Building a Multi-Granularity Sensor Network Using 2-dominating Sets

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1. Introduction

Wireless sensor networks (WSN) have a wide range of applications, such as environmental monitoring and precision agriculture. In these applications, WSN are usually tasked to monitor the change of environmental phenomena and report useful information. Environmental phenomena have different levels of spatial, temporal and thematic granularities. The ability of the WSN to observe multi-granularity environmental phenomena depends on the number of sensors deployed in the network, their sensing frequency and their sensing resolution. The sensor nodes in a WSN are usually inexpensive, battery-powered, and have limited processing and communication capabilities. Thus, energy efficiency is the key requirement in the system design of a WSN (Gregory and William, 2000). We introduce a novel multi-granularity sensor network topology to enable the efficient observation of environmental phenomena at different levels of spatial granularities.

2. Network Topology

In-network aggregation is a well studied approach to achieve energy efficiency. In this section, two existing network topologies are discussed, and a new network topology will be introduced. There are two types of commonly-used sensor network structures for in-network aggregation. The first is the peer-to-peer flat structure as in Fig. 1(a) and (d), in which sensor nodes are organized as a *communication graph* (e.g., Lian et al. 2007). The second is the tree structure in Fig. 1(b) and (e), in which sensor nodes are organized as an aggregation tree (e.g., Madden et al. 2002). The root of the tree is the sink, and the precedence relationship between two nodes can be defined by, for instance, the geographic locations of the sensor nodes. The in-network aggregation is achieved in the flat structure by peer-to-peer communication in the same level, and achieved in the tree structure by aggregation from leaf nodes to the root node of the tree in multiple levels. We use *single-level communication* and *multi-level aggregation* to distinguish the two approaches in the flat and tree structures respectively.

Both flat and tree structures have limitations for monitoring environmental changes. For example, an environmental phenomenon with a circular shape appears and starts to expand in a region deployed with a WSN, and the WSN is tasked to monitor the size of the phenomenon. In the flat structure, the size of the circle can be calculated by aggregating the data along the boundary of the circle. However, if the circle expands continuously, the size of the circle need to be re-calculated by numerous in-network aggregations along the boundary. The frequent boundary traversals can become costly especially when the size of the circle is large with respect to the density of sensor nodes.

On the other hand, the tree structure can avoid frequent long distance traversals, since the parent nodes can aggregate change reports from their children, and only report to the upper level when the number of reports exceed a designed threshold. The tree structure shows the advantages of multi-level aggregations, however in the tree structure two spatially-correlated nodes at the same level will lose their correlation if they have different parents.

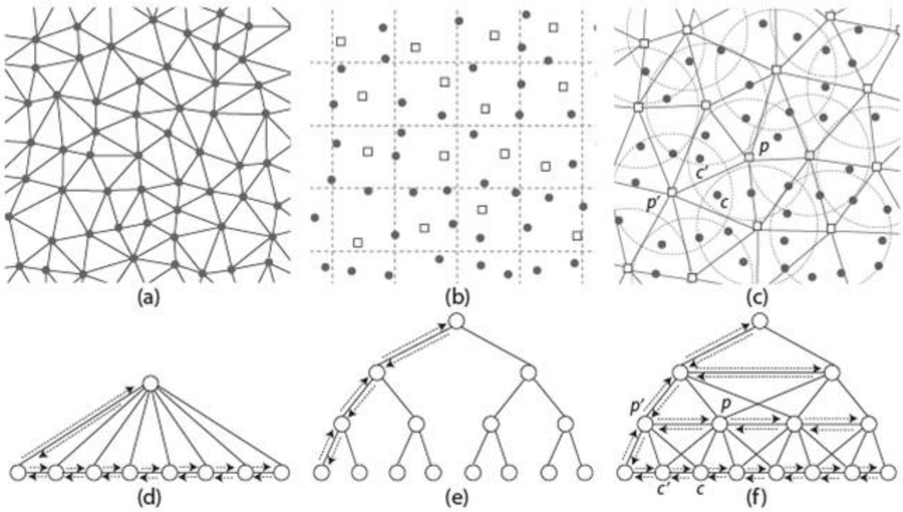

Figure 1. Sensor network structures. (a) flat structure, (b) tree structure, (c) multi-graph structure, (d)-(f) illustrate the topology of sensor nodes for the corresponding network structures. (b) shows only two levels of the tree structure, where circles and squares are nodes at lower and upper levels respectively. Similarly (c) shows only two levels of the multi-graph structure.

We propose a novel multi-granularity sensor network structure for in-network aggregation. The proposed network structure will be organized as multi-levels of communication graphs with different node densities, as in Fig. 1(c) and (f). We define spatial granularity as the density of sensor nodes, and thus the proposed structure will have multiple levels of spatial granularities. Sensor nodes at the upper level graphs can aggregate data from nodes at the lower level graphs. Also, as illustrated in Fig. 1(e) and (f), a significant difference between tree structure and the proposed structure is that in the tree each node has exactly one parent (except the root), but in the proposed structure each node can have multiple parents. The above property of the proposed structure ensures that any two neighboring nodes at the same level can communicate via multi-hop routings. In this case, the proposed structure should have both capabilities of single-level communication and multi-level aggregation, and thus energy efficiency should be achieved while maintaining spatial-correlated information in the network.

3. Multi-Granularity Sensor Network

A WSN is modeled as an undirected graph G = (V, E), where V is a set of sensor nodes and E is a set of undirected edges {v, v'} that represent the direct communication links between the nodes v ∈ V and v' ∈ V. The neighbours of a node v are the nodes that have links with v, i.e., *nbr*(v) = {v' : {v, v'} ∈ E}. G is constructed as a unit disk graph

(UDG), where there is a link {v, v’} $\in$ E between v and v’ if the distance of the two nodes is not longer than a unit communication range u. We planarize the UDG using the Delaunay criterion (Preparata and Shamos, 1985), as in Fig. 2(a).

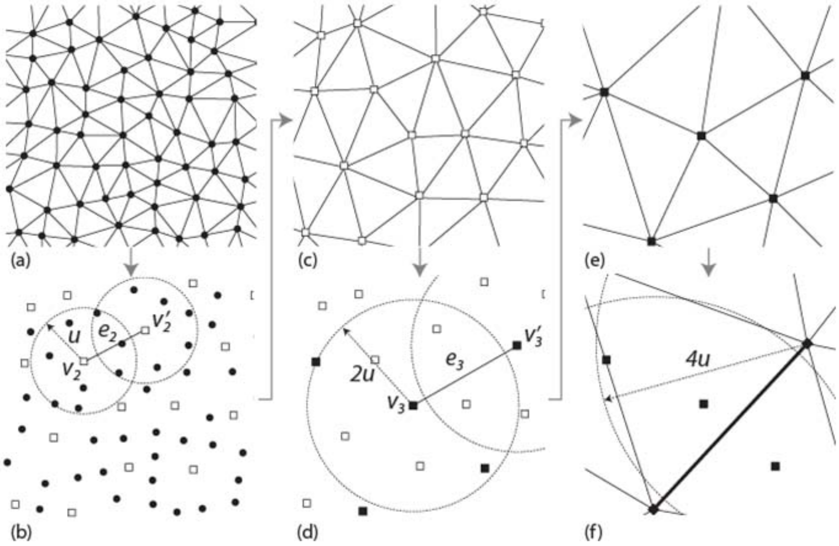

Figure 2. Multi-granularity sensor network. (a) level one graph, (c) level two graph, (e) level three graph. The edges of the graphs at each level are restricted by a unit disk, where the lower level graphs have smaller radius and thus shorter edges, and the upper levels have larger radius and longer edges, as in (b), (d), and (f).

We use the concept of 2-dominating set to build the proposed multi-granularity sensor network. Given a graph G = (V, E), a 2-dominating set S is a subset of V such that each vertex of G not contained in S has at least two neighbours in S. In a decentralized network, a 2-dominating set can be used as backbones for allocating resources and organizing communication, etc. A minimal 2-dominating set allows for placing the resources or facilities at minimal costs. Our objective is to select minimal 2-dominating set in WSNs for building multi-granularity sensor network. Note that minimal 2-dominating set problem is NP-hard, so that we have heuristic solutions for the problem.

Given the graph G = (V, E) as the first level of granularity, our first task is to select a minimal 2-dominating set S of the graph G to build the second level graph, denoted as $G_2 = (V_2, E_2)$. The selected set S will become the nodes in G_2, i.e., S = V_2, and E_2 is a set of edges among the nodes V_2.

A 2-dominating set provides an adjacency structure that is valuable for generating topology. The 2-dominating set ensures that for a parent p $\in$ V_2 (noting that S = V_2) and a node v $\in$ V-V_2, where {p, v} $\in$ E, there always exists a parent p′ $\in$ V_2 such that {p′, v} $\in$ E (p is used to specify a parent node). We define that only the immediate (one-hop) neighbours *nbr*(p) of a parent p are the children of p. We also define that there is an edge between two parents p and p′, i.e., {p, p′} $\in$ E_2, if the two parents have at least one common child v, where {v, p} $\in$ E and {v, p′} $\in$ E, as illustrated in Fig. 2(b). The built second level graph G_2 is shown in Fig. 2(c). Similarly, to build the third level graph G_3, we need to select a new and smaller 2-dominating set from G_2, as in Fig. 2(d) and (e). We have implemented our approach in a simulation environment. Our approach can run decentralized in a WSN, where each sensor node only has local knowledge of its immediate neighbours. Also, our decentralized approach is energy efficient, and it can produce sub-optimal results. One of the simulation results is presented in Fig. 3(a)-(d).

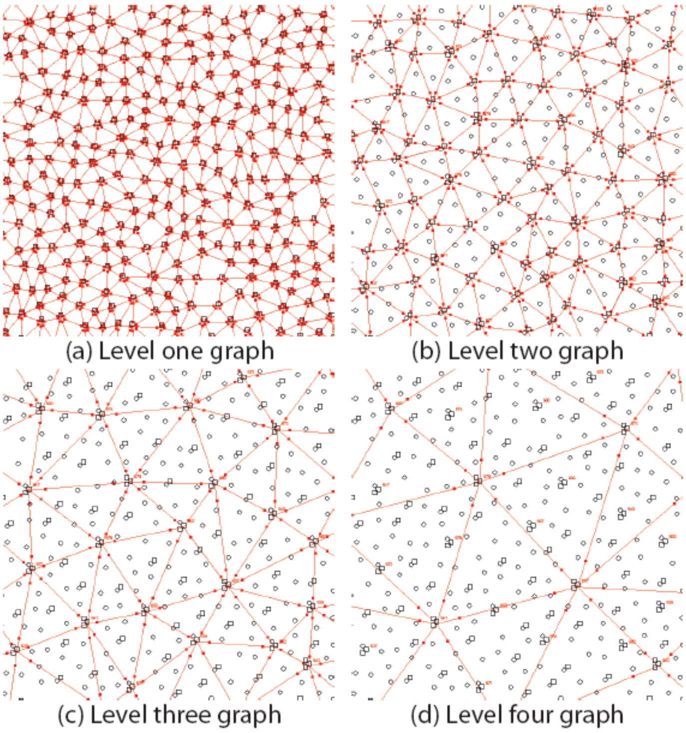

Figure 3. Simulation results of a multi-granularity sensor network.

4. Conclusion

We have presented a topology-based approach to select a subset of sensor nodes as parents for constructing multi-granularity sensor network. The built multi-granularity network combines the capabilities of tree structure and peer-to-peer structure, such that it can achieve both peer-to-peer communication at the same level and aggregation at multiple levels. The result can be applied for change detection in multiple granularities, as investigated in Shi and Winter (2009).

References

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