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A Low-Energy Adaptive Clustering Hierarchy Architecture with an Intersection-based Coverage Algorithm in Wireless Sensor Networks

Young-Long Chen[1*]
[1,3]Department of Computer Science and Information Engineering
National Taichung University of Science and Technology
Taichung 404, Taiwan
ylchen66@nutc.edu.tw

Fu-Kai Cheung[2], and Yung-Chi Chang[3]
[2]Institute of Communication Engineering
National Yunlin University of Science and Technology
Yunlin 640, Taiwan
jackalrice@hotmail.com, dream11026@gmail.com

***Abstract*—In wireless sensor networks (WSNs), the sensor nodes are randomly deployed, and energy is limited. Energy consumption reduction is therefore very important. To extend the system lifetime, we used the intersection-based coverage algorithm (IBCA) to address lifetime; its introduction causes sensor nodes to enter sleep mode when not operating. This algorithm can achieve reduced energy consumption in transmission. And we then combine IBCA with Low-energy adaptive clustering hierarchy (LEACH) architecture to improve system performance. Simulation results show that the performance of our proposed LEACH architecture with IBCA perform better than LEACH architecture with phase-based coverage algorithm (PBCA) in terms of energy consumption, number of surviving nodes and sensing areas.**

Keywords*—system lifetime; energy consumption; LEACH; IBCA; PBCA; sensing areas

I. INTRODUCTION

In a wireless sensor network (WSN), a large number of wireless sensors are randomly scattered to collect environmental condition data of an area, such as humidity, temperature, pressure, solar radiation and concentration of carbon dioxide [1]-[3]. The wireless data collectors deliver the data to a base station (BS) by radio wave, infrared rays, or optical fiber transmission [4]. WSNs [5] consist of thousands of resource-constrained wireless sensor nodes. Each wireless sensor node is able to independently manage operations [6]. In WSNs, the lifetime of a node is dependent on its power consumption rate because the sensors are usually located in dangerous or inaccessible areas, and the battery cannot be replaced. When designing WSN architecture, the control of energy consumption is a primary problem [7].

Heinzelman et al. [8] proposed a Low-energy adaptive clustering hierarchy (LEACH) protocol for a distributed network. The LEACH architecture divided the sensor nodes into several clusters, with each cluster choosing a sensor node as the cluster head (CH). Through the strength of the ADV message, each sensor node identifies itself as a cluster member with the CH [9], [10].

When sensor nodes are randomly deployed, the result is uneven density. This will cause coverage issues [11]. When a node's sensing range is overlapped, it is called a redundant node. Redundant nodes are entered into sleep mode, which does not affect the overall sensor field or connectivity. Sleep mode is a way to extend the system lifetime.

Quang and Takumi [12], [13] proposed a phase-based coverage algorithm (PBCA) capable of locating all redundant nodes, in order to upgrade LEACH system performance. The results show that a combination of LEACH architecture and PBCA provides excellent system efficiency compared with the original LEACH architecture.

Wang et al.'s [14], [15] proposed intersection-based coverage algorithm (IBCA) is capable of locating all redundant nodes. The selected number of redundant nodes that can enter sleep mode will be larger than that of PBCA, so IBCA can improve the system performance more than PBCA can.

In this paper, we propose a scheme involving the application of IBCA to the LEACH architectures. Our scheme can indentify redundant nodes in order to improve energy consumption each round, and thereby reduce sensor node mortality rates.

The rest of this paper is organized as follows. We add IBCA to the LEACH architecture in Section II. In Section III, we simulate and analyze LEACH, LEACH with PBCA, LEACH with IBCA and compare the performance of four architectures. Finally, this paper is concluded in Section IV.

II. LEACH ARCHITECTURE WITH IBCA

A. The LEACH Architecture Introduced

Heinzelman et al. [8] proposed the LEACH architecture operation. Each cluster member delivers data directly to the cluster head, rather than to the distant base station. As a result, the energy consumed by the cluster members is merely the amount required during data transmission between cluster members and the cluster head, although the cluster head requires a larger amount of energy to perform data aggregation

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and implement data transmission to the base station. It should be noted that in LEACH architecture, the system is composed of variable clusters for each round.

LEACH protocol is mainly divided into two phases. The first is the setup phase; there is a probability $P_i(t)$ that each sensor node will be specified as the cluster head in the initial round. The average expected value of the cluster head number is defined as:

$$E[CH] = \sum_{i=1}^{K} P_i(t) \times 1 = \alpha$$

where $E[CH]$ is the average expected value of the number of cluster heads, T is the total deployed number of sensor nodes in a WSN, $P_i(t)$ is the probability that node i will decide it is to become a cluster head at time t and α is the cluster quantity.

In order to prevent nodes serving as a cluster head in consecutive rounds, (2) determines the probability that each node will become the cluster head:

$$P_i(t) = \begin{cases} \dfrac{\alpha}{T - \alpha \times (r \mod \dfrac{T}{\alpha})} & , C_i(t) = 1 \\ 0 & , C_i(t) = 0 \end{cases}$$

where r is the current round and t is increased by unity in the event that all the cluster members have acted as the head. $C_i(t) = 0$ indicates that node i has been the cluster head this round. $C_i(t) = 1$ indicates that a node has not yet been the cluster head this round. LEACH architecture requires that each cluster member serve as the head once for each T/α round. Each node i should choose to become a cluster head with probability $P_i(t)$ at round r.

B. IBCA

Wang et al. [14], [15] proposed the IBCA, which uses intersections to judge if certain sensor nodes can enter sleep mode. It was noted that both intersections of a target sensor node's sensing range with other nodes' sensing ranges and intersections on the perimeter of the total sensing range, are k-coverage; as a result, the target sensor node will be k-coverage. This method requires the coordinate location information of all sensor nodes, and the computational complexity is O(N^3), wherein M is the number of neighbors of the target sensor node. This method uses the intersection generated from the area of two circles to judge the overlap problem. Fig. 1 shows an intersection of the sensing ranges of two sensor nodes. The target sensor node u_y and the sensing range of neighboring sensor node u_x will intersect at two points, which are intersection 1 and intersection 2.

The IBCA [14], [15] has a wider judgment condition $(d < 2R)$ than the PBCA [12], [13] does, where d is the distance from a sensor node to the target sensor node, R is sensing range; hence, the number of selected sensor nodes that can enter sleep mode will be larger than that of PBCA, because the number of sensor nodes that can be used for judgment will become larger. That is, any neighbor node of the target sensor node can be used for judgment. However, since there are more neighbor nodes that can be used for judgment, the calculation will then become more complicated, and the implementation time will also become longer.

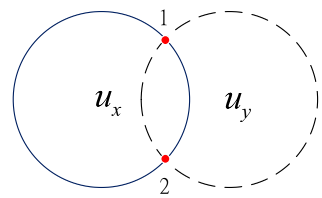

Fig. 1. Intersection of two sensing ranges.

In [14], [15], IBCA provide redundancy rules for nodes. If two conditions are established, the target node u_y is considered a redundant node. Considering a set of its overlapped neighbor nodes $M(u_y)$, neighbor nodes $u_x \in M(u_y)$, the sensing range of each sensor node is R and d is the distance from neighbor node u_x to target node u_y.

Condition 1: The distance from u_x to u_y should be less than or equal to twice the sensing range R. We obtain (3) as follows:

$$d(u_y, u_x) \le 2R, \forall u_x \in M(u_y)$$

Condition 2: The target node u_y must check all the intersections within its sensing range. Here, the intersections are generated by node u_y and its neighbor nodes u_x. Each intersection then overlaps coverage by each neighbor node's sensing range at least once.

Each sensor is able to determine whether its intersections are covered by inspecting the above two conditions. If intersections of a sensor node u_y are covered by other sensor nodes' sensing ranges, it is a redundant node which can enter sleep mode.

C. The LEACH Architecture with IBCA

In this section, we propose the application of the IBCA algorithm [14], [15] to LEACH architecture [8]. The complete IBCA algorithm is shown in Algorithm 1. First, we use the IBCA algorithm to find the redundant sensor nodes. Next, these redundant sensor nodes enter sleep mode in order to reduce the energy consumption of the WSN. We then set up the LEACH architecture with the active sensor nodes using IBCA. In our algorithm, all the sensor nodes can be divided into two modes: active mode or sleep mode. Therefore, the fewer nodes that are active, the lower the energy consumption for each round will be.

Algorithm 1: IBCA Algorithm

Parameter definition:
Define S as the set composed of the sensor nodes entered into sleep mode.
Define A as the set composed of the sensor nodes in active mode.
Define L as the set composed of live sensor nodes.
Define AN as the number of live sensor nodes.
Define $M(u_i)$ as the set composed of neighbor nodes of the target sensor node u_i.
Define $I(u_i)$ as the set composed of the intersections of u_i and $M(u_i)$ where $I(u_i)$ must be overlapped by other sensor node at least once.

Start:
1: In the first place, all the live nodes belong to A.
2: Locate $M(u_i)$, **where** $u_i \in L$, $M(u_i) = \{u_j \mid d(u_i, u_j) \leqq 2R_s\}$, **where** $u_i \neq u_j$ and $u_j \in L$ and $u_j \in A$.
3: Compute the intersections of u_i and neighbor nodes, **where** $u_j \in M(u_i)$.
4: Determine whether u_i is permitted to enter sleep mode.
If $I(u_i)$ is an empty set, **then** u_i is a redundant node permitted to sleep, that is, $u_i \in S$. **Otherwise**, p_i must remain active, i.e. $u_i \in A$.
5: **If** $i \neq AN$, $i++$, **go to** 2. **Otherwise**, terminate.

First, the IBCA algorithm, the system finds the redundant sensor nodes which are fully covered by neighbor nodes' sensing ranges, and enters them into sleep mode. After executing the IBCA algorithm, the LEACH architecture will use only active sensor nodes. The system will compare the residual energy of each sensor node and select the active sensor node with the maximum remaining energy as the cluster head. Let these redundant sensor nodes enter sleep mode in order to reduce the energy consumption of the WSN. The remaining nodes of the WSN then form LEACH architecture. The flowchart diagram is shown in Fig. 2.

III. Simulation Results

In this paper, we propose LEACH architecture with IBCA. We simulate and compare the system efficiencies, which are LEACH architecture [8], LEACH architecture with PBCA [13], LEACH architecture with IBCA. We compare the system efficiencies, which are based on total residual energy, number of deceased nodes and total sensing area. Our simulations are performed using C programming language. The simulation assumed 100 sensor nodes randomly distributed over a 100 meter by 100 meter field, a sensing radius of 15 meters and BS located at (50, 150), with the parameters specified in Table I. From Heinzelman et al. [8], the optimal cluster number k_{opt} is employed in the LEACH architecture.

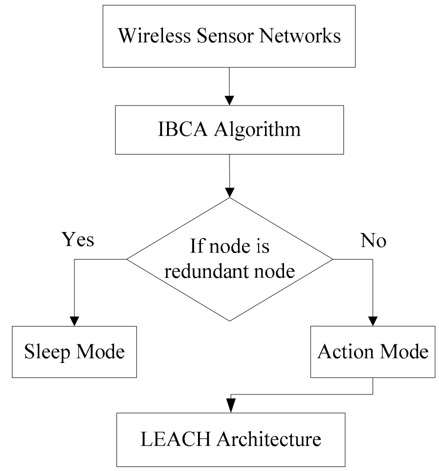

Fig. 2. The flow chart diagram of LEACH architecture with IBCA.

Fig. 3 shows the total residual energy each round. Our novel LEACH architecture with IBCA obtained a large total residual energy in each round. The original LEACH architecture has the lowest residual energy, owing to the absence of IBCA. In addition, the LEACH architecture with IBCA has greater residual energy than does LEACH architecture with PBCA because IBCA can select more sensor nodes to enter sleep mode than PBCA can. The main reason for this is that the number of sensor nodes that can be used for judgment will become greater.

The number of deceased nodes each round is shown in Fig. 4. In the original LEACH architecture, the first node dies at about round 290, and the 20th node dies at about round 354. In the LEACH architecture with PBCA, the first node dies at about round 301, and the 20th node dies at about round 397, while in LEACH architecture with IBCA, nodes die at rounds 315 and 409, respectively. Therefore, it is demonstrated that our LEACH architecture with IBCA has the lowest sensor node mortality rate, while the original LEACH architecture has the highest.

TABLE I. Parameter Setting in Simulation.

Variables	Value
Initial energy	$E_{init} = 0.25$ J
BS location	(50, 150)
Number of package	$l = 4000$ bits
Electronic circuit energy	$E_{elec} = 50$ nJ/bit
Energy consumed in data fusion for each signal	$E_{DA} = 5$ nJ/bit/signal
Amplifier energy of free space	$\varepsilon_{fs} = 10$ pJ/bit/m^2
Amplifier energy of multi-path	$\varepsilon_{mp} = 0.0013$ pJ/bit/m^2

Total sensing area is shown in Fig. 5. Prior to round 300, the four architectures cover the same sensing area. After round 600, the LEACH architecture with IBCA maintains the largest sensing area, and the original LEACH the smallest. Thus, it is shown that for sensing area each round, the LEACH architecture with IBCA covers the maximum sensing area, while the original LEACH covers the minimum. The main reason for this is that the LEACH architecture with IBCA has an extended system lifetime.

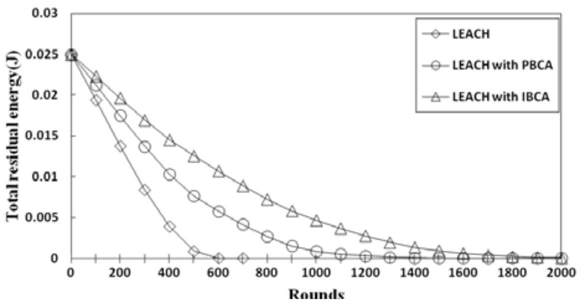

Fig. 3. Comparison of total residual energy each round.

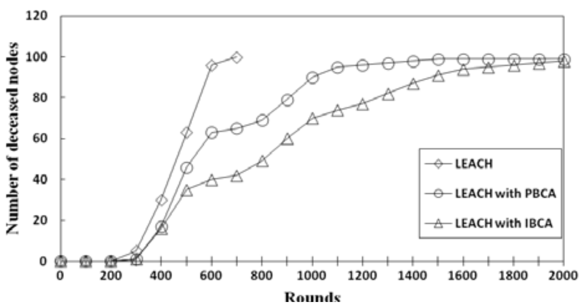

Fig. 4. Comparison of the number of deceased nodes each round.

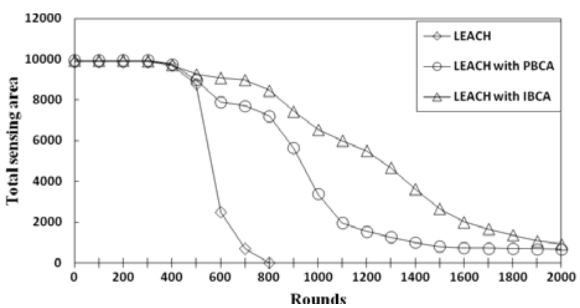

Fig. 5. Comparison of total sensing area each round.

IV. CONCLUSIONS

In this paper, we proposed LEACH architecture with IBCA. By using IBCA, the WSN's sensor nodes are classified into two types, i.e., active nodes, which responsible for detecting data, and the sleep mode nodes, which remain idle. Therefore, the entire system requires less live sensor nodes to cover a sensor field. The nodes to enter sleep mode are determined using IBCA, and do not perform any functions, which reduces energy consumption. Finally, the system is constructed by only active nodes, further reducing the energy consumption of the WSN. On the other hand, IBCA selected a greater number of redundant nodes than did PBCA, the main reason being that, with IBCA, a greater number of sensor nodes can be used for judgment. For this reason, the application of IBCA to the LEACH architecture improves the system lifetime.

Simulation results indicate that our proposed IBCA combined with LEACH demonstrate excellent performance compared with both the original LEACH architecture and LEACH architecture combined with PBCA, in terms of total residual energy, death rate of sensor nodes and total sensing area.

REFERENCES

[1] P. Bonnet, J. Gehrke, and P. Seshadri, “Querying the physical world,” *IEEE Pers. Commun.*, vol. 7, no. 5, pp. 10-15, Oct. 2000.

[2] J. Burrell, T. Brooke, and R. Beckwith, “Vineyard computing: sensor networks in agricultural production,“ *IEEE Pervasive Computing*, vol. 3, no. 1, pp. 38-45, Jan./Mar. 2004.

[3] D. Estrin, L. Girod, G. Pottie, and M. Srivastava, “Instrumenting the world with wireless sensor networks,“ in *Proc. IEEE International Conference on Acoustics, Speech, and Signal Processing*, Salt Lake City, USA, pp. 2033-2036, Jun. 2001.

[4] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “A survey on sensor networks,“ *IEEE Commun. Mag.*, vol. 40, no. 8. pp.102-114, Aug. 2002.

[5] J. N. Al-Karaki, R. Ul-Mustafa, and A. E. Kamal, “Data aggregation and routing in wireless sensor networks: optimal and heuristic algorithms,“ *Computer Networks*, vol. 53, no. 7, pp. 945-960, May. 2009.

[6] P. Kumarawadu, D. J. Dechene, M. Luccini, and A. Sauer, “Algorithms for node clustering in wireless sensor networks: a survey,“ in *Proc. IEEE 4th International Conference on Information and Automation for Sustainability,* Colombo, Sri Lanka, pp. 295-300, Dec. 2008.

[7] M. J. Islam, M. M. Islam, and M. N. Islam, “A-sLEACH: an advanced solar aware leach protocol for energy efficient routing in wireless sensor networks,“ in *Proc. IEEE 6th International Conference on Networking,* Sainte-Luce, France, pp. 1-4, Apr. 2007.

[8] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, “An application-specific protocol architecture for wireless microsensor networks,“ *IEEE Trans. Wireless Commun.,* vol. 1, no. 4, pp. 660-670, Oct. 2002.

[9] B. Huang, F. Hao, H. Zhu, Y. Tanabe, and T. Baba, “Low-energy static clustering scheme for wireless sensor network,“ in *Proc. IEEE International Conference on Wireless Communications, Networking and Mobile Computing,* Wuhan, China, pp. 1-4, Sept. 2006.

[10] B. Wei, H. Y. Hu, and W. Fu, “An improved LEACH protocol for data gathering and aggregation in wireless sensor networks,” in *Proc. IEEE International Conference on Computer and Electrical Engineering,* Phuket, Thailand, pp. 398-401, Dec. 2008.

[11] C. F. Huang and Y. C. Tseng, “The coverage problem in a wireless sensor network,” in *Proc. ACM 2th International Conference on Wireless Sensor Networks and Applications,* San Diego, USA, pp. 115-121, Sept. 2003.

[12] V. T. Quang and M. Takumi, “An algorithm for sensing coverage problem in wireless sensor networks,” in *Proc. IEEE Sarnoff Symposium,* Princeton, New Jersey, pp. 1-5, Apr. 2008.

[13] V. T. Quang and M. Takumi, “A novel gossip-based sensing coverage algorithm for dense wireless sensor networks,” *Computer Networks,* vol. 53, no. 13, pp. 2275-2287, Aug. 2009.

[14] X. Wang, G. Xing, Y. Zhang, C. Lu, R. Pless, and C. Gill, “Integrated coverage and connectivity configuration in wireless sensor networks,” in *Proc. 1st International Conference on Embedded Networked Sensor Systems*, Los Angeles, CA, USA, pp. 28-39, Nov. 2003.

[15] X. Wang, G. Xing, Y. Zhang, C. Lu, R. Pless, and C. Gill, “Integrated coverage and connectivity configuration for energy conservation in sensor networks,” *ACM Trans. Sensor Networks,* vol. 1, no. 1, pp. 36-72, Aug. 2005.