A mini Survey on Energy Efficient Clustering in Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) are composed of large number of sensors equipped with battery that has limited energy. In order to increase the lifetime of sensor nodes and to reduce the energy consumption clustering techniques have been used from last two decades. Resent development in wireless communication technology like 3rd Generation Partnership Project Long Term Evaluation (3GPP LTE) and Long Term Evaluation Advance (LTE-A) the application of Wireless sensor networks (WSNs) is increased. With the development of future fifth generation (5G) cellular network, IEEE 802.16e and IEEE 802.16m energy harvesting of sensor become very important. This paper presents a detail survey of two most used clustering algorithms Low Energy Adaptive Clustering Hierarchy (LEACH) and Hybrid energy efficient distributed (HEED) and some existing clustering protocol based on LEACH and HEED.

Keywords: *LEACH, HEED, Clustering, WSNs.*

1. Introduction

With development of wireless communication technology such as 3rd Generation Partnership Project Long Term Evaluation (3GPP LTE) and Long Term Evaluation Advance (LTE-A), fifth generation (5G) cellular network, IEEE 802.16e and IEEE 802.16m the development of wireless sensor networks (WSNs) becomes more fascinating for improving the living standard of people. Wireless sensor networks (WSNs) are composed of densely distributed micro devices embedded with wireless connectivity, signal processing and sensing ability called sensor, that are used to monitor the information and send the information to base station (BS). Life of sensor node depends on life of battery. Removal of dead node cause changes in topology and may require re-routing of packet. As a result energy management is important issue in designing WSN, sensor node and communication protocol.

In clustering technique sensor nodes (SNs) are divided in groups called cluster. In each cluster a cluster Head (CH) is elected, which is responsible of generating transmission schedule, gathering data from sensor and transmit the aggregated data to the BS. The process of electing CH is called clustering. The requirement of efficient clustering is that all the clusters are of same size and CH are present at the centre of cluster. Some of the existing survey papers for clustering in WSNs of the last few years are given in table 1. In the next section survey of various clustering techniques are given. In section 3 various criteria are discussed for measurement of performance of clustering algorithms and section 4 comparative analysis of clustering algorithms based on some parameter are conducted. Finally conclusion is given in section 5.

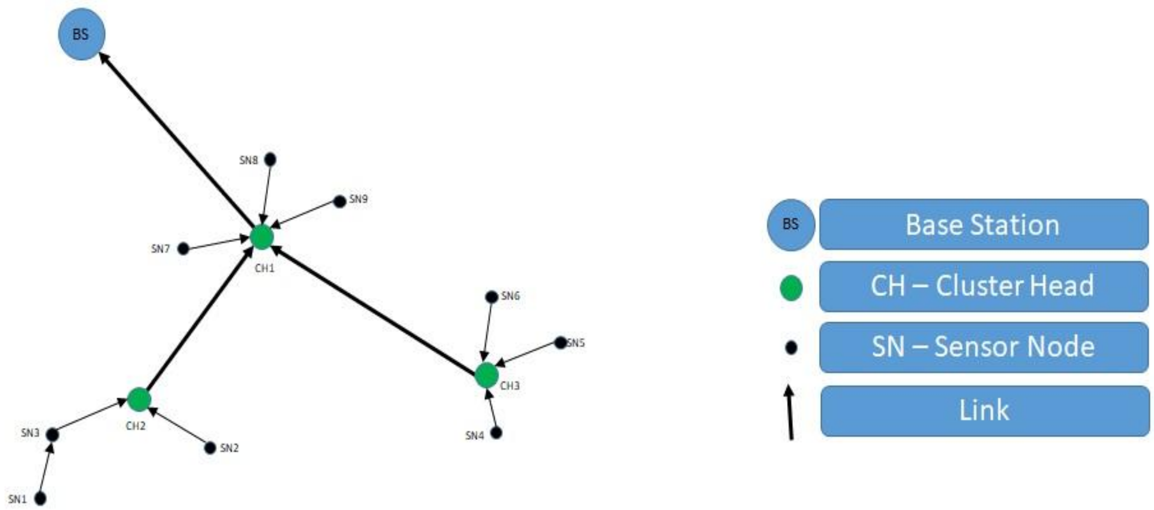

Figure 1. Example of clustering in WSN

Figure 1. Shows the example of clustering in WSN containing three cluster head (CH1, CH2 and CH3) and nine sensor node (SN1, SN2, SN3…SN9) and a base station

Table 1. Survey papers for clustering in WSNs

year	Author name	Title of paper
2010	(Hosseinzadeh & Alguliev, 2010)	Hierarchical routing in wireless sensor networks: a survey
2011	(Boyinbode, Le, & Takizawa, 2011)	A survey on clustering algorithms for wireless sensor networks
2012	(Liu, 2012)	A survey on clustering routing protocols in wireless sensor networks
2014	(Afsar & Tayarani-N, 2014)	Clustering in sensor networks: A literature survey
2015	(Liu, 2015)	Atypical Hierarchical Routing Protocols for Wireless Sensor Networks: A Review
2017	(Xu, Collier, & OHare, 2017)	A Survey of Clustering Techniques in WSNs and Consideration of the Challenges of Applying Such to 5G IoT Scenarios

2. Clustering Algorithms

In this section, survey on comprehensive survey on Low Energy Adaptive Clustering Hierarchy (LEACH), Stable Election Protocol (SEP), Hybrid energy efficient distributed (HEED), Power-efficient gathering in sensor information systems (PEGASIS), Concentric clustering scheme (CSS) and Balanced Energy-Efficiency (BEEM) clustering algorithm clustering algorithms are presented.

2.1 Low Energy Adaptive Clustering Hierarchy (LEACH)

LEACH developed by (Heinzelman, Chandrakasan, & Balakrishnan, 2000) is clustering protocol that increases networks lifetime by periodic re-clustering. The operation of LEACH consists of rounds. Each round is divided into two phase: Cluster setup and steady state phase.

2.1.1 Cluster Setup Phase

In cluster setup phase CH election, Cluster formation and Time Division Multiple Access schedule (TDMA) schedule are performed by CH. These operations are as follows:

CH selection: Each SN selects a random number between 0 and 1. If the generated random number of a SN is less then threshold value $T(n)$ of any node then the SN is elected as CH. The value of $T(n)$ is calculated using equation 1.

$$T(n) = \begin{Bmatrix} \frac{p}{1-p\left(r-mod\,\left(\frac{1}{p}\right)\right)} \\ 0 \end{Bmatrix} \qquad \begin{matrix} : if\ n\ \in G \\ : otherwise \end{matrix} \tag{1}$$

Where p is the desired percentage of SN to become CH, r is the current round and G is the set of SN that have not been elected as SN in previous $\frac{1}{p}$ rounds. If a SN becomes a CH it cannot become CH until remaining member of cluster becomes CH. As r gets closer to $\frac{1}{p}$ the SN that have not been elected as CH in previous $\frac{1}{p}$ has greater chance of becoming CH. Thus, in $\frac{1}{p}$ every node of cluster will become CH.

Cluster formation: After the CH is elected it broadcast Advertisement message to all the SN, if a SN receives more than one Advertisement message it sends a join message to become the member of cluster depending on signal strength of Advertisement message of CH.

Assignment of TDMA: Once the clusters are created and each CH identifies their member, in order to avoid collision of data by SNs, CHs creates Time Division Multiple Access schedule (TDMA) and transmit it to their member. TDMA schedule is broadcast back to cluster to tell each node when it can transmit.

2.1.2 Steady State phase

In steady state phase TDMA schedule is used for transmission of data from SN to CH and from CH to BS are performed. These operations are as follows:

Data transmission from SN to CH: Members of cluster transmit data to their CH in their allotted time slot. In order to increase the life time only one SN sends data to CH during its allotted time, other members of cluster are in sleep state at that time. This reduces collision of data among SN and energy dissipation.

Data transmission from CH to BS: After the CH receives data from all the SNs of cluster, the CH aggregates the data and sends the data to BS. Carrier Sense Multiple Access (CSMA) protocol is used to send data from CH to BS.

2.2. Stable Election Protocol (SEP)

SEP proposed by (Smaragdakis, Matta, & Bestavros, 2004) is an extension of LEACH. It was designed for heterogeneous WSN that uses two levels of heterogeneity, normal node and advance node. SN with higher energy level is known as advance nodes that have higher probability of becoming CH. In SEP the CH election process is based on weighted probability of SN. The weighted probability of normal node p_{nrm} and advance node p_{adv} are calculated using equation 2 and 3 respectively.

$$p_{nrm} = \frac{p_{opt}}{1+\alpha m}, \tag{2}$$

$$p_{adv} = \frac{p_{opt}}{1+\alpha m}\,(1+\alpha) \tag{3}$$

Where, m is fraction of advanced nodes and α is additional energy factor between advanced and normal nodes, p_{opt} is optimal probability of SN to become CH and its value is given by.

$$p_{opt} = \frac{k_{opt}}{n}$$

Where k_{opt} is number of CH per round.

2.3 Hybrid Energy Efficient Distributed (HEED)

HEED proposed by (Lin & Tsai, 2006) is based on LEACH but the selection of CH is based on high residual energy. The CH election process is divided into number of iteration and in each iteration SN which are not covered by any CH double their probability to become CH. In each CH election process the CHs are classified into two types: *tentative* and *final* CHs. Initially some SN are selected tentative CH randomly. The probability to become CH is calculated using equation 4.

$$CH_{prob} = C_{prob} \; \frac{E_{residual}}{E_{max}} \tag{4}$$

Where, CH_{prob} is the probability that the SN will become CH, C_{prob} is the probability that the SN will elect itself as CH; it is only used to limit the number of CH. $E_{residual}$ is the residual energy remaining if the battery currently and E_{max} is initial energy of battery. A SN considers itself covered if it receives advertisement message from either *tentative* or *final* CHs. If a SN is not covered by any CHs and it's CH_{prob} is higher than a randomly generated number, it will elect itself as a tentative CH. If it's CH_{prob} reaches to 1 and is still not covered by any *tentative* of *final* CHs, claims itself final CH and broadcast advertisement message. A *tentative* CH becomes *final* CHs if C_{prob} reaches to 1. If a SN completes its execution and is not covered by any *final* CHs, it claims itself final CH. the steady state phase is same as in LEACH.

2.4. Power-efficient Gathering in Sensor Information Systems (PEGASIS)

PEGASIS proposed by (Lindsey, Raghavendra, & Sivalingam, 2002) is improved version of LEACH instead of forming cluster it forms a chain of SN. A SN communicates with its left and right node. The data transmission takes in one direction from one node to another forming the chain. Each SN aggregates the collected data with its own data and sends it to neighboring node. If SN receives data from both of its left and right neighboring node is elected as CH and it will transmit the data to BS.

2.5. Concentric Clustering scheme (CSS)

CSS proposed by (Jung, Han, & Chung, 2007) improve the energy efficiency of PEGASIS. Considering BS as center of network each SN assigns itself a level depending on signal strength received from BS the level number increases with the increase of the distance to the BS. For each level the SN aggregates the collected data with its own data and sends it to neighboring node as in PEGASIS. The CH transmits the aggregated data the CH of one level lower CH.

2.6. Balanced Energy-Efficiency Multihop (BEEM) clustering algorithm

BEEM proposed by (Xu, O'Hare, & Collier, 2014) and smart BEEM by (Xu, O'Hare, & Collier, 2017) is based on HEED, CH_{prob} is calculated considering node density using equation 5.

$$CH_{prob} = C_{prob} \; \frac{E_{residual}}{E_{max}} * min\left(\frac{Node\ Degree}{D_{avg}}, 1\right) \tag{5}$$

Where D_{avg} is average density of network and is calculated using equation 6

$$D_{avg} = \pi\, r^2 \; \frac{Num_{sensor}}{Area} \tag{6}$$

r, is the default communication range of the SNs (normally it is set to the cluster radius), Num_{sensor} is the total number of SNs in the network and *Area* refers the area covered by SN. D_{avg} is also the value for average node degree. To reduce the number of rounds, equation (5) is divided into three parts: randomly (C_{prob}), residual energy $C_{en} = \frac{E_{\text{residual}}}{E_{max}}$ and node density $C_{de} = min\left(\frac{Node\ Degree}{D_{avg}}, 1\right)$ to decompose the probability to become CH, and three conditions that are used to determine whether SN can elect itself *tentative* or *final* CH are:

1) $C1 = \langle (Random\ (0,1) \leq C_{prob}) \rangle$
2) $C2 = \langle \frac{E_{\text{residual}}}{E_{max}} \geq 1 \rangle$
3) $C3 = \langle \frac{Node\ Degree}{D_{avg}} \geq 1 \rangle$

After each round, value of C_{en} and C_{de} are doubled respectively. A SN will not participate in CH election process when value of either C_{en} and C_{de} reaches 1.

3. Performance Measurement criteria

In this section various parameter are discussed by (B, Soni, & Tyagi, 2015) are used for performance evaluation of clustering algorithm.

Network Lifetime: time interval from the beginning of network till the first SN of networks runs out of energy.

Energy efficiency: using less energy to perform the operation.

Throughput: total number of packets successfully delivered.

Number of Alive node per round: total number of nodes that has not runs out of energy in each round.

Number of Cluster Head per round: total number of nodes that are elected as CH in each round.

Network Latency: amount of time required to travel a message from source to destination.

Reliability: ability to deliver packets without failure.

4. Comparative Analysis

In this section, the performance of different protocols is compared on parameters like Network Lifetime, Energy efficiency; Network Latency and throughput etc. are presented in table 2.

Table 2. Comparison for different types of clustering in WSNs

Algorithm	Distributed	Network Lifetime	Energy Efficiency	Through-put	Number of Alive node	Reliability	Cluster stability	Network Latency
LEACH	Yes	Low	Low	Low	Low	No	Low	High
SEP	Yes	Moderate	Moderate	Low	Low	No	Moderate	Low
HEED	Yes	High	High	High	High	No	High	Low
PEGASIS	No	Low	Low	Low	Low	No	Low	High

CSS	No	Low	Low	Low	Low	No	Low	High
BEEM	Yes	High	Very high	High	High	Yes	High	Low

5. Conclusion

In this paper survey of various clustering algorithms are performed and the two algorithms LEACH and HEED are explained in detail. It also gives comparison of various clustering algorithms on parameters like Network Lifetime, Energy efficiency; Network Latency and throughput etc. This survey may provide researcher some help and motivate them for future work and improvement in existing clustering algorithms. The development of future fifth generation (5G) cellular network, IEEE 802.16e and 802.16m has made energy harvesting of sensor very important As the clustering reduces energy consumption of WSNs there will be always research scope in energy efficient clustering.

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