Analysis of wireless sensor networks and evaluation of clustering in these networks

Sanam Ansari
Cappadocia University,School of Applied Sciences,Software Development , Nevshehir,Turkey
Kioumars Abdi
Cappadocia University, Cappadocia Vocational School,Computer Programming, Nevshehir,Turkey

Abstract

The rapid development of computer networks and the need for self-aware networks and systems have led to a lot of research in this field. One of these networks is wireless sensor network.The wireless sensor network has a large number of sensor nodes with limited energy that are scattered in a geographical area. This network interacts with the physical environment and receives environmental information through sensors and reacts through agents. One of the important issues in these networks is increasing the lifespan and stability of the network based on its topology. The long communication distance between the sensors and the sink in a wireless sensor network consumes a lot of energy and also reduces the network lifetime and its stability, since clustering, as one of the topology management methods for the stability of networks Wireless sensor can reduce the energy consumption requirement as the most important challenge in WSNs, in this article, we investigate wireless sensor networks and clustering in these networks.

Keywords: wireless sensor networks, network lifetime, clustering, protocol.

Introduction

Wireless sensor networks consist of a large number of sensor nodes scattered in an environment. This type of network is a suitable means to collect and send environmental information or inform about the occurrence of an event to a central node. These networks have their own characteristics and limitations that differentiate sensor networks from other networks. A sensor network consists of a large number of sensor nodes that are widely distributed in an environment and collect information from the environment. The location of the sensor nodes is not necessarily predetermined and clear. Such a feature makes it possible to leave them in dangerous or inaccessible places. On the other hand, this means that the protocols and algorithms of sensor networks must have the ability to self-organize. Another unique feature of sensor networks is the ability to cooperate and coordinate between sensor nodes. Each sensor node has a processor on its board, and instead of sending all the raw data to the center or to the node that is responsible for data processing and conclusions, it first performs a series of basic and simple processes on the data it has obtained. and then sends the semi-processed data.

Wireless Sensor Network (WSN) can be self-configured and infrastructure-free to monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion, or pollutant levels. The collected data is then sent through a network to a location intended for processing and review. A sink or base acts as an interface between users and the network, and information can be retrieved from the network using query injection. In general, a wireless sensor network consists of hundreds or thousands of nodes or nodes of sensors. Sensor nodes can communicate with each other using radio signals. A wireless sensor node is equipped with sensor and processor elements, radio receivers and transmitters, and circuit power supply elements. Each individual node in a wireless sensor network (WSN) has limitations such as processing speed, limited data storage capacity, and communication bandwidth.

After choosing a group of nodes, they are responsible for organizing a suitable infrastructure and usually use multiple hubs to communicate with each other. Then the designated sensors start collecting information. Also, wireless sensors respond to queries sent from a control unit and based on them execute specific commands or provide measurement samples. The working mode of sensor nodes may be continuous or activated by a specific event. GPS and local positioning algorithms can be used to obtain location and location information. Wireless sensors can be configured to react to certain conditions.

Design of wireless sensor networks

Unlike conventional networks, a WSN has its own design and resource limitations. Resource constraints include limited amount of energy, short communication range, low bandwidth, and limited processing and storage in nodes. Design limitations depend on the application and the environment to be monitored. The environment plays a key role in determining the size of the network, how the nodes are distributed, and the network topology. The size of the network varies according to the considered environment. For closed environments, a small number of nodes are required to form a network in limited spaces, while open spaces may require more nodes to cover a larger area. When the environment is inaccessible to humans or the network contains hundreds to thousands of nodes, a contingent broadcast is preferable to a planned broadcast. Obstacles in the environment can also limit the communication between nodes, which actually affect the network (or topology) coherence.

Sensor network applications

Wireless sensor network has important applications. Among them, remote monitoring of the environment and target tracking can be mentioned. The availability of wireless sensors, especially in recent years when sensors are smaller, cheaper, and smarter, makes these

capabilities possible. These sensors are equipped with wireless mediators that enable the communication of sensors together and the formation of a network. The design of a wireless sensor network is significantly dependent on the application, and factors such as the environment, the design goals of that environment, cost, hardware, and system limitations must be considered.

WSN applications can be divided into two groups:

•Monitoring

• Tracking

Monitoring applications include indoor/outdoor monitoring, health and wellness monitoring, power monitoring, asset location monitoring, process and production automation, and structural and vibration monitoring. Tracking applications include tracking objects, animals, humans, and vehicles.

WSNs have great potential for applications such as:

• Pursuing and monitoring military objects

• Natural disaster relief

• Biopharmaceutical health monitoring

• Seismography and exploration of accident-prone environments

A WSN in tracking and monitoring military objects can be used to detect and identify intruders. Specific examples can be mentioned spatial correlation and coordinated movements of troops and tanks. In natural disasters, sensor nodes can sense the environment and detect disasters before they occur. In biomedical applications, surgeries to implant sensors can help in monitoring the patient's health. To sense tremors, by spreading sensors in volcanic areas, earthquakes and eruptions can be detected.

Types of sensor networks

Wireless sensor networks can be classified into two groups in terms of structure:

• Structured

• Unstructured

An unstructured WSN is a type that consists of a large collection of sensor nodes. Sensor nodes may be distributed in a domain as an ad hoc network. Once the nodes are deployed, the network is left to perform monitoring and reporting tasks. In an unstructured WSN, network maintenance such as connection management and fault detection is difficult because the number of nodes is large. In a structured WSN, part or all sensor nodes are distributed with a previous map. The advantage of a structured network is that fewer nodes can be distributed, and as a result, it will require less maintenance and lower management costs. Because of this, fewer nodes can be broadcasted because the nodes are placed at certain points to cover the area, but there may be areas that are not covered in the broadcast as needed.

Lifetime of wireless sensor networks

One of the important issues of wireless sensor networks is increasing the lifetime and stability of the network based on its topology. The long communication distance between the sensors and the sink in a wireless sensor network consumes a lot of energy and also reduces the lifetime of the network and its stability. For example, clustering is one of the methods. Topology control for the stability of wireless sensor networks can reduce the energy consumption requirement as the most important challenge in WSNs.

Topology of wireless sensor networks

The inherent topology of the sense/task network is the graph topology. Because the communication of the nodes is wireless and in the form of public broadcasting, and each node communicates with several other nodes that are within its range. Efficient algorithms in data collection and object tracking applications consider network spanning trees. Because traffic is

basically in the form of data moving from several nodes to one node. Topology management must be done carefully. An essential step in topology management is the initial network setup. Nodes that have not previously had any initial communication must be able to communicate with each other during deployment and initialization. Topology management algorithms in the initial setup should allow the membership of new nodes and the removal of nodes that fail for some reason. Topology dynamics is one of the characteristics of sense/work networks that challenges its security. Providing dynamic topology management methods to cover security issues is one of the topics that has a lot of work to do.

Consuming power of nodes

Sense/work network nodes should have low power consumption. Sometimes the power source is a 1.2 volt battery with 5.5 energy. It is an ampere-hour that should provide the necessary power for a long period of time, for example, nine months. In many applications, the battery is not replaceable. Therefore, battery life practically determines the life of the node. Because a node acts as a router in addition to receiving information (by a sensor) or executing a command (by a hacker), a malfunctioning node will remove it from the topology and will result in network reorganization and rerouting of the passing packet. In the hardware design of nodes, it is important to use designs and parts that have low consumption and to provide the possibility of sleep mode for the whole node or for each part separately.

Clustering protocols in WSN network

Clustering is an efficient technique for maintaining energy balance in wireless sensor networks (WSNs) that does so using data aggregation. Aggregation means collecting data from the nodes inside the clusters, which of course we will talk more about these concepts later. Since the clustering method reduces the number of routed packets in the network, as a result, clustering routing protocols are used in WSN to achieve energy efficiency. In WSNs, clustering provides various advantages such as greater scalability, lower load, lower energy consumption, data aggregation, collision avoidance, load balancing, latency reduction, fault tolerance, greater robustness, connectivity assurance, and maximizing network lifetime. and so on. In clustering algorithms, the cluster head node bears a lot of additional load due to some activities, such as data aggregation, sending data to the well, etc. Therefore, cluster head nodes are subject to premature death due to high energy consumption compared to other nodes. Therefore, choosing the right cluster head is one of the main challenges in sensor network clustering, and in fact, this parameter is one of the important factors in increasing the data received in the well and reducing the network lifetime.

LEACH protocol

In recent years, several clustering protocols have been proposed in order to increase the lifespan of the Jesgar network. The LEACH protocol is one of the clustering algorithms that uses the distributed clustering method. In the LEACH algorithm, the cluster head is selected based on a probabilistic model. Other nodes also select the cluster head based on the shortest distance. However, the LEACH protocol does not guarantee the uniform distribution of cluster heads in the environment, and in some stages, due to the use of a probabilistic model to select the cluster head, a node may be selected as the head of the cluster that does not deserve to be the head of the cluster.

Performance of the LEACH protocol

As we said, the LEACH protocol is a routing protocol based on a clustering mechanism in which nodes are linked together to create separate clusters. Therefore, each cluster has a head node called the cluster head, which collects the data of the cluster members, then sends it to the sink. In the LEACH protocol, sensor nodes are gathered into groups called clusters. Each cluster

chooses a node to become a leader (cluster head) and this selection is done completely randomly and in such a way that in each round out of p rounds only one node is chosen as the cluster head and p is an arbitrary percentage of the number of clusters. As a result, for each node there is p/1 probability to be the head of the cluster and it cannot be selected in the next rounds. As a result, all nodes have the same chance of being selected as the head of the cluster and the rest of the nodes are members of the cluster (or head non-cluster) become and choose a cluster head for themselves according to the proximity.

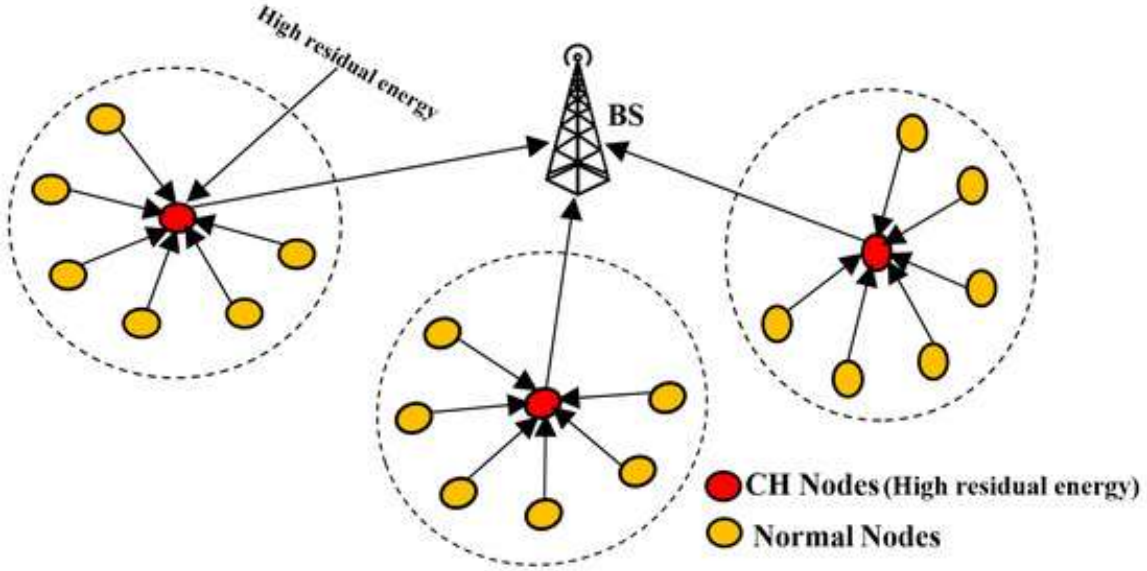

Figure 1: LEACH protocol architecture

Leach protocol performance steps

The operation of the leach protocol is divided into several steps:

1- Installation stage

Each phase begins with a setup operation where the clusters are organized. In this step, cluster heads and clusters are selected. As we said before, the selection of the cluster head is done randomly and depends on the random number that is chosen by the sensor at the beginning of each round and its number is between 0 and 1.

If that number in each sensor is closer to the threshold value specified by the following equation, then the node is selected as the cluster head.

$$T(n) = \begin{cases} \frac{P_L}{1-P_L*(r \bmod (1/P_L))}, n \in C \\ 0 \qquad\qquad\qquad \text{otherwise} \end{cases}$$

where P_L is the percentage of cluster heads in each round, r is the current round, and c is the number of nodes that have not been cluster heads in $P_L/1$ period. Then, according to the signal they receive from the cluster head, the stronger the signal is, If it is more, it is a sign of its proximity to the head of the cluster, they form a cluster. After the clusters are formed, each cluster head sends a TDMA schedule to its cluster member nodes. This schedule specifies the time interval in which each node is allowed to send its information to the cluster head node.

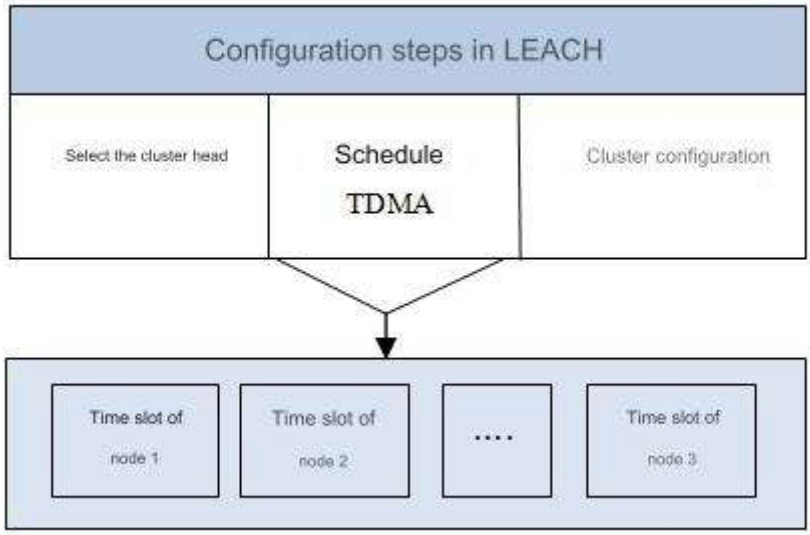

Figure 2: Steps of Leach settings

2- Transfer stage

Following the installation stage is the data transmission stage, which consists of several frames and is longer than the first stage. In this stage, each subscriber node collects its information from the environment and transmits the information to It sends to its cluster head, so the only overhead for them is intra-cluster communication. The cluster head groups and compresses the data received from the cluster members, then sends the accumulated data to the sink node using CDMA code (to avoid collisions). Cluster head nodes need more energy, so choosing a fixed node causes a quick energy drain, which is not fixedly selected in the LEACH protocol. On the other hand, the selected nodes are selected considering the same energy, which in practice may be a node with low energy, which is considered one of the disadvantages or limitations of the leach protocol. Also, the use of data aggregation/combination in the cluster heads reduces the volume of messages sent to the base station and saves energy.

Advantages of LEACH protocol

Less energy consumption is one of the advantages of the LEACH protocol. This is done in such a way that the LEACH protocol improves the lifetime of wireless sensor networks by reducing the number of transmission packets through the formation of clusters and reduces energy consumption in WSNs. Data aggregation helps reduce data communication and save energy. Intra-cluster and inter-cluster connections make us consume less energy in the network, because they reduce the cost of the distance between the farthest nodes and the sink. In addition, the fact that only the cluster heads are responsible for transferring data to the sink also helps save energy. Cluster members communicate with their respective cluster heads, which significantly helps reduce data transmission and energy conservation. In addition, the length of the routing table stored in each sensor node is reduced because connections are made in clusters. LEACH uses TDMA scheduling to avoid node interference. CDMA code is used by the protocol to avoid cluster collisions. In addition, in the LEACH protocol, nodes are placed in sleep mode until their turn to send data. Therefore, this work reduces the number of transmissions in times such as cluster head selection and cluster formation, which reduces both the system overhead and the energy of the nodes is saved.

Disadvantages of the LEACH protocol

In contrast to these advantages, the LEACH protocol also has some limitations. For example, the placement of cluster heads and the number of clusters in each round cannot be guaranteed due to the random selection of cluster heads. Therefore, the probability of choosing a node with lower energy or a further distance is the same as choosing a node with higher energy and a closer distance. As a result, if these nodes are selected as the cluster head, they will exhaust their energy earlier than other nodes, and this means the life of the cluster head will be short. Another problem of the LEACH protocol is that, as we said, it ignores the remaining energy of nodes in the selection of cluster heads. However, the cluster head has higher traffic costs than conventional devices due to its role in acquiring data from all its cluster members, as well as aggregating and sending it to the sink. Another drawback is that the cluster head node uses a single hop to communicate with the sink node, which makes the LEACH protocol unusable for large networks.

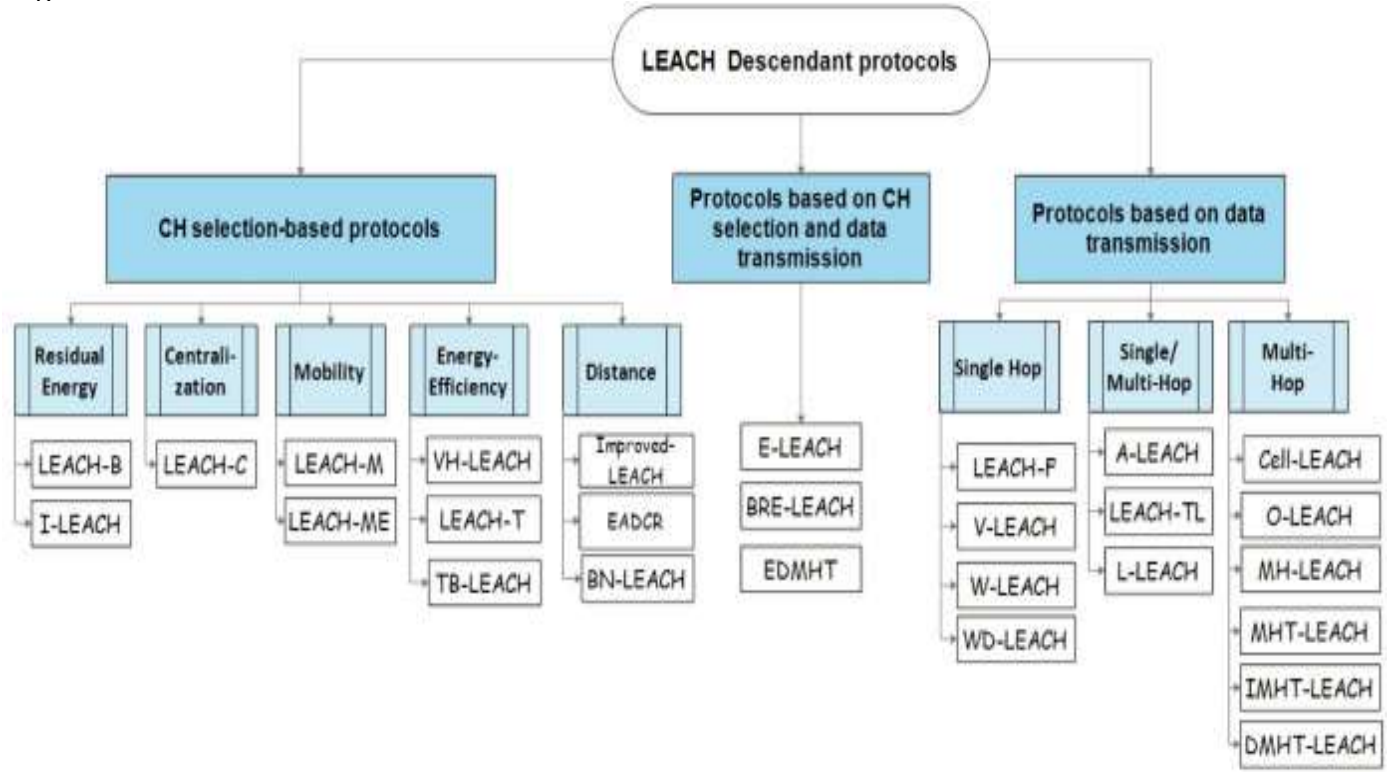

Figure 3: Classification of protocols derived from the LEACH protocol

Clustering methods in WSN network

Among other common techniques for clustering sensor networks is the use of K Means algorithm and Fuzzy C Means (FCM) algorithm. In the simple type of these algorithms, first the required number of points are randomly selected, then the nodes choose one of the centers of the clusters according to the shortest distance to the center of the cluster and join that cluster. and create new clusters. By repeating the same procedure and averaging the distance of the nodes to the center of the current cluster, new centers for the clusters will be obtained.

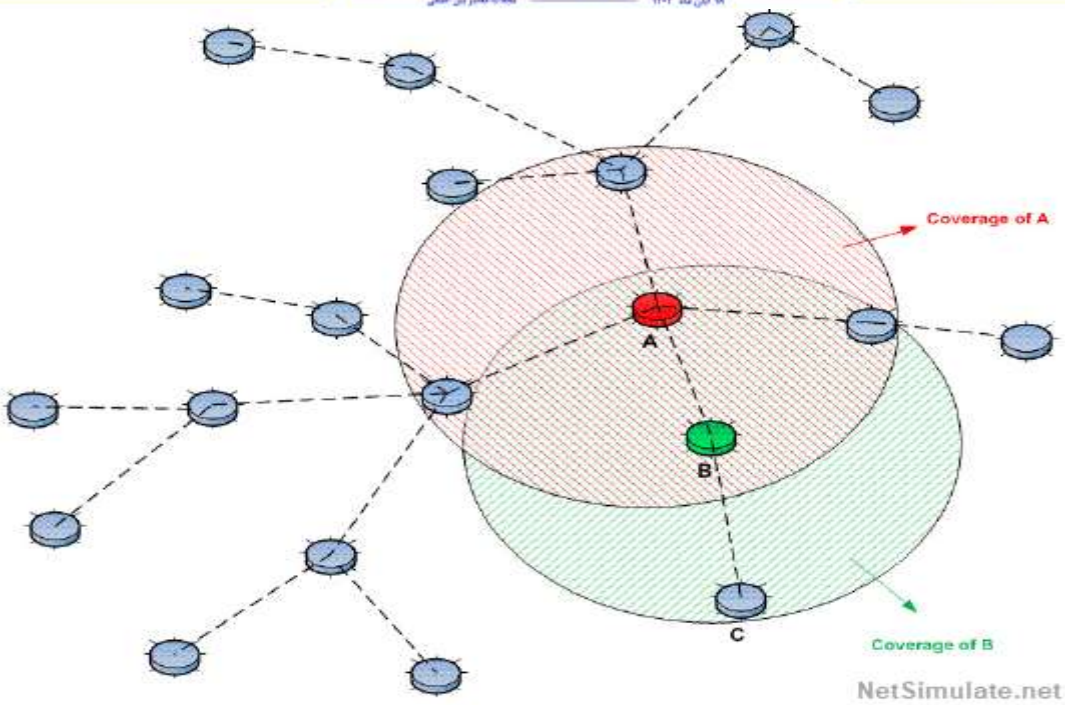

Figure 4: An example of a cluster network with maximum distance

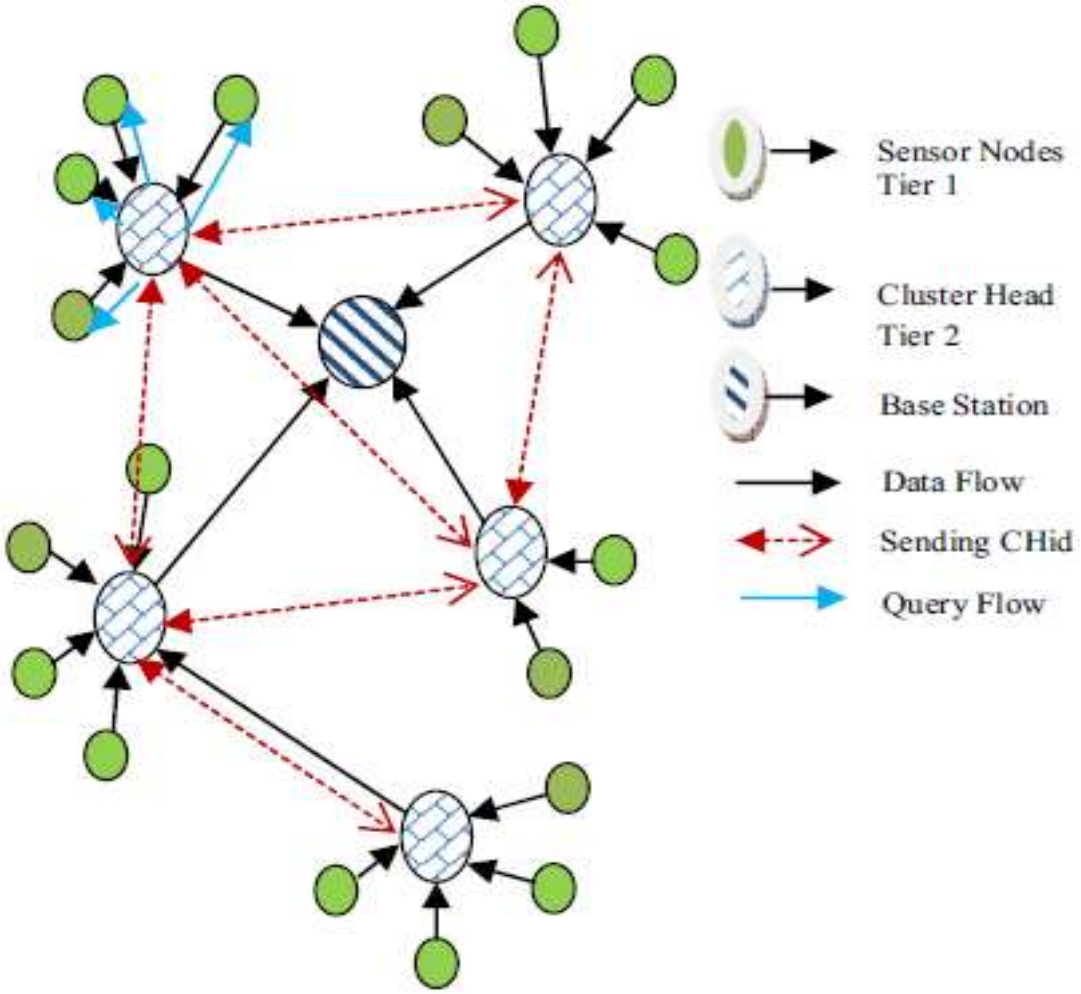

Figure 5: Sending sensitive data with clustering and aggregation

This algorithm does not pay attention to the appropriate number of cluster heads and also does not pay attention to other parameters such as distance to the well, sent traffic, degree of neighborhood, local distance, etc. At the time of choosing the cluster head, it creates non-optimal clusters, which results in reducing the lifetime of the sensor network. The clustering methods that have been proposed so far are among the classic clustering methods.

Classical clustering

Classical clustering methods are highly sensitive to the starting points and often due to incorrect selection of these points, the algorithm in question converges towards the local optimal points and moves away from the global optimal points. It is clear that the clustering of the sensor network with the aim of minimizing the energy consumption is an NP Hard problem.

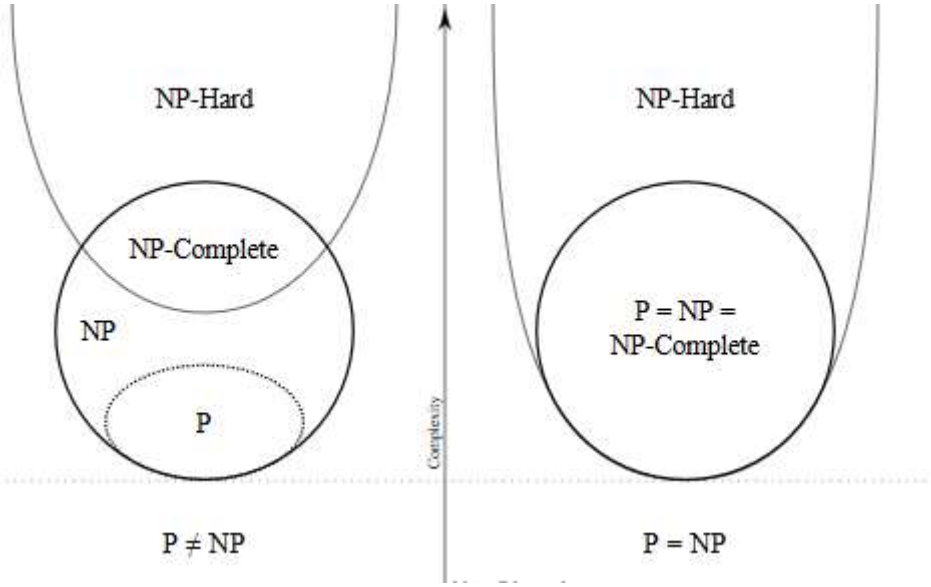

Figure 6: Diagrams for NP-complete, NP-hard, NP and P problems

Since meta-heuristic algorithms are an effective approach for solving complex optimization problems in various sciences, therefore, using these algorithms is useful for solving clustering problems.

Conclusion

Numerous routing protocols based on the clustering technique have been suggested owing to its advantages. These advantages like data aggregation, load balancing, less energy consumption, and scalability. LEACH is treated as the first classical energy-efficient protocol using the clustering routing. It was proposed to raise the lifetime and decrease the consumption of energy in the network.If you have been with us until now, you have noticed that in the field of wireless sensor networks, several routing protocols based on the clustering technique have been proposed due to their advantages. We discussed the advantages and sometimes disadvantages of these protocols. We named the LEACH protocol as the first classic energy-efficient protocol using cluster routing and explained how it works. We also understood that the LEACH protocol increases the lifespan and reduces energy consumption in the network.

References

1. KaurMandeep *et al.* Data aggregation algorithms for wireless sensor network: A review Ad Hoc Netw. (2020)
2. SahooBiswa Mohan *et al.* Particle swarm optimization based energy efficient clustering and sink mobility in heterogeneous wireless sensor network Ad Hoc Netw. (2020)
3. Arora (Research Scholar)Vishal Kumar *et al.* A survey on LEACH and other's routing protocols in wireless sensor network Optik (2016)
4. WattA.J. *et al.* Wireless Sensor Netw. for monitoring underwater sediment transport Sci. Total Environ. (2019).
5. Beshkani, Mohammad Kazem and Pile Kohi, Imran and Mohammadieh, Seyed Ali, 2023, Investigation of clustering methods in wireless sensor networks to increase lifetime and optimize energy consumption in these networks, 8th International Conference on Technological Development in Electrical Engineering of Iran, Tehran , https://civilica.com/doc/1766946.
6. Bahramizadeh, Amirhossein and Adeli, Betoul and Beshkani, Mohammad Kazem, 2022, increasing the quality of routing in wireless sensor networks based on neural networks, the 14th National Conference on Electrical, Computer and Mechanical Engineering, Shirvan, https://civilica.com/doc/ 1458082
7. Adeli, Batul and Noori, Behzad and Jafari, Majid and Beshkani, Mohammad Kazem,2022,Reduce power consumption and increase reliability in wireless sensor networks based on a new algorithm,The Second International Conference on Science, Engineering and the Role of Technology in New Businesses,https://civilica.com/doc/1506673.