



The Third Information Systems International Conference

Comparison on energy-efficient cluster based routing algorithms in wireless sensor network

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Abstract

Wireless sensor networks (WSNs) nowadays considered as a hot research topic because of its wide range of applications in various fields. Recently, advancement in electronic communications has led to multi-purpose sensor nodes with low-cost and power consumption. Wireless sensor networks are composed of limited power sensors, which their power supply could not be replaced or recharged. So, less power consumption will increase the lifetime of these networks. Therefore, providing efficient routing algorithms with less energy consumption is desirable. Among many routing algorithms, approaches based on clustering, result less energy consumption. In this article, all well-known routing algorithms based on clustering which focus on saving energy got reviewed. Each algorithm is described in detail and its pros and cons are discussed explicitly. Then some important metrics such as scalability, message overhead and algorithm complexity are used for comparing cluster-based algorithms and give an insight to challenges in this field.

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Peer-review under responsibility of organizing committee of Information Systems International Conference (ISICO2015)

Keywords: Wireless sensor networks, energy consumption optimization, Clustering algorithms, Clustering based routing;

1. INTRODUCTION

Advances in wireless sensor networks and its applications such as medicine, agriculture, military, environmental monitoring, tracking purposes and etc., has led to introduction and development of wireless sensors with low-cost and power consumption [1-3]. Wireless sensors are powered by battery and since most of wireless sensors are distributed in hostile environments, it is impossible for humans get access to them. Besides that, inexpensive sensors and non-rechargeable battery result in emerging energy-efficient routing algorithms [4-6]. Lack of energy will enforce the nodes to getting die and useless and finally this phenomenon causes failure of the whole network goals. If all nodes of the network start to send and receive data directly, this strategy causes a rapid depletion of energy [7, 8]. This fact makes energy of each sensor node is a major constraint [9, 10]. The main objective of routing algorithms in wireless sensor network is defining an energy-efficient and reliable route for data from sensors to the base station [11, 12].

In this article, cluster based routing algorithms which had been proposed in recent years and aimed to reduce energy consumption and leads to an increase in network lifetime and scalability are surveyed.

2. ALGORITHM BASED ON CLUSTERING

Routing techniques based on clustering, potentially are the most effective way to reduce energy consumption in wireless sensor networks and have been widely being used recently [13-17]. This section will give an introduction for these algorithms and describe in detail their advantages and disadvantages.

1) *LEACH*^b, *LEACH-C*^c

Hitherto, many clustering algorithms have been proposed to optimize energy consumption and LEACH hierarchical algorithm was the most famous one. This algorithm played an important role for development of new algorithms [18]. In this algorithm cluster heads are selected randomly and after determination of cluster heads, any non-clustered node choose its cluster head based on its distances. With respect to problems of this algorithm which are, non-uniform distribution of cluster heads and choosing cluster-head randomly without considering the remaining energy of cluster head, LEACH-C algorithm proposed [19]. In this algorithm formation of clusters is performed in centralized manner and done by the base station. In LEACH-C, base station should guarantee uniform distribution of energy among all the clusters. To this end the algorithm defines a threshold for energy and each node that has more energy than the threshold will be candidate for being clusters head.

2) *TEEN*^d

This algorithm is one of hierarchical algorithms which were introduced for the reactive sensor network and is based on LEACH algorithm. The clustering process use two thresholds named soft and hard threshold. The aim of this threshold is reducing transmitted amount of data between nodes. Hard threshold is one of the rules for transmitting. If the value obtained from a sensor is greater than this threshold, the data will be sent. Otherwise, information is not sent to the base station. Soft threshold is a threshold that gives the algorithm more flexibility. In one scenario if the value of one node is less than the hard threshold but the difference between two recently values of the node is more than the Soft threshold, data will sent to the base station [20].

3) *EEHC*^e

EEHC is a distributed randomly clustering algorithm for heterogeneous wireless sensor environments. In this algorithm cluster heads collecting data from other nodes in different clusters and after aggregation sends them to the base station [21]. This algorithm consists of two phases called Initialization and Development.

At the first phase which called cluster in the unit level, each sensor node announces itself as a cluster head with probability P to its neighboring nodes in communication range. This node called a candidate cluster head. All nodes which are in K step range of the node, receive wide range of this announcement for being cluster head. Each node has received such message and it's not a cluster head, joins to the nearest cluster.

In the second phase, which is called multi-level clustering, hierarchy clustering levels are created. In fact second phase of the algorithm guarantees reduction in energy consumption by clustering nodes which are far from the base station and uses intra cluster communication instead.

^b Low-Energy Adaptive Clustering Hierarchy

^c LEACH-Centralized

^d Threshold sensitive Energy Efficient sensor Network

^e Energy Efficient Heterogeneous Clustered

4) *DDAR*^f

This algorithm uses a dynamic approach for choosing cluster heads. Also DDAR uses two-level hierarchical clustering, (CH and SCH^g are the closest nodes to sink station) for energy consumption. In this algorithm energy consumption is 15.5% less than the LEACH protocol. Dynamic selection of cluster heads can reduce unnecessary cluster heads selection. More than that when a large number of nodes in the network are dead, network can pursue its job even with low number of alive nodes. In addition, to reduce energy consumption of cluster heads that are far from the base station, the algorithm uses the average distance from the node to the base station for selecting cluster heads. Nodes which are far than the average distance will not be selected as a cluster head. In fact, SCH is suitable for saving energy of cluster heads which are far from base station [22].

5) *WCA*^h

WCA algorithm is another clustering algorithm. In this algorithm cluster head selection depends on the degree of node, node speed, distance to neighbors, remaining battery lifetime and the period time which a node was a cluster head. Respect to these parameters each node assigned a value. Then the node broadcasts the values as its weight to all other nodes and the node will be selected as the cluster head that its weight is the highest among its neighbors. Otherwise, the node joins as a member to neighbor cluster. In this algorithm the size of cluster is considered limited to saving energy [23].

6) *ACT*ⁱ

ACT Clustering algorithm tuning the cluster size and transmission range [24]. The algorithm considers the network topology into separated levels. Cluster size in each level is equal but this size is different from clusters at other levels. This algorithm assumed that sensor nodes contain the same initial energy and cluster sensor network in three phases: Setup, data transfer and maintenance of cluster.

Setup phase: In this phase base station divide network topology into K level. Clusters near the base station are considered as the smallest cluster and the clusters that are farthest away from the station are considered as the largest cluster. Then at this stage, base station calculates the radius of clusters, number of levels and select cluster heads based on their placement in an ideal location (which ideal location is usually the center of the cluster).

Data transfer phase: After setting up the cluster, cluster heads are collecting and aggregating data. For data transmission a cluster head aggregate data at high level and send it to next cluster head at a lower level and this process continues until the data transferred to the station.

Cluster maintenance phase: This step is used for avoiding multi clustering in each round and for necessary migrate cluster heads between other nodes. Additionally, this phase decided the level of cross-sectional data. In cluster head migration, if the energy of cluster head in each cluster reaches a certain threshold (I.e. 15% of its primary energy) another node in the same cluster (which is close to the ideal point) will be selected as a new cluster head. During this migration, a message will be broadcast changes in cluster head. In the cross-section data, whenever the base station determine that each node in the first level cannot serve as cluster head, the base station do broadcast message that means permit cluster heads in the second level to transfer data directly to the station, (this approach also applies to the other levels).

7) *HCTE*^j

The algorithm take advantages of two cluster head for balancing energy in each cluster. Each of these cluster heads in each cluster is responsible for different tasks. Also, this algorithm use multi-hop transfer

^f Dynamic clustering and Distance aware Routing

^g Super Cluster Head

^h Weighted Clustering Algorithm

ⁱ Arranging Cluster sizes and Transmission ranges

^j Hierarchical Clustering based routing algorithm with applying the Two cluster heads in each cluster for Energy balancing

mechanism for routing data from cluster head to the base station [25]. HCTE algorithm consists of five phases:

Phase 1: This Phase using a method similar to cluster head selection in HEED algorithm (based on a probability of remaining energy) [26]. (The cluster head is used for intra cluster communication).

Phase 2: This phase the formation of clusters is completed and each node tries to find the best cluster head for joining. To this end, every node computes itself confidence level based on perch transfer within the cluster head and competes with other nodes and according to its highest confidence join to the cluster head.

Phase 3: In this phase, the second cluster head got announced. All nodes in the cluster competing with each other based on self-confidence value and finally node with the highest confidence value introduces itself as the second cluster head. (The cluster head is used for inter communication usage).

Phase 4: This step is schedule data transmission which is similar to LEACH algorithm. Both of them use time division multiple access for data transmission.

Phase 5: This step is using multi-hop data transfer.

The network lifetime is 35% longer than LEACH because exploit multi-hop data transfer and hence prevent unbalanced energy consumption.

8) *CCM*^k

This algorithm is a combination of chaining and clustering[27]. In fact, the CCM combines the advantages of both algorithms PEGASIS [28](where the nodes at the level as they were connected to each other like a chain and the last node is connected to the base station) with low energy consumption and LEACH with low delay in the transmission of information. In this algorithm, nodes are considered homogeneous.

This algorithm consists of three phases are formed: creating cluster, creating chain and data transferring.

Phase 1: Each node sends its position to all neighbors in the radio range R. Each node computes own weight (that is, its inverse-distance to other nodes in its neighborhood) and based on this computation the cluster heads are elected. Then the normal nodes join them based on their distance from the cluster heads.

Phase 2: Chain is formed in each cluster. The farthest node in the cluster to the cluster head is selected as the first node of the chain. Then nodes join to each other based on the distance and finally, the nearest node to the cluster head will be joined.

Phase 3: In this phase cluster chain re-formed based on cluster heads distance to the base station and data transmitted through this chain. It considered that farthest head from basestation as the first node of the chain and the nearest one as the last node.

9) *LEACH-VF*^l

LEACH-VF is a hybrid algorithm of LEACH algorithm and virtual forces idea [29]. In this algorithm virtual forces applied to each cluster nodes to the move sensor in a way that maximize the coverage area and minimize energy consumption. LEACH-VF uses two types of virtual force: Attractive force and Repulsion force. Attractive force causes the nodes move towards the cluster head in order to reduce energy used for communication. Repulsive force eliminates overlapping in clusters which maximize coverage area. This algorithm consists of three phases:

Phase 1: Setup and formation of clusters which are very similar to LEACH approach.

^k Chain Cluster-based Mixed

^l LEACH with Virtual Force

Phase 2: Calculation of energy and virtual displacement in sensor nodes.

Phase 3: data transmission, which is the same as LEACH.

10) SLGC^m

In SLGC the network seen as a grid. In this algorithm cluster heads are selected based on calculating the center of gravity (distance from each other) and the node's energy threshold for the current round and the next round. Select cluster heads for the next round leads to reduce the volume of messages that in each round is used for control and acknowledges nodes to send data to the cluster head. This algorithm increases the network lifetime and reduces energy consumption [30].

11) MWBCAⁿ

MWBCA algorithm uses weighting function for clustering [31]. The function is a linear combination of the power transmission, remaining energy of node, the number of neighbors and durations that the node was cluster head. Each node broadcast its aggregated weight to neighbors and a node with minimum weight will be selected as the cluster head. The algorithm avoid node of premature death due to excessive energy costs, elected all nodes alternately as a cluster heads. Nodes with higher residual energy are more probability to become cluster heads.

3. Comparison of clustering algorithms

In this section, algorithms that have been proposed in pervious section are compared with each other based on important features of clustering algorithms. In Table 1 shown comparison of these algorithms. Also in Table 2 shown advantages and disadvantages of them.

4. Conclusion

One of the most important issues in sensor networks is optimal use of resources in the network. Because in these networks, usually replacement of energy supply and reusing of a node is not affordable or is in environments where there is no possibility of exchanging. Therefore, saving energy consumption in each node will significantly reduce the cost of network maintenance and increases lifetime of the network. Cluster-based routing scheme is an efficient method which uses less energy through aggregation and data combination to reduce the number of messages sent to the central station. In this article cluster-based routing methods have been reviewed and finally these methods are compared and evaluated.

Table 1: Comparison of Different Clustering Routing Protocols in WSNs

	Scalability	Transmission delays	Distribution nodes	Control message overhead	Uniform distribution of energy	Energy efficiency	Inter cluster structure	Algorithm complexity	Clustering Structure
LEACH	Very Low	Very Low	Randomly	Low	Very Low	Very Low	1-Hop	Very Low	Hierarchically
LEACH-C	Very Low	Very Low	Randomly	Medium	Medium	Low	1-Hop	Low	Hierarchically
TEEN	Low	Low	Randomly	Low	Medium	Very High	multi-hop	High	Hierarchically
EEHC	Very Low	Very Low	Randomly	Low	Low	Low	1-Hop	Low	Hierarchically
DDAR	Medium	Low	Randomly	High	Medium	Medium	multi-hop	Medium	Hierarchically

^m Select Grid Clustering

ⁿ Multi-Weight Based Clustering Algorithm

	Scalability	Transmission delays	Distribution nodes	Control message overhead	Uniform distribution of energy	Energy efficiency	Inter cluster structure	Algorithm complexity	Clustering Structure
WCA	Medium	Low	Randomly	Very High	Medium	Very Low	multi-hop	High	Hierarchically
ACT	Very Low	Low	Uniform	Very High	Medium	Medium	multi-hop	High	Hierarchically
HCTE	Very Low	Very Low	Randomly	Low	High	Very Low	multi-hop	Medium	Hierarchically
CCM	Very Low	Low	Grid	High	Medium	Very Low	multi-hop	Medium	Hierarchically
LEACH-VF	Very Low	Very Low	Randomly	Low	Low	Low	multi-hop	Medium	Hierarchically
SLGC	Very Low	Very Low	Randomly	Low	Medium	Medium	multi-hop	Medium	Grid base
MWBCA	Very Low	Very Low	Randomly	High	High	Medium	multi-hop	Medium	Hierarchically
PEGASIS	Very Low	Very High	Randomly	Medium	High	Low	1-Hop	High	Chain base
HEED	Very Low	Medium	Randomly	Medium	Medium	Medium	1-Hop multi-hop	Medium	Hierarchically

Table 2: Advantages and Disadvantages of Different Clustering Routing Protocols in WSN

	Advantage	Disadvantage
LEACH	<ol style="list-style-type: none"> 1. Reduce the control messages overhead 2. Low complexity algorithm 	<ol style="list-style-type: none"> 1. Non-uniform distribution of cluster heads 2. Select the cluster head without considering the remaining energy 3. Send data in 1-Hop
LEACH-C	<ol style="list-style-type: none"> 1. Optimal number of clusters 2. Uniform distribution of cluster heads 3. Select the cluster head based on the residual energy 	<ol style="list-style-type: none"> 1. Send data in 1-Hop
TEEN	<ol style="list-style-type: none"> 1. Control over the useful data transfer 2. Suitable for time-critical applications 	<ol style="list-style-type: none"> 1. Unsuitable for periodic report requiring applications 2. Ability to waste time slots (base station may not be able to detect the number of live and dead nodes because it could only if the threshold-specific data are send) 3. If the cluster heads in the communication range of each other, they may have lost, because publishing is done only by cluster heads
EEHC	<ol style="list-style-type: none"> 1. Nodes are considered heterogeneous in terms of energy 2. Consider residual energy of cluster head for selection 	<ol style="list-style-type: none"> 1. Cluster heads Send data in 1-Hop
DDAR	<ol style="list-style-type: none"> 1. Dynamic adjustment of the number of cluster heads 	<ol style="list-style-type: none"> 1. The need for real-time protocol for measuring data continuously
WCA	<ol style="list-style-type: none"> 1. Cluster size limitation 2. Node tries to re-connect to the cluster head only if disconnected. 	<ol style="list-style-type: none"> 1. Need to know the weight of nodes 2. Each node needs to store all data nodes, before initialize network 3. Excessive amount of computing and communications, and energy consumption 4. The overhead of data collection and rapid death of the cluster head node 5. Instability in the network topology
ACT	<ol style="list-style-type: none"> 1. Choose the size of clusters according to their distance from the station (to reduce the cluster head near the station) 2. Increase energy of cluster head close to the station for inter communications cluster-head 3. A uniform distribution of energy consumption intra cluster heads 4. Avoid clustering in each round 	<ol style="list-style-type: none"> 1. The problem in addressing coverage of wireless network
HCTE	<ol style="list-style-type: none"> 1. Uniform distribution of energy 	<ol style="list-style-type: none"> 1. Low scalability

	Advantage	Disadvantage
CCM	1. Reduce high overhead for choosing cluster head selection compared to LEACH 2. Long transmission delay reduction compared to PEGASIS	1. High transmission delay if it does not support the CDM 2. Unsuitable for large-scale networks
LEACH-VF	1. Non overlap in the Coverage 2. Non holes In the Coverage	1. Low energy efficiency 2. Non uniform distribution of energy
SLGC	1. Reduce the control messages overhead	1. Non energy efficiency in small-scale networks
MWBCA	1. Uniform distribution of energy	1. High control messages overhead to form the selection of a suitable cluster head
PEGASIS	1. Uniform distribution of energy conception 2. Reduce overhead by dynamic clustering	1. Long delay in sending information 2. Weak scalability 3. Requires a general knowledge of the network 4. Unsuitable for variable network topology
HEED	1. Scalability for multi-hop communication 2. Uniform distribution of energy inter clustering	1. Non uniform distribution of energy conception 2. High overhead

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