A Clustering Method for Energy Efficient Routing in Wireless Sensor Networks

TAEWOOK KANG, JANGKYU YUN, HOSEUNG LEE, ICKSOO LEE, HYUNSOOK KIM, BYUNGHWA LEE, BYEONGJIK LEE, KIJUN HAN

Department of Computer Engineering
Kyungpook National University,
1370 Sankyuk-dong, Book-gu, Daegu, KOREA

Abstract: Low-Energy Adaptive Clustering Hierarchy (LEACH) is one of the most popular distributed cluster-based routing protocols in wireless sensor networks. Clustering algorithm of the LEACH is simple but offers no guarantee about even distribution of cluster heads over the network. And it assumes that each cluster head transmits data to sink over a single hop. In this paper, we propose a new method for selecting cluster heads to evenly distribute cluster heads. It avoids creating redundant cluster heads within a small geographical range. Simulation results show that our scheme reduces energy dissipation and prolongs network lifetime as compared with LEACH.

Key-Words: - Energy Efficient, Routing, Wireless Sensor Networks, LEACH protocol, LEACH-C protocol

1 Introduction

Wireless sensor networks consist of a large number of low-power multifunctional sensor nodes with sensing, limited computation and wireless communications capabilities. Recent advances in sensor technology have enabled the development of small, low-cost and low-power sensors, that can be connected via a wireless networks. In wireless sensor networks, sensors are densely deployed so that it can be applicable to a variety of fields that include surveillance, military, national security, and chemical or biological detection. [1-3]

Many routing protocols have been proposed for wireless sensor networks. The main goal the routing protocols in wireless sensor networks is to find ways for improvement of energy efficiency and reliable transmission of sensed data to the sink. Almost all of the routing protocols can be classified according to the network structure as flat, hierarchical, or location-based [2]. And hierarchical routing protocols can be classified again according to the clustering tactics as distributed or centralized fashion. For example, LEACH (Low-Energy Adaptive Clustering Hierarchy) [4], HEED (Hybrid Energy-Efficient Distributed clustering) [5] use distributed tactics, and LEACH-C (LEACH-Centralized) [6], BCDCP (Base-station Controlled Dynamic Clustering Protocol) [7] use centralized tactics.

In this paper, we propose a new cluster-based routing protocol in order to distribute cluster heads evenly over the network and reduce energy dissipation. Our scheme tries to evenly distribute cluster heads over the whole network and avoid creating redundant cluster heads within a small range so that it can increase the network lifetime.

The remainder of this paper is organized as follows: In section 2, we review some conventional cluster-based routing protocols. In section 3, we propose a new distribution scheme of cluster heads. Section 4 contains performance evaluation of our scheme throughout simulations. Finally, we conclude the paper in section 5.

2 Related works

The main goal of cluster-based routing protocol is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a cluster and by performing data aggregation and fusion in other to decrease the number of transmitted messages to sink and transmission distance of sensor nodes.

Cluster-based routing protocol is classified into distributed and centralized clustering algorithms depending on the manner of selecting the cluster heads. In the distributed clustering algorithm, every sensor node deployed in the sensing field independently determines its role (whether it acts as a cluster head or not) based on the probabilistic value and/or residual energy. In centralized clustering algorithms, by contrast, sink node takes the leading role in selecting the cluster heads. Sink node knows geographical position, residual energy and neighbor information of all sensor nodes. Based on this information, sink node selects cluster heads and broadcasts sensing field in order to organize clusters.

2.1 LEACH protocol

When including a subsection you must use, for its heading, small letters, 12pt, left justified, bold, Times New Roman as here. Low-Energy Adaptive Clustering Hierarchy (LEACH) [4] is one of the most popular distributed cluster-based routing protocols in wireless sensor networks. LEACH randomly selects a few nodes as cluster heads and rotates this role to balance the energy dissipation of the sensor nodes in the networks. The cluster head nodes fuse and aggregate data arriving from nodes that belong to the respective cluster. And cluster heads send an aggregated data to the sink in order to reduce the amount of data and transmission of the duplicated data. Data collection is centralized to sink and performed periodically.

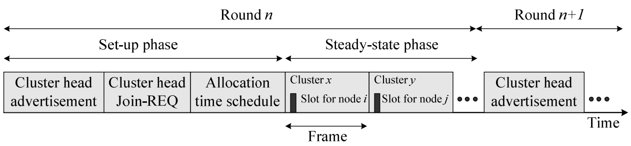


Fig. 1. Time line of LEACH protocol

The operation of LEACH is generally separated into two phases, the set-up phase and the steady-state phase, as shown in Fig. 1. In the set-up phase, cluster heads are selected and clusters are organized. In the steady-state phase, the actual data transmissions to the sink take place. After the steady-state phase, the next round begins.

During the set-up phase, when clusters are being created, each node decides whether or not to become a cluster head for the current round. This decision is based on a predetermined fraction of nodes and the threshold *T(n)*. The threshold is given by

where p is the predetermined percentage of cluster heads (e.g., p = 0.05), r is the current round, and G is the set of nodes that have not been cluster heads in the

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

last $1/p$ rounds. Using this threshold, each node will be a cluster head at some round within $1/p$ rounds. After $1/p$ rounds, all nodes are once again eligible to become cluster heads. In LEACH, the optimal number of cluster heads is estimated to be about 5% of the total number of nodes. Each node that has elected itself a cluster head for the current round broadcasts an advertisement message to the rest of the nodes in the network. All the non cluster head nodes, after receiving this advertisement message, decide on the cluster to which they will belong for this round. This decision is based on the received signal strength of the advertisement messages. After cluster head receives all the messages from the nodes that would like to be included in the cluster and based on the number of nodes in the cluster, the cluster head creates a TDMA schedule and assigns each node a time slot when it can transmit.

During the steady-state phase, the sensor nodes can begin sensing and transmitting data to cluster heads. The radio of each non cluster head node can be turned off until the node's allocated transmission time. The cluster heads, after receiving all the data, aggregate it before sending it to the sink. Each cluster head communicates using different CDMA codes in order to reduce interference from nodes belonging to other clusters.

2.2 LEACH-C protocol

LEACH offers no guarantee about the placement and/or number of cluster heads. In [6], an enhancement over the LEACH protocol was proposed. The protocol, called LEACH-C, uses a centralized clustering algorithm and the same steady-state phase as LEACH. LEACH-C protocol can produce better performance by dispersing the cluster heads throughout the network.

During the set-up phase of LEACH-C, each node sends information about its current location (possibly determined using position finding system as shown in Fig. 1) and residual energy level to the sink. In addition to determining good clusters, the sink needs to ensure that the energy load is evenly distributed among all the nodes. To do this, sink computes the average node energy, and determines which nodes have energy below this average. The sink finds

clusters using the simulated annealing algorithm [8] to solve the NP-hard problem of finding k optimal clusters [9]. This algorithm attempts to minimize the amount of energy for the ordinary nodes to transmit their data to the cluster head.
Once the cluster heads and associated clusters are found, the sink broadcasts a message that obtains the cluster head ID for each node. If a cluster head ID matches its own ID, the node is a cluster head; otherwise the node determines its TDMA slot for data transmission and goes sleep until its time to transmit data. The steady-state phase of LEACH-C is identical to that of the LEACH protocol.

3 Problem Solution
In this section, we propose a method for selecting cluster heads and describe the details of the scheme.

3.1 Calculation of area
In general, the sensor nodes are scattered randomly. Assuming that sensor nodes are uniformly distributed over the sensing field, then approximately the same number of sensor nodes are contained in the same area of sensing field. Fig. 2 shows that an $M \times M$ network field is divided into four regions with the same area.

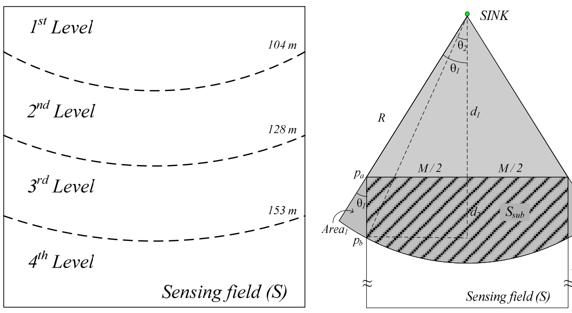


Fig. 2. Calculation of area (S_{sub})

In the triangle which connects p_a, p_b, and the sink $\Delta(p_a, p_b, SINK)$, we can get θ_1 and θ_2 in Fig. 2 by the 2nd law of cosines as follows

$$\theta_1 = ACOS\left(\frac{d_1}{\sqrt{(M/2)^2 + d_1^2}}\right) \quad \theta_2 = ACOS\left(\frac{\sqrt{R^2 - (M/2)^2}}{R}\right) \tag{2}$$

Let R be the radius of the sector with the origin at the sink, and then we get $Area_1$ by

$$Area_1 = \left(\pi \times R^2 \times \frac{\theta_1 - \theta_2}{2\pi}\right) - \left|\Delta(p_a, p_b, SINK)\right| \tag{3}$$

So, the shaded area, denoted by S_{sub}, can be calculated by

$$S_{sub} = (\pi \times R^2 \times \frac{\theta_1}{\pi}) - \left\{\left(\frac{M}{2} \times d_1\right) + (2 \times Area_1)\right\} \tag{4}$$

where d_1 be the distance from edge of the sensing filed to the sink.
For our experiment, 400 nodes are randomly deployed in a $100m \times 100m$ field and the sink is located $75m$ away from the field edge. Through 65000 experiments, we can see that the field with an area of $10000m^2$ is equally divided into four equal regions when R is $104m$, $128m$, and $153m$.
Table 1 shows the number of nodes contained in each region as R is varied. This table shows that each region has approximately the same number of nodes as we predicted.

Table 1. The number of nodes contained in each region

Region	1st level	2nd level	3rd level	4th level
Radius	$R \le 104$	$104 < R \le 128$	$128 < R \le 153$	$R > 153$
Area (A_i)	2484.2	4966.6	7523.1	
The number of nodes	100.488	99.492	98.364	101.655

3.2 Basic concept of our scheme
As previously described, cluster heads need to be evenly distributed over the whole network for saving energy. In our scheme, we try to avoid redundant creation of cluster heads in a small area.

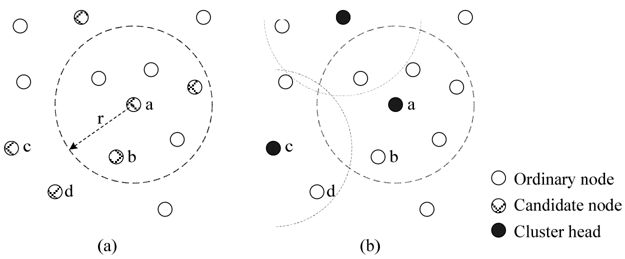


Fig. 3. Basic concept of our scheme

The sensor nodes are randomly deployed and some of them are initially selected as candidate nodes using Eq. 1. The nodes that have not been selected as cluster heads for the last 20 rounds are chosen to become candidate nodes. We can increase the number of candidate nodes per round by increasing the value of p in Eq. 1. One of the candidate nodes broadcasts an advertisement message within its range. Nodes receiving this advertisement message are ruled out the qualification of candidate node. In Fig. 3 (a), node a, b, c, and d are elected for candidate nodes among the sensor nodes. First, node a broadcasts an advertisement message within the range r. Node b receiving the advertisement message from node a is ruled out the qualification of candidate nodes. After that, node *d* is also ruled out the qualification by the same process. As a result, node *a* and *c* are actually selected for cluster heads as shown in Fig. 3 (b). Fig. 4 shows state transition diagram of each sensor node.

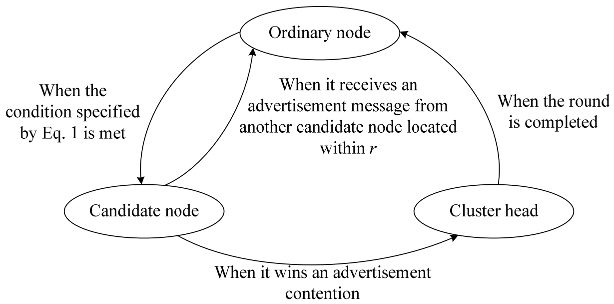


Fig. 4. State transition diagram of each sensor node

3.3. The set-up phase

The main activities in the set-up phase are election of candidate nodes, selection of cluster heads, scheduling at each cluster, and discovery of cluster head for CH-to-CH data transmission. During set-up phase, each node first decides whether or not it can become a candidate node in each region for the current round. This decision is based on the value of the threshold *T(n)* as used in LEACH protocol. As seen in Eq. 1, *p* should be given a large value in order to elect many candidate nodes. Cluster heads are elected among the candidate nodes.

We utilize an advertisement message to elect cluster heads. For this, the candidate nodes use a CSMA MAC protocol. Each candidate node broadcasts an advertisement message within its transmission range. This range is dependent on the maximum distance between the levels. In our scheme, the advertisement range is given double of the maximum distance (about 55 *m*) to cover other levels. When a candidate node is located within $\alpha \times$ *Advertisement_Range* where the value of α is predetermined between 0 and 1, it has to give up qualification of candidate node and has to stop joining the competition.

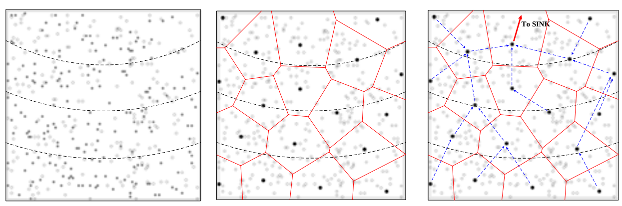
Ordinary node, by contrast, decides the cluster to which it will belong for this round. This decision is based on the signal strength of the advertisement message. After each node has decided to which cluster it belongs, node must transmit its data to the appropriate cluster head (which is a member of the same cluster).

After cluster head receives all the messages from the nodes that would like to be included in the cluster and based on the number of nodes contained in the cluster, the cluster head creates a TDMA schedule and assigns each node a time slot when it can transmit. Each cluster head broadcasts this schedule back to the nodes in the cluster.

Finally, cluster heads form CH-to-CH routing path for data transmission of the steady-state phase. After schedule creation, each cluster head performs cluster head discovery to find an upward cluster head to reach the sink. For this, each cluster head utilizes two-way handshake technique, with REQ and ACK message. Each cluster head broadcasts REQ message within advertisement range. Upward cluster head receiving this REQ message transmits ACK message back to the cluster head that transmitted REQ message. When the node that transmitted REQ message receives ACK message, it chooses this cluster head which transmitted ACK message as the next hop. If cluster head cannot find upward cluster head, it chooses the sink as the next hop.

3.4. Steady-state phase

The steady-state phase of our scheme is similar to other cluster-based routing protocol. Main activities of this phase are sensing and transmission of sensed data. Each sensor nodes senses and transmits the sensed data to its cluster head according to own time schedule. When all the data has been received, the cluster head perform data fusion or/and aggregation in order to reduce the amount of data. Finally, each cluster head transmits data to the sink along the CH-to-CH routing path which have been formed during the set-up phase. After all the data is transmitted or a certain time is elapsed, the network goes back into the set-up phase again and the next round begins by electing candidate nodes.



Election of candidate nodes (b) Formation of clusters (c) Data transmission to sink

Fig. 5. Example of operation by our scheme

Fig. 5 shows operation an example of our scheme. In Fig. 5 (a), candidate nodes (grayed dot) are elected using threshold function by themselves. There are numerous candidate nodes more than cluster heads. The cluster heads are selected throughout transmission of the advertisement message as shown in Fig. 5 (b). Finally, Fig. 5 (c) shows an example of CH-to-CH routing path to the sink for data transmission. Each cluster head transmits aggregated data to the sink along this routing path.

4 Performance Evaluation

We evaluate our scheme throughout simulations. For the simulations, we assume a network model similar to the one used in the conventional routing protocols, with the following properties:

• All sensor nodes are immobile.
• Each sensor node initially has uniform energy level.
• A fixed sink node is located 75m away from the edge of network.
• The sensor nodes are equipped with power control capabilities.

For the experiments, the network parameters and the communication energy parameters are set as shown in Table 2. We simulate 1000 different network topologies with these parameters.

Table 2. Simulation parameters

The number of nodes (N)	400 nodes
Field size (S)	$100m \times 100m$, $[0, 100]^2$
Distance to the sink	$75m$, location is (50, 175)
The initial energy of sensor node	$2J$
The data packet size (k)	500 bytes (4000 *bits*)
E_{Tx} and E_{Rx}	$50nJ / bit$
Free space (ε_{FS})	$10pJ / bit / m^2$
Multipath fading (ε_{MP})	$0.0013pJ / bit / m^4$
The energy for aggregation (E_{DA})	$5nJ / bit / signal$
Threshold distance (d_0)	$87m$

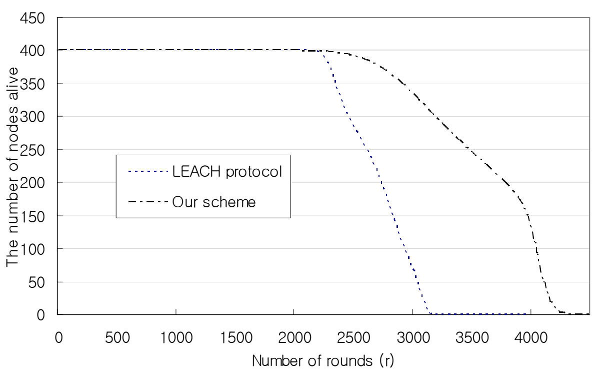


Fig. 6. System lifetime By our scheme and LEACH

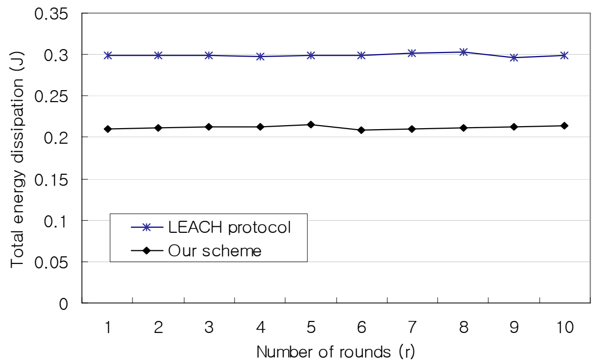


Fig. 7. Average of total Energy dissipation by our scheme and LEACH

Fig. 6 shows the number of nodes alive in each round. In Fig. 6, our scheme is compared with the LEACH protocol. This figure clearly shows that our scheme has a longer life time than LEACH protocol. Fig. 7 shows the total energy dissipation in each round. In this figure, our scheme exhibits a reduction in energy dissipation over LEACH protocol. This is because our scheme removes unnecessary redundant creation of cluster heads and utilizes CH-to-CH routing path.

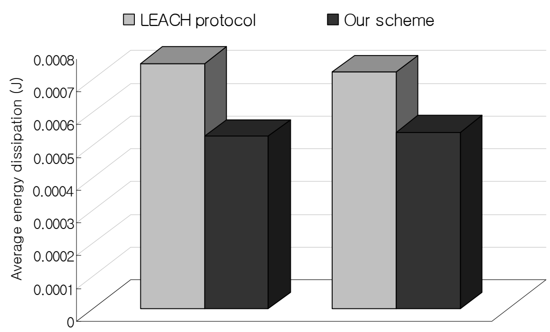


Fig. 8. Energy dissipation of each node

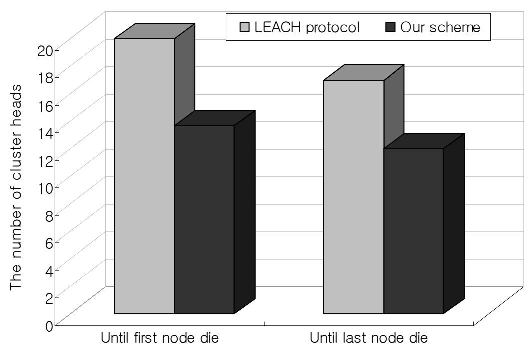


Fig. 9. The average number of cluster heads

Fig. 8 shows the average energy dissipation at each node per round. Until the first node dies, in LEACH protocol and our scheme, each node consumes about 0.749 and 0.526 mJ, respectively. Fig. 9 shows the average number of cluster heads until the first node dies and the last node dies. As shown in this figure, LEACH protocol selects as many cluster heads as 5% of the total number of nodes since it uses a fixed probability (e.g.,), but our scheme produces a smaller number of cluster heads and shows a variation in the number of cluster heads depending on the network condition.

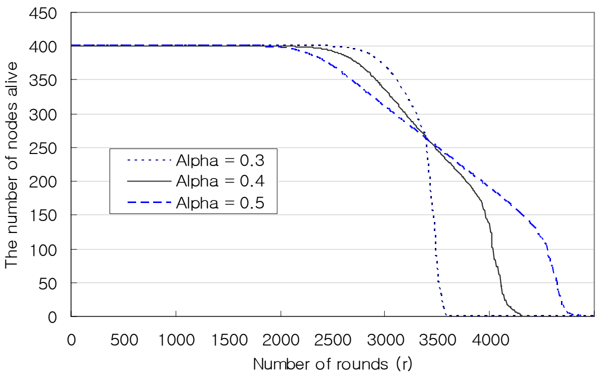


Fig. 10. System lifetime when alpha value is varied

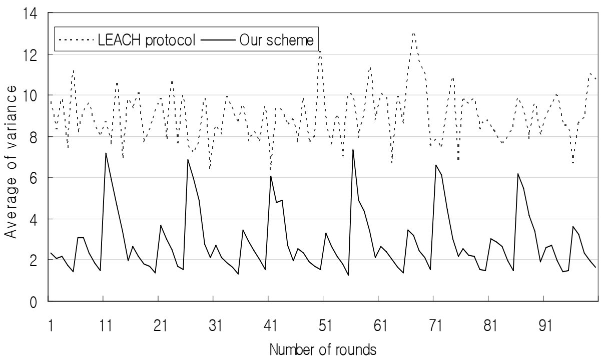


Fig. 11. Variance of cluster size (the number of nodes contained in the cluster)

Fig. 10 shows variation of system life time as alpha value is varied. This figure shows that system has a tradeoff between the time when the first node die and the time when the last node die depending on alpha value. Fig. 11 shows variance of the cluster size which indicates the number of cluster members. This figure shows that our scheme offers more uniform clusters than LEACH protocol.

5 Conclusions

The cluster formation algorithm of LEACH protocol offers no guarantee about distribution of cluster heads since the cluster heads are only selected in a random fashion. In this paper, we have proposed a distribution scheme of cluster heads to reduce energy dissipation by avoiding unnecessary redundancy. Simulation results show that our scheme offers a better performance than the LEACH protocol in terms of network lifetime.

References:

[1] I.F. Akyildiz et al., "A Survey on Sensor Networks," *IEEE Communications Magazine* Volume 40, Issue 8, Aug 2002, pp.102-114.

[2] Al-Karaki, J.N., Kamal, A.E., "Routing Techniques in Wireless Sensor Networks: a Survey," *IEEE Wireless Communications* Volume 11, Issue 6, Dec 2004, pp.6 - 28.

[3] K. Akkaya, M. Younis, "A Survey of Routing Protocols in Wireless Sensor Networks," *Elsevier Ad Hoc Network Journal* Volume 3, Issue 3, May 2004, pp.325-349.

[4] W.R. Heinzelman et al., "Energy Efficient Communication Protocol for Wireless Sensor Networks," *Proceedings of the 33rd Hawaii International Conference on System Science* Volume 2, Jan 2000.

[5] Younis, O., Fahmy, S., "HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks," *IEEE Transactions on Mobile Computing* Volume 3, No. 4, Oct-Dec 2004, pp.366 - 379.

[6] W. B. Heinzelman et al., "An Application-Specific Protocol Architecture for Wireless Microsensor Networks," *IEEE Transactions on Wireless Communications* Volume 1, No. 4, Oct 2002, pp.660 - 670.

[7] Muruganathan, S.D. et al., "A Centralized Energy-Efficient Routing Protocol for Wireless Sensor Networks," *IEEE Radio Communications* Volume 43, Issue 3, Mar 2005, pp.S8 - 13.

[8] T. Murata et al., "Performance evaluation of genetic algorithms for flowshop scheduling problems," *Proceedings 1st IEEE Conference Evolutionary Computation* Volume 2, Jun 1994, pp.812 - 817.

[9] P. Agarwal et al., "Exact and approximation algorithms for clustering," *Proceedings 9th Annual ACM-SIAM Symposium Discrete Algorithms*, Jan 1999, pp.658 - 667.