1. Introduction

A wireless sensor network (WSN) consists of small low energy sensing nodes capable of sensing a phenomenon and sending the data to the sink. Advances in the field of wireless communication, Micro Electro Mechanical Systems (MEMS) technology have led to the development of low cost, multifunctional [1] tiny sensor nodes which consume less power. WSNs are basically data gathering networks in which data are highly correlated and the end user needs a high level description of the environment sensed by the nodes[1]. WSNs are deployed to monitor physical events or the state of physical objects such as bridges in order to support appropriate reaction to avoid potential damages [2]. The nodes and the related protocols in a WSN should be designed to be extremely energy efficient as battery recharging may be impossible [3].

A sensor node cannot function without the power unit as this unit supports all the other functions in a sensor node. With every sensor node there are two very crucial associated parameters namely:

- Sensing range ($R_s$): It is the maximum distance upto which sensing node can sense a phenomenon.
- Transmission range ($R_t$): It is the optimum distance over which a sensor node can transmit data.

The basic purpose of WSN is to sense a phenomenon and send it back to the Base Station (BS). No human intervention takes WSN to the whole new level and because of this the WSNs have various applications and can reach where humans can’t, like in battle field surveillance, disaster prone areas, detection on a gas leak in nuclear power plants etc. The sensor nodes are deployed in a specific region (inside the phenomenon or close to it) and are deployed randomly or manually. Typically in WSN, nodes coordinate locally to gather and process data and send it to common sink[4]. The BS is assumed to contain infinite energy. Nodes in WSN are driven by limited battery power and are not rechargeable. The energy contained in a sensor node is consumed in various processes such as sensing, processing and communication. Since, the nodes have limited operating power, energy optimization becomes extremely imperative for a WSN to function for a longer time. Energy of nodes and energy usage are key factors in determining the lifetime of whole network.

One of the most important challenges of a WSN design is to develop a protocol so that the
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randomly deployed numerous sensing units behave in a collaborative, cooperative, coordinated and organized way. Each node needs to send the data to its neighbour nodes and finally to the sink. Network routing protocol design becomes quite critical in the case of WSNs as compared to conventional communication networks [5]. Among various proposed network routing protocols, hierarchical routing protocols or clustering greatly contribute to system scalability, lifetime, and energy efficiency [6].

Many researches investigating the field of energy optimization of WSN and many energy efficient routing protocols such as the minimum transmission energy and LEACH[3] (low energy adaptive clustering hierarchy) protocol have been proposed, where the concept of clustering, cluster head (CH) and techniques like data aggregation and data fusion are used which help in increasing the efficiency of the network[7].

Clustering is a useful mechanism in WSNs which helps to cope with scalability problems. When combined with data aggregation, clustering may increase the energy efficiency of the network. Moreover, by assigning a special role to the CHs, clustering makes the network all the more robust and vulnerable to attacks [8]. In direct communication WSN, the sensor nodes directly transmit their sensed data to the sink without any coordination between the two. However, in cluster based WSNs, the network is divided into clusters. Each node exchanges its information only with its CH which transmits the aggregated information to BS[9]. Data aggregation at CHs causes a significant reduction in the amount of data sent to the BS and results in saving both energy and bandwidth resources [10]. Effective clustering algorithm leads WSN to operate efficiently. However, the major challenges are the equal distribution of each cluster over the entire sensor network and the energy dissipation caused by the frequent information exchange between selected CH and nodes in the cluster in every setup phase of cluster formation[11].

The network lifetime in a WSN can be defined as the time at which the first node runs out of its energy. A lot of energy of the WSN is utilized in performing various actions

1. Clustering the network,
2. Cluster head selection
3. Finding the optimum routing path,
4. Data transmission from one node to another using single or multiple hops,
5. Data aggregation and interpretation.

The network lifetime depends on all the above factors. Less the energy utilization, and more the network lifetime.

The most important phase of cluster-based routing protocols is the CH selection procedure that ensures uniform distribution of energy among the sensors, and consequently increasing
the lifespan of a sensor network [12, 13]. Once the CHs are identified, they form a backbone network to periodically collect, aggregate, and forward data to the BS using the minimum energy (cost) routing. This method significantly enhance the network lifetime compared to other known methods. The major challenges include equal distribution of each cluster over the entire sensor network and the energy dissipation caused by the frequent information exchange between selected CH and nodes in the cluster in every setup phase of cluster formation [11, 4]. If CH is selected on the basis of the concept of maximum number of nodes connected, then it may happen that one or more unique nodes are not connected to any of the selected CHs. In such case some outliers may be created which are not connected to any of the CHs, although they are in the transmission range. This algorithm deals with the CH selection based on the unique node concept. A unique node is the one which is not connected to any other CHs. The algorithm proposed in this research work uses two parameters, namely, number of neighboring nodes and the residual energy for the selection of CH in WSN.

Most of the current clustering protocols are top-down approaches, which first formulate a global knowledge of a WSN, specifying but not detailing the first-level nodes. Based on this global knowledge, the protocols first build the upper level of clusters by selecting certain nodes as CHs. Then they group the rest of the nodes into the designated cluster as cluster members. Many algorithms randomly select the CHs. In such a case, it might happen that the CH may have lower energy than its member nodes. Such CH may died out quickly which usually results in low quality of the clusters.

The motivation of our research is to provide efficient clustering without requiring the global knowledge of network by reversing the clustering approach from top-down to bottom-up[14]. With the bottom-up approach, sensing nodes build clusters before they select CHs. In this manner, the bottom-up approach can be a better way to implement self-organization, scalability and flexibility. Such a bottom up clustering is called agglomerative clustering.

Usually location data is used to calculate the distance between the sensing nodes to perform clustering. This type of clustering is called quantitative agglomerative hierarchical clustering. But the location data may not always be available[15] due to reasons like Global Positioning System (GPS) failures or cost involved or time taken to calculate the exact location of the sensors. To avoid this, Received Signal Strength (RSS) or RSS Indicator (RSSI) is used to find out the distance between the nodes. This type of clustering is called qualitative agglomerative hierarchical clustering. The current research work compares the different agglomerative protocols for qualitative and quantitative data.

Maximum energy consumption takes place in communicating the data from the nodes to the sink [16]. To minimize the energy consumption while sending the data to the sink, multiple sinks are used. The proposed work intends to reduce the energy utilization by deploying multiple sinks. Generally a WSN is based on many-to-one communication concept
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of having many sensors transferring the data to a common single sink. The proposed work demonstrates the importance of multiple sink in a WSN [17]. The most important advantage of having multiple sinks is to shorten the routing path between a sensing node and the sink. If the area to be sensed is very huge and the sensors are randomly deployed, then it happens that even a very effective routing protocol fails. Even if clustering is used, the nodes waste a lot of energy in sending the data to long distances. If the sink or the next CH is within the transmission range of the sensor then the energy consumed in free space is related with distance as [18](Section 4.2)

$$E \propto d^2$$

(1.1)

where \(d\) is the distance from source to destination node. But if the sink or the next CH is not within the transmission range of the sensor node then the link follows multipath propagation model for wireless scenario. In such a case, energy consumed is related with distance as [18](Section 4.2)

$$E \propto d^4$$

(1.2)

So, to save energy, it becomes very important to reduce the distance between the node and the sink or the next CH. The above problem is solved by using multiple sinks in a WSN. The current research work concentrates on two basic aspects related to multiple sinks WSN, namely:

1. Finding optimal number of sinks
2. Finding the position of sinks

Multiple sinks deployment makes the WSN robust so that even if one of the sinks fail, other sinks can take the charge and prevent the WSN from failing[19].

As there are multiple sinks, the distance from the node to the sink reduces, thus there is no need of multiple hops. Multiple sinks reduce the distance the sensed data needs to travel and hence correspondingly reduce the energy consumption considerably. Another disadvantage of a single sink WSN is that of energy imbalance between the nodes close to the sink and the ones which are far off [20]. The network is restructured by modifying the number of nodes connected to a sink[21]. The current research work proposes an algorithm for network restructuring in a multiple sink WSN so as to reduce the energy consumption and increase the network lifetime. This energy balancing through network re-structuring optimizes the network lifetime. The number of non-connected nodes is considerably reduced. The implementation is done in MATLAB which demonstrates the aforesaid statements.
1.1. Motivation and Objective

Wireless sensor networks (WSNs) are being used in a variety of application like border surveillance, ocean bed tracking, military field etc. In all such applications, sensors are deployed randomly and are unattended for a very long time. The network should be able to work for a long duration without any human intervention. The nodes should be able to cover maximum possible area. The motivation of the current research work concentrates on such a WSN which are energy efficient and have maximum coverage. Our objective is to design WSN to ensure

- Minimal energy consumption,
- Maximum coverage and connectivity
- Optimized network lifetime.

1.2. Contribution of Thesis

The thesis contributes by proposing novel algorithms for single and multiple sinks WSN. The algorithms aim to minimize the energy consumption, maximize the coverage and connectivity and optimize the network lifetime. The thesis is divided into two parts. The first part contains the work proposed for single sink and the second part contains the algorithms proposed for multiple sinks.

Single Sink

A Wireless Environmental Monitoring System (WEMS) is proposed using data aggregation in a bidirectional hybrid protocol [4]. A framework for energy efficient routing protocol is proposed for homogeneous WSN using sensing range as the parameter [9]. If two nodes are sensing the same area or if the node is falling in the sensing range \( R_s \) of another node connected to the same CH then it is of no use to sense same data using multiple sensors. This reduces the energy efficiency of the network and as we have limited available operating power for wireless networks, this will be a major reason for shortening the lifetime of network. An improvement over this approach is the proposed merging algorithm. Performance analysis of hierarchical agglomerative clustering is performed in a WSN using quantitative and qualitative data [14]. A cluster head selection algorithm is proposed for a homogeneous WSN ensuring full connectivity with minimum number of isolated nodes [13].
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Multiple Sink

The most important advantage of having multiple sinks is to shorten the routing path between a sensing node and the sink. Two algorithms have been proposed for multiple sinks. One is for increasing the lifetime of a WSN using Multiple Sinks [19]. The second is for lifetime optimization through energy balancing [21]. The network is restructured by modifying the number of nodes connected to a sink.

1.3. Organization of Thesis

The second chapter of the thesis deals with the review of literature. It discusses the various terms, methodologies and protocols proposed by different researchers in the field of WSN. It also talks about the coverage and connectivity issues and their remedies. The third chapter deals with a novel clustering algorithm for Wireless Environmental Monitoring System. It is an application based algorithm having features which are suitable for a system used to monitor critical environmental conditions, such as temperature, humidity, intrusion, and smoke. Another clustering algorithm is proposed which uses sensing range as a parameter for clustering. The proposed algorithm solves the major constraint of WSN i.e. energy consumption. The algorithm makes the WSN a quite energy efficient network as the concept of merging in a multi-hop network is proposed in which if two sensing nodes are falling in the same sensing range then they will work in sleep and active mode as a result of which less energy will be used.

The author proposes a Hierarchical Agglomerative Clustering algorithm in the fourth chapter. The motivation of the research is to provide efficient clustering without requiring the global knowledge of network by using the bottom-up called the Hierarchical agglomerative clustering (HAC). If the distance between the sensing nodes is calculated using their location then it’s quantitative HAC. If the received signal strength is used to calculate the distance between the nodes then it’s qualitative HAC. The comparison of the various agglomerative clustering techniques applied in a WSN is also done. The author proposes a novel approach to ensure full Coverage and Connectivity in Single Sink in the fifth chapter. The second part of thesis deals with multiple sinks. The chapters 6 and 7 deal with algorithms to increase life time in multiple sinks. As the energy consumption of the network is reduced, the lifetime of the network is considerably increased. Every chapter’s introduction contains the critical literature review and the motivation to reach to the novel approach.