Energy Efficient Design of Wireless Sensor Network: Clustering

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Abstract— One of the significant criteria of wireless sensor network is energy efficiency. Focused on the energy problem, researchers design a few algorithms based on clustering in the present era but lack of proper mathematically rigor justification. To fill this research gap, a system and method has been proposed with a mathematical proof induced from the concept of Hessian matrix of multi variable calculus for Energy efficient techniques of data gathering or routing in Wireless Sensor Networks. It is assumed that Wireless Sensor Nodes are distributed in a multidimensional space. Illustrations verify that the proposed system mathematical design for any clustering approach promises a low-energy communication structure.

Keywords—Clustering; Sensor; Gateway; Hessian Matrix

I. Introduction

Wireless Sensor Networks (WSNs), as scattered web of sensors that have the ability to sense, process and communicate, and is increasingly used in various fields including engineering, health and environment, to monitor remote locations at lower cost. Sensors (a.k.a nodes) in such networks are responsible for four key tasks i.e. data aggregation, sending data, receiving data and data processing. This implies that they must efficiently exploit their resources like memory usage, CPU power and energy. This increases sensor’s lifetime and productivity. Energy consumption has become one of the main challenges of using WSNs. To overcome this challenge, from last few years there have been increasing efforts to minimize energy consumption using new algorithms and techniques on different layers of the WSN, including the hardware layer (i.e., sensing, processing, transmission), network layer (i.e., protocols, routing) and application layer. Energy-constrained sensors are expected to run autonomously for long periods. However, it may be cost-prohibitive to replace exhausted batteries or even impossible in hostile environments. On the other hand, unlike other networks, WSNs are designed for specific applications which range from small-size healthcare surveillance systems to large-scale environmental monitoring. Thus, any WSN deployment has to satisfy a set of requirements that differs from one application to another.

In wireless sensor network (WSNs), having battery powered sensors are coordinated to gather information about a sensed variable and communicate the information to a base station/sink, in many applications, replacement of battery in the sensor is difficult or even not possible. Thus, the design of protocols in such network must be energy efficient. Various researchers proposed hierarchical energy efficient routing/fusion algorithms such as LEACH (Low Energy Clustering Hierarchy), HEED etc. In such algorithms, a group of wireless sensor nodes forming a cluster have a representative leader called cluster head. Periodically the cluster head is rotated among the members of the cluster. The cluster heads essentially participate in the data fusion and routing the sensed packets to the base station/ sink. In many interesting applications, the sensors are geographically distributed with certain distance between them. In most existing energy efficient algorithms, distance between sensors is not taken into account for deciding the cluster head. In this research paper we formulate the problem of choosing the cluster head (taking into account the distance between sensors along with other factors) as a quadratic optimization problem and solve the problem. The cluster head is chosen to be centroids of sensor position coordinates.

II. Literature Review

In [1], Anastasi et al. presented an extensive survey on WSNs and various approaches used for energy consumption, like duty cycling, data driven approaches and some of the mobility based approaches. Some authors have applied a clustering based energy efficient algorithm [2]. Authors organized WSNs in a two-layer manner with clustering algorithm, and then, the missing data was recovered based on this two-layer structure. Wireless sensor networks use battery-operated computing and sensing devices as we want them in ad hoc manner. So, a medium-access control (MAC) protocol- S-MAC has been designed for wireless sensor networks by [3]. Another energy efficiency approach was proposed by authors in [4] and analyzed the method of controlling network lifetime and found node density as a major parameter which has significant role to control network lifetime. They proposed a Probability Density Function (PDF) and derived its intrinsic characteristics like covariance, mean etc. Also they have developed a node deployment algorithm based on PDF to avoid energy problem.

In order to maximize the network lifetime, energy consumption should be optimized. In cluster-based WSNs, cluster heads or gateways perform activities, such as data collection from its member nodes, data aggregation, and data exchange with the base station. Hence, load balancing of gateways in WSNs is one of the crucial and challenging tasks to maximize network lifetime. In order to address this problem, a shuffled frog leaping algorithm (SFLA) is improved by suitably modifying the frog's population generation and off-spring generation phases in SFLA and by introducing a transfer phase [5] . Authors have designed a novel fitness function to evaluate the quality of the solutions produced by the improved SFLA. A time synchronization algorithm energy efficient wireless sensor networks has been proposed in [6]. In [7] Multi-Factors Backpressure Scheduling (MFBS) algorithm have been proposed. The algorithm focuses on introducing new link-weights for energy efficient scheduling in smart WSNs. Besides queue backlog differential nodal residual energy as well as the shortest path between neighbors (nodes) are also jointly considered into the transmission during scheduling decision. Packets generated from one node will be transmitted to a neighbor node that has higher residual energy and a shorter distance to the transmitter.

A genetic algorithm inspired clustering algorithm has been given by authors in [8]. The algorithm uses genetic algorithm based approach to find optimal clusters that consumes less energy. Few authors have applied data aggregation based approaches for efficient energy WSNs. In data aggregation data from different sources are aggregated to an intermediate node. A routing algorithm called cluster-chain mobile agent routing (CCMAR) is proposed by [9]. This algorithms combines both low energy adaptive clustering hierarchy (LEACH) and power-efficient gathering in sensor information systems (PEGASIS). Similarly a ring clustering based approach for energy efficient WSN has been given in [10]. As signals move in circular direction hence a ring domain communication topology can effectively use 360° signal transduction while also reducing message collision during the transmission process. Most of the previous work on clustering has adopted a two-layer hierarchy, so three-layer scheme has been introduced in [11] and applied three layered architecture on hybrid of centralized gridding and distributed clustering. The grid heads are determined in a centralized manner, and then the CHs are determined in a distributed manner. Using three-layer hierarchy, the number of nodes that communicate with base station reduced, and results in energy conservation.

III. Proposed Approach

Consider a WSN system in which all the sensor nodes are randomly deployed together with a couple of gateways and as soon as they are positioned, they become static. All sensor nodes are assigned to a gate way when they are within communication range. Therefore, each sensor node has a couple of gateways and it is allocated to only one gateway selected amongst them. The sensor nodes gather the significant local data and transfer it to the corresponding gate ways. On getting the data, the gateways process them to reduce the redundant data within their cluster. It is assumed that a wireless communication link is established between two nodes only if they are within the inter cluster distance (communication range). An example for clustered based WSN is presented in Figure 1.

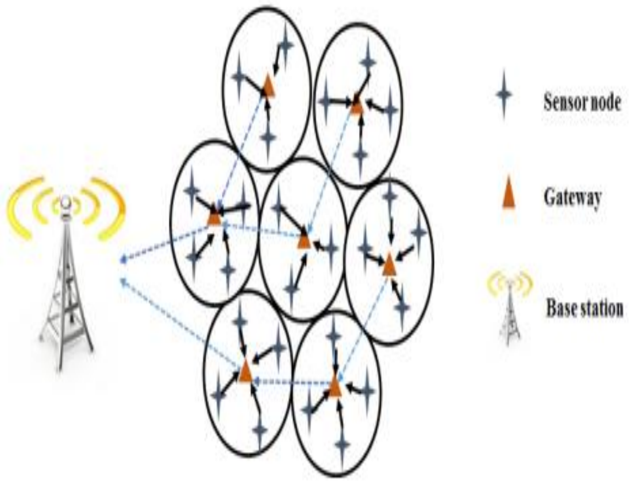

Figure 1: Cluster based WSN with gateways

Problem Formulation:

Consider N data points or sensor nodes in M-dimensional pattern space i.e. M-dimensional vectors that are totally N of them. $\overline{(S_1)}$, $\overline{(S_2)}$, …., $\overline{(S_N)}$, with $\overline{(S_j)}$ = [$\overline{(s_{j1})}$, $\overline{(s_{j2})}$, ….., $\overline{(s_{jM})}$,] for $1 \leq j \leq N$. Let $\overline{(G_0)}$ be the desired centroid or gateway i.e. $\overline{(G_0)}$ = [$g_{01}, g_{02}, ..., g_{0M}$].

Theorem: Consider n sensor nodes positioned in a M-Dimensional Space. Centroid of N points in M-dimension minimizes the sum of squared distances from the points to the centroid (Gateway) in a Euclidian distance based cluster of all the n-sensor nodes within its communication range.

Proof: Compute $\overline{G_0}$, i.e. centroid in such a way that sum of squares of Euclidean distances (from centroid to patter) is minimized.

$$J(\overline{G_0}) = \sum_{j=1}^{N} \sum_{i=1}^{M} [s_{ji} - g_{oi}]^2$$

We could like to solve this unconstrained optimization problem. Differentiating we have

$$\frac{\delta J(\overline{G_0})}{\delta \delta J(g_{0i})} = \sum_{j=1}^{N} 2 \left[s_{ji} - g_{0i}\right](-1) \text{ for } 1 \leq i \leq M$$

Setting it to zero, we have

$$\sum_{j=1}^{N} S = (N)(g_{0i}) \text{ for } 1 \leq i \leq M$$

Thus we can say that

$g_{0i} = \frac{1}{N}\sum_{j=1}^{N} s_{ji}$ for $1 \leq i \leq M$

i.e. $g_{01} = \frac{1}{N}\sum_{j=1}^{N} s_{j1}$ and so on.

We will now prove that like centroid

$(\overline{G_0} = [g_{01}, g_{02}, \dots, g_{0M}])$

is indeed a global minimum point i.e. we compute second partial derivative and reason that hessian matrix is positive definite i.e. eigenvalues are all positive and we have a diagonal Hessian matrix.

$$\frac{\delta^2 J(\overline{G_0})}{\delta g_{0i}^2} = \sum_{j=1}^{N} \frac{\delta}{\delta\, G_{0i}} \left[-2\left(s_{ji} - g_{0i}\right)\right] = \sum_{j=1}^{N} +2 = 2N$$

Also, it readily follows that

$$\frac{\delta^2 J(\overline{G_0})}{\delta g_{0k}\, \delta g_{0i}} = 0$$

For $k \neq i$.

Thus hessian matrix is positive definite diagonal matrix as $N > 0$

$$\begin{bmatrix} 2N & 0 \ \dots & 0 \\ 0 & 2N \dots & 0 \\ 0 & 0 \dots & 2N \end{bmatrix}$$

Conclusion: In this paper, we have proposed a new approach to improve the energy efficiency of the wireless sensor network by placing the base stations in the appropriate locations such that the squared Euclidean distances from the sensors to the base stations are minimized. We have used the concept of Hessian matrix of multi variable calculus to improve the energy efficiency and identify the base station locations such that the energy consumption is minimized. The proposed methodology is supported with problem formulation and necessary proofs. The proposed mathematical design will significally support and improve the low-energy networks.

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