A Contemporary Survey on Clustering Techniques for Wireless Sensor Networks

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Abstract
Low power wirelessly interconnected devices forms a self-configured system called Wireless Sensor Network (WSN) which brings out numerous applications in today's world. Nodes in WSN are spatially distributed and wirelessly inter-connected devices mainly involved in sensing the deployed region and recording the details of physical circumstances for instance hotness, humidity, noise vibrations, load etc,. The sensor observations are collected through a centralized node called sink from there the end-user control system receives the data for further analysis. After the deployment, nodes form a group among themselves called clusters and select one among them as Cluster Head (CH) which plays as a gateway to move the data further in the network. Clustering is very crucial in solving lots of issues in WSN especially in lifetime, scalability, energy saving and interoperability of the network. Many clustering approaches exist for WSN which are differs in terms of CH selection, cluster count, cluster structure, data aggregation policy, energy efficiency and Inter-cluster and Intra-cluster communication. This paper presents a robust comparative analysis of various clustering techniques with their merits and demerits in WSN. It also furnishes the CH selection and working principle of clustering protocols under each category which would help end user to choose the appropriate method with respect to the application requirements and also assist the researchers to address the revealed challenges in clustering process of WSN.

Keywords: WSN, Clustering, Sensing, Intra-cluster communication Inter-cluster communication, Adaptive, Load Balancing.

1. INTRODUCTION

WSN consists of a vast number of low-cost, low-energy and multi-function sensor nodes used in a particular field. These sensor nodes are thin, but they have built-in microprocessors and radio transceivers, giving them the ability to not only sense, but also process data and communicate. They communicate across a limited duration using a wireless channel and work together on a shared mission, such as environmental monitoring, military surveillance, or industrial operations management [1]. Sensor networks have specific characteristics and constraints when compared to conventional wireless communication networks, such as massive node deployment, rechargeable batteries, and self-configurable nodes, Unstable sensor Nodes, Application-Specific Energy, Processing, and Storage Constraints, no global identification, routine topology transitions, data redundancy, many-to-one flow[2]. The WSN consists of numeric nodes, each with one or more sensors attached to hundreds or thousands. Fig.1 depicts the traditional architecture of WSN.

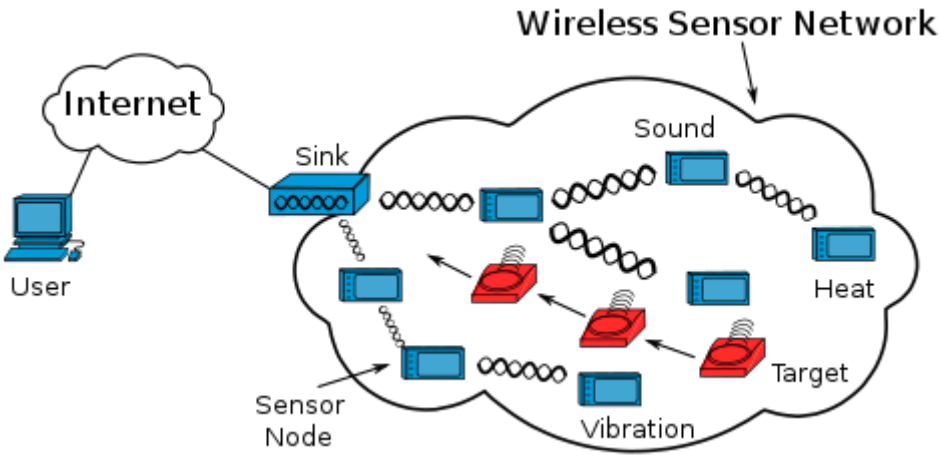

Fig.1. Architecture of WSN

A component of sensor is shown in Fig. (2), this consists of a sensor unit, a processing unit, a transceiver and a control unit. It also includes application-specific upgrades includes a positioning system, electric generator and cellular device. ADC transforms the analogue signals from the sensors into digital signals that are then sent to the processing unit [3].

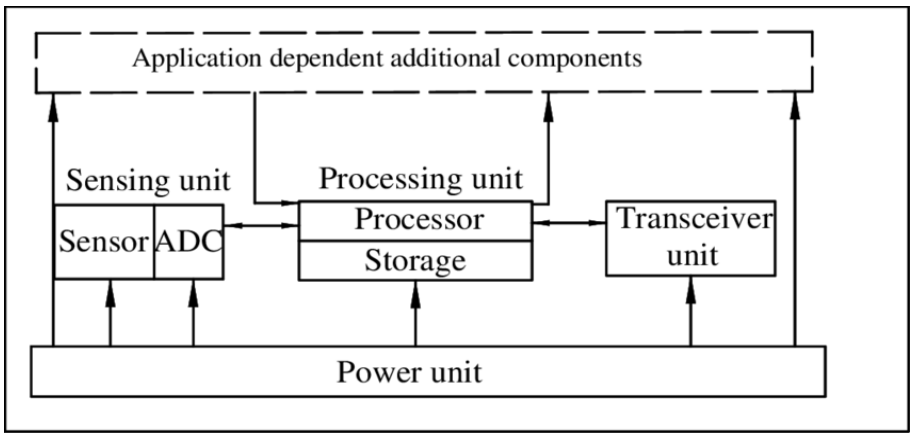

Fig.2. Components of a sensor node

The processing unit is normally attached to a small storage unit and is able to monitor the procedures allowing the sensor node to work with other nodes to complete the sensing tasks assigned. Energy supported by a power system like solar cells [4]. Fig. (3) Shows a compact wireless sensor node functional block diagram. The massive increase in WSN use over the last decade necessitates the development of aggregation protocols in massive surroundings. This is accomplished through a clustering process in which CH typically handles the more complex tasks like data fusion and aggregation, while member nodes handle the basic sensor nodes (MN). The method of cluster construction creates a two-stage hierarchical system, with the higher level CH nodes and the lower level of the cluster nodes [5]. CH nodes consume more resources than MNs when they transmit long-term data than member nodes.

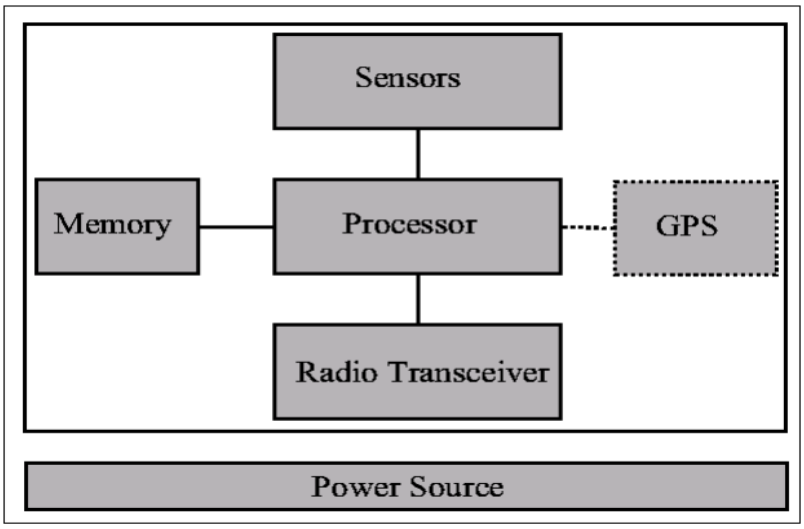

Fig.3. Fundamental block diagram of a node in WSN

2. CLUSTERING IN WSN

A cluster is created by the node group and a cluster head (CH) governs the local interactions between cluster members, as seen in Fig. (4). Cluster participants collaborate with the head of the cluster in order to conserve time and compile the gathered data and merge it into a cluster head [6].

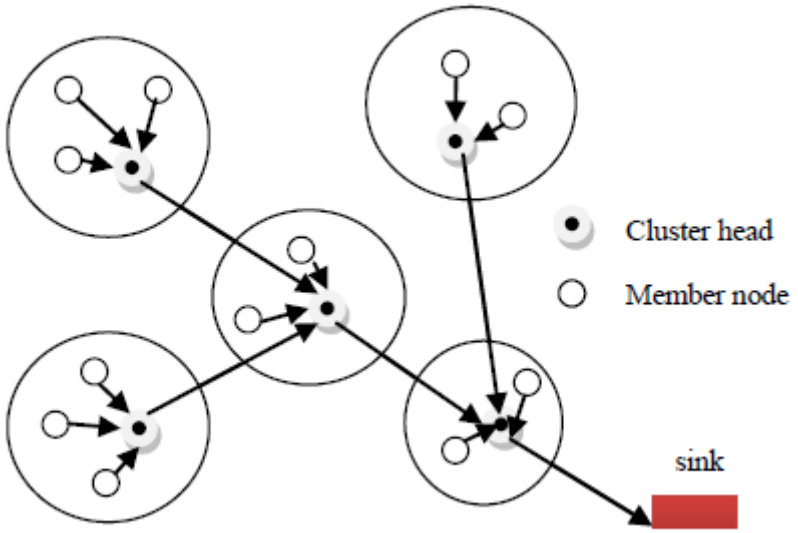

Fig.4. Clustering in WSN

Clustering in WSN has a number of benefits, including the following:

- It helps to increase network scalability and reduce energy usage by aggregating data.
- It will concentrate route configuration inside the cluster
- Limits the range of inter-cluster connections to the head of the cluster
- It prevents redundant message passes across sensor nodes.

Before going through the various classification options for WSNs clustering algorithms, it's important to understand a few key parameters about the entire clustering process in WSNs [7-10]. Furthermore, these parameters are used to compare and categorise the different clustering approaches.

i. **Cluster count:** CH choice and construction methods inevitably contribute to a varying number of clusters in most recent probabilistic and randomised clustering algorithms. The

collection of CHs and hence the number of clusters are nevertheless predetermined in certain published methods.

ii. **Intra-cluster communication:** In certain early clustering methods, communication between a sensor and the allocated CH is expected to be immediate. However, where the sensor nodes have a restricted contact range and the number of sensory nodes is extremely large and there are limited numbers of CHs, intra-cluster multi-hop communication is always essential.

iii. **Message count:** The number of messages to be exchanged for the cluster head range is the number of messages. There are several messages to be sent, so the cluster head selection process takes plenty of resources. There are many algorithms that include message transmission, such as cluster head selection.

iv. **Stability:** Clustering schemes are said to be adaptive if the members of a cluster are not set. Otherwise, since the cluster count does not change during the clustering process, we can consider it set. A sensor network's reliability is improved by using a fixed cluster count.

v. **Intra-cluster topology:** It specifies whether the cluster's communication is direct or multi-hop between sensor nodes to cluster head. However, the range of the sensor affects contact. The cluster head count was restricted by this range.

vi. **Cluster formation methodology:** If CH's are just ordinary sensor nodes and time efficiency is the principal criteria of architecture, clusters are spread in the most recent approaches, without synchronisation. In a few earlier approaches, a centralised (or hybrid) approach was employed; one or more coordinator nodes have been used for separating and managing the whole network off-line.

vii. **Cluster-head selection:** Some proposed algorithms (especially heterogeneous ones) allow cluster heads to be pre-assigned. In most uniform environments, however, CHs are selected either probabilistically or totally on a random basis from the deployed nodes set or according to other more exact parameters (residual energy, connectivity etc.).

3. TYPES OF CLUSTERING

WSN has a number of clustering modes based on a many attributes. Fig.(5) illustrates the proposed comparative study focuses on clustering classification based on intra or inter cluster communication of nodes in WSN.

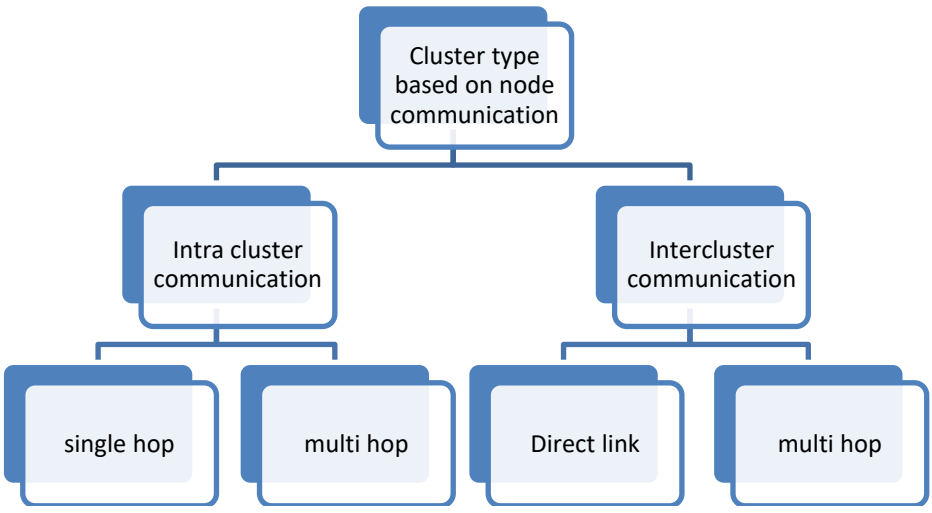

Fig.5. Classification of Clustering in WSN

Intra-cluster communication refers to communication between members of a cluster; typically, this communication occurs through single-hop or multi-hops from members to the cluster's leader. Inter-cluster communication refers to communication between clusters of a network for the purpose of transmitting cluster data to the outside through its cluster head [11], [12]. This transmission can be made in a single hop to sink or in multiple hops between CHs to sink. Fig. (6) Depicts single-hop vs multi-hop communication scenario of WSN. It is easy to add data to the cluster head and to communicate it only through other cluster heads via single-hop networks to the base station [13], [14]. If more than one hop was necessary to send data to the cluster head, it is said that the network is multi-hop. The obtained data must be authenticated by the sensor node [15-17]. Table.

1 depicts the communication strategy between clusters is used to classify the clustering protocols for WSN.

4. PROTOCOLS BASED ON SINGLE HOP (INTRA -CLUSTER) COMMUNICCATION

a) LEACH

LEACH (Low Energy Adaptive Cluster Head), the first popular WSN clustering protocol was proposed in [18], [19]. In which sensors are clustered into clusters and certain nodes are randomly selected as cluster heads with some chances that each round is cluster heads. Since LEACH is a distributed algorithm, cluster count is not fixed. Due to the distributed algorithm, each node can choose a random number to pick itself as the CH. Because of the randomness of the random number generator, each node can be equally numbered in the collection of the cluster head.

b) LEACH-C

In this protocol the location and energy level of the nodes are transferred to the base station with a centralised approach. Cluster heads are randomly selected and this protocol reduces the number of cluster heads. Since the node status far from the base station is difficult to relay, this protocol is not suitable for larger networks [20], [21]. Since the cluster head location is still rotating, information cannot be provided on a timely basis.

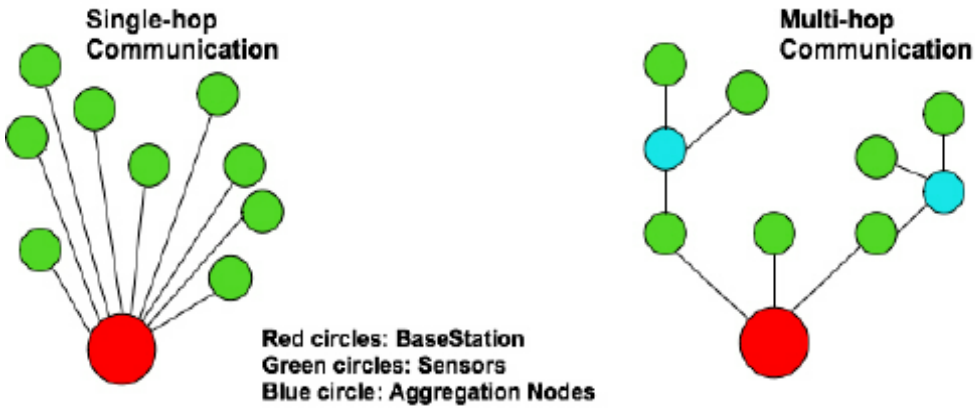

Fig.6. Single-hop Vs Multi-hop Communication

c) HEED

The use of residual capacity, node grades or density as the primary parameters for the creation of clusters to achieve balance of power is suggested in HEED over LEACH protocol [22]. The algorithms in this protocol regularly choose cluster heads based on two basic parameters. The primary parameter is the residual energy of each node and, in terms of cluster density or node level, the intra-cluster touch is the second [23]-[25]. In probabilistic terms, the primary parameter chooses the original group heads, while the secondary parameter splits relationships. HEED cannot answer the number of clusters per round and are not consciously heterogeneous.

d) PRODUCE

Distributed clustering [26] algorithm that organises the network using clustering of unequal sizes. It was calculated using localised probabilities and stochastic geometry-based multi-hop routing. Range clusters that are further from the BS have larger cluster sizes in this algorithm, whereas clusters that are closer to the BS have smaller cluster sizes. On each rank, a different probability is allocated for the selection of the cluster head. Because of the variable cluster count, the proposed protocol results in unequally sized clusters.

5. PROTOCOLS BASED ON MULTI HOP (INTRA- CLUSTER) COMMUNICATION

a) HSR

The Efficient Routing Protocol for Heterogeneous Sensor Network suggested in [27]-[30] with the use of a limited number of powerful high-end sensors with a large number of low-end sensors. Each sensor node in this scenario is static and conscious of its own location. During the cluster formation process the cluster heads are selected based on signal power by the nodes. The data is transmitted to the sink by the Cluster Heads via multi-hop transmission. The suggested solution is static, making it unsuitable for broad coverage scenarios.

Table 1.Cluster based protocols based on their communication strategy

CLUSTER CHARACTERTICS	CLUSTER COMMUNICATION															
	INTRACLUSTERCOMMUNICATION								INTERCUSTERCOMMUNICATION							
	SINGLE HOP				MULTI HOP				DIRECTLINK				MULTI HOP			
PROTOCOL NAME	LEACH		HEED	PRODUC		C4SD	NDBC	TBC		DWEHC	DEEC	DEBC	UCR		ECBDA	DCLB
NODE DEPLOYMENT	Random	Random	Random	Random	Random	Random	Random	Random	Random	Random	Random	Random	Random	Random	Random	Random
HETEROGENITY (Y/N)	N	N	N	N	Y	Y	Y	N	N	N	Y	Y	N	N	N	N
LOCATION AWARENESS(Y/N)	N	N	N	Y	Y	Y	N	Y	N	N	N	N	N	N	N	Y
CLUSTER HEAD MOBILITY		FIXE	FIXE		FIXE	FIXE	FIXE	FIXE		FIXE	FIXE	FIXE	FIXE		FIXE	FIXE
CLUSTER COUNT	VARIAB	VARIAB	VARIAB LE	VARIAB	VARIAB LE	VARIAB LE	FIXED	VARIAB LE	VARIAB	VARIAB LE	VARIAB LE	VARIAB LE	VARIAB LE	VARIAB	VARIAB LE	VARIAB LE
CH SELECTION	PURE	PURE	PURE PROBABILITY	DISTANCE	DISTANCE	WEIGHTEDPROBABILITY	NEIGHBOR	NEIGHBOR & DISTANCE	WEIGHTED	WEIGHTED PROBABILITY	WEIGHTED PROBABILITY	WEIGHTED PROBABILITY	PURE & WEIGHTED	PURE	WEIGHTED PROBABILITY	NERIGHBOR &LOCATION
MESSAGE COUNT	N	N	N	Y	Y	N	Y	Y	N	N	N	N	N	N	N	Y

CLUSTERING METHOD	DISTRIBUTED	CENTRALIZED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED	DISTRIBUTED

b) C4SD

A clustering structure for the distribution of data information is used by the proposed cluster-based Service Discovery for Heterogeneous WSN [31] protocol. The hardware and weight of each node in this protocol are unique. If any node has more power, it should be selected as the head of the cluster. These nodes are allocated for the service registrations of the cluster [32], [33]. A service lookup visits only the directory nodes, which results in a low cost of discovery.

c) NDBC

Sanjeev Kumar Gupta et al. [34] propose node grade based classification as an extension to the life of heterogeneous WSNs (NDBC). The authors used two kinds of sensor nodes in this paper: advanced and normal nodes. There is greater energy in advance nodes than in regular nodes. The advanced Nodes are selected from their energy and network node degree as cluster heads. In order for the selection of cluster heads to be carried out, the authors used NDBC to reduce the cost of communication between sensor nodes.

d) TBC

The Wireless Sensor Network method proposes traffic based clustering approach [35]-[37] to build a system that takes topology (cluster size and hierarchical level number) in line with the traffic trends and sensor node density implemented in the particular area of interest. The authors propose to construct a network topology in various regions of total network coverage based on the node density. This will remove bottlenecks and lead to a longer network life due to the correct balance of load. According to the suggested protocol, long distance sensor nodes lose power faster than sensor nodes closest to them.

6. PROTOCOLS BASED ON DIRECT LINK (INTER CLUSTER COMMUNICATION)

a) SEP

Heterogeneity is introduced by a Stale Election Protocol for Heterogeneous Wireless Sensor Networks [38] that stretches the time interval to the time of the first node that is known to die as the age of stability. This protocol uses the weighted choice probability of each cluster head depending on the rest of the energy in each node. The authors extended the LEACH protocol with the exception of consideration of heterogeneity. The cluster count of this algorithm is erratic and the unstable time of the algorithm is not optimal.

b) DWEHC

The proposed distributed weight-dependent energy efficient hierarchical clustering protocol [39] is geared to high energy consumption by producing balanced cluster sizes and optimising intra-cluster topology. Each sensor node calculates its weight after positioning the nodes in its place. The cluster head will be chosen as the most important node in the neighbourhood, with the remaining nodes members. The protocol is not working well in terms of stability time, given the vast amount of energy used in finding neighbours.

c) DEEC

In [40] there is a hierarchical clustering algorithm for heterogeneous WSN. The DEEC cluster heads are selected based in probability on the ratio of the residual energy of each node to the average energy of the network. Before reaching a general solution for multilevel heterogeneity, the algorithm examines two layers of heterogeneous nodes. DEEC determines the optimal value for network life to

determine the reference energy each node can expend in a round. In this method, cluster count is variable, resulting in uneven clusters.

d) DEBC

The collection of cluster heads forms the Heterogeneous Wireless Sensor Networks [41]. In DEBC, cluster is based on the radio-based probability between the node's residual power and average network power [42]. Cluster heads are more likely than low-energy nodes to be of high initial and residual energy. This protocol builds on the LEACH and SEP protocols by the consideration of two degrees of heterogeneity and expanding to multi hop heterogeneity.

7. PROTOCOLS BASED ON MULTI HOP (INTER- CLUSTER COMMUNICATION)

a) UCR

In order to reduce the hot spot problems in WSNs, an unequal Cluster-based Routing protocol is introduced for the wireless sensor networks [43]. It is an autonomous competitive algorithm, which picks up cluster heads based on local knowledge such as residual energy in the neighbouring node. Cluster heads near to the base station could have smaller cluster sizes, so cluster heads could use less energy to process intra-cluster data and should hope to use more energy for the transmission of inter-cluster relay traffic. The protocol completes the cluster head selection process in two stages due to its variable cluster count, which takes time and results in uneven cluster size.

b) ECLCM

A probabilistic clustered energy model is proposed for estimating the energy used in a WSN multi-hop [44]-[46]. Each sensor node selects itself as a cluster head with a specified probability, without sharing information with other nodes. The TDMA schedules ordered by the cluster heads or sink nodes are used for the communication of all nodes. If the shortest number of hops from a sensor node exists with more than two cluster headings, the node randomly selects one. That goes on until every node selects or becomes one cluster-head. TDMA plans are arranged by the cluster heads or sink node for all nodes to connect. Collisions of data should also be prevented. The suggested protocol results in unequally large clusters due to the variable cluster count. Multi hopping is responsible for network holes at the base station.

c) ECBDA

ECBDA was suggested in [47] to increase network lifespan as a cluster-based aggregate solution. One node from each cluster is selected as the cluster head based on its residual energy and connectivity cost factor during the cluster head election process. During the maintenance period, the residual energy of the cluster head is controlled every round. If the residual energy is less than the appropriate threshold value, a new cluster head will be chosen from the same cluster. The suggested protocol results in a narrow cluster that provides a more energy-efficient transfer from the cluster head to the base stations.

d) DCLB

Distributed load-balancing clustering in inter-cluster communication clusters was suggested for efficient cluster formation and balances the load in [48]. In terms of energy efficiency and load-balancing, size (range) is important for multi-hop cluster head contact. It avoids energy failure and maintains the cluster to have a balanced load because at any step in the clustering phase it checks the data volume. Because of the variable cluster count, the suggested protocol generates unequally large clusters.

8. CONCLUSION AND FUTURE WORK

Heterogeneity can stretch the life of the network and improve its reliability in wireless sensor networks. Clustering is a successful technique in wireless sensor networks to reduce energy use and ensure reliability. Many protocols were proposed to operate under heterogeneous networks of wireless

sensors. Many of the new heterogeneous network energy efficiency protocols are built on the clustering approach, which has shown that it is beneficial to reduce energy consumption in wireless networks [49]. This paper concludes that a comparative study of various WSN clustering protocols aids researchers in identifying challenges in applying them in real-world scenarios and making informed decisions in the future. Further, this survey will be enhanced with more cluster parameters involved to form the clusters.

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