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Clustering Algorithms for Heterogeneous Wireless Sensor Network: A Survey

Vivek Katiyar, Narottam Chand, Surender Soni
Department of Computer Science and Engineering
National Institute of Technology Hamirpur, Hamirpur (H.P.), INDIA
vivek.kat@gmail.com

ABSTRACT

The last few years have seen an increased interest in the potential use of wireless sensor networks (WSNs) in various fields like disaster management, battle field surveillance, and border security surveillance as described by Quaritsch (2010), Hart (2006), Bokareva (2006) and Dudek (2009). In such applications, a large number of sensor nodes are deployed, which are often unattended and work autonomously. Clustering is a key technique used to extend the lifetime of a sensor network by reducing energy consumption (Younis 2003). It can also increase network scalability. Researchers in all fields of wireless sensor network believe that nodes are homogeneous, but some nodes may be of different energy to prolong the lifetime of a WSN and its reliability. In this paper, we study the impact of heterogeneity and survey different clustering algorithms for heterogeneous WSNs; highlighting their objectives, features, complexity, etc.

Key words: Clustering, Energy efficiency, Heterogeneity, Stability, WSN

1. Introduction

With the advances in the technology of micro-electromechanical system (MEMS), developments in wireless communications and wireless sensor networks have also emerged (Akyildiz 2002). Wireless Sensor networks (WSNs) have become the one of the most interesting areas of research in the past few years. A WSN is composed of a number of wireless sensor nodes which form a sensor field and a sink. These large numbers of nodes, having the abilities to sense their surroundings, perform limited computation and communicate wirelessly form the WSNs (Romer 2002). Specific functions such as sensing, tracking, and alerting as described by Shorey (2006), can be obtained through cooperation among these nodes. These functions make wireless sensors very useful for monitoring natural phenomena, environmental changes (Hart 2006), controlling security, estimating traffic flows, monitoring military application (Bokareva 2006), and tracking friendly forces in the battlefields. These tasks require high reliability of the sensor networks. To make sensor networks more reliable, the attention to research on heterogeneous wireless sensor networks has been increasing in recent past (Duarte-Melo 2002, Lu 2006, Liyang 2007, Chun-Hsien 2007).

A sensor network can be made scalable by assembling the sensor nodes into groups i.e. clusters. Every cluster has a leader, often referred to as the cluster-head (CH). A CH may be elected by the sensors in a cluster or pre-assigned by the network designer. The cluster membership may be fixed or variable. A number of clustering algorithms have been specifically designed for WSNs for scalability and efficient communication. The concept of cluster based routing is also utilized to perform energy-efficient routing in WSNs. In a hierarchical architecture, higher energy nodes (cluster heads) can be used to process and send the information while low energy nodes can be used to perform the sensing. Some of routing protocols in this group are: LEACH (Heinzelman 2000), PEGASIS (Lindsey 2002), TEEN (Manjeshwar 2001) and APTEEN (Manjeshwar 2001).

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Clustering has numerous advantages. Some of these are:

1. Clustering reduces the size of the routing table stored at the individual nodes by localizing the route set up within the cluster (Akkaya 2005).
2. Clustering can conserve communication bandwidth since it limits the scope of inter-cluster interactions to CHs and avoids redundant exchange of messages among sensor nodes.
3. The CH can prolong the battery life of the individual sensors and the network lifetime as well by implementing optimized management strategies (Younis 2003).
4. Clustering cuts on topology maintenance overhead. Sensors would care only for connecting with their CHs (Hou 2005).
5. A CH can perform data aggregation in its cluster and decrease the number of redundant packets (Dasgupta 2003).
6. A CH can reduce the rate of energy consumption by scheduling activities in the cluster.

Researchers generally assume that the nodes in wireless sensor networks are homogeneous, but in reality, homogeneous sensor networks hardly exist. Even homogeneous sensors have different capabilities like different levels of initial energy, depletion rate, etc. In heterogeneous sensor networks, typically, a large number of inexpensive nodes perform sensing, while a few nodes having comparatively more energy perform data filtering, fusion and transport. This leads to the research on heterogeneous networks where two or more types of nodes are considered. Heterogeneity in wireless sensor networks can be used to prolong the life time and reliability of the network. Heterogeneous sensor networks are popular, particularly in real deployments as described by Freitas (2009) and Corchado (2010).

Most of the recent energy efficient protocols designed for heterogeneous networks are based on the clustering technique, which are effective in scalability and energy saving for WSNs. In this paper, we categorize clustering algorithms proposed in the literature for heterogeneous wireless sensor networks (HWSNs). We also summarize a collection of published schemes, stating their features and shortcomings. Rest of the paper is organized as follows. Section 2 and Section 3 describe the heterogeneous model for wireless sensor networks and classification of clustering attributes respectively. In Section 4 we present a survey of clustering algorithms for heterogeneous wireless sensor networks with comparison among them and classify depending upon clustering attributes described in section 3. Lastly, Section 5 concludes the survey work.

2. Heterogeneous Model for Wireless Sensor Networks

This section presents a paradigm of heterogeneous wireless sensor network and discusses the impact of heterogeneous resources (Yarvis 2005).

2.1. Type of Resource Heterogeneity

There are three common types of resource heterogeneity in sensor nodes: computational heterogeneity, link heterogeneity, and energy heterogeneity.

Computational heterogeneity means that the heterogeneous node has a more powerful microprocessor, and more memory, than the normal node. With the powerful computational resources, the heterogeneous nodes can provide complex data processing and longer-term storage.
Link heterogeneity means that the heterogeneous node has high-bandwidth and long-distance network transceiver than the normal node. Link heterogeneity can provide a more reliable data transmission.

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Energy heterogeneity means that the heterogeneous node is line powered, or its battery is replaceable. Among above three types of resource heterogeneity, the most important heterogeneity is the energy heterogeneity because both computational heterogeneity and link heterogeneity will consume more energy resource.

2.2. Impact of Heterogeneity on Wireless Sensor Networks

If we place some heterogeneous nodes in sensor network it shows the following benefits:

Response time: Computational heterogeneity can decrease the processing latency and link heterogeneity can decrease the waiting time, hence response time is decreased.
Lifetime: The average energy consumption will be less in heterogeneous sensor networks for forwarding a packet from the normal nodes to the sink, hence life time is increased.
Further, it is also known that if in a network, heterogeneity is used properly then the response of the network is tripled and the network's lifetime can be increased by 5-fold (Yarvis 2005).

2.3. Performance Measures

Some performance measures that are used to evaluate the performance of clustering protocols are listed below.

Network lifetime: It is the time interval from the start of operation (of the sensor network) until the death of the first alive node.
Number of cluster heads per round: Instantaneous measure reflects the number of nodes which would send directly to the sink, information aggregated from their cluster members.
Number of nodes per round: This instantaneous measure reflects the total number of nodes and that of each type that has not yet expended all of their energy.
Throughput: This includes the total rate of data sent over the network, the rate of data sent from cluster heads to the sink as well as the rate of data sent from the nodes to their cluster heads.

3. Classification of Clustering Attributes

Network architectural parameters like in-network data processing, node deployment and capabilities are best described in (Abbasi 2007). Clustering objectives like load balancing and fault-tolerance, increased connectivity, reduced delay, minimum cluster count, maximal network longevity are also described with reference to the homogeneous wireless sensor networks. Abbasi *et al.* (2007) also presented a classification of clustering attributes as clustering properties, cluster head capabilities and clustering process. Our survey of heterogeneous clustering algorithms is also based on some of the attributes described in (Abbasi 2007).

Classification of Clustering Attributes: Here we summarize the set of attributes that can be use to categorize and differentiate clustering algorithms of HWSNs.

3.1. Cluster properties: Quite often, clustering schemes strive to achieve some characteristics for the generated clusters. Such characteristics can be related to the internal structure of the cluster or how it relates to others. The following are the relevant attributes:

- **Cluster Count:** CHs are predetermined in some of the published approaches like Gupta (2003), Gupta *et al.* (2003), Verma (2008) and Li (2007), thus, the number of clusters is preset. CH selection algorithms generally pick randomly CHs from the deployed sensors hence yields variable number of clusters.

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- **Intra-cluster Topology:** Some clustering schemes are based on direct communication between a sensor and its designated CH, but sometimes multi-hop sensor-to-CH connectivity is required.
- **Connectivity of CH to BS:** CHs send the aggregated data to the BS directly or indirectly with help of other CH nodes. It means, there exists a direct link or a multi-hop link.

3.2. Cluster-head Capabilities: The following attributes of the CH node are differentiating factors among clustering schemes:

- **Mobility:** CH may be stationary or mobile. In most cases, they are stationary. But sometimes, CHs can move within a limited region to reposition themselves for better network performance.
- **Node Types:** Generally sensor nodes among the deployed sensors are designated as CHs, but sometimes sensor nodes equipped with significantly more computation and communication resources are selected as CHs.
- **Role:** Some of the main roles of the CHs are simply relaying the traffic, aggregation or fusion of the sensed data.

3.3. CH Selection Based on:

- **Initial Energy:** This is an important parameter to select the CH. When any algorithm starts it generally considers the initial energy.
- **Residual Energy**: After some of the rounds are completed, the cluster head selection should be based on the energy remaining in the sensors.
- **Energy Consumption Rate:** This is another important parameter that considers the energy consumption rate $V_i(t)$ based on following formula:

$$V_i(t) = \frac{E_{initial} - E_i(t)}{r - 1}$$

  Where $E_{initial}$ and $E_i(t)$ are the initial energy and residual energy of each node respectively and r is the current round.
- **Average Energy of the Network**: The average energy is used as the reference energy for each node. It is the ideal energy that each node should own in current round to keep the network alive.

The above listed clustering attributes are used to classify the clustering algorithms in the next section.

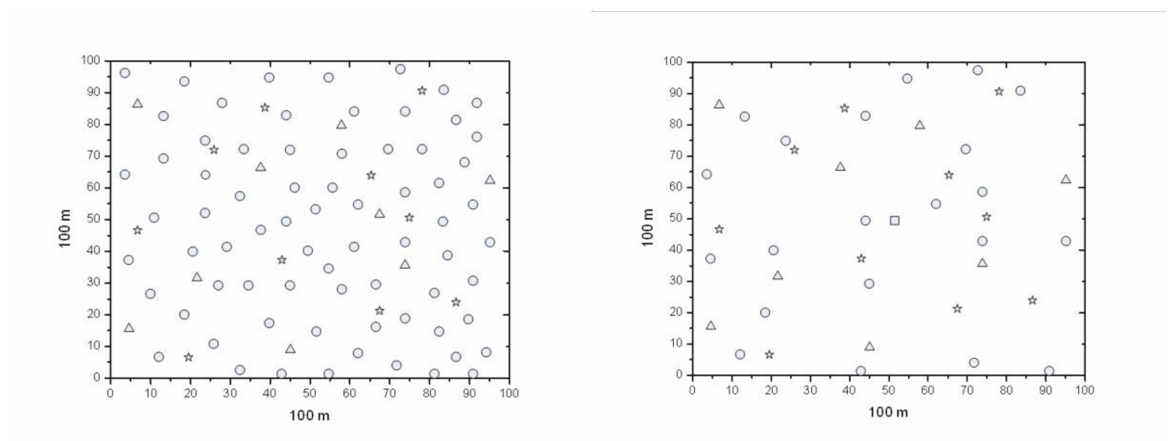
4. Clustering Algorithms for HWSNs

A WSN is composed of hundreds of sensor nodes distributed randomly. Clustering is one of the best ways to extend the lifetime of a sensor network by reducing energy consumption. It can also increase network scalability and lifetime. In this section, we present a literature survey of distributed algorithms for clustering in WSNs. Clustering algorithms for HWSNs should be energy efficient to take the advantages of node heterogeneity. Clustering algorithms in this paper are classified based on two main criterions: according to the energy efficiency and stability. Selection of cluster head in energy efficient techniques generally depends on the initial energy, residual energy, average energy of the network, or energy consumption rate or combination of these. The stable election protocols for clustered HWSN prolong the time interval before the death of first node i.e. stability period.

4.1. Energy-Efficient Clustering Protocol for HWSNs

The concept of cluster based routing is also utilized to perform energy-efficient routing in WSNs. Efficient organization of sensor nodes into clusters is useful in reducing energy consumption in WSNs. Many energy-efficient routing protocols are designed based on the clustering structure of HWSNs like Haibo (2009), Lu (2008), Paruchuri (2005) and Liang (2009). Each clustering algorithm has mainly two phases: the cluster setup phase and steady state phase. For heterogeneous WSNs, a very critical task for clustering protocols is to select the cluster head so that least energy is consumed, and hence prolong the lifetime. In this section, we look into various energy-efficient cluster head selection protocols for HWSNs like EEHC (Kumar 2009), DEEC (Qing 2006), SDEEC (Elbhiri 2009), DBEC (Duan 2007) and C4SD (Marin-Perianu 2008).

Energy Efficient Heterogeneous Clustered Scheme: Kumar *et al.* (2009) proposed an energy efficient clustered scheme for HWSNs based on weighted election probabilities of each node to become cluster head. It elects the cluster head in distributed fashion in hierarchal WSN. This algorithm is based on LEACH (Low Energy Adaptive Clustering Hierarchy) (Heinzelman 2000), the most popular clustering protocol in WSN. In the LEACH algorithm, there is an optimal percentage p_{opt} of nodes that has to become cluster head in each round. This algorithm works on the election processes of the cluster head in presence of heterogeneity of nodes. Figure 1 shows heterogeneity of the network, the snapshots when all nodes are alive and how the normal nodes die after some rounds.



(a) (b)

Figure 1: Normal, advanced and super nodes are shown by circle, triangle and star respectively (Kumar 2009). (a) Network Structure and (b) Network after some rounds

Distributed Energy-Efficient Clustering Algorithm for HWSN: Qing *et al.* (2006) proposed DEEC; a distributed multilevel clustering algorithm for heterogeneous wireless sensor networks. DEEC selects the cluster-heads with the help of probability based on the ratio between residual energy of each node and the average energy of the network. How long different nodes would be cluster-heads, is decided according to the initial and residual energy. The authors assume that all the nodes of the wireless sensor network are equipped with different amount of energy, which is a source of heterogeneity.

DEEC is also based on LEACH; it rotates the cluster-head role among all nodes to expend energy uniformity. Two levels of heterogeneous nodes are considered in this algorithm and after that a general solution for multi-level heterogeneity is obtained. Working of DEEC is as follows: all the nodes need to know the total energy and lifetime of the network. Average energy of the network is used as the reference energy. Thus, DEEC does not require any global knowledge of energy at every election round. When a new epoch begins, each node s_i computes the average probability p_i by the total energy $E_{total,}$ while estimate value R of lifetime is broadcasted by the base station. Now p_i is used to get the election threshold $T(s_i)$. This threshold decides node s_i to be a cluster-head in the current round.

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An improvement of this algorithm is proposed as Stochastic DEEC by Elbhiri, Saadane, and Aboutajdine (2009). The cluster head selection in overall network is based on nodes' residual energy in the Stochastic Energy-Efficient Clustering (SDEEC). This protocol is based on DEEC with new strategies. The Stochastic strategy is the key idea where the intra-clusters transmission is reduced. Like DEEC, this approach considers the two-level heterogeneity, but it conserves energy by making non-CH nodes sleep, unlike DEEC. This protocol divides the network into dynamic clusters.

According to the protocol, all non-CH nodes send data to respective CHs in their allocated transmission time. The CH node must keep its receiver on, in order to receive all the data from the nodes in the cluster. Some signal processing is performed by CH to compress the data into a single signal when all the data is received. After this phase, each CH sends the aggregated data to its prime CH. Each non-CH can turn off to the sleep mode to conserve the energy. The drawback in the protocol is that if non-CH nodes turn off to the sleep mode when CH is performing aggregation, how they will come to know about the next round of CH selection.

Distributed Energy Balance Clustering Protocol for HWSNs: In Distributed Energy-Balance Clustering algorithm (DEBC), a probability based clustering algorithm was proposed by Changmin Duan and Hong Fan (2007). DEBC elects cluster heads based on the knowledge of the ratio between remaining energy of node and the average energy of the network. This protocol also considers two-level heterogeneity and then it extends the results for multi-level heterogeneity. DEBC is different from LEACH, which make sure each node can be cluster head in each $n_i=1/p$ rounds. DEBC chooses n_i according to the node i and remaining energy E^k_i in round k. p_i denotes the probability of node i being cluster head in each n_i rounds. With the help of p_i, probabilities for advanced and normal nodes to be CH can be calculated and this can be further extended to multi-level heterogeneity.

Cluster-Based Service Discovery for Heterogeneous Wireless Sensor Networks: Marin *et al.* (2008) proposed an energy efficient cluster-based service discovery protocol (C4SD) for HWSNs. The problem addressed in this paper is to design a service discovery protocol that is suitable for heterogeneous WSNs and reduces the workload of the resource constrained devices. Authors proposed a cluster based solution, where a set of nodes are selected, based on their capabilities. In this algorithm each node is assigned a unique hardware identifier and weight (capability grade). Higher the capability grade more suitability for CH role. These nodes act as a distributed directory of service registrations for the nodes in the cluster. Since the service discovery messages are exchanged only among the directory nodes and the distribution of workload according to the capabilities of the nodes, the communication costs are reduced. The proposed clustering algorithm reacts rapidly to topological changes of the sensor network by making decisions based only on the 1-hop neighborhood information, avoids chain reactions and constructs a set of sparsely distributed CHs. The clustering algorithm is simulated and compared with distributed mobility adaptive clustering (DMAC) (Basagni 1999). The result shows that it outperforms DMAC.

4.2. Stability-oriented Clustering Protocols for HWSNs

The protocols discussed below increase the stability period of wireless sensor networks. Stability period is actually the time interval before the death of the first node. It is very important for the applications where the response from the sensor nodes must be reliable. Protocols surveyed in this category are: SEP (Smaragdakis 2004), EDFCM (Haibo), Base-station initiated clustering (Varma 2008), ZREECR (Li 2007), DECP (Wang 2007) and a steady clustering scheme for HWSN (Liaw 2009)

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Stable Election Protocol for Clustered HWSNs: Smaragdakis G. *et al.* (2004) describe the impact of heterogeneity on the heterogeneous-oblivious protocols and instability of the protocols like LEACH, in the presence of heterogeneity, once some nodes die. The authors describe the problems that can occur due to heterogeneity of nodes. They propose Stable Election Protocol (SEP) (Smaragdakis 2004), a heterogeneity-aware protocol. It does not require energy knowledge sharing but is based on assigning weighted election probabilities of each node to be elected cluster head according to their respective energy. By using this approach, authors ensure that the cluster head is randomly selected based on the fraction of energy of each node; this assures that each node's energy is uniformly used. In SEP, two types of nodes (normal and advanced) are considered. It is based on weighted election probabilities of each node to become cluster head according to the remaining energy in each node. This prolongs the stability period i.e. the time interval before the death of the first node. The problem that arises with the heterogeneity-oblivious protocols is that if the same threshold is set for both normal and advanced nodes then there is no guarantee that the number of cluster heads per round per epoch will be $n \times p_{opt}$. SEP uses the following characteristic parameters of heterogeneity, namely the fraction of advanced nodes (m) and the additional energy factor between advanced and normal nodes (α). SEP talks about the fairness constraint on energy consumption i.e. advanced node get the chances to become the CH more often than the normal nodes.

The solution of SEP is more applicable compared to any solution which assumes that each node knows the total energy of the network in order to adapt its election probability to become a cluster head according to its remaining energy. In this approach, a weight is assigned to the optimal probability p_{opt}. This weight must be equal to the initial energy of each node divided by the initial energy of the normal node. Let p_{nrm} and p_{adv} be the weighted election probability for normal nodes and the advanced nodes respectively. In order to maintain the minimum energy consumption, the average number of cluster heads per round per epoch must be constant and equal to $n \times p_{opt}$.

Virtually, there are $n\cdot(1+\alpha\cdot m)$ nodes with energy equal to the initial energy of a normal node. In the heterogeneous scenario, the average number of cluster heads per round per epoch is equal to $n\cdot(1 + \alpha\cdot m)\cdot p_{nrm}$. The weighed probabilities for normal and advanced nodes are, respectively:

$$P_{nrm} = \frac{P_{opt}}{1+\alpha.m}$$

$$P_{adv} = \frac{P_{opt}}{1+\alpha.m}(1+\alpha)$$

With help of these weighted probabilities thresholds for normal nodes and advanced node can be calculated. In most rounds, no cluster head is selected by SEP. In such rounds where no CH is selected, the data packets cannot be transmitted to the base station. This is a great disadvantage to the reliable transmission in the networks, especially for some important real-time transmission tasks.

Novel Stable Selection and Reliable Transmission Protocol for Clustered HWSN: H. Zhou *et al.* propose a model of energy and computation heterogeneity for heterogeneous wireless sensor networks. They also propose a protocol named Energy Dissipation Forecast and Clustering Management (EDFCM) for HWSNs. This algorithm balances the energy consumption round by round, which will provide the longest stability period for network. The heterogeneous model they consider is composed of three types of nodes including Type_0, Type_1 and some management nodes as shown in Figure 2. Type_0 and Type_1 nodes vary in capabilities of sensing, energy and software. They have the responsibility of sensing events, while the management nodes perform management of both types of nodes during cluster formation. EDFCM is specially proposed for heterogeneous networks to provide the longer lifetime and more reliable transmission service.

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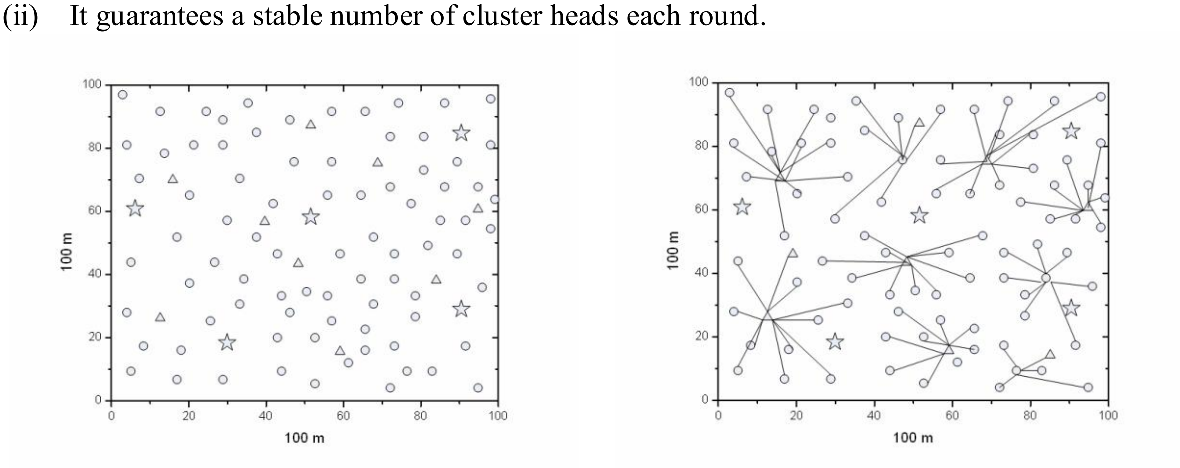
Unlike the other energy efficient protocols, the process of cluster head selection in EDFCM is based on a method of one-step energy consumption forecast. It uses the average energy consumptions of the two types of cluster heads in previous round for this purpose. The more remaining energy in a node after the operation of next round, higher the chances of node to be selected as a cluster head. In EDFCM protocol, the operation of network can be divided into two phases: cluster formation phase and data collecting phase. Cluster formation phase of EDFCM is very similar to that of LEACH, but there are two differences:

(i) The selection probability is a weighted function.
(ii) It guarantees a stable number of cluster heads each round.



(a) (b)

Figure 2: Type_1 and Type_2 nodes are shown by circle and triangle respectively and management nodes by star. (a) Network Structure and (b) Clustering in EDFCM (Haibo, In Press).

Base Station Initiated Dynamic Routing Protocol: S. Verma *et al.* (2008) propose a routing protocol that is based on clustering and uses heterogeneity in nodes to increase the network lifetime. In this scheme, some nodes which are stronger than other nodes in terms of power, computational capability and location awareness, work as the cluster heads. They forward information to their parents, towards the base station by aggregating all the information from their clusters members.

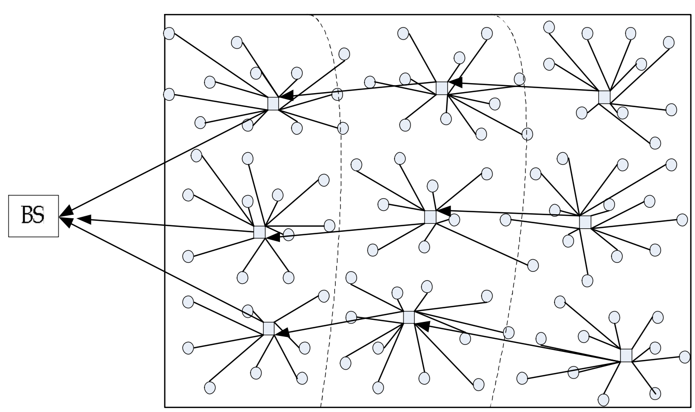


Figure 3: Cluster hierarchy in sensing field (Verma *et al.* 2008).

Following assumptions are considered in this scheme: all nodes are deployed uniformly in the field and CHs will be assumed dead only when their energy is very less. There is no collision between inter cluster and intra cluster communication. Transmission power of the CH is adjusted in such a way that

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only single hop broadcast is possible. In this algorithm, how far a CH is from the BS, is defined as level. Low level means that CH is near to the BS and if level is high it means CH is away from BS accordingly. Data flow will be always from higher level to lower level. Decision of levels by base station is based on the range of the CH and normal node. Ranges of all the nodes are enough to ensure the connectivity and coverage.

Structure of the network considered in this approach is shown in Figure 3. BS sets its level to zero and broadcasts a packet to initiate the scheme. Base station mentions that this packet is only for CHs. Since the CHs have different signal strength from normal nodes, they receive the packet and set their levels accordingly. When the CHs of first level are selected, they broadcast their level. CHs at lower level receive the packet according to the signal strength. They choose their parent from upper level CHs only. This process is repeated again and again until all CHs are connected. CH now broadcast a message that all sensor nodes should join the CH according to the RSS (Radio Signal Strength). Communication between CH and sensing nodes is single hop, while communication between different CH is multiple hops. All CHs sends their position, level and energy consumption to the BS at the end of the round. BS then analyzes the energy consumption of different CH at the same level.

Routing Protocol for Balancing Energy Consumption in HWSN: Li X. *et al.* (2007) developed and analyzed a protocol based on residual energy and energy consumption rate (REECR). This protocol is an improvement of the previous work by the same authors (Li *et al*. 2007). They presented the protocol based on the REECR rather than periodic rotation and stochastic election. REECR protocol was not perfect in balancing the energy and stability of network, so they proposed a zone based improvement of this REECR protocol, naming ZREECR (Zone-Based Residual Energy and Energy Consumption Rate). This protocol improves the stability period. The problem that is considered in this work is that the cluster head may be very near or very far from BS. In such a case, balancing the energy consumption is a very tough task and leads to instability.

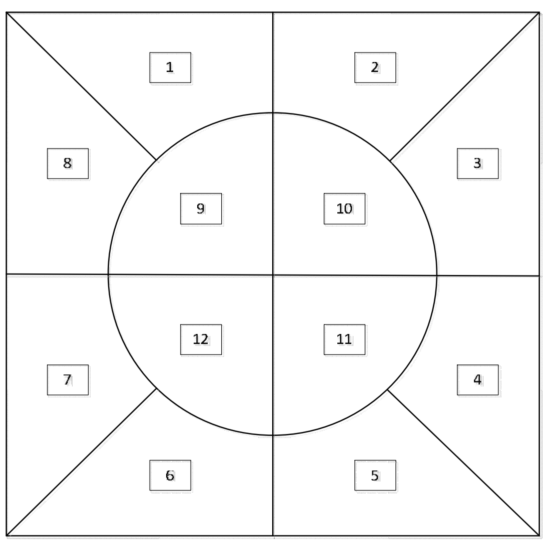

Figure 4: A schematic diagram of different size zones (Li *et al.* 2007).

To solve this problem, the authors propose a zone based solution named ZREECR. This protocol divides the network into fixed-size zones, depending upon distance and orientation from base station as shown in Figure 4. There are 12 fixed side zones that are shown in the Figure 4. It is expected that clusters near to the BS have smaller cluster sizes because CHs have to relay the data from the farther

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CHs to the BS. In this way CHs will save some significant amount of energy in intra-cluster data processing as well as inter-cluster relay traffic.

The heterogeneous model of the network considers two type of node varying in energy; type_0 and type_1. In the first round the CHs are selected at geometric centers of the zones. This avoids the situation of the very near and very far node to become CH. But in the second round the selection of the CH in each zone based on residual energy and energy consumption rate as follows:

$$P_i(t) = \frac{E_i^{\alpha}(t)}{V_i^{\beta}(t)}$$

Where $P_i(t)$ is the possibility of each node to be selected as a cluster-head in each zone, and α are β weight coefficients. $E_i(t)$ is the current residual energy of each node and $V_i(t)$ is the energy consumption rate of each node. CHs collect the data from all sensor nodes in the network, aggregate it and send it to the BS. While forwarding the data to the BS every CH selects the closest CH in the direction of the BS. Although the authors presented an improvement in their work but this protocol is not energy efficient, compared to the previous one because the selection of the CH is done locally on zone level, and not on the network level; but on the other hand it is more stable than REECR.

A distributed election clustering protocol (DECP) for HWSN: X. Wang *et al.* (2007) proposed a distributed election clustering protocol named DECP for two-level HWSN that prolongs stability region. DECP elects the CH based on remaining energy and communication cost. This protocol is based on Average Power Distinction (APD) to evaluate the power level of the nodes. This means that the nodes with high residual energy have more chances to become CH than nodes with less energy. In the clustering process, all the nodes broadcast its current energy information and in the meantime also collect the energy message from the other nodes. When nodes have sufficient information about its neighbors, such as distance and current energy, nodes calculate the communication cost and broadcast it to their neighbors. Now, CH nodes are elected based on the minimal cost. And all non-cluster-head nodes chose one nearest cluster-head to join the cluster. This protocol provides better stability region and it also does not need global energy knowledge.

The steady clustering scheme for HWSN: A protocol based on SGCH (Steady Group Clustering Hierarchy) is proposed in (Liaw 2009). This protocol divides all nodes into groups by initial energy. This algorithm proceeds in two steps: grouping stage and data transmission stage. Groups are generally clusters. In this algorithm, BS broadcasts a Group Head Request (GHR) to all nodes. Every node sends back the acknowledgement (ACK) with ID and initial energy information. BS selects the group head by sending a Group Head GH message and group ID. Now every group head finds its member by sending group request message to all nodes. Following this way, algorithm forms the groups (clusters). Algorithm considers the multilevel heterogeneity of sensor nodes in terms of energy. Results show that stability period is prolonged.

Table. 1: Comparison of the Presented Clustering Algorithms for HWSN

Clustering Approach	**Energy Efficient**	**Location Aware-ness**	**Balanced Clustering**	**Cluster Stability**	**Heterogeneity Type**	**Clustering Methodo-logy**	**Heterogeneity Level**
Kumar 2009	High	No	Yes	Moderate	Energy	Distributed	Three
Qing 2006	High	No	Yes	Moderate	Energy	Distributed	Two
Elbhiri 2009	High	No	Yes	Good	Energy	Distributed	Two
Duan 2007	High	No	Yes	Good	Energy	Distributed	Two/

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							Multilevel
Marin-Perianu 2008	High	Yes	No	Moderate	Energy and Link	Centralized	Multilevel
Smaragdakis 2004	Low	No		Good	Energy	Distributed	Two
Haibo	Low	Yes	Yes	Very Good	Computational and Energy	Distributed	Three
Varma 2008	Low	Yes	OK	Good	Computational and Energy	Centralized	Two
Li 2007	Low	Yes	Yes	Good	Computational and Energy	Centralized	Two
Wang 2007	Ok	No	Yes	Very Good	Energy	Distributed	Two
Liaw 2009	Low	No	Yes	Good	Energy	Centralized	Multilevel

Table 1 compares the various clustering algorithms discussed above on various points like energy efficiency, location awareness, cluster stability, clustering methodology, heterogeneity level and balance clustering. Table 2 classifies the algorithms based on clustering attributes discussed in section 3.

Table. 2: Classification of Surveyed Algorithms Based on Clustering Attributes

Clustering Approach	**Clustering Properties**			**Cluster Head Capability**			**CH Selection based On**			
	Cluster Count	**Intra-cluster Topology**	**Connectivity of CH to BS**	**Mobility**	**Node Type**	**Role**	**Initial Energy**	**Residual Energy**	**Energy Consumption Rate**	**Average Energy of Network**
Kumar 2009	variable	Fixed (1-hop)	Direct Link	Fixed	Sensor	Relaying	X	√	X	X
Qing 2006	variable	Fixed (1-hop)	Direct Link	Micromobile/Fixed	Resource rich	Aggregation	X	√	X	√
Elbhiri 2009	variable	Fixed (1-hop)	Direct Link	Micromobile/Fixed	Resource rich	Aggregation	√	√	X	X
Duan 2007	variable	Fixed (1-hop)	Direct Link	Micromobile/fixed	Resource rich	Fusion, relaying	X	√	X	√
Marin-Perianu 2008	variable	Multi-hop	Multi-hop	Mobile	Resource rich	Relaying	√	X	X	X
Smaragdakis 2004	variable	Fixed (1-hop)	Direct Link	Fixed	Sensor	Aggregation	X	√	X	X
Haibo	variable	Fixed (1-hop)	Direct Link	Fixed	Sensor	Aggregation	X	√	X	X
Varma 2008	Fixed	Fixed (1-hop)	Multi-hop	Fixed	Resource rich	Aggregation, Compression	√	X	X	X
Li 2007	Fixed	Fixed (1-hop)	Multi-hop	Fixed	Sensor	Aggregation	X	√	√	X
Wang 2007	variable	Fixed	Direct	Fixed	Resource	Relay	X	√	X	√

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			Link		rich					
Liaw 2009	Fixed	Fixed (1-hop)	Direct Link	Fixed	Resource rich	Aggregation Relay	X	√	X	√

5. Conclusion

Wireless sensor networks are an interesting area of research. Sensor networks are not always homogeneous, they may be heterogeneous too. Heterogeneous wireless sensor networks are more complex than homogeneous ones. Clustering is a good technique to reduce energy consumption and to provide stability of network in wireless sensor networks. This paper surveyed some of the research protocols in this area. Most of them are based on clustering. They are classified according to energy efficiency and stability of network. We summarize a number of schemes, stating their strengths and limitation. Finally we conclude that the heterogeneous wireless sensor networks are more suitable for real life applications as compared to the homogeneous counterpart.

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