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Data Collection in WSNs Using Mobile Element and Hierarchical Routing

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Abstract—*the collection of data from large-scale wireless sensor networks (WSNs) is a challenging task and these two approaches can increase the efficiency:*
1)By hierarchical routing based on node clustering and 2) by mobile elements (MEs).
Since either method has benefits and drawbacks, this paper presents a combined approach, called node-density-based clustering and mobile collection, to combine the hierarchical routing and ME data collection in WSNs. A number of cluster heads (CHs) collect information from cluster members and then an ME visits these CHs to collect data. First, for a randomly deployed WSN, a new CH selection approach based on the node density is proposed. The benefit is that the nodes which are surrounded by more deployed nodes are more likely to be CHs. Thus, the efficiency of both ME data collection and intracluster routing is improved. Second, a low-complexity traveling track planning algorithm is designed for an ME to pass by all CHs Extensive simulations show that the proposed topic leads to not only remarkable performance improvement but also swap between the network energy saving and the data collection latency.

Index Terms—Data collection, mobile element (ME), wireless sensor networks (WSNs), cluster head (CH).

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I. Introduction

How to minimize the extend the lifetime and energy dissipation of wireless sensor networks (WSNs) is a challenging issue, especially for large-scale WSNs because of long geographical distances for data delivery, large numbers of sensors, and big amounts of data to be collected. The research community has proposed to exploit the mobility of super nodes or travelers to collect information from sensors, such as a mobile sink [1]–[3]. An example is the structural health monitoring [4]. Sensor devices are deployed at different positions in a large-scale civil infrastructure. A radio-controlled helicopter flies along a designated path to collect data from the sensors. In this way, the mobile element (ME) takes the full responsibility and moves to every sensor node to collect data by short-range single-hop radio communications. Such approach is suitable for delay-tolerant networks

(DTNs) [5]. An ME can deliver messages from remote sensors to a BS in a “store-carry-forward” way. By exploiting the mobility of the ME, the long-distance transmissions are avoided and a large amount of energy can be conserved. However, a long traveling trip and huge energy supply on the ME are

required and it also results in a large data collection latency. Hence, this approach may not be feasible for large-scale WSNs. Combining the ME-based data collection and hierarchical clustering seems a promising way to achieve a better tradeoff between the energy consumption and the data latency. In the schemes proposed in [2], [6], and [7], sensors send their data to nearby CHs via multihop routing and an ME then passes by the CHs to collect the data. In this way, the ME visits only the CHs instead of all the sensor nodes. Alternatively, one or more mobile sinks can sojourn through a network and the sensors deliver data via multihop routing to the mobile sink(s) [3]. Thus, the intracluster multihop routing requires much fewer hops compared to the pure clustering-based methods and meanwhile the trip length of the ME or mobile sinks and the data latency can be significantly reduced. Although the hierarchical routing and the ME-based (or mobile sink-based) methods have been extensively studied, combining them together for data collection is less explored. In this paper, a combined approach, called density-based clustering and mobile collection, is proposed. Considering sensors are randomly deployed in a sensing area, we first offer CH-selection algorithm based on the density of node. The density property is defined as the number of peripheral nodes inside its certain range. Second, an algorithm of low computational complexity to plan the traveling path for an ME to pass by all CHs. The algorithm is easy but efficient to calculate the optimal track with hundreds of visiting vertices, so it is suitable for the ME path planning after sensor nodes have been grouped into clusters. Third, to further improve the efficiency of the ME data collection. A VH can cache and forward the data from some other nodes together with its own data to the ME when it passes by. Using VHs, work load of CHs and multihop routing can be reduced. This operation includes two steps.

1) Initialization stage, base station collects the location information of all nodes and track of the ME is planned. Then the role of each node as a CH, VH, or normal node (ND) is broadcast to the whole network. 2) Data collection stage, the ME travels through the track repeatedly and collects data from nodes. This combined approach gain the advantages of the traditional hierarchical routing and the ME data collection.

II. Related work

Inspired by the potential applications and technical challenges, industry and academia have made intensive studies on the data collection methods in WSNs. Due to the special network architecture, multihop routing is usually required in WSNs, which can be divided into flat, hierarchical, and location-based routing [9]. However, such traditional data collection by radio transmission consumes much power to compensate the exponentially increasing path loss and to relay data from other nodes.

Recently, another approach has emerged using one or more mobile sinks to move throughout a sensing field and collect data directly from the sensors via short-range wireless communications. Many research efforts on this topic have focused on how to schedule the optimal mobility (or travel route) of ME(s) so that the cost for collecting data, such as the energy consumption and data collection latency, can be minimized.

III. Combined approach to data collection

In this section, the data collection scheme, the routing algorithm, CH selection, and ME path planning are described in details.

A. Overall Procedure

We consider aWSN in which ME can travel around in the sensing area to communicate with sensors. Every sensor node has a fixed transmission range which is a circular area with radius of r. And every node has a unique identification and is equipped with a GPS module to monitor its geographic location. The position of the BS is prestored in the sensor nodes. The ME broadcasts beacon signals periodically when it is traveling through the sensing area and a node communicates with the ME when it hears the beacon. The proposed hybrid approach combines the hierarchical routing and the ME data collection, and consists of two stages:

1) The network initialization stage and
2) The data collection stage.

The procedure for network initialization is as follows.

1) First the WSN is initialized, and then every node broadcasts a HELLO message containing its ID and GPS location to the neighbor nodes. So every node can realize the number of its neighbor nodes and their positions.

2) Using geographic multihop routing each node sends its location information to the Base Station.

3) After gathering the location information of all the nodes, Base Station plans the data collection track based on the local node density. These steps are listed below.

a) The BS selects the CHs according to the density of each node which is defined as the number of peripheral nodes inside a certain range.

b) The BS plans the optimal traveling track for the ME to pass by all the CHs.

c) Except the CHs, the nodes which are within the radio range of the ME track are labeled as VHs.

Thus, all sensors are partitioned into three categories:

1) CHs 2) VHs 3) NDs.

4) The BS broadcasts a configure packet to all the nodes in the network which contains two lists, one including the IDs and locations of the selected CHs and the other containing the information for the VHs. The broadcasting can be achieved by the restricted flooding method.

5) When a node receives the configure packet, it first determines whether it is a CH or VH by looking up its ID in the two lists. If it is an ND, it calculates the distances to all the CHs and VHs and associates itself with the closest one. After the network initialization stage, all nodes in the WSN have identified their “roles” and the optimal traveling track for the ME has been planned by the BS based on the node density.

Then, the geographic information of the track and the positions and IDs of the CHs are input into the ME. The ME will travel along the track periodically to collect data from the CHs and VHs. For example, the track is prestored in the memory of the on-board computer of a drone, and then it flies along the track using the GPS positioning and automatic navigation.

Please note that both CHs and VHs can gather data from NDs and upload them to the ME. However, CHs are used to plan the ME’s travel track but the VHs are not. Actually, the VHs are determined after the track has been planned. The procedure of the data collection stage is listed as follows.

1) If a node is a CH or VH, it will hold its data and wait for the ME. Otherwise, an ND delivers its data to the nearest CH or VH using the same local geographic routing method as in the network initialization.

2) The ME travels along the track and keeps transmitting beacon signals.

3) When a CH or VH hears the beacon signal, it transmits the locally aggregated data to the ME directly. An ALOHA-like media access control (MAC) mechanism is utilized to coordinate the transmissions from the sensor nodes to the ME. When a node hears the beacon signal, it first waits for a random time and then transmits. If frame collision occurs due to simultaneous transmissions, the ME will not reply the acknowledgement (ACK). Then, the nodes perform random back off and retransmit until the data are successfully delivered.

4) When the ME completes the round trip and comes back to the BS, it has collected the data from all the sensors. Obviously, the ME may just move into the radio range of a CH and receive data by wireless transmission over the distance of r. In a hierarchical routing approach, the power consumption of a CH is usually faster than the other NDs. First, when a CH is running out of power, it broadcasts a message to its neighbors inside its radio coverage which are the "one-hop children nodes." Then, these nodes no longer forward packets to the CH and instead cache the data by themselves. The ME still moves to the position of the CH and broadcasts the beacon signals at the CH's location as before. Then, these one-hop children nodes transmit their data to the ME directly because the ME is inside their radio range. In this way, the CH is actually replaced by the ME and the one-hop children nodes become VHs automatically. The advantage of this method is that the CH replacement is localized and does not affect other clusters. Thus, the current track of the ME and the VHs do not need to change, so the overhead to deal with the CH dynamics is minimized.

B. Local Geographic Multihop Routing

A node delivers its location information to the BS in the initialization stage and an ND needs to deliver its packets to the nearest CH or VH in the data collection stage. In both cases, multihop routing is needed. Since each node has obtained the locations of itself and its neighbors, a geographic routing mechanism that works with local topological information can be utilized [16]. A simple energy-aware local geographic routing with void avoidance algorithm. The basic idea is that a node selects the neighbor which is closest to the destination as the next hop. In this protocol, the packet header contains a packet sequence number, which begins with 1 and increases by 1 for every new generated packet.

Algorithm 1. Multihop Routing Algorithm

```
Initialization:  set all the neighbors of the tagged node, denoted by $\Omega$;
while packets to be forwarded do
    Calculate distance from every neighbor to destination;
    Check Packet ID in the Transmission Table;
    if the Packet ID is duplicated then
        Get the next-hop node, denoted by nh, from the Next-Hop Node ID field in this Packet ID record;
        Find the neighbors whose distances to the destination are larger than that of nh; these neighbors form a set denoted by $\Omega\_$;
        Find a neighbor in $\Omega\_$ which is closest to the destination, denoted by n_h;
    else
        Add the Packet ID in the Transmission Table;
        Find a neighbor in $\Omega$ which is closest to the destination, denoted by n_h;
    end if
    Use n_h as the next hop and update the Next-Hop Node ID field with n_h in this Packet ID record;
    Forward the data packet to n_h;
    When the node n_h transmits the packet, the tagged node overhears the packet and extracts the value of El from the header;
    if El < E0 then
        Remove the node n_h from the neighbor set $\Omega$;
    end if
end while
```

C. Density-Based CH-Selection Algorithm

In this algorithm CHs are selected according to the node density. The density property is defined as the number of the peripheral nodes that are in the circle with the radius of R and centered at the node

Algorithm 2. CH-Selection Algorithm

```
Initialization: define the residual set, $\Phi$, which includes all the nodes;
Initialization: define the CH set, $\Psi$, which is empty;
Initialization: define the cluster range radius, R;
Get the initial set size $N = |\Phi|$;
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while $N \geq 1$ do
    for i = 1 to N do
        For the i-th node in $\Phi$, denoted by Ni, draw a circle with radius R and centered at Ni;
        Let $\Gamma$ = {the nodes in $\Phi$ and inside the circle};
        Check the multi-hop routing from all nodes in $\Gamma$ to Ni;
        Let $\Lambda$ = {the nodes in $\Omega$ which cannot reach Ni};
        Update node set by $\Gamma = \Gamma - \Lambda$ to exclude the isolated nodes;
        Get the density of Ni, $Di = |\Gamma|$;
    end for
    Get the node with the largest density, $Nc = \max_{Ni \in \Phi} \{Di\}$;
    Update the CH set by $\Psi = \Psi + Nc$;
    Update the residual set by $\Phi = \Phi - \Gamma$;
    Update the set size by $N = |\Phi|$;
end while
```

D. Traveling Path Planning Algorithm for an ME

First all sensors are grouped and the n ME only visits the CHs, by this number of RPs visit reduced. Considering this feature, we introduce a simple path-planning algorithm with a very low complexity. It is named by optimal nearest-neighbor algorithm and shown in

Algorithm 3. Optimal Track Planning Algorithm

```
Initialization: define the visiting vertex set, $\Phi$, which includes all the CHs and the BS. Suppose there are totally N vertices in $\Phi$, i.e., $N = |\Phi|$.
Definition: d(vi, vi+1) is the distance between the two vertices, vi and vi+1.
Set the BS as the initial starting vertex and annotate it by v1.
Remove the BS, v1, from the set $\Phi$, i.e.,$\Phi = \Phi - \{v1\}$.
Set i = 1;
while $\Phi$ is not empty do
    Find the CH in $\Phi$ which is nearest to vi and annotate it by vi+1;
    Find the CH in $\Phi$ which is nearest to vi+1 and annotate it by vi+2;
    Remove the CHs of vi+1 and vi+2 from the residual set $\Phi$, i.e.,$\Phi = \Phi - \{vi+1, vi+2\}$;
    Set i = i + 2;
end while
Set i = 3;
for i < N do
    if d(v1, v2)+d(vi, vi+1)>d(v1, vi)+d(v2, vi+1) then
        Change the order (v1, v2, vi, vi+1) into (v1, vi, vi+1, v2);
    end if
    i = i + 1;
end for
Output: the sequence of the CHs, vi ($1 \leq i \leq N$), that the ME should visit in order.
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A. WSN Model and Parameters

We consider a typical large-scale WSN of shape circle has area A and radius R.

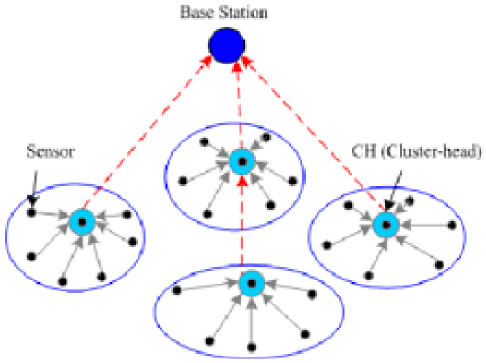

Figure:1WSN Model

In analytical model of the data collection process the whole network is covered by clusters and the ME contacts the CHs. where the sensor nodes within the radio coverage of the ME become VHs. Since a node obtains the positions of all its neighbors in the network initialization stage, it can estimate the transmission distances to its neighbor nodes for data forwarding. A CH or VH receives beacon signals from the ME and can estimate the transmission distance according to the beacon signal strength. Thus, a sending node can adjust the transmission power according to the distance to the receiver [18].

IV. Conclusion

This paper represents a combined data collection approach for large-scale WSNs that combine the ME and cluster-based routing. This approach can minimize the power consumption of sensors and ME and save the power in the data collection. The node density-based CH selection, local geographic routing with void avoidance and low-complexity ME path planning algorithm has been proposed obtained. The hybrid data collection approach opens up significant operation options for the data collection in large-scale WSNs. Using multiple MEs in the hybrid data collection may be more efficient, but scheduling the traveling paths is also more challenging and requires further investigation. In addition, combining network partitioning and ME data collection is also an interesting topic for future research.

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