PECA: Power Efficient Clustering Algorithm for Wireless Sensor Networks

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ABSTRACT: *A wireless sensor network (WSN) is a form of network that consists of randomly distributed devices/nodes in a known space. In this kind of environment there are two major concerns that governs the efficiency, availability and functionality of the network, namely power consumption and fault tolerance. This paper introduces a new algorithm that is Power Efficient Cluster Algorithm (PECA). The main focus of the proposed algorithm is to reduce the power consumption required to setup the network since it is the stage where power is used the most. This is achieved by reducing the total number of radio transmission required for the network setup. As a fault tolerance approach, the algorithm stores some information about each node for easier recovery of the network should any node fails in the network. The proposed algorithm is compared with Self Organizing Sensor (SOS) algorithm; the result shows that PECA consume significantly less power than SOS.*

Keywords: Wireless Sensor Network, Power Efficient Cluster Algorithm, Self organizing sensor algorithm

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1. Introduction and Related Work

A wireless sensor network (WSN) is a form of network that consists of randomly distributed devices/nodes in a known space. Each node is typically equipped with radio transceiver, power source (usually a battery), processor, memory and/or other wireless communication device such as GPS receiver. WSN was originally developed for military purposes in the battle filed. For example in a rescue operation these sensors that can be dropped by an airplane prior the actual operation, can reduce the risk of the operations by having the rescue crew aware of the overall situation [1]. However, the development of such networks has encouraged the healthcare, industrial, environmental and other industries to utilize this technology. The size of each sensor node varies from 1 foot squared box to the size of a golf ball.

There are few challenges that faces the routing protocols, and hence the network formation in WSN. 1) Although in some applications the nodes' locations in Wireless Sensor Networks (WSN) is known and prefixed, however, the majority uses random distribution of nodes, which makes it difficult since the locations of the nodes are unknown. 2) The data flow from multiple nodes to a central base station. 3) Data redundancy since many nodes could sense the same phenomena and hence producing redundant data. 4) Last and most important of all, is the power constraint and the limitation of radio transmission and communications among the WSN nodes [1].

According to [1] power consumption in WSN is closely related to its architectural issues, that is 1) Network dynamics, 2) Network deployment, 3) Energy consideration 4) Data Delivery Model 5) Node Capabilities, and 6) Data aggregation. The WSN formation and setup has a great influence on power consumption and hence the network life time.

The main contribution of this paper is a new algorithm that significantly reduces the power consumption during the setup of a wireless sensor network, and hence prolongs the network life.

This solution relies on GPS technology to locate each node in the network. According to [14] this may be a limitation especially in the urban areas were GPS signals are estimated to be around 15-40% less accurate due to magnetic disturbances, masking, unfavorable error propagation and other line of sight limitations. On the other hand WSN is normally applied in areas where human intervention is not probable, therefore the urban areas limitation is considered a major limitation.

Normally WSN nodes are distributed in an environment in which usual maintenance of the node is very difficult or highly undesirable, therefore the power source within the node is only and most valuable resource since it cannot be replaced. Hence keeping the network alive by using minimum resources is a big challenge [12]. The transmission of data between WSN nodes consumes most of the node's power. One way to reduce this consumption is by grouping nodes into small groups within the transmission range of each node (cluster). Each cluster has a cluster-head that is usually at the center of the cluster radius and has the largest number of nodes within its transmission range [6]. Figure 1 illustrates clustering in WSN.

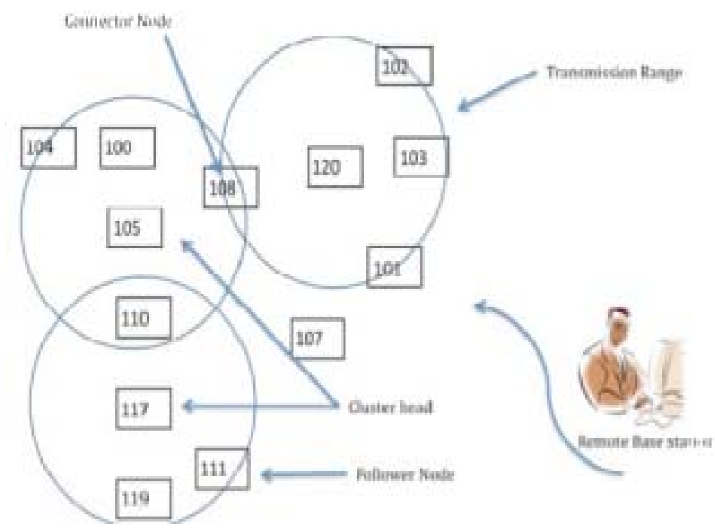

Figure 1. Example of WSN

The cluster approach normally puts a large constraint on the cluster head since it is the communication center, and hence loses its battery power rapidly [13]. The cluster algorithms in WSN aim to build the network in a way in which data can be transferred between the network and base station with minimum radio transmission to reduce power consumption, on the other hand good algorithms must also build the network with maximum fault tolerance rate possible, which is another challenge beside power consumption [8].

There are two main types of routing protocols in WSN, 1) the Data-Centric, and 2) the Clustering-Based approaches. The Data-Centric approach is reliable and robust solution to WSN, however despite many attempts to reduce the power consumption it is still power hungry approach, also due to its design it suffers relative delay in relaying the collected data to the base station. The clustering based approach on the other hand is more energy aware protocol, where many of the radio transmissions required in the data-centric approach is waved and compromised by a dedicated cluster node that forwards the collected data to another cluster node till the base station is reached [2].

Many algorithms were introduced in the literature for the clustering of WSN [13], for example, Low- Energy Adaptive Clustering Hierarchy (LEACH). This protocol is self-organizing, that uses the clustering techniques to form the network. The principle idea behind this protocol is the random rotating of cluster heads in the network, which is divided into two phases, namely, the setup and the transmission phases. The idea is to reduce the power consumption and prolong the lifetime of the network by reducing the load on the cluster heads that normally drain the power due to the overwhelming radio transmission [7].

Centralized Low-Energy Adaptive Clustering Hierarchy (LEACH-C) is very similar to the LEACH protocol except that the decision of the next round of cluster heads is instructed by the base station rather than the self re-organizing technique in LEACH. During the initial setup of the network the information regarding the location and power level of each node is sent to the base station. Unlike LEACH, the base station is in a position to form much more effective clusters since it has the advantage of the global knowledge of the network. For example the cluster heads in each round are optimal, whereas in LEACH varies from round to another because it does not have the global knowledge of the network [11].

Power Efficient Gathering in Sensor Information Systems (PEGASIS) protocol reduces the power consumption of WSN by forming "local collaboration" between sensor nodes. This protocol organizes the sensor nodes in a chain format where only one neighbor of the cluster is used to transmit the collected data. The next round, this neighbor is changed to the next in the chain, and so on. This will reduce energy by reducing the radio communication between the cluster heads and the neighbors [11].

Based Station Controlled Dynamic Clustering Protocol (BCDCP) protocol is similar to LEACH and LEACH-C in the sense that cluster heads function is rotated among nodes, and the base station is going to take a big portion of the rotating operations to reduce power consumption. Further, the cluster selection is performed by the level of power in each node. The nodes are grouped and sorted based on power level and then, the cluster head operation is given to the node with high power level. The remaining nodes (those were not selected as cluster heads) are passed through a simple algorithm of splitting mechanism to obtain the number of neighbors for each cluster head. This was proven to be more efficient than LEACH, LEACH-C and PEGASIS [11].

Algorithm for Cluster Establishment (ACE), uses a random function to select "candidate" nodes, further it depends on a manually adjusted parameters to control the creation of a new cluster [4].

Shin et al. [13] introduced the Self-Organizing Sensor (SOS) networks. This algorithm aims to reduce power consumption by minimization the number of Cluster Heads. Unlike ACE, SOS does not use manually adjusted parameters, the results of both algorithms were compared and SOS proven to be more efficient in terms of network formation. SOS does not consider problems such as fast dying clusters heads.

This paper introduces a new clustering algorithm that is using less radio transmission to form the clustering network than SOS, and hence the proposed Power Efficient Cluster Algorithm (PECA) will create a more power efficient WSN than SOS if both were applied to the same network.

2. Power efficient clustering algorithm

In order to define the research problem we need to establish few facts regarding WSN. First, WSN nodes are normally (as mentioned earlier) distributed in areas where human intervention is not probable.

Second, each node operates using a battery as the only source of power and therefore energy is precious. Third, the nodes are randomly scattered, therefore it is imperative to organize the communication between these nodes for the network to deliver its purpose. Forth, radio transmission is energy hungry process. Fifth, the initialization and setting up the network is the stage were power is significantly consumed. The challenge is to form a cluster network between these nodes with minimum radio transmissions in order to preserve energy and hence prolong the lifetime and efficiency of the WSN.

This algorithm aims to reduce the power consumed to setup a WSN, it accomplishes this by attempting to lower the total number of radio transmission transactions between the nodes at this stage. The contribution of this algorithm does not include the data transmission and routing protocols; it merely covers the power consumption during the very beginning of setting up the network and just before the actual data transmission.

2.1 PECA algorithm

The algorithm assumes the following

- The sensors are distributed randomly in a known sized field
- The nodes are of the same type in terms of radio transmission and battery power
- Each node has a built-in GPS receiver
- Each node has a unique numerical ID

In this section the proposed algorithm is illustrated using in Table 1 Follows is a description of each column

Step No: This shows the sequence order as the algorithm executes

Step Details: This illustrates a single process details of the algorithm

Step Result: This explains the output of the process just executed

Process type: This determines if the process is using the radio transmission or not.

Considering Figure 1 as an example of WSN distribution, Table 2 illustrates an example of the table created in node 105, the number between the {} represents the step number in Table 1. Note that the location parameters are just for illustration and are not real figures.

The table in each node (as illustrated in Table 2) has two sections, the self and neighbors information. The node ID is hard-coded and known to the node before deployment into the network. All other information are gathered and stored in the node's memory as the network gets formed.

Step No	Step details	Step Result	Process Type
1	Using the GPS receiver each node identifies its current position in the network	Each node stores its GPS format location in its own memory	Communication
2	Each node broadcasts its ID and GPS location to every node in its transmission range	Each node will have a table of IDs and locations of each node in its transmission range.	Communication
3	Each node calculates the number of its neighbors using the table created in step 1	The number of neighbors for each node is known and recorded in the node parameters	Processing
4	Each node broadcasts the number of its neighbors to every node in its transmission range	The table created in step 1 will have the number of neighbors of each node in its transmission range.	Communication
5	Each node Look-up the table (updated in step 3) and finds the largest number of neighbors for each node, if the node ID matches the largest number then it make itself as Cluster Head, otherwise it is a follower.	Each node will know if it is a cluster head or a follower.	Processing
6	Broadcast those collected information	The network is formed; each node status is updated accordingly. And the table is updated with the status of each node.	Communication
7	Look-up the table and see if there are 2 cluster heads in the table or more if yes change the status to a connector	The connectors are identified	Processing
8	Broadcast the new status to all its neighbors	The network is complete.	Communication

Table 1. Steps of PECA

Incase of a connector node such as node 110, its table would show that it has 2 cluster head nodes in its transmission range i.e. 105, and 117 and therefore it changes its status to connector. This scenario would determine all cluster heads, followers and connectors in the network, and each node would have enough information to transmit data across the network to the base station.

Node Parameters			
ID	105	Location {1}	E 208.456.88, N 048.56.87
Status {5}	Cluster Head	Neighbors {3}	4
Neighbors Parameters			
ID {2}	Location {2}	Neighbors {4}	Status {6}, {8}
108	E 208.456.89, N 048.56.88	3	Connector
110	E 208.456.90, N 048.56.89	3	Connector
100	E 208.456.91, N 048.56.90	3	Follower
117	E 208.456.92, N 048.56.91	2	Cluster Head

Table 2. Example of a table created in each node in PECA network

As indicated earlier each node (in PECA algorithm) has a unique absolute integer, this number is hard-coded into its memory. This unique ID serves two major purposes. One, it uniquely identifies a node among other nodes in the network. And two, it is used to decide which node gets to be the cluster head if two nodes have the same number of followers in their transmission ranges. In this case two nodes on the network has the same neighbors and consequently the same number of followers, therefore both nodes are a legitimate candidate to be the cluster head of the group. PECA, then checks to see the two nodes numeric unique IDs and promotes the higher ID node to be the cluster of that group. For example if the two nodes have the IDs 10, and 20, the node with ID 20 will be assigned to be the cluster head in that case.

2.2 Power consumption in WSN

This section aims to define how much a sensor consumes power? And how long does it last on average? Considering Mica2 sensor using two AA batteries. The specifications of any sensor include: range, transmit, receive and sleep current draw. Range is usually specified in meters and communication range is usually larger than the sensing range. Manufacturers usually specify how much current is drawn in every operation.

For example for Mica2: Transmit operation consumes 27 mA, Receive operation consumes 10 mA, and Sleep operation consumes 1 microA

On average 8 mA in active mode and 15 microA in Sleep mode. Now, let us assume that the sensor is always in active mode, how long would it last operating?

Each battery has a capacity that is measured in Wh (Watt hour) or Ah (Ampere hour) (1 Watt = 1 Joul / Second)

$$\text{Watt} = \text{V (volt)} * \text{A (current)}, \text{ hence} \quad \text{Wh} = \text{Ah} * \text{V}$$

Usually an AA battery has a capacity of 2100 to 2900 mAh (average of 2500 mAh) and is operating at 1.5 volt. This means that if we draw a constant current of 2500 mA (at a constant voltage of 1.5 V) from the battery it would die after one hour. However, if we consume a constant current of 1250 mA the battery would last for 2 hours.
Now since Mica2 is using one 1.5 v battery, this means that it would have a capacity of 2500 mAh (2500 mA ---> 1 hour) Now if we assume that we need to receive data all the time (receive current draw = 10 mA) this implies that the batteries would last for 2500 / 10 * 1 hour = 250 hours.

3. Comparing SOS with PECA

As illustrated in section 2, PECA stores a table in each node that holds information about all the nodes in its transmission range. SOS on the other hand does not, and this poses a dilemma in case of a crash. Hence, SOS would require establishing the network from scratch, which require many radio transmissions that is power hungry. Moreover not having a table such as PECA would eliminate the possibility of programming for each node individually.

PECA assumes that each node has a GPS receiver built-in; this is used to locate each node in the network, once they are disbursed in the field. This assumption was based on the fact that GPS technology is now available and feasible to be installed on the WSN nodes. The idea is that each node would broadcast its GPS location, and knowing the transmission radius of each node it is easier to identify the neighbors for each node and determine the cluster heads and connectors accordingly.
In PECA the number of radio transmissions to build the network is significantly less compared to those of SOS, nevertheless the number of cluster heads, connectors, and followers are the same. Moreover in SOS topology, it is required to do a number of iterations to find the cluster head to be accurate. As number of iteration increases, accuracy will increase.

To obtain accurate results when analyzing WSN algorithms, three major factors needs to be tested, namely 1) the number of nodes in the network, 2) the size of the area where the nodes to be disbursed, and 3) the transmission radius that each node is capable of communicating within. PECA was tested against SOS using these three factors as variables to study the impact of changing these values on the overall consumption of power. As mentioned earlier the radio transmission operation is the function that consumes most of the WSN nodes' power, hence we will use the total number of messages sent and received in each scenario to determine which algorithm is power efficient.

For example Table 3 shows the results of the test where the number of nodes in the network is variable i.e. 50,100 and 150, and the area and the transmission radius are constants. The "Total Send" and "Total Rcvd" parameters represent the total number of radio transmissions sent or received respectively in a given network by all nodes. The "AVG Send" and "AVG Rcvd" indicate the average radio transmissions sent or received for each node in a given network. And finally CH, CN and FN are the number of Cluster Heads, Connector Nodes and Follower nodes respectively after the network is created and the algorithm is terminated in a given network.

Constants: Area = 2000 * 2000, Radius = 200									
No	Nodes	SOS				PECA			
1	50	Total Send	203	AVG Send	4.06	Total Send	58	AVG Send	1.16
		Total Rcvd	129	AVG Rcvd	2.58	Total Rcvd	28	AVG Rcvd	0.56
		CH	42	%CH	85.2	CH	42	%CH	84.4
		FN	6	%FN	12.6	FN	7	%FN	15
		CN	1	%CN	2.2	CN	0	%CN	0.6
2	100	Total Send	391	AVG Send	3.91	Total Send	134	AVG Send	1.34
		Total Rcvd	313	AVG Rcvd	3.13	Total Rcvd	131	AVG Rcvd	1.31
		CH	73	%CH	73.1	CH	69	%CH	69.5
		FN	21	%FN	21.4	FN	28	%FN	28.5
		CN	5	%CN	5.5	CN	2	%CN	2
3	150	Total Send	573	AVG Send	3.82	Total Send	223	AVG Send	1.486
		Total Rcvd	550	AVG Rcvd	3.666	Total Rcvd	286	AVG Rcvd	1.906
		CH	95	%CH	63.4	CH	89	%CH	59.6
		FN	43	%FN	29.066	FN	53	%FN	35.666
		CN	11	%CN	7.53	CN	7	%CN	4.733
		CH	158	%CH	35.311	CH	143	%CH	31.911
		FN	177	%FN	39.422	FN	205	%FN	45.711
		CN	113	%CN	25.266	CN	100	%CN	22.377

Table 3. PECA & SOS comparison where number of nodes is variable

Based on the fact that radio transmission in a WSN is power hungry. The more radio transmission is required to setup a WSN, the more power is consumed. Hence, the tests that are carried out focus on the total number of radio transmissions sent and received from and to each node in the network in order to have a fully functional (ready for communication) WSN using both PECA and SOS algorithms. In this test PECA uses a significant less amount of power to construct the network than SOS, nevertheless the more nodes in the network the more power is required from both algorithms which is inevitable due to the complexity of the network as the number of nodes increases. The conclusion is then drawn to determine which algorithm is more power efficient in terms of setting-up a WSN based on the total number of radio transmission calculated upon the termination of each algorithm.

Another test was carried out where 200 nodes (constant value) are disbursed randomly in variable sized fields. The square areas of 500, 1000, 1500, and 2000 where used to examine the impact of area size upon the radio transmissions required and hence the power consumption. As the area increases both SOS and PECA consume less power, however, on average, PECA consume 50% less power than SOS in this test. Unlike PECA the average radio messages sent in SOS algorithm decreases as the number of nodes increases in the network, which is efficient. However the total number of radio transmissions is significantly less in PECA than SOS. This concludes that PECA consumes less power than SOS regardless of the number of nodes in the network.

The third important factor of determining power consumption within WSN is the transmission radius of each node in the network. Hence a third test was conducted where the transmission radius of each node varies from 25 to 100 divided on 4 tests. SOS algorithm consumes less power as the transmission radius of the node increases; on the other hand PECA consumes more power as the transmission rate of each node increases. However, the overall number of radio transmissions required to setup the network is significantly less in PECA than SOS. That was evidenced even with the largest radio transmission radius tested. Therefore this test concludes that PECA is more power efficient. Moreover it is very unlikely to have a node in the WSN that has a very large transmission radius that would make a significant difference in the obtained results.

Table 4 summarizes the comparison results between SOS and PECA algorithms in terms of power consumption. The rate was calculated using the total number of radio transmission (sent and received) required for each scenario. For example, SOS would require 5 times the power required for PECA to establish a WSN where the area = 2000*2000, transmission radius = 200 and there are 50 nodes in the network. As illustrated in the table, PECA power efficiency rate varies from 2 to 10 which is a significant deference where power is precious. In general SOS tend to gain efficiency as the number of nodes, transmission radius, or the network area increases. However in its best case scenario (according to the tests conducted in this paper) SOS consumes twice as much energy to setup the network.

Test description	Variable Value	SOS:PECA
Variable Number of nodes Constants: Area = 2000 * 2000, Radius = 200	50	5:1
	100	3:1
	150	2:1
Variable Transmission radius Constants: Area = 2000*2000, Nodes = 200	25	5:1
	50	4:1
	75	3:1
	100	2:1
Variable size of Network area Constants: Radius = 200, Nodes = 200	500*500	7:1
	1000*1000	10:1
	1500*1500	2:1
	2000*2000	2:1

Table 4. Power efficiency rate between SOS and PECA

As mentioned earlier, if 2 nodes have the same number of followers within their transmission range, PECA would promote the node with the higher ID to be a CH, and demote the other to be FN. During the development of this scenario, few tests were conducted and the results were compared to those of SOS, and the results were indeed interesting.

Although PECA required more radio transmissions (compared to the tests above) to overcome this dilemma, it was evidenced that PECA is more reliable than SOS. The empirical results showed that PECA generated more clusters yet more connector nodes and hence higher availability rate of the network.

We believe that the late experiment is a great opportunity for future and further research of PECA algorithm. In this paper the main concern was to reduce the power consumption (as illustrated in details above), however the above results could be used so PECA could have a high level of fault tolerance as well as being power conservative.

4. Conclusion

This paper introduces a new cluster algorithm that aims to reduce the power consumption in WSN. The results of the proposed algorithm (PECA) were compared to those of SOS and the following were concluded. First, PECA incorporates the GPS technology (which is feasible nowadays) to locate a node in the network and saves significant amount of radio transmission used to form the network if compared to SOS algorithm. Second, the distance between cluster heads in PECA are not maximized; hence less energy is required than SOS to communicate between cluster heads. Third, in order to achieve its goal of having the least number of cluster heads in the network, SOS algorithm minimized the distance between CH, which results in less connector nodes between clusters and consequently less reliable network. PECA on the other hand does not minimize the distance between cluster heads, yet they have slightly the same number of CH, and consequently more connectors in the network.

The table formed and stored in each node in PECA opens a great opportunity to enhance the routing protocol in WSN. This is planned to be the future research of this paper.

Relying on GPS receivers to locate the node in the network poses a limitation, that is, all nodes in the network must have clear eyesight to the sky, and hence PECA algorithm would not operate in closed environment applications.

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