A STUDY ON METRICS BASED CLUSTERING ALGORITHMS IN WIRELESS SENSOR NETWORKS

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ABSTRACT

Wireless Sensor Networks have a large number of advantages and applications. Also there exist number of disadvantages that are to be addressed. One such problem is energy consumption and battery life which are inversely proportional to one another. One way to overcome this problem is by reducing the communication range and the number of packets sent via the link. This method is termed as Clustering. Clusters have a single head, which aggregates facts from all the nodes in the cluster and that node is the only link in-between the cluster and base station. This paper presents a review of methods and metrics that can be followed to form those clusters and to elect their Common Cluster Head(C-CH).

Keywords': Wireless Sensor Network, energy consumption, communication range, aggregates, Clustering, Cluster Head, Base Station

INTRODUCTION

In today's world, Wireless Sensor Network (WSN) play a vital role. Real time application such as temperature monitoring system, war field mapping system, creating target aware homes, may be listed as some of examples where WSN is used but their usage is endless. As the size of battery is small and energy consumption for the task of a sensor node is higher, there are chances for the nodes to die. This results in breakage of the chain communication wherein the nodes die continuously, which finally makes the network fail. This is one of the major challenges in this kind of network. Naturally, sensor nodes are mostly ad hoc in nature, organizing them in a particular structure would be another challenge in this field. After a lot of research, a common solution for both these problems is to form cluster of nodes. By this system, power consumption is reduced by aggregating data from all nodes in the cluster and a common head of cluster called Cluster Head(CH) communicates to the Base Station. This also organizes the system in a hierarchical structure. Components of this structure are listed:

A. *Sensor Nodes:* Interior components that are used in WSN. They perform all important and basic task of the network: Sensing, Computing and Communicating.
B. *Clusters:* Organizational structures of WSN. Dense nodes that are deployed in the required environment are broken into simple groups called clusters for network management purpose.
C. *Cluster Heads (CH):* Organizational heads of the clusters, responsible for management, maintenance and routing in a cluster.
D. *Gateway (GW):* Nodes that are capable to hear two or more CH.

E. Base Station: Upper most level in the hierarchical structure of WSN. They provide a link between the network and end user.

There are multiple factors that must be considered while developing a WSN:

i. Cost of Clustering must be minimal
ii. Selection of cluster heads and clusters
iii. Real time operation that are to be performed
iv. Synchronize data
v. Data aggregation methodologies

Main process that is carried out in these clusters are: every node in a cluster forward data to their CH, CH either forward the packet to all other nodes or send it to the GW node to transmit to other CH. Only CH and GW take part in communication with the BS. This paper gives an insight into methods and metrics that can be used to perform clustering in a network.

METRICS BASED CLUSTERING ALGORITHMS

Clustering of nodes is based on some metrics or parameters that decide whether the node is fit to join the cluster or to become the CH.

i. Single Metric based clustering algorithm
ii. Multiple Metric based clustering mechanism

A. Lowest ID Clustered Algorithm:

Node has a unique node ID. Algorithm is based on this unique ID. Lowest-ID clustering algorithm chooses a node with least possible ID as Cluster Head when compared to the other nodes in the cluster[3]. Periodically the nodes broadcast the list of nodes it can hear. When the nodes receive the list, node ID are compared and the node that hears to the nodes with higher node ID is declared as the CH. This concludes that CH of the cluster has the lowest node ID than all the other nodes in the particular cluster. This is the simplest method, whereas the disadvantage is that some incapable nodes are prone to die due to energy drain.

B. Highest Connectivity Clustering Algorithm (HCC):

HCC is based on communication range of the nodes[4]. Nodes periodically communicate with the nodes that are in the communication range. Node with highest node connectivity is selected as the CH. There are chances for the CH to vary if at least any one of the node moves from the communication range of the nodes. Periodically the highest degree is measured to check the local highest node degree. Re-clustering becomes possible when two CHs move into a communicating range. This may reduce the throughput. The main reason for this disadvantage is the unlimited number of nodes in a cluster.

C. K-Hop Connectivity Algorithm:

The same metrics of the previously mentioned algorithms is adopted[5]. This algorithm overcomes Lowest ID and Highest Connectivity algorithms, considering both the node ID and communication range of the node by setting upper bound(U) and lower bound(L), for number of nodes that can exist in a cluster. Number of CH formed is based on the U and L. When the number of nodes is less than L, then nodes combine with the nearby clusters, if the contrary occurs clusters are split into two.

D. Load Balancing Clustering (LBC):

Algorithm carries out load balancing for the elected CH. It does not allow a particular node to be the CH over a particular timeslot[6]. Initially CH is selected based on the variable ID that is dynamic in nature. Node with highest ID becomes the CH. When the upper bound of the timeslot is attained, then ID of CH is set to 0. When this happens, the neighbouring CH with highest ID takes the role of the new CH. The disadvantage is that redesign occurs even when CH does not reach the maximum utilization within the upper bound of timeslot.

E. Residual Energy algorithm (ResEn):

Each cluster has the chance to select the CH in each node[7]. CH selected nodes are based on the remaining energy level available in each of the nodes. A threshold value $T(n_0)$ is set based on the energy ratio left out with respect to the initial energy of the nodes. Nodes set a chance number between 0 and 1, if the chance number of the node is less than the $T(n_0)$ then node is assigned as the CH. Selected nodes broadcast itself as the CH with its unique ID to all the nodes within its scope.

F. Stable Clustering scheme considering energy and mobility (SCEM):

The algorithm is executed in 2 phases [8]: Setup phase and cluster Management. In the Setup phase, CHs are elected based on the calculation on three factors: Location, mobility, residual energy. Every node in the cluster decides by itself, whether it can become the CH or no,t by evaluating the weight based on the metrics. Node with highest weight is elected as the CH.

Mobility : Considered as a metric to understand the movement speed and direction along its neighbours. If this metric is let off then leaving rate is increased. Speed is compared with other neighbours by using Mahalanobis distance.

Location: Considered as the secondary metric, measures the distance to the mean coordinates. Mahalanobis equation measures the distance to the centre on the ellipsoid.

Residual energy: Ratio of remaining energy with respect the nodes initial energy. As the remaining energy increases, degree of energy of the node decreases.

Nodes wait for time slot to communicate to declare CH message with the other node which avoids collision. Other nodes, based on their connectivity and energy dissipation with the CH decide their parent CH.

G. Multiple Criteria Decision Making (MCDM):

Optimal CH is selected based on fuzzy decision making approach [9]. Decision making is based on Trapezoidal fuzzy and integral hierarchical fuzzy. Every node has a chance to identify whether it has the opportunity to become the CH using the hierarchical fuzzy integral. The main metrics that we account for the CH selection are: energy level, quality impact and location of nodes. Sub metrics considered are residual energy, communication cost, link quality, resume number and node eccentricity. Trigger condition for CH reselection is based on the mobility of nodes and remaining energy. Nodes create a composite value. After a timeslot, nodes broadcast the composite value to all the nodes. Based on the First Declaration Wins rule, node that first declares itself as the CH gets the additional privilege and the responsibilities.

H. Coverage and Energy Responsive CH Selection Algorithm:

Algorithm aims at CH selection, based on three critical factors [10]: Nodes Energy, Location and Coverage Metrics. Proposed algorithm is based on LEACH and HYENAS. Initially all

nodes aim at calculating the coverage metrics, but since it is a tedious task, approximate energy observed to communicate a beacon message is calculated. Coverage metrics is directly proportional to equivalent overlapping area of nodes.

Higher the residual energy, larger chance for the node to become the CH.

Relative distance between the node and the base station is lesser, then the chance of the node to become the CH is higher.Lesser the coverage cost, higher the probability of the node to become the CH.

Advantage of this may be: energy consumption for beacon message transmission may not consume the actual energy consumption for actual packet transmission.

I. Density Based Clustering Scheme:

The scheme aims to increase the lifetime of the nodes by considering the node density of the network [11]. It works better when there is an uneven distribution of nodes. Density based LEACH algorithm dynamically adjusst the nodes participation in the cluster. Algorithm is organized into 3 stages for clustering.

i. *Pre-Clustering phase:* Initially calculates the radius of every node, then transmits the packet message to identify the nodes within its radius. By counting the packet messages, each node identifies the density of nodes around itself. Based on this density, probability of the the node joining the cluster is decided.

ii. *Setup phase:* CHs are selected for the clusters, random threshold values are chosen between 0 and 1. When the probability of the node is more than the determined threshold value, nodes become CH for the particular round. CH declares new responsibility to the nodes and based on the acknowledgement received, counts the total number of nodes in the particular cluster.

iii. *Steady State phase***:** Based on the population in the cluster, CH assigns timeslot for nodes for message transmission. Nodes communicate to the CH and finally aggregated value is transmitted to the base station.

J. Optimized Far Zone LEACH(OFZ-LEACH) using Exponential weighted average:

Exponential weighted average scheme updates the nodes contact probability. Routing table contains the following entries: node ID, cluster ID, time stamp and nodes contact probability[12]. Gateway table also contains the above entries. Algorithm actually aims at grouping nodes into clusters based on their mobility. Gateway nodes that connect these clusters are selected based on the contact probability of nodes. Nodes build the connectivity packet and transmit to all neighbours. Once the gateway gets enough reply, network graph is drawn. Links connect the nodes, strength of the link is contact probability of nodes. Based on network graph, shortest path algorithm is designed to enable packet communication between CH and base station. Once routing is over, the packet transmission occurs between nodes via Inter and Intra cluster routing. By measuring this communication cost, Far Zone members are determined. Once this Far Zone is formed, Far Zone Head is randomly selected for the first round purpose. Time slots are assigned for nodes for transmission to the Zone, aggregation occurs and data is transmitted to Base Station.

K. Single Hop Active Clustering Algorithm (SHAC):

Algorithm is based on Active Clustering. The first phase of the algorithm is to find a tentative CH, then this node broadcasts the complete CH message to all the nodes [13]. Finally it broadcasts the

received message, which includes number of nodes added to this CH. Based on the prior knowledge, final CH is selected and final CH message is broadcasted to nodes. Next stage of the process is to balance the energy consumption based on the cost function in the bottleneck area, assign nodes to their respective CH.

L. Passive Clustering multipath routing protocol:

Algorithm is an event driven process. As soon as the event occurs, entire network is organized in the form of clusters based on passive clustering [14]. Cluster Head selection is in the form of rounds. All nodes remain in the initial state unless an event occurs. Once an event occurs, event centre activates and sends some data packet, recognizing that nodes have entered first round. Nodes in the cluster head ready state, after waiting for delay period, if the node satisfies the conditions based on the First Declaration Wins rule, broadcast message to all other nodes. As the CH is ready, joining message is sent to all the nodes within the shortest distance. Once the nodes are organized CH broadcast a message to the intra cluster nodes .This stimulates the transmission timeslot for every node. Next step is to establish the multipath routing. CH must be in an active state when the node tends to initiate this multipath routing. When a node receives a message for the first time, sender ID is recognized as the parent node. This is identified as main path; if any other spare path with a lower cost is identified, it is discarded. This may lead to flooding and to overcome this, multipath extension occurs that increases the throughput of the nodes also.

M. Backoff hierarchical clustering algorithm:

Using backoff technique algorithm, the major goal of load balancing is achieved and also distributes CH uniformly throughout the network [15]. As with all the algorithms there exist two phases of execution, set phase and steady phase. In the set stage, nodes with higher residual energy tend to become the CH with K-hop neighbours. In case node does not receive any message within the timeslot, node declares itself as the CH and broadcasts the message. On receiving the message, nodes stop the timer and become subordinate nodes. These subordinate nodes calculate the distance between them and CH, decides on to which CH they must join to. Nodes that are neither CH nor belonging to any other Cluster, become CH called forced CH. These forced CH link directly to Base Station. At the end of the entire rounds, CH aggregates data from all its subordinate nodes and communicates to processing centre. When the entire network is complete, nodes enter into steady state phase.

N. Weighted Clustering Algorithm for Mobile Ad-Hoc network(WCMA):

In Mobile Ad-Hoc network, stability of nodes are decided by the associated and dissociated nodes with the cluster. CH and Clusters decide the stability and topology of nodes [16]. WCA considers the degree, battery power, transmission rate and mobility of node. Any or all of the parameters can be considered to elect the CH for the cluster. Nodes share responsibility of becoming the CH in a distributed pattern. Based on diameter of the underlying network graph, timestamp for the nodes to resist as the CH is decided. These metrics are kept around a predefined threshold value to facilitate optimal operations on the MAC protocol. Non periodic CH selection is facilitated for non procedural form of electing CH.

O. ***Advanced efficiency and Stability combined weight based distributed clustering algorithm*:**

Algorithm combines weight based and distributed clustering with hierarchical clustering algorithm, that optimizes performance of network and allocates resources for mobile nodes [17]. This scheme optimizes the network performance in dynamic MANET and minimizes energy consumption. To select the CH, algorithm uses the concept of "LOCAL-MINIMA" instead of "GLOBAL-MINIMA", to calculate least possible weight for all nodes in the network. This decreases the initial set overhead generated in the set phase. In the set phase, nodes select a pre CH, node with lowest possible weight among its neighbouring nodes in single hop. Weight comparison is made between nodes to decide CH. Even if nodes disconnect from CH due to their mobility, it maintains link with the GW nodes. If this link with GW is made impossible then re-clustering occurs. Therefore mobility of nodes is managed such that it does not affect the cluster organization and stability. So this leads to role sharing among nodes of the same cluster.

P. Connectivity, Energy and Mobility driven Weighted Clustering algorithm:

Algorithm considers either one of the metrics or a combination of the following metrics to elect the CH, node with lowest mobility, highest degree, highest transmission range and higher battery life [18]. Algorithm is distributing in nature, so all the nodes get an equal chance to act as a CH. As in all algorithms , there exist two phases: CH selection phase and maintenance phase(combining members for clusters). Nodes broadcast their merits to the neighbours for comparison, best among them are chosen as CH. In the maintenance phase, nodes join the cluster that are to the maximum of two hops distance. CH stores all information about the member nodes. This enables easier inter-cluster and intra cluster communication among nodes.

Q. Vote Based Clustering Algorithm:

Algorithm is based on residual energy and neighbour node number for every mobile node. As in all networks, each node has a unique ID [19]. Initially nodes broadcast the basic message through a common channel. This basic message packet contains node ID, cluster ID, vote and load balance information on nodes. Vote concept is based on node location and power information. Each node sends the HELLO message in the first cycle. If a node is new to the network they reset clusterhead ID and becomes the member. When each node receives HELLO message, they count the number of received messages. Each node sends its hello message to other nodes along with ‘t’ vote value. In the second round, each node identifies the highest sender, its cluster and CH. If a tie occurs with the highest number of Hello messages then node with lower ID will get priority, every node will come to know its respective CH at the end of the second cycle.

R. Energy Efficient Static Clustering Algorithm (EEPSC):

Algorithm aims at overcoming the shortcomings of dynamic clustering algorithm, by introducing a temporary CH that helps for load balancing among the nodes. EEPSC introduces a setup phase where node selection occurs and the second phase introduces static clustering. To set a cluster node, broadcast the number of clusters to be formed and send the join message to all nodes. All nodes do not join, but instead send their ID in correspondence with the nodes and inform the Base Station. Based on the received message, node is randomly selected to act as temporary CH which reduces the work flow of CH. This temporary node elects the CH, with the highest energy level

for that particular round. In every round, nodes re-cluster which does not affect the nodes in any way. In the second phase in a particular time slot nodes communicate their packet to Base Station via CH after aggregating data.

S. Distributed clustering for Mobile Ad-HoC Network (DMAC):

Main target in the algorithm is to partition a mobile ad-hoc network into clusters[21]. First stage is to choose the correct CH node. Node with largest weight is elected as CH. Main advantage of this algorithm is that by associating nodes weight with mobility related parameters, nodes that can best suit the responsibilities of the nodes can be elected. When the weight of the node is extremely proportional to weight of nodes, then the mobility of node reduces. These less mobility nodes are elected as CH. These stable nodes reduce the overheads that occur due to cluster maintenance. Distributed clustering algorithm and Distributed mobile clustering algorithm are suited for both mobile and distributed nodes. The algorithm is based only on single metrics, weight based on mobility of related parameters.

T. Adaptive Weighted Cluster Based Routing:

Weight of the node is based on stability, connectivity and energy level of the nodes [22]. CH calculation has weighted factor value. CH can be selected by the following weight formula:

$W=p_1m_1+p_2m_2+p_3m_3$

were m1,m2,m3 are the three metrics respectively and p_1,p_2,p_3 are weighting factors. Node with lowest weight can be assigned as CH with extra responsibilities. Nodes that join these clusters are termed as considered nodes. Once the considered nodes are identified then the algorithm terminates.

U. Link Aware Clustering Mechanism for energy efficient routing in WSN (LCM):

Nodes report to sink node with a particular frequency [23]. Algorithm aims at selecting the CH and GW nodes based on PTX(Predicted Transmission Count). PTX value is based on Passive clustering technique that depends on state of the node and link condition. Based on PTX value nodes are assigned with priority, node with highest priority is assigned as GW node or CH node. With reference to the threshold assigned, neighbouring nodes are PTX value are compared and subdivided into two subsets. If none of the PTX value satisfies threshold then nearby value is fixed as PTX value. Node with highest PTX value is assigned as GW and CH nodes based on previous state of nodes.

V. Hierarchical Clustering Algorithm:

This is a distributed randomized clustering algorithm which organizes the nodes in a hierarchical fashion[24]. System selects CH for Level 1, then for Level 2 and so on. In level 1, nodes select their CH based on certain probability, remaining nodes are forced to join clusters that are available. Nodes in level 1 automatically become CH in level 2, and this decision is broadcasted to all the nodes. Probability of CH in a level depends on the following parameters: number of nodes, number of levels and probability of number of CH in level 1.

W. Weighted Energy Distance Based Cluster Head Selection Algorithm:

Sensor nodes based on the topological information are collected through the localized interaction. CH aggregates those data and transfer it to the base station[25]. CH selection probability is based on the following parameters:

Nodes residual energy: nodes with highest residual energy is selected.
Centrality: nodes location in the cluster must have equal distance from all nodes of a cluster.
Frequency of the CH required: total number of times the node has been selected as CH is calculated to stop electing the same node from becoming the CH again.
Cost function is calculated based on the above mentioned parameters. Node with lowest cost function is identified, other nodes send the join message containing their ID and details of their residual energy to CH and join the respective clusters.

X. Mobility Based Adaptive Clustering Algorithm:

Algorithm aims at partitioning entire network into number of N-hop clusters. This based on (p, t) metrics [26], that is: every node remain in the cluster for a particular time period "t" with a probability factor "p" irrespective of the hop distance in between the nodes. Network needs a quantitative bond between the node and this is carried out with respect to the future state of the network. The scheme is made adaptive with respect to nodes mobility.

Y. 3-hops Between Adjacent Cluster-head(3-h BAC):

Algorithm introduces a new node status called Cluster guest, which defines that nodes are not within the communication range of any CH but within the range of any of the Cluster Member[27]. When these nodes decide based on the nodes localization, these nodes cannot become the CH or Cluster member decides to act as cluster guest. This enables data collection over a longer range of communication between nodes.

ADVANTAGES

Techniques mentioned in this paper discuss about various metrics depending on which the clusters and CH of the network can be elected. In the case of LCA, CH is selected based only on the ID of the nodes, whereas HCC is based on the nodes connectivity. To overcome the disadvantages of the above said algorithms, K-Hop connectivity algorithm that defines the boundary for the number of nodes in a network is used. Dynamic nodes that require load balancing uses the LBC algorithm. ResEn algorithm best suites the network that concentrates only on the energy consumption of the node and the lifetime of the network. Mobile networks that are unaware of their neighbours use the SCEM algorithm. Networks that are designed for specific purpose requires to satisfy the QoS factors and such network uses the MCDM. Coverage and energy responsive CH selection algorithm depends on the location factor and coverage metrics of the network. Density based clustering algorithm is best suited for dense and unevenly distributed nodes. OFZ-LEACH deals with optimization of nodes based on time stamp of nodes. Passive clustering generally is implemented in the event driven networks. There are number of algorithms that works based on the weight of the nodes. Weight factor of nodes depends on various factors like node ID, residual energy and mobility of nodes.

SUMMARY OF CLUSTERING ALGORITHMS

A summary of all the above specified algorithms is given in the table below:

S.No.	Algorithm	Parameters used
1	Lowest- ID Clustering Algorithm	Unique ID

2	Highest Connectivity Clustering Algorithm	Communication range of nodes
3	K-Hop connectivity Algorithm	Number of nodes in network
4	Load Balancing Clustering	Dynamic Variable ID, time slot
5	Residual Energy Algorithm	Residual Energy
6	Stable Clustering Scheme based on energy and Mobility	Mobility, Location and Residual Energy, time slot
7	Multiple Criteria Decision making	Trapezoidal Fuzzy and Hierarchical Fuzzy
8	Coverage and Energy Aware Cluster Head Selection Algorithm	Residual Energy, Relative distance between node and Base Station, Coverage Cost
9	Density Based Clustering Scheme	Node density of the network
10	Optimized Far Zone LEACH	Node ID, Cluster ID, Time Stamp, Node Contact Probability
11	Single Hop Active Clustering Algorithm	Maximum number of nodes in the cluster, Cost function
12	Passive Clustering multipath routing protocol	Event Driven process
13	Backoff Hierarchical Clustering Algorithm	Time slot and Backoff concept
14	Weighted Clustering Algorithm	Degree, Battery power, Transmission rate, Mobility of nodes
15	Advanced Efficiency and Stability combined Weight based Distributed clustering algorithm	Local minima information
16	Connectivity, Connectivity, Mobility Driven weighted clustering algorithm	Lowest mobility, Highest degree, Highest transmission range and Highest Power consumption.
17	Vote Based Clustering Algorithm	Residual Energy, Neighbouring node number, Basic message, Vote value
18	Energy Efficient Protocol with static clustering	Temporary CH, Static clustering
19	Distributed Clustering for Mobile Ad-Hoc network	Weight factor
20	Adaptive Weighted Cluster Based Routing	Stability, Connectivity and Energy level of nodes and Weighting factor
21	Link Aware Clustering Mechanism	Node status and Link condition
22	Hierarchical Clustering Algorithm	Number of nodes, Number of levels, Number of CH in level 1
23	Weighted Energy Distance based Cluster Head Algorithm	Residual energy, centrality, frequency of CH occurrence
24	Mobility Based Adaptive Clustering Algorithm	Time slot and probability
25	3-hop between Adjacent Cluster Head	Custer Guest node

Table: Summary of the Clustering algorithm

CONCLUSION

Clustering is the best solution for energy efficiency and to organize nodes in a dense network. This paper depicts various Clustering algorithms, with special reference to the metrics on which they depend on. Performance of the nodes vary in accordance with the metrics on which they depend. Techniques specified in this paper are more capable than the conventional algorithms. Need for more stable, organized, energy efficient schemes for effective data gathering in Wireless sensor Network is discussed.

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