A Survey on Clustering Algorithms for Wireless Sensor Networks

Olutayo Boyinbode[1], Hanh Le[1], Audrey Mbogho[1], Makoto Takizawa[2] and Ravi Poliah[3]

[1]Computer Science Department, University of Cape Town, South Africa.
[2]Computer and Information Science Department, Seikei University, Japan
[3]Information & Communication Technology, Parliament of the Republic of South Africa
{oboyinbode, hanh, ambogho}@cs.uct.ac.za,
makoto.takizawa@st.seikei.ac.jp and rpoliah@parliament.gov.za

***Abstract*- A wireless sensor network (WSN) consisting of a large number of tiny sensors can be an effective tool for gathering data in diverse kinds of environments. The data collected by each sensor is communicated to the base station, which forwards the data to the end user. Clustering is introduced to WSNs because it has proven to be an effective approach to provide better data aggregation and scalability for large WSNs. Clustering also conserves the limited energy resources of the sensors. This paper synthesises existing clustering algorithms in WSNs and highlights the challenges in clustering.**

Keywords-Wireless Sensor networks; Clustering algorithms; Energy consumption,

I. INTRODUCTION

Recent advances in Micro-electromechanical systems (MEMS)-based sensor technology, low-power digital electronics, and low-power radio frequency (RF) design have enabled the development of relatively inexpensive and low-power wireless micro sensors. Wireless Sensor Networks (WSNs) have given rise to many applications including environmental monitoring and military surveillance. In these applications sensors are usually remotely deployed in large numbers and operated autonomously. In these unattended environments, the sensors cannot be charged, so energy constraints is the most critical problem that must be considered. In large WSNs sensors are often grouped into clusters. Clustering is essential for sensor network applications where a large number of ad-hoc sensors are deployed for sensing purposes. If each and every sensor starts to communicate and engage in data transmission in the network, great data congestion and collisions will be experienced. This will drain energy quickly from the sensor network. Clustering is a method used to overcome these issues. In clustered networks, some sensors are elected as cluster heads (CHs) for each cluster created. Sensor nodes in each cluster transmit their data to the respective CH and the CH aggregates data and forwards them to a central base station. Clustering facilitates efficient utilization of limited energy of sensor nodes and hence extends network lifetime. Although sensor nodes in clusters transmit messages over a short distance (within clusters), more energy is drained from CHs due to message transmission over long distances (CHs to the base Station) compared to other sensor nodes in the cluster. Periodic re-election of CHs within clusters based on their residual energy is a possible solution to balance the power consumption of each cluster. Clustering increases the efficiency of data transmission by reducing the number of sensors attempting to transmit data to the base station. Aggregating data at CHs via intra-cluster communication also helps in eradicating data duplication. Clustering is proposed because of its network scalability, energy saving and network topology stability [15]. Clustering schemes reduce the communication overheads among the sensor nodes. Clustering algorithms however have some disadvantages such as additional overheads during Cluster head (CH) selection, assignment and cluster formation process. Many clustering algorithms have appeared in the literature, and the aim of this survey is to highlight their commonalities, strengths and weaknesses. The following are the components of a clustered WSN.

Sensor node: A sensor node is the main component of a WSN. Sensor nodes perform functions such as sensing; data storage; routing; and data processing.
Clusters: Clusters are the hierarchical units for WSNs. Large sensor networks need to be broken down into clusters to simplify tasks such as communication between the base station and the cluster heads.
Cluster heads: Cluster heads (CHs) are the leader of a cluster. CHs are often required to organize activities in the cluster. These tasks include data-aggregation, organizing and relaying the communication schedule of a cluster.
Base Station: The base station (BS) provides the communication link between the sensor network and the end-user. It is normally the sink in a WSN.

978-0-7695-4167-9/10 $26.00 © 2010 IEEE
DOI 10.1109/NBiS.2010.59

End User: The data in a sensor network can be used for a wide-range of applications [1]. Data are generated in WSNs in response to queries received from the end user.

In this paper we present some existing clustering algorithms for WSNs. We also compare these algorithms based on metrics such as residual energy, uniformity of CH distribution, cluster size, delay, hop distance and cluster formation methodology.

The rest of the paper is organised as follows: Section II presents the challenges for clustering algorithms and the process of clustering. In Section III, we present the classification and comparison of some clustering algorithms. Section IV concludes the paper.

II. CLUSTERING OVERVIEW

A. Challenges for Clustering Algorithms

Clustering schemes play an important role in WSN; these can effectively improve the network performance. There are several key limitations in WSNs that clustering schemes must consider.

• Limited Energy: Wireless sensor nodes are small-size battery operated sensors, so they have limited energy storage. It is not practicable to recharge or replace their batteries after exhaustion. The clustering algorithms are more energy efficient compared to the direct routing algorithms. This can be achieved by balancing the energy consumption in sensor nodes by optimizing the cluster formation, periodically re-electing CHs based on their residual energy, and efficient intra-cluster and inter-cluster communication.

• Network Lifetime*:* The energy limitation on nodes results in a limited network lifetime for nodes in a network. Clustering schemes help to prolong the network lifetime of WSNs by reducing the energy usage in the communication within and outside clusters

• Limited Abilities*:* The small physical size and small amount of stored energy in a sensor node limits many of the abilities of nodes in terms of processing, memory, storage, and communication.

• Secure Communication*:* The ability of a WSN to provide secure communication is ever more important when considering these networks for military applications [1]. The self-organization of a network has a huge dependence on the application it is required for. An establishment of secure and energy efficient intra-cluster and inter-cluster communication is one of the important challenges in designing clustering algorithms since these tiny nodes when deployed are unattended to in most cases.

• Cluster formation and CH selection*:* Cluster formation and CHs selection are two of the important operations in clustering algorithms. Energy wastage in sensors in WSN due to direct transmission between sensors and a base station can be avoided by clustering the WSN. Clustering further enhances scalability of WSN in real world applications. Selecting optimum cluster size, election and re-election of CHs, and cluster maintenance are the main issues to be addressed in designing of clustering algorithms. The selection criteria to isolate clusters and to choose the CHs should maximize energy utilization.

• Synchronization***:*** When considering a clustering scheme, synchronisation and scheduling will have a considerable effect on the overall network performance. Slotted transmission schemes such as TDMA allow nodes to regularly schedule sleep intervals to minimize energy used. Such schemes require synchronization mechanisms to setup and maintain the transmission schedule.

• Data Aggregation*:* Data aggregation eradicates duplication of data. In a large network there are often multiple nodes sensing similar information. Data aggregation allows differentiation between sensed data and useful data. Many clustering schemes providing data aggregation capabilities [2] must carefully select a suitable clustering approach.

• Repair Mechanisms*:* Due to the nature of Wireless Sensor Networks, they are often prone to node mobility, node death, delay and interference. All of these situations can result in link failure. When designing clustering schemes, it is important to look for mechanisms that ensure link recovery and reliable data communication.

• Quality of Service (QoS)*:* From an overall network standpoint, we can look at QoS requirements in WSNs. Many of these requirements are application dependant such as acceptable delay and packet loss tolerance. Existing clustering algorithms for WSN mainly focus on providing energy efficient network utilization, but pay less attention to QoS support in WSN. QoS metrics must be taken into account in the design process.

B. Clustering Process

There are two main steps in clustering, which are CH selection and cluster formation.

CH selection could be classified into three types, centralization by the BS, decentralization by the sensor nodes or hybrid selection by some information provided by the BS and some by the nodes themselves.

1. The main concerns in selecting CHs are:

+ Distance between CHs and the BS to ensure that CHs are not too far from the BS, making inter-cluster communication or communication between CH and BS expensive

+ Uniform CH distribution so that CHs are not cluttered. Cluttered CHs can cause long distance between non-CH nodes and their corresponding CH. In other words causing high energy consumption for intra-cluster communication

+ CHs perform extra tasks for WSNs such as: data aggregation and forwarding therefore energy at the CHs might be depleted quickly. CH re-selection or rotation is another concern in clustering. In re-selecting a CH, one must consider how much overhead in terms of energy consumption and time it takes.

+ Residual Energy in a sensor node to be elected as a CH.

+ Time delay: how long it takes to select a CH and to form a cluster. This parameter could mean the communication disruption during that period.

2. The main concerns in joining a CH for a sensor node are:

+ Distance between a node and a CH. This is often presented as signal strength between CHs and the node itself.

+ Number of hops from a node to its CH

+ Cluster size: the decision whether or not a node joins a cluster also depends on the size of a cluster. The number of nodes in a cluster represents the accumulated energy in a cluster and also extra energy consumption for the CH to serve its cluster. What is the reasonable size for a cluster is another research question? Cluster size and cluster geographical distribution might be conflicting

In the following section, different clustering algorithms will be presented based on the above mentioned process/criteria and some by Abbasi and Younis [9] such as Cluster Count. Cluster Count is the number of CHs which could be predetermined and thus the numbers of clusters are preset.

III CLUSTERING ALGORITHMS

A. Existing Clustering protocols

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

1. Low-Energy Adaptive Clustering Hierarchy (LEACH) [2]: LEACH forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. Initially a node decides to be a CH with a probability p and broadcasts its decision. Each non-CH node determines its cluster by choosing the CH that can be reached using the least communication energy. The algorithm provides a balancing of energy usage by random rotation of CHs. It forms clusters based on the received signal strength and uses the CH nodes as routers to the base-station. All the data processing such as data fusion and aggregation are local to the cluster.

LEACH provides the following key areas of energy savings:

• No overhead is wasted making the decision of which node becomes cluster head as each node decides independent of other nodes

• CDMA allows clusters to operate independently, as each cluster is assigned a different code.

• Each node calculates the minimum transmission energy to communicate with its cluster head and only transmits with that power level

Changing the CH is probabilistic in LEACH; there is a good chance that a node with very low energy gets selected as a CH. When this node dies, the whole cluster becomes non functional. LEACH also forms one-hop intra- and inter cluster topology where each node can transmit directly to the CH. Then the aggregated data is transmitted to the base-station. Consequently, it is not applicable to networks deployed in large regions.

LEACH is not applicable if the CHs are far from the base station. Therefore, a large number of algorithms have been proposed to improve LEACH, such as PEGASIS [10], TEEN [11], APTEEN [12], MECH [18], LEACH-C [19] EEPSC [20] etc.

2. Two-Level LEACH (TL-LEACH) [4] is a proposed extension to the LEACH algorithm. It utilizes two levels of cluster heads (primary and secondary) in addition to the other simple sensing nodes. In this algorithm, the primary cluster head in each cluster communicates with the secondary, and the corresponding secondary communicate with the nodes in their sub-cluster. Data-fusion can also be performed as in LEACH. In addition, communication within a cluster is still scheduled using TDMA time-slots. The organization of a round will consist of first selecting the primary and secondary cluster heads using the same mechanism as LEACH, with the a priori probability of being elevated to a primary cluster head less than that of a secondary node. Communication of data from source node to sink is achieved in two steps [4]:

1) Secondary nodes collect data from nodes in their respective clusters. Data-fusion can be performed at this level.

2) Primary nodes collect data from their respective secondary clusters. Data-fusion can also be implemented at the primary cluster head level.

The two-level structure of TL-LEACH reduces the number of nodes that need to transmit to the base station, effectively reducing the total energy usage. It might not be effective if the CH is far from the base station

3. Energy Efficient Clustering Scheme (EECS) [6] Energy Efficient Clustering Scheme is a clustering algorithm in which cluster head candidates compete for the ability to elevate to cluster head for a given round. This competition involves candidates broadcasting their residual energy to neighbouring candidates. If a given node does not find a node with more residual energy, it becomes a cluster head. Cluster formation is different than that of LEACH. LEACH forms clusters based on the minimum distance of nodes to their corresponding cluster head [2]. EECS extends this algorithm by dynamic sizing of clusters based on cluster distance from the base station. The result is an algorithm that addresses the problem that clusters at a greater range from the base station requires more energy for transmission than those that are closer. Ultimately, this improves the distribution of energy throughout the network, resulting in better resource usage and extended network lifetime. However clusters closer to the base station may become congested which may result in early CH death.

4. Hybrid Energy Efficient Distributed Clustering (HEED) [5]*:* HEED is a multi-hop clustering algorithm for Wireless Sensor Networks. CHs are chosen based on two important parameters: residual energy and intra-cluster communication cost. Residual energy of each node is used to probabilistically choose the initial set of CHs, as commonly done in other clustering schemes. In HEED, Intra-cluster communication cost reflects the node degree or node's proximity to the neighbour and is used by the nodes in deciding to join the cluster. Low cluster power levels promote an increase in spatial reuse while high cluster power levels are required for inter-cluster communication as they span two or more cluster areas. HEED provides a uniform CH distribution across the network and better load balancing. However, knowledge of the entire network is needed to determine intra-cluster communication cost. HEED is a distributed clustering scheme in which CH nodes are picked from the deployed sensors. HEED considers a hybrid of energy and communication cost when selecting CHs. Unlike LEACH, it does not select cluster -head nodes randomly. Only sensors that have a high residual energy can become cluster-head nodes. HEED has three main characteristics:

For a given sensor's transmission range, the probability of CH selection can be adjusted to ensure inter-CH connectivity.

In HEED, each node is mapped to exactly one cluster and can directly communicate with its CH. The algorithm is divided into three phases:

1. Initialization phase: The algorithm first sets an initial percentage of CHs among all sensors. This percentage value, C_{prob}, is used to limit the initial CH announcements to the other sensors. Each sensor sets its probability of becoming a cluster-head, CH_{prob}, as follows:

$CH_{prob} = C_{prob} * E_{residual}/E_{max}$, where $E_{residual}$ is the current energy in the sensor, and E_{max} is the maximum energy, which corresponds to a fully charged battery.

CH_{prob} is not allowed to fall below a certain threshold p_{min}, which is selected to be inversely proportional to E_{max}.

2. Repetition phase: During this phase, every sensor goes through several iterations until it finds the CH that it can transmit to with the least transmission power (cost). If it hears from no CH, the sensor elects itself to be a CH and sends an announcement message to its neighbours informing them about the change of status. Finally, each sensor doubles its CH_{prob} value and goes to the next iteration of this phase. It stops executing this phase when its CH_{prob} reaches 1. Therefore, there are 2 types of cluster head status that a sensor could announce to its neighbours:

Tentative status: The sensor becomes a tentative CH if its CH_{prob} is less than 1. It can change its status to a regular node at a later iteration if it finds a lower cost CH.

Final status: The sensor permanently becomes a CH if its CH_{prob} has reached 1.

3. Finalization phase: During this phase, each sensor makes a final decision on its status. It either picks the least cost CH or pronounces itself as CH. HEED enables well distributed cluster heads across the network. Several iterations involved in cluster formation in HEED can lead to overhead cost. Cluster heads near the base station may die earlier.

5. Energy-efficient unequal clustering (EEUC) [7]: 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) 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. It solves the hot spot problems; cluster size is proportional to the distance to base Station. However, the extra global data aggregation adds overheads to all sensors and degrades the network performance, especially for a multi-hop network.

6. Energy Efficient Hierarchical Clustering (EEHC)[16] is a distributed, randomized clustering

algorithm for WSNs. CHs collect data from the non cluster head node in different clusters and send an aggregated report to the base-station. This technique is divided into two phases; initial and extended. In the first stage, also called single-level clustering, each sensor node announces itself as a CH with probability p to the neighbouring nodes within its communication range. These CHs are named as the volunteer CHs. All nodes that are within k hops range of a CH receive this announcement either by direct communication or by forwarding. Any node that receives such announcements and is not itself a CH becomes the member of the closest cluster. Forced CHs are nodes that are neither CH nor belong to a cluster. If the announcement does not reach to a node within a preset time interval t that is calculated based on the duration for a packet to reach a node that is k hops away, the node will become a forced CH assuming that it is not within k hops of all volunteer CHs. The second phase, called multi-level clustering builds h levels of cluster hierarchy. The algorithm ensures h-hop connectivity between CHs and the base station. In inter cluster communication this algorithm ensures that the energy dissipated by CHs far from the base station is reduced because these CHs don't need to transmit to base station. The CHs closest to the base station are at a disadvantage because they are relays for other CHs.

7. Multihop routing protocol with unequal clustering (MRPUC) [17] MRPUC is a distributed clustering scheme which operates in rounds, and each round is separated into three phases: cluster setup, inter-cluster multihop routing formation and data transmission. Each node gathers the correlative information of its neighbour nodes and elects a node with maximum residual energy as the cluster head. The cluster heads closer to BS have smaller cluster sizes to save the energy for heavy inter-cluster forwarding task. The regular nodes join clusters where the cluster heads have more residual energy and are closer to them. An inter-cluster routing tree is constructed as network backbone, and data is transmitted to BS via multp. This algorithm prevents early CHs death because the inter cluster communication also depends on the residual energy. CHs route to the neighbouring CH having the highest residual energy. The Inter-cluster multihop routing formation may cause an additional overhead.

8. Power-efficient and adaptive clustering hierarchy (PEACH) [14]: 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) 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 neighbour nodes. PEACH is applicable in both location-unaware and location-aware sensor networks. Based on its overhearing characteristics, PEACH saves energy consumption of each nodes and hence prolong network lifetime.

9. Sensor Web or S-WEB [13] divide the sensing field into clusters bordered by two arcs of two adjacent concentric circles and two adjacent radii originating at the BS. Each cluster is identified by angle order (β) and the order of Signal Strength threshold (δ).

To do so, the BS in S-WEB will send beacon signals for every α degree angle, one at a time. Sensors that receive the beacons at time slot i will measure their signal strength to determine their relative distances to the BS. Let T be a predefined distance (which is inversely proportional to the received signal strength). All sensors which receive beacon signals at angle order βi ($=i*\alpha$) with signal strength of $\delta j*T$ (within sector j) will be in the same group/cluster, denoted as (βi, δj). Nodes with the same (β, δ) or in the same cluster can select a CH based on its residual energy. Since nodes in the same cluster know about each other, the role of being a CH can be rotated to prolong the lifespan of CH. S-WEB is a hybrid technique since most tasks are performed by the nodes, except the beacons are generated from the BS.

B. Comparison of the Clustering Algorithms

Table 1 summarises the clustering algorithms surveyed in this paper.

Table 1. Summary of the clustering algorithms

	Cluster Head (CH) Selection						Cluster Formation for non-CH nodes			
Scheme	**Distributed/ Centralized /Hybrid**	**Distance from CH To the BS**	**CH Uniform Distribution**	**Overhead In CH selection**	**Residual Energy**	**Delay**	**Distance non-CH to CH**	**Cluster Size**	**Hops**	**Overhead to join a cluster**
LEACH	Distributed	No	No	Low	No	Low	Yes	No	1	Low
LEACHC	Centralized	Yes	Yes	High	Yes	High	Yes	Yes	1	High
TL-LEACH	Distributed	No	No	Medium	No	Med	Yes	No	2	High
HEED	Distributed	No	Yes	High	Yes	high	No	Yes	1	Low
EECS	Distributed	Yes	Yes	Low	Yes	Low	Yes	Yes	1	Low
EEHC	Distributed	No	No	Low	No	Low	Yes	No	K	high
MRPUC	Distributed	Yes	Yes	Low	Yes	Low	Yes	No	1	Low
PEACH	Distributed	No	No	Low	No	Med	Yes	No	K	Low
S-WEB	Hybrid	Yes	Yes	Low	Yes	Med	Yes	Yes	1	Low
EEUC	Distributed	Yes	Yes	Low	Yes	low	Yes	Yes	K	low

IV. CONCLUSION

Clustering is most suitable for large scale wireless sensor networks and a useful topology-management approach to reduce the communication overhead and exploit data aggregation in sensor networks. There exists a large number of clustering algorithms and some are reviewed in this paper. We have focused mostly on distributed clustering approaches, because they are more suitable for large-scale sensor networks. However energy consumption during cluster formation and maintenance is still high; the compelling challenges for clustering algorithms are how to schedule concurrent intra-cluster and inter-cluster transmissions, how to compute the optimal cluster size, and how to determine the optimal frequency for cluster head rotation in order to maximize the network lifetime.

References

[1] I.F. Akyildiz et al., Wireless sensor networks: a survey, Computer Networks 38 (2002) 393–422.

[2] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy- Efficient Communication Protocol for Wireless Micro sensor Networks" Proceedings of the 33rd Hawaii International Conference on System Sciences (HICSS '00), January 2000, pp. vol.2:10.

[3] Wendi B. Heinzelman, Anantha P. Chandrakasan,Hari Balakrishnan, " An Application-Specific Protocol Architecture for Wireless Microsensor Networks", IEEE Transactions on Volume 1, Issue 4. 2002, pp.660 – 670

[4] V. Loscri, G. Morabito and S. Marano, "A Two-Level Hierarchy for Low-Energy Adaptive Clustering Hierarchy", Proceedings of Vehicular Technology Conference 2005, vol3, 1809-1813

[5] O. Younis and S. Fahmy, "HEED: "A Hybrid Energy-Efficient Distributed Clustering Approach for Ad Hoc Sensor Networks," IEEE Transactions on Mobile Computing, 2004, vol. 3, no. 4

[6] M. Ye, C. Li, G. Chen and J. Wu, "An Energy Efficient Clustering Scheme in Wireless Sensor Networks," Ad Hoc & Sensor Wireless Networks, 2006, Vol.1, pp.1–21,

[7] 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.

[8] N. Kim, J. Heo, H. Kim, and W. Kwon, "Reconfiguration of cluster heads for load balancing in wireless sensor networks," Computer Communications, vol. 31, pp. 153-159, January 2008.

[9] A. Abbasi, M. Younis, "A survey on clustering algorithms for wireless sensor networks, "

Computer Communications, vol. 30, pp. 2826-2841, October 2007.
[10] 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.
[11] 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.
[12] 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.
[13] Le Hanh, Doan Hoang and Ravi Poliah S-Web: an efficient and self-organizing Wireless Sensor Network Model. the 2nd International Conference on Network-Based Information Systems, Turin, Italy 2008
[14] 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.
[15] 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.
[16] S. Bandyopadhyay, E. Coyle, An energy efficient hierarchical clustering algorithm for wireless sensor networks, in: Proceedings of the 22nd Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2003), San Francisco, California,April 2003.
[17] Bencan Gong, Layuan Li, Shaorong Wang, Xuejun Zhou, Multihop Routing Protocol with unequal Clustering for Wireless Sensor Networks International Colloquium on Computing, Communication, Control, and Management, (ISECS2008) pg 552-556 2008
[18] Ruay-Shiung Chang and Chia-Jou Kuo , An Energy Efficient Routing Mechanism for Wireless Sensor Networks, Proceedings of the 20th International Conference on Advanced Information Networking and Applications (AINA’06) IEEE Computer Society 2006
[19] Wendi B. Heinzelman, Anantha P. Chandrakasan,Hari Balakrishnan, “ An Application-Specific Protocol Architecture for Wireless Microsensor Networks”, IEEE Transactions on Volume 1, Issue 4. 2002, pp.660 – 670
[20] AnAmir Sepasi Zahmati, Bahman Abolhassani, Ali Asghar Beheshti Shirazi, and Ali Shojaee Bakhtiari, Energy-Efficient Protocol with Static Clustering for Wireless Sensor Networks, World Academy of Science, engineering and Technology Vol 28, 2007 pp69-72