AN INTRODUCTION TO BASIC CONCEPTS OF CLUSTERING METHODS IN WIRELESS SENSOR NETWORKS

[1]Ramegowda.K, [2]Dr.R.Sumathi
[1]M.tech, [2]Professor, Department of CSE
Siddaganga Institute of Technology-Tumkur
Email: [1]rgk2025@gmail.com, [2] rsumathi@sit.ac.in

ABSTRACT
Wireless sensor networks (WSNs) are new generation of computer networks which have many potential applications and unique challenges. They usually consist of hundreds or thousands small sensor nodes such as MICA2, which operate autonomously; conditions such as cost, invisible deployment and many application domains, lead to small size and limited resources sensors. WSNs are susceptible to energy criterion and most of traditional networks architectures (i.e. Flat) are unusable on WSNs; due to count of existent sensor nodes, large-scale networks and their constraints. Also, WSNs have dynamic topology. One of most important method against to these problems is clustering. Clustering leads to more scalability, energy efficiency and prolong network lifetime in large-scale WSNs. As a result, this paper is focused on clustering in WSNs. It is including of: an overview of WSNs and clustering in WSNs, consist of its functionality, advantages, weaknesses, applications and various classifications. This work enables us to verify the purpose and capabilities of the WSNs and clustering techniques; also, the goal and effects of clustering techniques on WSNs are introduced. This would enable WSNs designers and managers to design and manage WSNs, more significant.
KEYWORDS : **Wireless Sensor Network (WSN), Clustering, Advantage, Weakness, Application**, Architecture, Classification, Design Criteria.

1. INTRODUCTION
Wireless Sensor Networks (WSNs) are homogeneous or heterogeneous systems consist of many small devices, called sensor nodes, that monitoring different environments in cooperative; i.e. sensor nodes cooperate to each other and combine their local data to reach a global view of the operational environment; they also can operate autonomously [1, 2]. In WSNs there are two other components, called "aggregation points" (i.e. cluster-heads deployment locations) and "base station" (i.e. the Sink deployment location), which have more powerful resources and capabilities than usual sensor nodes. As shown in Figure1, cluster-heads (CHs) collect information from their nearby sensor nodes, aggregate and forward them to the base station (Sink) to process gathered data [1, 3, 4]. Factors such as wireless, unsafe, unprotected and shared nature of communication channel, untrusted and broadcast transmission media, deployment in hostile and open environments, automated and unattended nature and limited resources, make WSNs vulnerable and susceptible to many types of criteria; therefore, in attending to the WSNs' constraints in energy resources and radio transceiver power, clustering is a vital and complex requirement for these networks. Also, the clustering mechanisms can guarantee the scalability and manageability of these networks. This paper is focused on

clustering and its different aspects in WSNs. Therefore, the main purpose of this paper is presenting and discussing on energy constraint and scalability problems in WSNs and solving it by using clustering mechanisms. Since, clustering used is also leads to the WSNs' scalability and energy efficiency.

This paper makes us enable to identify the different dimensions of clustering techniques in WSNs to solving the energy limitation problem in these networks. The rest of this paper is organized as following: in section 2 the research motivation has been presented, in summarized; Section 3 expressed an overview of WSNs and their different dimensions; Section 4 considering clustering in WSNs and its various aspects; Section 5 will represent the reached results and conclusion; and finally future works, some proposed topics to research, are drawn in section 6.

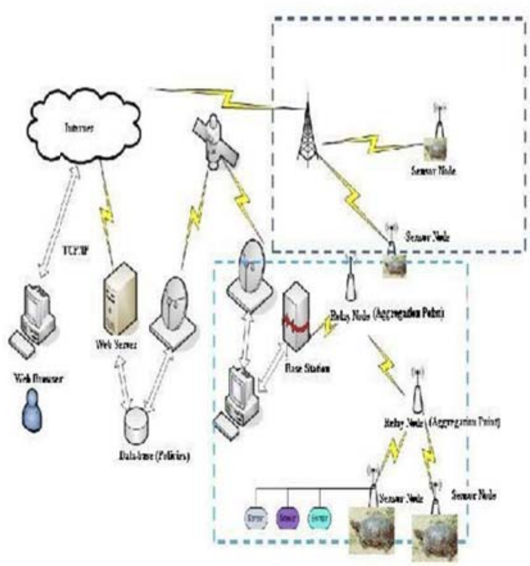


Figure1. WSNs'communication architecture

2. RESEARCH MOTIVATION

Wireless Sensor Networks (WSNs) are a new class of wireless networks which has special properties and challenges [4, 5]. Into these networks' architecture, nodes dissipate into operational environment in random/pre-defined or uniform/non-uniform and verifying, control and processing special events and then, informing and transferring collected data to the sink. Each sensor node has limited energy and in often applications, there is not possibility of changing or replacing energy resources. So, the nodes' lifetime is depending to remainder energy into their battery, in severity. By attention to the nodes limited energy and most of their energy (about 80 percentages) is consumed for communicating to other nodes or cluster-heads or sink (depending to the WSN architecture; the best appropriate way to using of energy in optimal is nodes clustering. By using this method, the WSN divide into some independent sets (called clusters) which each cluster is including of some sensor nodes and a Cluster-Head (CH). Each node is member of a cluster; transferring its sensed data to its associated cluster-head. Then, that cluster-head aggregates reception data and then, send it to the sink. Clustering has advantages such as data aggregation, facilitating data collection, organizing an appropriate structure for scalable routing and efficient data dissemination on the WSNs. The goal of using clustering methods on WSNs is reducing the volume of transferred and received data and as a result, consumed power reduction. Variety constraints of WSNs such as energy, memory and processing power limitations leads to necessity of attending to proper clustering methods anymore.

2. AN OVERVIEW OF WSNS

Sensor is a tiny device which detects and measures amount of physical parameters, or an event occurrence, or an object existence; then, it converts that value to electrical signal; finally, if necessary, it actuates a special operation by using electrical actuators [5, 6]. WSN is a computer network with following major features [6, 7, 8]:

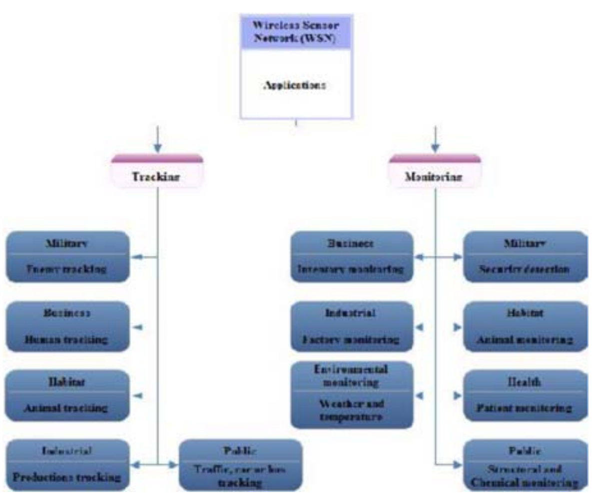
- Infrastructure-less;
- No public address, often;
- Consists of many tiny sensor nodes (small size, low-cost and low-power); Nodes distribution along with high-density in operational environment;
- Insecure radio links;
- Application-oriented;
- Different communication models:

hierarchical/distributed WSNs; or homogenous/heterogeneous WSNs;

- Limited resources of sensors (radio range, bandwidth, energy, memory and processing capabilities);

- Having decision making capability to react to the events, including: automated structure (local decision making), semi-automated (decision making by sink) and combinational (clustering structure);
- Main application domains of WSNs are: monitoring and tracking (as shown in following figure, Figure2 (a)); therefore, some of the most common applications of these networks are: military, medical, environmental monitoring, industrial, infrastructure protection, disaster detection and recovery, agriculture, intelligent buildings, law enforcement, transportation and space discovery (as shown in Figure2 (b)).

The taken approach in the WSN is a combinational model; i.e. hierarchical and distributed. In continue of this section, it will be presented an outline of different aspects of WSNs, such as their characteristics, architecture and vulnerabilities.



(a)

(b)

Figure 2. WSNs' applications

3.1. WSNs Characteristics

A WSN is a homogenous or heterogeneous system consisting of hundreds or thousands of low-cost and low-power tiny sensors to monitor and gather real-time information from deployment environment [4, 9]. Common functionalities of WSNs' nodes are broadcasting and multicasting, routing, forwarding and route maintenance. The sensor's components are: sensor unit, processing unit, storage unit, power supply unit and wireless radio transceiver; these units are communicating to each other, as shown in Figure3. Some of most important characteristics of these networks are:

- Wireless communications and weak connections;
- Low reliability and failure capability in sensor nodes;
- Dynamic topology and self-organization;
- Hop-by-hop communications (multi-hop routing);
- Hostile nature of deployment environment [2, 10, 11];
- Cooperation of sensor nodes and other WSNs' devices to each others;
- Inter-nodes broadcast-nature communications;
- Ease of extendibility and configuration Scalability;
- Direct communication, contact and interaction with physical environment;
- Usually single-purpose and application-oriented networks;
- Putting down and consistency capabilities of sensor nodes on different operational environments;
- Automatically and non-interrupted operation;
- Communication management capability between mobile nodes;
- Hardware limitations of sensor nodes;

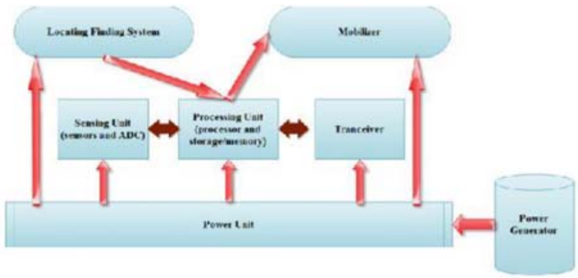


Figure 3. Sensor node's architecture

3.2. Different Types of WSNs' Architectures

As shown in following figure (Figure4), on WSNs' architecture, there are components such as sensor nodes, aggregation points (cluster-heads), base stations (central server or sink), network manager, security manager, and user interface. These components participate to each other; thus, they help to the WSN to operate, correctly [2, 12]. Figure4 shows different kinds of WSN's architectures; as follows:

3.2.1. Direct Communication Architecture

Each sensor nodes communicates to the sink, directly. Thus, this architecture is not Appropriate for wide WSNs; i.e. it is not scalable.

3.2.2. Multi-hop and Peer-to-Peer Architecture

- Sensor nodes have routing capability;
- This architecture is not scalable; because sensor nodes which place nearby to the sink, they are using for packets routing between other nodes and the sink, usually; therefore, if the WSN be widespread, traffic of such nodes will increase; consequently, their energy will be waste, consumed and finished; so they go out of the WSN, in fast;

3.2.3. Multi-hop Based on Clustering

 Sensor nodes make a clustering structure;
 Choosing a cluster-head for any cluster; each cluster-head can communicate to the sink, directly; thus, each clusters' nodes send their gathered data to the corresponding cluster-head;
 Problem: the weakness of this architecture is: most communication operations are doing by cluster-heads; thus, their energy will be consumed, decreased and wasted, sooner than other nodes (if the cluster-heads be had weak capabilities or on homogenous WSNs);
 Solution: changing the role of cluster-head between corresponding cluster nodes, dynamically; or using from strong and heterogeneous cluster-heads;

3.2.4. Multi-hop, Clustering and Dynamic Cluster-Heads Architecture

 This architecture solves the weakness of previous architecture by dynamically change the role of cluster-head among corresponding cluster's nodes [4, 13, 14];

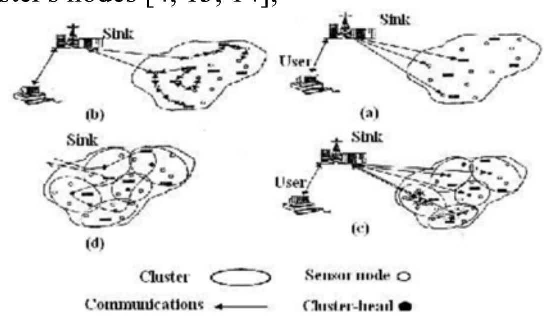


Figure 4. Different types of WSNs' architectures: (a) Direct communication architecture; (b) Multi-hop and peer-to-peer architecture; (c) Multi-hop based on clustering architecture; (d) Multi-hop, clustering and dynamic cluster-heads architecture;

3.3. Vulnerabilities and Challenges of WSNs

WSNs are vulnerable against many kinds of attacks and threats; some of the most common reasons are:

 •Theft (reengineering, compromising and replicating);
• Limited capabilities and resources (DoS attacks risks, constraint in using encryption);
• Random deployment;
• Deployment on open/dynamic/hostile environments (physical access, capture and node destruction);
• Insider attackers;
• Inapplicable traditional network common security techniques (due to limited devices and their resources, deploying on open environments and interaction with physical environment);
• Requirement to redesigning security architectures and protocols;
• Unreliable communication (connectionless packet-based routing unreliable transfer, channel broadcast nature conflicts, multi-hop routing and network congestion and node processing Latency);

• Vulnerability and susceptibility against eavesdropping (since using unique communication frequency in wireless connections of WSNs);

• Unattended nature and operation (Exposure of physical attacks, managed remotely, no central management point);
• Dynamic structure, unpredictable topology and self-organization;
• Sensor nodes' selfishness;
• Requiring to forwarding and routing sensed information to a shared destination, called sink;
• Existing redundancy in gathered traffic;
• Fault tolerant;
• Cost of sensor nodes' development and their production;
• Size and precision of sensor nodes;

4. CLUSTERING ON WSNS

Clustering means dividing sensor nodes in virtual group according to some rules (called cluster) and then, sensor nodes belonging in a group can execute different functions from other nodes [15, 16, 17].

4.1. Clustering Definition

Clustering is involving grouping nodes into clusters and selecting a Cluster-Head (CH) [18, 19],
• Members of a cluster can communicate with their CH directly or multi-hop;
• CH can forward the aggregated data to the Sink through other CHs or directly

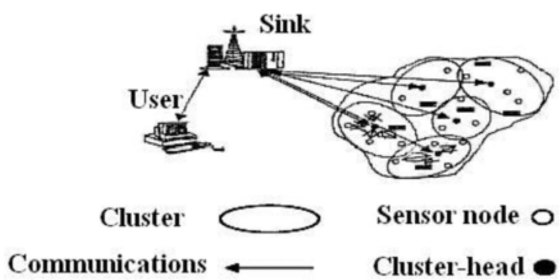


Figure 5. Clustering overview

In high-level approach, clustering algorithms have three main phases, including of: clusters formation phase, construction phase (selecting CHs) and maintenance phase (intra-cluster resource management, adaptation to external perturbations and then disruption or rotation). Also, required time interval for construction phase is too less than maintenance phase; i.e. Time (Construction phase) << Time (Maintenance phase).

4.2. Clustering Goals and Necessity

As Figure6 is showing, some of common goals of clustering in WSNs are:
• Data aggregation and limits data transmission [19, 20];
• Facilitating the reusability of the resources;
• CHs and gateway nodes can form a virtual backbone for inter-cluster communications;
 • Cluster structure gives the impression of a smaller and more stable network;
• Improve network lifetime: reducing network traffic and the contention for the channel;
 • Grouping of similar objects or sensors in our context (logical organizing);
• Topology control by load balancing [21, 22] and network scalability;

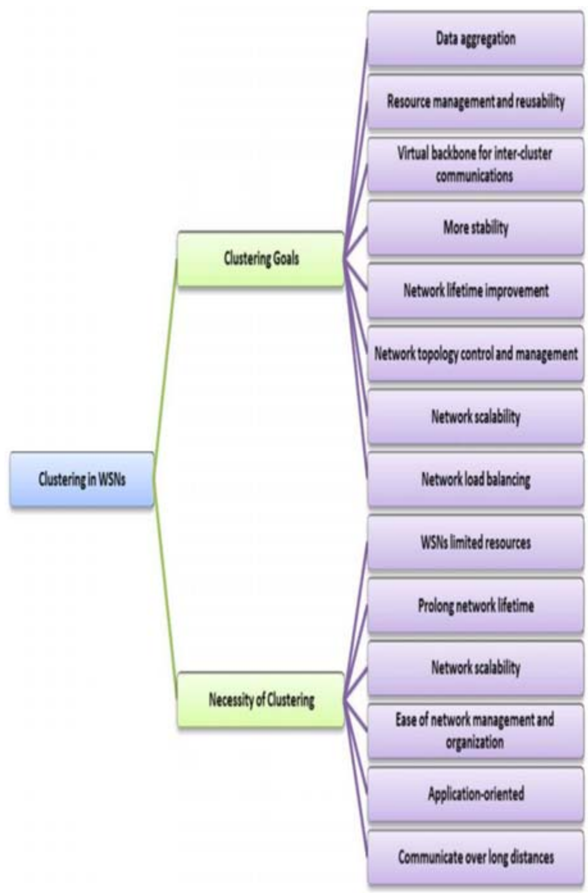


Figure 6. Goals and necessity of clustering in WSNs

Also, in attention to the Figure6, there are several key limitations in WSNs which clustering methods should be considered; they are as following:
• Limited Energy and other resources [5, 37];
• Prolong network lifetime;
• Network scalability [23, 35, 36];
• Ease of network organization and management;
• Application-oriented;
• Communicate over smaller distances: Have more hops to sink -> Compute before sending -> Do some pre-processing -> Local processing Local administration -> Clustering necessity;

- Battery lifetime is not the only one concern: Limited processing and small memory in nodes -> Whole WSN application cannot be comprehended in each node -> Distribute application -> among neighbouring nodes -> Clustering necessity;

4.3. Significant Criteria and Applications of Clustering

As following Figure (Figure7) is showing, this section presented effective parameters on designing clustering techniques for WSNs, such as:

- Clusters formation way;
- Synchronization;
- CHs selection criteria [34, 38];
- Real-Time Operation;
- Number of clusters;
- Intra-cluster/Inter-cluster communications;
- Nodes and CH mobility;
- Algorithm complexity;
- Multiple levels architectures (i.e. First level (lowest level): sensor nodes; Second level: CHs; Third level: CHs of CHs (CHs which their cluster members are CHs of lower level));
- Overlapping;

Figure7 also represents some of common applications of clustering in WSNs, too. Including of:

- hierarchical routing protocols [23, 24];
- data gathering/aggregation protocols;
- network organization and management;
- significant energy savings;
- balanced and distributed energy consumption [25, 26, 39];

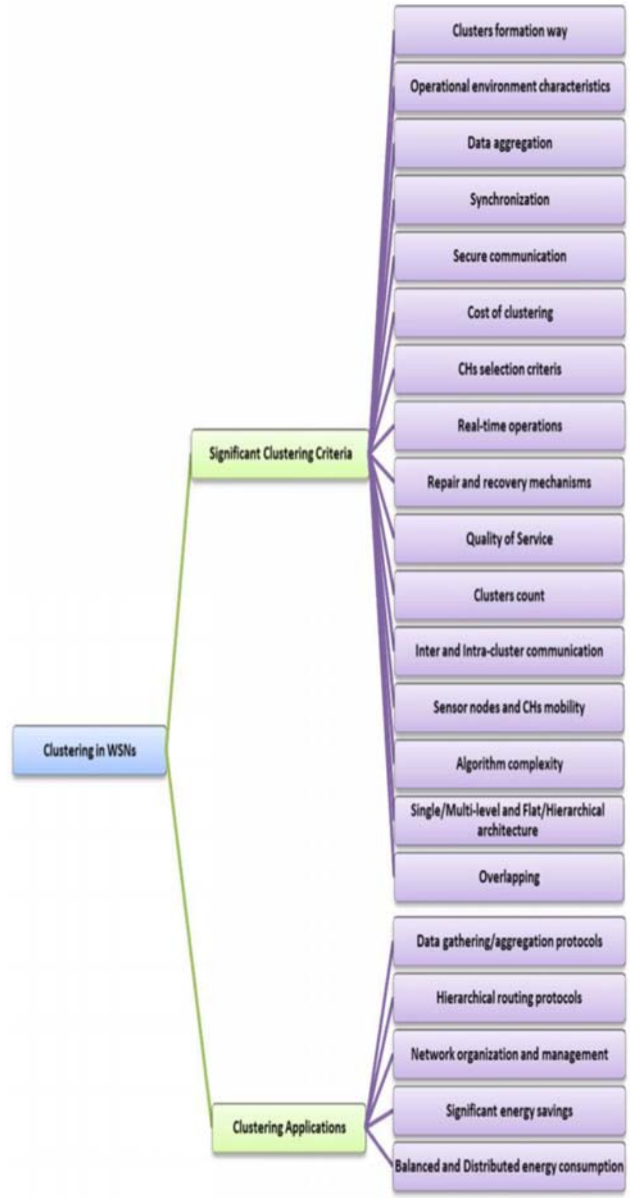


Figure 7. Applications and significant design criteria of clustering in WSNs

4.4. Clustering Advantages and Weaknesses

According to the Figure8, this section expressed some of most important advantages of clustering on WSNs, such as data aggregation and summarization, reducing volume of transmitted data, decreasing the count of nodes which taking part in data transmission, network lifetime prolonged, scalability in large-scale WSNs, communication overhead reduction (for both single and multi-hop communications), delay reduction (than flat networks), load balanced distribution [21, 27, 44] (than flat architectures), more regularity (network easier management), establishing multi-hop, more regular, more stable, better and more distance communications, stability of network topology in sensor network level [40, 41] (reducing the overhead and cost of keeping the topology) and collecting information from operational environment by nodes, in periodical (reducing the consumed energy and redundancy reduction). Also, Figure8 is representing some of most common weaknesses or problems about existent clustering techniques which they expressed why not to use existent clustering methods, again. Including of:

• Clustering extensively studied in data processing and wired networking;

□• Different assumptions , various operational environment and design constraints;

• Large number of nodes and large-scale WSNs, i.e. distributed over centralized approaches [42, 43, 46];

□• Nodes are unaware of locations, i.e. algorithms must use only neighbouring information;

• Energy constraints minimal message overhead is allowed;

•Due to harsh environment periodic re-clustering, partial network infrastructure degradation;

• Parameters for clustering are not constants and evolve over time and operational environments;

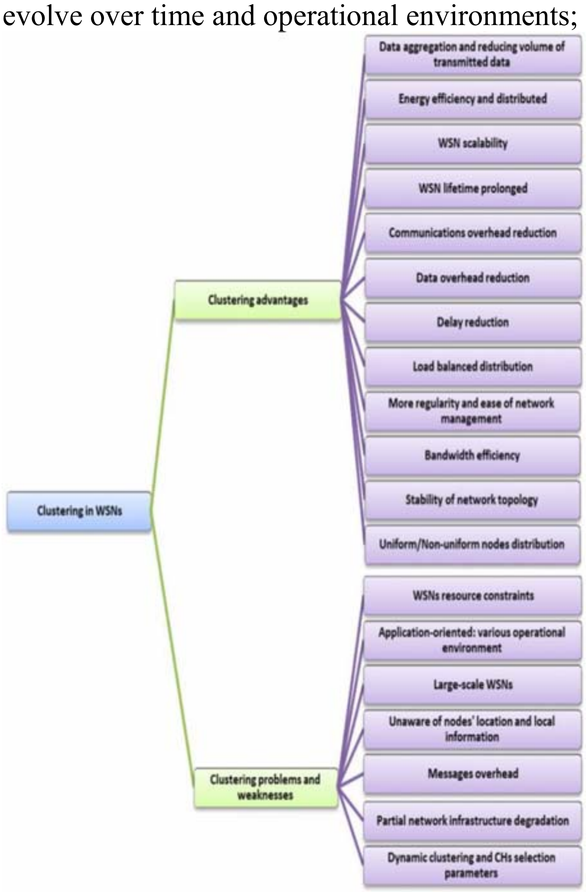


Figure 8. Advantages and disadvantages of clustering in WSNs

4.5. Classification of Clustering Algorithms

4.5.1. Based on Cluster-Head Selection Method

This section discussed on: "Which mechanism is used to select CHs"? It has many possible ways, such as:

□• □ Node identifier: each sensor node must have unique ID and their IDs are uniformly distributed;

□• Node with larger degree or higher weight in priority criteria (combined metrics such as remainder energy, distance and mobility to derive the node's significance);

4.5.2. Based on How Execution of Clustering Method

□• Centralized techniques [30, 31, 32]

□ •

▪ Accessible global information about whole WSN topology;

▪□ Impractical in very large-scale networks;

□• Distributed techniques [45, 47]

▪ Suitable for large-scale WSNs;

□▪ Only neighbouring and local information are accessible;

•□ Iterative/Non-iterative approaches

▪ Before node makes decision, it waits for special event or other nodes to take their decision;

▪ After receiving event or decision of other nodes, it decides whether to be CH or Not (I not, it should select a CH and should be member of a cluster);

□• Probabilistic/Deterministic techniques [28, 29, 33, 48]

▪ Each node decides independently (become CH or Not);

□▪ Rapid convergence while keeping balanced cluster sizes;

4.5.3. Comparison of Classification Techniques

•□ Distributed vs. Centralized

□▪ Distributed has constant message overhead; vs. messages overhead;

▪ Distributed demands more computation; vs. Centralized needs minimal computation;

•□ Iterative vs. Probabilistic

▪ Iterative takes time to converge, several steps; But, Probabilistic has rapid convergence, typically;

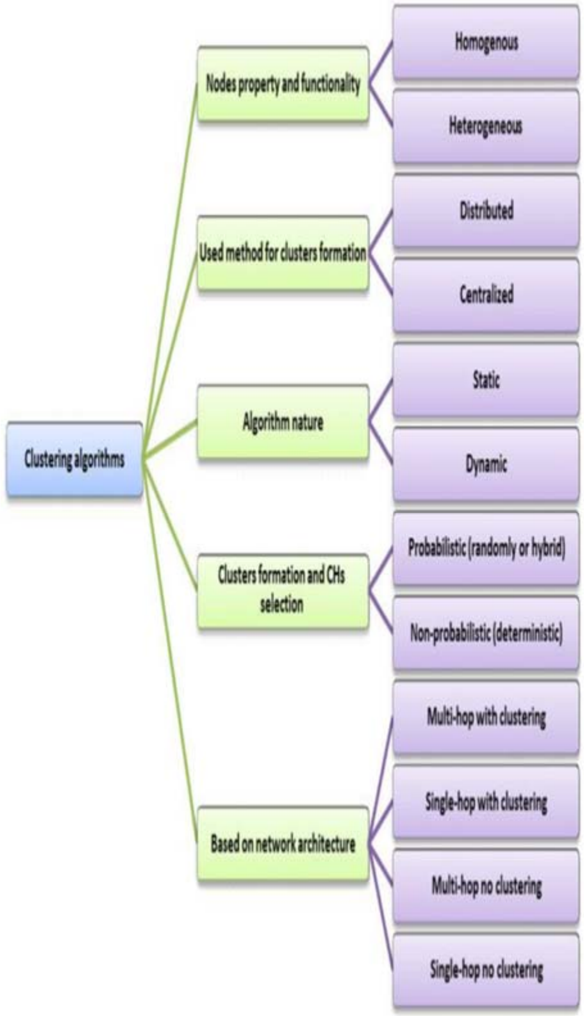


Figure 9. Classification parameters of different clustering techniques in WSNs

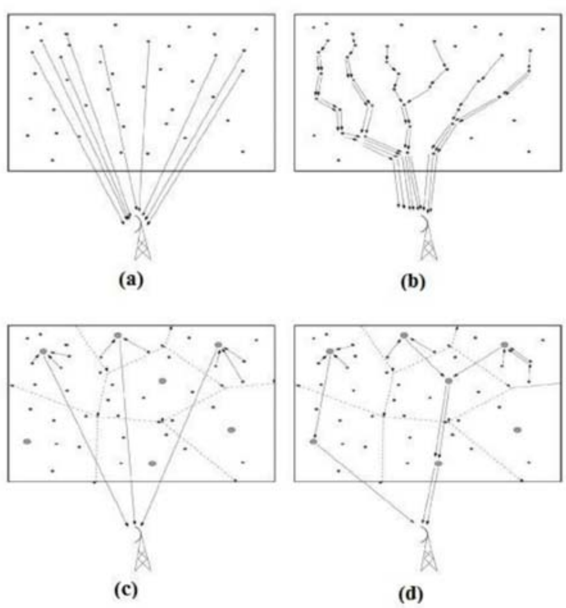


Figure 10. Different types of clustering methods based on the WSN architecture (a) Single-hop no clustering; (b) Multi-hop no clustering; (c) Single-hop with clustering; (d) Multi-hop with clustering;

5. CONCLUSION

Generally, clustering in WSNs has been of high interest nowadays. This paper tried to present the main dimensions and characteristics of clustering in WSNs. This paper discussed on WSNs and their various aspects such as their characteristics, architectures and vulnerabilities, clustering in WSNs and its different dimensions respect to its goals, necessity, applications, significant clustering design criteria, advantages, disadvantages and its different classifications. Some of most important findings of this paper are as following:

• One of most important feature which leads to more uniform and balanced distribution of the energy consumption is the periodic selection of CHs (rotation of the CH role for energy distribution) among all the nodes of the network or between members of associated cluster;

•Time complexity of clustering algorithms is difficult to be kept low as in leading probabilistic or random clustering algorithms;

• In large-scale WSNs (parameters such as number of sensors and area covered), especially in real-time applications, clustering leads to possibility of multi-hop inter/intra cluster communications -> Multi-level cluster hierarchies -> preserving energy efficiency independent of the growth of the network;

•In WSNs, the nodes' resources limitations such as energy playing a vital role in designing any protocol such as clustering. In addition, Quality of Service metrics such as delay, data loss tolerance and network lifetime expose reliability issues when designing recovery mechanisms for clustering schemes. These important characteristics are often opposed, as one often has a negative impact on the other;

Optimal clustering in terms of energy efficiency should eliminate all overhead associated not only with the CH selection process, but also with node association to their respective CHs;

• Further improvements in WSNs reliability should consider possible modifications to the re-clustering mechanisms following the initial CH selection. These modifications should be able to adapt the network clusters to maintain network connectivity while reducing the wasteful resources associated with periodic re-clustering;

• Clustering algorithms are different in many parameters such as their CH selection criteria, clusters formation methods, communication types, applications and architectures;

• Dynamic clustering: if in clustering method, after the first round, the role of CH change between any one of all member of each cluster, periodically -> leads to better load balanced and more fairness and more seamless energy consumption;

• Clustering has three main sections, including of clusters formation, CHs selection and maintenance phase. Required time for CH selection is too less than maintenance phase; i.e. Time (CH selection phase) << Time (Maintenance phase);

• Some of most important challenges in CH selection phase of clustering in WSNs are:

▪ How to divide the WSN into some of separated clusters;

▪ Node cannot be member of two clusters (overlapping);

▪ CHs communicates to sink directly or via other CHs;

• Some of most important problems of existent clustering algorithms which leading to their impracticality are as following:

▪Clustering extensively studied in data processing and wired networking;

▪ Different assumptions, various operational environment and design constraints;

▪ Large number of nodes and large-scale WSNs, i.e. distributed over centralized approaches;

▪ Nodes are unaware of locations, i.e. algorithms must use only neighbouring information;

▪Energy constraints minimal message overhead is allowed;

▪ Due to harsh environment periodic re-clustering, partial network infrastructure degradation;

▪ Parameters for clustering are not constants and evolve over time and operational environments;

• Clustering leads to hierarchical routing and data gathering, efficient scalability, data aggregation independent to the growth of the WSN, reducing the total amount of communications, prolonging the WSN lifetime and making more efficient use of the critical resources of WSNs such as energy;

• There is no universal clustering algorithm which fits to all situations and different operational environments, because clustering design decisions are depending on applications and deployed environments.

6. FUTURE WORKS

There are several additional issues should be further studied in future research. Some of the most challenging and proposed topics of these issues are including of:

• Development of a generic method for finding the optimal number of clusters in order maximize the energy efficiency;

•Developing a method for estimation of the optimal frequency of CH rotation/reelection to gain better energy distribution and efficiency;

• Presenting some strategies to keeping the total overhead low;

• Discussing on clusters overlapping and boundary nodes;

Designing a new clustering protocol for WSNs with following specifications: be localized, and thus distributed, fully exploit the locally available information in making the best decisions, be computationally efficient, minimize the number of message exchange among the nodes and be energy efficient and thus extend network lifetime;

• Presenting some energy efficient CHs selection methods;

•Proposing some new dynamic clustering techniques for WSNs;

•Presenting some techniques to solving this problem in construction phase of clustering in WSNs: "How to divide network into set of disjunctive clusters";

•Presenting some techniques to answering this question in construction phase of clustering in WSNs: "CHs communicates to sink directly or via other CHs";

•Proposing some strategies to solving deployment challenges of WSNs, including of:

▪ Ensuring connectivity inside and between clusters;

▪ Transmission and MAC: scheduling transmission inside and between clusters including of inter-cluster communication (such as TDMA) or communication between clusters;

▪ Selecting optimal rate of CH rotation/change;

▪ Presence of node's duty cycle (sensor nodes can operate in different states such as active, sleep and idle listening; some of them consume less energy and are more energy efficient than others);

▪ Computing optimal cluster sizes;

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