Distance Aware Intelligent Clustering Protocol for Wireless Sensor Networks

Navin Gautam and Jae-Young Pyun

Abstract: **Energy conservation is one of the most important issues for evaluating the performance of wireless sensor network (WSN) applications. Generally speaking, hierarchical clustering protocols such as LEACH, LEACH-C, EEEAC, and BCDCP are more efficient in energy conservation than flat routing protocols. However, these typical protocols still have drawbacks of unequal and high energy depletion in cluster heads (CHs) due to the different transmission distance from each CH to the base station (BS). In order to minimize the energy consumption and increase the network lifetime, we propose a new hierarchical routing protocol, distance aware intelligent clustering protocol (DAIC), with the key concept of dividing the network into tiers and selecting the high energy CHs at the nearest distance from the BS. We have observed that a considerable amount of energy can be conserved by selecting CHs at the nearest distance from the BS. Also, the number of CHs is computed dynamically to avoid the selection of unnecessarily large number of CHs in the network. Our simulation results showed that the proposed DAIC outperforms LEACH and LEACH-C by 63.28% and 36.27% in energy conservation respectively. The distance aware CH selection method adopted in the proposed DAIC protocol can also be adapted to other hierarchical clustering protocols for the higher energy efficiency.**

Index Terms: **Cluster, cluster head, gateway-CH, primary tier, routing path, secondary tier.**

I. INTRODUCTION

Recent advances in micro-electro-mechanical systems and low power and highly integrated digital electronics have led to the development of micro-sensors [1]. Such sensors are generally equipped with data processing and communication capabilities. These sensors have the ability to communicate either among each other or directly to an external base station (BS). These sensors can be networked in many applications that require unattended operations, hence producing a wireless sensor network (WSN) [2].

WSN is constrained with resources such as energy, bandwidth, and computational capabilities. Therefore, performance of WSNs depends upon MAC, routing, and other higher layer protocols. Specifically, routing protocols highly affect the performance of WSN. Currently, many routing protocols have been proposed in order to achieve energy efficiency in WSN. On the basis of network structure, these routing protocols can be divided into flat routing, hierarchical clustering routing, and location-based routing [2]. Flat routing protocols like sensor protocol for information via negotiation (SPIN), directed diffusion, and rumor routing are not efficient in energy conservation as compared to the hierarchical clustering routing protocols like low energy adaptive clustering hierarchy (LEACH), leach-centralized (LEACH-C), routing protocol of wireless sensor networks based on dynamic setting cluster, enhanced energy-efficient adaptive clustering (EEEAC), and base station controlled dynamic clustering protocol (BCDCP) [2], [3]. On the other hand, location based routings might consist of flat routing or hierarchical routing and in this category of routing too, hierarchical clustering routing protocols obtain greater energy conservation as compared to the flat counterparts [2]. In hierarchical clustering routing protocols, clusters are created and a cluster head (CH) is assigned to each cluster. These CHs have the responsibilities of collecting, aggregating the data from their respective clusters, and transmitting these data to the BS (we use CH and CH node interchangeably in this work). The aggregation of data at CHs greatly reduces the energy consumption in the network by minimizing the total data messages to be transmitted to the BS. Also, the CHs act as local sinks for the data, so that data are transmitted over a shorter transmission distance [2].

One issue affecting the performance of WSN routing is the distribution of energy load in the network [4], [5], [6]. In order to achieve fair distribution of energy load in the network, popular routing protocols such as LEACH and LEACH-C divide the network into a number of clusters [7], [8]. However, these protocols don't have intelligent CH selection methods, resulting in increased energy consumption. To overcome these drawbacks in LEACH and LEACH-C protocols, routing protocol of wireless sensor networks based on dynamic setting cluster selects CHs dynamically [9]. On the other hand, EEEAC and BCDCP consider average residual energy of nodes and average node distance [10], [11]. However, these protocols try to minimize the average distance between the non-CH nodes and the CH nodes only and thus fail to minimize the distance between the CHs and the BS [9], [10], [11]. Therefore, these protocols have similar or a little bit lower energy consumption as compared to that of LEACH and LEACH-C. In order to mitigate this drawback, we propose distance aware intelligent clustering (DAIC) protocol that minimizes the energy depletion in the CHs by considering the transmission distance between CH nodes and the BS. Also, the proposed DAIC protocol calculates the number of CHs dynamically according to the number of alive nodes in the network.

The rest of the paper is organized as follows: Sections II and III present the effect of distance on energy consumption and related works and motivation. Similarly, Sections IV and V present proposed DAIC protocol design and operation and sim-

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N. Gautam is with the Department of Information and Communication Engineering, Chosun University, Gwangju, Korea, email: navin@stmail.chosun.ac.kr.

J.-Y. Pyun (corresponding author) is with the Department of Information and Communication Engineering, Chosun University, Gwangju, Korea, email: jypyun@chosun.ac.kr.

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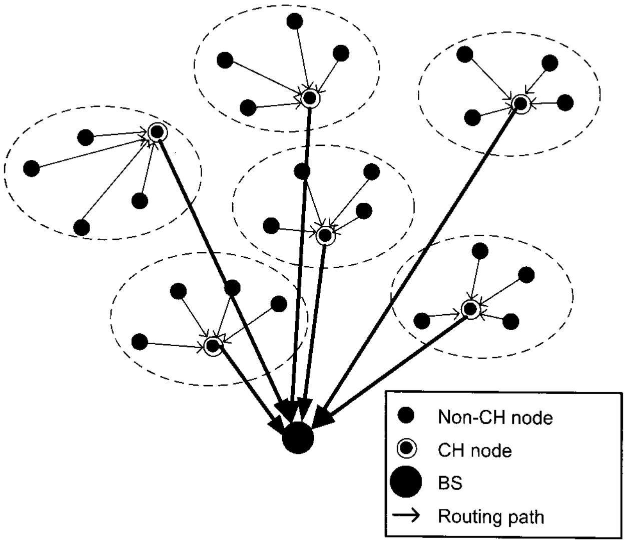

Fig. 1. Topology of LEACH protocol.

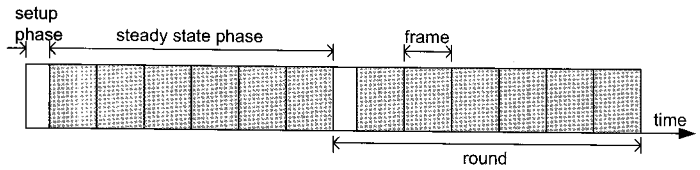

Fig. 2. LEACH protocol operation.

ulation results, respectively. Finally, we conclude this paper in Section VI.

II. EFFECT OF DISTANCE ON ENERGY CONSUMPTION

For a first order radio model, the total energy for a transmitter to send a k-bit message over a distance d is given by

$$E_{Total}(k, d) = E_{elec}k + \epsilon_{amp}kd^2 \tag{1}$$

where ϵ_{amp} is the energy constant for the radio transmission and E_{elec} is the energy per bit [7].

The first term $E_{elec}k$ in (1) is the energy used to run the circuitry to handle k-bit message. The second term $\epsilon_{amp}kd^2$ is the energy for transmitter to send k-bits over distance d. This second term is the reason for variable energy consumption in a network, as d is variable. Therefore, as the distance d and the number of bit k increase, the energy spent for the transmission of message increases. The sensor nodes adjust the transmission power according to the transmission distance d. Hence, energy can be conserved by minimizing the transmission distance. Also, by compressing the data before transmission, we can conserve considerable amount of energy.

To study the effect of transmission distance on energy consumption, we simulated LEACH protocol with BS located at various positions. We deployed 100 sensor nodes in a square area of 100 m × 100 m starting from the origin (0, 0) and BS located at positions (50, 50), (50, 175), (200, 200), and (250, 250). As shown in Fig. 3, the energy spent was the least when the BS was located at the position (50, 50), slightly higher at the positions (50, 175) and (200, 200), and highest at (250, 250). Therefore, (1) and simulation result in Fig. 3 validate the argument that the energy consumption increases as the transmission distance between CH node and BS increases.

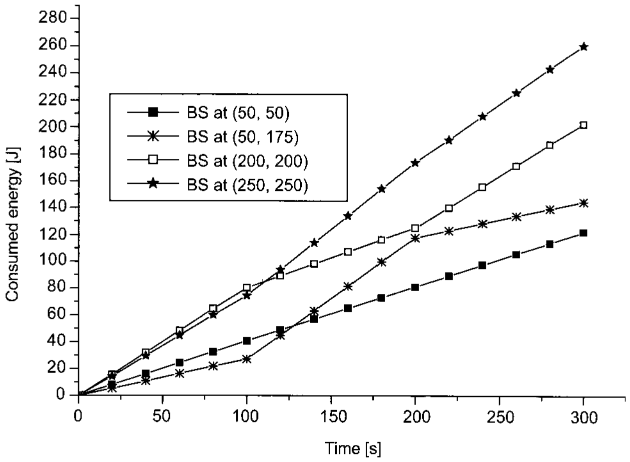

Fig. 3. Effect of distance on energy consumption.

III. RELATED WORKS AND MOTIVATION

Various routing protocols have been proposed in order to achieve the energy conservation goal in WSN. However, hierarchical clustering routing protocols are proven to perform best in conserving the energy as compared to flat routing protocols [3].

LEACH proposed in [7] is a hierarchical routing protocol that obtains energy efficiency by using clustering of sensor nodes to reduce the distance between source nodes and sink and the number of data messages to be transmitted to the BS. The basic topology of the LEACH protocol is shown in Fig. 1. The operation of LEACH is organized into rounds, where each round consists of a setup phase and a steady state phase as shown in Fig. 2.

During the setup phase, the nodes organize themselves into local clusters, with one node acting as the local BS or CH. Nodes elect themselves as CHs with certain probability. These CH nodes broadcast their status to the other nodes in the network. Each node in the network chooses a cluster with which the node can communicate with minimum energy. The role of the node as a CH is moved to next CH node in each round. LEACH uses randomized rotation of the high-energy CH position such that it rotates among the various sensors in order not to drain the battery of a single sensor. During the steady state phase, data transmission occurs. In order to avoid collision during data transmission, each node is assigned its own TDMA slot by the CH node. Each node then transmits during its own TDMA slot and goes to sleep in other nodes' transmission slot. In addition, LEACH performs local data fusion to compress the data to be sent from the clusters to the BS, further reducing energy dissipation and enhancing system lifetime [7]. Thus, LEACH achieves energy efficiency by reducing the total number of data messages to be transmitted and by the introduction of a small number of dedicated CH nodes for data collection, fusion, and transmission. However, LEACH does not take into account of the distance and the residual energy of the nodes to be elected as CH node. Thus, there are chances that energy consumption in the network is not distributed in uniform manner.

LEACH-C proposed in [8] uses a central control algorithm to produce better clusters by dispersing the cluster head nodes throughout the network. Thus, LEACH-C uses a centralized clustering algorithm and the same steady-state protocol as LEACH [8]. During the setup phase, all the nodes send their position and energy information to the BS. Using these information, the BS finds a predetermined number of CHs in the network. Then, the BS selects CHs from among the nodes which have energy greater than average energy of all sensor nodes in the network. With these candidate CHs, the BS finds clusters by using the simulated annealing algorithm [12]. The steady state phase of LEACH-C is similar to the steady state phase of LEACH. LEACH-C differs from LEACH only in that it uses centralized algorithm to select the CH nodes. LEACH-C has drawback in that it only takes into account of the energy in the nodes while selecting CHs. Thus, the nodes which are far away from the BS use up more energy when they act as CH nodes.

In routing protocol of wireless sensor networks based on dynamic setting cluster, the desired number of CH nodes is calculated dynamically as opposed to LEACH and LEACH-C where the number of CHs is decided in the beginning of the network setup [9]. This protocol saves energy in the network by avoiding the selection of unnecessarily large number of CHs even when a large number of nodes are dead in the network. However, this protocol does not consider transmission distances from nodes to CH and CH to BS.

EEEAC protocol divides the network into small sub-areas, each with a CH [10]. The selection of CH is done merely on the basis of residual energy of nodes in the sub-area, i.e., the node with the highest residual energy is selected as CH node in the sub-area.

BCDCP protocol splits the network into a number of clusters such that the distances between the CHs are roughly equal and number of nodes in each cluster are also more or less equal [11]. This protocol considers only the distance among the CH nodes for multi-hop data transmission. Therefore, energy consumption is reduced only between the communicating CHs, not between the CHs and the BS. This is the unequal energy depletion that is not solved in the previous protocols.

The shortcomings discussed in the preceding paragraphs suggest the need for new energy efficient routing protocol and are the motivating factors behind our work. We exploit the fact that the transmission distance has a great effect in energy consumption in the network, as shown in Section II, and propose a new routing protocol which we name as DAIC. The proposed DAIC protocol achieves the energy conservation goal by reducing the transmission distance between CH nodes and the BS as well as among the CH nodes. Furthermore, the proposed DAIC protocol uses dynamic method for determining the number of CH nodes in the network and employs data compression at the CH nodes so as to further reduce the energy consumption in the network.

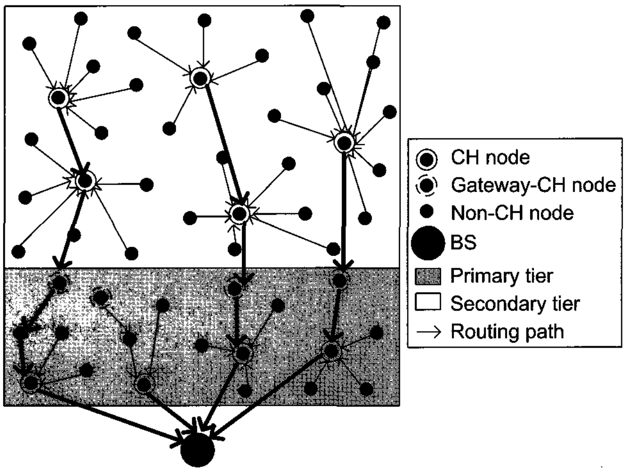

Fig. 4. Topology of proposed DAIC protocol.

IV. PROPOSED DAIC PROTOCOL DESIGN AND OPERATION

The proposed DAIC protocol achieves energy conservation goals by exploiting the facts that the energy consumption during data transmission depends upon the distance over which the data have to be transmitted as shown in (1) and Fig. 3 and that the sensor nodes adjust their transmission power depending upon the data transmission distance. Also, the number of CHs in the network is set dynamically to avoid maintaining unnecessarily large number of CHs in the network. The major novelty of this work is that the network is divided into a number of tiers and CHs are selected in each tier and gateway CHs are selected in each tier except the one furthest from the BS. Theoretically, a network can be divided into any number of tiers, depending upon the density of nodes in the network. However, for simplicity we divide the network into two tiers.

The proposed DAIC protocol operation is divided into rounds as in LEACH and LEACH-C protocols. Each round has both setup and steady state phases. The setup phase consists of network setup, routing path construction, and schedule creation phases. The steady state phase comprises the data transmission phase. The proposed DAIC protocol operation is described in the subsections below.

A. Network Setup Phase

This phase consists of activities like tiers formation, CH selection, cluster setup, routing path formation from non-CH nodes to the CH nodes, and schedule creation for transmission of data in each cluster. In the beginning of this phase, each node sends its current location and residual energy status to the BS. Based on the location information, the BS finds the vertical distance of itself from each node. This vertical distance is used to allocate the node to one of the primary or secondary tiers. Moreover, the vertical distance is used for selecting the CHs and gateway CHs in the tiers. All the processes involved in this phase requires some complicated calculations. However, since all the calculations are executed in the BS, these calculations will have no effect on energy consumption of the nodes.

The vertical distance is calculated as shown in (2). Let

$$d_v = \begin{cases} x - x_{bs}, & \text{if } (x_{bs} \le \frac{x_3-x_1}{y_3-y_1}(y_{bs}-y_1)+x_1) \;\&\; (\frac{y_4-y_1}{x_4-x_1}(x_{bs}-x_1)+y_1 \le y_{bs} \le \frac{y_3-y_2}{x_3-x_2}(x_{bs}-x_2)+y_2), \\ & \text{for } (x_{bs} \le \min(x_1,x_3)) \;\&\; (\min(y_1,y_2) \le y_{bs} \le \max(y_2,y_4)) \\ & \| \text{ if } (x_{bs} \ge \frac{x_4-x_2}{y_4-y_2}(y_{bs}-y_2)+x_2) \;\&\; (\frac{y_3-y_2}{x_3-x_2}(x_{bs}-x_2)+y_2 \le y_{bs} \le \frac{y_4-y_1}{x_4-x_1}(x_{bs}-x_1)+y_1), \\ & \text{for } (x_{bs} \ge \min(x_2,x_4)) \;\&\; (\min(y_1,y_2) \le y_{bs} \le \max(y_3,y_4)), \\ y - y_{bs}, & \text{if } (y_{bs} \le \frac{y_2-y_1}{x_2-x_1}(x_{bs}-x_1)+y_1) \;\&\; (\frac{x_4-x_1}{y_4-y_1}(y_{bs}-y_1)+x_1 \le x_{bs} \le \frac{x_3-x_2}{y_3-y_2}(y_{bs}-y_2)+x_2), \\ & \text{for } (y_{bs} \le \max(y_1,y_2)) \;\&\; (\min(x_1,x_3) \le x_{bs} \le \max(x_2,x_4)) \\ & \| \text{ if } (y_{bs} \ge \frac{y_4-y_3}{x_4-x_3}(x_{bs}-x_3)+y_3) \;\&\; (\frac{x_3-x_2}{y_3-y_2}(y_{bs}-y_2)+x_2 \le x_{bs} \le \frac{x_4-x_1}{y_4-y_1}(y_{bs}-y_1)+x_1), \\ & \text{for } (y_{bs} \ge \min(y_3,y_4)) \;\&\; (\min(x_1,x_3) \le x_{bs} \le \max(x_2,x_4)). \end{cases} \tag{2}$$

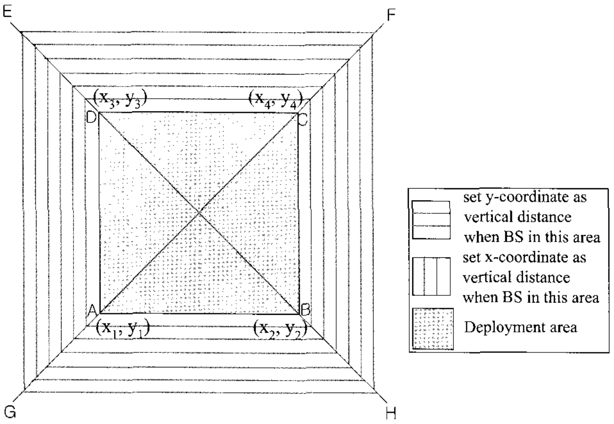

Fig. 5. Selection of vertical distance.

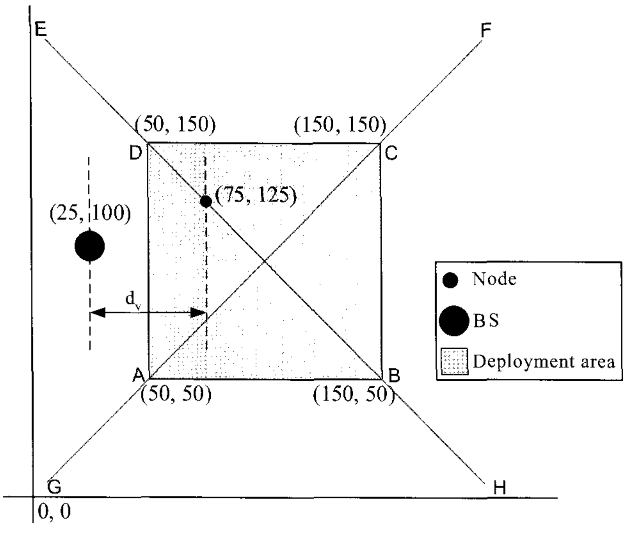

Fig. 6. Illustration for selection of vertical distance.

$(x_1, y_1), (x_2, y_2), (x_3, y_3)$, and (x_4, y_4) be the co-ordinates of corners of the deployment area as shown in Fig. 5. Then, by using the co-ordinate geometry, we can find the vertical distance of each node.

In (2), d_v is the vertical distance of the node from the BS, x is the x-coordinate of the node, x_{bs} is the x-coordinate of the BS, y is the y-coordinate of the node, y_{bs} is the y-coordinate of the BS. It should be noted that the BS might be located anywhere inside or outside the deployment area. However, for general deriving general relation we have assumed that BS is located outside the deployment area. For the first case where $d_v = x - x_{bs}$, in the first condition the inequality relation $x_{bs} \le \frac{x_3-x_1}{y_3-y_1}(y_{bs}-y_1)+x_1$ gives the points left to the line AD. Also, the inequality relation $\frac{y_4-y_1}{x_4-x_1}(x_{bs} - x_1) + y_1 \le y_{bs} \le \frac{y_3-y_2}{x_3-x_2}(x_{bs} - x_2) + y_2$ gives the points above the line AG and below the line ED. Hence, the first condition for first case gives the points inside the boundary GADE. Similarly, in the second condition for the first case, where $d_v = x - x_{bs}$, the inequality relations give the points inside the boundary FCBH. Therefore, the inequalities in the two conditions for the first case, where $d_v = x - x_{bs}$ give the location of the BS within the boundary GADE and FCBH, respectively. In such a case, the x-coordinate value is taken as vertical distance of the node from the BS. Similarly, the inequality conditions for $d_v = y - y_{bs}$ give the position of BS inside the boundary GABH and EDCF. In such case, y-coordinate value is taken as the vertical distance of the node from the BS. Note that if the BS lies inside the deployment area, then y-coordinate of the node is selected as vertical distance. Fig. 5 shows the area in which x-coordinate or y-coordinate can be chosen as vertical distance by using conditions in (2).

As an example, we calculate the vertical distance using (2) with Fig. 6. Let $(x_1, y_1) = (50, 50)$, $(x_2, y_2) = (150, 50)$, $(x_3, y_3) = (50, 150)$, and $(x_4, y_4) = (150, 150)$. Let BS be at $(x_{bs}, y_{bs}) = (25, 100)$ and let the node is at $(x, y) = (75, 125)$. Then, if we substitute these coordinate values to evaluate the conditions in (2), only the inequalities in the first condition of first case will be valid i.e., only the condition $x_{bs} \le \frac{x_3-x_1}{y_3-y_1}(y_{bs} - y_1) + x_1 \& \frac{y_4-y_1}{x_4-x_1}(x_{bs} - x_1) + y_1 \le y_{bs} \le \frac{y_3-y_2}{x_3-x_2}(x_{bs} - x_2) + y_2$, for $x_{bs} \le \min(x_1, x_3) \& \min(y_1, y_2) \le y_{bs} \le \max(y_2, y_4)$ will be valid. The result after evaluation will be $25 \le 50$ & $25 \le 100 \le 125$, for $25 \le 50$ & $50 \le 100 \le 150$, which is absolutely true. Therefore, x-coordinate should be taken as vertical distance and is given by $d_v = x - x_{bs} = 75 - 25 = 50$.

With the vertical distances determined from (2), the BS calculates the average vertical distances of nodes from the BS by summing up the vertical distances of all the nodes from the BS and dividing the calculated value by the total number of nodes. The nodes that have the vertical distance less than the average vertical distance of nodes from the BS are selected as members of primary tier. Now, the BS computes average energy level of all the nodes in the primary tier. Then, the BS chooses a set of nodes, denoted by S, whose energy levels are greater than the average energy of the nodes in the primary tier. Primary-CHs for each round will be chosen from the set S, which ensures that only the nodes with sufficient energy are selected as

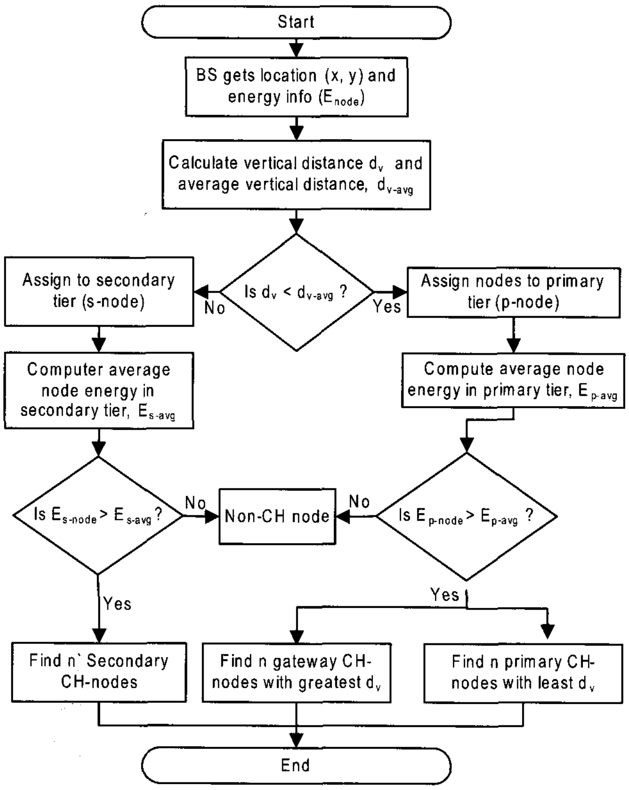

Fig. 7. Flowchart for network setup in proposed DAIC protocol.

primary-CHs, while the nodes with low energy can prolong their lifetime by performing the tasks that require low energy. The percentage of nodes to be selected as primary CHs, secondary CHs, and gateway CHs is defined before the network setup. On the basis of this defined percentage, the BS calculates the number of primary-CHs, denoted by n, depending upon the number of alive nodes in the primary tier. These n nodes have energy greater than average energy of all nodes in the primary tier. From the set S, n nodes with greatest vertical distance from the BS are selected as gateway-CHs for the secondary tier. Each gateway-CH is actually an ordinary sensor node in primary tier. The gateway-CHs are just relay nodes for forwarding the data from the secondary-CHs to the primary-CHs. Instead of any general node, DAIC chooses nodes at the greatest vertical distance in the primary tier as gateway-CH nodes so as to reduce the transmission distance between the secondary-CHs and the gateway-CH nodes in the primary tier.

Similarly, the nodes that have vertical distance greater than the average vertical distance of the nodes from the BS are selected as members of secondary tier. Then, the BS computes average energy level of all nodes in the secondary tier, and chooses a set of nodes, denoted by S', whose energy levels are larger than the average energy value. In this tier also, secondary-CHs are chosen from the set S'. The BS calculates the number of secondary-CHs denoted by n', similar to the primary-CHs and selects them from the set S'. Flowchart for the network setup is shown in Fig. 7.

With these selected CHs, the BS finds the clusters by using simulated annealing algorithm [12]. This algorithm attempts to minimize the amount of energy for non-CH nodes to transmit their data to the CH nodes by minimizing total sum of squared distances between all non-CH nodes and the closest CH nodes.

After the decision of primary-CHs, secondary-CHs, gateway-CHs, and their associated nodes, the BS broadcasts a message containing the primary-CH ID for each node in primary tier, secondary-CH ID for each node in secondary tier, and gateway-CH ID for each secondary-CH in secondary tier. The node then checks for its own ID, sent primary-CH IDs or secondary-CH IDs, and gateway-CH IDs. For the nodes in primary tier, if the primary-CH ID matches with its own ID, then the node is a primary-CH, otherwise it is just a member of one of the clusters in primary tier. Similarly, for the nodes in secondary tier, if the secondary-CH ID matches with its own ID, then the node is a secondary-CH, otherwise it is just a member of one of the clusters in secondary tier. And if for the nodes in primary tier, the gateway-CH ID matches with its own ID, then the node is a gateway-CH, otherwise it is just a member of one of the clusters in primary tier. The nodes associate themselves with their respective CHs and form clusters in primary and secondary tiers.

As mentioned earlier, DAIC divides the network into two tiers. The advantage of dividing the network into tiers is that nodes with short distance from the BS and high residual power can be selected as CHs. Therefore we can obtain equal energy depletion between nodes. Also, we use vertical distance to divide the network into tiers because we are interested in dividing the network into a number of flat rectangular tiers. Euclidean distance as in has not been used to divide the network into tiers as in [13] because the network will be divided into circular tiers by using Euclidian distance, which is not in accordance with the concept of dividing the network into flat tiers in our work.

B. Routing Path Construction Phase

Once the CHs, gateway CHs, and associated nodes are decided, the BS constructs a routing path by connecting all the CH nodes in the secondary tier with gateway CHs in the primary tier. Similarly, the gateway CHs are connected to their respective CH nodes in the primary tier as shown in Fig. 4. Thus, the proposed protocol distributes the burden of routing evenly among the CHs in the primary tier by selecting CHs near to BS.

C. Schedule Creation Phase

After the CHs, gateway CHs, associated nodes, and routing path are created, the nodes in each cluster determine their TDMA slots for data transmission and go to sleep until the time for their own data transmission. The use of TDMA slots for data transmission minimize the collision and thus help to achieve better performance in both energy conservation and number of data transmission to the BS.

D. Data Transmission Phase

Data transmission occurs in the steady-state phase of protocol operation. The steady-state phase of the proposed DAIC protocol is identical to that of LEACH and LEACH-C protocol. The major activities in this phase are: Data sensing and gathering, data fusion and compression, and data routing which are explained in subsections below.

Table 1. Simulation parameters.

Type	Value
Transmitter Amplifier	10^{-12}J
Data Bit	2000 bps
Number of nodes	100
Number of primary-CHs	5%
Number of secondary-CHs	5%
Number of gateway-CHs	number of primary-CHs
Initial Energy of node	10 J
Position of BS	(50,50) and (50,150)

D.1 Data Sensing and Gathering

The proposed DAIC protocol is a proactive routing protocol, i.e., the sensor nodes sense the environment continuously and transmit the sensed data to their respective CHs or BS. Therefore, in the beginning of the data transmission phase, the data have to be gathered at the CHs where they go through some operations before they are transmitted to the BS. To aggregate data, sensor nodes transmit the sensed data to the CH nodes where they are buffered as in LEACH and other hierarchical clustering protocols [7].

D.2 Data Fusion and Compression

From (1), we can conclude that the size of data also affects the energy consumption in the node. The data gathered in the CH nodes are huge in number as well as in size. Therefore, to conserve the energy in the network, these data need to be compressed into a single data message before transmitting to the BS. The CHs fuse the data gathered from the sensor nodes into a single data message and compress the fused data so that relatively smaller sized data messages are transmitted to the BS.

D.3 Data Routing

The compressed data are transmitted to the gateway-CH nodes or BS along the path determined in routing path construction phase. The gateway-CH nodes collect the data from secondary-CH nodes and forward them to the primary-CH nodes. The primary-CH nodes then transmit the aggregated data to the BS.

The proposed DAIC protocol operates in rounds similar to LEACH and LEACH-C protocol. After each round of communication, the phases explained above are repeated.

V. SIMULATION RESULTS

A. Simulation Environment

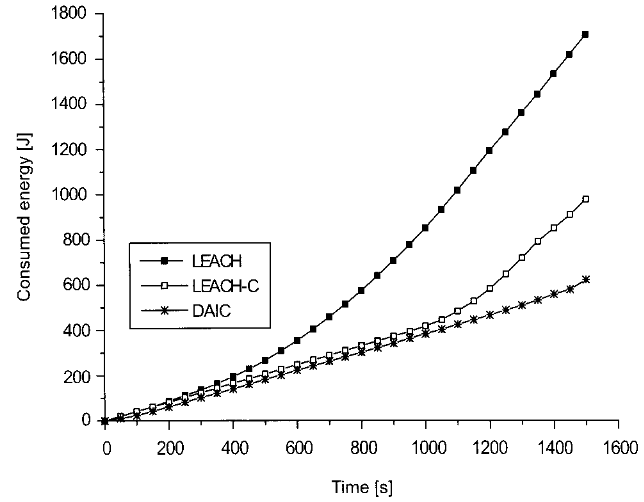

Fig. 8. Energy consumption over simulation time (BS at center).

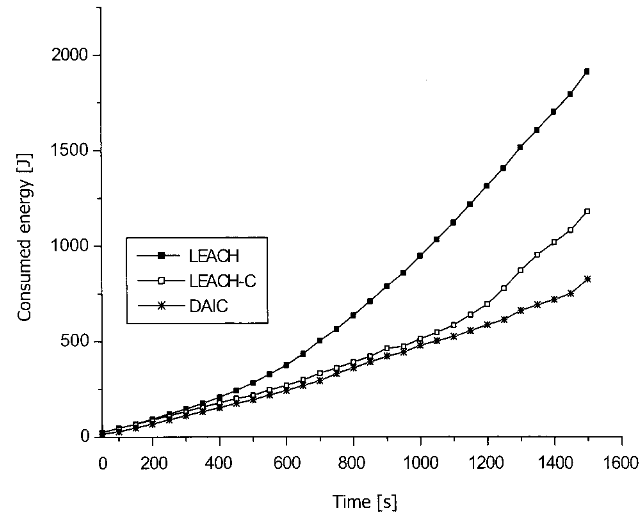

Fig. 9. Energy consumption over simulation time(BS not at center).

We used ns-2.27 for performance evaluation of the proposed DAIC protocol [14], [15]. At this simulation environment, a network of 100 nodes is deployed in an area of 100 m × 100 m with BS at center (50, 50) and BS at not at center (50, 150). We set the initial energy of each node to 10 J. The number of CHs in the primary tier was set to 5% of total alive nodes in the primary tier, which is discussed to be suitable in [7]. Similarly, the number of CHs in the secondary tier was set to 5% of total alive nodes in the secondary tier and the number of gateway-CHs was set to be equal to the number of CH nodes in the primary tier. The channel bandwidth was set to 1 Mbps. The packet header size was set to 25 bytes and size of each data was set to 500 bytes. We assumed that no energy was consumed when the node stayed idle or went to sleep and the energy was spent only during data transmission and reception. The simulation time was set to 1500 seconds. The detail simulation parameters are summarized in Table 1.

B. Performance Evaluation

We compared the proposed DAIC with typical routing protocols LEACH and LEACH-C by using three performance metrics: energy consumption over simulation time, number of nodes alive over simulation time, and the number of data received at the BS. The first performance metric, energy consumption over simulation time gives an idea of the rate of consumption of energy in the network and the second metric, number of nodes alive over simulation time gives an idea of the time over which the network can send the data before all the nodes in the network die. Similarly, the third metric, number of data received at the BS gives an estimation of the effectiveness of the network

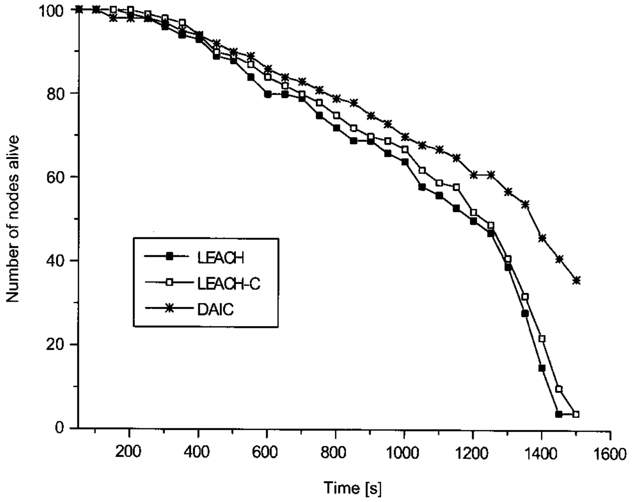

Fig. 10. Number of nodes alive over simulation time (BS at center).

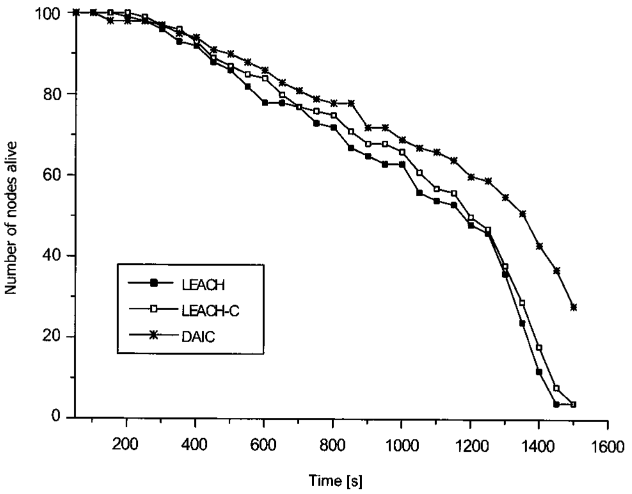

Fig. 11. Number of nodes alive over simulation time (BS not at center).

in transmitting the sensed data to the BS without collision or packet loss.

The simulation results are shown in Figs. 8–12. Fig. 8 shows the simulation results for energy consumption over simulation time. As shown in Figs. 8 and 9 , the proposed DAIC protocol consumes about one third and about two third energy as compared to LEACH and LEACH-C protocols respectively. In the beginning, the energy consumption in proposed DAIC protocol is more or less similar to the energy consumption in LEACH-C protocol. However, as the simulation time increases, DAIC performs better in terms of energy conservation as compared to LEACH-C. This is because, in the beginning all the nodes are alive and have high energy. Therefore, there are chances that some of the nodes near to the BS might be selected as CH nodes in case of LEACH-C too. But as the simulation time increases, some of the nodes near to the BS get drained away with battery power, and thus there are more chances for greater number of distant nodes to be selected as CH nodes. Also, since randomization method is applied to select CHs in LEACH-C, it is not necessary that nodes near to the BS are selected as CHs all the time. Whereas, in case of proposed DAIC protocol, always high energy nodes, that are at closest distance from the BS, are selected as primary CHs. Also, as opposed to the proposed DAIC protocol, there is no dynamic selection of CHs in LEACH-C, which adds to the greater energy consumption in LEACH-C. Similarly, Figs. 10 and 11 show that our DAIC protocol performs well in terms of number of nodes alive over simulation time. Our proposed DAIC scheme has 36 alive nodes, whereas LEACH and LEACH-C have 4 alive nodes at the simulation time of 1500 seconds when BS is at center.

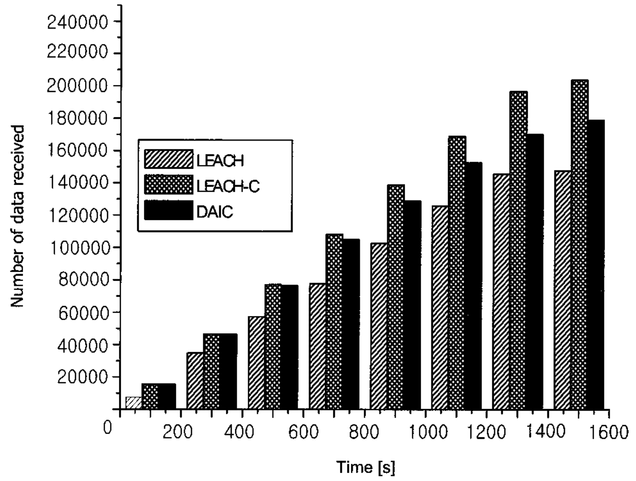

Fig. 12. Number of data received at BS over simulation time.

In Figs. 10 and 11, we can see that the number of nodes started decreasing from the almost 200 seconds during 1500 simulation seconds. That is, the number of alive nodes is 100 up to almost 200 seconds of simulation time as in [7] and [8]. We think that the slight slope differences in LEACH and LEACH-C simulation results are due to the different PHY transmission power and MAC parameter conditions. The number of alive nodes after the completion of simulation time determines the life of the network. More the number of alive nodes after simulation time, longer will be the life of the network. Therefore, from the simulation result shown in Fig. 10, we can conclude that the network lifetime of proposed DAIC protocol is also greater than that of LEACH and LEACH-C.

Fig. 12 shows the number of data received at the BS. The result shows that for the proposed DAIC protocol, the number of data received at the BS is more or less equal to the number of data received at the BS for LEACH-C protocol. But as the simulation time increases, the number of data received is slightly lower for DAIC as compared to LEACH-C. This is an obvious result, as we set the CHs dynamically, which has result of a slightly small number of data transmission because of small number of CHs as compared to LEACH-C. In this paper, we have not shown the simulation results for routing protocol of wireless sensor networks based on dynamic setting cluster, EEEAC, and BCDCP. However, from the performance evaluation of BCDCP in [11], we can infer that the proposed DAIC protocol is more than 6% efficient in energy conservation as compared to the BCDCP protocol because BCDCP is showing 30% energy efficiency as compared to LEACH-C, whereas the proposed DAIC is showing 36.27% energy efficiency as compared to LEACH-C under the very similar simulation environment [11]. Even though this relative and quantitative comparison is a little ambiguous, we are sure to get much higher energy performance, if CH-to-BS distance awareness concept of DAIC is adapted into LEACH, LEACH-C, EEEAC, and BCDCP.

VI. CONCLUSION

In this paper, we described DAIC protocol for energy efficient routing in WSN. The proposed DAIC protocol outperforms classical hierarchical routing protocols such as LEACH and LEACH-C by dividing the network into primary and secondary tiers and selecting the primary CHs in the primary tier at the nearest distance of the BS. These primary CHs are assigned with the duty of collecting the data from the other non-CH nodes in the primary tier and the CH nodes at the secondary tiers and transmitting the collected data to the BS. For fair distribution of energy load in the network, DAIC uses rotation of CH roles in each round of communication and selects CHs on the basis of residual energy. Also, a considerable amount of energy is conserved by determining the number of CHs dynamically depending upon the number of alive nodes in the network so as to prevent the unnecessary selection of a huge number of CHs even when a large number of nodes are dead.

Our simulation results show that the proposed DAIC protocol is at least more than 36% and at most more than 63% efficient in conserving energy as compared to the classical hierarchical clustering routing protocols such as LEACH and LEACH-C respectively. Consequently, the proposed DAIC can be adapted to a routing protocol for energy-sensitive WSN applications owing to its energy-efficient features.

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Navin Gautam received Bachelor's degree in Computer Engineering from Kathmandu University, Dhulikhel, Nepal and Master's degree in Information and Communication Engineering from Chosun University, Gwangju, South Korea in 2007 and 2010, respectively. Currently, he is working as a Full Time Lecturer in Kantipur Engineering College, Tribhuwan University, Nepal. His research interests include mobile ad hoc and wireless sensor networks.

Jae-Young Pyun was born in JangSeong, JeollaNamdo, Korea, on February 1972. He received a B.S. degree from Chosun University, an M.S. degree from Chonnam University, and a Ph.D. degree from Korea University, Korea, in Electronics Engineering, in 1997, 1999, and 2003, respectively. From 2003 to 2004, he was with Samsung Electronics, where he was involved in research and development of mobile phone communication systems. In 2004, he joined the Department of Information & Communication Engineering at Chosun University, where he is currently an Assistant Professor. His research interests include Mobile QoS, mobile video communication, and protocols over WSN and VANET.