A Survey on Centralised and Distributed Clustering Routing Algorithms for WSNs

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***Abstract*—Wireless sensor networks have a wide range of applications because they can be adapted for various environments. They can operate independently in harsh places where a human presence is risky or even impossible. Since their life time is dependent on their batteries and replacing or recharging their batteries is impossible in rough places, it is necessary to find energy efficient routing protocols for them. In this paper, a number of well-know energy efficient routing algorithms for WSNs have been classified and presented based on their attributes.**

***Index Terms*—Wireless Sensor Networks, Clustering, Energy Efficiency, Centralised algorithms, Distributed algorithms, Uniform distribution.**

I. Introduction

Wireless Sensor Networks (WSNs) have experienced noticeable growth over the past decade due to their adaptability and rapid advances in technology. In order to monitor an environment, a large number of sensors, numbering hundreds or even thousands of nodes, can be deployed and cooperate with one another in data collection. Data sensed by each sensor can be collected by the network and transmitted to the sink. Due to their adjustable and in-expensive attributes, they have a wide range of applications such as environmental monitoring, chemical detection, health-care services, emergency response, surveillance missions, vehicular movements, volcanic earthquake timing, and weather forecasting [1]–[3]. Distributed sensors in WSNs can be organised in an ad-hoc manner and can be used in harsh places where a human presence is hopeless or risky [4].

Energy efficiency is essential for this sensor network's effectiveness because recharging or replacing their batteries is hard in harsh places. Over the past decade, a large number of studies have been conducted in order to propose energy efficient algorithms for WSNs [5]–[8]. The main factor of energy consumption for WSNs is their communications [9].

Clustering sensors into smaller groups has an important role in conserving the energy of network sensors, and therefore in increasing network lifetimes, especially when we consider that neighbouring sensors might sense similar events. In clustering, a high number of sensors are grouped into small clusters, each cluster has a Cluster Head (CH) and other sensors are Cluster Members (CMs). Sensors need to transmit their sensed data to their CH using low-power short-distance transmitting. CHs aggregate and send the collected data to a sink using high-power long-distance transmitting. Thus CHs' energy might run out earlier than others [10].

The proper number and scale of clusters is essential for clustering effectiveness, otherwise the network can not benefit from clustering advantages. A large number of clusters leads to a large number of CHs in the network. Consequently, a large number of CHs have to communicate with the sink using long-distance transmission. On the other hand, a small number of clusters leads to clusters with big diameters, and in each cluster a large amount of energy is consumed to send data from CMs to CHs. Consequently, a trade-off should be made between these two opposite circumstances [11].

Distributing CHs uniformly throughout the network is another influencing factor for clustering effectiveness. Arranging CHs too close or too far from each other might lead once more to clusters that are too small or big. In both cases, the result is inefficient energy protocols [6], [12].

In this paper, we describe a number of well-known clustering energy efficient routing algorithms for WSNs which have been proposed by researchers so far.

II. Features of WSNs

WSNs have different features which can have an impact on designing efficient routing algorithms. These features can be used to compare different protocols and algorithms. A number of WSN features are as follows [1]:

- **WSNs vs Ad-hoc Networks:** WSNs are a kind of ad-hoc network. Ad-hoc networks are infrastructure-less and cooperation-based networks which means that the network topologies must be decided by the network sensors themselves. Nevertheless, sensor nodes are more limited in capabilities and are deployed more densely than other ad-hoc networks [13].
- **Sensor Positions are not Engineered or Predefined:** This feature allows random separation of sensors in the environment. Thus, all sensors, their algorithms, and their protocols need to have self-organising capabilities.
- **Data Gathering:** The sensor nodes have processing ability. They therefore can carry out simple data gathering procedures and transmit only the required and processed data to the next sensor.

- **Homogeneous vs Heterogeneous Sensors:** WSNs can be categorised as either homogeneous or heterogeneous networks. Homogeneous networks are those with sensors that have similar processing and communication abilities. Meanwhile, in Heterogeneous networks, the processing, communication, or battery capabilities of sensor nodes can vary. In particular, their hardware design can be varied [13], [14].
- **Mobile vs Stationary Sensors:** WSNs can be divided into two groups; static and dynamic networks. In the static networks, sensors are arranged in fixed positions and each node can gather the relevant data within its sensing range. In dynamic networks, sensors can be attached to moving objects such as animals, vehicles, or humans [15].
- **Location-aware vs Location-unaware Sensors:** Sensor nodes can be location-aware or location-unaware. Location-aware nodes know their position in the network using equipment such as GPS-capable antenna, location-unaware sensors do not know their position in the network. Centralised algorithms can be used for location-aware sensors because they are based on sensor positions, whereas distributed algorithms can be used for location-unaware sensors [16].
- **Single-hop vs Multi-hop Networks:** Based on the number of hops from sensors to the sink, WSNs can be further divided into single-hop and multi-hop networks. In single-hop networks, sensors directly deliver their sensed data to the sink. In multi-hop networks, sensors transmit their sensed data to the sink using intermediate nodes [17]. An example of single-hop and multi-hop networks is shown in Figures 1 and 2. As we see in these figures, in multi-hop networks some of the nodes operate as the main paths for other nodes. Thus, their energy might drain quicker than others.

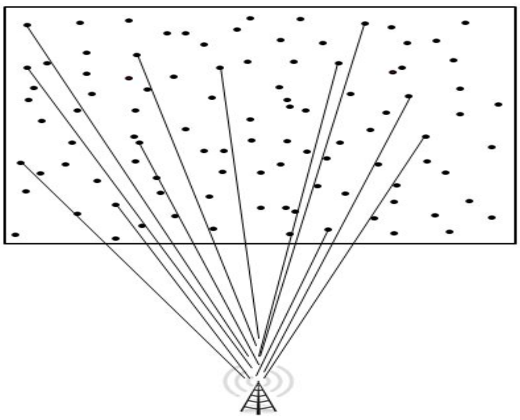

Fig. 1: An example of a single-hop routing protocol.

- **Proactive vs Reactive Networks:** Sensor networks can be classified as proactive and reactive networks based on their targets. The proactive networks monitor an area and deliver the sensed data to the sink. The reactive networks meanwhile not only monitor an area but also

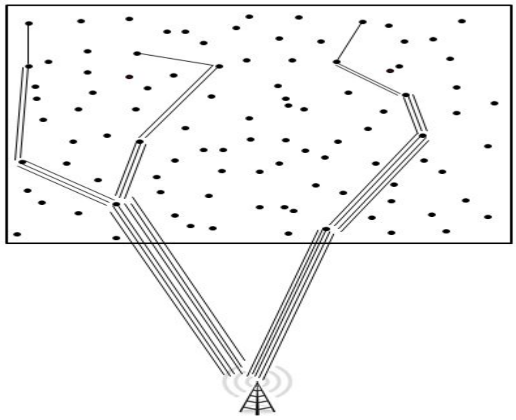

Fig. 2: An example of a multi-hop routing protocol.

immediately react to sudden changes according to the sensed attributes. Reactive networks are well suited for real-time applications [18].
- **Scalability:** Scalable algorithms can be employed in a wide range of efficient WSNs. WSNs consist of a large number of sensors spread over a wide geographical area. The number of sensor nodes is in the order of hundreds to millions depending on their applications. Network performance must not significantly degrade as the node density or network size increases. Designing scalable routing protocols is crucial for a wide range of WSNs. Single-hop algorithms are more scalable than multi-hop algorithms, because in multi-hop algorithms the number of hops might increase by increasing the number of sensors, and this leads to unacceptable latency for sending packets from sensors to the sink [1], [14].

All of the clustering algorithm of WSNs can be classified into either Distributed or Clustering algorithm types. These two classifications are presented in the next two sections.

III. Distributed Clustering Algorithms

Distributed clustering algorithms can be used for location-unaware sensors. That is, these sensors are not aware of their network position and all of their routing decisions have to be made based on their internal information. A number of well-known distributed routing algorithms for WSNs are as follows:

1) One of the most well-known clustering algorithms for WSNs is **Low Energy Adaptive Clustering Hierarchy (LEACH)** [5]. LEACH is a popular algorithm not only because of its clarity and efficiency, but also for its introduction of the CHs rotation theory. Rotation of CHs addresses the need for load balancing among the network sensors. In the LEACH algorithm, the lifetime is divided into a number of rounds. Each round contains set-up and stable phases. In the set-up phase, the CHs are elected and the clusters are shaped. In stable phases meanwhile, events are sensed by sensors and are sent to the sink via CHs. The procedure of CH election is conducted in an ad-hoc manner, using random number

generation in each sensor. In the LEACH algorithm, each CH advertises its role to all of the other sensors and the other sensors join to the closest CH using the received signal strength. In the LEACH algorithm, the CHs aggregate the collected data in order to decrease the amount of transmitting data and the consequent energy cost. The main drawback in the LEACH algorithm is that random election of CHs across the network might not lead to uniform distribution of them throughout the network and the algorithm might not benefit from the clustering method efficiently. Figure 3 shows an example of shaped clusters in the LEACH algorithm.

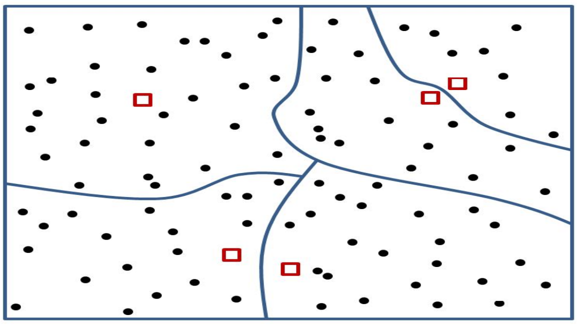

Fig. 3: An example of shaped clusters in the LEACH algorithm.

2) **Power-Efficient GAthering Sensor Information Systems (PEGASIS)** [19] is another routing algorithm for WSNs. PEGASIS, instead of forming clusters, forms a chain from sensors into the sink. The sensors are executing a greedy algorithm in order to form a chain. Each node sends its sensed events to a close neighbour which is in the chain. Eventually, all data are aggregated in one node and only one node transmits the aggregated data to the sink using long-distance transmission. PEGASIS removes the clustering overhead but it introduces the chain shaping overhead. Also, it needs multi-hop data transmission from sensors into the sink which leads to a packet delay problem.
3) **Threshold sensitive Energy Efficient sensor Network (TEEN)** [18] is another algorithm which is designed for re-active networks. In the TEEN algorithm, an event is reported to the sink if it has interesting attributes. This algorithm proposes an efficient approach in terms of energy and is suitable for real time applications. Nevertheless, it is not suitable for regular data gathering applications. TEEN provides a trade-off between the accuracy and energy consumption applications.
4) **Hybrid Energy-Efficient Distributed (HEED)** [13] is another clustering algorithm which offers uniform distribution of CHs across the network. HEED considers the sensors' residual energy and their communication cost to shape the clusters. In HEED two sensors are considered as neighbour sensors as long as they are within each others' power range. Therefore, two neighbouring sensors would not be elected as CHs coincidently. Also in HEED, similar to LEACH, CHs form a single-hop routing protocol from CHs into the sink. Figure 4 shows an example of a single-hop routing protocol from CHs into the sink. HEED showed substantial outperformance in terms of energy efficiency when compared with LEACH.

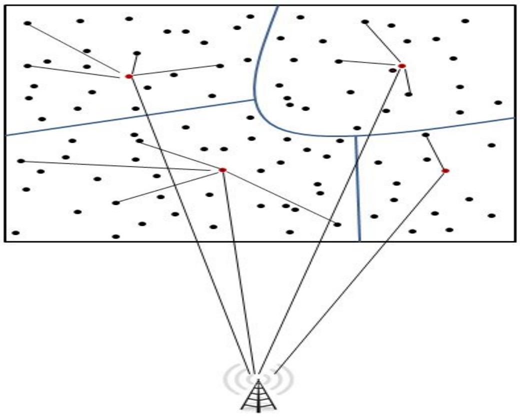

Fig. 4: An example of a Single-hop routing from CHs into the sink.

5) **Self Organising Protocol (SOP)** [20] considers CH-to-CH multi-hop data transmission from CHs to the sink in order to lessen the energy dissipation in the network. In SOP, once the clusters are shaped, CHs organise a multi-hop backbone. Each sensor transmits its data into its CH directly and each CH transmits its data to the sink via a number of intermediate CHs. Consequently, SOP is more energy efficient than LEACH at the cost of bringing more latency. Figure 5 illustrates an example of a CH-to-CH multi-hop clustering routing algorithm.

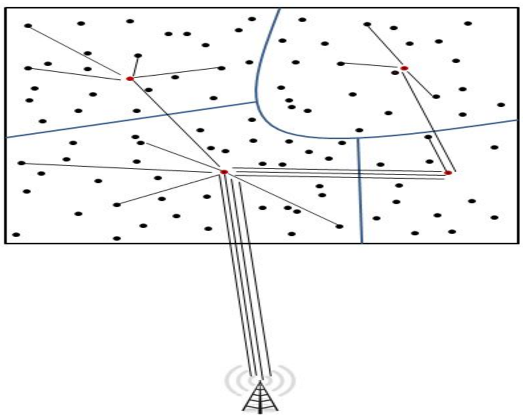

Fig. 5: An example of a CH-to-CH multi-hop clustering network.

6) **Stable Election Protocol (SEP)** [21] and **Powered by Ambient Energy Harvesting (HEAP)** [22] are two

clustering algorithms which are designed for heterogeneous nodes in the network. SEP assumes a percentage of sensors are powerful sensors and are equipped with more battery power than others. HEAP meanwhile assumes a percentage of sensors are super nodes and have unlimited battery powers. In SEP, the powerful sensors have more of a chance of being elected as CHs and in HEAP the super nodes are used as relays in order to perform a multi-hop routing from ordinary sensors into the sink. In SEP the ordinary sensors have a smaller chance of being elected as the CHs, while in HEAP, they do not have any chance and all of the routing duty is performed by super nodes. These two algorithms extend the stable-phase of the network depending on the percentage and the initial energy of the powerful and super nodes.

7) **Adaptive algorithm** [23] is a distributed hierarchical clustering algorithm which benefits from a message passing technique in order to shape equal clusters [23]. In this algorithm, a number of messages are exchanged between sensors to find out their position across the network. Thus, more equal clusters are shaped by choosing proper CH positions. An example of cluster shapes before and after applying this algorithm is illustrated in Figure 6. In their experiments, this algorithm is compared with LEACH and LEACH-C in terms of the energy efficiency metric and shows outperformance of LEACH but not LEACH-C, which is a centralised algorithm. Nevertheless, this algorithm includes a large amount of overhead in the set-up phase due to the high volume of message passing.

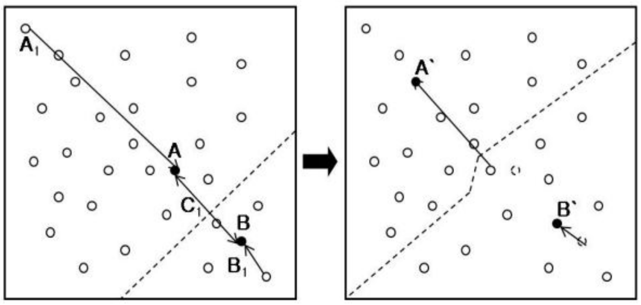

Fig. 6: An example of cluster shapes before and after applying the adaptive algorithm [23].

8) **Wireless Sensor Network Clustering with Artificial Bee Colony (WSNCABC)** [24] algorithm is another algorithm in which a message transferring technique is used in order to find sensors' distances from each other. This information is delivered to the sink and the sink elects the CHs using an Artificial Bee Colony method. The sink then broadcasts these CHs into the network and each node finds its closest CH using the signal strength. WSNCABC outperformed the LEACH algorithm in terms of energy efficiency by up to 70% in their experiments in which the sink's position was very close to the network edge. Nevertheless, WSNCABC includes a large amount of overhead in the set-up phase due to the large number of messages passed between sensors.

9) **Bayesian algorithm** [25] is another energy efficiency optimisation routing protocol which uses the Bayesian game theory. In this algorithm, the network life time is divided into three steps including: initial step, CHs election, and stable step. In the initial step, the sink broadcasts initial information to all of the sensors. In the CHs election step, each sensor broadcasts an amount of its information such as its residual energy and its neighbours to other sensors and also to the sink. Then, each sensor forms a routing table containing its routing information. In this algorithm, the average number of hops from sensors to the sink was considered as its real-time property and the algorithm showed a high reliability in real-time systems when studied. However, this algorithm does not seem efficient enough again if the sink's is far away from the network edge due to the large amount of message passing between sensors.

10) **Avoid Near Cluster Heads (ANCH)** [6] is one of the newest distributed clustering algorithms designed for uniform distribution of CHs throughout the network area. This algorithm increases the number of potential CHs across the network using a regression method. Then, it eliminates a number of nominated CHs due to their close position to other CHs in order to meet the optimum number of CHs. The ANCH algorithm is considerably more efficient than LEACH and HEED in terms of network energy consumption and network lifetime. In addition, both of its time and message complexities are $O(N^2)$, which is equal to LEACH and better than HEED [12], [26]. Also, it has an analytical model which brings up a credible theoretical basis for this algorithm [12], [26]. Figure 7 shows an example of shaped clusters in the ANCH algorithm.

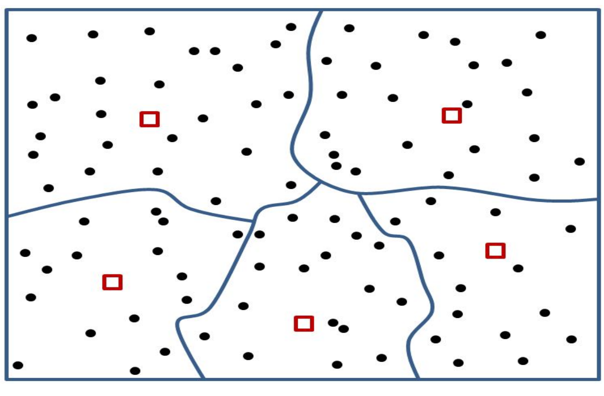

Fig. 7: An example of shaped clusters in the ANCH algorithm.

Characteristics of the above-mentioned distributed algorithms are summerised in Table I.

Algorithm	Description	Advantages	Disadvantages
LEACH	Rotates CHs periodically in order to distribute their duties among all sensors equally.	All sensors have almost equal lifetime.	May lead to non-uniform CHs distribution.
PEGASIS	Forms a chain from sensors into the sink.	Removes clustering overheads.	Brings up a forming chain overhead.
TEEN	Designed for re-active applications.	Suitable for event based applications.	Unsuitable for regular data gathering applications.
HEED	Considers sensors' residual energy and their communication cost.	Uniform CH distribution.	High overhead in set-up phase.
SOP	Forms a multi-hop CH-to-CH backbone.	Energy efficient.	Is not scalable and leads to packet delay.
SEP	Benefits from powerful nodes.	Prolongs the network lifetime.	Unsuitable for homogeneous networks.
HEAP	Benefits from super nodes.	Prolongs the network lifetime.	Unsuitable for homogeneous networks.
Adaptive	Performs a message passing procedure to form equal clusters.	Uniform CH distribution.	High overhead.
WSNCABC	Uses Artificial Bee Colony in order to form equal clusters	Uniform CHs distribution.	High overhead.
Bayesian	Uses the Bayesian game theory to form equal clusters.	Uniform CHs distribution.	High overhead.
ANCH	Increases the number of potential CHs and eliminates a number of them due to their close position to other CHs.	Uniform CHs distribution, efficient time and message complexities, and has a theoretical basis	Needs more analytical models.

TABLE I: Summary of Distributed routing algorithms.

IV. Centralised Clustering Algorithms

Centralised clustering algorithms can be used for location-aware sensors. That is, sensors that are aware of their network position and all of whose routing decisions can be made in central locations such as the sink. A number of well-known centralised routing algorithms for WSNs are as follows:

1) A centralised version of the LEACH is **Centralised LEACH (LEACH-C)** and it was proposed by the authors of LEACH [27]. In the LEACH-C algorithm, each sensor knows its position in the network and consequently the number and position of CHs are selected in an optimum manner. In experiments, LEACH-C showed up to 40% outperformance using an energy efficiency metric when compared with LEACH.
2) **Base Station Controlled Dynamic Clustering Protocol (BCDCP)**, is another centralised clustering algorithm for WSNs [28]. BCDCP uses multi-level clustering in a manner that each CH serves an approximately equal number of sensors. In the BCDCP algorithm, all CMs send their sensed data to their CHs and CHs conduct a CH-to-CH multi-hop routing to deliver their data to a higher level CH, which is selected randomly (see Figure 5). Finally, only one CH communicates directly with the sink. Experiments have shown that BCDCP outperforms LEACH, LEACH-C, and PEGASIS in terms of energy efficiency and extending the network lifetime.
3) **Power Efficient and Adaptive Clustering Hierarchy (PEACH)** [29] is a centralised probabilistic multi-level clustering algorithm for WSNs. In this algorithm, each sensor can obtain the source and destination of packets by hearing the neighbouring sensors. Based on this heard information, this algorithm can shape the clusters without a number of clustering overheads such as advertising, joining, and synchronising. PEACH decreases the message communication costs and improved the energy consumption and network lifetime compared with those of existing clustering methods.
4) **Optimised Lifetime Enhancement (OLE)** [30] is another centralised algorithm which forms a chain from sensors into the sink. Each node sends its sensed events to a close neighbour which is in the chain. OLE used a particle-swarm-optimisation heuristic instead of the greedy algorithm of PEGASIS. OLE allows nodes to direct communication with the sink an unequal number of times based on their residual energy. OLE should be executed in the sink and its results distributed into the network before starting the stable phase. However, in the event of a lack of frequent communications with the sink, it can be executed in individual clusters by a local leader and the local information can be sent to the sink in order to shape the optimised chain. In their experiments, this algorithm prolonged the network lifetime compared with that of PEGASIS.
5) **Fuzzy Logic algorithms** [31], [32] are two centralised algorithms proposed for WSNs. In both of these algorithms, CHs are selected in the sink by employing fuzzy logic theories and are broadcasted to the network. Both of these algorithms use three factors as their algorithms' inputs. These three factors in [31] are *sensors' centrality, sensors' density*, and *sensors' residual energy*. In [32] meanwhile these three factors are *distance of sensors from the sink, sensors' density*, and *sensors' residual energy*. Both of these algorithms outperformed the LEACH algorithm in terms of energy efficiency in their experiments.

Characteristics of the above-mentioned centralised algorithms are summerised in Table II.

V. Conclusion

Wireless sensor networks have merited significant attention over the past decade because of the rapid advances in their technologies and their adaptable nature. In this paper, the influencing features in energy efficient designing of their routing algorithms is presented. Moreover, a summarised taxonomy

Algorithm	Description	Advantages
LEACH-C	A centralised version of LEACH.	Optimum number and position of CHs.
BCDCP	Uses a multi-level clustering and only one CH communicates directly with the sink.	An almost equal size of clusters.
PEACH	Shapes clusters using a neighbor listening technique.	Removes clustering overhead.
OLE	Forms a backbone chain using an heuristic optimisation.	Uniform CH distribution.
Fuzzy Logic	Uses fuzzy logic methods in order to form clusters	Uniform CH distribution.

TABLE II: Summary of Centralised routing algorithms.

of these routing algorithms, along with their strengths and limitations is also presented.

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