Hybrid Cluster Mesh organization scheme for Energy Efficient Wireless Sensor Networks

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Abstract: Wireless Sensor Networks(WSNs) have become a main technology for ubiquitous computing environments. In WSNs, battery recharge or replacement is impossible because sensors are left unattended after deployment. Therefore, WSNs need a networking protocol scheme to increase the life time of sensor nodes. In this paper, we propose a Hybrid Cluster Mesh(HCM) scheme which recognizes the density of neighbor nodes and each node decides its topology itself.

1. Introduction

Wireless sensor networks have caused industrial demands and various research areas with development of smart sensors and wireless networking technologies in ubiquitous environments[1]. Because hundreds or thousands of nodes are deployed in the large sensor field and each sensor node operates based on a battery, replacement or recharge of each sensor node is unfeasible and the exhaustion of battery causes an interruption of sensor nodes and sensor fields.

In this paper, we propose a hybrid cluster mesh(HCM) scheme which determines a sensor network topology adaptively in consideration of the distributed pattern of deployed sensor nodes. Each sensor node recognizes neighbor nodes, analyzes energy consumption between cluster and mesh topology, and adopts a more energy-efficient topology itself. HCM scheme uses a weight-based clustering algorithm to compare energy consumption of each node[2],[3]. When a sensor node decides to become mesh topology, it doesn't need to send additional packets to select the cluster head. Therefore, HCM can reduce the number of messages which are transmitted for clustering and construct more energy-efficient topology.

2. Hybrid Cluster-Mesh(HCM) Scheme

If we observe the sensor network from the point of view of each sensor node, it can be modeled as a local sensor topology which has one sensor node and its neighbor nodes with one-hop distance. Each local sensor topology can be chosen by cluster or mesh topology determined by an energy consumption ratio of two topologies. We assume that the distribution of deployed sensor nodes consists of a group of local sensors.

In this paper, we consider two conditions – an active/sleep period and a message transmission process – as parameters for energy consumption. First of all, we assume that each node has an active/sleep period. The cluster head keeps up the active state during the entire beacon period, and the cluster members stay a short period of active state and a long period of sleep state[4]. Mesh nodes reiterate active/sleep period independently.

We define the energy consumption ratio between two topologies as

$$\rho_1 = \frac{Mesh}{Cluster} = \frac{T_{m-active} \cdot E_A (N_M + 1)}{T_{c-active} \cdot E_A \cdot N_M + T \cdot E_A} \qquad (1)$$

where T is a beacon period, $T_{m\text{-active}}$ is a active period of mesh nodes during T, E_A is the energy consumed in active period, and $T_{c\text{-acitve}}$ is the active period of cluster members during T.

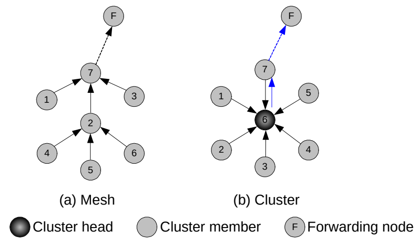

Figure 1. Message transmission path model

A message transmission process of mesh and cluster topology also must be considered with the active/sleep period which is evaluated by (1). In the mesh topology, if we assume that each sensor node knows an address of a sensor node which is used to forward the data and exists in the one-hop distance, mesh nodes transmit data like figure 1(a). We don't care transmission from node 7 to node F because that is transmission out of the local sensor topology. Therefore, the upper three nodes of figure 1(a) have a one-hop transmission path and the lower three nodes have a two-hop transmis-sion path. Assume that each sensor node is uniformly distributed locally and has a message to be delivered to the sink node. The total averaged number of message transmissions is given by

$$M_{Mesh} = \frac{1}{2} \cdot p \cdot N_M + 2 \cdot \frac{1}{2} \cdot p \cdot N_M = \frac{3}{2} \cdot p \cdot N_M \qquad \textbf{(2)}$$

where N_M is the number of sensor nodes that correspond to cluster members in the cluster topology and p is the probability of an event. There are N_{M+1} nodes in the mesh topology.

We assume that messages of cluster members are sent to the cluster head which aggregates received data and forwards the aggregated data to the neighbor node like figure 4(b). Therefore in the cluster topology, the total averaged number of transmissions is given by

$$M_{Cluster} = p \cdot N_M + (1-(1-p)^{N_M}) \quad (3)$$

Based on (1), (2), and (3), let's define an energy consumption ratio(ECR) of mesh topology to cluster topology as

$$\rho = \frac{Mesh}{Cluster} = \frac{\frac{3}{2} \cdot \lambda \cdot p \cdot N_M \cdot E_{Tx} + T_{m\text{-}active} \cdot E_A (N_M + 1)}{(B_r + \lambda \cdot (p \cdot N_M + (1-(1-p)^{N_M}))) \cdot E_{Tx} + T_{c\text{-}active} \cdot E_A \cdot N_M + T \cdot E_A} \quad (4)$$

where T is a beacon period, B_r is a beacon transmission rate, λ is a message arrival rate during T, and E_{Tx} is transmission energy for a message. In this paper, we use the ECR of mesh to cluster, ρ, as a threshold value which is used to determine the topology type of each local sensor topology and exchanged with neighbor nodes to determine which node will be a cluster head.

3. Simulation Results

In this section, we evaluate the performance of the proposed HCM scheme via simula-tions. HCM is compared with cluster and mesh topologies.

Table 1. simulation parameters

Parameters	Value
Number of nodes	100(GRID), 100~180(Random)
Data rate	250kbps
Packet size	50byte
Event rate	5sec
Number of event nodes	3
Dimension	100m * 100m
Message arrival rate(λ)	1s
Probability of an event(*p*)	0.03
Tx range	15m
Tx/Rx/Idle energy	31/30/30(mW)
Simulation Time	200sec

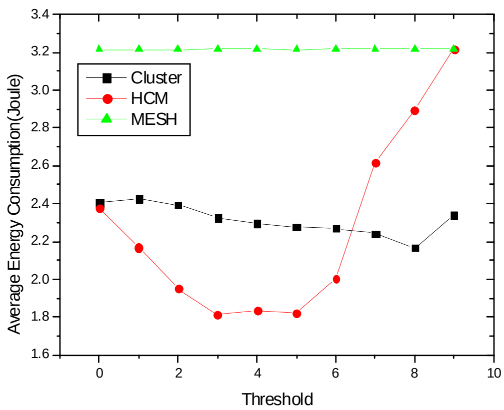

Figure 8. Energy consumption according to increase of ECR threshold value.

Figure 8 shows the average energy consumption of HCM, cluster and mesh topologies in the GRID distribution. Beacon period, T, is 1 second, active period of cluster members is 10 percent of T and active period of Mesh nodes is 30 percent of T. It shows that 3 or 4 is the proper number for energy efficient clustering.

Figure 10 shows the average energy consumption according to the increase of the number of nodes in randomly distributed sensor nodes. We can see that HCM consumes less energy than both cluster and mesh with 100 nodes and this advantage is maintained regardless of an increase in nodes.

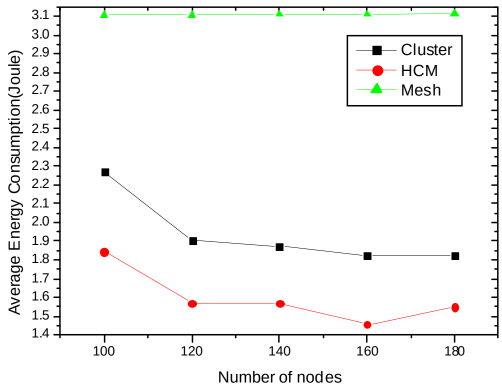

Figure 10. Average energy consumption according to increase of nodes distributed randomly.

4. Conclusions

In this paper, we have proposed an energy-efficient hybrid topology for wireless sensor networks. The proposed HCM scheme recognizes the density of neighbor nodes and each node decides its topology itself based on the proposed ECR condition. With this process, HCM is able to form a hybrid sensor network topology which has both cluster and mesh topologies in a single sensor network.

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