the whereabouts of the nodes of its family so that an appropriate clustering model can be formed and the right cluster head is selected thus reducing the power consumption and other essential performance metrics[5]. We've considered a heterogeneous sensor network model where the base station deploys a cluster head to a particular cluster according to their geometrical shapes which the nodes of the cluster have gained. The base station chooses the node for the purpose such that the power consumption requirement is minimized. In the process of cluster formation what is needed by the base station is the coordinates of the nodes of its network. In short for cluster formation, the exchange of locations information is required, thus nodes only have to know their own coordinates and those of the destination including the base station and later on i.e. after cluster formation, the coordinates of its cluster head. The nodes have nothing to do with other sensor devices. Due to device's limited process and storage capabilities, we're proposing simplified model architecture should be designed so as to make communication in these networks efficient and simple at the same time [6].

If we consider various geometrical shapes with same area, they've different distances from the point of symmetry to the extreme points or boundaries. Hence the communication time is different and the energy consumption changes for different geometrical shapes. For a fixed area of the geometrical shape, performance metrics can go up or down depending upon the probability density of the network and the density of nodes in the geographical area. When the network is set up, the sensor nodes assign themselves to arbitrary coordinates and register themselves with the base station sending their locations [3]. The base station then forms clusters and finds the cluster head to get an optimum energy consumption and network throughput. If the concentration of a cluster increases a limit sub clusters are formed to reduce the overhead on one node. The data is aggregated from various sensor nodes by their cluster heads respectively. Numerous papers have been published where the simulation results showed the improvement of network performance in terms of throughput, delay and power consumption [1, 4].

Through the rest of the paper, we define the architectural model in section 2. Section 3 describes the energy – conscious approach where the performance of the network

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can be optimized through adapting to various geometrical figures. In section 4 we analyze the efficiency of the various geometrical shapes. Section 5 deals with the Experimentation Validation. In Section 6 we consider the past work done to optimize the power consumption of the sensor network. This section is followed by the related work and finally the conclusion.

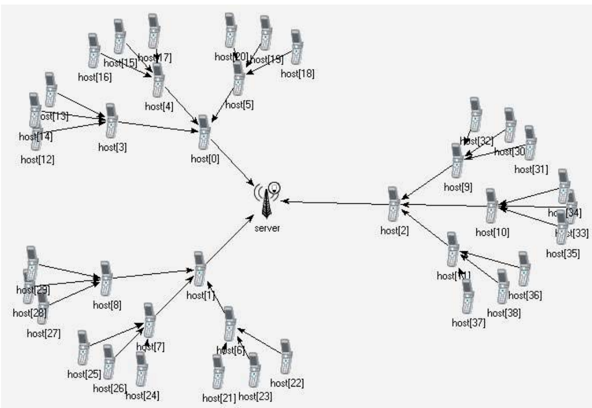

Figure 1. Cluster based sensor network model

II. ARCHITECTURAL MODEL

The system architecture for the sensor network is depicted in Fig. 1. In the architecture sensor nodes are grouped into clusters that are controlled by a single command node known as the cluster head. The sensors are capable of radio - based communication and are responsible for probing the environment. In our architecture the cluster head is chosen by the base station such that the cluster head is at equal and minimum distances from the other nodes in the cluster. There could be many criteria of cluster formation such as communication range, number and type of sensor node and geographical locations [10]. In this paper, we consider the geographical locations as the prime criteria for selection of the cluster head by the base station. The base station maintains a database, which is pre-fed on it for all possible geometric shapes in terms of coordinated values. It stores the stores the physical coordinate values of all other sensor nodes which are sent by the sensor node belonging to it after their random deployment on the area of interest. Based on the received coordinates of the nodes, the base station makes an intelligent but local decision and categorizes them into different clusters. The base station does this according to the shape of the clusters and the probability density of the region enclosed by the shape and it also forms the cluster head [12]. We have taken into consideration the three basic geometrical topologies viz. Circle, Square and Equilateral Triangle though this work can be extended for other geometrical shapes also but there is no need to consider other geometries as all other topologies in two – dimensional can be derived from these basic topologies. It is mathematically proved that the point of symmetry is at equal distances from the vertices or the edges of the topology. For the topologies presented above the point of geometric symmetry are Centre, Diagonal – Intersection and Centroid respectively. Fig. 2, 3 and 4 shows the scattering of nodes for the different shapes respectively. So the cluster head could be chosen closer to these specific points of symmetry. Our results show that the energy consumption not only depends on the location of the cluster head but also on the number of nodes that are associated with each cluster head [19]. Another parameter that affects the power consumption of the network on the whole is the density of nodes in each cluster. The area of the geometrical shape is also responsible for the energy consumption and collision ratio of the complete network.

The cluster head organizes the sensor nodes in the cluster and combines the data received from its cluster members to consider the data for energy commitment, remaining sensor energy, sensor location, link traffic etc. [15]. The system architecture which we've considered promotes the idea of clustering to ensure scalability also. The formation of cluster can account for resource requirements at the cluster head to cope up with the responsibility of managing the assigned sensors [18].

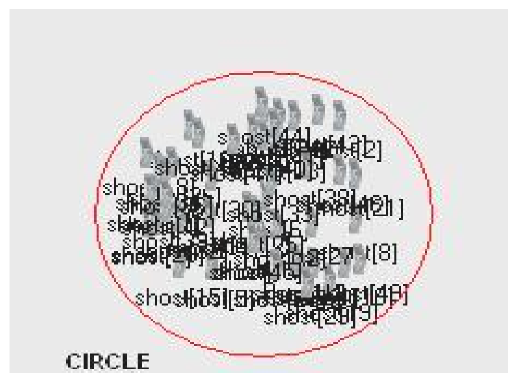

Figure 2. Circular topology

Figure 3. Square topology

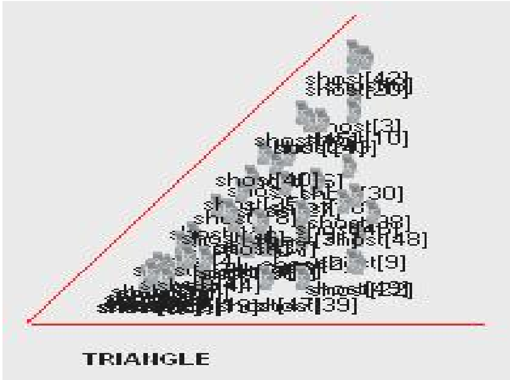

Figure 4. Equilateral triangle topology

The base station receives the location of each node and matches this location pattern with the database to identify the closest geometrical topology. This geometrical topology can change from session to session. The base station regularly keeps a check that a cluster does not get overloaded. If the cluster has more nodes than a pre – defined limit, base station makes a sub cluster to reduce the overload. This is employed using the technique of data aggregation. If a node dies out due to low power or any other reason the base station deploys the node closest to the breakdown node.

III. Energy Conscious Approach

In this section, we discuss an approach to manage the sensor network with the main objective of extending the life of the sensors in a particular cluster. Focus is mainly on the topology adjustment and the message routing. Sensor energy is central in deciding on changes to the networking topology. In addition, message traffic between the sensors and the cluster head is arbitrated in time to avoid collision and to allow turning of the sensor node when not needed. There is the mechanism in the node which switches on the sensor device only when it has something to transmit.

We assume that nodes, sensors and cluster heads, are connected by bi – directional wireless links with the cost associated with each direction. Each link may have a different cost for each direction because of difference in energy levels of the nodes at each end. The cost of the path between two nodes is defined as a sum of the cost of the link traversed. To optimize the results and power consumption factors we should find a least cost path from this node to the cluster head. To account for energy conservation, delay optimization and other performance metrics, we define the following cost function for a link between nodes *i* and *j*.[12]

$$\sum_{K=0}^{7} CF_k = c_0 \times \left(disance_{ij}\right)^l + f\left(energy_j\right) + c_2 / T_j$$

$$+ c_3 + c_4 + c_5 + c_6 \times disance_{ij} + c_7 \times overall\ load$$

Where: $distance_{ij}$: Distance between nodes *i* and *j*

$energy_j$: Current energy of each node *j*

CF_k are cost factors defined as follows: [13]

- CF_0: Communication Cost, where c_0 is a weighting constant and the parameter *l* depends on the environment. This factor reflects the cost of the wireless transmission power, which is directly proportional to the distance raised to some power *l*.
- CF_1: Energy stock. This cost factor favors nodes with more energy. The more energy the node contains, the better it is. The function '*f*' is chosen to reflect the battery remaining lifetime.
- CF_2: Energy consumption rate, where c_2 is the weighting constant and T_j is the expected time under the current consumption rate until the node *j* energy level hits the minimum acceptable threshold.
- CF_3: Relay enabling cost, where c_3 is a constant reflecting the overhead required to switch an inactive node to become a relay.
- CF_4: Sensing state cost, where c_4 is a constant added when the node *j* is in a sensing state.
- CF_5: Maximum connections per relay: once this threshold is reached, we add an extra constant c_5 to avoid setting additional paths to it.
- CF_6: Propagation delay, where c_6 is the result of dividing a weighting constant by the speed of wireless transmission.
- CF_7: Queuing cost for each sensor node s whose link passes through the node *j*.

It should be noted that some of the CF_i's factors are conflicting. For example, to minimize the transmission power, we need to use multiple short distances leading to more number of hops and thus increasing the relay. The weighting constants c_i's are system defined that we have considered in the simulation work. As mentioned earlier, the nodes turn their receiver on at a predetermine time in order to hear the cluster head's decision.

IV. Efficiency of Topologies of Various Shapes

In this section we mathematically calculate the efficiency of various geometrical shapes in which the sensor nodes self organize in clusters or sub-clusters in terms of power consumed, communication cost, transmission delay. In various geometrical shapes we consider the distance from the cluster heads to the maximum density area near the centre of symmetry of the shape to be *a* units. The analysis is done for some two dimensional shapes where we consider the area as the resulting metric. Fig 5 shows the various shapes considered.

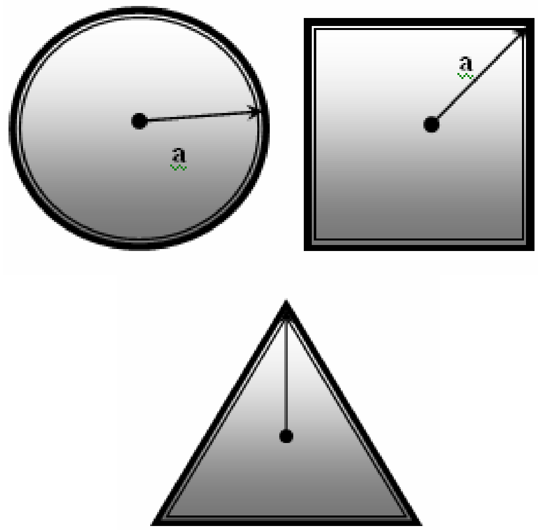

Figure 5. Symmetric Points of the Geometrical shapes.

V. Experimental Validation

The performance of the sensor network was analyzed using a standard simulation tool, as the real sensor network setup with actual sensor nodes was not possible. During the simulation part various input parameters as described below are considered for different sessions. As a result the performance metrics was calculated for the geometrical shapes of similar enclosing area and fixed number of sensor nodes. Our results show that an equilateral triangle has better power consumption and other performance metrics than a circular or a square topology [7]. It is proved through our simulation results that if the cluster head is located at the centroid of the triangular topology the performance yielded are the best. The idea could be extended to three Dimensions for topologies like a cube, a sphere and a tetrahedron [9]. The performance metrics in three Dimensions is however out the scope of this paper. The work may be extended to the next edition of the paper.

A. Performance Metrics

The following metrics were used to capture the performance of various topologies [12]:

- *Time for the last node to die*: This metrics along with the time to network partition, gives an overall indications of network life time.
- *Average delay per packet*: Defined as the average time a packet takes from a sensor node to the cluster head.
- *Average energy consume per packet*: The shape that minimizes the energy per packet will, in general, yields better energy savings.

B. Simulation Environment

The Simulation work was carried out by using OMNet++ - Discrete Event Simulation System Version 3.2. The simulator was used in complement with the Visual C++ version 7 which was used for the Graphical User Interface. Random positions were created for placing the nodes and the base station to show the mobility in the sensor network.

C. Experimental Results

Table 1, 2 and 3 shows the various parameters obtained for the Circular, Square and Equilateral Triangular topologies taken one at a time. The results show that the channel utilization of the triangle is optimum for a given fixed number of nodes. We consider the enclosed area of the figures to be constant where the distance from the symmetry point and the boundaries (end – vertices) is considered to be 100 pixels in our simulation environment. The ratio of the total number of collisions to the total transmitted packets is lowest in the triangular topology, thus retransmission of the packet is minimum, which in turn saves the power consumption of the sensor node. As a result this grossly affect the total receive time of the messages. Figure 7, 8 and 9 shows the graph of Channel Utilization, Collision Ratio and Total Receive Time for different topologies considered one at a time for different number of nodes

TABLE I
Performance Metrics for Circular Topology

nodes	duration	total fram	Collided	Receive	Collision	Utilization
10	100.416	445	1	0.421736	0.001608	0.004231
15	100.05	696	8	0.646408	0.012071	0.006467
20	100.078	949	8	0.887264	0.012186	0.0089
25	100.019	1215	11	1.13478	0.015643	0.011351
30	100.018	1447	15	1.34803	0.022623	0.013787
35	100.024	1691	35	1.5489	0.050101	0.015491
40	100.034	1984	37	1.81927	0.053098	0.018208
45	100.025	2255	48	2.05537	0.067562	0.020557
50	100.075	2503	59	2.27147	0.08413	0.022716

TABLE II
Performance Metrics for Square Topology

nodes	Duration	total fram	collided	receive	collision	utilisation
10	100.002	458	4	0.427448	0.005604	0.004291
15	100.002	695	5	0.65212	0.007077	0.006534
20	100.213	953	7	0.893928	0.009866	0.008949
25	100.066	1225	7	1.15192	0.010274	0.01152
30	100.053	1463	20	1.35374	0.028554	0.013583
35	100.011	1696	24	1.5689	0.034656	0.015694
40	100.037	1995	39	1.82594	0.055116	1.182981
45	100.007	2244	39	2.06203	0.055603	0.020623
50	100.016	2500	70	2.24862	0.100214	0.022502

TABLE III
PERFORMANCE METRICS FOR TRIANGULAR TOPOLOGY

nodes	Duration	total fram	collided	receive	collision	utilisation
10	100.111	442	1	0.41888	0.001842	0.004207
15	100.085	710	7	0.662592	0.009868	0.006633
20	100.001	910	6	0.912968	0.007768	0.00913
25	100.179	1240	17	1.14811	0.025248	0.011502
30	100.02	1470	23	1.35565	0.032541	0.013597
35	100.04	1767	26	1.63268	0.036362	0.016343
40	100.39	1994	42	1.81832	0.061001	0.018207
45	100.027	2274	56	2.05727	0.077376	0.020579
50	100.02	2552	63	2.31146	0.088417	0.02313

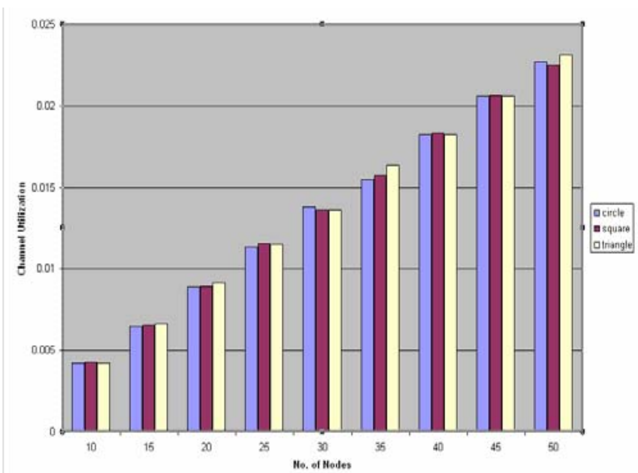

Figure 6. Number of nodes vs. Channel Utilization.

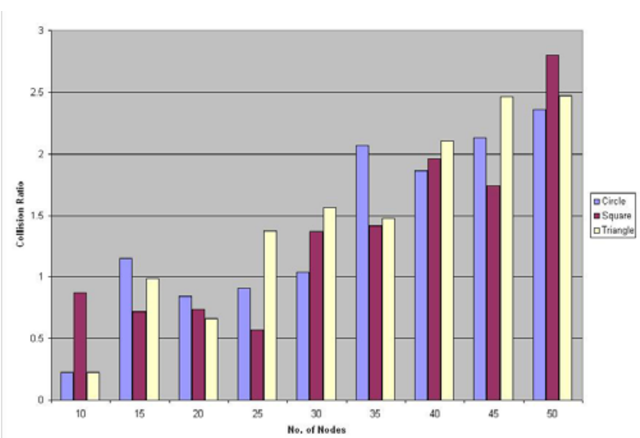

Figure7. Number of nodes vs. Collision Ratio.

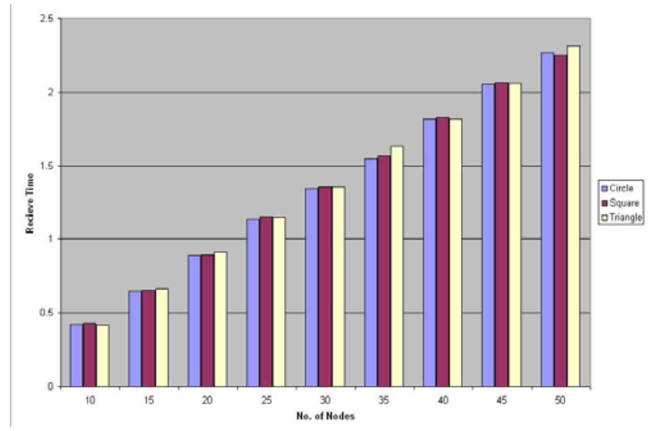

Figure8. Number of nodes vs. Receive Time.

The simulation was carried out on the sensor networks where clusters were given different geometrical shapes and hosts were mobile. Graph was plotted between number of nodes and various parameters like collision rate, receive time, collision time and channel utilization. Fig.9 shows the obtained graph.

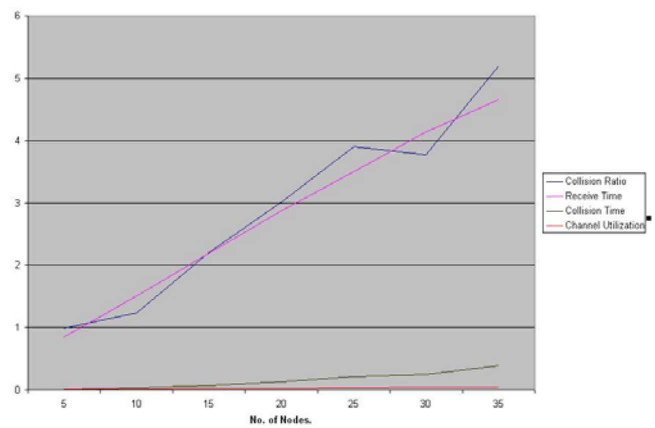

Figure 9. Number of nodes vs. other parameters for heterogeneous sensor networks.

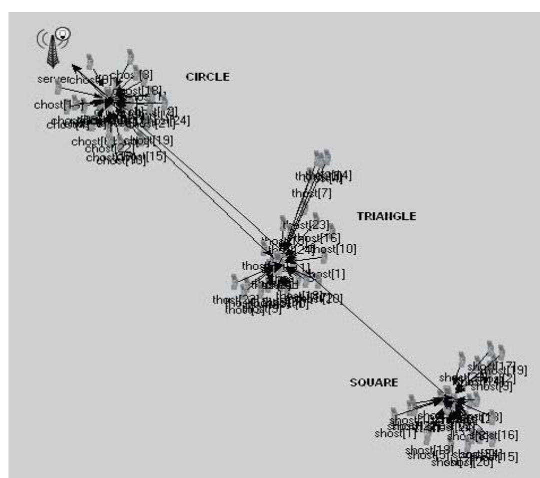

Figure 10. Various topologies in heterogeneous sensor networks

Table 4 shows the Performance metrics of a Heterogeneous Sensor Network.

TABLE IV
PERFORMANCE METRICS FOR HETEROGENEOUS SENSOR NETWORKS

Nodes	Duration	total fram	Collided	Receive	collision	Utilization
5	100.008	913	9	0.852	0.013939	0.008541
10	100.015	1623	20	1.50702	0.030897	0.0151
15	100.016	2402	53	2.1877	0.071736	0.021881
20	100.003	3210	97	2.87218	0.134893	0.028724
25	100.005	3978	155	3.4986	0.208894	0.03502
30	100.005	4696	177	4.13549	0.247185	0.041359
35	100.009	5438	283	4.65242	0.388646	0.046526

VI. RELATED WORK

Lin C.R. & Gerla M., , IEEE Journal on Selected Areas of Communications, 15(7), September 1997 give a new direction to the idea of clustering through their paper “Adaptive Clustering for Mobile Wireless Networks” where they have considered the cost factor for different nodes based on parameters like distance between the nodes and energy consideration[12]. A similar work in the paper “Optimized Broadcast Protocol for Sensor Networks” by Durresi A., Paruchuri V.K., Iyengar S.S., Khannan R., an attempt was made to reduce the energy consumption by Optimizing Broadcasting through Adaptive Geometric Approach [7]. Wu, S.; Candan, K.S. published a paper on Power Aware single and multipath geographical routing Ad-hoc networks [18]. In the paper PEGASIS author Lindsey S. & Raghavendra C.S., an attempt was made to reduce the power consumption by the sensor node through hierarchical clustering [13].

VII. CONCLUSION

As far as our knowledge goes ours is the first work to make an attempt to reduce the energy consumption by the sensor nodes by implementing various topologies. Analysis of various parameters shows that the best possible geometric topology in two dimensions is the Equilateral Triangle. The Circular topology has the poorest performance in terms of power consumption of a node. The nodes considered in the simulation work are mobile. So, they take different positions in different sessions for data exchange.

VIII. FUTURE WORK

We have considered the simulation work done for the topologies of 2 dimension shape. However, the work can be extended to three dimensions to have better performances and for practical uses and in practice we encounter the nodes organizing themselves in a three Dimensional orientation. We have not considered the security features for the sensor networks as in our work to be a part of same family. There may be incorporation of new unsecured devices that could register falsely with the Base Station and Distort the Shape of the topology.

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