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Review Article

Clustering an Energy Optimization Technique in Wireless Sensor Networks: Taxonomy and Review

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Abstract

Wireless sensor networks (WSN) are increasingly finding their way in diverse applications be it the realization of IoT or real-time monitoring of the environment, health, defense, and even domestic ones. A wireless sensor network consists of a large number of small self-configurable sensor nodes that are capable of performing functions of sensing, processing, and communication of information. Sensor nodes are inherently constrained in terms of energy, computational and communicational capabilities. Most of the sensor nodes are battery-powered with a limited supply of energy. The battery of a sensor node is hard/ impossible to be replaced once deployed. Lifetime of a sensor node or sensor network is concerned with energy, and it is strictly constrained. Most of the energy of a sensor node is consumed during communication, therefore; energy efficiency should be the prime focus while designing the hardware and software of wireless sensor networks. Clustering is an energy optimization technique that can increase the energy efficiency and prolong the network lifetime. Various aspects of clustering presented in this paper include different types of cluster-based networks, clustering process and evaluation metrics. A brief insight into present trends on clustering is also included.

Keywords: *Wireless sensor Networks (WSN), unique constraints, lifetime, clustering, load balancing and quality of service.*

1. Introduction

Wireless sensor networks are finding their way in every sphere of the modern-day smart world owing to their vast range of applications. Wireless sensor networks are used in surveillance, environment monitoring, real time health and home monitoring, etc. Wireless sensor networks (WSN) are cheap, small in size and often with little or no underlying infrastructure [1]. WSNs consist of a large number of small sized sensor nodes that are randomly deployed in an area of interest. A sensor node is responsible for collection of data, information processing and communicating that data for further processing, analysis and storage [2]. A small battery usually powers a wireless sensor node with a limited capacity and in most of the cases it is nearly impossible to replace that once exhausted [3]. Such a wide range of applications often comes with certain challenges that are different from other wireless networks; they have limited energy, computational (processing and storage) and communicational capabilities.

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M. A. Matin [4] defines Wireless sensor network as, "Wireless Sensor Networks (WSNs) can be defined as a *self-configured* and *infrastructure-less* wireless networks to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to a main location or sink where the data can be observed and analyzed."

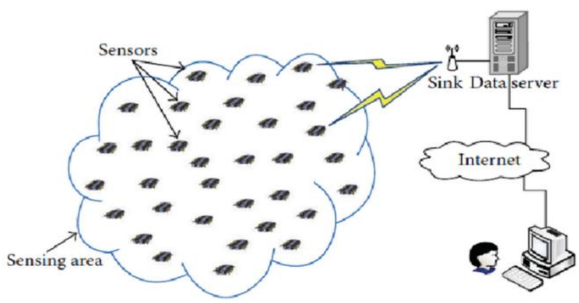


Figure 1: Wireless Sensor Network [5]

The rest of this paper is organized as follows: Section 1.1 discusses the applications and challenges in clustering. Section 3 describes the taxonomy of clustering in wireless sensor networks based on characteristics, methods, process, and routing and performance metrics for evaluation. Section 4 provides an insight of current literature, relying on clustering and load balancing in wireless sensor networks. Finally, Section 5 discusses the conclusion and future work.

1.1 Applications and Challenges of Wireless Sensor Networks

WSNs are often used for low-power and low-data rate applications owing to the constraints of limited energy, bandwidth and communication capabilities. WSN are being used in various fields ranging from military to domestic ones. In military applications WSNs can be used for surveillance, object tracking or can be deployed in and around important sites like nuclear plants, telecom centers or oil and gas plants for protection. Besides they are used for emergency and disaster prediction, health monitoring and in smart home applications [6]

Unlike a centralized system, a wireless sensor network is subject to a set of unique constraints such as finite power supply (typically a battery), limited computational and communicational capabilities.

2. Clustering with Load Balancing

Wireless sensor networks have very diverse applications and this gives rise to certain unique challenges in the realization of an efficient wireless sensor network. Among these various challenges three major constraints faced by the WSN's are Energy, hardware resources and communication bandwidth constraints. Energy is directly concerned with the lifetime of a WSN. Lifetime is the duration from the deployment of the sensor nodes in an operational environment until the first node dies or become inactive. Most of the sensor nodes are battery powered and it is almost impossible to replace those batteries once these nodes are deployed in the intended regions (massive and random deployment in harsh and hostile environments). It is always desired to prolong the life of a WSN or it should at least sustain until the completion of the operation. Thus, energy in a wireless sensor network is strictly constrained. The energy consumption of a sensor node is a wireless sensor network is mainly dependent on the factors like, number of rounds, sensing (whether continuous or event driven), topology (flat or hierarchical), distance from the sink and activity schedule (Figure 2a). Energy consumption in a WSN is mainly due to communication, sensing and computing sub-systems [8].

Fig 2b shows the portion of energy consumed by each subsystem. As seen from the fig communication takes most of the available energy [9]. The energy consumption of a node directly depends on the distance from the sink and the load on that node. Larger the distance and higher the load, greater is the energy consumption and subsequently more quickly the energy of the sensor node is exhausted. Network topology is also determinate in the lifetime of the WSN. Therefore, to extend the network lifetime along with maintaining the Quality of service (QoS) in a network, an energy efficient way of communication that will include networking among sensor nodes and routing of the sensed information, is needed. Load balancing with clustering is a technique to reduce the consumption of energy thereby extending the network lifetime.

Clustering involves grouping of sensor network into small groups called clusters; each having an individual head called cluster head and several cluster members. Clustering of sensor nodes in a network is important for solving various problems like scalability, energy efficiency and lifetime in wireless sensor networks [2]. Load balancing is a method to fairly distribute the load in a network in order to prevent the premature death of some overburdened nodes. Even after clustering, some nodes (cluster heads, relay nodes and nodes close to base station) with heavy load suffer with a quick energy exhaustion leading to reduced network stability. Load balancing improves the lifetime of the network, as all the nodes will have similar energy consumption rate based on the distributed traffic [1].

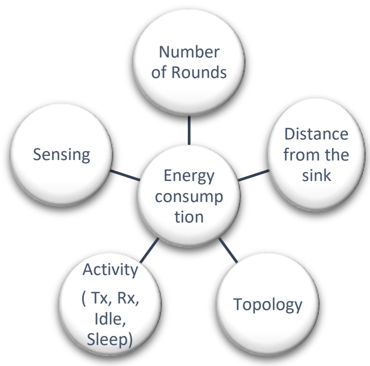


Figure 2a: Factors responsible for energy consumption [Self].

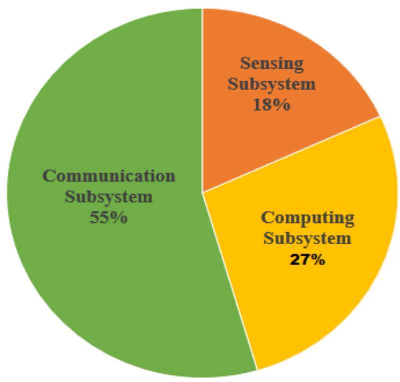


Figure 2b: Energy consumption Proportion [9]

2.1 Clustering

Based on network topology a network can be classified as flat or hierarchical cluster-based networks. In flat networks, every sensor node in the network performs the similar function and is connected with each other using multi-hop communication [10.] It involves flooding technique to deliver a message from source to destination wherein the entire network is involved. Such type of communication technique is not feasible for large networks as it involves higher energy consumption, data redundancy, high delays and unequal consumption of energy of sensor nodes due to varying load.

Whereas in cluster-based networks, a network is divided into small groups each consisting of a cluster head and several cluster members. In cluster-based networks communication takes place either as intra-cluster or inter-cluster communication over short distances as compared with the flat networks.

2.1.1. Components of a cluster

Clustering involves logical organization of a sensor network into small and easily manageable groups each having a cluster head (CH) and several members (MN) [7].

1) Cluster head

Each cluster has a local leader or coordinator called a cluster head. Cluster head performs various functions such as collection of data from its member nodes, aggregation of collected data and forwarding that aggregated data to the base station.

2) Cluster members

In addition to the cluster head, a cluster has several members called member nodes. Member nodes are mainly responsible for sensing of information for the region of interest. These member nodes forward all the information to the cluster head using intra-cluster communication.

3) Gateway node

Gateway nodes are responsible for communication between different cluster heads.

2.1.2. Parameter metrics of cluster based WSN's:

In order to design an efficient clustering technique several factors of a wireless sensor network are taken into consideration. An algorithm is designed as per requirements arising from these parameters. Some of the parameters are discussed as under:

1) Node Type: In a WSN sensor node (CH or MN) can be either static or dynamic in nature. A static or stationery node has a fixed position in the cluster whereas a dynamic node changes its position w.r.t other nodes. In case of dynamic nodes, a challenging problem is retention of cluster for a long time and a subsequent packet loss.
2) Network Type: In WSN, cluster formation follows two approaches; distributed and centralized. In distributed approach is of probabilistic nature wherein a node can become either cluster head or member node based on certain parameters calculated at node level. Whereas, in centralized approach entire network information is required at the base station for cluster formation and selection of cluster heads [10].
3) Energy Efficient Cluster: Clustering should be efficient in terms of energy consumption as wireless sensor nodes have an energy source with limited capacity (small batteries).
4) Cluster Communication.

In a cluster-based network, communication can take place as either intra-cluster or inter-cluster communication [11].

a. Intra-cluster Communication: Communication taking place within each cluster is termed as intra-cluster communication. It can be either single-hop or multi-hop. In single hop intra-cluster communication, all member nodes send their sensed data directly to the cluster head whereas in multi-hop intra-cluster communication data passes through intermediate nodes. Single-hop intra-cluster performs efficiently as compared to multi-hop intra-cluster communication in terms of energy conservation.

b. Inter-cluster Communication: Communication taking place among various clusters is called inter-cluster communication. Either a cluster head can forward the data to the base station directly in a single hop or it can be forwarded to other relay nodes for further transmission resulting in multi-hop communication (Fig 3). In case of larger networks, multi-hop inter-cluster communication performs better in comparison to single-hop inter-cluster communication.

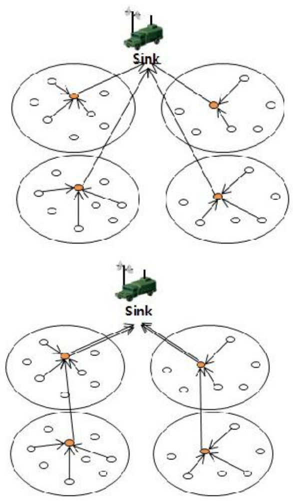


Figure 3: Single-hop and Multi-hop cluster communication [12]

5) Homogenous or heterogeneous cluster

A cluster having all the nodes similar in terms of energy and other hardware recourses is called a homogenous cluster. In a homogenous cluster sensor node can act as cluster head or cluster member. Whereas, a cluster in which the cluster heads are predefined and are equipped with higher energy and more powerful communicational and computation recourses is called a heterogeneous cluster [13].

6) Fixed or adaptive cluster

In terms of the size, a cluster can be either of fixed or adaptive nature. Clustering in which every cluster has a fixed number of member nodes is called a fixed cluster technique. In adaptive or dynamic clustering the size of the cluster varies on the bases of factors like distance from the base station and traffic load on a particular cluster head (Fig 4). In terms of energy consumption and stability of the network adaptive clustering is considered to be more efficient [14].

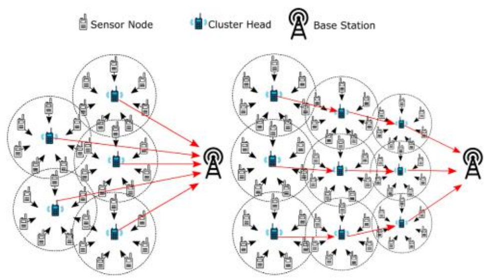


Figure 4: Fixed and Adaptive cluster [15]

2.2 Load Balancing in Wireless sensor networks:

After cluster formation many of the problems stated above need to be addressed. Load balancing is a technique that is used to solve the energy optimization problem of the sensor nodes for extending the network lifetime. Load balancing is used to address the issues of cluster head selection, dead lock, cluster size, selection of relay nodes, stability, aggregation and transmission of data, intra and inter-cluster communication, etc. (Fig 5).

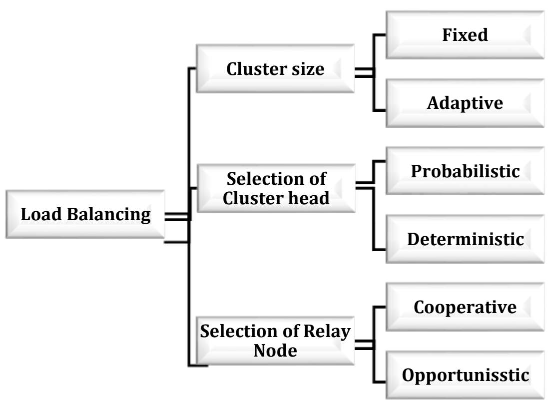


Figure 5: Load Balancing Parameters [self]

By applying load balancing, the lifetime of the network depends upon the life of all the nodes in the network as issue of unequal consumption of energy is addressed. In the selection of cluster head load balancing is achieved by considering certain weight value based on various parameters like initial energy of the sensor nodes, residual energy of nodes, distance from the base station, number of neighbors, fairly distribution of cluster heads [16].

2.3 Clustering-A Sequential Process

The process of grouping a wireless sensor nodes in a network commonly known as clustering consists of a sequence of steps, mainly divided into following phases (Fig 6):

1) Selection of Cluster head
2) Cluster Formation: Grouping of sensor nodes into clusters.
3) Data transmission phase

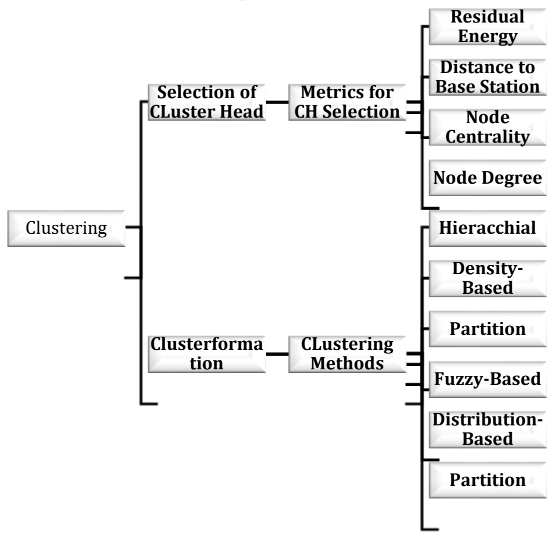


Figure 6: Different stages in clustering [self].

Phase I: Selection of cluster head

After random deployment of sensor nodes in an area, the first step is to organize the sensor nodes into groups each having a local coordinator and few members. A sensor node is selected as leader commonly known as cluster head. Selection of a cluster head is a complex problem in clustering process. The Cluster Head selection is based on several metrics like distance between cluster head and sink node, nodes and cluster head; residual energy of nodes; number of nodes in a cluster (cluster density); number of neighbors (node degree); node weight and signal strength (RSSI) [15].

Phase II: Cluster Formation

After selection of cluster head the process to cluster formation begins. Clustering of a wireless sensor networks can be dome in a variety of ways depending upon the feasibility and requirements in a task under consideration. A cluster is generally made up of a single cluster head and several member nodes [17].

Phase III: Data Transmission phase

The data transmission phase can be sub-divided into following sub-phases:

1) Collection and aggregation of data
2) Routing of data from source to sink.

i. Collection and aggregation of data

A wireless sensor network consists of a large number of sensor nodes that are meant for collection of the data or information for the region of interest. Each sensor node may be equipped with one or more sensors. A sensor node is mainly deployed to monitor various environmental parameters like temperature, humidity, light, pressure, etc., health monitoring or for object surveillance in defense application. Once deployed, a sensor node starts to collect the information as per the requirement of a particular application. The collection of information or sensing is usually done in following modes [18].

a. Continuous.
b. Event-driven.
c. Hybrid

a. **Continuous mode**: In continuous mode, a sensor node keeps actively monitoring the environment at regular intervals or as per a predefined schedule. Such type of data collection is usually done in real-time application and consumes more energy than other modes.
b. **Event-driven mode:** In this mode, information is collected only when there is any change in the parameters being measured or under observation for example a change in temperature recorded previously, change in health parameters of a patient, or detection of an object in the field of surveillance. This mode is considered to be energy efficient than continuous mode.
c. **Hybrid mode:** Hybrid mode of data collection is characterized by the presence of both continuous and event-driven mechanisms.

The sensed information if forwarded to the cluster head for aggregation in a single hop or multiple hops, single-hop being more preferred. The cluster head applies different data aggregation techniques on the raw data collected from member nodes before forwarding it to the sink node or relay node. Data aggregation is done to reduce the amount of data being forwarded and to reduce the latency in the data. This results in a considerable decrease in the network traffic and saves the communication bandwidth (Fig 7).

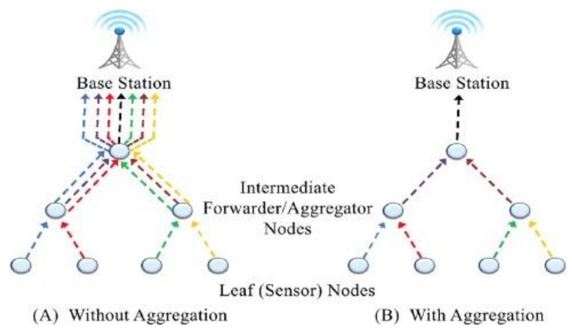


Figure 7: Data aggregation in WSN [18]

ii. Routing of Data from source to sink:

After data aggregation the cluster head forwards the data to the next level, it can be a relay node or directly to the base station or sink node in case of single hop communication. There are various approaches of routing topology and path establishment as well (Fig 8).

a. Routing Topology

In Wireless sensor networks, assigning an identifier or numeric number (similar to IP address) to a particular sensor node is infeasible because of massive and random deployment [20]. Therefore, routing of data is a challenging task in wireless sensor networks.

Data Centric Routing: In data centric protocols focus is laid on the data or information rather than on the source of the data. Sink node collects data from a region of interest without knowing the actual source of data. Sensor Protocols for Information via Negotiation (SPIN) is an example of data centric protocol [21].

Location based Routing: In location-based routing source node is aware about the geographic location of the destination node and sends data to that specific location only. It is also known as geographic or position based routing. The source node knows the location of its direct neighbors only and path establishment and packet forwarding is based on the location information. Geographical location of the nodes can be obtained through various methods like GPS, RSSI, etc. Examples of such routing protocols include Geographic Energy Aware Routing (GEAR) and Geographic Adaptive Fidelity (GAF) [22].

Tree Bases Routing: In Tree- based routing technique, sensor nodes are constructed in a tree fashion with data following from leaf nodes to the parent node and then to root nodes. It involves data gathering at each individual node [17].

Grid-Based Routing: In Grid-based routing topology entire network area is divided into virtual grid structure (called a cell-usually equally sized square area). From each individual cell a leader is selected which collects the data and forwards it to the sink. The main aim of this setup is to fairly distribute the load in the network [23] [24]. *STING* (Statistical Information Grid Clustering Algorithm) algorithm is an example of grid-based routing topology.

b. Path establishment

Establishing a route or path for transmission of data is an essential part of a routing protocol in wireless sensor networks. Such type of task is more important in case of multi-hop transmission as a route needs to be established from source node to the destination node via multiple relay or intermediate nodes in contrary with a direct path in case of single-hop transmission of data [25].

Proactive Protocols: In Proactive routing protocols, routes are established in prior to the demand, hence also known as table-driven protocols. In such type of protocols, a routing table is explicitly maintained to keep the list of all routes along with the transmission cost. However, a main drawback of such protocols is the overhead in generating the routing table. Popular example of such type of protocol is Optimized Link State Routing (OLSR).

Reactive Protocols: In reactive routing protocols, a route is established based on demand or query from the sink node. In such type of protocols, no routing tables are maintained. Some examples of such protocols are Ad-hoc on-demand distance vector system (AODV) and Dynamic Source Routing (DSR). However, such type of protocols introduces a delay in transmission of data.

Hybrid Protocols: These protocols have the characteristics of both the reactive and proactive protocols and tend to overcome the demerits in them.

3. A comparative analysis of various recently proposed techniques for energy efficiency in WSNS

Wireless sensor networks are used for variety of application ranging from military to domestic one and such a diverse range of applications gives rise to various challenges that are different from traditional wireless network systems. Wireless sensor networks are inherently constrained in terms of energy, computational capability and communicational capacity. Lifetime of a wireless sensor network depends upon the available energy [7]. For extending the lifetime of wireless sensor network several algorithms have been proposed based on efficient utilization of energy. Many have discussed about load balancing and clustering as a solution for energy optimization along with maintaining the quality of service as per requirement. A detailed analysis of literature is mentioned in table 1.

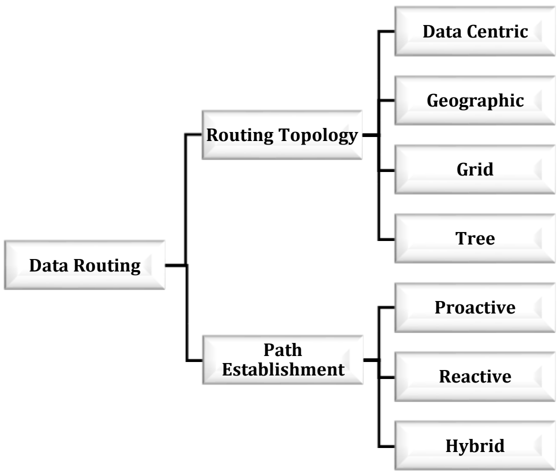


Figure 8: Data Routing in WSN

Table 1: Comparative analysis of various clustering and Load Balancing Algorithms

Algorithm	Network topology Direct data transmission / Cluster based	Nature	Methodology	Data Routing	Objective
LEACH [30]	Cluster based with Direct data transmission	Probabilistic	Random selection of CH based on predefined threshold value. CH role is rotated among all sensor nodes.	Single-hop data routing from CH to BS.	Improve network lifetime by reducing communication overhead.
HEED [29]	Hierarchical Cluster based	Hybrid	Probabilistic selection of initial set of cluster heads followed by deterministic selection based on factors like RE and a cost function for intra-cluster communication.	Multi-hop intra as well as inter-cluster communication.	Improve network lifetime, scalability and load balancing.
EIAMRLB [31]	Cluster based with Direct data	Deterministic	Cost function based on residual energy and	Multipath transmission based on	Load balancing to improve network

	transmission		interference	reinforcement weights.	lifetime.
EEDUC [32]	Hierarchical Cluster based	Deterministic	Fitness function based on RE, ND and D_BS	Multi-hop routing.	Addressing the energy hole problem.
GTEBR [33]	Direct data transmission using forwarding nodes.	Probabilistic	Geographical Routing Protocols (GRPs) like EGT and CGT.	Multi-hop with direct transmission between forwarding node and BS	Extend the network lifetime.
ILCSA [34]	Hierarchical cluster based with adaptive cluster size	Deterministic	Optimization function based on distance between CH and BS	Multi-hop with direct transmission between CH and BS	To improve network lifetime by adjusting the cluster size.
EELBCS [35]	Hierarchical Cluster based	Deterministic	Candidate weight and relay cost based. Parameters considered include RE, ND, No_MN, intra cluster radius.	Multi-hop inter-cluster routing	Improve network lifetime along with energy consumption and performance
BECA [36]	Hierarchical Cluster based	Probabilistic	CH organized into multiple parallel paths for data forwarding to BS.	Multiple parallel paths for inter-cluster communication	To address the energy-hotspot issue
IGP-C [37]	Hierarchical Cluster based	Deterministic	Eligibility weight and load factor for cluster head selection and clustering.	Multi-hop inter-cluster routing based on relay nodes selected by a utility function.	To reduce the data transmission delay and enhance the network lifetime.
EADC [38]	Hierarchical Cluster based	Deterministic	Selection of CH based on RE within a fixed competitive radius.	Direct or Relay based routing depending upon D_BS.	Load balancing by uniform distribution of CH.
DEACP [39]	Hierarchical Cluster based	Deterministic	Selection of CH based on RE, ND, D_BS, D_MN and cluster size is determined using system parameter Rcomp. Node heterogeneity is considered.	Intra-inter cluster multi-hop communication.	Prolonging network lifetime by distributing energy consumption.
EBLCR [40]	Hybrid(direct as well as relayed)	Probabilistic	Path establishment based on AODV routing Protocol and mode of date transmission is chosen based on RE and load on a node.	Direct data or relay transmission based on Packet Reception Ratio.	Energy optimization using cooperative routing.
EESAA [41]	Hierarchical Cluster Based	Probabilistic	LEACH protocol based with sleep and wake mechanism in place.	Multi-hop with direct transmission between CH and BS.	Improving the network lifetime along with quality of service.

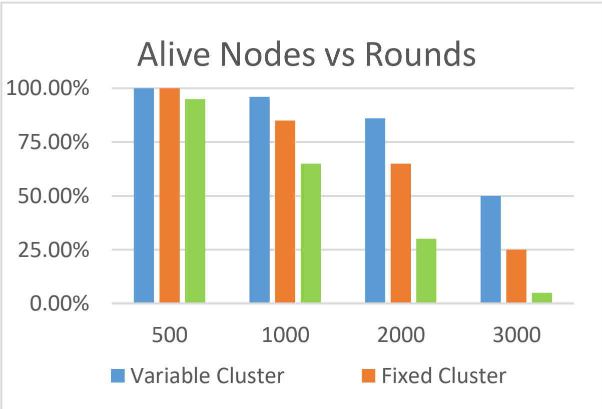
4. Performance analysis of various algorithms

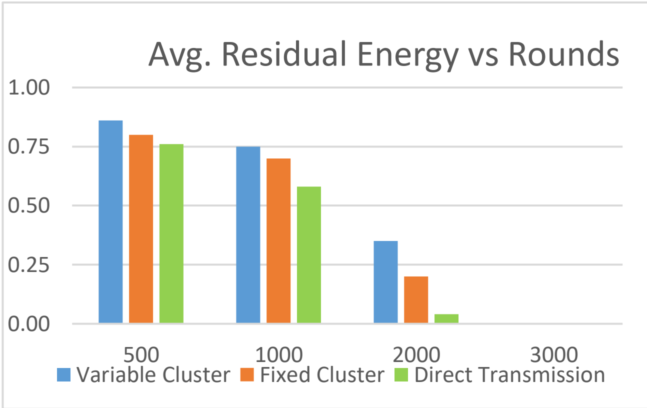
Performance analysis of various algorithms is carried by grouping them in three categories [Table 2]. First include those algorithms that are based on direct data transmission from cluster head nodes to the base station. Second include those which employee inter-cluster routing but with fixed cluster size. Third group represent those algorithms that are cluster based with adaptive cluster size. The performance metrics include average lifetime of sensor nodes, residual energy (in joules) and throughput of the network.

Table 2: Performance Analysis

Algorithm	Network topology Direct data transmission / Hierarchical Cluster based	Nature	Methodology	Data Routing	Objective
FBUCA [42]	Hierarchical Cluster Based	Deterministic	Selection of CH is based on a fuzzy fitness function, chance. It takes into account RE, ND, D_BS and node centrality.	Multi-hop inter-layer routing	Energy optimization and load balancing.
MW-LEACH [43]	Hierarchical Cluster Based	Deterministic	Selection of CH based on RE degree and D_BS.	Adaptive multi-hop approach.	Minimizing energy consumption and prolonging network lifetime
NEEF [44]	Hierarchical Cluster based	Deterministic	A fuzzy based algorithm for CH selection and cluster formation depending upon multiple fitness functions.	CH aggregates date from MN are forwards it to BS directly.	To improve average energy and lifetime of network.
EEUC	Hierarchical Cluster	Hybrid	Proper selection of CH and	Multi-hop routing	Load balancing

[45]	based on Fuzzy Inference system.		Cluster size depending on a Fuzzy fitness function based on RE and D_BS	with selection of relay nodes based on RE and its D_BS.	prolonging network Lifetime
E-FUCA [46]	Hierarchical Cluster based on Fuzzy Inference system.	Deterministic	Selection of CH, Cluster size and routing based on RE, ND, D_BS, Neighbor distance and node centrality, hop distance.	Fuzzy based routing to determine optimal relay node.	Extending lifetime by addressing Hotspot problem.
BS is Base Station D_BS is Distance to base station RE is Residual energy ND is Node degree or number of neighboring nodes				CH is Cluster Head MN is Member nodes NC is Network center. D_MN is distance between CH and MN	





Wireless sensor networks have wide range of applications and they have a set of unique constraints; limited computational, communicational and energy supply. Sensor nodes in WSNs are mostly battery and it is hard to recharge or replace these batteries once exhausted. Therefore, lifetime of a WSN is dependent on the limited power supply and is thus highly constrained. Several techniques have been proposed to increase the energy efficiency and prolong the life of the WSN. Clustering is one such technique that involves grouping of sensor nodes into clusters. In this paper a detailed literature on various aspects of clustering is presented. The paper aims to present its readers a detailed survey of clustering process, steps and performance metrics used to evaluate the performance of the cluster-based wireless sensor networks. A comparative analysis is carried to evaluate the performance of several proposed protocols on clustering.

Future work may include heterogeneous nodes, adaptive cluster size to avoid hot spot issues, fair and optimal distribution of cluster heads, optimal selection of cluster heads with minimal overhead, hybrid approach (classical, optimization or machine learning) in selecting the cluster head with increased energy efficiency.

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