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An Efficient Clustering Scheme for Cluster-Based Protocols in Mobile Wireless Sensor Networks

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Abstract

Self-organization clustering is based ona variety of studies for MWSNs (mobile wireless sensor networks) as well as WSNs (Wireless Sensor Networks). The size of the sensor field in MWSNs is often larger than in WSNs. When the sensor field is too large, energy inefficiency may result when cluster-heads broadcast an Advertisement Message over the sensor field area.In this paper, we calculate the optimal transmission range for broadcasting an Advertisement Message efficiently. We analyze the number of non-receiving nodes in relation to the transmission range when self-organization clustering protocols are used in mobile environments and propose aTTC (Two-Tier Clustering)method to reduce the number of non-receiving nodes that result when the transmission range is controlled. TTC evenly distributes cluster-head nodes over the network field and prevents any cluster-head clumping generated by self-organization clustering. Consequently, our TTC protocol result in reduced data loss, increased energy efficiency, and enhanced sensor network field robustness by reducing the number of Advertisement Message non-receiving nodes.

Keywords: *clustering, cluster-head, non-cluster-head, transmission range, Advertisement Message, data loss, energy efficiency, Two-Tier Clustering, non-receiving node*

1. Introduction

WSNs consist of a large number of sensor nodes that are densely deployed in a region of interest to collect data about a target or event and enable a variety of sensing and monitoring applications[1].As sensor nodes are constrained in energy due to battery life, the energy efficiency of each sensor node is a crucial factor in WSN technology and there have been many studies to minimize the energy consumption of sensor nodes[2-7].Clustering is a technique that can effectively reduce the energy consumption of sensor nodes and has been widely used in WSNs.

In clustering protocols, nodes are organized into many clusters according to specific requirements, or metrics, and one of the nodes in a cluster becomes a cluster-head node. Each non-cluster-head node transmits to the cluster-head node instead of sending data to the base-station individually. Compared with flat routing protocols in WSNs, clustering routing protocols have several advantages: such as enhanced scalability, reduced circuit load, increased robustness and less energy consumption [8].

In conventional clustering, network sensor nodes are organized into small groups called clusters. Then, one sensor node from each cluster is selected to act as a cluster-head, which then allows other sensor nodes to join it and form the cluster field [9]. As cluster-head nodes are fixed in conventional clustering, sensor nodes acting as cluster-heads are expected to consume more energy as compared to other sensor nodes due to their long-range transmission

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of data to the base station. This results in uneven energy consumption amongst sensor nodes in the network.

Self-organization clustering proposed in [10] uses a randomized rotation of the high-energy cluster-head position such that it rotates among the various sensors in order to avoid draining the battery of an unlucky sensor. In self-organization clustering, each node generates a random number independently. If the number is less than a calculated probabilistic threshold, the sensor node becomes a cluster-head node. Each node that has elected itself as a cluster-head broadcasts an Advertisement Message to the rest of the nodes. The non-cluster-head nodes that have received the Advertisement Message from the cluster-head nodes then decide on the cluster to which they will belong. This decision is based on the signal strength of the Advertisement Message each node receives. Self-organization clustering reduces data traffic amongst nodes and reduces the time needed to configure the clusters as well.

Self-organization clustering has been utilized in several studies as an energy-efficient routing protocol for both MWSNs and WSNs. MWSNs are becoming increasingly useful in a variety of potential civil and military applications; such as intrusion detection, habitat and environmental monitoring, disaster recovery, hazard and structural monitoring, traffic control, inventory management in factory environments and health related applications, etc [6]. In MWSNs, it is difficult to adapt self-organization clustering methods without some modification. Since the LEACH(Low Energy Adaptive Clustering Hierarchy) protocol using self-organization clustering assumes a sensor field size of 50m X 50m,it is possible to broadcast the Advertisement Message for clustering throughout the sensor field efficiently. However, the sensor fields in MWSNs are often larger than those in WSNs. When the sensor field is too large, energy inefficiency may result when cluster-heads broadcast an Advertisement Message throughout the sensor field. Limiting the transmission range of the Advertisement Message is a requirement in this case. Detrimentally, when the transmission range is limited, Advertisement Message non-receiving nodes can be generated due to self-organization clustering. In self-organization clustering strategies, sensors elect themselves to be cluster-heads independently. This cannot guarantee the even distribution of cluster-heads over the entire sensor-network field or even the election of an optimal percentage of cluster-heads.

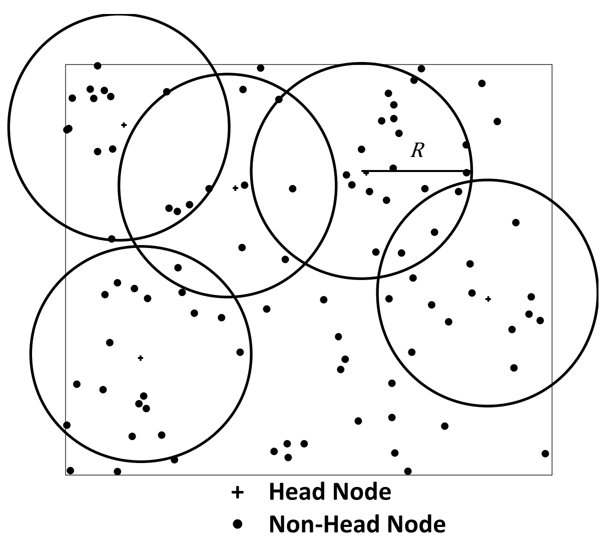

Figure 1. Self-Organization Clustering

Figure 1 shows Advertisement Message receiving and non-receiving nodes when the transmission radius is (R). Non-receiving nodes are those not included in any transmission circles.

In this paper, we analyze the number of non-receiving nodes in relation to the transmission range when self-organization clustering protocols are used in mobile environments. In addition, we suggest TTC (Two-Tier Clustering) to reduce the number of non-receiving nodes, thus resulting in reduced data loss and increased energy efficiency. Existing self-organization clustering protocols achieve clustering in one step, whereas our proposed method is a two step process. Initially, in order to create clusters in our proposed method, each node decides whether or not to become a cluster-head node according to a pre-determined ratio. Each node that has elected itself a cluster-head broadcasts an Advertisement Message to the other nodes within a radius (R). Non-cluster head nodes will decide the cluster to which they will belong after they receive a few Advertisement Message from various cluster-heads and compare signal strengths. After each node has selected its cluster, it must inform the cluster-head node that it will be a member of that cluster. That is the first step in our clustering method. After a predefined waiting time, the nodes that have not received any Advertisement Message decide once again whether or not to become a cluster-head node. The nodes that have become head nodes configure their clusters as they did in the first step. TTC can reduce the number of nodes which do not belong to clusters compared with existing self-organization clustering protocols for any arbitrary (R).

The rest of this paper consists of as follows: In Section 2, we review some of the cluster-based routing protocols in WSNs and in MWSN. In Section 3, we analyze the number of nodes that are not receiving an Advertisement Message: what we call a non-receiving node. Section 4 presents a computational formula for determining transmission range. Section 5 introduces our TTC method. In Section 6, we present the results of our simulation in order to evaluate our TTC and other protocols. We conclude our paper in Section 7.

2. Related Work

A large number of cluster-based routing protocols use a scheme whereby sensors elect themselves to be cluster-heads by calculating independently. Self-organized clustering saves nodal energy and reduces the latency time required to transmit control messages amongst the nodes and with a base station. In this section, we survey some studies that adopt self-organized clustering methods.

LEACH is one of the most popular hierarchical routing protocols for WSN [10]. LEACH has inspired the design of several other protocols that try to improve overall performance and/or the cluster-head selection process[2][6]. In some studies, the LEACH protocol has been improved by supporting node mobility[1][11-13]. In the LEACH protocol, each node decides whether or not to become a cluster-head in relation to the other nodes. This decision is based on the suggested percentage of cluster-heads for each network. Each node generates a random number between 0 and 1, and if the number is less than a certain threshold which is computed in advance, the node becomes a cluster head for the current round. Each node that has elected itself as a cluster-head then broadcasts an Advertisement Message to the rest of the nodes. Each non-cluster-head node self-determines the cluster to which it will belong based on the strength of the Advertisement Message signal it receives.

LEACH-Mobile (Low-Energy Adaptive Clustering Hierarchy-Mobile) supports the mobility of a sensor node by adding its membership declaration to the LEACH protocol. The basic idea in LEACH-Mobile is to confirm whether a mobile sensor node is able to communicate with a specific cluster-head as it transmits a message requesting data transmission back to the mobile sensor node within a time slot allocated in the TDMA schedule for a wireless sensor cluster. If the mobile sensor node does not receive this data from the cluster-head within the allocated time slot, it will send a join-request message during the next time slot requesting that it belong to another cluster head[11].LEACH-ME(LEACH-Mobile Enhanced Protocol) has improved the performance of LEACH-Mobile by enhancing the data transfer rate between the cluster-head and the collector nodes even though the nodes are mobile[11].

CBR (Cluster Based Routing Protocol) enables those mobile sensor nodes that disconnected from their cluster heads to rejoin the network through other cluster-heads within a short time. The mobility and traffic-adapted scheduling based MAC design enables the cluster-heads in WSN to reuse free or unused timeslots to support the mobility of sensor nodes. To facilitate this process, two owners are created for each timeslot: an original owner and alternative owner such that CBR can adapt to sensor node mobility and message traffic volume. This protocol records new mobile sensor nodes in simple database tables and serves these nodes whenever a free or unused timeslot becomes available [13].

MBC (Mobility-Based Clustering Protocol) takes an estimated connection time into account in order to build a more reliable connection path depending on the stability or availability of each link between a non-cluster-head sensor node and a cluster-head node. In the MBC protocol, a node elects itself as a cluster-head based not only on its residual energy, but also on its mobility in order to achieve balanced energy consumption amongst all nodes and thus a longer overall network lifetime. During clustering, a non-cluster head node takes into account its connection time with, and its distance from, a cluster-head as well as the residual energy and node degree of that cluster-head [1].

These peer-reviewed papers all have in common the adoption of independent cluster-head node election methods.

3. Analysis of Non-receiving Nodes for Advertisement Message

In self-organization clustering, each node generates a random number independently. If the random number is smaller than the threshold calculated by the percentage of head nodes and the number of rounds, then that node becomes a head node. The nodes that become cluster-heads broadcast an Advertisement Message to the other nodes. When the transmission range for broadcasting an Advertisement Message is limited to a radius of (R), non-receiving nodes can be generated in the network field. When a node does not receive any Advertisement Message from any cluster-head nodes, it loses a chance to send its data. In this section, we analyze the number of non-receiving Advertisement Message nodes at transmission radius (R).

In order for a node to receive an Advertisement Message, the node must be located within transmission range of the head node in the cluster. Let n_i as a coordinate (x_i, y_i),n_j as a coordinate (x_j, y_j). Set Nb_{n_i} is a set of nodes in the transmission range from node n_i. When $n_j \in Nb_{n_i}$, n_j satisfies

$$(x_i - x_j)^2 + (y_i - y_j)^2 \leq R^2 \qquad (1)$$

$$(x_i - x_j)^2 + (y_i - y_j)^2 = 0 \quad if \;\; n_i = n_j \quad (n_i, n_j \in Nb_{n_i}) \qquad (2)$$

Once the node in Set Nb_{n_i} becomes a head node, node n_i can receive an Advertisement Message. In other words, when the node n_i cannot receive an Advertisement Message fro many node in Set Nb_{n_i},this means that no node in Set Nb_{n_i} can become a cluster-head node.

We can calculate the probability that no node in the Set Nb_{n_i} can be a head node, i.e. the probability that noden_i cannot receive an Advertisement Message. Beforehand, the threshold to become a head node is formulated as follows [1].

$$\theta = \frac{p}{1-p(r \bmod 1/p)} \quad (3)$$

Where $p$is the ratio between the number of cluster-heads and the total number of sensor nodes,$1/p$ is the expected number of nodes in one cluster, and r is the index of the current round.

Assuming that the number of sensor nodes located in a geographical area follows a Poisson Distribution, the number of elements in Set $Nb_{n_i}$is λ on average. If Y nodes out of λ nodes in set Nb_{n_i} become cluster-heads, Y is a binominal random variable.[14]

$$Y \sim \mathrm{B}(\lambda, \theta) \quad (4)$$

$P(Y = 0)$is the probability that Y=0, which is the same as the probability that no node will become a cluster-head in Set Nb_{n_i}.

$$P(Y = 0) = \binom{\lambda}{0}\theta^0(1-\theta)^\lambda (5)$$

In formula (5), $P(Y = 0)$ is the probability that node $n_i$will become a non-receiving node. Figure 2 shows the probability that node n_i cannot receive an Advertisement Message as the transmission radius (R)varies in a 1000mX1000m sensor field with a 1000 node random topology. Let $p = 0.05$.

As in Figure 2, the smaller the transmission radius, the larger the probability of a node becoming a non-receiving node.

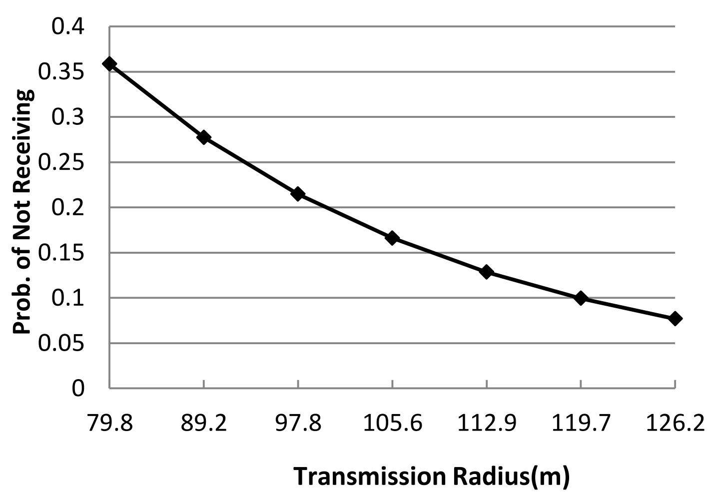

Figure 2. Probability of Non-Receiving Node In Relation to Transmission Radius

We suppose the packet size k=500bit, energy for transmission E_{elec}=50nJ/bit, and energy for transmission signal amplification$\epsilon_{amp} = 100pJ/m^2$[10].The transmission energy of an Advertisement Message is:

$$E_{T_X}(k, R) = E_{elec} * k + \epsilon_{amp} * k * R^2 \qquad (6)$$

Since the transmission energy required is proportional to the square of the distance, controlling the transmission range is necessary. In MWSNs, because the field size can be larger, we need to restrict the transmission radius (R). In Figure 3, as the transmission radius increases, the energy required to transmit an Advertisement Message also increases.

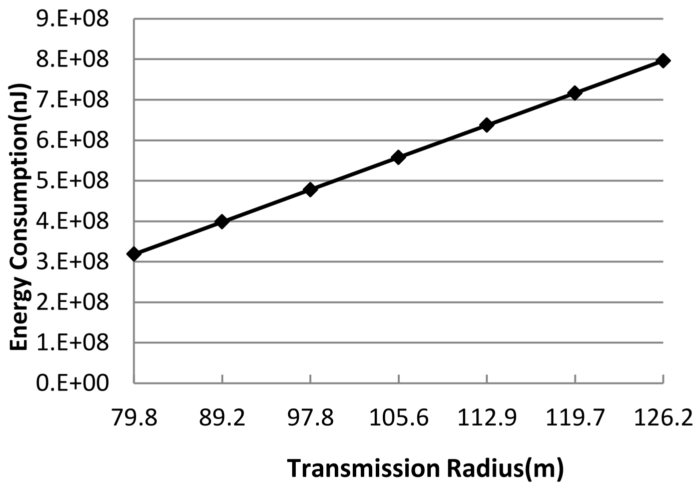

Figure 3. Energy Consumption to Transmission Range

Using equation (5), we can calculate the number of non-receiving Advertisement Message nodes in a given sensor network. Assume *N* sensors are distributed randomly in a network field with the size of *F* that is monitored.

$$N_{non-r} = (1 - \theta)^{\lambda} N \qquad (7)$$

We can calculate λ in relation to R as follows

$$\lambda = \frac{N\pi R^2}{F} \qquad (8)$$

From formula (7), a graph in Figure 4 shows the number of non-receiving nodes in relation to the transmission radius (R) in a 1000mX1000m sensor field with several 1000 node topologies that are randomly distributed.

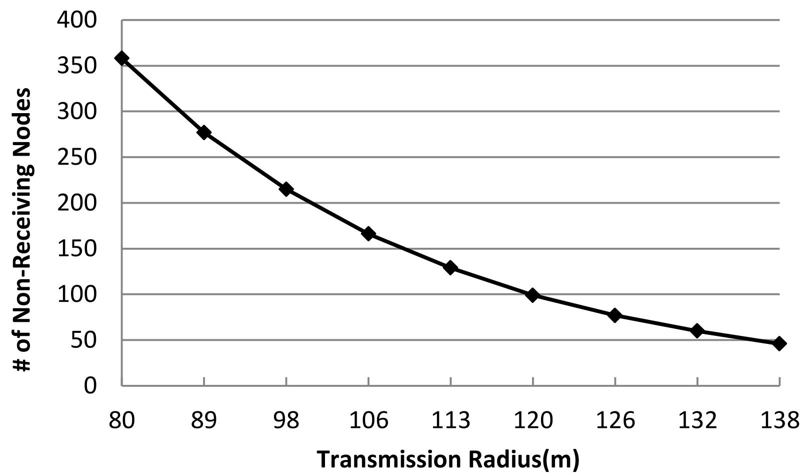

Figure 4. Analysis of Number of Non-Receiving Nodes

As we see in Figure 4, when the transmission radius is 80m, there are 358 nodes that cannot receive an Advertisement Message. When the transmission radius is 89m or 98m, then the number of non-receiving nodes is 277 or 215 respectively.

When we simulate the number of non-receiving nodes in the same environment, the number of non-receiving nodes that deviate from the number generated by the formula (7) may become critically large, as shown in Figure 5.

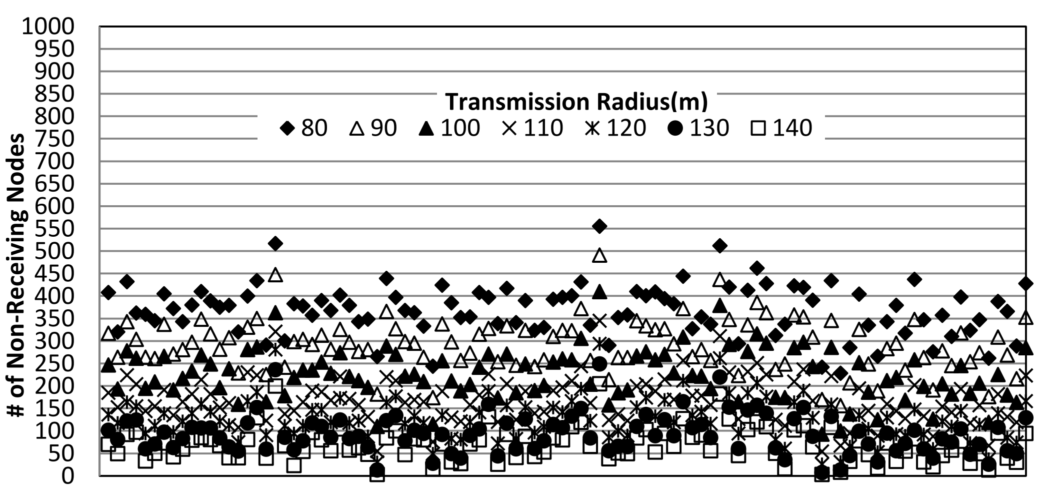

Figure 5. Distribution of Non-Receiving Nodes

4. Computing Transmission Range

In simulations with the LEACH protocol in which self-organization clustering was proposed, the cluster-heads can broadcast an Advertisement Message to the entire sensor field to facilitate cluster configuration because the field size is comparatively small (50m X 50m). However, some network sensor-fields can be bigger as the applications of sensor networks vary. Especially in MWSN, the field size can be much bigger than that in WSNs that consist entirely of fixed sensor nodes. In order to improve energy efficiency in MWSN, the transmission range needs to be controlled. In this section, we calculate the adaptive transmission radius of Advertisement Message for MWSN.

In MWSN, the number of nodes in each cluster is variable. Assuming that the number of sensor nodes located in a cluster follows a Poisson Distribution, in order to generate $p \cdot N$ cluster-heads, each cluster should include at least *1/p* sensors.

We can find the probability that there are*1/p* or more sensors within a cluster for any arbitrary point. The probability is:

$$\mathrm{P}\left(\mathrm{X} \geq \frac{1}{p}\right) = 1 - \sum_{x=0}^{\frac{1}{p}-1} e^{-\lambda} \frac{\lambda^x}{x!} \quad (9)$$

From this equation, we can obtain the average number of node λ, which makes the probability one.

Minimum transmission range (*R)* to contain the average number of nodeλ is:

$$R = \sqrt{\frac{\lambda F}{\pi N}} \quad (10)$$

5. TTC: Two-Tier Clustering

In self-organization clustering, if a non-cluster-head node does not receive any Advertisement Message, it cannot belong to any cluster and successfully transfer its sensing data through a cluster-head to the base station.

In existing self-organization clustering protocols, clustering is performed at the set-up phase: consisting of head election, transmission of an Advertisement Message and the join-cluster decision of non-head nodes. The basic idea of TTC is to perform the set-up phase twice to reduce the number of non-receiving nodes that are excluded from clusters.

In TTC, let p' as a ratio of cluster-head nodes in the first step andp'' as a ratio of cluster-head nodes in the second step. The entire ratio of cluster-head nodes *p* will be:

$$p = p' + p'' \quad (11)$$

For the first step in clustering, each node decides whether or not to become a cluster-head node independently. Each node generates a random number between 0 and 1 and compares that number to the thresholdθ' calculated by a predetermined ratio of cluster-head nodes and the number of transmission rounds. If the former is smaller than the latter, the node becomes a cluster-head node.

$$\theta' = \frac{p'}{1 - p'(r \bmod 1/p')} \quad (12)$$

The nodes that have become cluster-head nodes broadcast an Advertisement Message to the rest of the nodes within a radius of (*R)*. Each non-cluster-head node decides the cluster to which it will belong for each round. This decision is based on the signal strength of the received Advertisement Message. After each node has determined its cluster-head, it sends that cluster-head a join-message. The nodes which have not received any Advertisement Message in the first step perform the second step of clustering.

N'denotes a set of nodes which have not been included in any clusters at the first step. $\theta''$is the threshold that the nodes in set N' use to decide whether or not they will become cluster-heads at the second step. All nodes in set N'can independently calculate the thresholdθ''.

Formulae (5) and (8) influence the average probability for the existence of non-receiving nodes in the field influenced by transmission radius (R). To generate $p'' \cdot N$ cluster-heads among the nodes in set N', the threshold θ'' is :

$$\theta'' = \frac{p''}{(1-\theta')^{\lambda}} \qquad (13)$$

$(1-\theta')^{\lambda}$is the ratio of non-receiving nodes after the first step in clustering.

Each non-receiving node from the first step generates a random number and compares it with the thresholdθ'' for the second step. If the generated random value is less than θ'', then the node becomes a cluster-head node. Elected cluster-head nodes broadcast an Advertisement Message to the rest of the nodes within a radius of (R). In the second step, each non-cluster-head node sends a response message to the cluster-head node after it decides which cluster it will belong to by repeating the same process as in the first step. The nodes that have received Advertisement Message from several cluster-head nodes respond to the head node that has broadcast the strongest Advertisement Message signal.

6. Performance Evaluation

To evaluate the performance of our TTC, we simulate LEACH-mobile and MBC together.

We assume 1000 nodes are scattered randomly in a 1000mX1000m sensor field. The total percentage of cluster-head nodes is 5%.

Table 1. Simulation Parameter

Parameter	Value
Number of sensor nodes	1000
Network size	1000x1000
Node deployment mode	Random distribution
Percentage of cluster heads	5%
Average speed of node	5 m/s
Max speed of node	25 m/s

In LEACH-Mobile, each node calculates a threshold θ using formula (3) and generates a random number to decide for itself to become a cluster-head node or not. Then, each self-elected cluster-head node broadcasts an Advertisement Message to the sensor nodes within its transmission radius. At this time, the nodes that cannot receive the Advertisement Message will become non-receiving nodes.

In MBC, they consider both the residual energy and the current speed of each sensor node in cluster-head election in order to avoid the selection of low energy nodes as cluster-heads and balance the energy consumption among all nodes. Thus, the thresholdθ_{new} is multiplied by the factors representing the residual energy and the current speed of a node:

$$\theta_{new} = \frac{p}{1-p(r \bmod 1/p)} \times \left(\frac{E_{n\_current}}{E_{max}} \times \frac{v_{max}-v_{n\_current}}{v_{max}}\right) \qquad (14)$$

Where $E_{n\_current}$ is the current energy, $v_{n\_current}$ is the current speed, E_{max} is the initial energy and v_{max} is the maximum speed of the node. Using this threshold, the nodes with more residual energy and lower speed will have a higher probability of being elected as cluster-heads[1].

In TTC, we suppose the percentage of cluster-head nodes is 4% in the first step of cluster head node election and 1% in the second step in order to generate the same percentage of cluster-head nodes as in LEACH-Mobile and MBC.

Figure 6 shows the average number of non-receiving nodes that cannot receive an Advertisement Message after simulations using each clustering strategy.

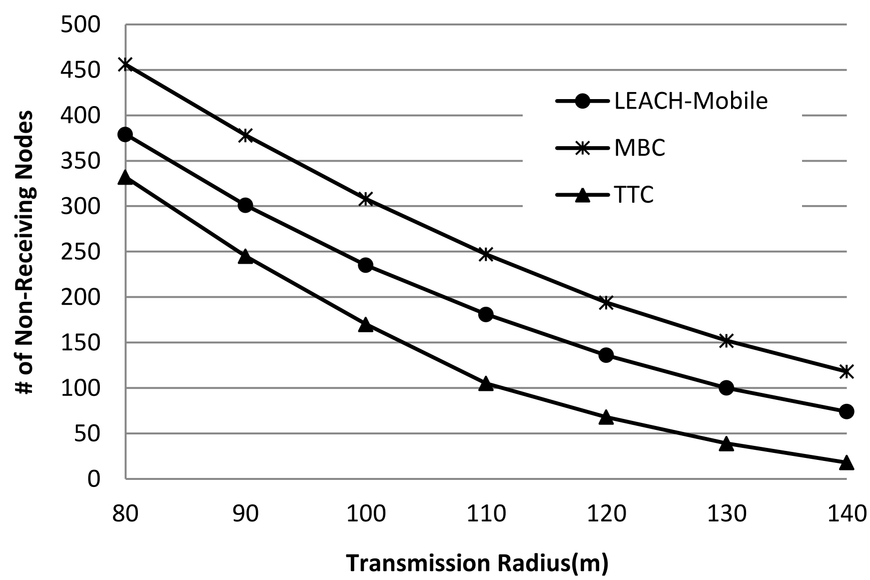

Figure 6. Comparison of the Number of Non-Receiving Node

From the results of this simulation, TTC reduces the number of non-receiving nodes by more than 12 % compared with LEACH-Mobile and achieves a 27% reduction when compared with MBC. As the transmission radius increases, the number of non-receiving nodes is reduced. In our proposed strategy, when the transmission radius is 140m, a more than 75% reduction in the number of non-receiving nodes is achieved compared with LEACH-mobile and a 84% reduction is achieved compared with MBC.

Independent cluster-head node election can result in an exclusive concentration of cluster-head nodes in one area and, in an extreme situation, the non-election of any cluster-head node. TTC reduces the statistical likelihood of these potentially critical problems by using a two-step self-selection method for cluster-head nodes. Figure 7, Figure 8, Figure 9 shows a distribution of non-receiving nodes in each strategy when the transmission radius is 130m. As Figure 9 shows, cluster-head nodes which are distributed evenly will prevent data loss from some areas of the cluster field in TTC.

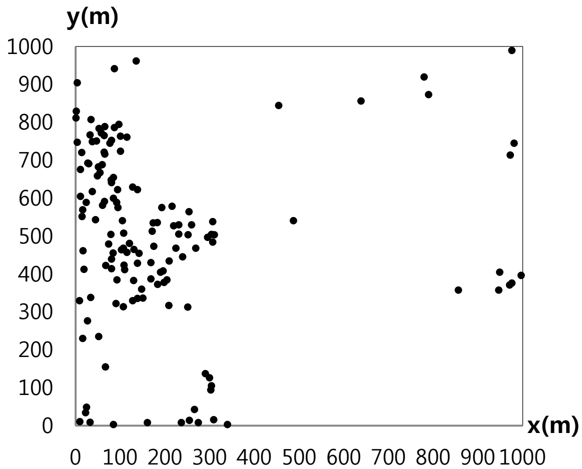

Figure 7. Distribution of Non-Receiving Node(112 node sample) inLEACH-Mobile

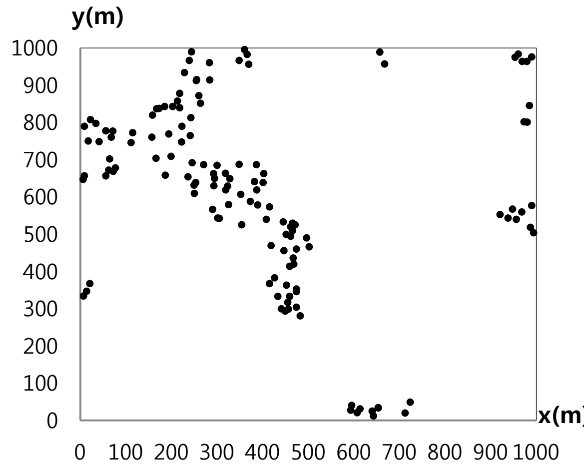

Figure 8. Distribution of Non-Receiving Nodes (136 node sample) in MBC

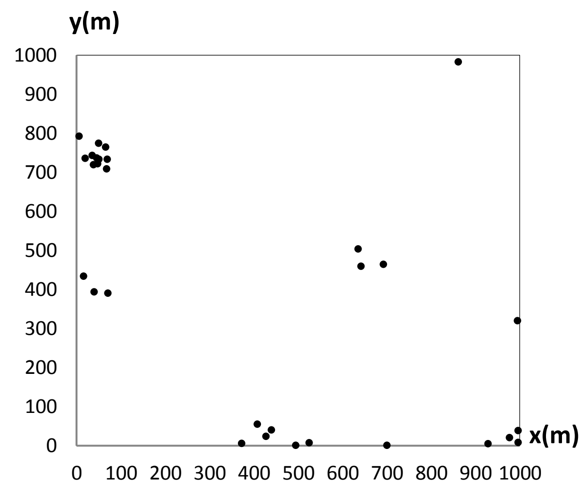

Figure 9. Distribution of Non-Receiving Nodes (33 node sample) in TTC

TTC has some additional circuit energy overhead due to the additional transmission of Advertisement Message in order to configure the clusters in two steps. However, if this method can reduce the number of non-receiving nodes in a given transmission radius when cluster-head nodes broadcast an Advertisement Message, an overall reduction in both energy consumption and data loss will result.

7. Conclusion

Self-organization clustering is one of the popular protocols utilized to reduce energy consumption in WSN or MWSN. In this paper, we analyzed the number of non-receiving nodes in relation to transmission range when we used self-organizational clustering in mobile environments. In addition, we suggested our TTC in order to reduce the number of non-receiving nodes created in a cluster field. To evaluate the proposed method, we compared the number of non-receiving nodes in TTC with those in LEACH-Mobile and MBC through simulation, and found that our TTC reduced the number of non-receiving nodes excluded from clusters. In this study, we limited the transmission radius for Advertisement Message in order to produce efficient and evenly distributed self-electing cluster-heads, reduce data loss from non-receiving nodes, and reduce energy consumption while increasing the overall robustness of a sensor network. Specifically, we found that our TTC reduced data loss and increased energy efficiency according to the adaptive distribution of cluster-head nodes throughout a network field of any given radius. These beneficial effects more than compensate for the additional energy requirements and time overheads that result from the two-step clustering in our TTC protocol.

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