An Efficient Clustering Scheme for Data Aggregation Considering Mobility in Mobile Wireless Sensor Networks

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Abstract

This paper presents an efficient clustering scheme for data aggregation considering mobility to reduce the network lifetime in Mobile Wireless Sensor Networks (MWSNs). In MWSNs, an accurate data aggregation is affected by failure in time-critical data transmission due to the differences of mobility between cluster head and its members. Consequently, selecting a node with dissimilar mobility from members as a cluster head can lead to unstable clustering. Hence, we propose a clustering scheme considering the mobility and energy to minimize the number of nodes that moves away from the current cluster head before the next cluster formation. The proposed scheme is processed in two-stages. During the first phase of clustering, all nodes calculate their potential score based on the similarity of movement, residual energy and density in distributed manner. Each node decides whether the node itself should be a cluster head or not using a potential score. The second stages, each node select its cluster head among those cluster head candidates considering the link connection time and an amount of energy to transmit the collected data. A higher residual energy node with the smallest movement deviation is selected as a cluster head. In addition to, we propose a mobility adaptive slot utilization to reduce the idle slot. The experimental result shows that the proposed scheme can provide an efficient data aggregation in terms of network lifetime and the number of nodes leaving its cluster head.

Keywords: *Clustering, Mobile Wireless Sensor Networks, Data aggregation*

1. Introduction

In the recent years, the technological advances in Micro-Electro-Mechanical Systems (MEMS) have facilitated the development of smart sensors which can be applied to a variety of purposes [1]. Mobile Wireless Sensor Networks (MWSNs) has been appeared as a result of the convergence of a high-performance smart sensor technology and mobile wireless communication technology. MWSNs is one of the rising technologies for numerous areas of application, such as battlefield surveillance, remote healthcare, land monitoring for smart farming and environmental monitoring, and so on [2, 3, 4].

For data collecting in MWSNs, the mobile sensor nodes are used to acquire information reflecting the changes of the surrounding environment. Mobile sensors nodes transmit information towards the sink if and when they detect environmental events or the changes of indicated phenomenon.

This kind of deployment creates large number of redundant sensory data. Routing of such redundant data not only saturates network resources, but also consumes nodes energy. This gives rise to new and unique challenges in data management and information processing techniques [1]. Thus, data aggregation may be effective technique in this context because it reduces the number of packets to be sent to sink by aggregating the similar packets in an energy efficient manner to enhance network lifetime [5]. However, an efficient data gathering using wireless sensor nodes in MWSNs still requires solutions to a number of technical challenges that stem primarily from the constraints imposed by simple wireless sensor devices such like as low processing power, limited battery lifetime and small storage capacity which required very efficient resource utilization [6]. In addition, rapidly changing topology and frequent link failures due to the mobility pose serious issues in routing of MWSNs [7].

Some routing protocols for data aggregation assume that each sensor node can directly send data to the sink, which is not a realistic assumption because of inherent constraints of wireless sensor nodes. To support some of those constrained functions and better data aggregation sensor nodes are often grouped into disjoint, non overlapping subsets called. Clusters create hierarchical WSNs which incorporate efficient utilization of limited resources of sensor nodes and thus extends network lifetime. Cluster head communicates with each member nodes and then sends the aggregated data directly to the sink.

Various clustering techniques including Low-Energy Adaptive Clustering Hierarchy (LEACH), which is typical clustering in WSNs, have been proposed by grouping the sensors into clusters and assigning specific tasks to the sensors in the clusters. Cluster-based architectures in wireless sensor networks (WSNs) have the advantage of providing scalable and resource efficient solutions [8]. For WSNs or MWSNs, some cluster based energy efficient schemes have been investigated in many ways [6, 9, 13-14].

In MWSNs, the number of leaving nodes that moves away from the current cluster head before the next new cluster head selection process affects the accurate data aggregation and causes transmission delay for the collected information. Due to the difference of mobility between the cluster head and its members, a time-critical data may not be accurately transmitted to sink. In addition, the transmission delay and unnecessary energy consumption may occur to each sensor node as the result of searching for a new cluster head and being allocated a slot for data transmission. For example, if a cluster head moves in a different direction or different speed from its members, a number of member nodes will move away from their cluster head. Hence, in a mobile environment, it is desirable that a sensor node which has a similar mobility as its members and has high energy should be selected as a cluster head to reduce the number of leaving nodes and prolong the network lifetime. The leaving rate increases as the similarity of the mobility between the cluster head and its members is low. Therefore, we propose an efficient clustering scheme for data aggregation considering mobility and energy to reduce the the case of sensor nodes which once belonged to one cluster moving to another cluster.

The proposed scheme is processed in two-stages. In the first stage, the candidates of cluster head are selected based on the potential score considering the mobility, energy and density. After finishing the process of selecting the candidates of cluster head, the rest of the nodes that are not elected as cluster heads join the best effective cluster head in terms of link connection time and energy. In our scheme, by using the Mahalanobis distance, we select as a cluster head a sensor node that has a similar average speed and average moving direction as its neighbors. The Mahalanobis distance [10-11] as described in Section 2, is a standard distance metric used to compare two statistical distributions, which provides a useful way to measure the similarity. Results from the experimental implementations have demonstrated that the proposed cluster head selection scheme prolongs the network lifetime and reduces the number of leaving nodes.

The rest of this paper is organized as follows. In Section 2, we review some clustering schemes in MWSNs. Section 3 presents our clustering scheme. Next, in Section 4, we present some simulation results in order to evaluate the proposed scheme. Finally, we conclude our paper in Section 5.

2. Related Works

In this section, we review some clustering schemes for MWSNs and explain the concept of the Mahalanobis distance as it is applied in similarity of movement of our scheme.

2.1. Clustering Schemes

A number of previous investigations have explored a variety of ways to improve the problems that might occur from applying LEACH based clustering schemes to MWSNs [12-15].

LEACH(Low-Energy Adaptive Clustering Hierarchy) presented in [12] is the very first protocol that uses clustering for extending the network lifetime in WSNs. In LEACH, cluster heads are randomly selected by turns with a certain probability consider the remaining energy in order not to drain the battery of a single sensor node. Although LEACH improves the performance in terms of evenly energy dissipation, its applications are limited on fixed sensor nodes without considering mobility. As the LEACH protocol does not take into account the mobility of the sensor nodes after the setup phase for cluster head selection within a round, the LEACH protocol is accompanies by serious data losses in MWSNs [13-14].

LEACH-ME(LEACH-Mobile Enhance protocol): The LEACH-ME enhance the LEACH-M based on a mobility metric remoteness for cluster head election. They ensures high success rate in data transfer between the cluster head and the collector nodes even though nodes are moving [13].

LEACH-M(LEACH-Mobile) is introduced to support mobility by adding membership declaration to the existing the LEACH protocol. LEACH-M uses the same setup procedure of the LEACH protocol. The basic idea in the LEACH-M is to confirm whether a mobile sensor node is able to communicate with a specific cluster head, as it transmits a message which requests for data transmission back to mobile sensor node from cluster head within a time slot allocated in TDMA schedule of a cluster head [14].

M-LEACH(An Energy Efficient Routing Scheme for Mobile) has been proposed based on using the LEACH protocol to support mobile sensor nodes; it also reduces the consumption of the network resource in each round [15]. The idea of M-LEACH is to divide the sensing area into sub-areas and try to optimize the location of the cluster heads in those sub-areas. In M-LEACH, to determine the cluster head, they compute the cost considering the x and y coordinates of the sensor nodes and their velocities. A sensor node with the smallest cost is then selected as a cluster head. However, this means a slowly moving sensor node is likely to become a cluster head. The leaving rate might be increased due to the relatively slow velocity of its cluster head. Also they present a way to select cluster head for. For each cluster head, the willingness is calculated considering the remaining energy of the cluster head and the total the number of nodes in the cluster. The willingness indicates the availability of the cluster for a new node to join it. Then, the rests of the cluster heads calculate the cost using the willingness of a cluster head and the distance between sensor nodes and cluster head. With the cost, the sensor nodes belong to the cluster head with the smallest value. Frequent disconnection between cluster head and members will be occurred in case the mobility of the two sensor nodes is different although the distance between of them is short. Above all, these computations are performed by the base station and then the information is broadcasted to all sensor nodes. This is not reasonable in mobility environment.

CES(Cluster-based Energy-efficient Scheme) proposed in [6] for MWSNs was designed based on LEACH protocol. The CES relies on weighing k-density, the residual energy and the mobility parameters in the cluster head election. This protocol re-elects new cluster head as the cluster head that moves to another cluster [9].

2.2. Mahalanobis Distance

The Mahalanobis distance is a standard distance metric used to compare two statistical distributions, which provides a useful way to measure similarity. The Mahalanobis distance is based on correlations between variables by which different patterns can be identified and analyzed [10]. The Mahalanobis distance measures the distance to the center of the error ellipsoid, normalized by the covariance ∑ of the distribution p(x,y) [11].

Formally, the Mahalanobis distance of multivariate vector $p=(p_1,p_2,p_3,\ldots,p_n)$T from a group of values with mean $\mu=(\mu_1,\mu_2,\mu_3,\ldots,\mu_n)$T and covariance matrix $\sum^{-1}$ is defined as:

$$D_M(p) = \sqrt{(p-\mu)^T \sum^{-1} (p-\mu)} \quad (\mathbf{1})$$

For example, two objects are displayed by using black circles as markers in Figure 1. The two object are at the coordinates (7,0) and (0,5) from the center μ of the distribution respectively.

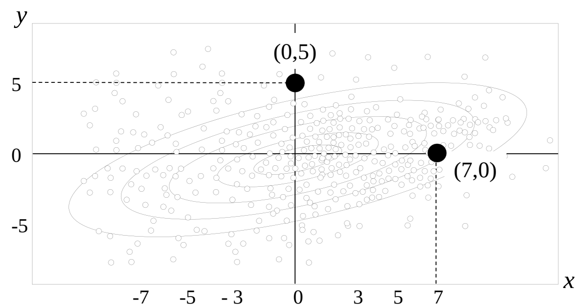


Figure 1. Concept of the Mahalanobis distance

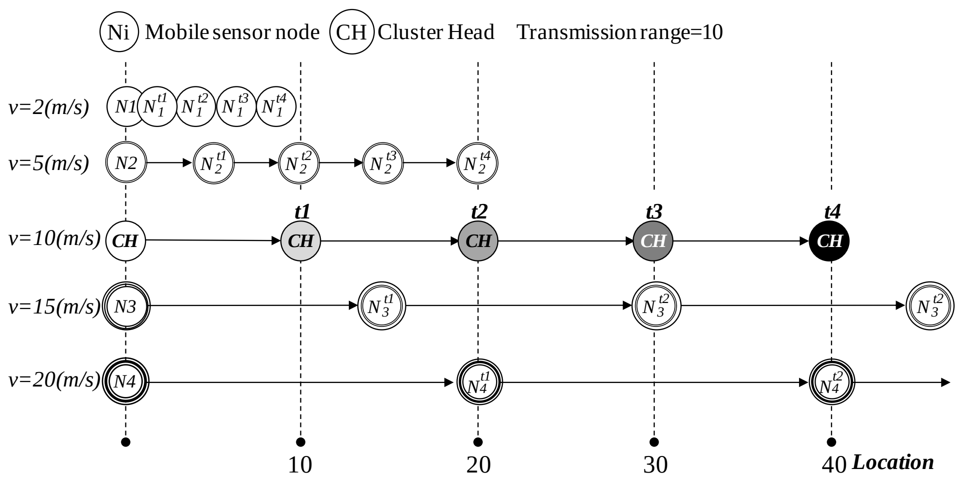
The question is that which marker is closer to the multivariate center of this distribution? The Euclidean distances are 5 and 7 respectively. By Euclidean distances, the point at (0,5) is closer to the center. However, for this distribution, the variance in the y-axis is less than the variance in the x-axis, so in some sense the point (0,5) is more standard deviations away from the center than (0,7). It means that the point at (7,0) is closer to the center in the sense that it is more likely to be observed an object near (7,0) than to be observed one near (0,5). The probability density is higher near (7,0) than it is near (0,5) [16].

3. Problem Statements

In this section, we examine the effects of the mobility on the leaving rate and why it should be minimized.

3.1. Leaving Rate

A leaving node is defined as a node that moves away from its parent cluster head before the process of a new cluster head election. The leaving rate means a probability that the number of nodes move away from their cluster head given a certain amount of time. The leaving rate increases in the case where the difference of the mobility between the cluster head and the members is large. For example, assume that there are *n* mobile sensor nodes with the difference mobility dispersed in a specific area as shown in Figure 2. If cluster heads are elected without considering the mobility such as their speed and movement direction, the leaving rate is increased. M_{CH}^{t1} means that the members in cluster head at time *t1*. The cluster head has the two members *{N2, N3}* at time *t2* due to the difference mobility between its members. The same phenomenon may be occurred in case the cluster head move with the different direction. If cluster head moves to the right and the members move in the opposite direction, a significant number of nodes become disjointed from the current cluster head as time passes. Path breakage results in large packet delay and packet loss, hence more energy consumption.



$$M_{CH}^{t1} = \{N1, N2, N3, N4\},\ M_{CH}^{t2} = \{N2, N3\},\ M_{CH}^{t3} = \{none\}$$

Figure 2. Member State Depending on the Mobility of Cluster Head

Therefore, the speed and movement direction have to be considered for stable clustering. And, it is desirable that a node moving to the same direction at a similar speed with the other nodes is selected as a cluster head.

3.2. Mobility in LEACH based Clustering

In general, in the LEACH based protocol for MWSNs, each round is divided into a setup phase and a steady state phase as shown in Figure 3. Basically, the LEACH based protocol has many rounds and each round has two phases, a setup phase and steady state phase as shown in Figure 3.

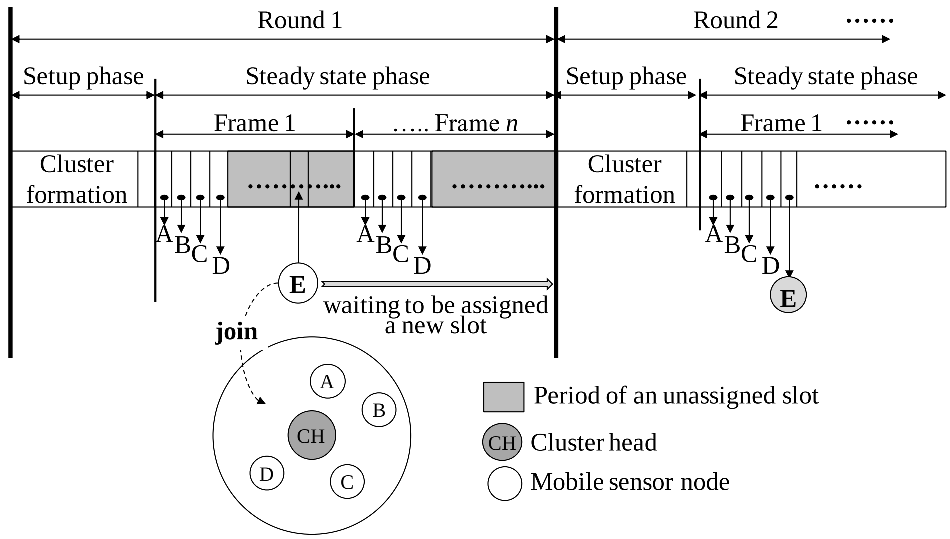


Figure 3. Time Line showing LEACH based Clustering Protocol

Each round begins with a setup phase when the clusters are organized followed by a steady state phase. LEACH uses a Time Division Multiple Access (TDMA) or a Code Division Multiple Access (CDMA) to reduce inter-cluster and intra cluster collisions. During the setup phase, some nodes are elected as cluster heads according to a variety of criteria for selection and the rest of the nodes are organized into clusters. In the steady state phase, the cluster heads set up a TDMA schedule and transmit this to their members as shown in Figure 3. Members send data to their cluster head only during assigned slots according to the TDMA schedule and each cluster head sends the aggregated data to the sink directly in the CDMA way.

In MWSNs, the sensor nodes may physically move from their location, either because of motion in the medium such as water or air. As a result, the network topology is affected by such node joins and failures. Thus, the fixed frame time of MAC protocols like as the LEACH causes performance degradation in a number of ways.

As shown in Figure 3, the nodes which newly join a cluster head have to wait until the newly elected cluster head assigns a slot to them at the next round. For example, if some mobile sensor nodes *A*, *B*, *C* and *D* are being in the cluster head, each node is allocated the slot for transmitting the collected data to its cluster head as shown in Figure 3. A mobile sensor node *E* which newly joins the cluster head cannot get the opportunity to transmit until the next round starts. At this time, a transmission delay occurs. Therefore, the transmission delay can be reduced by maintaining the cluster without changing their members until the new cluster heads are elected. On the contrary, a waste of slot as many as the number of members leaving the cluster head can be also occurred.

4. Proposed Scheme

The proposed scheme is processed in two-stages. In the first stage, the candidates of cluster head are selected based on the potential score considering the mobility, energy and density. After finishing the process of selecting the candidates of cluster head, the rest of the nodes that are not elected as cluster heads join the best effective cluster head in terms of link connection time and energy.

4.1. Cluster Head Candidate Selection

In our proposed scheme, all nodes calculate its waiting time using the potential score to implicitly determine a cluster head candidate. In contention based MAC protocol, all nodes wait to avoid severe collisions and contention among nodes for data transmission. A waiting time can be computed as follows:

$$Waiting\ time = WT_{Max} * PS_{CH} \quad (\mathbf{2})$$

where WT_{Max} is a predefined maximum waiting time and PS_{CH} indicates the potential score for cluster head candidate selection based on three factors for each node, such as its mobility, residual energy and density.

According to equation (2), each node waits to transmit the cluster head announcement (*CHA*) messages. A node with a small waiting time can early broadcasts a *CHA* packet early because its waiting time is short. During the waiting time, the rest of nodes which received *CHA* packets give up rebroadcasting to prevent broadcast storms and they then select the best cluster head.

Each node decides whether to be a cluster head or not by evaluating the potential score PS_{CH} by itself. The node with the highest score is elected as a cluster head. The potential score for node *i* is calculated as:

$$PS_{CH} = w_1 \times SM + w_2 \times DE + w_3 \times DD \quad \left(* \sum_{i=1}^{3} w = 1 \right) \quad (\mathbf{3})$$

where w_1, w_2 and w_3 are the corresponding weighting factors. We assume w_1, w_2,w_3 >0 and each weighting factors can be chosen depending on the application. In addition, the potential score PS_{CH} ranges from 0 to 1. The three factors used above in equation (3) are the similarity of movement, the degree of energy and the degree of density, respectively.

In the above equation (3), the first weighting factor, the Similarity of Movement(*SM*) is a correlation related to the similarity of the speed and direction of movement with its neighbors. If cluster heads are elected without considering mobility parameters such as the speed and direction of movement, the leaving rate is increased. Hence, selecting a cluster head with a large similarity of movement with its members can reduce the number of leaving nodes.

Each node can evaluate the *SM* between the speed and movement direction of its neighbors by using the Mahalanobis distance which can easily determine the similarity between two probability distribution sets [17]. By the Mahalanobis distance, the similarity of the mobility ψ_m is defined as follows:

$$\psi_m(\mu_m, \delta_i) = (\mu_m - \delta_i)^T \sum{}^{-1} (\mu_m - \delta_i) \quad (\mathbf{4})$$

where μ_m is the mean for the speed and movement angle respectively, and δ_i is the mobility of a node *i*. The speed and movement angle can be predicted by referring to the previous history of movement. *SM* increases as the differences in the speed and movement angle are great. The node with the lowest *SM* moves at close to the mean speed and movement angle of their neighbors.

In second weighting factor in equation (3) is the Degree of Energy (*DE*), which denotes the ratio of the residual energy to the initial energy. *DE* is defined as:

$$DE = \left(1 - \frac{E_{\mathrm{Residual}}}{E_{Initial}} \right) \quad (\mathbf{5})$$

where $E_{Residual}$ and $E_{Initial}$ mean the amount of residual energy of a node and the amount of initial energy, respectively. A node with the highest residual energy has the lowest *DE*.

As result of our scheme represented above in equation (3), a node which has a similar mobility with its neighbors is more likely to be elected as a cluster head with a higher residual energy.

The last weighting factor in equation (3) is density. The Degree of Density (*DD*) can be calculated as followings:

$$DD = \left(1 - \frac{D_{Ni}}{D_{Avg}}\right) \quad (6)$$

where D_{Ni} is the number of nodes within the transmission range and D_{Avg} is the average density of entire network. If a value of *DD* is less than 0, *DD* is set to be 0.

As a result of our scheme represented above in equation (3), a higher residual energy node with the smallest movement deviation is likely to be a cluster head because its waiting time is shorter. It can be minimized the changes of its members and energy consumption through the entire network. The rest of nodes which received cluster head announcement packets give up rebroadcasting to prevent broadcast storms and they then select the best cluster head. By selecting the cluster heads with the smallest movement deviation, the changes of the members can be minimized.

4.2. Joining a Cluster Head

After finishing process of electing cluster head, the rest of the nodes that are not elected as cluster heads join the best effective cluster head by considering the link connection time and energy consumption parameters. Each node selects its parent cluster head according to its energy consumption and Link Connection Time (*LCT*). The mobility factor *LCT* was proposed in [18]. Once cluster is organized, all nodes can send data at just a specially assigned slot in the next round after a certain period of time. Frequent disconnection from cluster head can cause the packet loss and transmission delay. Therefore, each node should select a cluster head that consume less energy for transmission to prolong the network lifetime. In addition, to reduce the leaving nodes, LCT between node and cluster head should be longer.

Thus, we induce the weight of a parent cluster head selection (W_{PCH}) using above two metrics, as follows:

$$W_{PCH} = \alpha LCT + \beta\left(1 - \frac{E_C}{E_R}\right) \quad (7)$$

where E_C and E_R mean the amount of energy consumed for transmission and the amount of residual energy of each node, respectively. Each node determines the new cluster head using above two metrics. Consequentially, to organize a stable cluster, each node selects the cluster head which has the lowest energy consumption for transmission and the longest *LCT*. During the *LCT*, two mobile nodes will remain connected within transmission range of each other as shown in Figure 4.

Let (x_i,y_i) be the coordinated of cluster head and (x_j,y_j) be that of mobile sensor node *N*. Also the cluster head and mobile sensor node *N* move to the moving angel θ_i and θ_j with speed v_i and v_j, respectively.

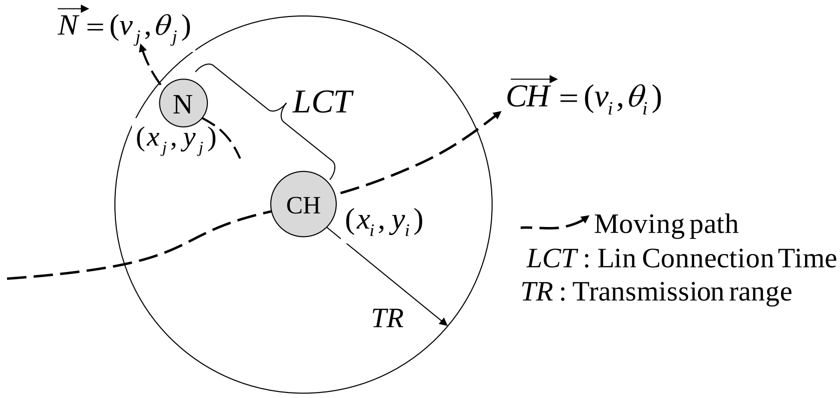


Figure 4. Link Connection Time (*LCT*) between Cluster Head and Mobile Sensor Node

LCT can be predicted using the mobility of node such as the speed and moving direction as below Eq.(8). [18-19].

$$LCT = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \quad (8)$$

where $a=v_i cos\theta_i - v_j cos\theta_j$, $b=x_i-x_j$, $c=v_i sin\theta_i - v_j sin\theta_j$ and $d=y_i-y_j$. If two nodes have zero relative velocity, *i.e.*, $v_i=v_j$ and $\theta_i=\theta_j$, the link will remain forever as *LCT* will be ∞.

4.2. Slot Utilization

To increase the slot utilization, each cluster head determines the number of their members through the request and acknowledgement sections as shown in Figure 5. During the request period (*R*), a sink broadcasts its location, velocity and the amount of energy. Each node received the request messages sends an acknowledgement to the sink.

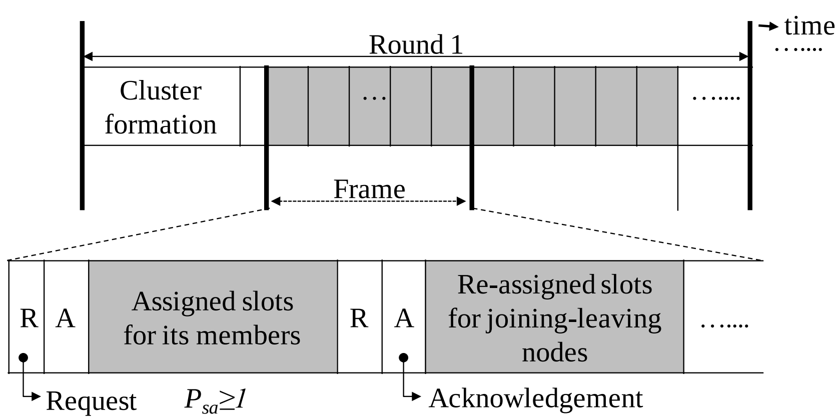


Figure 5. Slot Utilization for Supporting Mobility

As shown in Figure 5, if the probability of slot allocation (Pr_{sa}) is greater than 1, cluster head assigns the slots to the node. The probability of slot allocation is calculated based on the *LCT* as follows:

$$\Pr_{sa} = \left(\frac{LCT}{Round\ time} \right) \quad (9)$$

By assigning the same number of slots to their members, the unused slots can be reduced. In addition, through the rescheduling, the cluster head removes the slots which are assigned to the left node and re-allocates the slot to the newly join node.

5. Performance Evaluation

To evaluate the performance, we simulated our scheme. We consider that sensor nodes are randomly placed over the two-dimensional field with following assumptions:

• The sensor nodes are mobile but the sink is immobile outside of the network field.

• The sensor nodes with global positioning system (GPS) devices can be aware of their location using a localization mechanism [20] and exchange their information with their neighbors periodically.

• They can aware the speed, movement direction and the amount of their residual energy.

• All nodes have identical processing and communication capabilities.

• We consider the density within the 1-hop.

Throughout the simulation, we set 100 X 100(*m*) network configuration. And we assume that the sink is located at (50, 175). The number of sensor nodes is 100, transmission range is 15*m*, the speed of mobile sensor varies from 2 to 10(*m/s*). For our experiments, we used a network topology and energy consumption including data packet size for the simulation which was based on some numeric parameters obtained from [12, 15, 21]. Also, we used the radio model that reflects MICA2 motes that is implemented with several adjustable parameters as follows [12]:

$$E_{totoal}(k,d) = (k \times E_{elec} + k \times E_{amp} \times d^2) + (k \times E_{elec}) \quad (10)$$

where $E_{total}(k,d)$ means that the energy consumption for transmitting *k*-bit messages with distance *d*. Table 1 lists the main simulation parameters.

We use the Reference Point Group Mobility (RPGM) model. The RPGM model was used for the motion of the sensor nodes. The RPGM model represents the random motion of a group of mobile nodes as well as the random motion of each individual mobile node within the group [22]. Group movements are based upon the path traveled by a logical center for the group. The logical center for the group is used to calculate group motion via a group motion vector [23].

To validate the performance, we compare our proposed scheme with LEACH and M-LEACH, which are typical clustering schemes in WSNs and MWSNs respectively.

Figure 6 represents a result of rounds 90% nodes alive. Figure 6 demonstrates that the sensor nodes in proposed scheme survived longer than the other schemes. In Figure 6, the *x*-axis represents the number of nodes alive per round and the *y*-axis represents the simulation time. LEACH selects the cluster heads without considering the location of the sensor nodes. In M-LEACH, the nodes relatively far from the cluster head can be somewhat since the node located in the average position of *x* and *y* coordinates at divided sub-areas is likely to be a cluster head. In our proposed scheme can prolong the network lifetime because the distance between cluster head and their members is small due to the consideration of density. Then, we can see that our scheme is a more effective scheme in terms of prolonging the sensor node lifetime, which is one of the most important factors in wireless sensor networks.

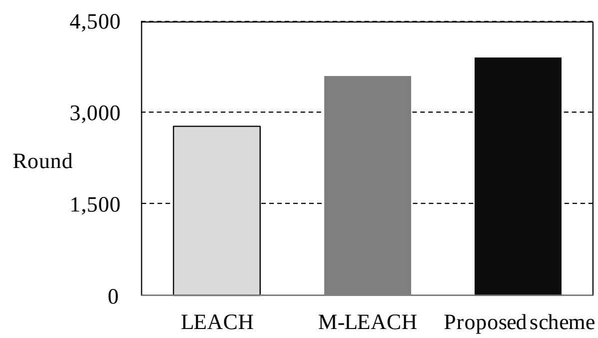


Figure 6. Lifetime of the Sensor Nodes

Figure 7 shows the average number of nodes that are similar in mobility to cluster head per round. Moving with similar mobility means that they move with the differences of speed and moving angle within $\pm$ 10 percentage points. Overall, we can see that the number of nodes which are similar in mobility to cluster head is reducing as sensor nodes are moving rapidly. But, our proposed scheme has a large number of nodes that are similar in mobility to cluster head compare with LEACH and M-LEACH. If cluster head and member move with similar mobility, it can reduce the cost for node to join a new cluster head. Hence, it demonstrates that our scheme can configure a stable clustering.

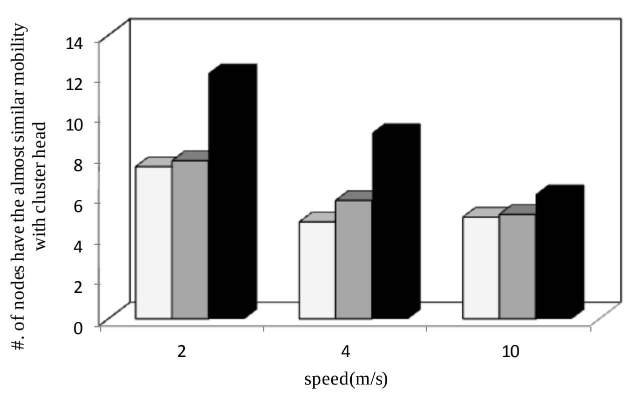


Figure 7. The Number of Nodes that are Similar in Mobility to Cluster Head

Figure 8 shows the leaving rate. The leaving rate is the ratio of nodes which move away from their cluster head before a new cluster head is selected in the next round. As shown in Figure 8, the leaving rate of proposed scheme is lower than other schemes because a proposed scheme is designed by considering the similarity of the mobility of sensor nodes. In M-LEACH, the leaving rate might be increased by selecting a slowly moving node as a cluster head. This result of the simulation also indicates that a proposed scheme is more effective for stable clustering compared to the other schemes.

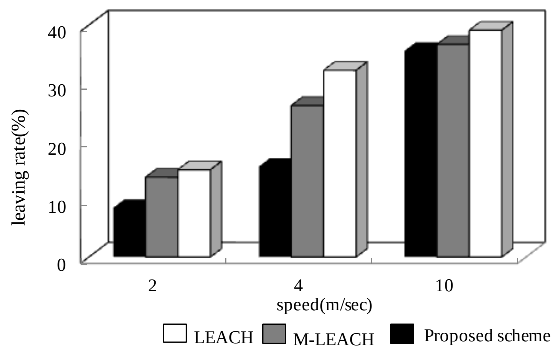


Figure 8. Leaving Rate

6. Conclusions

We have proposed a clustering scheme considering the mobility and energy to minimize the number of nodes that moves away from the current cluster head before the next cluster formation. To select an energy efficient cluster head, we use the following three factors; the similarity of movement, residual energy, density and link connection time. In addition, we propose a utilization of idle slots that can be discarded due to the mobility. In conclusion, our scheme obviously increases the life time and for MWSNs as compared with the other scheme. Nonetheless, our scheme still needs to be improved in various conditions and applications. As part of our future work we will extend our algorithm to enhance its accuracy by diversifying the factors.

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