CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

One of the most important challenges of WSN design is to develop a scheme that allows the numerous sensor nodes to be randomly deployed. These sensor nodes behave in a collaborative and organized way. WSNs are typically used for remote environment monitoring areas where providing the electricity is difficult. Therefore, the devices need to be powered by the batteries and alternative energy sources as briefed by Sendra et al (2011). Because battery energy is limited, the use of different techniques for energy saving is one of the prevalent topics in WSNs. These energy sources habitually consist of a battery with a limited energy resource. In addition, it could be inconvenient to recharge the battery, because nodes may be deployed in a hostile or unpractical environment.

Each sensor node has to maximize its own utility function. In addition, the entire network needs balance in the resource assignments in order to perform in a way that is useful and energy efficient. Many researchers have suggested many solutions for WSNs. In this chapter, a brief review of the work done in this area, the energy conservation schemes especially clustering, routing solutions and network data aggregation pertaining to energy efficiency is presented. Cluster based routing solutions proposed in the literature which is directly related to this work are detailed.

2.2 ENERGY CONSERVATION SCHEMES

Sensor networks are deployed in an ad hoc fashion, with the individual nodes remaining largely inactive for longer periods of time, but then becoming suddenly active when something is detected. Sensor Networks are generally battery constrained. The lifetime of a sensor network can be extended by jointly applying different techniques. For example, the energy efficient protocols are aimed at minimizing the energy consumption during network activities. However, a large amount of energy is consumed by the node components such as CPU, radio, etc. even if they are idle. The power management schemes are thus used for switching off the node components that are not temporarily needed.

These techniques are the basis for any networking protocol and the solution is optimized from an energy-saving point of view. Due to the fundamental role of these enabling techniques, stress the Prior to discussing the advanced classification of the energy conservation proposals, it is very significant to present the network-level and node-level architectures.

Obviously, the energy breakdown heavily depends on the specific node as given below:

- The communication subsystem has much higher energy consumption than the computational subsystem. It has been shown that by transmitting one bit may consume as much as executing a few thousands instructions. Therefore, communication should be traded for computation.

- The radio energy utilization is of the same order in the reception, transmission, and idle states, while the energy spending drops off at least one order of magnitude in the sleep state. Therefore, the radio should be turned off whenever possible.

- Depending on the specific application, the sensing subsystem might be another major source of energy consumption, so its energy consumption has to be reduced as well.

Based on the above architecture and energy breakdown, numerous approaches have to be exploited, at the same time, to reduce energy consumption in Wireless Sensor Networks. At a very common level, the three main enabling techniques are namely duty cycling, data-driven approaches and mobility are explained below.

2.2.1 Duty Cycling

Duty cycling is primarily focused on the networking subsystem. The most efficient energy-conserving operation is to put the radio transceiver in the (low-energy) sleep mode whenever the communication is not required. Ideally, the radio should be switched off as soon as there is no more data to be send/received, and it should be resumed as soon as a new packet data is available. In this way, nodes interchange between active and sleep periods depending on the network activity. This activity is generally referred to as duty cycling and duty cycle is defined as the part of time when the nodes are active during their lifetime.

2.2.2 Data Driven Approaches

Data driven techniques presented below are designed to reduce the amount of sampled data by keeping the sensing precision within an acceptable level for the application. Data-driven approaches can be separated according to the difficulty they address. In particular, data-reduction schemes address the case of unwanted samples, as energy efficient data acquisition schemes are mainly aimed at reducing the energy spent by the sensing subsystem.

It is important to discuss here one more classification level related to the data-reduction schemes. These techniques are in-network processing, data compression and data prediction. All these techniques aim at reducing the quantity of the data to be delivered to the sink node. Scenarios where nodes have limited energy and forward messages of different priorities are frequent in the context of wireless sensor networks.

2.2.3 Mobility Based Schemes

In case, if some of the sensor nodes are mobile, mobility can finally be used as a tool for reducing the energy consumption. In a static sensor network, packets coming from the sensor nodes track a multi-hop path towards the sink. Thus, a few paths can be more loaded than the others and nodes closer to the sink relay more packets so that they are more subjective to early energy reduction as stated by Mohapatra et al (2007). If some of the nodes such as the sink are mobile, the traffic flow can be changed if mobile devices are responsible for data collection directly from the static nodes.

Normal nodes wait for the channel of the mobile device and routes messages towards it, so that the communications take place in proximity either directly or at most with a limited multi-hop traversal. As a result, the ordinary nodes can save energy because the path length, contention and forwarding overheads are reduced as well. In addition, the mobile device can visit the network in order to extend more evenly the energy consumption due to communications. When the cost of mobilizing sensor nodes is excessive, the normal approach is to attach sensor nodes to the entities that will be roaming in the sensing field anyway, such as buses or animals.

Mobility based schemes can be classified as mobile-sink and mobile-relay schemes, depending on the type of the mobile entity. It is significant that when considering mobile schemes, an important issue is the type of control the sensor-network designer has on the mobility of nodes. A complete discussion on this point is emphasized by Jun et al (2005). Mobile nodes can be separated into two broad categories: they can be specifically designed as part of the network infrastructure or they can be a part of the environment. When they are part of the infrastructure, their mobility can be fully controlled and are, in general, robotized.

2.3 ROUTING PROTOCOLS IN WSNs

Recent advances in wireless sensor networks have led to many new protocols specifically designed for sensor networks where energy efficiency awareness is an essential consideration. Most of the attention, however, has been given to the routing protocols since they might differ depending on the application and network architecture. This section presents a classification for the various approaches pursued. In general, routing in WSNs can be divided into flat-based routing, hierarchical-based routing, and location-based routing depending on the network structure as shown in Figure 2.1.

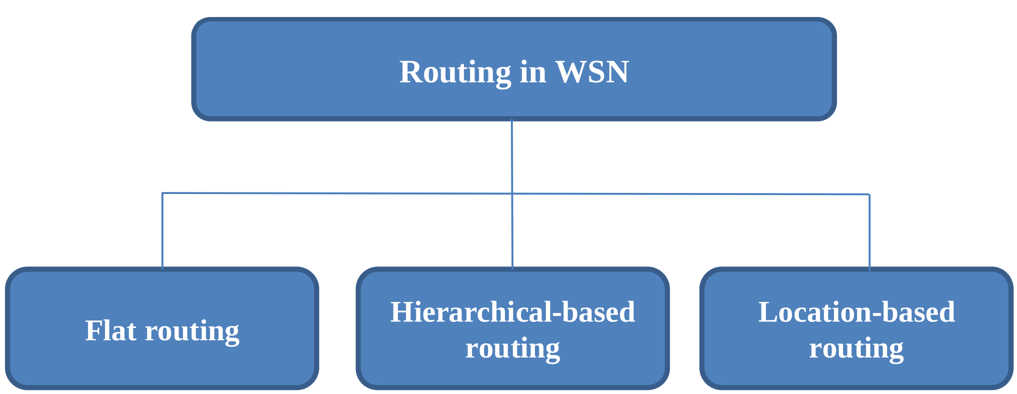

Figure 2.1 Classification of Routing in WSN

In flat routing, all the nodes are typically assigned equal roles or functionality. In hierarchical-based routing, the nodes will play different roles in the network. In location based routing, sensor nodes' positions are exploited to route data in the network. Many other protocols rely on timing and position information.

2.3.1 Flat Routing

In flat routing protocols, each node typically plays the same role and the sensor nodes collaborate with each other to perform the sensing task. Due to the large number of sensor nodes, it is not feasible to assign a global ID to each node. This reason has led to data centric routing where the BS sends queries to a certain area and waits for the data from the sensors located in the selected regions. Since the data is being requested through queries, attribute-based naming is necessary to specify the properties of each interested data. Early works on data centric routing like DD (Directed Diffusion) as discussed by Heinzelman et al (1999), SPIN (Sensor Protocols for Information via Negotiation) which has been dealt by Intanagonwiwat et al (2003).The algorithms were shown to save energy through data negotiation and by the elimination of the redundant data. These protocols have motivated the design of many other protocols with similar mechanism.

2.3.2 Hierarchical Based Routing

Hierarchical based (also called cluster based) routing was first used in wire line networks. It is a famous routing paradigm with advantages of scalability and efficient communication. The concept of hierarchical routing can also be utilized to achieve energy efficiency during routing process in WSNs. In the hierarchical structure network, higher energy nodes can be used as cluster heads which performs management and coordination within each cluster while low energy nodes can be kept as sleeping nodes unless they have data to send. In this way, it can largely contribute to the whole network scalability, lifetime as well as energy efficiency.

Hierarchical routing can also reduce energy consumption within a cluster by performing the data aggregation. Hierarchical routing mainly utilizes two-layer routing where one layer is used for communication between cluster heads and the other layer is used for the short range communication between cluster heads and ordinary nodes within the same cluster.

2.3.3 Location Based Routing

In location based routing protocols, it is assumed that the sensor location information is known. The sensor nodes are addressed by their location and the location information can be obtained either through GPS device or through certain positioning or localization algorithms like triangulation method.

2.4 CLUSTERING IN SENSOR NETWORKS

2.4.1 Introduction

The most essential requirements of WSNs are the ability to scale hundreds or even thousands of sensor nodes and to operate for the longer period of the time. Clustering has proven to be an effective technique that prolongs the network lifetime by reducing the energy consumption and provides the required scalability has been briefed by Heinzelman et al (2000). Essentially, a clustering algorithm determines a set of nodes that can provide a backbone to connect the network to the base station. This set of nodes is called Cluster Head (CH) set and the rest of nodes are called member nodes. The clustering algorithm assigns each regular node to be a member of one of the cluster head nodes. Thus the network is partitioned into groups called clusters, and each cluster has one cluster head node that works as a coordinator of this cluster as shown in Figure 2.2.

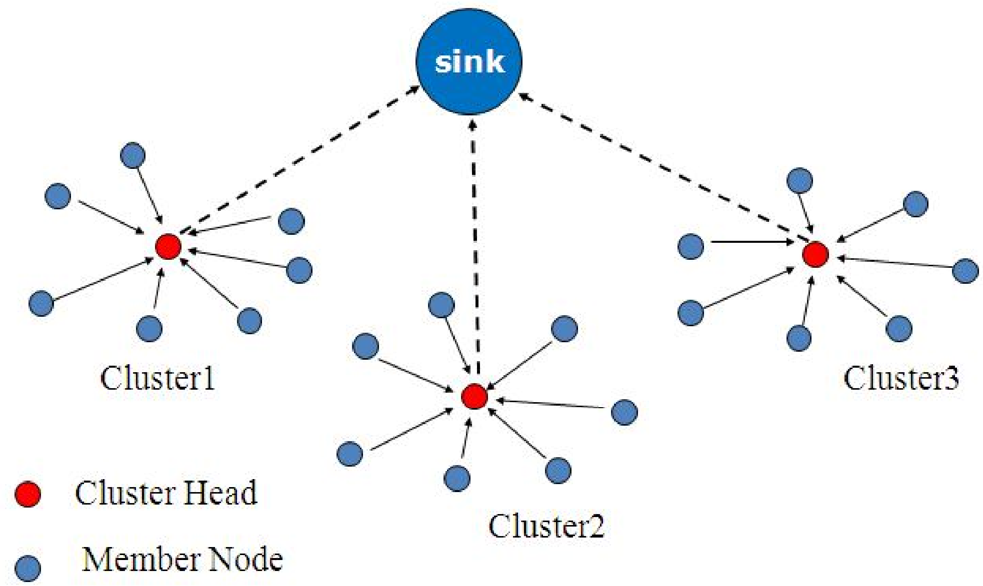

Figure 2.2 Clustering in WSN

A cluster head node has an extra burden as it must receive messages from its cluster members, aggregate them, transmit the aggregated message to the next hop towards the sink, and relay the aggregated messages originated by other cluster head nodes. Re-clustering the network is often necessary in order to achieve the load balancing.

2.4.2 Advantages and Objectives of Clustering

Compared with flat routing in WSNs, cluster based routing have a variety of advantages, such as more scalability, less load, less energy consumption and more robustness. In this section, the advantages as well as the objectives of WSN clustering as emphasized by (Liu 2012) as follows

More Scalability

In the clustering scheme, the sensor nodes are divided into a variety of clusters with different assignment levels. The CHs are responsible for data aggregation, information dissemination and network management, and the MNs for events sensing and information collecting in their surroundings. Clustering topology can localize the route set up within the cluster and thus reduce the size of the routing table stored at the individual sensor nodes has been quoted by Akkaya & Younis (2005). Compared with a flat topology, this kind of network topology is easier to manage, and more scalable to respond to events in the environment.

Data Aggregation/Fusion

Data aggregation/fusion, which is the process of aggregating the data from multiple nodes to eliminate the redundant transmission and provide the fused data to the BS, which is an effectual technique for WSNs to save energy as mentioned by Rajagopalan & Varshney (2006). The most popular data aggregation/fusion method is clustering data aggregation, in which each CH aggregates the collected data and transmits the fused data to the BS as briefly described by Yue et al (2012). Usually CHs are formed as a tree structure to transmit aggregated data by multi hopping through other CHs which results in significant energy savings.

Less Load

Since sensors might generate significant redundant data, data aggregation or fusion has emerged as an important tenet and objective in WSNs. The main idea of data aggregation or fusion is to combine the data from different sources to eliminate the redundant data transmissions, and provide a rich and multi-dimensional view of the targets being monitored.

Many clustering routing schemes with data aggregation capabilities requires careful selection for clustering approach. For clustering topology, all cluster members only send data to CHs, and data aggregation is performed at the CHs, which help to dramatically reduce data transmission and save the energy. In addition, the routes are set up within the clusters which thus reduce the size of the routing table stored at the individual sensor nodes has been quoted by Akkaya & Younis(2005).

Less Energy Consumption

In the clustering scheme, data aggregation helps to dramatically reduce the data transmission and save energy. Moreover, clustering with intra-cluster and inter cluster communications can reduce the number of sensor nodes performing the task of long distance communications, thus allowing less energy consumption for the entire network. In addition, only CHs perform the task of data transmission in clustering routing scheme, which can save a great deal of energy consumption.

More Robustness

Clustering routing scheme makes it more convenient for the network topology control and it responds to the network changes. It comprises of node mobility and unpredicted failures, etc. A clustering routing scheme only needs to cope up with these changes within the individual clusters, thus the entire network is more robust and more convenient for the management. In order to share the CH responsibility, CHs are generally rotated among all the sensor nodes to avoid the single point of failure in clustering routing algorithms.

Collision Avoidance

In the multi hop flat model, the wireless medium is shared and managed by the individual nodes, thus this model can result in low efficiency in the resource usage. On the other hand, in the multi hop clustering model, a WSN is divided into clusters and the data communications between the sensor nodes comprise of two modes namely intra-cluster and inter-cluster, respectively for data collection and for data transmission. Accordingly, the resources can be allocated orthogonally to each cluster to reduce the collision between the clusters and it can be reused cluster by cluster as briefed by Lee et al (2011). As a result, the multi-hop clustering model is the appropriate model for large-scale WSNs.

Latency Reduction

When a WSN is divided into clusters, only CHs perform the task of data transmissions out of the cluster. The mode of data transmissions only out of the cluster helps in avoiding collisions between the nodes. Accordingly latency is also reduced. Furthermore, data transmission is performed hop by hop usually using the form of flooding in flat routing scheme, but only CHs perform the task of data transmission in clustering routing scheme, which can decrease hops from data source to the BS, accordingly decreasing the latency.

Load Balancing

Load balancing is an essential consideration. It aims at prolonging the network lifetime in WSNs. Even distribution of the sensor nodes among the clusters is usually considered for the cluster construction where CHs perform the task of data processing and intra-cluster management .In general, constructing equal-sized clusters is adopted for prolonging the network lifetime since it prevents the premature energy exhaustion of CHs. Besides, multi-path routing is a method to achieve load balancing.

Fault-Tolerance

Due to the applicability of WSNs in a good many dynamic scenarios, the sensor nodes may suffer from the energy depletion, transmission errors, hardware malfunction and malicious attacks and so on. With applications such as hurricane modeling and tracking envisioned to utilize a large number of small sensor nodes, the cost of each sensor node is constrained. Owing to the significant constraints on the cost, and therefore on the quality of sensor nodes, and the often hostile environments in which they are deployed, sensor networks are prone to failure. Thus, the fault-tolerance proposed by Chitins et al (2009) revolutioned as an important challenge. In order to avoid the loss of significant data from key sensor nodes, the fault tolerance of CHs is usually required in these kind of applications, thus effective fault-tolerant approaches must be designed in WSNs. Re-clustering is the most intuitive method to recover from a cluster failure, though it usually disarranges the on-going operation. Assignment of CH backup is available scheme for recovery from a CH failure.

Guarantee of Connectivity

Sensor nodes usually transmits the data to one or more BSs via a single-hop or multi-hop routing in WSNs, thus whether the data is successfully delivered or not to the BS is mainly determined by the connectivity of each node to its next hop node along the path. Furthermore, sensor nodes that cannot communicate with any other sensor node which will get isolated and their data can never be transmitted to the BS. Therefore, the guarantee of connectivity is an essential goal of clustering routing protocols in WSNs. An important example stated by Freris et al (2010) is that when some information concerning all the sensor nodes needs to be collected by a designated fusion node in clustering routing protocols.

Energy Hole Avoidance

Generally, multi-hop routing is used to deliver the collected data to a sink or a BS. In those networks, the traffic transmitted by each node includes both self-generated and relayed traffic. Regardless of MAC protocols, the sensor nodes closer to the BS have to transmit more packets than those far away from the BS. As a result, the nodes closer to the BS tends to deplete their energy first, leaving a hole near the BS, partitioning the whole network, and preventing the outside nodes by sending the information to the BS, while many remaining nodes still have a plenty of energy. This phenomenon is called as energy hole. This energy hole concept has been stated by Li & Mohapatra (2007).

Maximizing the Network Lifetime

Network lifetime is an inevitable consideration in WSNs, because sensor nodes are constrained in power supply, processing capability and transmission bandwidth, especially for applications of harsh environments. Usually it is indispensable to minimize the energy consumption for intra-cluster communication by CHs which are richer in resources than ONs. Besides, sensor nodes that are close to most of the sensor nodes in the clusters should be prone to be CHs. Additionally, the aim of energy-aware idea is to select those routes that are expected to prolong the network lifetime in inter-cluster communications, and the routes composed of nodes with higher energy resources should be preferred.

Quality of Service

The network applications and the functionalities of WSNs prompt the requirement of quality of service (QoS). Usually, effective sample, less delay and temporary precision are required. It is difficult for all the routing protocols to satisfy all the requirements of QoS, because some demands may breach one or more protocol principles. Existing clustering routing approaches in WSNs mainly focuses on increasing the energy efficiency rather than the QoS support. QoS metrics must be taken into account in many real-time applications, such as battle-target tracking, emergent-event monitoring, and etc.

2.4.3 Clustering Attributes in WSNs

Cluster Characteristics

Variability of Cluster Count

Based on the variability of the cluster count, clustering schemes can be classified into two types such as fixed and variable ones. In the former scheme, the set of cluster-head are predetermined and the number of clusters is fixed. However, the number of clusters is variable in the latter scheme, in which CHs are selected, randomly or based on some rules, from the deployed sensor nodes.

Uniformity of Cluster Sizes

In the light of uniformity of cluster sizes, clustering routing protocols in WSNs can be classified into two classes like even and uneven ones, respectively with the same size clusters and the different size clusters in the network. In general, clustering with different sizes clusters is used to achieve more uniform energy consumption and avoid energy hole.

Intra Cluster Routing

According to the methods of intra cluster routing, clustering routing manners in WSNs also include two classes namely single-hop intra-cluster routing methods and multiple-hop ones. For the manner of intra-cluster single-hop, all MNs in the cluster transmit data to the corresponding CH directly. Instead, the data relaying is used when MNs communicate with the corresponding CH in the cluster.

Inter Cluster Routing

Based on the manners of inter cluster routing, clustering routing protocols in WSNs include two classes: single hop inter cluster routing and multiple hop inter cluster routing. For the manner of inter-cluster single-hop, all CHs communicate with the BS directly. In contrast to it, data relaying is used by CHs in the routing scheme of inter-cluster multiple-hop.

Cluster Head Characteristics

Existence

Based on the existence of cluster-heads within a cluster, clustering schemes can be grouped into cluster-head based and non-cluster-head based clustering. In the former schemes, there exist at least one CH within a cluster, but there is no CHs within a cluster in the latter schemes, such as some chain based clustering algorithms.

Difference of Capabilities

Based on the uniformity of energy assignment for sensor nodes, the clustering schemes in WSNs can be classified into homogeneous or heterogeneous ones. In homogeneous schemes, all the sensor nodes are assigned with equal energy, computation, and communication resources and CHs are designated according to a random way or other criteria. However, sensor nodes are assigned with unequal capabilities in heterogeneous environment, in which the roles of CHs are preassigned to sensor nodes with more capabilities.

Mobility

According to the mobility attributes of CHs, the clustering approaches in WSNs can also be grouped into mobile and stationary manners. In the former manners, CHs are mobile and membership dynamically change, thus a cluster would need to be continuously maintained. Contrary to it, CHs are stationary and can keep a stable cluster, which are easier to be managed. Sometimes, a CH can travel for limited distances to reposition itself for the better network performance.

Role

A CH can simply act as a relay for the traffic generated by the sensor nodes in its cluster or perform aggregation/fusion of collected information from sensor nodes in its cluster. Sometimes, a cluster head acts as a sink/BS that takes actions based on the detected phenomena or targets. It is worth mentioning, sometimes a CH acts in more than one role.

Clustering Process

Control Manners

Based on control manners of clustering, clustering routing methods in WSNs can be grouped into centralized, distributed and hybrid ones. In centralized methods, a sink or CH requires the global information of the network or the cluster to control the network or the cluster. In distributed approaches, a sensor node is able to become a CH or to join a formed cluster on its own initiative without global information of the network or the cluster. Hybrid schemes are composed of centralized and distributed approaches. In this environment, distributed approaches are used for the coordination between CHs, and centralized manners are performed for CHs to build individual clusters.

Execution Nature

Considering the execution nature of the cluster formation, clustering modes in WSNs can be classified into two classes' namely probabilistic or iterative ones. In probabilistic clustering, a probability assigned to all sensor nodes is used to determine the roles of the sensor nodes. In other words, each sensor node can independently decide on its own roles. Nevertheless, every node must wait until a certain number of iterations is achieved or for certain nodes to decide their roles before making a decision in iterative clustering manner.

Convergence Time

Considering the convergence time, clustering methods in WSNs can be grouped into variable and constant convergence time ones. The convergence time depends on the number of nodes in the network in variable convergence algorithms, which accommodate well to small-scale networks. After a fixed number of iterations, constant convergence time algorithms certainly converge regardless of the scale of the networks.

Parameters for CH Election

Based on the parameters used for CH election, the clustering approaches can be categorized as deterministic, adaptive, and random ones. In deterministic schemes, a special inherent attributes of the sensor nodes are considered, such as the identifier (ID), number of neighbors they have. In adaptive manners, CHs are elected from the deployed sensor nodes with higher weights, which includes such as residual energy, communication cost, and etc. In random modes, CHs are elected randomly without regard to any other metrics like residual energy, communication cost, etc. and it is mainly used in secure clustering algorithm.

Proactivity

According to the proactivity of clustering routing, clustering routing methods can be grouped into proactive, reactive, and hybrid ones. In proactive networks, all routes between source and the BS are computed and maintained before they are really needed regardless of the data traffic. Once a message arrives, it travels through a predetermined route to the BS. In contrast, no predetermined routes exist in reactive networks, in which the routing is chosen when a message needs to be delivered from source to the BS. Hybrid approaches use a combination of the above two ideas. For this kind of clustering routing, sometimes proactive clustering mode is adopted, but at other times reactive mode is used.

2.5 CLUSTER BASED ROUTING PROTOCOLS

Among the issues in WSN the consumption of energy is one of the most important issues. Regarding energy efficiency, Hierarchical routing protocols are found to be the best. By the use of a clustering technique they minimize the consumption of energy greatly in collecting and disseminating the data. Hierarchical routing protocols minimize the energy consumption by dividing nodes into clusters. In each cluster, a node with more processing power is selected as a cluster head, which aggregates the data sent by the low powered sensor nodes. In this section cluster based routing protocols for wireless sensor networks are discussed.

Heinzelman et al (2000) presented the LEACH (Low Energy Adaptive Clustering Hierarchy) protocol for WSNs of cluster-based architecture, which is a widely known and elegant clustering algorithm, by selecting the CHs in rounds. LEACH is a popular energy efficient adaptive clustering algorithm that forms node clusters based on the received signal strength and uses these local cluster heads as routers to the SINK. Since data transfer to the base station consumes more energy, all the sensor nodes within a cluster take turns with the transmission by rotating the cluster heads. This leads to balanced energy consumption of all nodes, and hence a longer lifetime of the network. A predefined value, P (the desired percentage of cluster heads in the network), is set before starting this algorithm. LEACH works in several rounds where each round has two phases, the setup phase and the steady phase. During the setup phase, each node decides whether to become a cluster head or not. Each node chooses a random number p between 0 and 1, which is the probability to elect itself as a cluster head. If the probability p is less than a threshold T(n) for node n , node n will become a cluster head for the current round r. This T(n) is calculated by using the Equation (2.1) as follows:

$$T(n) = \begin{cases} \frac{P}{1-P*(r \, mod \, \frac{1}{P})}, if \ n \ \in G \\ 0, \ \text{Otherwise} \end{cases} \tag{2.1}$$

During the steady phase, the sensor nodes can begin sensing and transmitting data to the cluster heads. The cluster heads also aggregate data from the sensor nodes in their cluster and sends data to the base station. After a certain period of time spent on the steady phase, the network goes into another round of selecting the cluster heads. The duration of the steady phase is longer than the duration of the setup phase in order to minimize the overhead. LEACH provides an optimized behavior for communication in WSNs based on self - organization methods. Mobility is also supported by LEACH, whereas new nodes have to be synchronized to the current round. Node failures may lead to less cluster heads to be elected than desired because the predefined P is a percentage of the total number of sensor nodes.

Considering a single round of LEACH, a stochastic cluster - head selection will not automatically lead to minimum energy consumption during the steady phase for data transfer of a given set of sensor nodes. For example, some of the cluster heads can be located near the edges of the network or some adjacent nodes can become cluster heads. In these cases, some sensor nodes are further away from a cluster head. However, considering two or more rounds, a selection of favorable cluster heads at the current round can result in an unfavorable cluster - heads selection in the later round. Regarding energy consumption, a deterministic cluster - head selection algorithm can perform a stochastic algorithm. The modification of the threshold equation by the remaining energy may bring up another problem. Since the remaining nodes have a low energy level after a number of rounds, the cluster - head threshold will become too low. Some cluster heads will not have enough energy to transmit data to the base station.

The network cannot work well although there are still nodes available with enough energy to perform this task. The threshold equation can be modified further by including a factor that increases the threshold for any node that has not been a cluster head for a certain number of rounds. The chance of this node becoming a cluster head increases because of the higher threshold.

Manjeshwar & Agrawal (2001) proposed, a hierarchical clustering based protocol developed for reactive networks in which nodes react immediately to sudden and drastic changes in the environment known as TEEN. Cluster formation and data transfer are done as in the LEACH protocol. At every cluster change the CH broadcast to its member's two threshold values along with other attributes - Hard Threshold (HT) and Soft Threshold (ST). These values as well as the environment are sensed by the nodes continuously. When the node finds that the sensed attribute has reached HT, the node switches on its transmitter and sends the sensed data.

The sensed value is stored in an internal variable SV in the node. In the current cluster period, the nodes will next transmit data only when the current value of the sensed attribute is greater than HT and the current value of the sensed attribute differs from SV by an amount equal to or greater than the ST. The use of HT and ST will reduce the number of transmissions in the network and hence it reduces the overall energy dissipation in the network. This scheme is suited for time critical data sensing applications.

EEHC developed by Bandyopadhyay & Coyle (2003) is a distributed, randomized clustering algorithm for WSNs. This technique is divided into two phases namely single-level clustering and multi-level clustering. In the single-level clustering, each sensor node announces itself as a CH with probability p to the neighboring nodes within its communication range. These CHs are named as the volunteer CHs. All nodes that are within k hops range of a CH receive this announcement either by direct communication or by forwarding. Forced CHs are nodes that are neither CH nor belong to a cluster. If the announcement does not reach a node within a pre-set time interval t that is calculated based on the duration for a packet to reach a node that is k hops away, the node will become a forced CH assuming that it is not within k hops of all volunteer CHs. The second phase, called multi-level clustering builds h levels of cluster hierarchy. The algorithm ensures h-hop connectivity between CHs and the base station. The CHs closest to the base station have disadvantage because they act as relays for other CHs.

Another popular energy - efficient node clustering algorithm is the hybrid, energy - efficient, and distributed (HEED) clustering approach for ad hoc sensor networks. HEED developed by Younis & Fahmy (2004) is a distributed clustering protocol which was proposed with four primary goals as follows: (1) prolonging network lifetime by distributing energy consumption, (2) terminating the clustering process within a constant number of iterations, (3) minimizing control overhead (to be linear in the number of nodes), and (4) producing well - distributed cluster heads and compact clusters. HEED periodically selects cluster heads based on a hybrid of two clustering parameters: The primary parameter is the residual energy of each sensor node and the secondary parameter is the intra- cluster communication cost as a function of neighbor proximity or cluster density. The primary parameter is used to probabilistically select an initial set of cluster heads while the secondary parameter is used for breaking ties.

The clustering process at each sensor node requires several rounds. Every round is long enough to receive messages from any neighbor within the cluster range. As in LEACH, an initial percentage of cluster heads in the network, C_{prob} , is predefined. The parameter C_{prob} is only used to limit the initial cluster – head announcements and has no direct impact on the final cluster structure. In HEED, each sensor node sets the probability CH_{prob} of becoming a cluster head as follows

$$CH_{prob} = C_{prob} * \frac{E_{residual}}{E_{max}} \qquad (2.2)$$

Where $E_{residual}$ is the estimated current residual energy in this sensor node and E_{max} is the maximum energy (corresponding to a fully charged battery), which is typically identical for homogeneous sensor nodes. The CH_{prob} value must be greater than a minimum threshold p min. A cluster head is either a tentative cluster - head , if its CH_{prob} is < 1, or a final cluster - head , if its CH_{prob} has reached 1.

During each round of HEED, every sensor node that never heard from a cluster head elects itself to become a cluster head with probability $CH_{prob.}$ The newly selected cluster heads are added to the current set of cluster heads. If a sensor node is selected to become a cluster head, it broadcasts an announcement message as a tentative cluster - head or a final cluster - head. A sensor node hearing the cluster - head list selects the cluster head with the lowest cost from this set of cluster heads. Every node then doubles its CH_{prob} and goes to the next step. If a node completes the HEED execution without electing itself to become a cluster head or joining a cluster, it announces itself as a final cluster - head. A tentative cluster - head node can become a regular node at a later iteration if it hears from a lower cost cluster head. Note that a node can be selected as a cluster head at consecutive clustering intervals if it has higher residual energy with lower cost. Since a WSN is assumed to be a stationary network, where nodes do not die unexpectedly, the neighbor set of every node does not change very frequently.

Here HEED does not need to do neighbor discovery very often. In addition, distribution of energy consumption of HEED extends the lifetime of all the nodes in the network, thus sustaining stability of the neighbor set. Nodes also automatically update their neighbor sets in multi-hop networks by periodically sending and receiving messages. The HEED clustering improves network lifetime over LEACH clustering because LEACH randomly selects cluster heads (and hence cluster sizes), which may result in faster death of some nodes. The final cluster heads selected in HEED are well distributed across the network and the communication cost is minimized.

Energy-efficient unequal clustering (EEUC) developed by Li (2005) is a distance based scheme, where the balance between the clusters are achieved. The size of the cluster near to the base station has lower cluster size compared to clusters that are far from the base station. In this scheme every node has the knowledge about the location and distance to the base station. In the data transmission phase the cluster head passes the data to the relaying node by using the following criteria

$$s_i.R_{CH} = \{s_j \mid d(s_i, s_j) \leq ks_i, R_{comp}, d(s_j, BS) < (s_i, BS)\} \quad (2.3)$$

Experiment result shows that the EEUC clearly improves network life time over LEACH and HEED.

BCDCP proposed by Muruganathan et al (2005), is a centralized clustering based routing protocol which utilizes a high-energy BS to set up clusters and routing paths, perform randomized rotation of CHs, and carry out other energy intensive tasks. The key idea in BCDCP is the formation of balanced clusters. BCDCP operates in two phases: setup and data communication phases. The major activities in setup phase are CH selection, CH-to-CH routing path formation and schedule creation from each cluster. CHs are selected by BS from a list of nodes whose energy level is greater than the average value. BCDCP then forms desired number of clusters by using an iterative cluster splitting algorithm. Using Balanced Clustering technique, all the clusters formed are allocated with CHs selected from the list, such that the load is evenly distributed on all CHs.

Once the clusters and the CHs have been identified, the BS chooses minimum energy path which is formed by connecting all the CHs using minimal spanning tree approach. To forward data to the BS, a CH is randomly selected. Finally the BS creates a TDMA schedule for all the clusters. In Data transfer phase, the CH gathers data from the cluster members fuses with its own data and forwards the data to BS through CH-to-CH routing path created in the setup phase. This protocol requires high energy BS to perform the energy intensive tasks as described above. Simulation results have shown that BCDCP out performs LEACH and PEGASIS. It is also observed that performance gain of BCDCP enhances with the increase in area of the sensor field.

PEACH developed by Yi et al (2007) supports the adaptive multilevel clustering in which clustering hierarchy is adaptively changed by circumstances. It can be used for the location aware and unaware wireless sensor networks. All existing clustering protocols can only support a fixed level of hierarchical clustering. Location-unaware PEACH protocol operates in a fully distributed manner. All sensor nodes are required to transmit and receive multiple packets to select cluster heads and join clusters. The packets are composed of advertisements and announcements from the cluster head nodes, and joined from the non-head nodes, and the scheduling information from the head nodes. However, Location Unaware-PEACH does not require additional transmission overhead except for overhearing a packet between other nodes. The simulation results demonstrated that PEACH significantly improves the lifetime and the energy consumption of the wireless sensor networks compared with existing clustering protocols.

EECS protocol proposed by Ye et al (2007) for wireless sensor networks better suits the periodical data gathering applications. This protocol is similar to the LEACH protocol where the network is partitioned into a set of clusters with one cluster head in each cluster. This protocol contains two phases namely cluster head selection and cluster formation phase. In the cluster head selection phase well distributed cluster heads are elected based on the residual energy. After the clusters are selected, PLAIN nodes in EECS chooses the cluster head by considering not only the saving in its own energy but also balancing the workload of cluster heads. It consists of two distance factors which are d(Pj ,CHi) and d(CHi,BS).Based on the following weighted function the PLAIN nodes will select their respective cluster heads

$$cost(j, i) = \omega \times f(d(P_j ,CH_i))+(1-\omega) \times g(d(CH_i, BS)) \qquad (2.4)$$

Where f and g are two normalized functions

$$f(P_j,CH_i)=\frac{d(P_j,CH_i)}{d_{f-max}};\ g(CH_i)=\frac{d(CH_i,BS)-d_{g-min}}{d_{g-max}-d_{g-min}}$$

where $d_{f\text{-}max}=\exp(\max\{d(P_j,CH_i)\})$, $d_{g\text{-}max}=\max\{d(CH_i,BS)\}$ and $d_{g\text{-}min}= \min\{d(CH_i,BS)\}$

EECS produces a uniform distribution of cluster heads across the network through localized communication with little overhead. Simulation results show that EECS is effective in the consumption of energy and it prolongs the network lifetime as much as 135% of LEACH. The advantages of EECS include: 1) fully distributed. 2) Low control overhead. 3) Load balanced clustering mechanism. But the Communication between cluster head and BS is direct (single-hop).

ECR uses the hybrid (cluster and chain) way to manage the networks. In ECR protocol once the topology is formed, the shape of cluster will not change, but the position of CH slips along the chain. Based on the Y direction distance from the sensing area and BS, the area is divided into several sub areas with same width. The nodes in each sub area form a cluster and nodes in each cluster organize them into a chain by themselves according to the order of their X-coordinate. The operation of ECR is initiated by the BS by selecting a CH-Leader randomly, leader of the CH chain. This is for the first round only but in coming rounds a node with maximum rest energy is selected as CH-Leader.

CH-Leader is the one which is responsible for transmitting data to the BS. The selected CH-Leader is also the CH of the cluster it belongs to. The other CHs are generated by a distributed algorithm based on their distance to the CH-Leader. A CH chain is formed by means of greedy algorithm with these CHs. During the steady state phase, CH gathers sensing data from non-CH nodes along the cluster-chain and processes them. The CH-Leader collects data from CHs along the CH chain, fuses them and transmits the data to the BS directly. Simulation results show that ECR protocol outperforms LEACH and PEGASIS in terms of network life time. As the clusters are fixed or static, ECR saves the energy for cluster rebuilding in each round and hence saves the overall energy.

Ghiasabadi et al (2008) proposed the ERP model which is a hybrid of clustering structure and chain based binary scheme. Nodes in the network are grouped into cluster chains with one node as CH. If there are N nodes then% of nodes are selected as CH. All nodes in a cluster use greedy algorithm to form a chain-based binary structure and this occur at every level in the hierarchy. For gathering the data in each round, each node sends its data to its neighboring node which fuses the data and sends it to its neighbor in a given level of hierarchy. The nodes that receive data in each level rise to the next level. Finally at the top level, the only node remaining will be the CH. Once the CHs take all the data from all the nodes in its cluster, it aggregates the data and sends the fused data to its neighboring CH. This occurs at every level in the hierarchy and at the top level a single CH remains and it sends the fused data to the BS. Thus this protocol uses chain-based binary scheme not only within the cluster but between CHs also. This will reduce the energy and delay cost as well as the computation overhead at BS. Experiments show that the delay cost of this protocol is much lesser than

LEACH. It is also observed that these results do not depend on the number of nodes in the network.

BCBE proposed by Zhang et al (2008) is a clustering based routing protocol which minimized the disadvantages of LEACH. The CHs may not be well distributed and the number of nodes in each cluster is distributed unequally. The prerequisite in this protocol is that the location information of two nodes and BS must be known and with this information every other node can compute its location. The protocol will arrange CHs in optimal positions for having balanced clusters. Simulations proved that a 100 node network has longest life time with 6 CHs.

Each node after calculating their coordinates, calculates its distance from all the optimal positions. The node with shortest distance will be elected as CH and it will broadcast the information. All other non-CHs nodes can join with a CH by sending an ACK message. Then the CH will calculate a TDMA schedule and broadcast it to the members. When the remaining energy of the CH falls below a certain value, it can choose a suitable cluster member as its successor, based on the highest fitness value of the cluster member. BCBE has a more balanced distribution of CH and cluster members than LEACH. The simulation results show that the life time when using BCBE is much longer than that of LEACH.

EMHR is proposed by Huang et al (2009) which is based on LEACH and employs multi-hop methodology for data transmission. CH selection for the first round is the same as in LEACH. In the next round CH is elected by comparing the energy value of all the nodes in the cluster and the largest energy node is selected as the CH. Then the elected node broadcasts the message of becoming the CH. In EMHR, the CH sends all the collected data of the cluster members to the BS by multi-hop. Each CH finds the optimized next-hop CH based on a weight function. By this way of a continuous selection next-hop CH, the data are passed along next-hop CH and the last CH sends all data to BS which saves the energy consumption of CH and hence reduces the overall energy consumption of the network. Simulations show that the energy strategy of electing CH decision in EMHR helps to achieve good performance in terms of network life time and balancing load among CHs energy consumption in wireless sensor networks.

CHIRON discussed by Chen et al (2009) is energy efficient protocol that split the sensing field into a number of smaller areas, so that it can create multiple shorter chains to reduce the data transmission delay and redundant path, and therefore conserve the node energy and prolong the network lifetime. The concept of using Beam Star topology helps the protocol to form multiple shorter chains which reduce the propagation delay as well as transmission paths and hence the network energy consumed is less.

The CBRP protocol which is proposed by Zarei (2010) in which the network is clustered by using some parameters and then constructing a spanning tree for sending aggregated data to the base station. The operation of CBRP is divided into two phases such as Cluster head selection phase and routing tree generation phase. In the cluster head selection phase the CH election is based on the Cluster Head Selection Value (CHSV), the largest CHSV value node will become the cluster head. In routing tree generation phase each cluster head will select their parent sensor node based on the Parent Selection Value (PSV). Next, the routing tree is constructed and the transmission takes place. CBRP considers the distance and residual energy of nodes and elects optimum cluster heads that can save more energy in nodes. Experimental results show that CBRP balances the energy consumption among cluster heads and as a result more energy is saved in the network.

Table 2.1 summarizes the cluster based routing protocols surveyed according to different metrics. The metrics considered are cluster formation, cluster head selection, Energy efficiency, scalability, load balancing and delay. The CH plays the specialized role of performing data aggregation and sending it to the BS on behalf the nodes within its cluster. To select CHs residual energy of the node and distance from CH to BS are taken as key parameters. Most of the protocols use single hop or multi-hop communication for intra-cluster and inter-cluster communication. The above discussed metrics have direct impact on the energy efficiency of the protocol.

Table 2.1 Comparison of Cluster based routing protocols

Protocol	Cluster Head Selection		Cluster Formation		Energy Efficiency	Scalability	Load Balancing	Delay
	Dist. CH to BS	Residual Energy	Nodes to CH	CH to BS				
LEACH	No	No	Single hop	Direct	Average	Yes	moderate	Low
TEEN	No	No	Single hop	Multi-hop	High	Yes	good	Medium
EEHC	No	Yes	Single hop	Multi-hop	Average	Yes	good	Low
HEED	No	Yes	Single hop	Multi-hop	High	Yes	moderate	Low
EEUC	Yes	Yes	Single hop	Multi-hop	Low	Yes	good	Low
BCDCP	No	Yes	Single hop	Multi-hop	High	Yes	moderate	Medium
PEACH	No	Yes	Single hop	Multi-hop	High	Yes	moderate	Medium
EECS	Yes	Yes	Single hop	Direct	Average	Yes	moderate	Low
ECR	No	No	Single hop	Multi-hop	Average	Yes	good	High
ERP	No	No	Single hop	Multi-hop	Average	Yes	moderate	Low
BCBE	Yes	Yes	Single hop	Direct	Low	Yes	good	High
EMHR	Yes	Yes	Single hop	Multi-hop	Low	Yes	good	High
CHIRON	No	Yes	Multi-hop	Multi-hop	Average	Yes	moderate	Medium
CBRP	No	Yes	Single hop	Multi-hop	Average	Yes	good	Medium

2.6 IN-NETWORK DATA AGGREGATION TECHNIQUES FOR WIRELESS SENSOR NETWORKS

In this literature survey, another important aspect of sensor networks, namely in-network aggregation and data management is also focused. These techniques allow to trade-off communication for computational complexity. Given the application area, network resource constraints, and the fact that local computation often consumes significantly less energy than communication, in-network data aggregation and management are at the very heart of sensor network research. Since sensor nodes might generate significant redundant data, similar packets from multiple nodes which can be aggregated so that the number of transmissions would be reduced.

Data aggregation is the process of combining data from different sources by using functions such as suppression (eliminating duplicates), min, max and average as discussed by Krishnamachari et al (2002). Some of these functions can be performed either partially or fully in each sensor node, by allowing sensor nodes to conduct in-network data reduction as stated by Intanagonwiwat et al (2000).In particular resource efficiency, timely delivery of data to the sink node and accuracy or granularity of the results are conflicting goals and the optimal trade-off among them largely depends on the specific application.

2.6.1 Basics of In-Network Aggregation

In typical sensor network scenarios, data is collected by sensor nodes in some area and needs to be made available at some central sink node(s), where it is processed, analyzed, and used by the application. In many cases, data generated by different sensors can be jointly processed while being forwarded towards the sink, e.g., a reading related to the same event or physical quantity, or by locally processing raw data is transmitted before fusing sensor together.

In-network aggregation deals with this distributed processing of data within the network. Data aggregation techniques are tightly coupled with how data is gathered at the sensor nodes as well as how packets are routed through the network, and have a significant impact on energy consumption and overall network efficiency (e.g., by reducing the number of transmissions or the length of the packets to be transmitted). In-network data aggregation can be considered a relatively complex functionality, since the aggregation algorithms should be distributed in the network and therefore require coordination among nodes to achieve better performance. It is also emphasized that data size reduction through network processing shall not hide statistical information about the monitored event. For instance, when multiple sensors collaborate in observing the same event, the number of nodes reporting it and the timings of the reports may reveal the event's size and/or dynamics, respectively.

In-network aggregation with size reduction

In-network aggregation with size reduction refers to the process of combining and compressing data coming from different sources in order to reduce the information to be sent over the network. As an example, assume that a node receives two packets from two different sources containing the locally measured temperatures. Instead of forwarding the two packets, the sensor may compute the average of the two readings and send it in a single packet.

In-network aggregation without size reduction

In-network aggregation without size reduction refers to the process of merging packets coming from different sources into the same packet without data processing. Assume that two packets carrying different physical quantities, e.g., temperature and humidity are to be received. These two values cannot be processed together but they can still be transmitted in a single packet, thereby reducing overhead.

The first approach is better able to reduce the amount of data to be sent over the network but it may also reduce the accuracy with which the gathered information can be recovered at the sink. After the aggregation operation, it is usually not possible to perfectly reconstruct all of the original data. The second approach, instead, preserves the original information (i.e., at the sink, the original data can be perfectly reconstructed).

Good aggregation functions for Wireless Sensor Networks need to meet additional requirements. In particular, they should take into account the very limited processing and energy capabilities of sensor devices, and should therefore be implementable by means of elementary operations. Also, different devices may be suitable for different types of operations, depending on their energy resources and computation capabilities. These facts need to be considered in the design of aggregation functions and routing protocols.

2.6.2 Performance Measure of Data Aggregation

There are many important performance measures of in network data aggregation. These performances are highly dependent on the desired application.

Energy Efficiency

By the in-network data-aggregation scheme, the functionality of the Wireless Sensor Network has increased. In this method every sensor nodes should have spent the same amount of energy in every data gathering round. A data aggregation scheme is energy efficient if it maximizes the functionality of the network. Network lifetime, data accuracy, and latency are some of the significant performance measures of data-aggregation algorithms. The definitions of these measures are highly dependent on the desired application.

Network lifetime

The network lifetime is defining the number of data fusion rounds. Till the specified percentage of the total nodes dies and the percentage depends on the application. simultaneous working of the all the sensor nodes is crucial hence the lifetime of the network is n number of round until the first nodes, which improves the energy efficiency of nodes and enhance the lifetime of whole network in some applications.

Latency

Latency is to evaluate data of time delay experiences by system, means data send by sensor nodes and received by base station(sink). Basically delay involved in data transmission, routing and data aggregation. Communication overhead evaluates the communication complexity of the network fusion algorithm.

Data accuracy

It is to evaluate a ratio of total number of reading received at the base station (sink) to the total number of generated. There are different types data of aggregation protocols like network architecture based data aggregation protocols, network-flow-based data aggregation protocols and quality of service aware data aggregation protocols designed to guarantee QoS metrics.

2.6.3 In-network Data Aggregation Techniques

Some authors present a novel minimizing the total energy consumption of a WSN in collecting sensory data from the whole network. The data generated by different sensors in WSN can be jointly processed while being forwarded toward the sink. In the past few years the network computation has been extensively studied. In terms of communication complexity the traditional distributed computation has been studied in noiseless networks. Giridhar& Kumar (2005) presented the computation of divisible functions and symmetric functions over noiseless sensor networks. Khude et al (2008) studied the scaling laws for the time and energy consumption complexity of type threshold functions computation over random wireless sensor networks. The performance of in-network computation is investigated in this work in terms of energy consumption and latency, while most of previous work concern only with the energy consumption.

The above approaches to in-network computation are based on tree-based protocols, where a forming spanning tree is rooted at the sink and then the computation results are aggregated up to the tree. However, there are many drawbacks to these approaches. Firstly, the network should provide undesirable information to establish and maintain routes, which results in energy consumption overhead. Furthermore, unreliable links in wireless sensor networks may cause the loss of all computation results since the computation results are only available at the sink.

On the other hand, the applications of compressive sensing for data gathering have been studied by Zheng et al (2012). Luo et al (2009) applied compressive sensing theory for efficient data gathering in a large scale wireless sensor network. They showed that the proposed scheme can substantially save communication cost and increase network capacity. Quer et al (2009) studied the behavior of CS in conjunction network topology and routing to transmit random projections of the sensor data in a data gathering WSN. Lee et al (2009) investigated CS for energy efficient data gathering in a multi-hop wireless sensor network. However, this work studies data gathering with compressive sensing from the perspective function such as computation and characterizes the scaling laws of both energy consumption and latency in random networks.

2.7 CONCLUSION

A review of Research work that aimed at reducing energy consumption so as to increase network lifetime was provided. Clustering was shown to prolong the network lifetime, providing the required scalability. In this chapter, the clustering algorithms developed for WSNs was discussed briefly and also explained cluster based routing protocols and in-network data aggregation. The most interesting research issue regarding cluster based protocols is how to form the clusters so that the energy consumption and contemporary communication metrics such as latency are optimized. Moreover, the process of data aggregation and fusion among clusters is also an interesting problem to explore.