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Eigenvector centrality based cluster size control in randomly deployed wireless sensor networks

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ABSTRACT

Cluster size control plays a significant role in balancing energy consumption and mitigating hot spot problem in wireless sensor networks. Cluster size control is necessary as clusters having higher member nodes consume significantly higher amount of energy while low member nodes in a cluster lead to under utilization of channel capacity. Further, cluster-heads located near to sink have to perform additional function of relaying data of other nodes. All these factors are responsible for hotspots or energy holes creation which in turn affect the network lifetime. In this paper, we propose a heuristic approach based upon Eigenvector centrality for cluster size control which we have named as Ev-CSC. While existing methods in literature consider distance of a cluster-head from sink, layered architecture, uniform deployment of nodes, prefixed sink location as a precondition, our proposed method does not have these constraints and is applicable to any kind of deployment, traffic pattern and node types. We have applied Ev-CSC on equal clustering methods and have also compared the same with state-of-the-art cluster size control methods. The experimental results demonstrate that our proposed method enhances the performance of respective equal clustering methods and performs better as compared to cluster size control methods.

1. Introduction

Wireless sensor networks (WSNs) are widely utilized to gather information needed by smart environments like weather monitoring, tracking and surveillance in military, utilities and industries and automation in shipboard transportation systems. While designing wireless sensor networks, energy efficiency and scalability are the prime factors. These networks are mostly deployed at places where human intervention is rarely feasible and thus there is remote possibility of uniform deployment density (Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002; Yick, Mukherjee, & Ghosal, 2008). Even in uniformly deployed networks, due to uneven consumption of energy, the network acquires the characteristics of uneven node densities in later communication rounds.

Clustering is an effective method for efficient use of available resources, robustness and scalability in both uniformly and randomly deployed WSNs. Nodes are partitioned into groups called clusters and based on node attributes some nodes are selected as cluster-heads (CHs), while remaining nodes become member nodes (Yu & Chong, 2005). In literature, constant cluster communication radius has been considered widely. However, due to non-uniform/random deployment, various clusters have unequal node densities. This in turn leads to unbalanced energy consumption by respective cluster-heads. Cluster-heads with higher node density consume higher energy and thus have lower time span. Failure of these nodes at early stage leads to disconnection and results in decrease in network lifetime. Thus, for balanced energy consumption, densely deployed regions require more clusters or small *cluster size* as compared to regions with low density deployment. Here, *cluster size* refers to number of member nodes as well communication radius. Further, by controlling cluster size, interference among sensor nodes and collisions can be reduced for CSMA and in case of TDMA; allocation of time slots within a cluster for member nodes becomes simpler.

In cluster based WSN, inter cluster communication is structured as an arrangement of one-hop and multi-hop communication mode. For one-hop communication, sensor nodes can communicate directly with sink, while for multi-hopping, nodes route their packets using multi hops until the packet reaches to the sink. Both these modes lead to an unavoidable problem of unbalanced energy dissipation. In case of one-hop communication, distant nodes from the sink consume higher energy and in case of multi-hop communication due to heavy relay traffic load, the nodes adjacent to sink consume higher energy (Soro & Heinzelman, 2005). This

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unbalanced energy consumption between cluster-heads necessitates cluster size control.

The existing methods of cluster size control can be divided into two categories. First category methods use a predefined threshold node degree value to determine the cluster size. These methods have the advantage of simplicity, but they do not take into account relay load, which is an important factor. In these methods to ascertain the desired number of nodes in the cluster, nodes are required to communicate probe messages at different available power levels. This results in increase in energy consumption and response time. Second category of cluster size control methods take into consideration distance of cluster-head from sink. These methods are suitable for uniform node deployment and layered architecture. In addition to this, the location of member nodes as well as cluster-heads is considered prefixed and it is invariably assumed that the position of sink is either in the middle of the network or at extreme corners. However, for real world application this scenario rarely exists as deployment of nodes is mostly random in WSNs.

In this paper, we have used graph-based approach to address above mentioned issues in wireless sensor networks. We model the network as a fuzzy graph and derive α-cut sets corresponding to various available power levels. Intra cluster communication load and relay load of a node determines its importance in fuzzy graph and we compute the same in terms of Eigenvector centrality i.e. PageRank. The prospective cluster-head adjusts the communication radius of the respective cluster on the basis of Eigenvector centrality and α-cut sets. The proposed method has been named as Eigenvector centrality based cluster size control (Ev-CSC).

The salient feature of Ev-CSC is that it provides all the benefits offered by related cluster size control methods while addressing their limitations in respect of prefixing node deployment, sink position and spatial arrangement of the network. In other words, this method enhances the applicability of the related cluster size control methods by making them independent of node deployment, location of sink position and spatial arrangement of the network. Unlike the solutions proposed in literature, the proposed method considers both the issues relating to non-uniform node degree and relay load. Also, it does not require large amount of initial communication at different power levels for constructing neighbor tables. This has been achieved by incorporating fuzzy approach with α-cut sets, which has the added advantage of providing a simpler and faster solution. Besides this, the proposed method allows the user and network provider to negotiate more flexible and mutually beneficial contracts. Also, it can be implemented on top of contention-based or non-contention-based MAC protocols. In the proposed method Ev-CSC, we have also constrained the cluster communication range with lower bound and upper bound. By doing so, we introduce a new representation of cluster size control in clustered WSNs that is more comprehensive than the conventional methods and has better applicability.

We evaluate the performance of equal clustering methods i.e. LEACH (Heinzelman, Chandrakasan, & Balakrishnan, 2002), HEED (Younis & Fahmy, 2004), PEACH (Yi, Heo, Cho, & Hong, 2007) and CHEF (Kim, Park, Han, & Chung, 2008) before and after applying the proposed cluster size control method. The simulation has been done to evaluate the performance of both individual clusters and that of entire network. The performance of the proposed method has also been compared with unequal clustering approaches *viz* PADCP (Cheng, Ruan, Cheng, & Hsu, 2006) and EUCS (Xu, Zhu, Luo, Wu, & Ren, 2012). The simulation results indicate that the performance of our method Ev-CSC is better in terms of network lifetime and energy efficiency.

This paper has been organized as follows. The paper begins with the related work in section 2. Section 3 covers the preliminaries through which basic definitions and network model is introduced. Section 4 presents the proposed method in detail. The effectiveness of the proposed method is evaluated through simulations in Section 5. The paper concludes with brief discussion of the method along with future considerations in Section 6.

2. Related work

In this section, we have organized the related work into three subsections with one subsection each for state-of-the-art equal clustering methods, node degree based cluster size control methods and relay load based cluster size control methods respectively.

2.1. Equal clustering methods

Equal clustering methods are based on the assumption of fixed cluster communication range. Various probabilistic, energy aware, and fuzzy logic based equal clustering methods exist in literature. In these methods, the main emphasis of the research is towards selection of efficient cluster-heads and rotation of cluster-heads. Most of equal clustering approaches available in literature are LEACH (Heinzelman et al., 2002) like structures. LEACH uses probability function to select and rotate cluster-heads periodically. Different from LEACH, in WCA (Chatterjee, Das, & Turgut, 2002), node degree is taken into account to select the cluster-head. A node with optimum number of neighbor nodes has more chances to become cluster-head, but in WCA no corrective measures have been taken to maintain node degree in accordance to network load. HEED (Younis & Fahmy, 2004), an iterative method of clustering considers a hybrid of energy and intra cluster communication cost while selecting cluster-heads. For non-uniform deployment, it is shown in the simulations of HEED that numbers of nodes catered by a cluster differ a lot. In EECS (Ye, Li, Chen, & Wu, 2005), during cluster-head election phase, a constant number of candidate nodes compete for cluster-heads according to the nodes' residual energy. During cluster formation phase, based upon distance of a node from cluster-head and distance of a cluster-head from the sink, member nodes decide which cluster-head to join. Similarly method proposed by Han, Eom, Park, and Chung (2007) takes distance from the sink and residual energy of node as the criterion for cluster-head election. Yi et al. (2007) has proposed PEACH, where nodes can recognize the source and the destination of packets transmitted by the neighbor node by overhearing the transmitted packets. Nodes choose the particular destination as their cluster-head. The destination node after receiving the packets for a definite time first aggregates the packets and then communicates it. For non-uniformly deployed networks, where the number of neighbor nodes is variable, cluster size control can enhance the performance of this method. Tarhani, Kavian, and Siavoshi (2014) have proposed distributed clustering algorithm named Scalable Energy Efficient Clustering Hierarchy (SEECH) to increase energy efficiency. The proposed method selects relay nodes in addition to cluster heads. The basic idea of the method is similar to the method proposed by Wang, Bi, Lu, and Zhang (2010), in which double cluster heads is selected; one for intra communication and one for inter communication. However in SEECH, the selection of cluster-head and relay nodes is based on residual energy and node degrees. A tentative cluster head with high residual and high node degree is selected as final cluster head and a tentative cluster-head with high residual energy and low node degree is selected as relay node.

Fuzzy inference system, due to its comparatively less computational burden has also been widely used in WSNs for clustering purpose. In Gupta, Riordan, and Sampalli (2005) a centralized approach using degree and closeness centrality has been proposed to elect cluster-heads wherein base station has to collect three fuzzy variables (concentration, energy and centrality) from all sensor nodes. Kim et al. (2008) has also proposed a fuzzy logic based