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Min-Distance Hop Count based Multi-Hop Clustering In Non-uniform Wireless Sensor Networks

Eunju Kim, Dongjoo Kim, Junho Park
Department of Information and Communication Engineering
Chungbuk National University, Cheongju, Chungbuk, Korea.

Dongook Seong
Department of Computer Science
Korea Advanced Institute of Science and Technology, Daejeon, Korea

Byungyup Lee
Department of Electronic Commerce
Paichai University, Daejeon, Korea.

Jaesoo Yoo
Department of Information and Communication Engineering
Chungbuk National University, Cheongju, Chungbuk, Korea.

ABSTRACT

In wireless sensor networks, an energy efficient data gathering scheme is one of core technologies to process a query. The cluster-based data gathering methods minimize the energy consumption of sensor nodes by maximizing the efficiency of data aggregation. However, since the existing clustering methods consider only uniform network environments, they are not suitable for the real world applications that sensor nodes can be distributed unevenly. To solve such a problem, we propose a balanced multi-hop clustering scheme in non-uniform wireless sensor networks. The proposed scheme constructs a cluster based on the logical distance to the cluster head using a min-distance hop count. To show the superiority of our proposed scheme, we compare it with the existing clustering schemes in sensor networks. Our experimental results show that our proposed scheme prolongs about 48% lifetime over the existing methods on average.

Keywords: *Non-Uniform Wireless Sensor Networks, Multi-hop Clustering, Energy Efficiency*

1. INTRODUCTION

Wireless sensor networks deployed in wide range of areas can be utilized in various applications such as the environment monitoring, medical systems, military application, monitoring of disaster, and U-City[1]-[3]. The sensor nodes in the sensor network have several hardware restrictions such as the limited wireless communication bandwidth, low computing power, and limited energy[4]-[6]. Therefore, techniques to efficiently use the limited energy and to prolong the lifetime of the sensor network are required.

In general, the data collected from geographically adjacent sensor nodes have similar values each other. When performing data aggregation in the process of data transmission using the characteristics, it is possible to achieve energy-efficient data transmission. The existing works proposed cluster-based data collection schemes to effectively aggregate duplicately collected values schemes. Cluster selects cluster head based on particular conditions, using these criteria member nodes of representative node consist of geographically close sensor nodes. As a result, one of cluster member nodes collects data of geographically close area, cluster head be able to effectively aggregate similar values which member nodes collect. Therefore, the clustering schemes can reduce the communication cost by transmitting the aggregated data in the course of data routing.

The existing proposed single-hop clustering schemes form

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* *Corresponding author. E-mail : yjs@chungbuk.ac.kr*
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clusters by selecting the member nodes for sensor nodes within radius of the communication[7]. As a result, the size of one cluster is restricted to 1-hop communication range. Therefore, a large network environment is difficult to efficiently build up clusters. So, multi-hop clustering schemes are proposed in a large sensor network environment to facilitate scalability of clusters [8]. Multi-hop clustering schemes which use criteria based on cluster heads have not selected nodes within 1-hop radius and select member nodes which are included within multi-hop radius and then one cluster is built. Even if the size of network is expanded sufficient scalability can are guaranteed.

The existing clustering schemes[7],[8] construct a cluster based on uniform network environments. But the existing clustering schemes can be formed non-uniform network according to geographical characteristics and node deployment method in real environment[9]. If the existing clustering schemes are applied in the non-uniform network environments, a cluster in a high density area contains more member nodes than a cluster in a low density area. Therefore, the existing clustering scheme forms the clusters that can cause unbalanced energy consumption. As a result, it decreases the lifetime of the sensor network.

In this paper, we propose a novel clustering scheme to construct balanced clusters in the non-uniform wireless sensor networks. The proposed scheme establishes a cluster based on the logical distance to the cluster head using a min-distance hop count. Therefore, it is possible to form the balanced multi-hop clusters in non-uniform sensor network environments. It is shown through performance evaluation that the proposed scheme prolongs about 48% network lifetime over the existing schemes on average.

The rest of this paper is organized as follows. Section 2 reviews and analyses the problems of existing clustering schemes. Section 3 proposes the proposed clustering scheme to form balanced cluster in non-uniform wireless sensor network environments. Section 4 shows simulated experiments and compares our results with the existing schemes. Finally, we conclude this paper and present some future works in Section 5.

2. RELATED WORK

Various works have been proposed to form efficient clusters in sensor network environments. LEACH(Low Energy Adaptive Clustering Hierarchy)[7] is a typical clustering scheme.

LEACH periodically selects randomized cluster heads to disperse energy consumption of cluster head in the cluster interior and consist of member nodes of clusters which include geographically close many nodes. Cluster heads accurately collect sensing data from member nodes of clusters and LEACH is a typical single-hop clustering scheme which forward collected information to a sink node. LEACH determines the probability(p) which signifies the probability of becoming cluster head of each node periodically according to the number of nodes and field to be known in advance. LEACH prolongs the network lifetime by changing cluster heads per the regular time. But the unbalanced clusters can are formed because LEACH scheme constructs clusters using the stochastic method without consideration of perimetric node states so cause unbalanced energy consumption by the included number of sensor nodes of a cluster. Absence of consideration about energy can be also the problem when clusters are formed.

MCBT(Multi-hop Cluster based Backbone Tree)[8] which considers node's residual energy and degree in Max-Min D(hop-count) cluster algorithm[10] forms the multi-hop clusters. Each node calculates flooding value using own residual energy, degree and performs Max-Min process D(hop-count) times when clusters are formed. Max process is the phase whose each node compares a flooding value with flooding values of neighbor nodes in 1-hop communication range and then saves the largest flooding value, Min process is the phase which compare flooding values and then saves the smallest flooding value. Then each node compares the flooding value in the Max-Min phase saved and selects the node whose initial flooding value and Min-D flooding value are same value as the cluster head and forms the cluster with cluster head as the center. But LEACH and MCBT form unbalanced clusters depending on the density of sensor nodes in non-uniform wireless sensor network so have the problem which inefficiently consumes energy.

Figure 2 shows to form unbalanced cluster in MCBT. As shown in C_1, C_2, C_3, the number of included sensor nodes in a cluster are different according to density of sensor node. Because a C_3 in high density area contains more member nodes than a C_2 in low density area, MCBT scheme can cause unbalanced energy consumption. As a result, it decreases the lifetime of the entire sensor network. In this paper, we propose a novel clustering scheme to construct balanced clusters in the non-uniform wireless sensor networks to solve this problem.

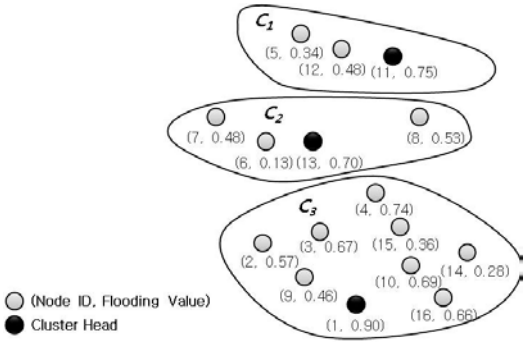


Fig.1. The Problem of MCBT

3. MIN-DISTANCE HOP COUNT BASED MULTI-HOP CLUSTERING IN NON-UNIFORM WIRELESS SENSOR NETWORKS

The proposed scheme selects member nodes using logical hop-distance through min-distance hop count scheme instead of absolute hop-distance used in the existing scheme. Therefore, the proposed scheme forms the balanced multi-hop clusters in non-uniform sensor networks. The proposed scheme performs phase of network initialization process to form clusters. Sensor nodes prepare initialization message like Figure 2 in the network initialization process. Each sensor node performs broadcasting of initialization message to all of the neighbor

nodes within 1-hop communication range. All of the nodes which receive initialization message can confirm location information of neighbor nodes within 1-hop range. This information is used as basic information to form clusters. To save basic information, sensor nodes have data storage structure as shown in figure 3. Once sensor nodes receive initialization message from neighbor nodes, nodes save received ID from Neighbor_Node_List of all neighbor nodes.

4	4	4	4
S.node_ID	S.node_x	S.node_y	Residual Energy

Network Initialize Packet Format

Fig.2. Message Structure of Network Initialization

Node_Type	isHead

Neighbor_Node_List	Neighbor_Node_ID
	...

Member_Node_List	Member_Node_ID
	...

Fig.3. Data Storage Structure

Figure 4 shows sensor nodes within the communication range of a cluster head in the sensor network and the point that is specified by a user. The selected node as initial cluster head sets up the cluster head(CH) in Node_Type attribute of data storage structure and other nodes set up member nodes(CM) of the cluster. The initial cluster head is the sensor node in the shortest distance from this point. We divide the sensor network into six direction area of the hexagonal shape with the cluster head node as the center. The reason is that it is possible to extend a cluster easily through the areas when choosing a node in the shortest distance within a communication range.

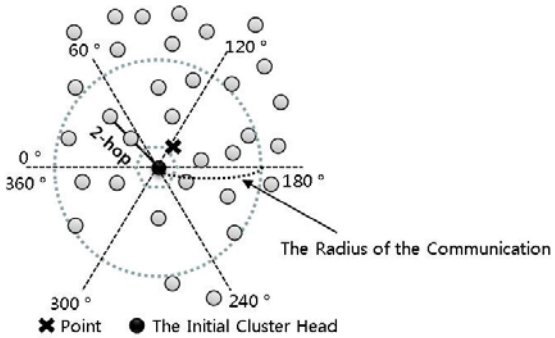


Fig.4. The Partition of the Range based on The Hexagonal Shape

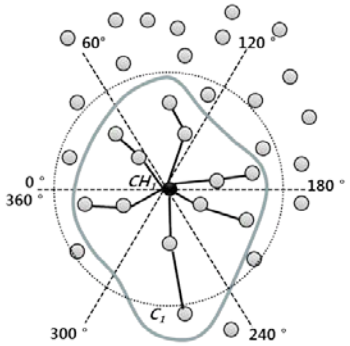
Figure 5 shows a cluster participation request message. The cluster participation request message is a message that cluster head by own criterion selects near neighbor nodes as member nodes of cluster within an angle range. So the initial cluster head sends the message that consists of the Cluset Head's ID, Sensor Node's ID, HopCount and Angle Range to a node in the shortest distance within an area with the same direction. If the node receives a message from a neighboring node, it transmits this message to a node in the shortest distance within the area with the same direction. The node that receives the message perceives itself as the leaf node of the cluster through HopCount information and sends Join_Message to the cluster head. The proposed scheme can construct the balanced multi-hop clusters in non-uniform networks because the initial cluster head selects member nodes using logical distances through min-distance hop count scheme.

4	4	4	4
CH.node_ID	S.Node_ID	HopCount	Angle

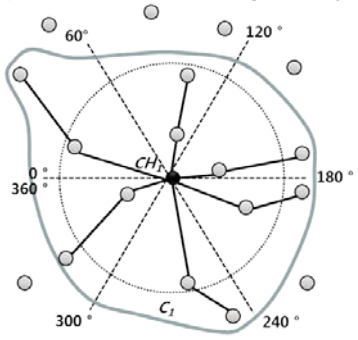
Demand Participation Packet Format

Fig.5. Data Structure of Cluster Member Participation Request

Figure 6(a) shows a cluster formed in a high density area and Figure 6(b) shows a cluster formed in a low density area. In the proposed scheme, cluster head selects the member nodes based on logical hop-distance using min-distance hop count information within same direction. Therefore, Regardless of density, the proposed scheme can form a balanced multi-hop cluster in non-uniform wireless sensor networks.



(a) A cluster formed in a high density area



(b) A cluster formed in a low density area

Fig.6. Forming Cluster According to Density of the Sensor Nodes

Figure 7 show a 2-hop cluster formed using min-distance hop count within the same direction. After a cluster (C_1) is formed, the proposed scheme finds out ($d+1$)th node among nodes in min-distance hop count by the leaf node within the same area.

The nodes CH_2 and CH_3 that are $(d+1)$th nodes from the leaf nodes of cluster C_1 are other cluster heads.

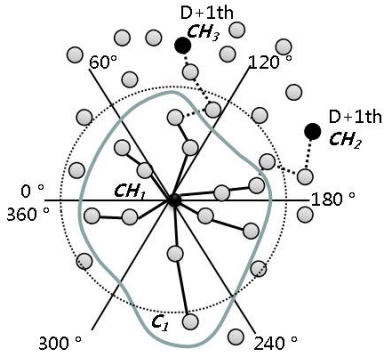


Fig.7. Selecting the Cluster Head

Figure 8 shows hierarchical clusters. The clusters C_2 and C_3 are constructed based on min-distance hop count in the same way as the cluster C_1. As a result, the entire sensor network gradually constructs hierarchical clusters centered on the initial cluster head.

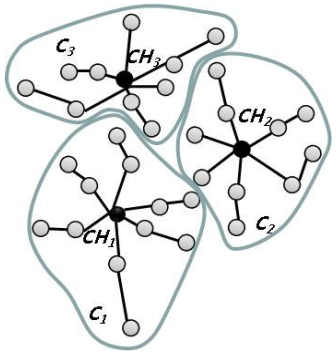


Fig.8. Expanding the Clusters

The proposed scheme overcomes the problems of the existing schemes that cause in-efficient use of energy from unbalanced clusters in non-uniform sensor networks. As a result, it increases the lifetime of the sensor network.

4. PERFORMANCE EVALUATION

In order to show the superiority of the proposed scheme, we compare our scheme with the existing clustering schemes through the performance evaluation. Our scheme is compared with LEACH[7] and MCBT[8]. The performance evaluation was carried out through the simulation parameters shown in Table 1. The model of the energy consumed for message transmission to a sensor node is {*MessageSize*} x ({*TransmissionCost*} + {*AmplificationCost*} x {*Distance*}^{2}), where the transmission cost was 50*nJ/b* and the amplification cost was set as 100*pJ/b/m*^{2}. The model of the energy consumed for receiving the message from a sensor node is {*MessageSize*} x {*ReceiveCost*}, where the receiving cost was set as *50nJ/b*[11][12]. We assume that 100~500 sensor nodes are deployed non-uniformly in 200m X 200m.

Table 1. Simulation Parameters

Parameter	Value
The size of sensor network	200m x 200m
The number of Sensor Nodes	100~500
The Radius of Communication	20m
Initial Energy	2.5J
The size of Data packet	16bytes

Figure 9 shows the construction costs of clusters in the proposed scheme and the existing scheme. The proposed scheme and the existing schemes increase the construction costs of clusters according to the number of sensor nodes. Unlike LEACH, The process to construct the clusters in MCBT and the proposed scheme that are multi-hop clustering schemes is complex. Therefore, they need a lot of sending and receiving messages among sensor nodes.

In the case of MCBT scheme, each node confirms its neighbor information through several broadcasting and consumes lots of energy to send and receive messages to compare flooding value. However, the proposed scheme is less energy consumption than MCBT scheme because sensor nodes send messages to the nearest sensor and perform one to one communication with the nearest sensor nodes. Meanwhile, LEACH which is a typical single-hop clustering scheme reduces the energy consumption because the number of the sending and receiving messages to construct clusters is small and the process to construct clusters is simple. However, a node with lower energy can be a cluster head in LEACH because it does not consider its remaining energy information. So a deviation of energy among cluster heads is high. LEACH also constructs unbalanced clusters because it does not consider basic information of each sensor node which consisted of clusters in non-uniform environments. Due to these problems, it decreases the lifetime of the entire sensor network.

As a result, the proposed scheme consumes high costs for initial construction of clusters as compared with the single-hop clustering scheme. However, the proposed scheme increases the lifetime of the sensor network because the proposed scheme can construct balanced multi-hop clusters in non-uniform environments. The simulation results show that construction costs of clusters decreased about 60% on average over MCBT.

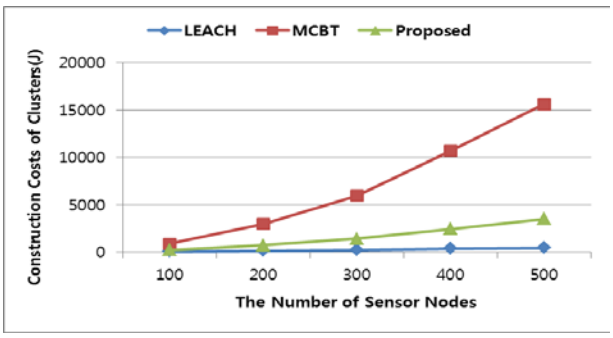


Fig.9. The Construction Costs of Clusters According to the Number of Sensor Nodes

Figure 10 shows the lifetime of the sensor network according to the number of sensor nodes in. As the number of sensor

nodes increases, LEACH and MCBT form unbalanced clusters depending on the density of sensor nodes in non-uniform wireless sensor network so have the problem which inefficiently consumes energy. But the proposed scheme restricts to increase the number of member nodes of cluster head nodes based on logical hop-distance using min-distance hop count. Therefore, the proposed scheme improves the network lifetime by configuring balanced clusters in the non-uniformly distributed environment. As a result, network lifetime improved about 48% on average compared with LEACH and MCBT.

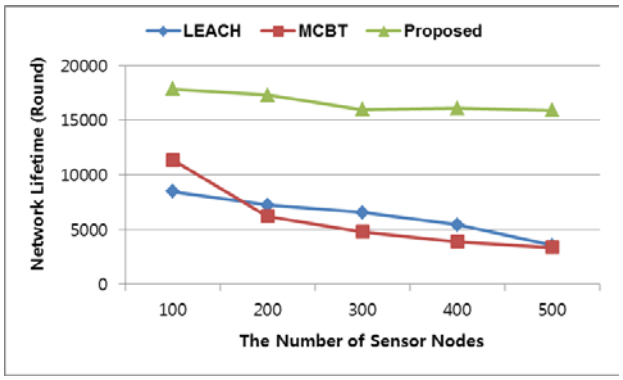


Fig.10. The Network Lifetime
According to the Number of Sensor Nodes

Figure 11 shows the standard deviation of the number of member nodes among clusters when the clusters are constructed in non-uniform sensor networks. LEACH and MCBT have a higher standard deviation of the number of member nodes than the proposed scheme when the clusters are formed in the environment that the distribution density of sensor nodes in each area is different. The reason is that the numbers of member nodes in the clusters are uniform through the clustering scheme based on logical hop-distances in the non-uniform sensor network.

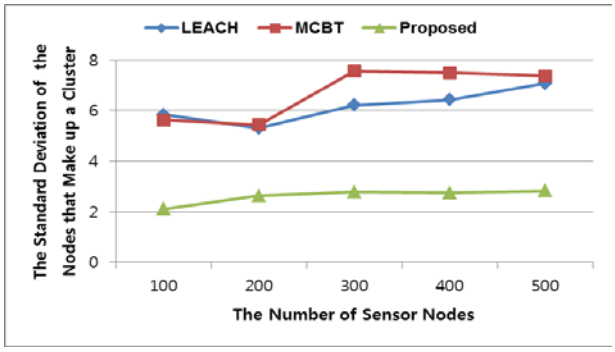


Fig.11. The Standard Deviation of the Number of Member Nodes That Make up a Cluster

5. CONCLUSION

Since the existing clustering schemes form unbalanced clusters depending on the density of sensor nodes in non-uniform wireless sensor network, they inefficiently consumes energy. In this paper, we have proposed a balanced multi-hop clustering scheme to solve the problems of the existing clustering schemes in the non-uniform wireless sensor network. The proposed scheme establishes a cluster based on the logical distance to the cluster head using a min-distance hop count. Therefore, it is possible to construct balanced clusters in the non-uniform sensor network. The proposed scheme significantly improves the network lifetime by consuming the energy equally in the entire sensor network. It was shown through performance evaluation that the proposed scheme improved about 48% network lifetime over the existing schemes on average.

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Eunju Kim
She received the B.S degree in the Department of Electronic Commerce from Paichai University, Deajeon, South Korea in 2009. She is currently working towards M.S. degree on Department of Information and Communication Engineering from Chungbuk National University, Cheongju, South Korea. Hers main research interests include database system, wireless sensor network and cloud computing.

DongJoo Kim
He received the B.S degree in the Department of Information and Communication Engineering from Chungbuk National University, Cheongju, South Korea in 2010. He is currently working towards M.S. degree on Department of Information and Communication Engineering from Chungbuk National University, South Korea. His main research interests include database system, wireless sensor network and cloud computing.

Junho Park
He received the B.S. and the M.S degree in the Departments of Information and Communication Engineering from Chungbuk National University, Cheongju, South Korea in 2008 and 2010 respectively. He is working towards Ph.D degree on Department of Information and Communication Engineering from Chungbuk National University, South Korea. His main research interests are the database system, wireless sensor network, RFID system, LMS, semantics and bioinformatics.

Dongook Seong
He received the B.S., M.S. and Ph.D. degrees in the department of Information and Communication Engineering from Chungbuk National University, Cheongju, South Korea in 2005, 2007 and 2011 respectively. He is now a post-Doc in Korea Advanced Institute of Science and Technology(KAIST), Daejeon, South Korea. His main research interests are the database system, wireless sensor network, distributed storage system and cloud computing.

Byungyup Lee
He received the B.S., M.S. and Ph.D. degrees in the department of Computer Science from Korea Advanced Institute of Science and Technology, Daejeon, South Korea in 1991, 1993 and 1991. He is now a professor in the department of Electronic Commerce, Paichai University, Daejeon, South Korea. His main research interests are the database system, xml, electronic commerce and intelligence information system.

Jaesoo Yoo
He received the B.S. degree in the department of Computer Engineering from Chonbuk National University, Jeonju, South Korea in 1989. And he received the M.S. and Ph.D. degrees in Computer Science in 1991 and 1995 from Korea Advanced Institute of Science and Technology, Daejeon, South Korea. He is now a professor in the department of Computer and Communication Engineering, Chungbuk National University, Cheongju, South Korea, where his research interests are the database system, multimedia database, distributed database, wireless sensor network and bio-informatics.