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A multi-level clustering scheme based on cliques and clusters for wireless sensor networks ☆

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ABSTRACT

Wireless sensor networks (WSNs) have a wide range of applications in our lifetime. Indeed, WSNs perform a various missions and tasks in odor localization, firefighting, medical service, surveillance and security. In order to accomplish these tasks, the sensors have to perform partitioning protocols to form an organization into clusters and cliques. The hierarchical clustering is the key solution for WSNs to deal with the scalability problems in a network composed of millions of nodes. In this paper, a new hierarchical partitioning scheme is presented, named MCCC. It is cliques and clusters based hierarchical scheme that takes into account the size of cliques and clusters, it also minimizes the number of hops between the cluster head and its nodes. The proposed scheme is motivated by the need to have minimum and maximum size for cliques and clusters. This hierarchical scheme is proposed to respond to the energy and memory constraints for WSNs.

1. Introduction

Wireless sensor networks (WSNs) have started to receive growing attention from the research and engineering communities in recent years. Potential applications of WSNs include detecting and countering pollution in coastal areas, performing oceanic studies of bird/fish migration and weather phenomena, detection and prevention of forest fires, deterring terrorist threats to ships in ports, destruction of mines in different environments facilitating/conducting urban search and rescue (USAR), detecting suspiciously active chemical/biological agents, etc., [1].

Sensor nodes are generally equipped with data processing and communication capabilities. The sensing circuit measures parameters from the environment surrounding the sensor and transforms them into an electric signal. Processing such a signal reveals some properties about objects located and/or events happening in the vicinity of the sensor. The sensor networks generally employ a large number of miniaturized devices that have the task of measuring ambient conditions and reporting such measurements to some sinks nodes using wireless communication links. Each sensor has an on-board radio that can be used to communicate with its neighbors and to send the collected data to sinks which communicate the aggregated information to a processing center, [1,2]. Due to the resource limitation, a solution for an application in WSNs should take into account the limited capabilities of these devices by using a few amount of memory and energy, whilst maximize the life time [3].

WSNs have the capability to do their tasks in unattended and rough environments where the contemporary human-in-the-loop cannot do the task due to the risk, inefficiency and infeasibility. Therefore, sensor nodes are deployed

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randomly in the area by a relatively uncontrolled means, and together form a network in an ad hoc manner with hundreds or even thousands of sensor nodes will be involved [4,5]. To do these tasks, sensor nodes have to perform self-organization protocols by partitioning the network into cliques and clusters to achieve the scalability, enhance the lifetime of the network and improve the QoS. A clique is a network where every node can communicate directly with every node, the size of a clique is the number of nodes in it. In a clique, the cluster head will be automatically at one hop from the sensor nodes of its clique. In each clique/cluster, the cluster head should register the identities and manage the tasks of routing, data aggregation and queries dispatch with the members of its cluster [6,7]. Therefore, if the number of nodes of the clique/cluster is very large, the cluster head needs a large memory capacity and high amount of energy capacity to manage its members for a given period of time. Since this is not always feasible, we should introduce the size of the cluster/clique as a new parameter in clustering protocols [8]. The hierarchical routing or cluster based routing protocols have been proposed in order to meet the energy efficiency and scalability requirement of the WSNs. The main issue is forming sub network clusters, encouraging multi-hop transmission and enabling data fusion [9].

Partitioning of WSNs plays a vital role in improving network performance on the resource management as routing delay, bandwidth consumption and throughput. After clustering, the network is divided into disjoint clusters. The goal therefore of the clustering is to organize sensor nodes into cliques and/or clusters to facilitate certain network operations such as data aggregation and routing. Indeed, clustering allows to split data transmission into intra-cluster within a cluster, and inter-cluster between clusterheads and the sink. This separation leads to significant energy saving since the radio unit is the major energy consumer in a sensor node [8].

Clustering is usually adopted by the research community to fulfill the scalability purpose and typically to reach very high energy efficiency and prolong the lifetime of the WSN. In addition, the clustering has other side benefits and the corresponding objectives [10]. Grouping the nodes into cluster limits the scope of intercluster interactions to clusterheads and avoids redundant exchange of messages among sensor nodes consequently it conserves the communication bandwidth. It can also be used to localize the route setup within the cluster and therefore decrease the size of the routing table stored at each node in the network. Besides, clustering can stabilize the network topology at the level of sensors and thus cuts on topology maintenance overhead. Sensors would care only for connecting with their clusterheads and would not be affected by changes at the level of inter-cluster head tier. The corresponding hierarchical routing and data gathering protocols imply cluster-based organization of the sensor nodes in order that data fusion and aggregation are possible, thus leading to significant energy savings [11].

In this paper, a new partitioning scheme is proposed; this scheme is motivated by the need to have a minimum and a maximum size for cliques and clusters. In fact, this size of clusters and cliques has a direct effect on the energy consumption [11]. The cluster head must register the identities of all nodes in its cluster. But that it may not be always feasible for large cluster because sensors have a limited memory capacity. In addition, the energy consumed to manage a large number of nodes will be very high, which involves a large number of election algorithms. Clustering with taking into account the size of cliques and clusters avoids a significant number of election algorithms because when the cluster/clique has a moderate size the cluster head may survive longer to manage its cluster. Within the hierarchical scheme the sensor nodes are organized into levels. In each level, there are normal sensor nodes and cluster heads of sensor nodes. A normal sensor node in a level L cannot be considered as a normal sensor for level $L+1$. The cluster heads in a level L are considered for the clustering procedure in level $L+1$ [8,12]. We call the super cluster head the cluster head of last level. The super cluster head manages the nodes via the normal cluster heads.

In the hierarchical partitioning methods available in the literature (see the next section), the cluster head can belong to another different geographic area in term of number of hops compared to its nodes. Therefore, the change of messages between the cluster head and its nodes is time-consuming. In our algorithm, we impose on the cluster head to belong to the same region by partitioning the network into cliques at the root level (level 0). Then, we partition the network with a hierarchical scheme into cliques, each clique will have a size between k and $2k$. The parameter k is a positive integer that refers to the size of the clusters and cliques. More precisely, the clusters and cliques will have size according to the parameter k, exactly sizes between k and $2k$. The choice of k depends on the memory capacity of the sensor nodes and the energy capacity of the cluster heads. If the sensor nodes can store a great number of nodes and the cluster heads has enough energy to manage a great number of nodes therefore k can be chosen large. Otherwise, it should be chosen small. To generate these cliques of level 0 we must goes through three steps in which we try to have a maximal cliques having size upper than k. The cluster head will be automatically at one hop to nodes, so every node can communicate directly with every node. In another step the cliques of the level 0 are divided into cliques having sizes between k and $2k$. This partitioning is repeated hierarchically every time that the number of cluster heads obtained is greater than $2k$. The procedure is repeated for the cluster heads, which are in the same clique to form new cliques for the next level. Once this procedure is finished, another procedure to maintain the hierarchy of the scheme is invoked; it is a hierarchical partitioning into clusters.

The remainder of this paper is organized as follows: the next section presents a brief description of related works. The Section 3 describes the contributions and the objectives. Section 4 presents the model of the sensor network. In Section 5, the proposed protocol is presented. In Section 6 we present how to manage the dynamicity of nodes for the proposed protocol. In Section 7, a discussion about the worst case message complexity is given. The evaluation of the performances of the presented scheme is presented in Section 8. The last section is for the conclusion and the suggestion for the future works.