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Energy Efficient Clustering Techniques for Wireless Sensor Networks-A Review

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Abstract—The applications of Wireless Sensor Networks (WSNs) are growing at rapid pace and providing pervasive computing environments. Energy constraints is the most critical issue in sensor applications and that needs be optimized to prolong the life of resource constrained sensor network. Clustering is an efficient technique to group the sensor nodes of entire network into number of clusters to support high scalability and provide better data aggregation by efficient utilization of limited resources of sensor nodes and that prolongs network lifetime.

In this paper, some widely explored clustering algorithms in WSNs are discussed on several aspects and characteristics such as clustering timings, clustering attributes, convergence rate etc. The advantages and disadvantages of corresponding clustering algorithms are also explained with suitable examples. The paper finally concludes with discussion on the challenges of clustering in WSNs with mentioning the future research topics.

Keywords-wireless sensor networks; clustering; energy efficiency; ad hoc networks.

Introduction

With rapid technological innovations in field of wireless communications, low power electronics and micro-electromechanical systems (MEMS) technology, wireless sensor networks (WSNs) are promoting usage of pervasive computing environments for various applications due to characterizing attributes of sensor nodes like its compact size, low-power resources, low-cost, and multi-functions [1-2]. Typically, a sensor node is comprised of a sensing unit, communication unit and data processing unit which makes it feasible to be used in many applications such as monitoring of battlefield, environment, healthcare and border protection and security surveillance. For these applications, large number of sensors are usually deployed in very remote area and operated autonomously. Therefore, it is not possible to recharge sensors so energy constraint is the most critical issue needs be considered.

In large scale WSNs, to support network scalability, these wireless sensor nodes are often put into clusters which are usually non-overlapped and disjoint to each other. Clustering is employed in WSNs to support network scalability, stability of network topology [3-5] and to save energy. Clustering basically lessens the communication overheads, hence decreases the consumptions of energy and avoids interferences among sensor nodes. However, some disadvantages are also caused by the corresponding clustering algorithms. For example, the selection of cluster-head (CH), its assignment and process of cluster construction cause additional overheads. The clustering algorithms must be elaborated to be used in different application environments to achieve enhanced lifetime, coverage, scalability, robustness and especially simplicity [6-8].

This paper presents a general taxonomy and classification of existing clustering algorithms for WSNs. This has also discussed several aspects and characteristics of some currently widely explored and employed clustering algorithms, focusing on their characteristics, objectives, and features, such as clustering timings, attributes, metrics, advantages and disadvantages.

The paper embodies the work which is organized as follows: The section II presents overview of clustering protocols in WSNs explaining the objective and design philosophy. This also classifies the various clustering approaches for WSNs. In section III, some kinds of clustering algorithms are explained with its pros and cons. Finally, the section IV summarizes the study of clustering algorithms for WSNs and raises some important direction for future research.

Overview of Clustering Schemes

Basic Objective

To achieve enhanced lifetime, scalability, coverage, robustness and especially simplicity in large scale WSNs, scalable architectural and management strategies are needed. To meet above objectives an efficient and scalable network layer protocol is needed. There are several routing protocols for mobile ad hoc network and wireless sensor networks. Flat routing protocols are mostly proposed to resolve the issue but these protocols do not perform well in large scale WSNs as being proactive or reactive in nature. Consequently, clustering routing protocols are mostly proposed [9-12] by the research community. In clustering approach, sensor nodes are basically grouped into individual geographically disjoint and usually nonoverlapped clusters and all the adjacent nodes may belong to one or more clusters based on different cluster construction mechanisms.

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In clustering schemes, each cluster has a leader called cluster-head (CH) which are responsible for coordinating communication between clusters and within the clusters required in cluster formation, data collection, data aggregation, and communication with base-stations. While the other nodes except the CH perform according to the role assigned in different status, functions and responsibilities based on network usages and topologies. In addition to achieve the desired scalability, most of clustering schemes improve the overall performance of applications of WSN in following ways.

1. Reducing Communication Overheads

As cluster members only communicate to CHs and CHs are responsible to send data to sinks or control rooms after employing data aggregation and fusion techniques. This way by decreasing the retransmission of broadcast or multicast packets clustering it dramatically reduces flooding overheads while meeting the network QoS requirements. This feature significantly saves energy and bandwidth resources by reducing data transmission, and scales well in creation of routing path during data transmitting phase.

2. Easy Maintenance

With clustering schemes, it is easy to control network topology and respond to network changes caused by network dynamics such as node mobility, node autonomy, unpredicted failures [13] and local changes. The entire network is now more robust and easy to maintain as these changes only need to be identified and managed within the individual cluster and not in the entire network. For the above reasoning, several efficient clustering algorithms have been proposed for WSNs [14-19].

3. More Scalability

Clustering algorithm groups sensor nodes of the network into clusters based on certain criteria. A cluster-head is elected in cluster which process data aggregation, disseminate information and manage the network. The clustering topology localizes the route set up inside the cluster and reduces the size of the routing table maintained and stored at the individual sensor nodes [7,20]. In comparison to flat topology, this hierarchical topology is managed easily and is more scalable in responding to events in the dynamic environment [21].

4. Data Aggregation/Fusion

This is the process of collecting data from multiple nodes and filters out redundant and useless data and transmits the processed data to the sink using effective route. This is effective technique to save energy [22] in WSNs. The most efficient way to implement data aggregation method is through clustering the network, wherein the cluster-head (CH) collects and process data before transmitting fused data to the sink [23]. Generally, clustering organizes multi-level clusters forming tree structure into network and CHs transmit processed data in multi-hops to other CHs and finally reaches to sink and results in significant energy savings [24].

5. Less Energy Consumption

The clustering routing scheme and data aggregation dramatically reduces transmission in entire network and hence reduces consumption of energy. Moreover, clustering reduces the number of sensor nodes participating in long distance data transmission using intra-cluster and inter-cluster communications as only CHs are responsible to transmit data to sink node and thereby saves a significant energy consumption.

6. More Robustness

Clustering eases to control network topology and efficiently responds to changes in network dynamics resulting due to increasing number of nodes, node mobility and link failures etc. A clustering based routing scheme has to control these changes within clusters and thus the entire network results in more robust network management. To distribute load equally cluster-heads are rotated among all the sensor nodes within the cluster and it also avoids single point failure in clustering routing algorithms.

7. Collision Avoidance

In flat topology, individual nodes share wireless medium and thus performs low in efficiently utilizing the resources due to collision and interference among nodes while in multi-hop clustered topology data communications occurs between cluster-heads in intra-cluster and inter-cluster way for collecting data and for transmitting data to sink respectively. This way resources are allocated orthogonally to each cluster hence reduce collisions between clusters and be reused as explained in [25]. As a result, the multi-hop clustering model is appropriate for large-scale WSNs.

8. Latency Reduction

In clustered model of WSNs the cluster-heads transmit the data to other cluster-heads only while data transmission takes hop by hop in form of flooding in flat model. This way clustered model results into lesser hops from data source to the sink and reduces collision also hence reduces latency.

9. Load Balancing

To prolong the lifetime of WSNs, load balancing plays vital role. Generally, equal-sized clusters are formed and CHs are rotated within the cluster to prolong network lifetime it avoids the premature energy exhaustion of certain overloaded CHs and multi-path routing helps achieve load balancing.

10. Fault-Tolerance

In many dynamic scenarios WSNs face harsh operating environment. The sensor nodes suffer from transmission errors energy leakage, unwanted attacks, hardware malfunction and so on. Applications like hurricane modelling and tracking utilizes many compact sized sensor nodes and due to cost constraint quality of sensor motes suffers and furthermore, their hostile operating environments networks cause failure. This way fault-tolerance is a big challenge to WSN applications [26]. To avoid the loss of significant data from CHs, effective fault-tolerant techniques must be developed for WSNs. The most intuitive approach to recover from a cluster failure is re-clustering which usually disarranges currently running operations. Alternatively, backing up the assignment of CH is a supporting scheme to recover from a CH failure.

11. Guarantee of Connectivity

The successful delivery of data to the sink is mainly dependent upon the connectivity of source node to its next hop node along the path to one or more BSs via a single-hop or multi-hop path created using routing scheme in WSNs. Furthermore, isolated sensor nodes cannot communicate their data to the sink node. Therefore, guarantee of connectivity is an essential requirement of any clustering routing scheme in WSNs [3,27].

12. Energy Hole Avoidance

Generally, in a WSN application multi-hop route is used to send data to sink. Each node except the source node along the route act as forwarder of traffic which includes both self-generated and relayed traffic to a sink and. As a result, regardless of MAC protocols the sensor nodes neighbouring to sink transmit more data packets than those far away from the sink [28] and deplete their energy first, creating a hole near sink. This phenomenon partitions the entire network worsens the performance of WSNs and preventing the outside nodes from sending their data to sink while many of remaining nodes still have energy. This phenomenon is called energy hole [29] and clustering avoids this phenomenon to occur

13. Mechanisms of Energy Hole Avoidance

Balancing of energy consumption may be categorized into three groups: node deployment, load balancing, and energy mapping and re-assigning [30]. Uneven clustering is one of the methods to balance the load. In this methodology, a smaller cluster closer to sink and a bigger cluster far away from the sink may be constructed so the energy consumption in processing data within the cluster will be smaller and thus more residual energy can be utilized to relay data from nodes belonging to larger cluster [31]. Thus, optimizing the cluster radius is very critical task to perform [32].

14. Maximizing of the Network Lifetime

Lifetime of a WSN network is an important consideration as sensor nodes are very critically resource constrained in processing capability, power supply, and communication bandwidth. Especially, in the WSN applications operating in harsh environments, energy consumption cannot be minimized for intra-cluster communication done by cluster-heads only and which are provided with richer resources than of remaining nodes. Besides this sensor nodes lying closer to most of the sensor nodes within the clusters are more likely to become CHs. Furthermore, objective of energy aware protocol is to choose those routes consuming lesser energy in expectance to enhance the network lifetime during inter-cluster communications.

15. Quality of Service

The sensor network applications and its vast functioning need quality of service (QoS). The routing protocols do not meet all the requirements of QoS as some demands may not comply to the rules. Existing clustering routing techniques mainly consider energy efficiency rather than QoS support. In many real-time applications such as emergent-event monitoring, and battle-target tracking etc. must be considered.

Design Philosophy

The implementation of any algorithm for the wireless sensor networks face a vast challenge. Design goals targeted in wireless sensor networks provide lesser than a basis for the design [33-35] in traditional networking. Clustering help achieving the targeted design goals for a given implementation.

The clustering algorithms generally perform in two phases, formation of cluster and cluster maintenance. Formation of cluster is referred to construct a layered cluster structure in the network initialization stage, while cluster maintenance is related to control, update and manage the network topology changes. Cluster heads (CHs) perform as a central controller and coordinator to perform the distributed sensing tasks in a local cluster. Choosing a node to be CH is the key task during the initialization phase [36] of sensor network. Initially when the cluster heads are chosen for the created clusters based on some predefined rules, those CHs inform their neighbours to permit them to be potential members to join by broadcasting some clustering information. Moreover, due to additional functions a CH thus requires more energy in comparison to other nodes in a cluster. Therefore, a cluster head cannot remain to be a cluster head for entire life of a network due to large energy consumptions. In case of energy exhaustion or nay failures, a new cluster head should be chosen to self-organize, self-heal and be robust to dynamic network topology while maintaining the underlying network connectivity in a dynamic environment [37]. Designer of clustering algorithm must consider several key attributes which are important in wireless sensor networks.

1. Cost of Clustering

Clustering organizes sensor network topology in layered structure and for which additional resources like communication and processing tasks are required to create and maintain clustered topology. Such extra costs are added as these resources are not utilized for data transmission or sensing tasks.

2. Selection of Cluster-Heads and Clusters

Although the clustering of network topology offers lots of advantages to applications in wireless sensor network still its designing for a specific application must carefully analyse the methodology to create clusters in the network. For example, deciding the number of nodes taken in a cluster or its diameter may affect its operation depending on the application scenario. This prerequisite how cluster is created or cluster-head is elected in application affects the performance of sensor network.

3. Real-Time Operation

One of the fundamental criterion in designing wireless sensor networks is to prolong its useful life. In applications like habitat monitoring [38-39], it is sufficient to receive the sensed data only but not the account the delay caused. In applications like military tracking [40], the issue of data acquisition in realistic time becomes important. For real time applications, when designing clustering algorithms, the delay caused by the clustering should also be considered and the time required for cluster recovery technique becomes also important.

4. Synchronization

In wireless sensor networks the limited resources of sensor nodes limits the functionality of sensor applications. In slotted transmission schemes like TDMA sensor nodes are allowed to sleep regularly to minimize energy consumption and these communication access mechanisms need synchronization mechanism to setup and maintain the transmission schedule. Thus, synchronization and scheduling mechanism in clustering algorithm affects network lifetime and the overall performance of network.

5. Data Aggregation

Data aggregation as major functionality of wireless sensor networks is a vital function of the sensor network. This is very common feature of densely populated sensor networks as multiple nodes senses similar information and data aggregation differentiates between sensed data and useful data by employing filter processing and this is fundamental processing in many sensor network applications [41]. This way the amount of data transferred in sensor network is minimized. Many clustering schemes employ data aggregation technique and thus emphasize on requirement of data aggregation while selecting a clustering approach.

6. Repair Mechanisms

By its virtue the wireless sensor networks often results into link failure due to node mobility, expired life and interference. While designing clustering algorithms, it is important to examine the mechanisms of link recovery and reliable data communication.

7. Quality of Service (QoS)

From overall performance of network the QoS requirements in wireless sensor networks is very important and many of these QoS needs are application dependant like acceptable delay and packet loss tolerance. Thus, it is important to analyse these metrics while selecting a clustering algorithm.

A. Classification of Clustering Approaches

According to variety of criteria clustering schemes are classified. Clustering schemes for mobile ad hoc networks (MANETs) are grouped into following categories by Yu and Chong [11].

1. Dominating Set Based Clustering,
2. Low Maintenance Clustering,
3. Mobility Aware Clustering,
4. Energy Efficient Clustering,
5. Load Balancing Clustering, and

According to the cost of a clustering algorithm measured qualitatively or quantitatively, Yu and Chong grouped the clustering cost in terms of the ripple effect of re-clustering, required explicit control message exchange, the stationary assumption, communication (message) complexity and constant computation round.

Wei and Chan [42] proposed following ways to classify the clustering schemes for wireless ad hoc networks,

1. Single-Hop or Multi-Hop,
2. Location-Based or Non-Location-Based,
3. Asynchronous or Synchronous (according to network topology) and,
4. Stationary or Mobile (according to network nodes).

However, according to above criterion, the same clustering scheme may be grouped into different categories during different cluster construction and maintenance phases.

But, the objectives of clustering routing protocols for ad hoc networks mainly rely on how to generate stable clusters in network with mobility of nodes. These clustering routing schemes mostly consider routing stability, and node reachability than energy consumption, network duration, and coverage in WSNs.

Abbasi and Younis [7] has defined a set of attributes to classify different clustering algorithms of WSNs. The major attributes considered are as follows:

1. Cluster properties such as cluster count, stability, intra-cluster topology and inter-CH connectivity;

2. Cluster-head capabilities like mobility, node types and assigned role,

3. Clustering processes such as methodology, objective of node grouping, process of cluster-head selection and its complexity.

This work also concluded with following clustering objectives for WSNs,

1. Load Balancing,
2. Fault Tolerance,
3. Enhanced Connectivity and Reduced Latency,
4. Minimal Cluster Count, and
5. Maximal Network Life.

Clustering algorithms for WSNs are also grouped based on convergence rate that means constant and variable convergence time algorithms. Generally, it is critical task to set a common criterion for existing clustering algorithms, including the similarities and differences between schemes in the same category.

According to property of cluster-head (CH), following attributes are listed as classification criteria of clustering algorithms for WSNs:

1. Existence- Depending on existence of CH within a cluster, clustering algorithms are grouped into either CH based clustering or non-CH based clustering.
2. Count variability-In some application environments, where cluster heads are predetermined or pre-set. Thus, clustering schemes can be grouped into fixed or variable cluster-heads clustering.
3. Selectivity-Ideally, all member nodes of cluster should be chosen to be a cluster head in a round-robin fashion to meet the objective of energy balancing, load balancing, and topology reconfiguration [43]. In pre-assigned cluster-heads the other deployed nodes are set by certain selection rules, and clustering schemes are classified into preassigned or dynamic selected.
4. Role in WSNs-Cluster head as a local coordinator for its cluster members, performs intra-cluster transmission and serve as a backbone node for higher cluster hierarchy. Thus, clustering schemes can be grouped into local or global ones.
5. Node Mobility- According to the mobility of cluster heads the clustering algorithms may be defined as stationary or mobile ones
6. Hop Distance- Based upon the hop distance between node pairs in a cluster, clustering algorithms are grouped into one-hop clustering or multi-hop clustering.
7. Explicit Control Messages-During formation of clusters or maintenance period of network, the clustering algorithms may need explicit clustering related information exchanged between node pairs, such as data packets or routing information. Thus, clustering algorithms may be grouped as proactive or reactive. In proactive case, cluster requires data and cluster member goes from sleep mode to active mode when sensing objects reach a threshold.
8. Overlapping.

   Generally, it is natural to group sensor nodes which are spatially closed to each other in the same cluster to avoid redundancy and overlapping. But in some scenarios where sensors nodes are scattered or not properly deployed not properly, the overlapping areas among clusters and nodes are found. Therefore, based on having overlapping sensor nodes among the clusters, clustering schemes are also grouped into clustering and non-overlapping clustering.

According to the proposed classification criteria for clustering, a comprehensive survey on some existing clustering algorithms is presented in the following section.

Clustering Algorithms for WSNS

This section, discusses some popular and efficient clustering algorithms for WSNs.

1. **Hierarchical Control Clustering Algorithm (HCC) [14]**

Clustering is very important mechanism for sensor networks which are comprised of hundreds or thousands of sensor nodes to meet desired scalability along with other performance measures. Basically, performance of these applications directly depends on the performance of routing protocol which transfers data from the deployed area to sink. Performance of these network may be optimized by employing energy efficiency, load balancing and data fusion [44] techniques. Th hierarchical control clustering scheme help reduce energy consumption and offers scalability. This technique performs effectively in one-to-many and many-to-one environments, and improves the performance of one-to-any, or broadcast communication environments. In above case if the current CH performs below a quality threshold it triggers the creation of new cluster-head. The cluster formation follows BFS (Breadth First Search) tree, which works by constructing a spanning tree in a time-period proportional to the diameter of the network. In the process author attaches a weight value to each node to elect cluster-head.

The aim of hierarchical control clustering is to construct multi-layer hierarchical clustering. In this scheme, a cluster is defined as a subset of vertices (sensor nodes here), whose induced graph is connected. In this clustering approach, each layer of the hierarchy has distinguished feature such that each cluster must be connected, all clusters must hold the constraint of its minimum and maximum size and a node in any layer must belong to a fixed number of clusters. In the scheme, each node discovers its sub-tree size and information of each of its children in the BFS tree. This clustering is very effective in dynamic environments means in network in presence of mobile nodes. But it does not strictly employ localized routing protocol as spanning tree is a global data structure and needs whole network traversed before its computing.

2. Low Energy Adaptive Clustering Hierarchy (LEACH) [45]

This is one of the most popular clustering scheme for WSNs. Being distributed, autonomous and application-specific clustering algorithm it significantly improves the lifetime of sensor network. In LEACH, it is part of assumption that every pair of nodes has one-hop distance and the load is uniformly distributed among all nodes. In initial phase with some probability a node broadcast the message that it is to be a CH and thus each non-CH node chooses to join that cluster which is reached with the least communication energy. This way cluster formation is based on the received signal's strength. CH nodes acts as routers to the base-stations and performs all data fusion and aggregation locally. This uses a fixed probability to elect a CH periodically and all nodes use same probability to be a CH during its lifetime and thereby avoids the unbalancing of load among cluster nodes. However, it is assumed that a CH node has longer communication range and can send the data to the base-station directly. However, in real environments this is not true for CH nodes to be regular sensors and all the nodes cannot reach to the base-station directly owing to signal propagation problems, like presence of obstacles in medium.

Thus, it is concluded that it cannot scale well in a large-scale network covering large areas. Moreover, it also assumes that energy consumption of each node to be a cluster head is equal. This scheme does not perform efficiently in a highly heterogeneous network comprising of different kinds of nodes and with non-uniform energy distributions. Therefore, to improve the performance of LEACH many algorithms like PEGASIS [15], HEED [16], TEEN [46], APTEEN [47], etc. have been proposed.

The work of PEGASIS significantly enhances network lifetime by employing TSP (Traveling Sales Person) heuristic and communication chain topology which reduces energy consumption at the cost of prolonged communication delay. In this, each node communicates only with two very closed neighbours around the communication chain and only a single predefined node does data aggregation and fusion then transmits to the sink node. The underlying technology of HEED employs both energy and communication cost to create CHs. As the energy is distributed nonuniformly among all nodes, so it avoids of having two nodes within each other's transmission range have the same probability to become CHs. Moreover, this offers flexibility in CH election to facilitate inter-CH connectivity for a specific transmission range of sensor nodes.

3. Algorithm for Cluster Establishment (ACE) [17]

Performing differently from other distributed clustering schemes, this scheme forms clusters out of network in a fixed number of iterations, which the node degree into account as the main attribute. In each iteration, a node estimates its potential before becoming a CH and steps down if it is not the best CH now After executing many iterations, it takes decision based on the available information. In case sensor node detects that many neighbouring nodes do not belong to any cluster, it elects itself as CH. It invites its neighbours to join it by broadcasting message which are enough to create a stable average cluster size. Forming new clusters and migrating from existing ones are the two functions of ACE. The main issue of this policy is to decide the number of iterations for ACE while meeting cost requirements and energy consumptions. Moreover, migration scheme causes additional overheads in ACE.

4. Energy Efficient Clustering Scheme (EECS) [18]

The proposal of EECS is to construct clusters of unequal sizes which is based on transmission distance of the normal node to the CH and distance of the CH to the sink. A weighted function is used to ensure that clusters farther away from the sink node have smaller sizes as to save energy in long-distance data transmission to the sink. The mechanism of EECS is more energy-saving than LEACH. Sensor nodes having more residual energy are more probable to be elected as the CH through local radio communication. In process of selecting CH some fixed number of nodes are elected as candidate node for CH by a pre-set probability. Then each candidate nodes informs its neighbours of their election in a provided time interval and if the candidate node detects more powerful node i.e. with more residual energy it will give up its candidature otherwise it becomes a cluster-head. Now each created cluster-head invites members to join its cluster. In cluster formation process, EECS sets a point where energy consumption between normal nodes to the CH and CH to the sink is balanced but this requires more global knowledge of the distances between the CH and the sink and aggregating data globally puts extra burden to all sensors.

5. Energy Efficient Unequal Clustering (EEUC) [48]

Owing to the deployment constraint in multi-hop WSNs, cluster-heads nearer to sink die faster as they perform much more transmission or traffic than nodes father from sink. This scheme tries to balance the energy consumption among clusters by making cluster sizes near the sink node smaller than the size of remote clusters from the sink node and hence saves more energy in intra-cluster communications and inter-cluster communications. The EEUC scheme is based on distance as like EECS and requires each node to have global knowledge of its locations and distance to the sink node. This aims to enhance the network lifetime and balance the load among the nodes. In spite of all these, extra global data aggregation cause overheads to all sensors and scales down the network performance, specifically in a multi-hop network but it prolongs the life by saving energy.

6. **Power Efficient and Adaptive Clustering Hierarchy (PEACH) [49]**

As most of existing clustering algorithms consume much energy, caused by cluster formation overhead and fixed level clustering especially in case of densely deployed wireless sensor networks. PEACH protocol has resolved this issue to some extent. But the above scheme of WSNs performs on minimizing the energy consumption of each node, and enhancing lifetime of network. In this scheme, cluster formation is done by utilizing overhearing characteristics of wireless communication. To provide adaptive multi-level clustering and avoiding additional overheads, overhearing a node help recognizing the source and the destination of packets transmitted by the neighbouring nodes. PEACH is applicable in both location-unaware and location-aware wireless sensor networks. The PEACH can significantly save energy consumption of each node, prolong the network lifetime, and is least affected by the deployment basis of sensor nodes compared with existing clustering protocols. There are many other elegant clustering algorithms, such as Fast Local Clustering [19], Lowest-ID Cluster Algorithm [50], Distributed Clustering algorithm [51] etcetera which efforts to save energy or reduce energy consumption.

Conclusions and Future Work

Discussion of various clustering techniques concludes that clustering offers better routing schemes for large scale wireless sensor networks and make it robust against dynamic topology changes caused by mobility of nodes, insertion of new node or moving out older nodes or node failures. Currently, there are excellent proposals of clustering schemes but here a review of some representatives is presented. Many of clustering techniques in WSNs has mainly considered energy consumption, data latency and network lifetime. These algorithms generally employ heuristic approach to estimate minimum number of clusters to ensure that any node in any cluster is at most k hops away from the cluster-head. However, energy consumption required to form cluster and maintain it is still an issue. The announcement, advertisement, joining, data acquisitions from entire network, and scheduling messages from sensor nodes are the overhead crated by cluster formation. Thus, network stability and its lifetime are major issues which need be considered while selecting clustering schemes in WSNs.

The work concludes by mentioning very interesting research issues in clustering techniques for WSNs and which are as follows:

1. To employ clustering in heterogeneous sensor networks where various types of sensor nodes with different communication and processing capabilities are deployed.
2. Energy efficient adaptive and distributed clustering approach are specifically demanded in large-scale multi-hop networks deployed with mobile nodes aware of their location or not.
3. The issues such as cluster coverage, fault tolerance, multi-hierarchy, security and node deployment are still open problems.

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