Lightweight Clustering Scheme for Wireless Sensor Networks Used in Disaster Relief

Yi Zheng*, Hiroshi Mineno, Tadanori Mizuno†‡

Abstract— **Most wireless sensor networks are driven with a battery. Lifetime maximization is thus very important when designing such networks. Clustering a network is an effective topology control scheme to enhance energy efficiency and scalability of large-scale wireless sensor networks. However, when using a wireless sensor network after a disaster, if sensor nodes cannot join any clusters, the detection area of the wireless sensor network is narrowed. Maximizing lifetime and minimizing the number of sensor nodes, that cannot join clusters is very important. To maximize the number of communicable sensor nodes, current clustering algorithms are based on exact location information of sensor nodes, such as those used with GPS and complex localization algorithms. The error of GPS is about 10 m, which is inadequate for disaster relief. Localization algorithms, on the other hand increase the traffic overhead of the network. Although localization accuracy will improve due to the advancement of localization technology, power consumption of the localization module and the increase in the sensor node's cost cannot be disregarded. We have proposed a lightweight clustering scheme for wireless sensor networks used in disaster relief and applied it in simulations. Simulation results show that the proposed clustering scheme is efficient and effective for maximizing the lifetime of a network and the number of communicable sensor nodes.**

Keywords: wireless sensor network, clustering, disaster relief

1 Introduction

A rescue operation immediately following a disaster is extremely important for saving lives. Following the Hanshin-Awaji Earthquake, the survival rate after the second day was very low (Fig. 1) [1]. By analyzing many big earthquakes in history, survival rates were found to become extremely low after 72 hours, so the first 72 hours after an earthquake are critical. However, immediately after such a disaster, especially during the first day, people panic easily, and rescue operations are often inefficient. A wireless sensor network can be used to improve the efficiency of rescue operations in which the number of rescue workers is limited, because it can immediately detect a survivor by identifying conditions such as sounds, vibrations, and concentration of carbon dioxide without a cable network infrastructure. However, sensor nodes used in wireless sensor networks are generally battery-driven, thus limiting the lifetime of the network. The clustering protocol has been proposed as an effective way to reduce the energy consumption of a wireless sensor network. If a sensor node is not in the area of any cluster, it cannot send its sensing data to a cluster head, and an event that occurs in its sensing area cannot be reported. The area of detection of the entire wireless sensor network is related to the number of communicable sensor nodes, which is influenced by the position of the cluster head. Each sensor node lifetime is the time until its remaining energy becomes 0. The network lifetime is the time when the first sensor node in the network depletes its energy. In this paper, we propose the Lightweight Clustering Scheme (LiCS), which selects cluster heads to cover all sensor nodes using a lightweight algorithm without exact location information on sensor nodes, and we evaluate the performance via simulation.

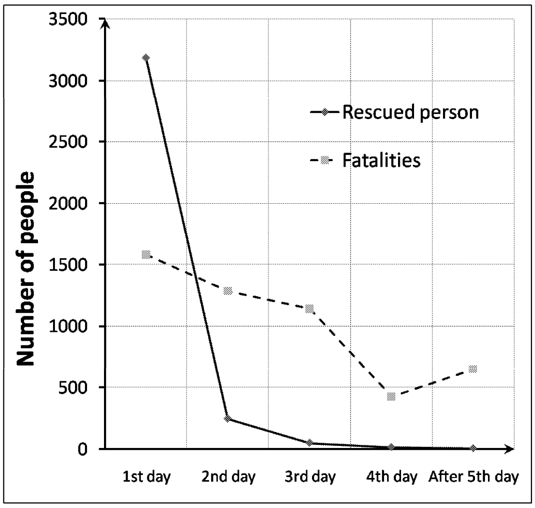

Figure 1: Hanshin-Awaji earthquake survival rates versus rescue time

*Graduate School of Informatics, Shizuoka University, 3-5-1 Johoku, Naka-ku, Hamamatsu, Shizuoka, 432-8011, Japan, Email:teiiz@mizulab.net

†Department of Computer Science, Shizuoka University, 3-5-1 Johoku, Naka-ku, Hamamatsu, Shizuoka, 432-8011, Japan

‡JST, CREST, 5 Sanban-cho, Chiyoda-ku, Tokyo, 102-0085, Japan

2 Related work

There have been several studies on reducing battery power consumption and extending network lifetime. Other methods have been proposed to maintain the detection capability of wireless sensor networks.

2.1 Sensor node with sleep mode

Turning off sensor nodes can extend a wireless sensor network's lifetime. A MAC layer protocol named S-MAC [2] was proposed, which sets sensor nodes into sleep mode to reduce energy consumption by a trade-off with latency. S-MAC uses a static duty cycle with adaptive listening. In contrast, T-MAC [3], which uses an adaptive duty cycle, and D-MAC [4], which renews active periods adaptively, have been proven to be more effective than S-MAC via simulation. For rare-event detection, if the incidence of events is low and event duration is long, for example during a forest fire, the sampling interval of the sensor node is set to operate for a longer period of time. Then microcontrollers that control the sensor node and the communication modules switch to sleep mode, and power consumption can be controlled. However, a long sampling interval disables sensor nodes from detecting events immediately, so the detection delay is longer.

When two or more sensor nodes are arranged in the detection radius of an event such as a fire, a different sleep mode time is set for each sensor node, and sleep scheduling is optimized to minimize the detection delay [5].

Research on the sleep mode of the wireless sensor node has been performed, but little research has been done on applications used in rescue operations after disasters such as earthquakes when there are incidences of high frequency events with short durations. An event may not be detected by a technique that increases the sampling interval time, and for that reason, this technique is not practical for rescue operations.

2.2 Clustering-based protocol

In multihop wireless sensor networks, when an event takes place in a detection area, the sensor node that detected the event generates and sends a information to a SINK node, which then analyzes the information. When a sensor node cannot transmit this information to a SINK node in a single hop, the information must be sent to the parent node of the sensor node. To relay the information, the parent node consumes more energy during multihop. This makes the parent node's lifetime shorter than that of an end sensor node. In clustering-based wireless sensor networks, where the whole network is divided into many clusters, a cluster member transmits the sensing information to a cluster head, which relays the information like a parent node in a multihop wireless sensor network. The operation in clustering protocols is to select a set of cluster heads from the nodes in the network. Low-Energy Adaptive Clustering Hierarchy (LEACH) [7] is a commonly used clustering-based protocol. In LEACH, repeated selection of cluster heads is performed by using a probability, which means each sensor node takes the role of cluster heads in a random rotating shift. Normal LEACH is not based on exact location information of sensor nodes. GPS-based LEACH (LEACH-C) was also proposed because electing cluster heads in an appropriate place will increase the lifetime of a wireless sensor network. LEACH assumes that all nodes can communicate directly with cluster heads, so the protocol is not suitable for large-scale applications in wireless sensor networks.

To enable the clustering protocol to handle a large-scale application, clusters with cluster communication ranges are proposed that only sensor nodes that are in the cluster communication range can become cluster members. Exact location information, for example, GPS, was used to select cluster heads, which can make all sensor nodes capable of cluster members [8] , [9]. In addition, localization algorithms without exact location information are proposed. The weighted clustering algorithm (WCA) [10] elects a cluster head by using parameters such as distance and angle. The hybrid, energy-efficient, distributed clustering approach (HEED) [11] elects cluster heads by using parameters such as the number of neighbor nodes and the power consumption of the communication module.

Researchers have shown that a clustering-based protocol is highly effective in a network simulation. The error of GPS is about 10 m, which is too large in disaster relief. In addition, the power consumption of the localization module and the increase in the sensor node's cost cannot be disregarded. On the other hand, parameter exchanges in localization algorithms increase the traffic overhead of the network and require a high performance SINK node such as a computer. However, preparing a lot of computers after a disaster is difficult. A lightweight clustering scheme with a simple algorithm is therefore needed for rescue operations.

3 Lightweight clustering scheme

3.1 Network and system models

In this work, we consider a wireless sensor network to be similar to the network model used in other studies [7],[11]. We assume the following properties about wireless sensor networks.

- All sensor nodes are stationary and uniformly distributed in a field.
- There is only one SINK node in the wireless sensor network. The SINK node does not have an energy constraint. For example, the SINK node can be connected to a large-capacity battery or some sort of

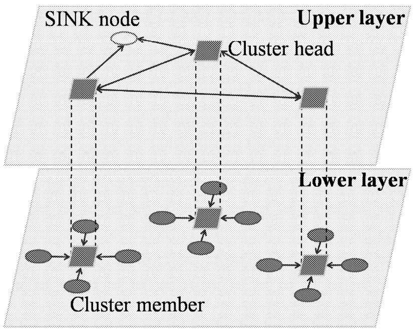

Figure 2: Network and system model

energy-charge system such as solar panels.

- The network topology has a two-layer structure (Fig. 2). The lower layer consists of one cluster head and many cluster members. The upper layer consists of may cluster heads and a SINK node. In our work, a cluster head cannot change its state to sleep mode, and an end sensor node can change its state to sleep mode when it does not need to transmit any sensing information. In the lower layer, an end sensor node transmits sensing information to a cluster head in a single hop. In the upper layer, cluster heads transmit signals to one another via mesh network topology. This enables the cluster heads to receive sensing information from an end sensor node and send it to a SINK node.

- Sensor nodes can control radio transmission power by using two levels. Cluster members only need to communicate with cluster heads when cluster members are in the communication range of cluster heads. However, cluster heads need to communicate with other cluster heads and the SINK node, which may be further than the cluster communication range.

- Cluster heads are elected by a time interval called a “round” (every several hours) as well as by other clustering protocols. Some sensor nodes are elected to be cluster heads in one round, and when the next round starts, new cluster heads are elected and new clusters are constructed. Since a cluster head cannot change its state to sleep mode in this study, there is no need to have a strict time synchronization.

- Initially, each sensor node has the same energy capacity, but the energy consumption of each sensor is different. The batteries cannot be changed after sensor nodes are deployed.

- The data flow of the entire network is unidirectional from cluster members to cluster heads and from cluster heads to the SINK node. There is no data flow from the SINK node to cluster heads and cluster members, so the SINK node does not participate in the election of cluster heads or in the construction of clusters.

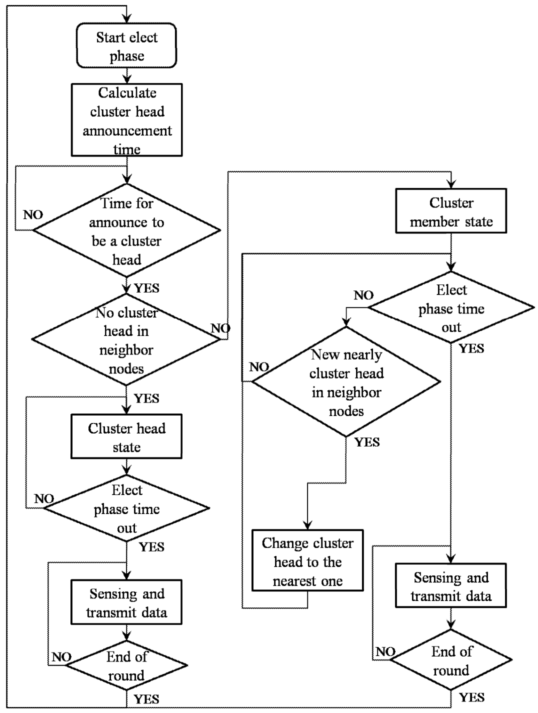

Figure 3: Cluster head election

3.2 Cluster head election algorithm

The target of this clustering scheme is a wireless sensor network that elects cluster heads autonomously. The SINK node is just a data collector, not a network construction coordinator. No parameters have to be sent to the SINK node, and the SINK node does not need to calculate which node will be a cluster head in the next round based only on a parameter that has been sent from sensor nodes. At the first round, cluster head election depends on the sensor node starting time. Figure 3 shows the flowchart of electing a cluster head from the second round. At the start of a round, each sensor node calculates its cluster head announcement (CHA) time. The CHA time is decide by the amount of energy remaining in the sensor node.

$$Time_a = \frac{E_i - Er}{E_i} \times k, \tag{1}$$

where E_i is the initial energy, E_r is the remaining energy of a sensor node, and k is a coefficient constant. Equation 1 indicates that a sensor node with low remaining energy will have a later CHA time. Sensor nodes that have an earlier CHA time become cluster heads, and broadcast their CHA message and end time of round. Sensor nodes check whether there are any cluster heads among their neighbor nodes before announcing they are cluster heads.

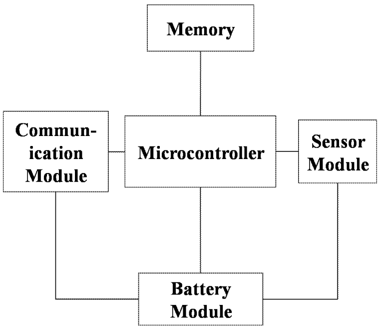

Figure 4: Sensor node structure

If there are any cluster heads among their neighbor nodes, sensor nodes do not announce they are cluster heads, but they join the nearest cluster as a cluster member. A sensor node that has become a cluster member checks for new cluster heads until an election phase timeout. When a new cluster head is nearer (has a stronger RSSI) than the current cluster head appears, end sensor nodes change their cluster head to the new one. However, if there is no cluster head among its neighbor nodes, a sensor node announces that it is a cluster head. After a round, sensor nodes will start a new election phase and elect cluster heads of the wireless sensor network.

4 Performance evaluation

4.1 Simulation outline and parameters

We evaluated the performance of LiCS via simulations. The wireless sensor node consisted of a microcontroller, communication module, sensor module, and battery module (Fig. 4). Energy consumption of the wireless sensor node is giben by

$$E = E_T + E_R + E_S. \tag{2}$$

Here, E_T is the energy consumption of a transmission contains data processing and signal amplification. The energy consumption of data processing, E_{proc} depends on factors such as modulation, filtering, and encoding. E_R is the energy consumption of a reception that also contains data processing, and E_S is the energy consumption of a sensor module.

Cluster heads in LiCS must announce they are cluster heads, receive sensing data from members of their clusters, and relay the data to the SINK node. Of course, cluster heads also detect events around them. Therefore, the energy consumption of a cluster head is expressed by

$$E_{CH} = E_{Td} + E_{Rd} + E_{Ta} + E_S. \tag{3}$$

Here, E_{Td} and E_{Rd} are the energy consumption for transmitting and receiving sensing data, and E_{Ta} is the energy consumption for transmitting CHA message.

Table 1: Simulation parameters

Number of sensor nodes	100
Simulation field	$50m \times 50m$ $100m \times 100m$ $150m \times 150m$
Position of SINK node	[0 m,0 m]
Transmission interval	1 s
Length of sensing data (l_d)	500 bits
Length of CHA message (l_a)	50 bits
Initial energy	50 J
k	2 s
T_{ep}, time of election phase	2 s
E_{proc}	$10pJ/bit/m^2$
ϵ_{fs}	50 nJ/bit
E_S	200 nJ/s
$E_{Standby}$	100 nJ/s
1 round	360 s
R_c, cluster communication range	30 m

Cluster members in LiCS need to receive CHA message, detect nearby event, and transmit sensing data to the cluster head. Therefore, the energy consumption of a cluster member is given by

$$E_{CM} = E_{Ra} + E_{Td} + E_S. \tag{4}$$

The value E_{Ra} is the energy consumed to receive a CHA message from the cluster heads, and E_{Td} is the energy consumed to transmit sensing data.

The energy consumption of sensor nodes without a cluster head is expressed by

$$E_{CNM} = E_{Standby}. \tag{5}$$

Here, $E_{Standby}$ is the standby energy consumption. We used a transmit and receive model [7]. When l-bits of sensing data is transmitted a distance d, the energy consumption of the transmission is as follows

$$E_T = l \times (E_{proc} + \epsilon_{fs} \times d^2), \tag{6}$$

and the energy consumption to receive this sensing data is

$$E_R = l \times E_{proc}. \tag{7}$$

Table 1 lists system parameters used in our simulations.

We assume that 100 wireless sensor nodes are dispersed in a field with uniform distribution and that cluster heads can communicate with the SINK node in a single hop. To evaluate the influence of different node densities, we set a simulation field with dimensions $50m \times 50m$, $100m \times 100m$, and $150m \times 150m$ and the position of the SINK node was [0 m,0 m]. The sensing and transmission interval was 1 second, the length of sensing data (l_d) was 500 bits, and the length of a CHA message (l_a) was 50

ISBN: 978-988-17012-2-0

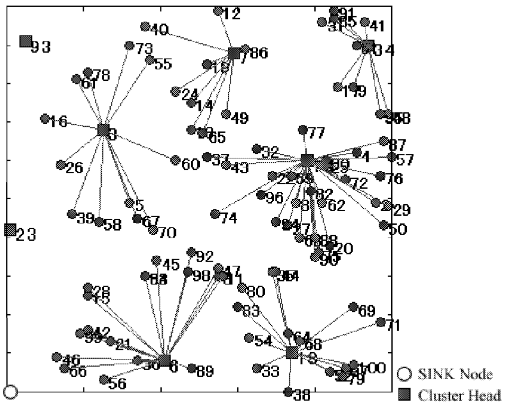

Figure 5: Simulation topology

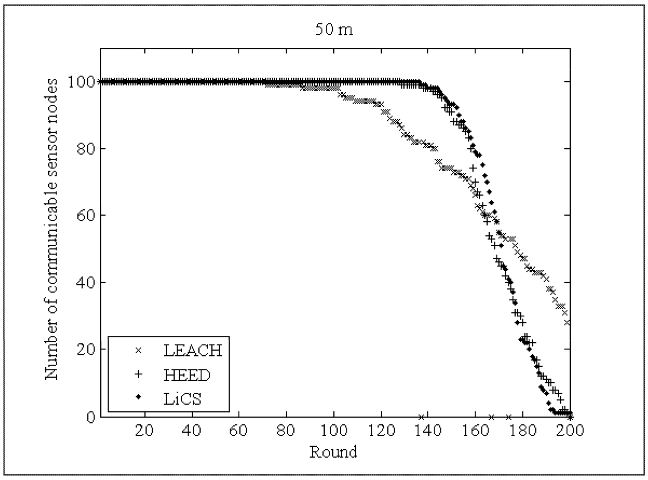

Figure 6: Number of communicable nodes in $50m \times 50m$ field

bits. Energy consumption per second of a cluster head in the data collection phase is given by

$$E_{chc} = l_d \times (n+1) \times (E_{proc} + \epsilon_{fs} \times d^2_{toSINKnode}) + l_d \times n \times E_{proc}, \tag{8}$$

and energy consumption per second of a cluster head in the cluster head election phase is

$$E_{chs} = l_a \times (E_{proc} + \epsilon_{fs} \times d^2_{R_c}). \tag{9}$$

Energy consumption per second of a cluster member in the data collection phase is

$$E_{cmc} = l_d \times (E_{proc} + E_{proc} + \epsilon_{fs} \times d^2_{toclusterhead}), \tag{10}$$

and energy consumption per second of a cluster member in the cluster head election phase is

$$E_{cms} = l_a \times E_{proc}. \tag{11}$$

Figure 5 is an illustration of the topology used in simulations. All cluster members are marked by solid circles, and cluster heads are marked by solid squares. The big white circle is the SINK node.

4.2 Simulation results

To evaluate the performance of LiCS, we compared it with the performance of LEACH and HEED using a simulation. LEACH randomly chose a cluster head for the next round without using exact location information, and when there was no cluster communication range in LEACH, every node could communicate with any other node in the network. The expected number of cluster heads in LEACH is 5 [7].

Simulation results of the numbers of communicable nodes are shown in Figs. 6, 7 and 8. In the figures, we observe that the performance of LiCS was better than that of LEACH, which used a random selection algorithm. LiCS also shows the same drop in the number of communicable nodes as HEED. In LiCS and HEED, although the selection algorithms are different, a sensor node will announce it is a cluster head if there is no CH in its cluster communication range, and the average number of CH numbers will be almost the same, which means that LiCS has the same drop in the numbers of communicable nodes as HEED. We also observed that the low density network reduces the effectiveness of LEACH and also that of LiCS and HEED. In LEACH, the distance between cluster members and cluster heads was longer than that of the high-density point, which increases the energy consumption of sensor nodes. In LiCS and HEED, to maximize the number of nodes that can communicate, more cluster heads were needed than those at a high-density point, which makes the node lifetime short.

The results of the number of CHAs sent by sensor nodes in each round are shown in Fig. 9. A lighter selection algorithm resulted in LiCS having fewer CHA messages than HEED.

5 Conclusion

In this paper, we proposed LiCS for disaster relief, a simple clustering scheme to increase the lifetime of wireless sensor networks and maximize the number of communicable sensor nodes. LiCS did not require exact location information of sensor nodes, which calculated by using localization modules such as GPS or complex localization algorithms. Not requiring a localization module means that the cost of sensor nodes was reduced, and no energy for a localization module was necessary. Having no complex localization algorithms means that the SINK node did not need to join the cluster head election phase, which means that low-performance SINK nodes can also be used in LiCS, and the overhead of parameters for clustering algorithms will not be transmitted in wireless sensor net-

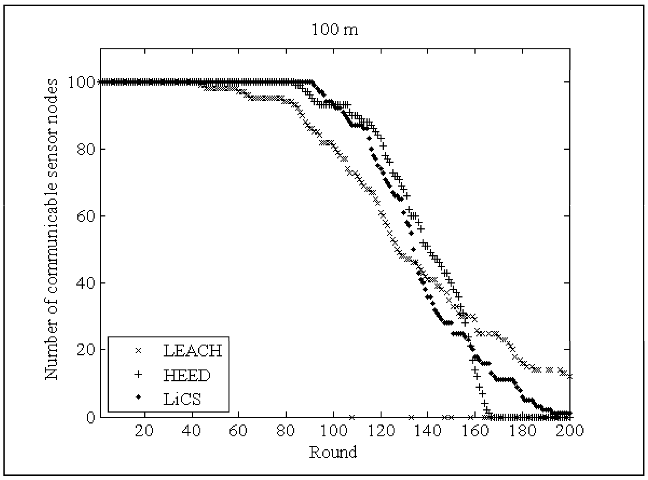

Figure 7: Number of communicable nodes in $100m \times 100m$ field

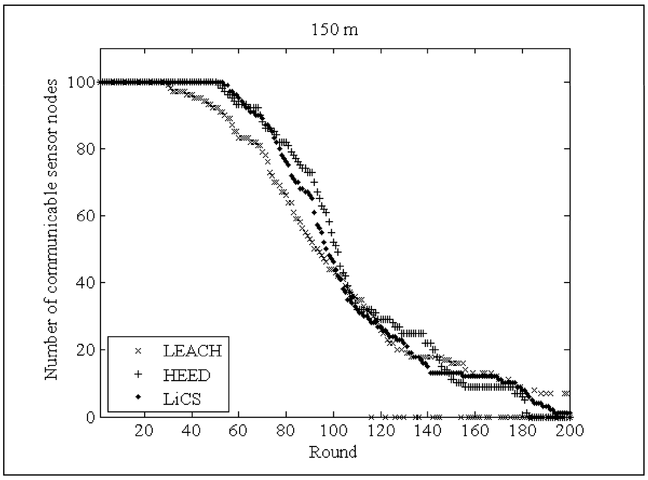

Figure 8: Number of communicable nodes in $150m \times 150m$ field

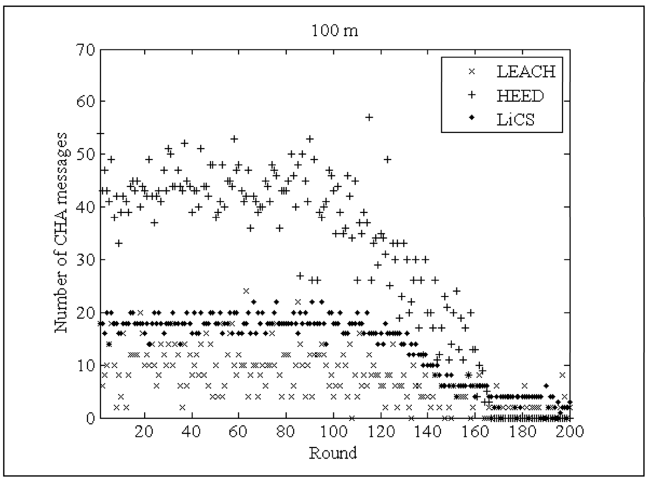

Figure 9: Number of CHA messages in $100m \times 100m$ field

works. In this study, we only evaluated the performance of LiCS with a static clustering communication range. In the future, we plan to evaluate the performance of LiCS with a dynamic communication range caused by a radio irregularity.

References

[1] Hyogo Police, "Rescue report" Police activity of Hanshin-Awaji Earthquake, pp. 71-75, 1996.

[2] Wei Ye, John Heidemann and Deborah Estrin, "An energy-efficient MAC protocol for wireless sensor networks", Proceedings INFOCOM 2002, Vol. 3 pp. 1567-1576, 2002.

[3] Tijs van Dam and Koen Langendoen "An adaptive energy-efficient mac protocol for wireless sensor networks", SenSys 2003, pp. 171-180, 2003.

[4] Gang Lu, Bhaskar Krishnamachari and Cauligi Raghavendra, "An adaptive energy-efficient and low-latency MAC for data gathering in sensor networks", IEEE WMAN 2004, pp. 863-875, 2004.

[5] Qing Cao, Tarek Abdelzaher, Tian He, and John Stankovic, "Towards Optimal Sleep Scheduling in Sensor Networks for Rare-Event Detection", IPSN 2005, pp. 20-27, 2005.

[6] Gang Lu, Narayanan Sadagopan, Bhaskar Krishnamachari, and Ashish Goel, "Delay efficient sleep scheduling in wireless sensor networks", INFOCOM 2005, pp. 2470-2481, 2005.

[7] Wendi Rabiner Heinzelman, Anantha Chandrakasan, and Hari Balakrishnan, "An Application-Specific Protocol Architecture for Wireless Microsensor Networks", IEEE Trans. on Wireless Communications, Vol. 1, No. 4, pp. 660-667, 2002.

[8] Kichan BAE and Hyunsoo Yoon, "Autonomous Clustering Scheme for wireless sensor Networks Using Coverage Estimation-Based Self-Pruning", IIEICE TRANS. COMMun., Vol. E88-B, NO. 3, pp. 973-980, 2005.

[9] Brian McLaughlan and Kemal Akkaya, "Coverage-based Clustering of Wireless Sensor and Actor Netwoks", IEEE Internation Conference on Pervasive Services, 2007, pp. 45-54, 2007

[10] Mainak Chatterjee, Sajal K. Das, and Damla Turgut, "WCA: A Weighted Clustering Algorithm for Mobile Ad Hoc Networks", Cluster Computing, Vol. 5, pp. 301-322, 2002.

[11] Ossama Younis and Sonia Fahmy "HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad-hoc Sensor Networks", IEEE Trans. on Mobile Computing, Vol. 3, No. 4, pp. 660-669, 2004.