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Energy Efficient Weighted Clustering Algorithm in Wireless Sensor Networks

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Abstract- With the advancement in communication and internet technologies, recently there have been many research efforts in the area of Wireless Sensor Networks (WSNs) to conserve energy. Clustering mechanisms have been applied to WSNs to enhance the network performance while reducing the necessary energy consumption. The goal of Weighted Clustering Algorithm (WCA) is to determine the cluster heads dynamically based on a combined weight metric that includes one or more parameters such as node degree, distances with respect to a nodes neighbors, node speed and the time spent as a cluster head. In this work, we have proposed a refined and improved version of WCA known as Energy Efficient Weighted Clustering Algorithm (EEWCA) to prolong the network lifetime by reducing energy consumption. EEWCA is designed and simulated with additional constraint on energy for the selection of cluster heads. Both the WCA and EEWCA schemes have been simulated using MATLAB. The proposed EEWCA behaves better than WCA for longer system lifetime.

Keywords: *WSN; MANETS; energy efficiency; cluster.*

GJCST-E Classification: *I.4.8, C.2.1*

Energy Efficient Weighted Clustering Algorithm in Wireless Sensor Networks

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Abstract- With the advancement in communication and internet technologies, recently there have been many research efforts in the area of Wireless Sensor Networks (WSNs) to conserve energy. Clustering mechanisms have been applied to WSNs to enhance the network performance while reducing the necessary energy consumption. The goal of Weighted Clustering Algorithm (WCA) is to determine the cluster heads dynamically based on a combined weight metric that includes one or more parameters such as node degree, distances with respect to a nodes neighbors, node speed and the time spent as a cluster head. In this work, we have proposed a refined and improved version of WCA known as Energy Efficient Weighted Clustering Algorithm (EEWCA) to prolong the network lifetime by reducing energy consumption. EEWCA is designed and simulated with additional constraint on energy for the selection of cluster heads. Both the WCA and EEWCA schemes have been simulated using MATLAB. The proposed EEWCA behaves better than WCA for longer system lifetime. The proposed work is simulated and performance is tested for number of clusters and average execution time. Simulation results show that the EEWCA outperforms WCA in terms of both the number of clusters formed and the execution time.

Keywords: WSN; MANETS; energy efficiency; cluster.

I. Introduction

With the popularity of cell phones and smart devices, computing devices have become cheaper, mobile and more distributed in daily life. Wireless Sensor Network (WSN) is a collection of sensor nodes organized into a co-operative network to accomplish a common task. Each sensor node consists of a processing capability, multiple types of memory (program, data or flash memories), RF transceiver, and a power source. In addition, the nodes accommodate sensors and actuators [1]. WSNs have been widely considered as one of the most important technologies for the twenty first century [2]. Enabled by recent advances in microelectronic mechanical systems (MEMS) and wireless communication technologies, tiny, cheap and smart sensors deployed in a physical area and networked through wireless links and the Internet; provide unprecedented opportunities for a variety of civilian and military applications, for example, environmental monitoring, battle field surveillance and industry process control [3]. After the initial deployment, sensor nodes communicate and self organize into an appropriate network often with multihop connections among sensor nodes. In most cases, it is very difficult and even impossible to change or recharge batteries for the sensor nodes. Distinguished from traditional wireless communication networks, WSNs have unique characteristics for example, denser level of node deployment, higher unreliability of sensor nodes, and severe energy, computation, and storage constraints [4] that present many new challenges in the applications of WSNs. In the past decade, WSNs have received tremendous attention from both academia and industry all over the world. It is envisioned that in the near future WSNs will be widely used in various civilian and military fields, and revolutionize the way we live, work and interact with the physical world [5]. The next section describes unique characterstics of WSNs.

Equipped with sensors, embedded microprocessors and radio transceivers, the sensor nodes have not only sensing capability but also data processing and communication capabilities [6]. Compared with traditional wireless communication networks such as cellular systems and MANETs, WSNs have unique characteristics and constraints that are listed below [7]. Sensor nodes are usually densely deployed in the field of interest. Thus, the data sensed by multiple sensor nodes has a certain level of redundancy [8]. Sensor nodes are usually deployed in harsh or hostile environments and the network operation is autonomous. As a result, the network undergoes frequent topology change and it is prone to physical damages or failures [3]. The following section briefs the hierarchical structure and clustering in WSNs.

a) Hierarchical structure and clustering in Wireless Sensor Networks

In a hierarchical network shown in figure 1, sensor nodes can be organized into clusters, where the cluster members send their data to the cluster heads that serve as relays for transmitting data to the sink. The collaboration among sensor nodes is very important in WSNs for two reasons: 1. Data collected from multiple sensor nodes can offer valuable inference about the system under study. 2. The collaboration among sensor nodes can provide trade-offs between communication cost and computation energy. Since it is likely that the data acquired from one sensor node are highly correlated with the data from its neighbors, data aggregation can reduce the redundant information

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transmitted in the network. It is well known fact that the energy consumed for transferring one bit of data can be used to perform a large number of arithmetic operations in a sensor processor [9]. When the base station is far away, there are significant advantages in using local data aggregation instead of direct communication. Clustering aggregates nodes into groups and facilitates practical deployment and operation of WSNs. Traditional (i.e. flat) routing and data dissemination protocols for WSNs may not be optimal in terms of energy consumption. The primary idea in clustering is to group nodes around a cluster head responsible for state maintenance and inter-cluster connectivity.

A node with lower energy can be used to perform the sensing task and send the sensed data to its cluster head at short distance, while a node with higher energy can be selected as a cluster head to process the data

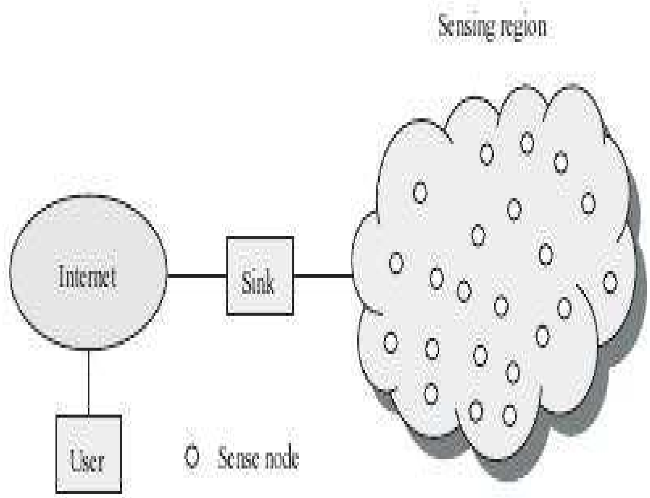

Figure 1: General Architecture of WSN

from its cluster members and transmit the processed data to sink. This process cannot only reduce the energy consumption for communication, but also balance traffic load and improve scalability when the network size grows. Moreover, data aggregation can be performed at cluster heads to reduce the amount of data transmitted to the sink and improve the energy efficiency of the network [10]. The major problem with clustering is how to select the cluster heads and organize the clusters [11]. Even routing mechanisms have been applied to sensor networks with hierarchical structures to enhance the network performance while reducing the necessary energy consumption [12]. In this context, there are many clustering strategies proposed in the literature. Next section highlights some of the important works carried out in this domain.

II. Related Works

In Highest Connectivity Cluster Algorithm [13], the node with the highest connectivity (connected to the most number of nodes) is elected cluster head, but in the case of a tie, the node with the lowest ID prevails. Mobility Based Metric for Clustering [14] proposes a local mobility metric such that mobile nodes with low speed relative to their neighbors have the chance to become cluster heads. By calculating the variance of a mobile node's speed relative to each of its neighbors, the aggregate local speed of a mobile node is estimated. A low variance value indicates that this mobile node is relatively less mobile to its neighbors. Consequently, mobile nodes with low variance values in their neighborhoods are chosen as clusterhead. Thus, a selected clusterhead can normally promise the low mobility with respect to its member nodes. However, if mobile nodes move randomly the performance may reduce. Clustering for energy conservation [15] assumes two node as master and slave. A slave node must be connected to one master node only and there is no direct connection between slave nodes. Each master node can establish a cluster based on connections to slave nodes. The drawback of this scheme are paging process before each round of communication consumes a large amount of energy. Master node election is not adaptive and the method of selecting the master node is not specified. In vote based clustering algorithm [16], researchers consider neighbor's number and remaining battery time of each mobile node. The basic concept is the Hello message, which is transmitted in the shared channel. Making use of node location and power information, this work proposes voting concept which is weighted sum of number of valid neighbors. The next section highlights the contribution of our work.

a) *Our Contributions*

The goal of Weighted Clustering Algorithm (WCA) [17] is to determine the cluster heads dynamically in Mobile Adhoc Networks (MANETs). The Cluster heads are selected based on a combined weight metric that includes one or more parameters such as node degree, distances with respect to a nodes neighbours, node speed, and the time spent as a cluster head. Wireless sensor networks are however little different from traditional wireless networks due to energy constraints. Besides in WSNs, prolonging network lifetime is an important issue. WCA cannot be applied directly to wireless sensor networks as it does not consider the energy constraint prevalent in WSNs. To have an improvement over WCA, we have proposed" Energy Efficient Weighted Clustering Algorithm (EEWCA)" that enhances network lifetime by reducing energy consumption. In EEWCA, we have considered an additional constraint on energy over WCA for the selection of cluster heads and to form clusters in WSNs. Both the WCA and EEWCA algorithms have been simulated using MATLAB. The proposed EEWCA behaves better than WCA in WSNS for longer system lifetime. The proposed work is simulated and performance is tested for the reduced number of clusters and reduced average execution time. The simulation results show that the EEWCA outperforms WCA in terms of number of clusters and execution time. The next part of this work describes the steps involved in WCA and EEWCA.

III. Algorithms

The following subsections explain both the WAC and EEWCA algorithms in detail.

a) Weighted Clustering Algorithm

The Weighted Clustering Algorithm (WCA) proposed for selecting cluster heads in MANETs, is based on a combined weight metric that includes the node degree, distances with respect to a nodes neighbors, node speed, and the time spent as a cluster head [17]. Each node broadcasts its weight value to all other nodes. A node is chosen to be a cluster head if its weight is the minimum among its neighbors; otherwise, it joins a neighboring cluster. Nodes in MANET can be modelled as a set of nodes and links, represented by a graph G = (V,E), where V is the set of nodes and E is the set of links. In MANETs, the transmission radii of all the nodes are assumed to be the same [17]. The equation 1 is used to calculate the effective combined weight (Wv) of a node v as a cluster head.

$$Wv = w1dv+w2Dv+w3Mv+w4Tv \qquad (1)$$

where v is the serial number (ID) of a mobile node, dv is the degree difference of node v, Dv is the sum of the distances between v and its neighbors, Mv is the average speed of node v, Tv is the cumulative time in whichnode v has acted as cluster head, and Wi is the weighted coefficient for the i-th factor. The degree of a node v is the number of nodes within the transmission radius of v excluding itself. The dv is the difference between the degree of a node v and a predefined degree M of an ideal node in a cluster. Wv is used to determine the goodness of a node as a cluster head. Lower the Wv value, better are the chances of node v to become cluster head.

- Input: A set of sensor nodes, each with the same transmission radius Rv, Individual cumulative time Tv and mobility speed Mv, the predefined ideal node number M in a cluster and the four coefficients w1 to w4.
- Output: A set of clusters with cluster heads and its members.

Algorithm 1 Weighted Clustering Algorithm

1: Begin
2: for Each sensor node do
3: Find the neighbors N(v) by using the equation
4: end for

$$N(v) = v'|distance(v, v') \leq Rv \qquad (2)$$

5: Calculate the degree dv of node v as the number of the neighbors of v that fall within its transmission radius Rv, not including itself
6: Compute the degree difference for each node v by using the equation

$$\delta v = |dv - M| \qquad (3)$$

7: Compute the sum Dv of the distances between node v and all its neighbors by using the equation

$$Dv = \sum_{v' \in N(v)} distance(v, v') \qquad (4)$$

8: Compute the running average of the speed for every node till current time T by using the following formula. This gives the measure of mobility and is denoted by Mv

$$Mv = 1/T \sum \sqrt{((X_t - X_{t-1}) + (Y_t - Y_{t-1}))} \qquad (5)$$

9: Assume an appropriate value of cumulative time Tv for each sensor node. Cumulative time is the time in

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which node v has acted as a cluster head. A larger Tv value with node v implies that it has spent more resources (for example energy).

10: Calculate the combined effective weight, Wv by using the equation

$$Wv = w1\delta v + w2Dv + w3Mv + w4Tv \quad (6)$$

11: Select the node with a minimum Wv as the cluster head.

12: Eliminate the chosen cluster head and its neighbors (cluster members) from the set of original sensor nodes.

13: Repeat Steps 1 to 12 for the remaining nodes not yet selected as a cluster head or until each node is assigned to a cluster.

14: All the mobile nodes are grouped into several clusters and each cluster has its own cluster head.

15: End

Although the WCA based on weighted coefficients, performs better than the earlier algorithms proposed in the domain of MANETs, it cannot be straight away used for WSN applications. In this work, the WCA is modified such that it can be used in WSNs with their specific energy constraint considered. The next part of our work describes the proposed EEWCA which is an improved version of WCA that takes care of energy constraints in WSNs.

IV. Energy Efficient Weighted Clustering Algorithm

The WCA algorithm was designed to select cluster heads dynamically in MANETs. It is not so appropriate to directly apply the WCA algorithm to WSNs since it does not take care of energy contraints and the transmission rate into consideration. In the real world, the assumption of homogeneous sensors may not be practical because sensing applications may require heterogeneous sensors in terms of their sensing and communication capabilities in order to enhance network reliability and extend network lifetime. Also, even if the sensors are equipped with identical hardware, they may not always have the same communication and sensing models. In fact, at the manufacturing stage, there is no guarantee that two sensors using the same platform have exactly the same physical properties. Heterogeneous nodes in WSNs can bring the benefits of reduced response time and increased life time. The proposed EEWCA has been worked out for heterogeneous WSNs to form clusters with the energy constraints being considered. In this algorithm, energy factor is added into the evaluation formula such that the nodes chosen as cluster heads may have a better behavior in heterogeneous sensor networks than those without this additional factor. Equation 7 is used to calculate the effective combined weight (Wv) of a node v as a cluster head.

$$Wv = w1\delta v + w2Dv + w3Mv + w4Tv + W5Cv \quad (7)$$

where Wv is used to determine the likliness of a node as a cluster head. The lower the Wv value is, the better v acts as a cluster head. v is the serial number (ID) of a mobile node, dv is the degree difference of node v, Dv is the sum of the distances between v and all its neighbors, Mv is the running average of the speed of node v, Tv is the cumulative time in which node v acted as a cluster head, wi is the weighted coefficient for the i-th factor and Cv is a characteristic factor of each node and is defined by the following equation 8

$$Cv = rv/Ev \quad (8)$$

Where rv the transmission rate and Ev is the initial energy of node v. After a fixed interval of time, the proposed algorithm is then re-run again to find new cluster heads for the purpose of getting a longer system lifetime. The detailed procedure for the EEWCA is described as follows.

- Input: A set of sensor nodes, each with the same transmission radius Rv, individual cumulative time Tv, mobility speed Mv, transmission rate rv, the initial energy Ev, the predefined ideal node number M in a cluster and the five weighted coefficients w1 to w5.
- Output: A set of clusters with cluster heads and its members.

Algorithm 2 Energy Efficient Weighted Clustering Algorithm

1: Begin

2: for Each sensor node do

3: Find the neighbors N(v) by using the equation

$$N(v) = v'|distance(v, v') \leq Rv \quad (9)$$

4: end for

5: Calculate the degree dv of node v as the number of the neighbors of v that fall within its transmission radius Rv, excluding itself.

6: Compute the degree difference for each node v by using the equation

$$\delta v = |dv - M| \qquad (10)$$

7: Compute the sum Dv of the distances between node v and all its neighbors by using the equation

$$Dv = \sum_{v' \in N(v)} distance(v, v') \qquad (11)$$

8: Compute the running average of the speed for every node till current time T by using the following formula. This gives the measure of mobility and is denoted by Mv

$$Mv = 1/T \sum \sqrt{((X_t - X_{t-1}) + (Y_t - Y_{t-1}))} \qquad (12)$$

9: Assume an appropriate value of cumulative time Tv for each sensor node. Cumulative time is the time in which node v has acted as a cluster head. A larger Tv value with node v implies that it has spent more resources (for xample energy).
10: Compute the characteristic factor Cv of every node by using the equation

$$Cv = rv/Ev \qquad (13)$$

11: Calculate the combined effective weight, Wv by using the equation

$$Wv = w1\delta v + w2Dv + w3Mv + w4Tv + w5Cv \qquad (14)$$

12: Select the node with a minimum Wv as the cluster head.
13: Eliminate the chosen cluster head and its neighbors (cluster members) from the set of original sensor nodes.
14: Repeat Steps 1 to 13 for the remaining nodes not yet selected as a cluster head or until each node is assigned to a cluster.
15: All the mobile nodes are grouped into several clusters and each cluster has its own cluster head.
16: End

V. Simulation Parameters

Both WCA and EEWCA have been simulated in MATLAB. There are totally fourteen mobile sensor nodes loaded with their initial simulation parameters (or factors) as shown in figure 2. Where SN

SN	Position	Rv	Mv	Tv	Rt	E
1	(3,3)	5	2	1	5	7.5
2	(4,7)	5	2	2	6	7.2
3	(4,12)	5	1	4	6	6.6
4	(7,15)	5	1	6	4	8.4
5	(11,15)	5	2	0	5	10
6	(15,20)	5	3	2	4	7.6
7	(7,4)	5	4	1	4	9.6
8	(11,6)	5	1	1	5	9.0
9	(15,4)	5	1	7	5	8.5
10	(17,8)	5	0	5	6	9.6
11	(18,17)	5	2	2	4	9.6
12	(15,15)	5	1	0	5	8.0
13	(5,9)	5	3	1	6	8.8
14	(7,12)	5	2	0	5	8.3

Figure 2: Input Parameteres for Simulation

represents the serial number of a sensor node, Position is the coordinate position(X,Y) of a sensor node, Rv represents the transmission radius of node v, Mv is the running average speed of node v, Tv represents the cumulative time, Rt is the transmission rate of node v and Ev represents the initial power on node v. The ideal degree of a node, M is set at 3 that means a cluster head can ideally handle 3 sensor nodes. The five coefficient values are set as follows: w1=0.5, w2=0.1, w3=0.05, w4=0.05 and w5=0.3 where the sum of these weights is equal to 1. For comparison, the same simualtion parameters are run with WCA. The result analysis is done in the next part along with the effect of number of input parameters and the execution time on the number of clusters generated.

VI. Results Analysis

There are two main parameters that have been used to evaluate the performance of EEWCA and WCA. These parameters are the number of input sensor nodes and execution time as described in the following sections.

* Number of nodes: When the simulation example (with 14 sensor nodes as input) is run with both EEWCA and WCA, the EEWCA performs better than WCA with less number of clusters formed as shown in the figure 3 as compared to figure 4

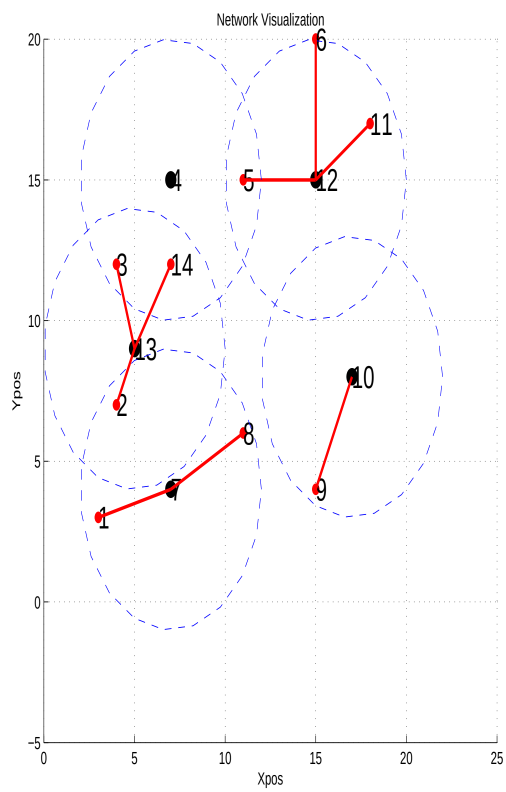

Figure 3: Clusters formed after simulating EEWCA

Thus EEWCA reduces the number of transmissions between the cluster heads and the base station. This reduces energy consumed in transmission of messages, thus prolonging the life time of a sensor network. The EEWCA and WCA are simulated with different number of input sensor nodes and the number of output clusters are noted down as shown in 5 and 6 respectively.

The graph 7 is drawn to compare the performance of both these algorithms with respect to the number of input sensor nodes against number of clusters formed. The graphs show that EEWCA forms less number of clusters compared to WCA for the same number of input sensor nodes.

* Execution time: While EEWCA and WCA are simulated for different number of input sensor nodes, the execution time in each of the cases is noted down. The following graph is drawn to plot execution times against number of inputs to compare the performance of both these algorithms. It is found that the average execution time of EEWCA is better compared to WCA. The execution times of both these algorithms for different number of input sensor nodes are listed in the figure 8.

VII. Conclusion

In WSNs, power usage is an important factor for network lifetime. The proposed EEWCA is an improved clustering algorithm based on the weighted clustering algorithm with a constraint of energy

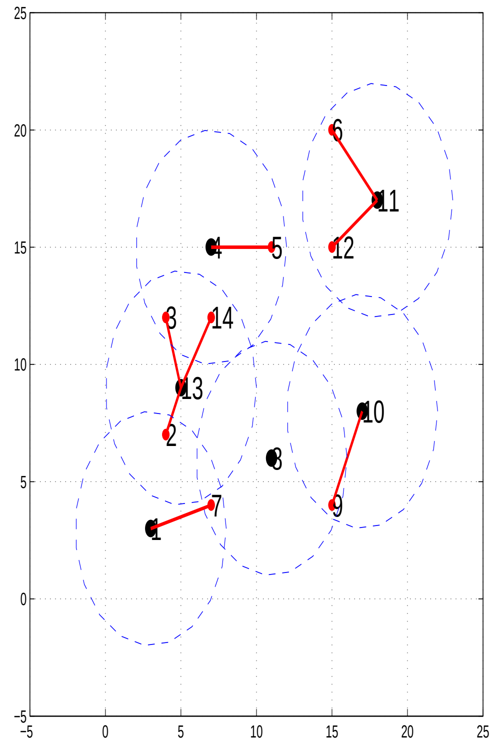

Figure 4: Clusters formed after simulating WCA

Number of sensor nodes (Input)	Number of clusters (Output)
8	4
12	4
14	5
16	6
18	8

Figure 5: Inputs and corresponding outputs of EEWCA

consumption for selection of cluster heads in mobile wireless sensor networks. The characteristics of sensor nodes including the power energy and the transmission rate are considered in the proposed algorithm. Experimental results have shown that the proposed algorithm behaves better than WCA on wireless sensor networks for long system lifetime. The proposed algorithm reduces the number of

Number of sensor nodes (Input)	Number of clusters (Output)
8	5
12	6
14	6
16	7
18	9

Figure 6: Inputs and corresponding outputs of EEWCA

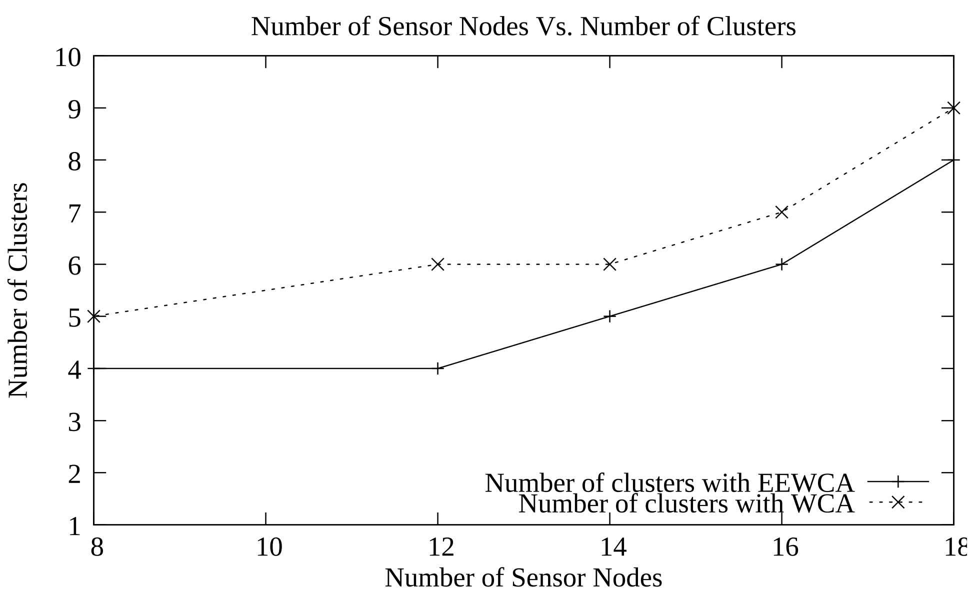

Figure 7: Performance of EEWCA and WCA

clusters compared to WCA for the same number of input sensor nodes. The average execution time of EEWCA is better than that of WCA when simulation runs are carried for different number input sensor nodes.

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Number of sensor nodes	Execution Time(Sec) (EEWCA)	Execution Time(Sec) (WCA)
8	0.309785	0.390993
12	0.284146	0.335276
14	0.314154	0.343704
16	0.309675	0.332417
18	0.340255	0.363349

Figure 8: Comparison of execution times of EEWCA and WCA