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A survey on clustering algorithms for wireless sensor networks

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Abstract

The past few years have witnessed increased interest in the potential use of wireless sensor networks (WSNs) in applications such as disaster management, combat field reconnaissance, border protection and security surveillance. Sensors in these applications are expected to be remotely deployed in large numbers and to operate autonomously in unattended environments. To support scalability, nodes are often grouped into disjoint and mostly non-overlapping clusters. In this paper, we present a taxonomy and general classification of published clustering schemes. We survey different clustering algorithms for WSNs; highlighting their objectives, features, complexity, etc. We also compare of these clustering algorithms based on metrics such as convergence rate, cluster stability, cluster overlapping, location-awareness and support for node mobility.

Keywords: Wireless sensor networks; Clustering algorithms; Scalability; Network architecture; Energy aware design

1. Introduction

Recent advances in miniaturization and low-power design have led to the development of small-sized battery-operated sensors that are capable of detecting ambient conditions such as temperature and sound. Sensors are generally equipped with data processing and communication capabilities. The sensing circuitry 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. Each sensor has an onboard radio that can be used to send the collected data to interested parties. Such technological development has encouraged practitioners to envision aggregating the limited capabilities of the individual sensors in a large scale network that can operate unattended [1–7]. Numerous civil and military applications can be leveraged by networked sensors. A network of sensors can be employed to gather meteorological variables such as temperature and pressure. These measurements can be then used in preparing forecasts or detecting harsh natural phenomena. In disaster management situations such as earthquakes, sensor networks can be used to selectively map the affected regions directing emergency response units to survivors. In military situations (Fig. 1), sensor networks can be used in surveillance missions and can be used to detect moving targets, chemical gases, or the presence of micro-agents.

One of the advantages of wireless sensors networks (WSNs) is their ability to operate unattended in harsh environments in which contemporary human-in-the-loop monitoring schemes are risky, inefficient and sometimes infeasible. Therefore, sensors are expected to be deployed randomly in the area of interest by a relatively uncontrolled means, e.g. dropped by a helicopter, and to collectively form a network in an ad-hoc manner [8,9]. Given the vast area to be covered, the short lifespan of the battery-operated sensors and the possibility of having damaged nodes during deployment, large population of sensors are expected in most WSNs applications. It is envisioned that hundreds or even thousands of sensor nodes will be involved. Designing and operating such large size network would require scalable architectural and management strategies. In addition, sensors in such environments are energy

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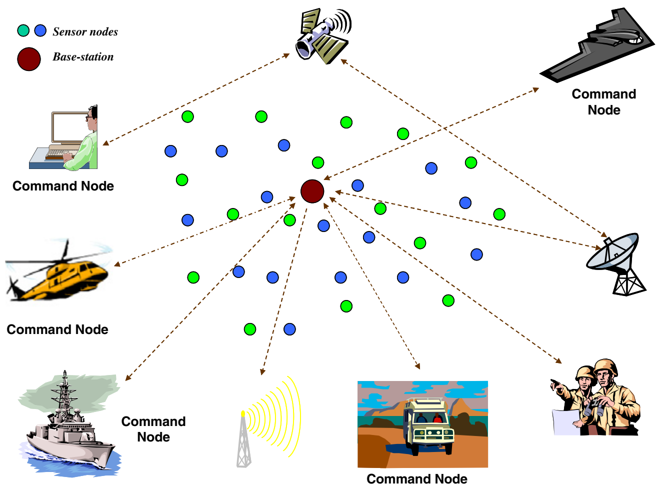

Fig. 1. An articulation of a sample WSN architecture for a military application.

constrained and their batteries cannot be recharged. Therefore, designing energy-aware algorithms becomes an important factor for extending the lifetime of sensors. Other application centric design objectives, e.g. high fidelity target detection and classification, are also considered [10].

Grouping sensor nodes into clusters has been widely pursued by the research community in order to achieve the network scalability objective. Every cluster would have a leader, often referred to as the cluster-head (CH). Although many clustering algorithms have been proposed in the literature for ad-hoc networks [11–15], the objective was mainly to generate stable clusters in environments with mobile nodes. Many of such techniques care mostly about node reachability and route stability, without much concern about critical design goals of WSNs such as network longevity and coverage. Recently, a number of clustering algorithms have been specifically designed for WSNs [16–20]. These proposed clustering techniques widely vary depending on the node deployment and bootstrapping schemes, the pursued network architecture, the characteristics of the CH nodes and the network operation model. A CH may be elected by the sensors in a cluster or pre-assigned by the network designer. A CH may also be just one of the sensors or a node that is richer in resources. The cluster membership may be fixed or variable. CHs may form a second tier network or may just ship the data to interested parties, e.g. a base-station or a command center.

In addition to supporting network scalability, clustering has numerous advantages. It can localize the route set up within the cluster and thus reduce the size of the routing table stored at the individual node [21]. Clustering can also conserve communication bandwidth since it limits the scope of inter-cluster interactions to CHs and avoids redundant exchange of messages among sensor nodes [22]. Moreover, 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 CHs and would not be affected by changes at the level of inter-CH tier [23]. The CH can also implement optimized management strategies to further enhance the network operation and prolong the battery life of the individual sensors and the network lifetime [22]. A CH can schedule activities in the cluster so that nodes can switch to the low-power sleep mode most of the time and reduce the rate of energy consumption. Sensors can be engaged in a round-robin order and the time for their transmission and reception can be determined so that the sensors reties are avoided, redundancy in coverage can be limited and medium access collision is prevented [24–27]. Furthermore, a CH can aggregate the data collected by the sensors in its cluster and thus decrease the number of relayed packets [28].

In this paper, we opt to categorize clustering algorithms proposed in the literature for WSNs. We report on the state of the research and summarize a collection of published schemes stating their features and shortcomings. We also compare the different approaches and analyze their applicability. In the next section, we discuss the different classifications of clustering techniques and enumerate a set of attributes for categorizing published algorithms. In Section 3, we summarize a collection of clustering algorithms for WSNs and present classification of the various approaches pursued. Finally, Section 4 concludes the paper.

2. Taxonomy of clustering attributes

Clustering techniques for WSNs proposed in the literature can be generally classified based on the overall network architectural and operation model and the objective of the node grouping process including the desired count and properties of the generated clusters. In this section we discuss the different classifications and present taxonomy of a clustering attributes. We later use such attributes to categorize and compare the surveyed clustering algorithms.

2.1. Classifying clustering techniques

2.1.1. Network model

Different architectures and design goals/constraints have been considered for various applications of WSNs. The following enlists some the relevant architectural parameters and highlight their implications on network clustering.

- *Network dynamics:* Basically WSNs consist of three main components: sensor nodes, base-station and monitored events. Aside from the few setups that utilize mobile sensors [29,30], most of the network architectures assume that sensor nodes are stationary [19,31,32]. Sometimes it is deemed necessary to support the mobility of base-station or CHs. Node mobility would make clustering very challenging since the node membership will dynamically change, forcing clusters to evolve over time. On the other hand, the events monitored by a sensor can be either