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UNEQUAL CLUSTERING ALGORITHMS IN WIRELESS SENSOR NETWORKS: A SURVEY

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Abstract

Internet of Things (IoT) is about connecting and communicating between sensors nodes. Wireless sensor network (WSN) being the most appropriate network of sensors nodes plays an important role in IoT. But due to battery drainage issues of the sensor nodes WSN has limited network lifetime. An efficient way to extend the network lifetime of WSN is clustering i.e. to group the sensor nodes of the entire network into number of clusters; but it gives birth to hot-spot problem. Unequal clustering is the best solution to overcome such problems, in which sensor nodes are grouped into clusters of unequal sizes and the size varies according to the cluster head (CH) distance from the base station (BS). In this paper an attempt has been made to compare different unequal clustering algorithms highlighting their various features and objectives.

1. Introduction

Rapid advancement in the field of IoT has led to the usage of WSN [22, 23] on a large scale.WSN is an ad-hoc network of sensor nodes commonly

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used in real time monitoring and tracking applications such as battlefield monitoring, environment, healthcare, disaster management and security surveillance. Sensor Nodes (SN) capture physical parameters such as temperature, pressure, humidity, vibration, infrared, PH etc and convert these parameters into digital form which is then forwarded to the end user application with the help of BS. A typical WSN scenario is shown in figure 1 below:

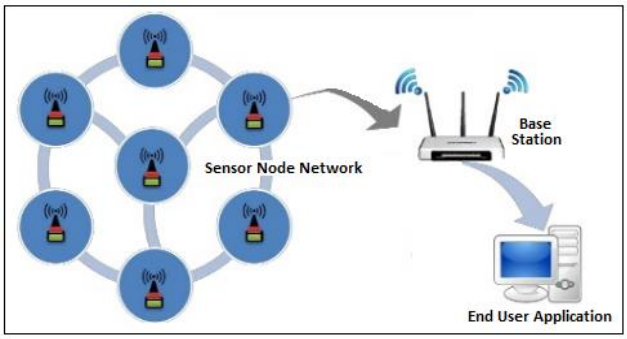

Figure 1. A typical WSN Scenario.

SN has resources in limited capacity like small battery size which drains out quickly while sensing and forwarding data. When deployed in remote areas, sensors needs to operate autonomously so replacement or recharging the battery [2] is not sometimes feasible. Therefore, astringent strategy is required to preserve the energy of the SN and to prolong the network lifetime of WSN. Innumerable techniques were proposed in literature by many investigators to conquer the problem of energy depletion of SN's, but one of the most extensively used techniques is clustering.

Clustering segregates the whole network into small networks called clusters; each clusterchooses a node called as CH [3] via an election and selection process. Only this authoritative CH [3] is responsible to send the data collected by the sensors to the BS via single hop or multi-hop communication [1]. During the election and selection of a SN as CH various parameters like: distance from BS, remaining energy, node degree and node density are taken into consideration.Also, there are two ways to communicate inside a clustered WSN: Intra-Cluster Communication and Inter-Cluster Communication. When one CH communicates within its own cluster

members then it is called as Intra-Cluster communication and when a CH of one cluster communicates with the CH's of other clusters then it is called as Inter-Cluster communication. Thus with the help of clustering, a SN communicates only with its CH in order to maintain its remaining energy and not to dissipate its energy by directly transmitting data to theBS. Besides many advantages like: reduced overhead, less delay, energy consumption and bandwidth utilizationclustering also leads to hot-spot problem. In a hot-spot problem, CH's located near to the BS are overloaded with two types of data: CH's own data in the form of intra-cluster data and relay [8] data in the form inter-cluster data received from other CH's. Because of this overloaded data CH's placed near to the BS will drain out their battery quickly and will disrupt the overall network operations of theWSN [24]. Many researchers have proposed different techniques to overcome hot-spot problem, but one of the most widely used technique is unequal clustering [4]. In unequal clustering, cluster size of a cluster is directly proportional to its distance from the BS.A general architecture of unequal clustering is shown in figure 2.

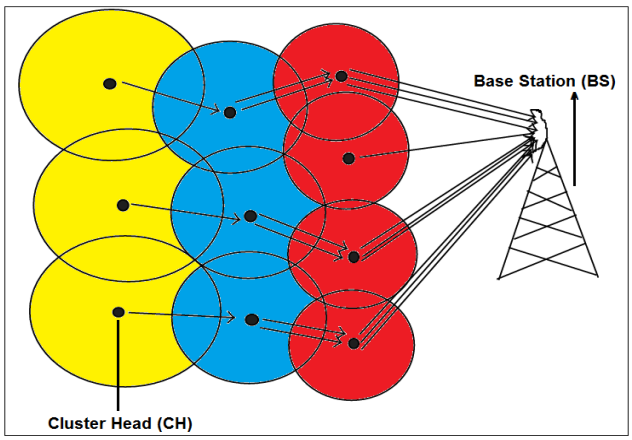

Figure 2. Unequal clustering architecture in WSN.

As shown in figure, when the distance of the cluster from BS increases, the size of the cluster also keeps on increasing (size of red cluster is the least and size of yellow cluster is the largest). Red cluster has the modest number of SN's because of its close proximity to the BS. So red cluster will spend less energy on intra-cluster traffic and it can contribute more energy on inter-cluster traffic. Equivalently, yellow cluster spends more energy in intra-

cluster traffic and less energy on inter-cluster traffic. In this way, unequal clustering brings load balancing [4] in the network by equalizing the energy requirement of CH's near BS and CH's distant from the BS. So in order to prohibit the network from hot-spot problem, unequal clustering techniques can be used to balance the energy consumption between the CH's.

In the last 10 years many researchers have surveyed on equal clustering algorithms and very few researchers [5,6] have focused on surveyingunequal clustering algorithms, this motivated us to do survey on unequal clustering algorithms. The rest of this paper is organized as follows. Unequal clustering objectives are discussed in the section 2. Deterministic algorithms and Probabilistic algorithms based on unequal clustering architecture are discussed in Section 3. Deterministic algorithms and Probabilistic algorithms are compared on the basis various parameters in Section 4 and the whole survey paper is concluded in Section 5.

2. Unequal Clustering Objectives

The unequal clustering objectives are more or less similar to equal clustering. However, most common objectives are energy preservation and getting rid of hot-spot problem. The rest of the objectives of unequal clustering algorithms are discussed in this section.

2.1. Scalability

The design of routing algorithm based on unequal clustering should ensure that the network has the intelligence to deal with large number of sensors in real time application scenarios.

2.2. Fault-Tolerant

The design and architecture of routing algorithm based on unequal clustering should ensure that it has the capability to deal with faulty nodes at any point of time in the network (faults can occur due to malfunction, dead battery or physical damage).

2.3. Data Aggregation/ Fusion

In WSN, a lot of similar data is usually sensed by different sensors placed in a physicalenvironment. This similar data is forwarded to the BS site,

leading to a dump ofredundant data at the BS. Routing algorithm should ensure that it has the competence to deal with such redundant data. Data aggregation is a useful technique to shun off redundant data.

2.4. Load Balancing

To prolong the network lifetime, load balancing [9] is required between the CH's placed closer to the BS and CH's farther from the CH. In multi-hop network scenario, to ensure stable network operations and to overcome hot-spot problem, systematic load distribution is required. Unequal clustering guarantees consistent load distribution between the CH's so that all the CH's exhaust same amount of energy and energy efficient network can be achieved.

2.5. Stabilized Network Topology

Only CH has the authorization to make topological changes in the WSN network because only CH has a routing table which keeps a record of node-id, location information and remaining energy information for its cluster members. In a heterogeneous WSN, whenever a SN battery is exhausted or SN changes its position then this information needs to be instantly communicated to the BS by the CH. Clustering algorithm should ensure to restart the clustering once again to stabilize the network topology.

2.6. Increased Lifetime

In real-time applications where sensed data is very sensitive and critical, maximizing the network lifetime of battery constrained sensors [7] is very important. CH's needs to be rotated between the cluster members on the basis of some selected parameters and cluster maintenance techniques needs to be applied to prolong the network lifetime.

3. Unequal Clustering Algorithms

Unequal clustering is an adequate way to evenly distribute the load between CH's and to wipe out the hot-spot problem. In this section an elaborative discussion on unequal clustering based routing algorithms is presented. On the basis of CH selection and computation of cluster range, the algorithms are classified into two categories: Probabilistic and Deterministic Algorithms.

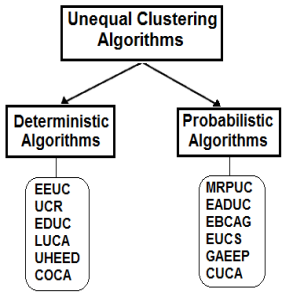

Figure 3. Classification of unequal clustering algorithms.

3.1. Probabilistic Algorithms

Probability based clustering algorithms are simple and energy efficient techniques with low time and message complexity. CH's are selected randomly in such algorithms and they have nearly optimal overhead. At the same time these algorithms can be integrated with parameters like residual energy, node connectivity, node location etc. to form the clusters. Some of the probabilistic algorithms are discussed below:

3.1.1. Energy Efficient Unequal Clustering (EEUC)

EEUC is a type of probabilistic algorithm which is widely used in data capturing applications [10]. In this type of algorithm, CH selection is firstly done locally and then by comparing residual energy of the shortlisted CH candidates. Multi-hop routing between unequal size clusters is used to send data to the end user application through the BS. As the cluster size varies according to its distance from the BS, this algorithm slashes the energy on intra-cluster traffic and saves energy for inter-cluster relay traffic. For a multi-hop data transmission, a far away CH selects a relay node in the network on the basis of two parameters: residual energy and its distance from BS.

3.1.2. Unequal Cluster based Routing (UCR)

UCR [11] partitions the network into unequal size clusters and it uses EEUC [10] for clustering process and EARP protocol for multi-hop routing process [25]. Unequal sized clusters are formed with the help of BS, who broadcasts a beacon signal to all the SN's in the network to know about its distance from each SN based on the RSSI(Received signal strength indicator). Tentative CH's are chosen randomly from the WSN network and according to

their signal strength unequal sized clusters are created in the WSN. To make a SN as its cluster member a CH broadcasts an advertisement message in the network and SN joinsa particular CH by comparing the RSSI of different CH's advertisements. Relay nodes for multi-hop inter-cluster routing are chosen based on the ratio of residual energy vsenergy cost.

3.1.3. Energy Driven Unequal Clustering (EDUC)

EDUC is a distributed algorithmwhich uses unequal clustering to avoid hot-spot problem in heterogeneous WSN[12]. This algorithm only takes into account single-hop communication and selects CH on rotational basis. It has two phases: cluster construction phase and data collection phase.Cluster construction phase has further two sub-phases namely: CH competition and cluster formation phase. In CH competition phase, CH's are competed against each other on the basis of some pre-selected parameters and during cluster formation phase, clusters are created in the WSN Network. Only once all nodes in the WSN can serve as a CH and a TDMA schedule is defined by the CH to avoid collision with intra-cluster traffic. This assumption of single-hop communication is not possible in many real time applications.

3.1.4. Location Based Unequal Clustering Algorithm (LUCA)

LUCA, is a distributed algorithm based on probability uses unequal clustering architecture to prevent hot-spotproblem[13]. Each SN has to maintaina timer clock with some random value in the initialization stage. If a SN, receives any CH advertisement message within this random timer then it associate itself with the cluster of the advertising CH otherwise it starts promoting itself as a CH and advertises as CH to its surrounding SN's. With the help of location information (via GPS)from the BS, LUCA organizes unequal clusters. Since all the nodes in LUCA require location information, it leads to overhead and makes it unsuitable forreal time applications.

3.1.5. Unequal Hierarchal Energy Efficient Distributed Clustering (UHEED)

UHEED is a distributed approach which maximizes the network lifetime [14] and it is also an improved version of HEED. This algorithm finds optimal cluster size using distance information of CH's from the BS. This distance also further helps to create unequal size clusters: small clusters are created

near to BS and large clusters are created farther from the BS. To create small size cluster it uses a competition radius formula. This architecture increases the network lifetime by decreasing the energy consumption requirement of the Intra-cluster traffic and saving more energy for inter-cluster relay traffic.

3.1.6. Constructing Optimal Clustering Architecture (COCA)

COCA [15] is a systematic technique with minimum energy consumption and maximum lifetime. This technique is always used in homogeneous WSN where all SN has equal energy and it explores the logical difficulties of unequal clustering methods. COCA develops optimal clustering architectureand routing to equalize the energy consumption of the WSN network. All the nodes in the network are competed against each other on the basis of residual energy. Node with the maximum residual energy is declared as a CH, which further selects a CH in the neighbor cluster as routing candidates.

3.2. Deterministic Algorithms

In deterministic algorithms, CH selection is done through standard metrics such as residual energy, node location, node density and distance from BS. This information is usually obtained by exchanging messages between the neighbors. Cluster formation takes places in a more authoritative manner that's why these algorithms are called deterministic algorithms. Heuristic based clustering algorithms are also categorized under deterministic unequal clustering algorithms. Many heuristic techniques generally used in WSN are Ant Colony Optimization, Genetic Algorithm, Particle swarm optimization and Artificial Bee Colony Optimization. Some of the deterministic algorithms are discussed below:

3.2.1. Multi-hop Routing Protocol with Unequal Clustering (MRPUC)

MRPUC [16] is a distributed approach which aims to overcome the hot-spot problem by equalizing the utilization of energy between all nodes of the network. In MRPUC, CH's are selected on the basis of residual energy and a SN joins that CH which has the minimum distance from BS and maximum residual energy. For productively transferring data to BS, a network backbone in the form a tree is constructed (for inter-cluster routing) using

relay nodes, which are selected on the basis of nominal energy consumption for relaying data.

3.2.2. Energy-Aware Distributed Unequal Clustering Protocol (EADUC)

EADUC is a multi-hop routing algorithm for heterogeneous WSN, which has low time and message complexity. It aims to provide un-interrupted coverage and uniform load distribution throughout the network[17].In EADUC, CH's are selected on the basis of aratio computed for SN residual energy against residual energy of the remaining nodes. Cluster radius is determined in this algorithm using residual energy and distance from BS which helps in making this network free from isolated points. Data needs to be transferred directly or through relay nodes is decided on the basis of a threshold distance, if the CH's distance from the BS is within the limits of this threshold then the CH sends the data directly otherwise it uses relay nodes.

3.2.3. Energy Balancing Unequal Clustering Approach for Gradient based routing (EBCAG).

EBCAG is a distributed clustering approach which mitigates the hot-spot problemby balancing the energy consumption of all CH's[18]. Optimal value of the cluster radius is decided on the basis of gradient value calculated for each SN. This gradient value in actual is the minimum number of hop counts. Now CH's are randomly selected with a probability T to make a set of CH's called as Tentative CH's. Final CH's out of this set is selected on the basis of residual energy. Further to complete the unequal cluster formation process the gradient value of the final CH's is used to find the cluster radius. In the data transmission phase, the sinking gradients of CH are used to forward data to the BS. In this way, EBCAG algorithm helps in balancing the energy requirement among CH's and prolongs network lifetime significantly.

3.2.4. Enhanced Unequal Clustering Scheme (EUCS)

Many clustering techniques involve periodically rotating the role of CH between SN's. This leads to more energy expenditure because a lot of energy is required during re-election process. EUCS [19] is proposed to retain energy during re-clustering process. In EUCS, re-election only takes place when the current energy of the CH beats the threshold value. This architecture helps in

eliminating the overhead of data gathering from SN's and re-election process. To decide which type of communication (single-hop/multi-hop) a CH should use to transfer data to the BS it uses a parameter called threshold distance. When the CH's distance from BS is below the threshold value it sends the data directly otherwise it uses relay nodes.

3.2.5. Genetic Algorithm based Energy-Efficient Adaptive Clustering Protocol (GAEEP)

GAEEP [20] is a heuristic algorithm which uses Genetic Algorithm (GA) to reduce the energy consumption of the WSN network. With the help of GA, it computes the optimal number of CH's required in the network and their position. There are many rounds in this algorithm and each round has two phases: setup phase and steady phase. BS of the WSN network runs the GA to compute the optimal number of CH's and their position. Inter-cluster routing from CH to BS takes place in the steady phase. To avoid collision with the intra-cluster traffic, each CH uses a TDMA schedule so as to designate slots to its cluster members. To reduce inter-cluster collision and reduce energy consumption, CH's uses CDMA. Because of heuristic nature GAEEP is more energy-efficient and reliable when compared with other unequal.

3.2.6. Coverage aware and Unequal Clustering Algorithm (CUCA)

CUCA is a single hop and first coverage based unequal clustering algorithm [21]. SN's whose sensing range is completely covered by the sensing range of its immediate neighbors are given high priority to be selected as CH. To form the clusters, CH calculates the cluster radius on the basis of its distance from the BS. A normal node's is always moved to sleep mode in this algorithm if its sensing range is also covered by the sensing range of its neighbors, this helps in preserving energy and helps to avoid redundant CH's in the WSN network. If overlapped nodes are not present in the network thenCH's are selected firstly on the basis of partially overlapped area and secondly on the basis of residual energy. With the help of such architecture CUCA eliminates hot-spot problem and prolongs the network lifetime by moving the completely covered non-CH node into sleep mode.

4. Comparison and Discussion

A comparison of unequal clustering based probabilistic and deterministic algorithms is presented in Table1. Algorithms are compared on the basis of different parameters like: CH Selection method, multi-hop routing, load balancing, energy consumption, data delivery rate, scalability and overhead. Deterministic approaches are non-probability based algorithms and it uses some metrics for CH selection like residual energy or distance from BS. Deterministic techniques are more reliable and controllable than probabilistic methods, but because of complexity and slower convergence they are not suitable for large scale WSN.

Table 1: Comparison of Unequal Clustering algorithms

Algorithm Name	Algorithm Type	CH Selection	Multi-hop Routing	Load Balancing	Energy Consumption	Data Delivery Rate	Scalability	Overhead
EEUC	Probabilistic Algorithms	Hybrid	Yes	Yes	average	Medium	low	low
UCR		Hybrid	Yes	Yes	average	High	medium	medium
EDUC		Random	Yes	Yes	low	Medium	medium	meium
LUCA		Random	Yes	Yes	average	High	low	high
UHEED		Hybrid	Yes	Yes	average	Medium	medium	low
COCA		Hybrid	Yes	Yes	low	High	high	medium
MRPUC	Deterministic Algorithms	Deterministic	Yes	Yes	average	Medium	low	medium
EADUC		Deterministic	Yes	Yes	low	Low	medium	high
EBCAG		Deterministic	Yes	Yes	average	Medium	medium	high
EUCS		Deterministic	Yes	Yes	average	Medium	low	medium
GAEEP		Heuristic	Yes	Yes	low	High	high	medium
CUCA		Deterministic	Yes	Yes	low	Medium	high	high

5. Conclusion

To make WSN network energy efficient clustering is the best alternative but it disrupts the network options due to the presence hot-spot problem. Unequal clustering is the best alternative to mitigate this problem and to increase the network lifetime. In this paper, an elaborative survey on unequal clustering algorithms is presented. We classified the unequal clustering algorithms into two types: Probabilistic algorithms and

deterministic algorithms. These algorithms are discussed along with their objectives, merits and demerits. From the survey, it is clear that probabilistic algorithms are best suitable to large scale WSN's but for critical and real time application deterministic algorithms with the combination of heuristic techniques to select CH's can be used. A comparison between the probabilistic algorithms and deterministic algorithms is also presented on the basis different parameters.

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