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Towards Clustering Algorithms in Wireless Sensor Networks-A Survey

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Abstract—**Wireless sensor networks (WSNs) are emerging as essential and popular ways of providing pervasive computing environments for various applications. In all these environments energy constraint is the most critical problem that must be considered. Clustering is introduced to WSNs because of its network scalability, energy-saving attributes and network topology stabilities. However, there also exist some disadvantages associated with individual clustering scheme, such as additional overheads during cluster-head (CH) selection, assignment and cluster construction process. In this paper, we discuss and compare several aspects and characteristics of some widely explored clustering algorithms in WSNs, e.g. clustering timings, attributes, metrics, advantages and disadvantages of corresponding clustering algorithms. This paper also presents a discussion on the future research topics and the challenges of clustering in WSNs.**

Keywords-wireless sensor networks;clustering;energy efficiency; routing protocol

I. INTRODUCTION

With advances in wireless communications, micro-electro-mechanical systems (MEMS) technology, and low-power electronics, wireless sensor networks (WSNs) are emerging as essential and popular ways of providing pervasive computing environments for various applications due to attributes such as small size, low-cost, low-power, and multi-functions [1,2]. Typical sensor nodes consist of sensing, data processing, and communicating components, making it feasible for a large number of applications in industrial, military, and agricultural applications, such as battlefield monitoring, environmental monitoring, disaster salvation and management, healthcare monitoring, border protection and security surveillance. In these applications, sensors are usually remotely deployed in large numbers and operated autonomously. Therefore, in these unattended environments, the sensors can not be recharged and energy constraint is the most critical problem that must be considered.

For the sake of network scalability in large scale WSNs, these wireless sensors are often grouped into individual disjoint and usually non-overlapped clusters. Clustering is proposed to WSNs because of its network scalability, energy-saving attributes and network topology stability [3,4,5]. Clustering scheme reduces the communication overheads, thereby decreasing the energy consumptions and interferences among sensor nodes. However, there also exist some disadvantages associated with corresponding clustering algorithms, such as additional overheads during cluster-head (CH) selection, assignment and cluster construction process.

To support features such as extended lifetime, scalability, coverage, robustness and especially simplicity, clustering algorithms must be elaborated for different application environments to achieve the above goals [6,7,8]. In this paper, we present a general taxonomy and classification of existing clustering algorithms for WSNs. We discuss several aspects and characteristics of some current widely explored and used clustering algorithms, focusing on their characteristics, objectives, and features, such as clustering timings, attributes, metrics, advantages and disadvantages. We also compare these clustering algorithms based on metrics such as hop distance, cluster mobility, cluster stability, cluster overlapping, complexity, convergence rate, and network scalability.

The rest of the paper is organized as follows: Section 2 presents the basic concepts of clustering and clustering routing protocols in WSNs. In Section 3, some kinds of clustering schemes and algorithms are compared. Finally, we summarize the study of clustering formation and routing techniques in WSNs and make some remarks on further research in Section 4.

II. OVERVIEW OF CLUSTERING SCHEMES

A. Basic Concepts

In large scale WSNs, scalable architectural and management strategies are required to achieve goals such as extended lifetime, scalability, coverage, robustness and especially simplicity. To fulfill these requirements, it is necessary to design an efficient and scalable network layer protocol. There exist a lot of routing protocols in mobile ad hoc network and wireless sensor networks. Flat routing protocols are firstly proposed to solve the problem. However, flat routing protocols can not scale well in large scale WSNs since they are mostly proactive or reactive.

Consequently, researchers and engineers moved to clustering routing protocols in recently years [9,10,11,12]. In Clustering schemes, sensor nodes are often grouped into

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individual geographically disjointed and usually non-overlapped clusters. All the adjacent nodes are in one ore more clusters according to different cluster formation mechanisms [11,12]. In clustering schemes, there would be a leader, often called cluster-head (CH). CHs are responsible for coordination between inter-clusters and intra-clusters, such as cluster formation, data collection, data aggregation, and communication with base-stations. Non-cluster-head nodes in a cluster, e.g., cluster members serve as different roles associated with different status, functions and responsibilities according to different network usages and topologies. A typical cluster structure can be found in [11].

Clustering schemes have some prominent advantages except for scalability, as listed in the following:

1) Less Overheads.

As all cluster members only send data to CHs and CHs only send data to base-stations or sinks after data aggregation and fusion within clusters, clustering schemes can dramatically alleviate flooding overheads while still fulfilling the network QoS requirements by decreasing the retransmission of broadcast or multicast packets. This feature significantly reduces transferring data, saves energy and bandwidth resources, and also scales well in routing path building phase and data transmitting phase.

2) Easy Maintenance.

After cluster formation, clustering schemes make it easier for network topology control and responding to network changes caused by network dynamics, node autonomy, node mobility, local changes and unpredicted failures [13]. Since all these changes only need to be detected, and managed within an individual cluster, not the entire network, the entire network is more robust and easy for maintenance and management.

For the above predominance, various excellent task-specific clustering algorithms have been proposed for WSNs [14-19].Basically, clustering schemes consist of two phases, cluster formation and cluster maintenance. Cluster formation is referred to how to construct a hierarchical cluster structure in the network initialization stage, while cluster maintenance is referred to how to update, control and manage the network topology changes caused by node mobility, failures, link breakage or some other reasons.

Since cluster heads (CHs) serve as a central coordinator to perform the distributed sensing tasks in a local cluster, which node is chosen to be a CH is the key problem during the entire network initialization phase [20]. When the first cluster heads are chosen according to some predefined rules, those CHs notify their neighbors by broadcasting some clustering information to permit their potential members to join.

Moreover, a cluster head consumes more energy than the other nodes in a cluster because it has additional functions. Therefore, a cluster head can not always act as a cluster head due to large energy consumptions. In case of failures or energy exhaustion, a new cluster head should be elected to provide self-organizing, self-healing, and robustness to network topology changes while maintaining the underlying network connectivity in a dynamic environment [21].

B. Classification of Clustering Schemes

Clustering schemes can be classified according to different criteria. Yu and Chong [11] grouped clustering schemes for mobile ad hoc networks (MANETs) into six categories according to different clustering objectives, which are listed as follows: Dominating-Set-based (DS-based) clustering, low-maintenance clustering, mobility-aware clustering, energy-efficient clustering, load-balancing clustering, and combined metrics-based clustering.

According to the cost of a clustering scheme in different aspects qualitatively or quantitatively, Yu and Chong also grouped the clustering cost terms into five categories, i.e., the required explicit control message exchange, the ripple effect of re-clustering, the stationary assumption, constant computation round, and communication (message) complexity.

Wei and Chan [22] proposed four possible ways to classify the clustering schemes in Ad Hoc networks, which are: single-hop or multi-hop, location-based or non location-based, asynchronous or synchronous (according to network topology) and, stationary or mobile (according to network nodes).

However, based on the above two classifications, the same clustering scheme may be grouped into different categories during different cluster construction and maintenance phases. Moreover, the objectives of clustering routing protocols for Ad hoc networks mainly focus on how to generate stable clusters in environments with mobile nodes. These clustering routing techniques mostly care more about node reachability and routing stability than network duration, energy consumption, and coverage in WSNs. Abbasi and Younis [7] enumerated a rich set of attributes that can be used to categorize and differentiate clustering algorithms of WSNs. The major attributes and the relevant attributes are listed as follows:

1) Cluster properties, including cluster count, stability, intra-cluster topology and inter-CH connectivity;

2) Cluster-head capabilities, including mobility, node types and Role;

3) Clustering process, including methodology, objective of node grouping, cluster-head selection and algorithm complexity.

Abbasi and Younis [7] also summarized five clustering objectives, i.e., load balancing, fault-tolerance, increased connectivity and reduced delay, minimal cluster count, and maximal network longevity. They grouped existing clustering algorithms for WSNs into two subsections according to their convergence rate, i.e., variable and constant convergence time algorithms.

In general, it is hard to set a common criterion for various underlying clustering schemes, including the similarities and differences between schemes in the same category. Based on the existing various classification criteria, we list the following attributes as classification criteria for WSNs according to cluster-head (CH) properties:

1) Existence.

Depending on whether there exist cluster-heads within a cluster, clustering schemes can be grouped into CH-based clustering and non-CH-based clustering.

2) Count variability.

In some application environments, the set of cluster heads are predetermined and thus the number of clusters is preset. Therefore, clustering schemes can be categorized into fixed or variable cluster-heads clustering.

3) Selectivity.

Ideally, all the cluster member nodes should be chosen to be a cluster head in a round-robin fashion to achieve load balancing, energy balancing, and topology reconfiguration [23]. According to whether cluster-heads are pre-assigned or chosen from the deployed nodes set by certain cluster-head selection rules, clustering schemes can be grouped into pre-assigned or dynamic selected.

4) Role.

In WSNs, cluster head can simple act as a local coordinator for its cluster members, perform intra-cluster transmission or serve as a backbone node for higher cluster hierarchy. Thus clustering schemes can be grouped into local or global ones.

5) Node mobility .

Clustering schemes can be grouped into stationary or mobile ones according to the mobility attributes of cluster heads.

6) Hop distance.

Depending on hop distance between node pairs in a cluster, clustering algorithms can be grouped into 1-hop clustering and multi-hop clustering.

7) Explicit control messages.

During cluster formation or maintenance period, it may require explicit clustering-related information exchanged between node pairs, such as routing information or data packets. Therefore clustering schemes can be grouped into explicit control message-dependent or non-explicit control message ones. In the latter, cluster is proactive to receive data and cluster member switches from sleep mode to active mode when sensing objects reach a threshold.

8) Overlapping.

In many applications, it is natural to group spatially close sensor nodes in the same cluster to eliminate redundancy and overlapping. However, in some cases when sensors scattered or placed not properly, there exist overlapping areas among clusters and nodes. Therefore, clustering schemes can be grouped into overlapping clustering and non-overlapping clustering.

Based on the proposed classification criteria for clustering, we present a comprehensive survey on some existing clustering algorithms in the following section.

III. CLUSTERING ALGORITHMS FOR WSNs

In this section, we classify and analyze some popular and effective clustering algorithms for WSNs.

A. Existing Clustering Routing Protocols

1) Hierarchical control clustering algorithm (HCC)

Clustering is especially useful for networks containing hundreds or thousands of nodes where scalability is the most concerned problem. In these applications routing performance is crucial for load balancing, energy efficiency, and data fusion [24]. Hierarchical control clustering (HCC)[14] can help reduce energy consumption and provide scalability. It is effective not only for one-to-many, many-to-one environments, but also one-to-any, or broadcast communication environments.

In [14], cluster formation process is triggered when the current CH falls below a quality threshold. And the cluster formation is based on a BFS (Breadth First Search) tree, which involves constructing a spanning tree in time proportional to the diameter of the network by doing a distributed breadth-first search. The author assigned a weight value to each node for cluster-head election. The goal of hierarchical control clustering is to form multi-tier hierarchical clustering. In hierarchical control clustering, a cluster is defined as a subset of vertices, whose induced graph is connected. In [14], the clustering scheme desires many goals for each layer of the hierarchy, such as: each cluster is connected, all clusters should have a minimum and maximum size constraint, and a node in any layer belongs to a constant number of clusters.

In the scheme, each node needs to discover its sub-tree size and each of its children's information in the BFS tree. When a node notes that its children and the sub-tree sizes have not changed for the last max-consecutive-static-sub-tree messages from its children, it terminates the cluster formation process. This clustering scheme is proven to be effective in dynamic environments, e.g. presence of mobile nodes. However, it is not a strictly localized routing protocol since the spanning tree is a global data structure and the whole network must be traversed before it can be computed.

2) Low energy adaptive clustering hierarchy (LEACH)

LEACH [25] is one of the most popular clustering algorithms for WSNs. It is an application-specific, distributed, and autonomous clustering algorithm and can significantly improve the network lifetime. In LEACH it is assumed that every node is reachable in one hop distance and the load distribution is uniform among all nodes. Initially a node elects itself to be a CH with a probability p and broadcasts its decision. Each non-CH node chooses to join a cluster that can be reached using the least communication energy. That is, cluster formation in LEACH is based on the strength of received signal. CH nodes serve as routers to the base-stations and all the data fusion and aggregation are performed locally.

LEACH uses a fixed probability to generate a CH periodically and all nodes have the same probability to be a CH during the network lifetime, which alleviates the load unbalancing among cluster nodes. However, it is assumed that CH node has longer communication range and can send the data to the base-station directly. This can not hold in real environments that the CH nodes are also regular sensors and not all the nodes can reach to the base-station directly due to signal propagation problems, e.g., due to the presence of obstacles. Consequently, it can not perform well in a large scale networks deployed in large areas.

Moreover, it also assumes that energy consumption is equal for each node to be a cluster head. It is not applicable in a highly heterogeneous network which consists of various kinds of nodes and has non-uniform energy distributions. Therefore, a large number of algorithms have been proposed to improve LEACH, such as PEGASIS [15], HEED [16], TEEN [26], APTEEN [27], etc.

PEGASIS significantly prolongs the network lifetime by using a communication chain topology and TSP (Traveling Sales Person) heuristic which saves energy but deteriorates the communication delay. In PEGASIS, each node only communicates with two closer neighbors around the communication chain. Only a single predefined node performs data collection, aggregation and transmissions to the sink node.

HEED uses a combination strategy of energy and communication cost to generate CHs. Since the energy is non-uniform distributed among all nodes, it is approximately avoided that two nodes within each other's transmission range have the same probability to become CHs in HEED. Moreover, the probability of CH election is flexible to provide inter-CH connectivity for a certain sensor's transmission range.

3) Algorithm for cluster establishment (ACE)

Different from other distributed clustering schemes, ACE [17] uses an emergent algorithm to cluster the sensor network in a fixed number of iterations, which uses the node degree as the main parameter. During each iteration a node is allowed to assess its potential as a CH before becoming real one and stepping down if it is not the best CH at the moment. When a node finishes executing a number of iterations (e.g., 3), it makes a decision based on the available information. The sensor node elects itself as a CH if it detects that many nodes in its neighborhood do not belong to any cluster. It broadcasts message to invite its neighbors to join it. These iterations are enough to achieve a stable average cluster size.

Generating new clusters and migration of existing ones are the two functional components of ACE. However, it is hard to decide the number of iterations for ACE while satisfying the communication cost requirements and energy consumptions. Moreover, migratory mechanism adds additional overheads in ACE.

4) Energy efficient clustering scheme (EECS)

EECS (Energy Efficient Clustering Scheme) [18] is proposed to produce clusters of unequal size in single hop networks in which cluster formation is based on transmission distance, e.g., distance from the plain node to the cluster-head and distance from the cluster-head to the base-station. EECS uses a weighted function ensure that clusters farther away from the base station have smaller sizes such that more energy could be saved for long-distance data transmission to the base station. Simulations show that EECS is more energy-efficient than LEACH.

Nodes with more residual energy have more probability to be elected as the cluster-heads through local radio communication. In a CH election phase, a fixed number of candidate nodes are elected by a preset probability. All candidate nodes broadcast election message within a time interval. A candidate will give up the competition if it finds a more powerful node with more residual energy. Otherwise this candidate will become a cluster-head finally. Then each cluster-head broadcasts an advertisement message in the network to recruit its members.

In cluster formation phase, EECS tries to find a balancing point between energy consumption between plain nodes to the cluster-heads and that between cluster-heads to the base station. However, it requires more global knowledge about the distances between the cluster-heads and the base station. And this extra requirement of aggregating data globally adds overheads to all sensors.

5) Energy-efficient unequal clustering (EEUC)

In multi-hop WSNs, there exists a hot-spot problem that CHs closer to the base station tend to die faster, because they relay much more traffic than remote nodes. EEUC (Energy-Efficient Unequal Clustering) [28] is proposed to balance the energy consumption among clusters, in which the cluster sizes near the sink node are much smaller than the clusters far away from the sink node in order to save more energy in intra-cluster communications and inter-cluster communications.

Actually, EEUC is a distance based scheme similar to EECS and it also requires every node to have global knowledge such as its locations and distances to the sink node. It tries to prolong the network lifetime and to balance the load among the nodes. However, the extra global data aggregation adds overheads to all sensors and deteriorates the network performance, especially for a multi-hop network.

6) Power-efficient and adaptive clustering hierarchy (PEACH)

Most existing clustering protocols consume large amounts of energy, incurred by cluster formation overhead and fixed-level clustering, particularly when sensor nodes are densely deployed in wireless sensor networks. To solve this problem, PEACH (Power-Efficient and Adaptive Clustering Hierarchy)[29] protocol is proposed for WSNs to minimize the energy consumption of each node, and maximize the network lifetime. In PEACH, cluster formation is performed by using overhearing characteristics of wireless communication to support adaptive multi-level clustering and avoid additional overheads. In WSNs, overhearing a node can recognize the source and the destination of packets transmitted by the neighbor nodes.

PEACH is applicable in both location-unaware and location-aware wireless sensor networks. The simulation results show that PEACH can significantly save energy consumption of each node, prolong the network lifetime, and is less affected by the distribution of sensor nodes compared with existing clustering protocols.

There are many other elegant clustering algorithms, such as Fast Local Clustering(FLOC)[19], Lowest-ID Cluster Algorithm (LID)[30] , Distributed Clustering algorithm(DCA) [31],3-hop Between Adjacent Cluster-heads (3hBAC) [32],Connected Dominating set Algorithm (CDS) [33],etc .Due to space limitation, we will only give comparison result in the following section.

B. Comparison of Survey Algorithms

Although clustering is feasible to achieve high scalability, less energy consumption and extended lifetime in a large scale WSNs, it also has some side effects and disadvantages due to additional overheads caused by cluster formation and maintenance. This will be an extra burden for energy-constrained or memory-limited nodes. During most cluster maintenance process, CHs periodically broadcast hello heartbeat messages to their members in order to be aware of the network changes. However, this extra message may add more energy consumption, communication traffic and risk of congestion and collision when node density increases. Therefore, there exists tradeoff between network scalability and energy consumption in clustering schemes.

Table 1 compares the clustering algorithms surveyed in this paper including various attributes.

TABLE I. COMPREHENSIVE COMPARISON FOR CLUSTERING SCHEMES

Clustering Schemes	Cluster Head Characteristics					Clustering Characteristics		
	Existence	Count	Selectivity	Role	Mobility	Hops	Control message	Overlapping
HCC	Yes	Variable	Pre-assign	Aggregation &Relaying	Possible	multi-hop	Yes	Yes
LEACH	Yes	Variable	Random	Aggregation &Relaying	Fixed BS	1-hop	Yes	No
PEGASIS	No	N/A	N/A	One for Aggr. &Relaying	Possible	1-hop	Yes	Possible
HEED	Yes	Variable	Random	Aggregation & Relaying	Stationary	multi-hop	Yes	No
TEEN	Yes	Variable	Random	Aggregation & Relaying	Possible	1-hop	Yes	Possible
APTEEN	Yes	Variable	Random	Aggregation & Relaying	Possible	1-hop	Yes	Possible
ACE	Yes	Variable	Random	Aggregation & Relaying	Possible	multi-hop	Yes	Very Low
EECS	Yes	Constant	Random	Aggregation & Relaying	Possible	1-hop	Yes	N/A
EEUC	Yes	Variable	Proportional	Aggregation & Relaying	Possible	multi--hop	Yes	N/A
PEACH	Yes	Variable	Probabilistic	Aggregation & Relaying	N/A	multi-hop	Yes	Possible
FLOC	Yes	Variable	Random	Aggregation & Relaying	Possible	multi-hop	Yes	Minimum
LID	Yes	Variable	Lowest-ID	Aggregation & Relaying	Possible	multi-hop	Yes	No
DCA	Yes	Variable	Bigger Weight	Aggregation & Relaying	Possible	1-hop	Yes	No
3hBAC	Yes	Variable	Lowest-ID	Aggregation & Relaying	Possible	1-hop	Yes	No
CDS	Yes	Variable	Minimum number	Dominating	Possible	1-hop	Yes	No

IV. CONCLUSIONS AND FUTURE WORK

Clustering schemes are better routing protocols suitable for large scale wireless sensor networks and robust at presence of topological changes caused by node motions, node failures, and node insertion or removal. Currently, there are a large number of excellent clustering routing protocols and we only review some representatives of them in this paper. Most of the research on clustering in WSNs mainly focuses on energy consumption, network lifetime, data latency, and non-functional goals, such as data integrity. These algorithms are mostly heuristic in nature and their goals are to generate minimum number of clusters to ensure that any node in any cluster is at most k hops away from the cluster-head. Most of them have a time complexity of O(n), where n is the total number of sensor nodes.

However, considerable energy consumption during cluster formation and maintenance is still problematic. The cluster formation overhead includes packet transmission cost of the advertisement, announcement, joining, global data acquisitions, and scheduling messages from sensor nodes. Therefore, node mobility and distribution, overhead and lifetime are major concerns when applying clustering schemes in WSNs.

Moreover, to support dynamic configuration and node distributions, adaptive multi-level clustering is expected.

It must be noted that almost all clustering routing protocols are application-specific and it is hard to find a clustering scheme applicable for all conditions. Some of the clustering algorithms can not be applied in real life networks because they generally ignore the actual network conditions and constraints, such as the mobility pattern and communication capability of nodes.

In summary, there are still many interesting research problems in clustering schemes for WSNs, such as:

1) It is still an open issue that how to perform cluster formation in heterogeneous sensor networks[34] where two or more types of sensors are deployed and each of them has different communication and processing capabilities, e.g., nodes with multiple transmission power levels.

2) In a large scale network containing mobile nodes, location-aware nodes and location-unaware nodes, distributed, energy efficient adaptive clustering approach with flexible number of iterations and capable of multi-hop communications are especially expected.

3) Fault tolerance, security, cluster coverage, multi-hierarchy, and application-specific requirements such as node placement [35] are still open questions.

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REFERENCES

[1] I. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, “Wireless sensor networks: a survey,” Computer Networks,vol. 38,pp. 393-422, April 2002.

[2] P. Baronti, P. Pillai, V. Chook, S. Chessa, A. Gotta and Y. Hu, “Wireless sensor networks: a survey on the state of the art and the 802.15.4 and ZigBee standards,”Computer Communications,vol. 30, pp. 1655-1695, July 2007.

[3] A. Amis, R. Prakash, T. Vuong, D. Huynh, “Max-min d-cluster formation in wireless Ad Hoc networks,” in: Proceedings of IEEE INFOCOM, Israel , vol. 1, pp. 32-41, March 2000.

[4] V. Kawadia, P. Kumar, “Power control and clustering in Ad Hoc networks,” in: Proceedings of IEEE INFOCOM, San Francisco, CA,vol. 1,pp. 459-469 , March 2003.

[5] K. Karenos,V. Kalogeraki,S. Krishnamurthy, “Cluster-based congestion control for sensor networks,”ACM Transactions on Sensor Networks ,vol. 4, pp. 1-39, January 2008.

[6] O.Younis, M. Krunz, S. Ramasubramanian, “Node clustering in wireless sensor networks: recent developments and deployment challenges,” IEEE Network , vol. 20, pp. 20-25, May 2006.

[7] A. Abbasi, M. Younis, “A survey on clustering algorithms for wireless sensor networks, ” Computer Communications, vol. 30, pp. 2826-2841, October 2007.

[8] J. Wan, D. Yuan,X. Xu, “A review of cluster formation mechanism for clustering routing protocols,” in: Proceedings of 2008 11th IEEE International Conference on Communication Technology(ICCT 2008),Hangzhou,China,pp.611-616, November 2008.

[9] J. Al-Karaki, A. Kamal, “Routing techniques in wireless sensor networks: a survey,” IEEE Wireless Communications, vol. 11,pp. 6-28, June 2004.

[10] K. Akkaya, and M. Younis, “A survey on routing protocols for wireless sensor networks,”Ad Hoc Networks,vol. 3, pp. 325-349, May 2005.

[11] J. Yu, P. Chong, “A survey of clustering schemes for mobile ad hoc networks,” IEEE Communications Surveys & Tutorials,vol. 7,pp. 32-48,January 2005.

[12] A. Abbasi,M. Younis, “A survey on clustering algorithms for wireless sensor networks,” Computer Communications,vol. 30,pp. 2826-2841, October 2007.

[13] Y. Li, M. Thai and W. Wu, “Topology control for wireless sensor networks,” Wireless Sensor Networks and Applications, Heidelberg: Springer, 2008, pp.113-147.

[14] S.Banerjee, S. Khuller, “A clustering scheme for hierarchical control in multi-hop wireless networks,” in: Proceedings of Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings(INFOCOM 2001), Anchorage ,Alaska, vol.2,pp.1028-1037, April 2001.

[15] S. Lindsey, C. Raghavendra, “PEGASIS: power-efficient gathering in sensor information systems,” in: Proceedings of 2002 IEEE Aerospace Conference, Big Sky, Montana, USA, vol.3,pp.1125-1130, March 2002.

[16] O. Younis, S. Fahmy, “HEED: A hybrid, energy-efficient, distributed clustering approach for Ad Hoc sensor networks,” IEEE Transactions on Mobile Computing,vol. 3,pp. 366-379, October 2004.

[17] H. Chan and A. Perrig, “ACE: an emergent algorithm for highly uniform custer formation,”Lecture Notes in Computer Science,vol. 2920,pp. 154-171, January 2004 .

[18] M. Ye, C. Li , G. Chen,J. Wu, “EECS: an energy efficient clustering scheme in wireless sensor networks”, in: Proceedings of 24th IEEE International Performance, Computing, and Communications Conference(IPCCC 2005), Phoenix, Arizona, pp.535- 540, April 2005.

[19] M. Demirbas, A. Arora, V. Mittal, “FLOC: a fast local clustering service for wireless sensor networks”, in: Proceedings of Workshop on Dependability Issues in Wireless Ad Hoc Networks and Sensor Networks (DIWANS’04), Palazzo dei Congressi, Florence, Italy, pp. 1-6, June 2004.

[20] S. Soro, and W. Heinzelman, “Cluster head election techniques for coverage preservation in wireless sensor networks,”Ad Hoc Networks, in press.

[21] J. Yu, P. Chong, “An efficient clustering scheme for large and dense mobile Ad hoc networks,” Computer Communications,vol. 30, pp. 5-16, December 2006.

[22] D. Wei, H.Chan, “Clustering Ad Hoc networks: schemes and classifications,” in: Proceedings of 3rd Annual IEEE Communications Society on Sensor and Ad Hoc Communications and Networks(SECON '06), Reston, VA, USA, pp. 920-926, September 2006.

[23] N. Kim, J. Heo, H. Kim, and W. Kwon, “Reconfiguration of clusterheads for load balancing in wireless sensor networks,”Computer Communications,vol. 31, pp. 153-159, January 2008.

[24] D. Wang, “An energy-efficient clusterhead assignment scheme for hierarchical wireless sensor networks,”International Journal of Wireless Information Networks,vol. 15, pp. 61-71, Feburary 2008.

[25] W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “An application-specific protocol architecture for wireless microsensor networks”, IEEE Transactions on wireless communications, vol. 1, pp. 660-669, October 2002.

[26] A. Manjeshwar, D. Agrawal, “TEEN: a routing protocol for enhanced efficiency in wireless sensor networks,” in:Proceedings of 15th International Parallel and Distributed Processing Symposium(IPDPS’01), San Francisco , CA, pp.2009-2015, April 2001.

[27] A. Manjeshwar, D. Agrawal, “APTEEN: a hybrid protocol for efficient routing and comprehensive information retrieval in wireless sensor networks,” in:Proceedings of International Parallel and Distributed Processing Symposium(IPDPS’02), Fort Lauderdale, Florida, pp.195-202,April 2002.

[28] C. Li, M. Ye, G. Chen, J. Wu, “An energy-efficient unequal clustering mechanism for wireless sensor networks,” in: Proceedings of 2005 IEEE International Conference on Mobile Adhoc and Sensor Systems Conference(MASS05), Washington,D.C., pp. 604-611, November 2005.

[29] S. Yi, J. Heo, Y. Cho, and J. Hong, “PEACH: power-efficient and adaptive clustering hierarchy protocol for wireless sensor networks,”Computer Communications,vol. 30, pp. 2842-2852,October 2007.

[30] C. Lin, and M. Gerla, “Adaptive clustering for mobile wireless networks”, IEEE Journal on selected arrears in communications, vol. 15, pp. 1265-1275, September 1997.

[31] S. Basagni, “Distributed clustering algorithm for ad hoc networks,” in: Proceedings of International Symposium on Parallel architectures, algorithm, and networks (I-SPAN), Fremantle, Australia, pp. 310-315, June 1999.

[32] J. Yu and P. Chong, “3hBAC (3-hop between adjacent clusterheads): a novel non-overlapping clustering algorithm for mobile Ad Hoc networks,” in: Proceedings of IEEE Pacific Rim Conference on Communications, Computers and Signal Processing (PACRIM '03), Victoria, B.C., Canada, vol. 1, pp. 318-321,August 2003.

[33] P. Wan, K. Alzoubi, O. Frieder, “Distributed construction of connected dominating set in wireless Ad Hoc networks,” in :Proceedings of IEEE INFOCOM 2002,New York, vol.3, pp.1597-1604, June2002.

[34] L.Qing,Q. Zhu, M. Wang,“Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks,” Computer Communications,vol.29,pp.2230-2237,August 2006.

[35] M. Younis, and K. Akkaya, “Strategies and techniques for node placement in wireless sensor networks: a survey,”Ad Hoc Networks,vol. 6, pp. 621-655,June 2008.