A Survey on Coverage Control Protocols in Wireless Sensor Networks

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***Abstract* - Coverage control algorithms play an important role in Wireless sensor network. Effective coverage control algorithms sense its coverage area with less energy spent. These coverage control models falls under various approaches like clustering, evolutionary, mobility based approaches. This paper makes a detailed survey on coverage control protocols coming under various classifications. In addition, it also discussed several protocols working mechanism with its evaluation metrics.**

Keyword- Wireless sensor networks, Coverage control, Energy efficiency, Disjoint set, Area Coverage, Evolutionary algorithms

I. INTRODUCTION

Wireless sensor network (WSN) consists of large number of small sized, low power, short-lived sensor nodes, which are limited in computation, memory capacity and radio range [17]. Sensor nodes measures environmental parameters through sensing, processing and communicating the data to the user. Success of the WSN is how to cover the whole network with minimum amount of energy. However, for achieving complete coverage more number of sensor nodes are needed which increase the energy utilization of the network. Efficient WSN uses only limited number of sensor nodes for providing full coverage.

In the implementation of sensor network, one of the fundamental issues that arise is coverage problem [18], which reflects how well sensors are monitoring. The ratio of total area covered to the total intended coverage area is called coverage ratio [16]. Network Coverage Quality [2] can be measured as the period from the network setup time with particular coverage ratio to the time up to that the intended area is covered with same coverage ratio.

Quality of Service of the sensor network is identified by its network coverage metrics. Similarly, individual sensor nodes quality and capacity is measured by its coverage metrics. To increase the lifetime of network, sensing unit of sensors are controlled using power management techniques by switching ON or OFF. Many protocols are used to minimize the coat and maximise the coverage area in the wide area network.

Based on the entity to be covered using the network, coverage have been categorized with respect to Area, Target and Barrier [16]. Area Coverage aims to cover the entire intended area; Target coverage concerns about particular predetermined points in the area whereas Barrier coverage about moving objects.

The prominent issue in sensor coverage is how to prolong the network lifetime with less energy spent. Based on application specific problems clustering and scheduling mechanism are widely used. Network Clustering divides nodes into clusters that depend upon the applications or protocols. A node is chosen as a Cluster Head (CH) among the sensor nodes based on some criteria such as residual energy of the node, coverage ratio of the node in the network, number of sensor nodes within its communication range and distance between them and the Base Station (BS). In most of the applications, Clusters members (CM) are having minimum overlapping coverage with other nodes. To maintain the balanced energy consumption of the network, even sized clusters are formed but in no uniform distributed network, it is not possible. To balance the energy level in the network intra and inter cluster techniques are used. In sensor scheduling, only a subset of nodes are to be activated for sensing and the other nodes in the clusters are to be kept in sleep mode for reducing the energy consumption. Though limited numbers of sensors are sensing the area, it should be same as the one covered by all the nodes in a cluster. In some cases, instead of clusters, multiple subsets of sensor nodes are formed for sensing the network and by applying some routing techniques, the sink node gathers the sensed data from those subsets.

Various routing techniques are used to find out the routing path for forwarding the sensed data to the base station. In clusters, using single-hop or multi-hop communications CH collects the sensed data from all the nodes that should be forwarded to the base station via neighbouring cluster heads. Routing path is to be selected which consumes minimum amount of energy for data transmission. Overall, for efficient wireless sensor

network, we have to concentrate on energy utilization and coverage life span. This paper mainly focuses on coverage control and proposes different protocols for achieving the complete coverage of WSN.

II. COVERAGE PATTERNS

Each sensor nodes capacity and quality is analysed through sensor coverage model. These models are used in WSNs for providing complete coverage of the network without any hole in conjunction with minimum amount of energy consumption. These models can be implemented in different geometrical shapes such as circle and hexagonal. One of the sensor coverage model is sector model (Figure 1) otherwise called as directional coverage model which is fully depends upon the angle and the sensing range of a sensor. That individual sensor has covered all the area within the sector. Another model is disk coverage model (Figure 2) in which a sensor sense the area within its sensing range in the form of circle. Disk coverage model uses minimum number of sensors for covering the entire network. In the other type, sensing area of a sensor is considered as hexagonal (Figure 3) or cell. This hexagonal model is used in most of the real time applications as mobile communications, which provides the complete coverage.

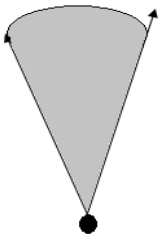

Fig 1. Sector Coverage Model

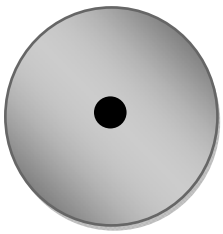

Fig 2. Disk Coverage Model

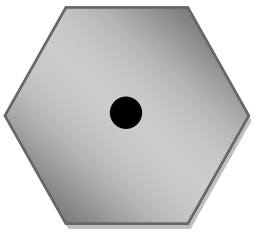

Fig 3. Hexagonal Coverage Model

III. CLASSIFICATION SCHEME

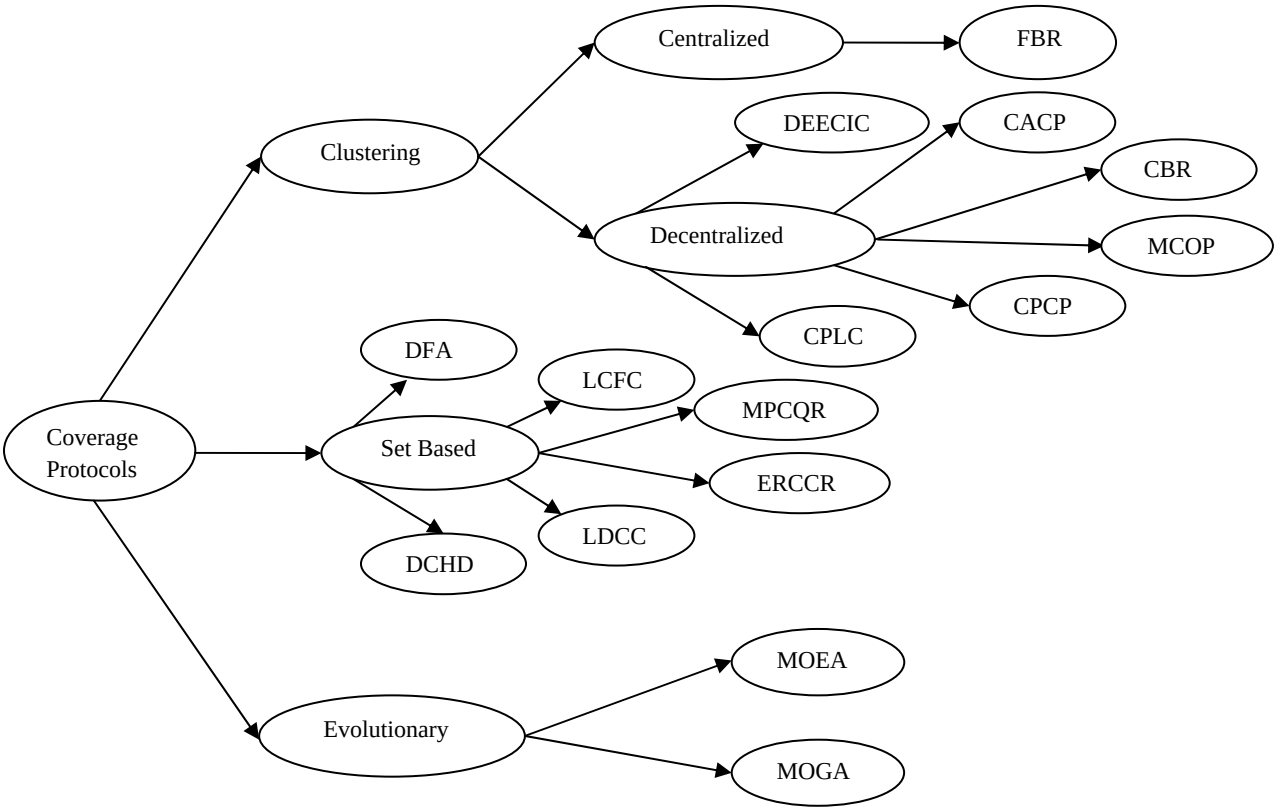

Fig 4. Classification scheme of coverage control protocols

A. CLUSTERING TECHNIQUES

Clustering approach is the one of the most used approach in coverage control of WSN. It divides the nodes in the network into different clusters for efficient governing of the network. A suitable Cluster Head node controls each cluster, to which its Cluster members will be reporting its data. This paper analyses some of the recent clustering protocols introduced for coverage control in Wireless Sensor Network.

1) DEECIC: DEECIC [1] (Distributed Energy Efficient Clustering Algorithm with Improved Coverage) is deployed for increasing the network lifetime along with improved coverage. It proposes an average cluster size for the formation of the clusters, which reduces end- to-end delay by limiting the communications within 2-hop members as well as efficiency in data fusion. Cluster head is selected from a dense area, which is having more residual energy and more number of neighbours (Node degree). If the cluster head dies due to the depletion of its energy, it will not affect the whole network coverage because of the redundancy in coverage by its neighbours. DEECIC updates cluster head by setting energy threshold(E_{th}) for each cluster head then checks that the remaining energy of a cluster head is less than its E_{th} if so that will be replaced by one of its neighbours in the next round. This will reduce the loss of data packets by the death of cluster head during the execution process and provides more coverage rounds than other algorithms as EECF and LEACH [19].

2) CACP: CACP [2] (Coverage-Aware Clustering Protocol**)** increases network coverage lifetime in wireless sensor network using two techniques such as network clustering and sensor scheduling. It uses a coverage aware cost metric for the selection of cluster head, which is having more redundancy in coverage. This will be achieved by means of sponsor sets in which node's sensing area is overlapped with other nodes in the sensor field. A layered self-activation algorithm is used for the selection of cluster members. Instead of activating all the nodes, a set of nodes is only activated for sensing its area. If the sensing area of one node overlaps with other node, it will enter sleep mode for preserving energy. CACP will minimize the average energy consumption per unit area and maximize the network coverage lifetime.

3) CBR: CBR [7] (Cluster-Based Routing Protocol) encompasses energy aware clustering algorithm EADC and Cluster Based Routing algorithm for non uniform node distributed Wireless Sensor Networks to reduce energy consumption among the nodes and to increase the network lifetime. EADC constructs the clusters with even size of members to balance the energy consumption among them. In order to balance the energy consumption among the cluster heads in non-uniform node distribution, Cluster Based Routing Algorithm with multi hop approach is introduced. If the distance between the cluster head and the Base Station (BS) is less than the threshold distance DIST_TH, it directly communicates to the BS otherwise use multi-hop approach to select the next cluster head neighbour for forwarding the data to the BS. A cluster head, which is having more residual energy, minimum number of members, more coverage ratio and nearest to the BS, is elected as a next hop for routing the data in the network. Network lifetime will be significantly improved by adjusting intra-cluster and inter-cluster energy consumption.

4) MCOP: MCOP [9] (Multi-Criterion Optimization) is proposed for the creation of clusters which ensures energy efficiency and coverage. In the beginning of clustering phase, each node is in the PLAIN state and calculates the probability to become a Cluster head (CH) by comparing its residual energy with the threshold value. If the probability is less than the threshold means nodes, change its state into CH contender state and broadcasts their residual energy to their neighbours within the competition range. Each node compares its residual energy with the receiving energy and finally nodes with higher residual energy are declared as CHs. Each CH sends CH Advertisement message to neighbours with its id and residual energy. If a node may receive more than one CH Advertisement message, it uses MCOP algorithm for selecting the proper CH by means of decision matrices and weight vector that is the distance from the node to the CH, distance between the CH and the Base Station and CH's residual energy. Clusters, which are formed by MCOP, improves network lifetime than EECS, LEACH and HEED [20] protocols.

5) CPCP: CPCP [12] (Coverage-Preserving Clustering Protocol) is proposed for providing the guarantee for complete coverage of the Wireless Sensor Network. Set of Cluster heads are elected from the densely populated area based on the remaining energy and redundancy in its coverage area. Cluster heads spreads across all over the network uniformly to avoid coverage holes. Cluster heads and active sensor nodes are to be selected by means of coverage-aware cost metrics. Route discovery message is generated to find path between cluster head and sink node. Each node delays the forwarding of the message to its nearby nodes based on its route cost. Then the non-CH nodes join its nearby CH nodes as its Cluster Members. Instead of activating all the nodes in the cluster, subset of sensor nodes are only activated, which covers the entire monitored area without redundancy in coverage. Thus, CPCP will preserve the network coverage with minimum energy consumption.

6) CPLC: CPLC [6] **(**Connectivity Preserving Localized Coverage Algorithm) is proposed for ensuring the coverage of Area of Interest (AOI) with minimum number of nodes to be activated as sets and maintaining the connectivity between the nodes. In a large-scale network, a node must be in the communication range of the other node for ensuring the connectivity and more than one cluster heads (Special Nodes) are elected randomly

from that region which can communicate with all the Common nodes within its clusters. Coverage algorithm in special nodes will form the set of nodes. This algorithm works in three different states; they are Inquire, Active and Sleep states respectively. After the deployment of the nodes, each node enters into inquire state. Cluster head broadcasts Hello message to all the common nodes along with their location co-ordinates. If a node may receive more than one Hello messages, it will select a cluster head based on the location, which is the nearest one, and send the reply messages along with the node's location. Likewise, sets are generated and their states are changed into either active or sleep states and each node is capable of covering the region independently. According to the coverage algorithm, only one set is activated at a time for reducing the energy consumption and prolong the network coverage lifetime by means of minimum overlapping between the nodes in the region.

7) FBR: FBR [15] (Flow-Balanced Routing protocol) is a centralized approach protocol for achieving energy efficiency and coverage preservation. It encompasses four algorithms as clustering algorithm, backbone construction, flow-balanced routing algorithm and rerouting algorithm. FBR executes Clustering Algorithm for forming the clusters only once at the beginning of the network deployment in which a sink broadcasts cluster formation message (CLS_FORM) among the nodes and sensor node which is having highest overlapping degree considered as a cluster head. Non-cluster heads join itself to the nearest cluster head to ensure coverage. Backbone construction algorithm constructs backbone of cluster heads along with the sink node by sending BN_CONST message to all nodes. The cluster head forwards the sensed data from its cluster members to the sink node by using the flow-balanced routing algorithm. In addition, flow-based routing balances the residual energy of the clusters. Rerouting algorithm is executed when the backbone (Cluster head) is not able to withstand for further rounds and declare a node having highest residual energy as a cluster head from the backbone construction instead of modifying the entire network. In this way, FBR provides both the power consumption and guaranteed coverage.

B. SET BASED APPROACH

Clustering protocols mainly groups its members based on the geographical location of the nodes. The nearby 1-hop or 2-hop nodes only form clusters for sensing activities. If the non-adjacent nodes in the network are forming a group to cover the intended region, then it is called as Disjoint set. Some of the Set based approaches have been analysed here.

1) DFA: DFA [3] (Distribution Free Approach) ensures the network coverage lifetime of the sensor network. It estimates network coverage intensity and the locations of the sensor nodes in the sensor field. It uses Kernel Density Estimator (KDE) to determine the distribution of sensor nodes. Nodes deployed with the GPS receivers for its location awareness. Therefore, instead of calculating the coverage intensity by the assumption of node's distribution, it estimates the intensity only by the exact distribution of nodes. This will increase the lifetime of network coverage.

2) LCFC: LCFC [4] (Low Coverage First Classifying Algorithm) proposes a K-set based scheduling for the creation of the sensor network with increasing network lifetime. Instead of choosing a set of sensor nodes to be activated randomly, it chooses the set of nodes, which are having most low coverage points. An area, which is covered by minimum number of nodes called low coverage points. This will reduce the overlap in network coverage as well as energy usage of the network. It provides highest average coverage rate than other scheduling algorithms and balance the coverage rate of the sensor sets.

3) MPCQR: MPCQR [5] **(**Minimum Perimeter Coverage of Queried Regions in a heterogeneous Wireless Sensor Network) encompasses two approaches for determining minimum number of Sensor Nodes (SNs) which provides the guaranteed perimeter coverage for the queried region. In the first approach, a node is declared as a Co-ordinate Node (CNode) which receives a query request for the interested region from the user. Similar to the sink node, CNode collects all the information about the region from the selected SNs in that queried region which ensures perimeter coverage. In the second approach, instead of CNode each SNs in the queried region selects the next neighbours to form the coverage neighbour set and then minimum perimeter coverage set is formed based on the sensing overlap of the nodes in the queried region. This approach provides more energy consumption, network lifetime and perimeter coverage lifetime than the other approaches used in Wireless Sensor Network.

4) DCHD: DCHD [8] (Distributed Coverage Hole Detection Protocol) is proposed for finding the coverage holes in Wireless Sensor Networks. It is achieved by means of two phases that is neighbour discovery phase and hole detection phase. In neighbour discovery phase, a node in the network is randomly chosen as a reference node, which broadcasts its location information to the nearest nodes. The receiving nodes calculate the distance (d1) between them and the reference node. If distance is less than the communication range (R_c), it is elected as a one-hop neighbour of reference node and the one-hop neighbour broadcasts reference node's location to its neighbours then they calculate distance (d2) between them and the reference node. If $d2 \leq R_c$, the node its elected as a two-hop neighbour of reference node. Neighbour list is formed with one-hop and two-hop neighbours in the neighbour discovery phase. After forming the neighbour list, hole detection algorithm is

executed by any node in the network in which a triangle is formed by its one-hop and two-hop neighbours by using this circum radius (R) and circum centre (Z) is calculated. If $R \leq R_s$ (Sensing range) algorithm declares no hole in coverage, otherwise hole is existed. Hole detection algorithm is used to find the coverage hole effectively irrespective of any shape and size of the region than other algorithms.

5) LDCC: LDCC [13] (Layered Diffusion-Based Coverage Control) is a new distance and location free coverage control protocol for providing the guaranteed coverage in Wireless Sensor Networks along with minimum energy consumption. It uses the hop count information for the activation of sensor nodes in the network instead of node's location information. Initially all the nodes are in the active state and they broadcast the hop count between them and the Base station (BS) to all the nodes within its communication range. A node with smaller hop count will be chosen as an active node and the BS will start coverage control process. The node itself will decide its state; it reduces overall computation cost of the network. LDCC protocol achieves high coverage ratio with minimum number of active sensor nodes.

6) ECCRA: ECCRA [14] (Energy-Efficient Coverage and Connectivity Preserving Routing Algorithm) is named as Location-Independent Energy Efficient Routing Algorithm mainly focuses the coverage and connectivity of the network to form effective sensor network. ECCRA divides the sensor nodes into multiple subsets, which are mutually exclusive and among the subsets, limited subset only kept to be active to ensure the network coverage ratio. Minimum hop count is to be calculated for each node at the routing phase and minimum hop count routing path is determined which ensures the connectivity among the subsets. In the data transmission phase, each subset forwards its sensed data to sink node. Thus, ECCRA reduces the energy consumption by activating limited subsets and increase the coverage lifetime of the fully connected network.

C. EVOLUTIONARY TECHNIQUES

In recent times, using evolutionary algorithms for Efficient Coverage Control in WSN is increasing. Mostly when coverage control is used with the increasing of Lifetime of the network evolutionary algorithms works best because of its global best solutions.

1) MOEA: MOEA [10] (MultiObjective Evolutionary algorithm) is proposed for maximizing the coverage and network lifetime of the Sensor Network. It is achieved by means of non-dominated or pareto optimal solutions. Performance of this algorithm is evaluated by three metrics such as size of the dominated space, set coverage metric and non-uniformity of the pareto front. Fuzzy mechanism is used along with MOEA for finding the best-compromised solution on the pareto front. Connectivity of the nodes in the network is an important metric for reducing the deployment cost and time of the sensor network.

2) MOGA: MOGA [11] (Multi-Objective Genetic Algorithm) in which lesser number of sensor nodes is to be selected from the dense area for providing full coverage to achieve Energy Efficient Coverage Control in Wireless Sensor Networks. It is based on some parameters as pareto dominance, pareto optimality and non-dominated sets and fronts. MOGA uses Elitism Non-Dominated Sorting Genetic Algorithm (NSGAII) for finding the best solutions to solve the coverage problem along with fast Non-Dominated Sorting (NDA) approach. NDA is used to discover the non-dominated fronts in the network. The cluster head executes Energy Efficient Coverage Control Algorithm (ECCA) to schedule the sensor nodes and broadcasts scheduling list to the nodes in the clusters. It reduces the energy usage of the computation process, which is carried out by each node.

TABLE I
Comparison of Recent Protocols for Coverage Control in Wireless Sensor Networks

S.No	Protocol	Coverage Type	Coverage Pattern	Type of Network	Approach
1	FBR	Area	Disk	Static	Centralized
2	DEECIC	Area	Disk	Static	Distributed
3	CACP	Area	Hexagonal	Static	Distributed
4	CBR	Area	Disk	Static	Distributed
5	MCOP	Area	Disk	Static	Distributed
6	CPCP	Area	Disk	Static	Distributed
7	CPLP	Area	Disk	Static	Distributed
8	DFA	Area	Disk	Static	Disjoint Set
9	LCFC	Point	Disk	Static	Disjoint Set
10	MPCQR	Area	Disk	Static	Disjoint Set
11	ERCCR	Area	Disk	Static	Disjoint Set
12	LDCC	Area	Disk	Static	Disjoint Set
13	DCHD	Area	Disk	Static	Disjoint Set
14	MOEA	Area	Disk	Static	Evolutionary
15	MOGA	Area	Disk	Static	Evolutionary

IV. CONCLUSION

In this article, we have surveyed the most recent protocols for coverage control in wireless sensor networks. In Table 1 the recent protocols have been classified using various real time metrics. The protocols itself have been classified under the new criteria and each one is evaluated by suitable metrics. Considering the various new application requirement in WSN, protocols have been designed and proposed by various authors. In this survey work, important issues affecting the network lifetime and coverage, is made as the classification criteria. In future, we planned to include more classification parameters considering the continuous evolving real time requirements.

REFERENCES

[1] Zhixin Liu, Qingchao Zheng, Lian Xue, Xining Guan, "A distributed energy-efficient clustering algorithm with improved coverage in wireless sensor networks", Future Generation Computer Systems 28 (2012) 780-790.
[2] Bang Wang, Hock Beng Lim, Di Ma, "A coverage-aware clustering protocol for wireless sensor networks", Computer Networks 56 (2012) 1599-1611.
[3] Miao Peng, Hui Chen, Yang Xiao, Suat Ozdemir, Athanasios V.Vasilakos, Jie Wu, "Impacts of sensor node distributions on coverage in sensor networks", Journal of Parallel and Distributed Computing 71 (2011) 1578-1591.
[4] GUO Jian, SUN Lijuan, WANG Rachuan, XIAO Fu, "A low coverage first classifying algorithm for wireless sensor networks", Procedia Engineering 15 (2011) 3825-3830.
[5] Ahmed M.Khedr, Walid Osamy, "Minimum perimeter coverage of query regions in a heterogeneous wireless sensor network", Information Sciences 181 (2011) 3130-3142.
[6] Sudip Misra, Manikonda Pavan Kumar, Mohammad S. Obaidat, "Connectivity preserving localized coverage algorithm for area monitoring using wireless sensor networks", Computer Communications 34 (2011) 1484-1496.
[7] Jiguo Yu, Yingying Qi, Guanghui Wang, Xin Gu, "A cluster-based routing protocol for wireless sensor networks with nonuniform node distribution", International Journal of Electronics and Communications (AEU) 66 (2012) 54-61.
[8] Hwa-Chun Ma, Prasan Kumar Sahoo, Yen-Wen Chen, "Computational geometry based distributed coverage hole detection protocol for the wireless sensor networks", Journal of Network and Computer Applications 34 (2011) 1743-1756.
[9] Nauman Aslam, William Phillips, William Robertson, Shyamala Sivakumar, "A multi-criterion optimization technique for energy efficient cluster formation in wireless sensor networks", Information Fusion 12 (2011) 202-212.
[10] Pyari Mohan Pradhan, Ganapati Panda, "Connectivity constrained wireless sensor deployment using multiobjective evolutionary algorithms and fuzzy decision making", Ad Hoc Networks 10 (2012) 1134-1145.
[11] Jie Jia, Jian Chen, Guiran Chang, Zhenhua Tan, "Energy efficient coverage control in wireless sensor networks based on multi-objective genetic algorithm", Computers and Mathematics with Applications 57 (2009) 1756-1766.
[12] Stanislava Soro, Wendi B. Heinzelman, "Cluster head election techniques for coverage preservation in wireless sensor networks", Ad Hoc Networks 7 (2009) 955-972.
[13] Bang Wang, Cheng Fu, Hock Beng Lim, "Layered diffusion-based coverage control in wireless sensor networks", Computer Networks 53 (2009) 1114-1124.
[14] Yan Jin, Ju-Yeon Jo, Ling Wang, Yoohwan Kim, Xiaozong Yang, "ECCRA:An energy-efficient coverage and connectivity preserving routing algorithm under border effects in wireless sensor networks, Computer Communications 31 (2008) 2398-2407.

[15] Yaling Tao, Yongbing Zhang, Yusheng Ji, "Flow-balanced routing for multi-hop clustered wireless sensor networks", Ad Hoc Networks 11 (2013) 541-554.
[16] Bang Wang, "Coverage Control in Sensor Networks", Computer Communications and Networks, (2010), Hardcover ISBN: 978 – 1 – 84996 – 058 – 8, Springer.
[17] I.F.Akyildiz, W.Su, Y.Sankarasubramaniam, E.Cayirci, "Wireless sensor networks: A survey", Computer Networks. 38 (4) (March 2002), 393 – 422.
[18] Bang Wang, "Coverage Problems in Sensor Networks: A Survey", ACM Computing Surveys, Vol.43, No.4, (October 2011), Article 32.
[19] W.B. Heinzelman, A.P. Chandrakasan, H.Balakrishnan.: Application specific protocol architecture for wireless microsensornetworks. IEEE Transactions on Wireless Communication, Vol 1, Issue 4, (2002) pp. 660-670.
[20] O.Younis, S. Fahmy.: HEED: A Hybrid, Energy-Efficient, Distributed clustering approach for Ad Hoc sensor networks, In: IEEETransactions on Mobile Computing 3 (4), (2004) pp. 366–379.