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Centre Clustering Wireless Sensor Network Performance Enhancement

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A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensor nodes (SNs). However, since WSN communications are likely to produce a broadcast storm, hierarchical clustering topology has been proposed to prolong the lifetime of WSNs by decreasing the SN energy consumption. Unfortunately, this network topology is still unstable owing to the overloading of cluster managers (CMs). In this study, we propose a WSN centre clustering mechanism (CCM) to improve the network topology stability, assist SNs within the working area, and take advantage of message exchanges.

1. Introduction

One of the new concepts associated with the "Future Internet" is the so-called "Internet of Things" (IoT).(1) IoT is a technological revolution that represents the future of computing and communications, and its development depends on the wireless sensor network (WSN). A WSN is a wireless network consisting of spatially distributed autonomous devices using sensor nodes (SNs) to cooperatively monitor physical or environmental conditions.(2) However, SNs are limited by their energy resources, memory, computation abilities, and communication capability.(3) Hierarchical clustering topology has therefore been proposed to prolong the lifetime of WSNs by decreasing the SN energy consumption.(4)

In WSNs, the cluster managers (CMs) forward the packets of all SNs. It may be because of this massive workload that CMs become paralyzed, and this can even affect the transmission of packets in the overall network.(5) Therefore, the cluster characteristic of CMs in WSNs is used in this study to build small clusters in this environment, and a CM is chosen in each cluster to form a hierarchal management structure to maintain WSN stability. In this study, we will therefore design a clustering and hierarchical manager election mechanism based on a WSN environment.

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2. Research Method

2.1 *Concept of proposed method*

WSNs often contain many small networks, with many SNs in each small network.[4] SNs gather and distribute information from different regions, and must transmit information amongst themselves. Therefore, a method of effectively clustering SNs and electing CMs is important in the maintenance of a stable network topology.[3] In this study, a centre clustering mechanism (CCM) underlying a centre-based WSN is proposed. The advantage of a centre-based CM in a cluster is that it can cover more SNs in a cluster, thus improving its scope for covering SNs in a network. Moreover, if there are more SNs in a cluster than a CM can handle, the cluster will be divided into subclusters depending on the CM's position, and new sub-CMs will be elected for the subclusters. This will result in hierarchal management, and will maintain effective overall network transmission.

The CCM in this study consists of the following four steps:

(1) First, calculate the centre of the network.

(2) Then, find SNs that are close to the centre of the network, and elect a suitable CM by computing the capabilities of those nodes.

(3) When the number of messages transferred by the CM in a cluster is greater than the bandwidth utilization percentage (BU%) set by the user, the CCM will divide the cluster into four subclusters based on the CM's position, and calculate the network transmission loading in each subcluster. If the transmission loading in each subcluster is greater than 25% of the CM's bandwidth, the CCM will repeat steps (1) to (3) in the subcluster. This ensures that the bandwidth of the CM in a cluster is able to handle the required information exchange, without increasing the CM's workload, since there are fewer nodes in the cluster.

(4) Building the hierarchal structure for transmitting messages depends on the relationship between the parent and child nodes of cluster CMs.

Via these four steps, the optimal CM in a network is found, based on cluster centres, and the SNs in the network area may be divided into different clusters to share the message transmission load by increasing the number of CMs. In addition, the message transmission structure proposed in this study consists of three steps:

(1) If the transmitting SN and receiving SN are in the same cluster, the message will be transmitted directly between the two SNs to reduce the CM workload.

(2) If the transmitting SN and receiving SN are in different clusters, the transmitting SN will first send the message to the CM in its own cluster. That CM will then forward the message to the CM directly above it in the hierarchal structure. Finally, the message will be forwarded between clusters by CMs to the receiving SN.

(3) If the receiving SN is located outside the overall transmission region of the transmitting SN, the message will be transmitted to the CM at the uppermost layer of the network, and the message will then be sent to the receiving SN by message exchange between CMs located at the uppermost layer of each transmission region.

2.2 *Centre clustering and CM election mechanism*

The basic concept of the CCM is to elect the most capable SN as a CM after each data exchange and comparison, allowing clusters to form gradually. Each SN will then be assigned to a unique cluster. This method involves three steps: (1) Clustering when the WSN is initialized, (2) clustering after SNs move in or out of clusters, and (3) processing when CMs fail.

First, the centre of the WSN is calculated, and CMs are elected recursively. Next, the calculation of the quantity of each SN is performed depending on the CMs' capacity and loading. Finally, the mechanism will perform clustering and build the network structure with hierarchal management. When computing the network centre, it is assumed that there are a total of i nodes in j clusters. The position of each node N_{ji} is (X_{ji}, Y_{ji}), and the position of the centre of the cluster j (CX_j, CY_j) can be computed using eq. (1):

$$CX_j = \Sigma X_{ji}/i,\ CY_j = \Sigma Y_{ji}/i \qquad (1)$$

After obtaining the position of the centre of cluster j, the CM can then be chosen based on the centre of the cluster. In these centre-based clusters, the distance between the centre and each of its surrounding SNs is the shortest possible distance within the cluster. This means that the coverage will improve the closer an SN is to the centre, and the CM should therefore be the SN closest to the centre. Thus, the distance d_{ji} between each SN and the cluster centre is computed using eq. (2), and the SN closest to the centre is elected as the CM.

$$\min d_{ji} = \sqrt{(X_{ji} - CX_{ji})^2 + (Y_{ji} - CY_{ji})^2} \qquad (2)$$

However, if the choice of CM is based only on the distance between an SN and the cluster centre, then it is possible that an SN with low power or low bandwidth could be chosen as a CM, which will negatively affect the transmission efficiency. Therefore, factors such as SNs' remaining power, workload, and bandwidth are considered when a CM is elected, to avoid such situations. Thus, the percentage of surplus power (e), workload (b), communication capacity (c), and distance to centre (d) will be transformed into a capacity value (p) according to eq. (3), while the weight values w_1, w_2, w_3, and w_4 will be defined according to the importance of each item in terms of meeting the various requirements.

$$p = (e) \times w_1 + (1/b) \times w_2 + (c) \times w_3 + (1/d) \times w_4,\ \Sigma w_i = 1 \qquad (3)$$

The clustering mechanism in this study will first choose SNs depending on user requirements. It will compute the capability of each SN using eq. (3), and then elect the most capable SN as a CM. When the CM of a cluster has been elected, the loading in the transfer of the CM must be considered to ensure that the chosen CM is able to take over the message forwarding work. Therefore, this study measures the BU% in CM packet exchanges in terms of its total bandwidth. If it is greater than the BU% set by the user, the CCM will segment the cluster into four subclusters based on the position of the CM in the cluster. CCM will perform clustering by reassigning the CM ID to SNs within the cluster. When the total bandwidth loading of SNs in a subcluster reaches 25% of the CM's total bandwidth, CCM will reelect a new CM in the subcluster to manage message transmission in the subcluster.

The advantage of a clustering method based on the bandwidth loading of a CM is that it can cluster and elect a CM based on the quantity of SNs in the network. Since the number of transmitted messages will be greater in a cluster with more SNs, the required number of clusters and managers will increase. This will ensure that all SNs have an equal portion of the backbone for message transmission in the network.

Once a child cluster is established, its CM will identify the managers in its parent clusters by exchanging messages. Hierarchal management structures built in this way are used to manage SNs and to transfer data throughout the entire network. When the transmitting and receiving SNs of a message are both in the same cluster, they will communicate directly to reduce CM loading. However, if the transmitting and receiving SNs of a message are in different clusters, the transmitting SN will first send its data to the CM in its own cluster, and the data will then be sent to the receiving SN by forwarding between cluster CMs. If the transmitting and receiving SNs are in different transmitting regions, then the data will be sent to the CM at the uppermost layer, and then forwarded via CMs at the uppermost layer to the receiving SN.

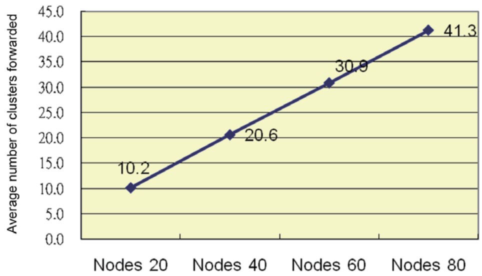
3. Results

The experiment is conducted in a 1000 × 1000 area. Attributes of each SN include the Node_ID, horizontal position (Pos_X), vertical position (Pos_Y), motion angle (Direction), moving speed (Speed), transmission region (Range), relative electric power % (Energy), relative workload % (Busyness), and relative bandwidth % (Bandwidth). NS2[(6)] is used to generate all parameters and 1000 nodes.

In the experimental design, the four weight values (w_1–w_4) of CCM are w_1 = 0.4, w_2 = 0.2, w_3 = 0.1, and w_4 = 0.3, and the BU of CM is 0.9. The experiments in this research are divided into two parts as follows:

Experimental design 1: SN quantities of 20, 40, 60, and 80 are used in the simulated network, and the CCM method is simulated 30 times. Each time, the number of SNs required to run the simulation is chosen randomly from the SN table, the number of clusters is recorded, as is the number of packets forwarded by the CM. The average number of clusters formed is shown in Fig. 1, and the comparison with the average number of packets forwarded by the CM is shown in Fig. 2.

The experimental results are shown in Figs. 1 and 2. The CM will devide its cluster into subgroups when the number of data transfers exceeds the CM's handling capability in this study. Hence, when the number of SNs increases, the number of CMs and clusters will also increase. When the number of CMs increases, because the number of hierarchical layers increases, the quantity of packets transferred by a CM will obviously increase, and these values rise with close linearity.



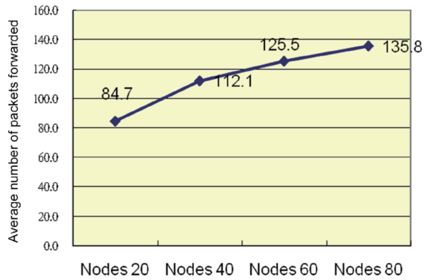


Fig. 1 (left). (Color online) Average number of clusters formed in experiment 1.
Fig. 2 (right). (Color online) Average number of packets forwarded by the CM in experiment 1.

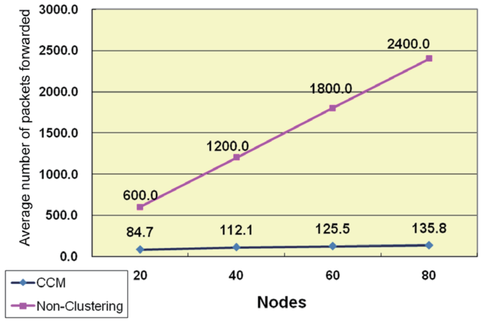


Fig. 3. (Color online) Average number of packets forwarded by nodes in experiment 2.

Results of experiment 2: SN quantities of 20, 40, 60, and 80 are used in the simulated network, the clustering scope is 150, and the CCM and non-clustering methods are simulated 30 times. Each time, the number of SNs required to run the simulation is randomly chosen from the SN table, and the number of packets forwarded by the CM is recorded. From the result shown in Fig. 3, since clustering is not considered in traditional WSNs, the number of packets forwarded by SNs will increase with an increase in the number of SNs. However, in CCM, SNs are assigned to clusters, and managed by CMs. Thus, transmitted packets are only forwarded by CMs. Therefore, the average number of packets forwarded is reduced, even if there is an increased number of SNs in the network.

4. Conclusions

In this study, we discuss the clustering and CM election mechanism based on the centre of a network. Formerly, many clustering and CM election methods did not consider the loading of the CM in WSN.[1,3,4] Therefore, we focus on the discussion of the clustering and CM election mechanism and try to reduce the clustering size to a possible manager loading. Moreover, factors such as the percentage of surplus power, degree of busyness, communication capacity, and distance to centre are used to elect the CM. On the basis of experimental results, we conclude that irrespective of the number of SNs in the network, the clustering method in this study can maintain network stability. Besides this, our method will realize more stable network topology and fewer packet transfers by the CM. Therefore, the CM may exist for a longer time.

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