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A Survey on Clustering Algorithms of Wireless Sensor Network

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Abstract – In the past decade, wireless sensor network (WSN) has been at focus of research. Wireless Sensor Network (WSN) technologies has almost entered in all the areas of modern day living. Ubiquitous sensing enabled by WSN measure its ambient ranging from different ecologies to urban environments, especially in unattended environments where sensors are in large numbers and operate autonomously. To support scalability sensor nodes are grouped into non-overlapping and disjoint clusters. In this paper, we present general classification and taxonomy of published clustering algorithms. We also compares the clustering schemes based on convergence rate, cluster overlapping, cluster stability, node mobility and location awareness.

Index Terms – Wireless sensor networks; Clustering algorithms; Scalability; Network architecture; Energy aware design

1. INTRODUCTION

Recent advances in low-power design and miniaturization have led to the development of tiny sensors that are capable of measure its ambient ranging from different ecologies to urban environments .Sensors are equipped with data processing and communication capabilities. Wireless Sensor networks have low-cost devices with wireless network capability limited battery energy limited transmit power and resource Constraints. The usage of tiny and cheap wireless sensors allows deployment of very large networks at feasible cost to provide a bridge between the physical world and the information systems .Such deployments will require routing schemes for scaling the large network in an energy-efficient way. And these routing schemes and mechanisms are required for collecting data from the real static or mobile environment.

Clustering has been widely pursued to achieve the network scalability objective by the research community. Every cluster would have a cluster-head (CH) as their leader. Many clustering algorithms have been for ad-hoc networks [11-15] the objective was generally to stabilize the clusters with mobile nodes. Many such techniques care about route stability and node without much concern of design goals such as coverage and network longevity. Recently, a number of clustering schemes have been designed for WSNs. These proposed techniques vary depending on the bootstrapping schemes and node deployment, characteristics of CH, network architecture and the operation model. A CH may be or pre-assigned or elected by the sensors in the cluster. In addition to network scalability, clustering has numerous other advantages. It can localize the route set up and reduce the size of the routing at individual nodes [21]. It can also reduce communication bandwidth and avoids redundant exchange of messages between nodes. Moreover, it can stabilize the network topology and reduce the topology maintenance overhead. The CH also implement management strategies to enhance the network operation and the network lifetime [22]. Furthermore, CH can aggregate the data collected by nodes thus decreasing the number of relayed data packets.

The rest of this paper is organized as follows, in section II we discuss the taxonomy of clustering attributes. In section III, we summarize different clustering schemes for WSNs. And finally section IV concludes the paper.

2. TAXONOMY OF CLUSTERING ATTRIBUTES

The proposed techniques for clustering in WSN's can be classified on the basis of operational model, network architecture and the objective of node grouping. In this section we discuss the taxonomy and classification of clustering attributes.

2.1. Classification based on network architecture

2.1.1. Network model

According to various applications of WSN's different architecture and design goals have been considered. The following enlists some architectural parameters and their implications on network.

- Network dynamics

Basically WSN's can be divided into three components i.e. sensor nodes, base-station and the event monitored. Most of the architectures assumes nodes to be stationary [19, 31, 32], apart from few that consider node mobility [29,30]. Sometimes node mobility becomes necessary which make clustering challenging as number of nodes will change dynamically with time. On the other hand, events monitored by sensors can be continual or intermittent depending upon the application. In continual events periodic continual events have stable clusters, but they unevenly distribute the load among the nodes. Intermittent events allows network to be reactive, they generate traffic only when reporting. But in some events it would require adaptive clustering strategies.

- In network data processing

Sensor nodes generate significant amount of redundant data, similar packets from multiple nodes can be aggregated to reduce the number of transmissions. Data aggregation combines the data of different sources using functions such as min, max and average [33], allowing sensor nodes to reduce in network data resulting in less energy consumption. Data aggregation is also done by signal processing techniques. In that case, a node is selected called as data fusion capable of producing signal using signal processing techniques such as beam forming [20]. Expecting CH's to perform data aggregation techniques limits the choice of CH's so that they are not overburdened [16]. Obviously, such design constraints affects the clustering scheme.

- Node deployment and capabilities

Another factor that influences the need and objective of network clustering is topological deployment of nodes. It is either deterministic or self-organizing. In deterministic deployment sensors are manually placed and routing paths are pre-determined. However in case of self-organizing systems, the sensor nodes are scattered randomly deployed in an ad hoc manner [8, 9, and 20]. In some setups different functionalities are associated with sensor nodes and that may affect the CH selection. In case of homogenous network sensor nodes have equal capacity in terms of communication, computation, and power; CHs are picked from the deployed sensors [20, 35, and 36]. In addition, the communication range and CH's proximity to the base-station are also required to be considered. Even if node can communicate directly with the base-station, it is better to pursue multihop routes. Therefore, inter-CH connectivity becomes an important issue that affects the clustering scheme [17, 37]. On the other hand, in heterogeneous WSNs some nodes may be designated for special tasks which then required either avoiding such nodes or limiting the CHs to subset of these nodes.

2.1.2 Clustering objectives

In literature clustering algorithms varies in their objectives. Often the clustering objective is set to meet the applications requirements. The following section discuss the objectives for network clustering.

- Load balancing

Even distribution of sensors are required where CHs are required to perform data processing or intra-cluster management [16]. It is intuitive to balance load among the sensors so that they can meet the required goals [38]. Load balancing is becomes an important issue in WSNs where CHs are selected from the available sensors[19]. In such setup, for extending the network lifetime equal-sized clusters are required to prevent the energy depletion in a subset of CHs and prematurely making them dysfunctional. In case of even distribution of sensors when CHs perform data aggregation, clusters should have equal number of node so that aggregated data can be send to the base-station for further processing.

- Fault tolerance

In many applications, WSNs are deployed in harsh environments and nodes are exposed to risk of physical damage and malfunction. In order to avoid the loss of sensors data fault tolerance become important. The most intuitive way is to re-cluster the network. However, it is resource burdening on the nodes and disruptive to on-going operation. Therefore contemporary methods of fault-tolerance are appreciated. Assigning backup CHs is the most pursued scheme in the literature for CH failure. Rotating the CHs among nodes within in the cluster another method for fault-tolerance and load balancing advantage [20].

- Increased connectivity and reduced delay

Inter-CH connectivity is an important issue in many applications unless CHs have long-haul communication capabilitie. WSN's must ensure a path from every CH to the base-station[17] or more restrictive on path length [40]. On the other hand in inter cluster connectivity data latency is a design objective. Delay is factored maximum number of hops allowed on a path. Like, K-hop clustering is K-dominating set problem [41-43].

- Maximal network longevity

The network's lifetime is a major concern, as sensor nodes are energy constrained especially for applications in harsh environments. When CHs have more resources than sensors, it is required to minimize the energy for intra-cluster communication [22]. Distance between CHs and sensors should be minimum in clusters [39,44]. for maximizing network's lifetime Combined clustering and route setup has also been considered [45]. Adaptive clustering is also a choice for network longitivity.

2.1.3 Taxonomy of clustering attributes

In this section we enumerate the attributes that categorizes and differentiate clustering algorithms. Based on the discussion above, we identify the following attributes.

1. Cluster properties

Often clustering schemes are proposed while keeping in mind strive to some characteristics for the generated clusters. Such characteristics can be related to the internal structure or how it relates to other clusters. The following are some relevant clustering attributes:

- Cluster count

In some published approaches the number of clusters are preset and the set of CHs are predetermined and thus CHs are randomly from the deployed sensors which usually yields variable number of clusters.

- Stability

When the clusters count and the node's membership changes overtime, the clustering scheme is called adaptive. Otherwise, it is considered fixed as sensors do not move among the clusters and number of clusters remains the same throughout the network lifetime.

- Intra-cluster topology

Some clustering schemes follow direct communication between a sensor node and its CH. However, in multi-hop case connectivity is sometimes required; when the sensor's communication range is limited or the CH count has limit.

- Inter-CH connectivity

CHs connectivity to the base-station is provisioned When the CH does not have capabilities for long haul communication In that case, the clustering scheme is required for establishing an inter-CH route from every CH to base-station.

2. Cluster-head capabilities

As discussed the network model influences the clustering approach; especially node capabilities and the in-network processing. The following are some factors which differentiate clustering schemes.

- Mobility

When a CH is mobile, cluster member changes dynamically and are required to be maintained continuously. However, stationary CH yield stable clusters and facilitate network management.

- Node types

As discussed earlier, in some cases a subset of sensor nodes are designated as CHs while in other setups CHs are equipped with special computation and communication powers.

- Role

A CH can act as a relay for the traffic generated in its cluster or perform aggregation on collected data. Sometime, a CH acts as a base-station that takes actions based on detected phenomena.

3. CLUSTERING PROCESS

The coordination of clustering process and the characteristics of algorithms are different among published clustering schemes. The following attributes are relevant:

- Methodology

When CHs are from the sensors within clusters, clustering is performed in a distributed manner. In centralized approach nodes are partitioned offline and cluster membership is maintained by a centralized authority. In hybrid schemes CHs are rich in resources.

- Objective

As discussed earlier several factors are considered for forming the clusters like load balancing, network connectivity, etc.

- Cluster-head selection

CH are randomly picked from deployed sensor nodes or are pre-assigned.

- Algorithm complexity and convergence rate

Depending on objectives and methodology algorithms are proposed. The complexity and convergence rate can be constant or dependent on number of sensors or CHs.

3.1 Clustering Algorithms for WSN's

Generally wireless sensor networks have large number of sensor nodes ranging from hundreds to thousands. Clustering is one of the effective means for managing the population of nodes. In this section a literature survey of published clustering algorithms is presented. The surveyed algorithms are divided into two subsections according to convergence rate i.e variable and constant convergence time algorithms, respectively.

3.1.1. Variable Convergence Time Algorithms

Time is an important factor in convergence of clustering algorithms. Some of the proposed algorithms such as LCA [48], CLUBS [53] have *O(n)* convergence time, where n is the number of sensor nodes. in some recent algorithms, e.g. [17] convergence time has showed their suitability for networks having large number of nodes. Variable convergence algorithms have more control over the cluster properties than the constant time algorithms.

- Linked Cluster Algorithm(LCA)

The algorithm proposed by Baker and Ephremides [48,49] is one of the earliest on clustering of networks the focus is on forming topology with mobile nodes. CHs are used for forming the backbone of network which is used by cluster members while on move. The Objective of the proposed algorithm is to directly connect the cluster members with CH. The algorithm assumes time-based medium access and synchronized nodes. First node broadcast its ID and listens to other nodes.in next round, a node broadcast its list of i-hop and 2-hop neighbours.A node with highest ID among its neighbors becomes a CH. Since LCA yield excessive number of clusters, approach is refined in [50]. The idea is to randomly select a node x as the first CH and assign its neighbors to form first cluster. Then the node y with lowest

ID is nominated as CH. The neighbors of y which are not reachable to x would become the member of second cluster and the procedure is repeated.

- Adaptive Clustering

In [51] Lin and Gerla studied the support of multimedia applications using CDMA in multi-hop mobile ad-hoc networks. . To minimize the data delay clusters are formed and a distinct code is assigned to each cluster. An ID based scheme of cluster selection is used similar to [48] and [50]. Similar to LCA, intra-cluster, single-hop topology is employed. The CHs arbitrates the communication codes with each other. The algorithm optimally control the cluster size by balancing the channels spatial reuse , and data delivery delay, by avoiding inter-cluster routing. For intra-cluster communication TDMA is used, however each cluster uses a distinct code.

- Random Competition based Clustering (RCC)

RCC [52] is basically designed for mobile ad hoc networks, but it is also applicable to Wireless Sensor networks. RCC focuses on cluster stability for supporting mobile nodes. . The RCC algorithm applies First Declaration Wins rule. After hearing claim by the first node, neighboring nodes join the cluster and give up in competition for CH. To maintain clusters, all CH in the network broadcast claim periodically. Being unaware of simultaneous claims of neighboring nodes a conflict may arise. To avoid this RCC employs a timer and uses node ID. Each node in network reset its time value, before claiming for CH. During this time if a node receives a CH claim from another node, it ceases the transmission of its claim. RCC resolve further solve the concurrent broadcast problem by using node ID, node having lower ID become the CH. RCC is proves more stable than other clustering algorithms such as [51].

- Energy Efficient Hierarchical Clustering (EEHC)

In [17] Bandyopadhyay and Coyle studied EEHC with with objective of maximizing network lifetime. CHs collect its sensors readings and send the aggregated data to the base-station. In this clustering is done in two stages initial and extended. In initial stage each node announces itself as CH with p probability by direct communication or by forwarding. All nodes that are in k hops range of CH receives this message. If the announcement does not reach to a node within preset time t it will automatically become a CH i.e a forced CH. In the second stage, multi-level clustering is done. Similar to [37] the clustering process is repeated at all the level of CHs to form additional tier. Sensor nodes transmit the data to level-1 (lowest level) CHs, then CHs at the level-1 send the aggregated data to level-2 CHs and process is continued. At top level CHs sends the aggregated data report to base station. operations The authors derive mathematical values of p and k for minimal energy consumption.

3.1.2 Constant convergence time algorithms

Clustering algorithms that converges in fixed number of iterations, regardless of nodes population are called constant convergence time algorithms. These algorithms pursue a strategy in which nodes independently execute the algorithm and base their membership decisions on their own and their neighbors state. In this section, we review number of published constant convergence time algorithms.

- Low Energy Adaptive Clustering Hierarchy (LEACH)

In [20] one of the most popular algorithm LEACH is proposed. It forms clusters on the basis of received signal strength and uses CH nodes for routing data to the base-station. All the data processing is local to the cluster. Initially a node decides to become a CH with probability p and then broadcasts its decision. Each non-CH node selects its cluster by choosing the CH with least communication energy. CHs are rotated periodically for balancing the load. The rotation is done by selecting a random number ‘‘T’’ between 0 and 1. A node becomes a CH if its number is less than the calculated threshold. Since the decision to become the CH is probabilistic, a node with very low energy can gets selected to become a CH. the CH is assumed to equipped with a long communication range so that the data can reach directly to base-station. LEACH forms one-hop inter- and intra cluster topology so that each node can transmit directly to the CH and then to base-station.

- Fast Local Clustering service (FLOC)

In [30] FLOC is proposed that produces equalsized clusters with minimum over-lapping. The assumed radio model classifies nodes as inner (i-band) and outer (o-band) based on the proximity to CH. I-band nodes suffer less interference in comparison to o-band nodes while communicating with the CH. FLOC favors i-band membership for increasing the robustness of the intra-cluster traffic. FLOC scales the converging in a constant time O(1), regardless of the network size. . It also has self-healing capabilities as o-band nodes can switch toan i-band node. Also new nodes can perform the algorithm and joins one of the existing clusters. It is unclear how data is disseminated across clusters.

Clustering approach	Convergence time	Node-mobility	Cluster overlapping	Location awareness	Energy efficient	Failure recovery	Balanced clustering	Cluster stability
LCA	Variable *O(n)*	Possible	No	required	No	Yes	OK	Moderate
Adaptive clustering	Variable *O(n)*	Yes	No	Required	N/A	Yes	OK	Low
RCC	Variable *O(n)*	Yes	No	Required	N/A	Yes	GOOD	Moderate
EEHC	Variable *O(k1+k2..+kh)*	No	No	Required	Yes	N/A	OK	N/A
LEACH	Constant *O(n)*	Fixed BS	No	Not required	No	Yes	OK	Moderate
FLOC	Constant *O(n)*	Possible	No	Not required	N/A	Yes	GOOD	High
MOCA	Constant *O(n)*	Stationary	Yes	Not required	Yes	N/A	GOOD	High

Table 1. Comparison of the presented clustering algorithms

- MOCA

In [59] Youssef et al. proposed MOCA, a distributed, randomized Multi-hop Overlapping Clustering Algorithm for organizing the nodes into overlapping clusters. The goal of the process is to make sure that each node is either a CH or within k hops distance from at least one of the CH, where k is preset cluster radius. The algorithm assumes that each sensor node in the network becomes CH with the probability p. Each CH then declare itself to the sensors nodes within its radio range. This advertisement is forwarded to all sensors that are at k hops distance from the CH. A node sends the request to all CHs in order to join their clusters. In the join request, the node includes IDs of CHs whose advertisement it has heard. The CH probability (p) is used for controlling the degree of overlap and number of clusters.

4. CONCLUSION

Wireless sensor networks (WSNs) have gained a lot of attention over past few years. An increasing list of military and civil applications can use WSNs for increased effectiveness; especially in remote and hostile conditions. Examples include combat field surveillance, border protection, disaster management. Clustering has become one of the most popular method for achieving scalability in WSNs. Significant attention in a large number of publications has been given to clustering algorithms. In this paper, we surveyed the number of research works and classified the different approaches. We developed a taxonomy of different relevant attributes, and categorized the different algorithms according to their objectives, clustering process and the desired properties.

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