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Assistant Cluster Head Clustering Algorithm based on Cluster Grading in Wireless Sensor Networks

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Abstract: Clustering is an effective approach for organizing a network into a connected hierarchy, load balancing, and prolonging the network lifetime. In this study, an assistant cluster head clustering algorithm based on cluster grading (ACHC-CG) in wireless sensor networks was proposed, it has three obvious features: Firstly, using sensor density to divide each cluster into one of three grades, grade coefficient is an important parameter to generate assistant cluster head. Second, it utilizes residual energy, transmitting distance and historical data to dynamic generate assistant cluster head. Last, assistant cluster head is responsible for exchanging data between neighbor cluster heads, while cluster head is responsible for receiving sensing data in cluster and processing to reduce the energy consumption of head to prolong network lifetime and prolong the interval of generating cluster head. Simulation results show that, compared with LEACH, ACHC-CG significantly balances nodes average energy consumption and prolong the network lifetime.

Key words: Wireless sensor networks, assistant cluster head, cluster grading, network lifetime, energy consumption

INTRODUCTION

With the development of wireless communication and electronics, Wireless Sensor Networks (WSNs) become an invaluable research area by providing a connection between the world of nature and that of computation by digitizing certain useful information. The wireless sensor network has applied in many applications, such as office/home automation, robot control, and automatic manufacturing. It can be used in various outdoor places such as river, mountain, bridge, road, and even in harsh environments like the desert or battlefield. For example, wireless sensor networks can be used to detect a forest fire based on temperature information received from a large number of distributed sensor nodes.

In direct communication WSN, the sensor nodes directly transmit their sensing data to the Base Station (BS) or Sink node, without any coordination between the two. However, in Cluster-based WSNs, the network is divided into clusters. Each sensor node exchanges its information only with its Cluster Head (CH), which transmits the aggregated information to the BS or Sink node. Aggregation and fusion of sensor node data at the CHs causes a significant reduction in the amount of data sent to the BS and so results in saving both energy and bandwidth resources. The general idea is to perform the cluster formation based on the Received Signal Strength Indicator (RSSI) and to use local Cluster Heads (CHs) as routers of data gathered by the sensors in their clusters towards the sink node. Since the distance among cluster members and the respective cluster-head is, in general, smaller than the distance between these sensors and the sink, sensors in a cluster save transmission energy. Clustering can also be beneficial for purposes of energy saving because it favors data fusion procedures. Cluster members can collaborate about recent data measurements and determine how much information should be transmitted to the sink node. By averaging data values collected within the cluster, the algorithm can trade data resolution for transmission power (Rocha *et al.*, 2012).

Some advantages of network clustering can be identified as (Abbasi and Younis, 2007): (i) Size reducing of the routing tables stored at each individual sensor node, (ii) Saving the communication bandwidth, since it limits the scope of the inter-cluster interactions to CHs and avoids redundant exchange of messages among sensor nodes, (iii) Stabilizing the network topology at the level of sensors and thus cuts on topology maintenance overhead and (iv) The use of optimized management strategies to prolong the battery life of the individual sensors.

RELATED WORK

In the past several years, research on clustering in WSNs has focused on developing centralized and distributed protocols to compute sets of CHs and to form clusters. Centralized approaches are rather inefficient in the case of large scale networks since collecting the entire amount of necessary information at the central control (Sink node) is both time and energy consuming. Distributed approaches are more efficient for large scale networks. In these approaches, a node decides to become a CH or to join a cluster based on the information obtained solely from neighbors within its proximity. In this section, we summarize the related works regarding the network clustering and say how our algorithm differs from them.

Heinzelman *et al*. (2000) and Gao *et al*. (2006) proposed an alternative clustering-based approach, called LEACH (Low-Energy Adaptive Clustering Hierarchy). Cluster-heads have the ability to communicate directly with the base station whereas other nodes forward their data through the cluster-heads (typically, the one closest to them). In order to share the energy load, the LEACH protocol uses a load-balancing procedure that allows different nodes to become cluster-heads at different times. A centralized version of LEACH, called LEACH centralized (LEACH-C) was proposed in (Heinzelman *et al*., 2002), wherein each sensor transmits its location information along its residual energy to the sink, and then the sink computes the average energy of all the sensors in network. Then, the sink determines the incapable nodes whose residual energies are less than the average energy. LEACH-FL (Ran *et al*., 2010) is an improvement on LEACH protocol which employs a similar approach to (5). This method uses three parameters (node residual energy, node degree and distance from BS) for computing the probability. The BS selects nodes with higher probability as CHs, using 27 fuzzy if then rules. Although this method has the same drawback of Gupta's method, it can have a better result than LEACH protocol. Energy Residue Aware (ERA) (Chen *et al*., 2007) clustering algorithm is another energy-aware hierarchical approach. It is also improved from LEACH by including the communication cost into the clustering which includes residual energy, communication energy from the CH to the sink and communication energy from the cluster members to the cluster head. ERA uses the same CH selection scheme as LEACH but provides an improved scheme to help non-CH nodes selects a ''better'' CH to join by calculating the clustering cost and finding CH according to maximum residual energy. RRCH (Nam and Min, 2007) performs cluster formation only once to avoid the high energy consumption during clustering phase. It uses a similar method to LEACH to set up clusters. After the clusters are set up, RRCH keeps the fixed clusters and uses the round-robin method to choose the node to be the CH within the clusters. Every node has a chance to be CH during a frame. When a node has been detected as an abnormal node, the CH modifies the scheduling information and broadcasts it to the entire cluster during frame modification; then its cluster members delete the abnormal node based on the received schedule information. Dynamic/Static Clustering protocol (DSC) (Bajaber and Awan, 2008) is an extension of LEACH-C. Using the scheme, each node gets its current location using a Global Positioning System (GPS) and sends the location information and energy status to the sink. The sink will then determine the number of CHs based on the collected information and broadcast the clustering result to each node. Each CH will also determine a TDMA scheme for its cluster members similar to LEACH. Compared with LEACH-C, the number of messages received at the sink for DSC is significantly reduced. However, it suffers similar problems that LEACH-C has. Bandyopadhyay and Coyle (2003) proposed another extension of the LEACH protocol where the multi-hop routing is applied. Similar to LEACH, every CH advertises itself to the neighboring sensor nodes, which relay the advertisement in a multi-hop fashion. The advertisement is forwarded to sensor nodes in at most h hops away. Cluster Members (CMs) that receive multiple CH announcements, elect the closest CH in terms of hop count. On the other hand, a sensor node which is neither a CH nor receives any CH announcement becomes a forced CH. CPEQ (Boukerche *et al*., 2006) adopts the CH selection scheme of LEACH. Instead of using the randomly selected node as a CH directly, CPEQ uses the randomly picked node to choose the node with the highest residue energy from its neighbors. To build clusters, CPEQ uses Time-to-live (TTL) to limit the size of the cluster and calculates the optimized routes from cluster members to their CHs. For inter-cluster communication, CPEQ also uses the optimized multi-hop routes among CHs and the sink. By performing data aggregation within clusters and calculating optimized routes, CPEQ reduces traffic collision and data transmission delay.

Shu *et al*. (2005) stress the importance of simultaneous design of clustering strategies and routing, and they provide two mechanisms for balancing power consumption, called routing-aware optimal cluster planning and clustering aware optimal random relay. The partitioning of a network into uniformly dispersed clusters is the focus of the ACE clustering algorithm (Chan and Perrig, 2004). ACE provides uniform clusters by reducing the overlap among the clusters established in the initial phase. Those nodes that have the largest number of either ''uncovered'' neighbors or neighbors in non-overlapping cluster areas are recruited as favorable new cluster head nodes. Several papers deal with the design of clustering methods for the case of non-uniform deployment of sensor nodes. For example in (Kawadia and Kumar, 2003), the authors consider the problem of power control and clustering in heterogeneous sensor networks. A clustered network structure is established to ensure that transmit power used by all nodes within the cluster converges to the same level. The authors in (Virrankoski, and Savvides, 2005) notice that in non-uniformly deployed networks where the node density is globally high, the network can be partitioned into locally isotropic non-overlapping clusters with small density variations that will have high correlation in sensor measurements. While these techniques aim to create uniform or coherent clusters, they do not consider the coverage-preserving task required by many sensor network applications. The problem of scheduling nodes to enter the sleep mode in cluster-based sensor networks was studied in (Deng *et al*., 2005). The authors proposed a linear distance-based sleep scheduling scheme, where the probability that a sensor enters the sleeping state is proportional to its distance from the cluster head, but such a scheme leads to unequal energy consumption of sensor nodes in the cluster. An autonomous clustering algorithm based on coverage estimation self-pruning is presented in (Bae and Yoon, 2005). The sensor nodes with the largest expected coverage are the best candidates for the cluster head roles.

Some unequal clustering mechanisms are proposed. An unequal clustering model in (Soro and Heinzelman, 2005) is first investigated to balance the energy consumption of cluster heads. The work focuses on a heterogeneous network where cluster heads (super nodes) are deterministically deployed at some pre-computed locations. In (Li *et al*., 2005), the authors propose an energy-efficient unequal clustering mechanism (EEUC). It partitions the nodes into clusters of unequal size, and clusters closer to the sink have smaller sizes than those farther away from the sink, each node is required to calculate the cost for all CHs.

SYSTEM MODEL

Network model: In order to facilitate the description of wireless sensor networks, we assume that the network consists of N wireless nodes which randomly deploy in A area, the whole area was divided into many K×K square and each square has a cluster head, the character as follows:

- The network is a static randomly deployed network. It means a large number of sensor nodes are randomly deployed in a two-dimensional geographic space, forming a network and these nodes do not move any more after deployment
- There exists only one Sink node, which is deployed at a relative static place and located outside of the wireless sensor networks
- The nodes have ideal sensing capabilities. In other words, the quality of the node's sensing does not change within the cluster range regardless of the distance from the node
- All sensor nodes have limited batteries, and to recharge the batteries is impossible, the energy consumed per bit for sensing, processing, and communicating is typically known, remaining energy can be estimated. As a result, measuring this remaining energy is not essential
- Each node in WSN has an initial amount of energy, E_r, and the Sink node is not limited in terms of energy, memory, and computational power
- Links are symmetric, i.e., node i and j can communicate using the same transmission power
- The sensor nodes within the distance r (i.e., the transmission range of the node) from the sink can communicate directly with the sink. All other sensor nodes are organized into clusters, and they communicate their data through their respective Chs
- The nodes can be either cluster heads or ordinary nodes
- The location of each node is known, namely, the location of node i is (x(i),y(i)), so the distance of two nodes can calculate through Eq. 1:

$$d_{i,j} = \sqrt{(x(i)-x(j))^2 + (y(i)-y(j))^2} \quad (1)$$

Energy consumption model: For a simplified power model of radio communication, the energy consumed per second in the key challenges in unlocking the potential of transmission is (Heinzelman *et al*., 2000):

$$E_{TX} = \left(e_t + e_d r^n\right) B \quad (2)$$

where, e_t is the energy/bit consumed by the transmitter electronics, and e_d accounts for energy dissipated in the transmit op-amp (including op-amp inefficiencies). Both e_t and e_d are properties of the transceiver used by the nodes, r is the transmission range used. The parameter n is the power index for the channel path loss of the antenna. This factor depends on the RF environment and is generally between 2 and 4. B is the bit rate of the radio and is a fixed topology management provides the distributed parameter in our study. Typical numbers for currently available radio transceivers are $e_t = 50\times10^{-9}$J/bit, $e_d=100\times 10^{-12}$J/bit/m (for n = 2) and B = 1 M bit/s (Heinzelman *et al*., 2000).

On the receiving side, a fixed amount of power is required to capture the incoming radio signal where e_r is the energy/bit consumed by the receiver electronics used by the node, usually $e_r = 50\times10^{-9}$ J/bit:

$$E_{RX} = e_r B \quad (3)$$

Now let us consider one-hop communication in a finite one dimensional network from ordinary node to head or head to neighbor head, if the source node i will generate A E_{rlang} and the distance of node i and node j is $d_{i,j}$, so the power consumed by this communication is then simply as the Eq. 4:

$$E_{TX}(i,j) = \left(e_t + e_d d_{i,j}^{\,n}\right) B A_i \quad (4)$$

where, $d_{i,j}$, can calculate through Eq. 1.

Node j as the receiver, the power consumed by this communication is then simply as the Eq. 5:

$$E_{RX}(j,i) = e_r B A_i \quad (5)$$

Suppose the initial energy of all nodes are same, namely, E_r, after a period of time, node i has transmits information n1 times and has receives information n2 times before T1(suppose the energy of node i is not smaller than the value and the information unit is A Erlang). the remainder energy of node i at T1 is then simply as the Eq. 6:

$$E_r(i) = E_r(i) - \sum_{k=1}^{n_1} E_{TX}(i, j_k) - \sum_{p=1}^{n_2} E_{RX}(j_p, i) \quad (6)$$

where, n_1 is the number of nodes which node i transmit data to next node, n_2 is the number of nodes which node j received data from other nodes.

ASSISTANT CLUSTER HEAD CLUSTERING ALGORITHM BASED ON CLUSTER GRADING

In this section, we describe the ACHC-CG algorithm in detail.

Cluster grading: In the case of uniform distribution, the number of nodes in each cluster maybe different, so we classify each cluster into one of three grades.

The degree of coverage is generally defined as the ratio of the total area covered by all nodes and the target area (Liu *et al*., 2006), wherein the total area covered by all nodes is the union set of each node covered area, so the degree of coverage is generally lea than or equal 1:

$$D\_{av} = \frac{\bigcup_{i=1,2,..N} A_i}{A} \quad (7)$$

where, D-av represents the average degree of coverage in entire network, Ai represents the coverage area of the i-th node, N is the number of nodes in entire network, A is the total area.

We assume that the cluster number is M, for each cluster C_i, head calculates its degree of coverage through Eq. 8:

$$D(C_i) = \frac{\bigcup_{i=1,2,..M_{Ci}} A_i}{K\times K} \quad (8)$$

where, M_{Ci} is the number of nodes in cluster C_i, Ai represents the coverage area of the i-th node in cluster C_i, cluster C_i is a K×K square.

Then, the cluster is divided into different grade, we assume ô is the threshold parameter, if $D(C_i)>D_{av}$, we define this cluster is a high density cluster (C_h); if ô $*D_{av}\le D(C_i)< D_{av}$, we define this cluster is a low-density cluster (C_l); if $D(C_i)<\tau *D_{av}$, we define this cluster is a sparse cluster (C_s), where τ is a parameter which can be adjusted by network environment.

Assistant cluster generating: In our scheme, cluster head is responsible for collecting sensing data from all nodes in cluster and receiving data from neighbor cluster head, cluster head compresses the data and send to assistant cluster head, the assistant cluster head is responsible for transmitting data to neighbor cluster head. In order to reduce energy consumption and prolong network lifetime, for each cluster, whether there is an assistant according to the node density and the distance between cluster head (CH_i) and sink node. The average distance between cluster head and sink node can compute through Eq. 9:

$$d(av) = \frac{\sum_{i=1}^{M} d_{CHi,\,sink}}{M} \quad (9)$$

where, $d_{CHi,sink}$ is the distance between cluster head CH_i and sink node, M is the number of cluster.

In cluster C_i, CH_i computes its average distance into cluster by Eq. 10:

$$d(C_i) = \frac{\sum_{j=1}^{N(C_i)} d_{j,\,CHi}}{M} \quad (10)$$

where, $N(C_i)$ is the number of nodes in cluster.

We assume that $D_{rx}(C_i)$ and $D_{tx}(C_i)$ is respectively represents the bytes of cluster head CH_i receiving data and transmitting data in T, so we compute the coefficient of assistant cluster for each cluster through Eq. 11:

$$T_{as}(C_i)=\lambda\times\frac{D_{\_av}}{D(C_i)}\times\frac{d_{CH_i, sink}}{d_{(av)}}\times\left(\frac{D_{RX}(CH_i)}{E_{RX}}+\frac{D_{TX}(CH_i)}{E_{TX}}\right) \quad (11)$$

where, λ is a variable parameter and can be dynamically adjusted according to the network environment, $\lambda\in(0,1)$. T is the cycle time.

For cluster C_i, if $T_{as}(C_i)$ is larger than threshold, it should generate assistant cluster head, then head respectively computes the sum of the residual energy of all nodes in cluster, the average residual energy $E_{r\_ave}(C_i)$:

$$E_{r\_ave}(C_i)=\frac{\sum_{j=1}^{M_{Ci}} E_r(j)}{M_{Ci}} \quad (12)$$

In order to balance the energy consumption of nodes in cluster C_i, which should generate assistant cluster head, only these nodes which their residual energy are larger than the average residual energy have the chance to become the assistant cluster head. We assume that $D_{CHi,CHj}$ is the bytes between cluster CH_i and its neighbor cluster CH_j, $d_{CHi,CHj}$ is the distance of cluster CH_i and its neighbor cluster CH_j, for these ordinary node s in cluster C_i which has the chance to become assistant cluster head, using Eq. (13) to compute the probability of becoming assistant cluster head:

$$p(s)=\frac{E_r(s)}{\sum_{q=1}^{t}(d_{CHi,\,CHq}\times D_{CHi,\,CHq})} \quad (13)$$

where, t is the neighbor cluster number of cluster C_i, $E_r(s)$ is the residual energy of ordinary node s.

Cluster head will select the node j as the assistant cluster head, which the residual energy of node j is greater than average residual energy and p_j is the maximum:

$$p(s)=\text{Max}\{p(s)\mid E_r(s)>E_{r\_ave}(C_i)\} \quad (14)$$

Assistant cluster head clustering algorithm based on cluster grading: In ACHC-CG algorithm, each node located in the one cluster throughout the life cycle, in order to balance the energy consumption, some of cluster will generate assistant cluster head, the specific steps as follows:

- **Step 1:** Initialization phase, when the nodes are randomly deployed in the sensing area, the network is divided into M cluster, all nodes in each cluster has the same residual energy, so cluster head is randomly generated from all nodes, the head broadcast information to all nodes in cluster and neighbor cluster, then head to construct member table and neighbor head table according to receiving information. Each table includes residual energy, location information (x_i,y_i), the number of bytes which transmitting data and receiving data and so on. Sink node sets up T as the cycle time and threshold and broadcasts to all cluster heads, then each cluster goes to the working phase
- **Step 2:** Working phase, ordinary node is responsible for sensing data and sends to cluster head, head is responsible for collecting information from ordinary nodes in cluster and receiving data from neighbor cluster head, then head handles with these data and transmits to next hop until T is over
- **Step 3:** if cluster C_i has not an assistant cluster head, cluster head CH_i computes its $T_{as}(C_i)$, if $T_{as}(C_i)$ is larger than threshold, cluster $T_{as}(C_i)$ uses Eq. (12-14) to generate assistant cluster head
- **Step 4:** Cluster head CH_i computes its residual energy and the average residual energy of cluster, if E_r(head) is less than the average residual energy $E_{r\text{-}ave}(C_i)$, cluster C_i go to step5 to generate a new head, else cluster head continues to next round and go to Step 2
- **Step 5:** if cluster C_i has an assistant cluster head, cluster head CH_i informs all nodes in cluster and its neighbor cluster heads that the assistant head is the new head and the old head becomes an ordinary node and go to step 2
- **Step 6:** if there is not an assistant cluster head and the residual energy of head is less then the average residual energy of cluster, the head selects an ordinary node as a new head which has the maximum in Eq. 15:

$$\rho(j)=\frac{E_r(j)}{E_{r\_ave}(C_i)}\times\frac{d_{j,\,CHi}}{d(C_i)} \quad (15)$$

where, j is an ordinary in cluster C_i, and ρ(j) is the probability of node j becoming the head which consider the residual energy and the distance between node j and cluster head CH_i.

SIMULATION RESULTS

This section presents the performance comparison with the proposed ACHC-CG algorithm and LEACH. In

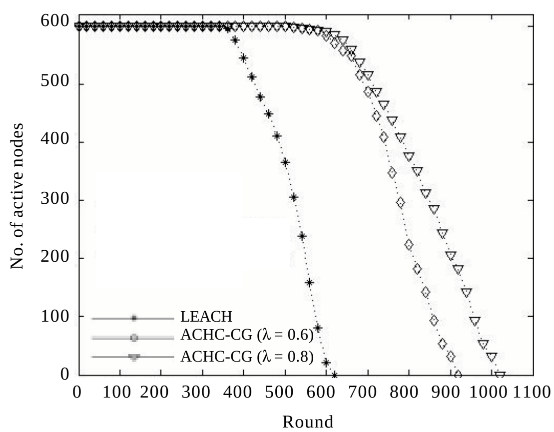

Fig. 1. Relation of the number of active nodes and rounds (λ = 0.6,0.8)

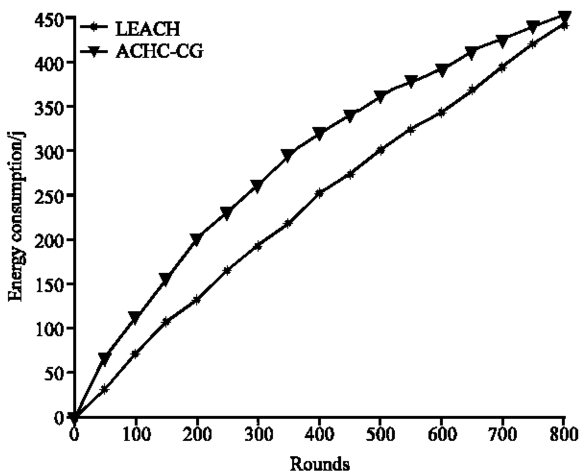

Fig. 2. Relationship between energy consumption and rounds

this simulation, we assume that there are 600 homogeneous sensors are randomly deployed within the sensing field 1000×1000 m. The area is divided into 10×10 cluster. Each cluster is 100×100 m. The location of the sink node is outside of the sensing field, and there is only one sink. Sensor nodes in cluster periodically sense events and transmit the data packet to the cluster head and heads transmit receiving data to next hop until to sink node.

We use two metrics to analyze and compare our simulation results for clustering and energy saving: network lifetime and energy dissipation. Figure 1 presents the number of nodes alive when using clustering protocols. This result is closely related with the network lifetime of the wireless sensor networks. In the case of networks using LEACH algorithm, the first event where a node runs out of energy occurs after 380 rounds and only 20 nodes are alive at 600 rounds, whereas in the case of ACHC-CG (λ = 0.6), it occurs after 620 rounds and 32 nodes are alive at 900 rounds, for ACHC-CG (λ = 0.8), it occurs after 650 rounds and 35 nodes are alive at 1000 rounds. Compared to LEACH, ACHC-CG algorithm prolong network lifetime by 38.7 and 41.5%, respectively, this is because LEACH only considers single-level clustering topology and does not optimize based upon transmission distance. While ACHC-CG utilizes the assistant cluster head to reduce cluster head energy consumption by residual energy, distance and historical data. More large value of λ, more clusters have assistant cluster head, when λ is 1, each cluster will generate an assistant head.

Figure 2 is the relationship between energy consumption and rounds, it can be observed that the average energy consumption of LEACH is larger than ACHC-CG, The increasing rate is closely related with unbalanced energy consumption in LEACH, the sensor node run out faster than ACHC-CG, the reason is that ACHC-CG can consider the residual energy, transmitting distance and historical data to generate assistant cluster head uniform energy consumption, so it can more useful to balance energy consumption and save the entire network energy.

CONCLUSION

Clustering protocol enables sensor nodes to reduce data packets by data aggregation on wireless sensor networks. In this work we proposed an assistant cluster head clustering based on cluster grading (ACHC-CG) in wireless sensor networks, ACHC-CG algorithm has three obvious features: Firstly, using sensor density to divide each cluster into one of three grades, grade coefficient is an important parameter to generate assistant cluster head. Second, it utilizes residual energy, transmitting distance and historical data to dynamic generate assistant cluster head. Last, assistant cluster head is responsible for exchanging data between neighbor cluster heads, while cluster head is responsible for receiving sensing data in cluster and processing to reduce the energy consumption of head to prolong network lifetime and prolong the interval of generating cluster head. Simulation results show that, compared with LEACH, ACHC-CG significantly balances nodes average energy consumption and prolong the network lifetime.

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