Universal Journal of Communications and Network 5(2): 23-36, 2017 http://www.hrpub.org
DOI: 10.13189/ujcn.2017.050201

Insights into Different Energy Efficient Routing Protocols for Wireless Sensor Networks

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Abstract Wireless Sensor Networks (WSNs) have become popular due to their adaptability and independency where direct human interventions are risky and impossible. WSNs consist of small sensor nodes powered with battery devices and have limited lifetime. Therefore, the most crucial concern in WSNs is their energy consumption and accumulating studies have proposed strategies for WSN designs by clustering the networks into small sub-groups, mainly called clusters. This review summarizes some of the most well-known clustering protocols that have been developed in the last few years. Furthermore, this survey classifies the clustering protocols into three clustering sub-groups including centralized, distributed and hybrid algorithms. Finally, a comparison between the proposed protocols is investigated based on their advantages and disadvantages as well as the considered parameters for clustering.

Keywords Wireless Sensor Networks, Cluster Head, Base Station, Network Clustering

1. Introduction

The Ambient Intelligent-based devices have become increasingly popular due to their applications in sensing and controlling environmental and health-related parameters as well as their adaptabilities and rapid advances without direct human interventions [1].

A Wireless Sensor Network (WSN) consists of a large number of sensors and has garnered great deal of focus due to their adjustability and low-cost attributes. Some, but not all, of the applications of the WSNs include environmental monitoring, health-care systems, intelligent building, vehicle movement surveillance, natural disasters, battle-field surveillance and missile target tracking. The main challenges involved in WSN applications include network coverage and energy consumption, which ultimately define the network lifetime, depending on the way that they are programmed and managed [2-7].

In order to optimize and balance the energy consumption within sensors of the WSNs and maximize its lifetime, ongoing and extensive research has focused on clustering protocols to group the sensor nodes into smaller clusters. These clustering protocols are summarized in the following sections. Clustering is a method to classify large networks into smaller and manageable clusters, in which each node (so called cluster members) belongs to a single cluster and is able to communicate with the Base Station (BS). The clustering methods differ in the decision of choosing the CHs and they have different performances and applications. CHs play pivotal roles in WSNs, since they are the leader nodes that aggregate and compress the data to minimize energy consumption and increase network lifetime. There are a number of parameters used for clustering approaches, such as nodes' battery, location, network throughput, location awareness, pro/re-activity and scalability of the network. The clustering methods are generally classified into three subgroups; Centralized Clustering in which the CH selection is performed by the BS, Distributed Clustering that all nodes cooperates in CH selection process and Hybrid Clustering methods that are the combination of centralized and distributed clustering in which the information is gathered from the BS and the nodes to perform the clustering. This review summarizes a number of well-known clustering protocols, focusing on energy efficient routing algorithms proposed in the last few years.

2. Centralized Clustering Protocols

In centralized approaches, BS selects the cluster heads. It is based on centralized authority and utilizes a vector quantization (VQ) for effective clustering. The central management is applied to form a fixed number of clusters and to select the CHs based on energy consumption within a WSN. These algorithms are summarized in Table 1.

2.1. Low Energy Adaptive Clustering Hierarchy-Centralized (LEACH-C)

LEACH-C is a centralized version of LEACH (described in the following sections) [8]. In this algorithm, each sensor is aware of its location and the BS selects the CHs. BS gathers the main information about the sensor nodes and their environment, and therefore, BS is capable of selecting the most appropriate CHs. Each node sends information on its energy level and location to the BS and subsequently, BS computes the average energy of the nodes. Thus, BS excludes the nodes from being a CH which has lower energy levels compared to the average energy of the network. For the remaining nodes, BS utilizes a simulated annealing algorithm to calculate the optimum number of clusters within the network.

2.2. Adaptive Clustering Hierarchy Based on Game-theoretic Techniques (ACGHT)

In this game-theory-based technique, each sensor represents a player to make the CH decision, utilizes a global positioning system (GPS) receiver and the nodes are static and homogenous [9]. In order to select the CHs, BS utilizes the network information and considers remainder energy and weight of the nodes based the energy pay-off function. Subsequently, it computes the number of CHs by determining the reference location and distributing data packet, which includes total remainder energy of sensors and their position field among all nodes to prolong the system lifetime. Furthermore, the nodes with lower remainder energy are kept out of being used quickly.

2.3. Base Station Controlled Dynamic Clustering Protocol (BCDCP)

In this centralized clustering protocol, the network lifetime is extended by the distributing the consumed energy among the nodes [10]. Following the computation of average energy consumption of the network by the BS, the nodes with higher energy levels compared to the average energy are categorized as “s” nodes and then, some of the nodes are randomly selected as the CHs. This protocol, therefore, uses a multi-level clustering approach to allocate almost equal number of nodes to each CH. Each CH conducts a CH-to-CH multi-hop routing method to transmit the data to a higher CH. Ultimately, a single CH communicates directly with the sink. BS selects an optimum route with the lowest energy to send data and utilizes a minimum spanning tree. In this algorithm, the nodes are considered to be homogenous and they use a Code Division Multiple Access (CDMA) protocol to send the information to the CHs.

2.4. Power Efficient and Adaptive Clustering Hierarchy (PEACH)

In PEACH algorithm, a node recognizes the source and the destination of the data packets by overhearing the neighboring sensors. Accordingly, this protocol selects the CHs without some clustering overheads such as advertisement, announcement, joining, synchronizing and scheduling message. Thus, this algorithm is a probabilistic energy-aware routing protocol and utilizes a multi-level adaptive clustering. This protocol enables sensor nodes to minimize data packets through aggregating the data and therefore, reduces the commination cost within the network [11].

2.5. Optimized Lifetime Enhancement (OLE)

OLE algorithm utilizes Particle Swarm Optimization (PSO) [12] and Simulated Annealing (SA) [13]. In OLE, a chain is formed from sensor nodes to the sink. Therefore, individual nodes are allowed to transmit unequal number of times directly to the BS based on their energy and location, rather than forming a greedy chain [14]. This algorithm is able to enhance the network performance through a balanced and sub-optimal dissipation of energy by the individual nodes, despite their random deployment. In order to form an optimal chain, OLE is also capable of being executed in both the sink before stating the stable phase and individual clusters by a local leader when the communication frequency is low.

2.6. Clustering based on Cluster head with Genetic Algorithm (CCGA)

This algorithm applies a multi-objective fitness function by computing the distance between the CHs, the number of the cluster members and the distances between the nodes and their CHs. This method first selects the CHs and then, performs the clustering [15]. Therefore, the CHs cannot be located in a relatively close distance and if the CH distribution is not uniform, more CHs have to be allocated for the areas with higher node densities. Furthermore, the number of nodes in each cluster should be balanced to consume same amount of energy for aggregating the data. Other parameters such as the reminder energy and optimum number of CHs were also applied in this algorithm and the number of space states is based on the permutation principle. In this method, the network lifetime is increased and the search space is decreased by enhancing the clustering speed and responding quicker.

2.7. Clustered WSN using Fuzzy Logic and Genetic Algorithm (CFGA)

CFGA uses a single-hop and multi-hop cluster communication protocol for inter-cluster and intra-cluster communication, respectively [16]. This algorithm uses a fuzzy interface engine and fuzzy modules to test all the nodes. Fuzzy Logic Controller (FLC) includes fuzzy interference, fuzzy rules, fuzzifier engine and defuzzifier. The node parameters that are considered in FLC include the distance from the BS and the energy and density of the nodes. Initially at each round, each node sends information about the node density, node energy and its distance from the BS to the fuzzy module, and depending on the fuzzy module output it can become a CH candidate. In this algorithm, the density of the nodes is defined by the number of neighboring nodes in its effective range. The fuzzy module output considers a timer for each node and starts counting down since it is defined. The node's timer that has the best performance within its predefined area, reaches to zero time point faster than others and candidates itself as a CH to the BS and thus, it prevents collision. Subsequently, the BS selects the best CH candidates based on the node location and energy consumption using the genetic algorithm. As a limitless energy source and powerful processor, BS executes the clustering in a balanced manner after receiving network information. This algorithm considers all nodes to be homogenous and to be dispersed randomly in the environment and the BS is located in the center of the network environment. The CHs cooperate in sending the aggregated data to the BS. After receiving and aggregating the data, each CH sends the data packet to the BS directly if the distance is short enough. Otherwise, it sends data to the other closest CH, and ultimately, sends the data to the BS indirectly and through a multi-hop inter-cluster communication. At the end of each round, clustering is performed again to select new nodes as CHs. Therefore, this algorithm uses a fuzzy module that is run in a distributed manner in all nodes and identifies the best nodes in each region as the CH candidates, followed by the centralized genetic algorithm implementation at the BS to determine the best CHs. Finally, it minimizes energy consumption and maximizes the network lifetime by creating a balanced and uniformed energy consumption.

2.8. Particle Swarm Optimization with Mobile Base Station (PSO-MBS)

PSO-MS is an approximation algorithm which aims to define the optimum routes and locations for the mobile BS and data collection according to the distance of the BS to the nodes [17]. It also divides the networks into clusters. PSO-MBS considers the nodes to be stationary, homogenous with constrained energy and to be capable of changing the data transmit power. The network has a BS, which is mobile and is initially located at the center of the sensing zone. PSO-MBS consists of a number of rounds consisting of two set-up phase and steady phase. During the set-up phase, the algorithm utilizes PSO to define the locations and the number of the clusters. During the steady phase, it utilizes TDMA method for data transmission and data aggregation.

2.9. Genetic Algorithm Based Energy Efficient Clusters (GABEEC)

This method performs the clustering based on genetic algorithm and uses a cluster-based approach to a static clustering with dynamic CH selection to maximize the network lifetime [18]. It considers two phases in clustering: the set-up phase, which is performed only once, and the steady phase. During the set-up phase, CH selection is performed based on a pre-defined number of sensors and the member nodes are assigned to the CHs based on their distances to the CHs. During the set-up phase, the communication between nodes and CHs is initiated using a Time Division Multiple Access (TDMA) schedule [19]. CH receives, aggregates and fuses the data packet into one packet and sends it to the BS. Following the data packet reception for all CHs, BS computes the energy of CHs and the member nodes. Therefore, an associate CH (from member nodes) is selected based on the residual energy and if the energy of the CH is less than the average energy it replaces the previous CH within the cluster. The fitness function of this algorithm considers three parameters including the round which first node dies, the round which last node dies and the cluster distance. While the clusters that were created in set-up space are remained unchanged and static throughout the network, CHs can be dynamically changed.

2.10. Mobile Sink Improved Energy-efficient PEGASIS-based Routing Protocol (MIEEPB)

MIEEPB is a multi-chain based protocol which considers the drawbacks of the long-chain based protocols and improves their energy consumption and delay in data transmission. It also reduces the stress on the nodes by introducing smaller chain and sink motility [20]. MIEEPB considers the sink to be mobile in a sojourn location for a sojourn time and creates multi-head chains to reduce the load of the chain head. The mobility of the sink significantly increases the network lifetime and enables the sink to acquire information from the all chains. For data transmission, the chain leaders send the data that was received from the corresponding nodes to the sink using a token passing method. Data aggregation that received data from the child nodes is performed using Data Centric Storage (DCS) by a data aggregation faction in the parent nodes [21]. The chain construction of MEEPB is similar to PEGASIS which starts when the sink has calculated the distance to the nods and found the farthest node, known as “end node”, where the chain formation starts. This chain formation continues as nodes find their nearest node that is not connected to a chain. Subsequently, the chain leaders are selected based on their weight Q that is computed by the nodes and is the ratio of the residual energy to the distance from the BS.

2.11. Enhance Cluster Based Routing for Mobile Wireless Sensor Network (ECBR-MWSN)

ECBR-MWSN is an enhanced multi-path LEACH protocol and tends to increase the network lifetime by considering a balance in node energy consumption [22]. This algorithm considers the nodes to be mobile and homogeneous with equal capability to communicate with the BS. It also considers the BS to be fixed. The CH selection is performed periodically by the BS by considering a few parameters as primary and secondary parameters. The main and primary parameter is the residual energy, which is used to define the initial CHs. The secondary parameters are taken into account to define the CHs when a tie has been formed. A tie is formed when a node is located within the range of two or mode CHs. These secondary parameters include node mobility and the distance to the BS. ECBR-MWSN is a reactive protocol since the routing is performed only when it’s required. The protocol has five phases, which include initialization, which starts after the node distribution, cluster formation, which uses a Density Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm [23], data transmission, which consists of single-hop and multi-hop method for inter-cluster and intra-cluster communication, and re-clustering and re-routing, which follows the same protocol as in cluster formation phase.

2.12. Energy Management Algorithm with Multiple Sinks (EMMS)

EMMS is proposed for the networks that have multiple mobile sinks [24]. The main aims of this algorithm are to balance the load among the mobile sinks and the energy among the nods in order to improve the energy efficacy, network lifetime and quality of the transmitted data. EMMS considers the multiple sinks to be mobile, each in a closed trajectory. The protocol consists of two sinks moving control and energy consumption balancing phases. For the mobile sink control, firstly, EMMS defines closed trajectories for the sinks with a similar length. Subsequently, it defines sojourn locations and times for each sink. Given that the trajectory for each mobile sink is closed, the sink can stop at any sojourn locations alongside the tour. For balancing the energy, the protocol performs rounds similar to LEACH algorithm.

3. Distributed Clustering Protocols

In distributed (de-centralized) clustering protocols, the CH selection is performed by the sensor nodes. Therefore, there is no centralized control on these networks and the CH decision is distributed among the nodes, leading to a reduced overhead. In distributed clustering algorithms, each node decides on its own probability to become a CH. Therefore, there are some advantages over centralized clustering algorithms. However, they may lose some clarities compared to centralized protocols (Table 1).

3.1. Low Energy Adaptive Clustering Hierarchy (LEACH)

In 2000, Heinzelman et al, [5] introduced a distributed single-hop clustering algorithm called LEACH. This algorithm introduced adaptive clusters and CH rotation, which results in distributed energy among sensors, data compression, balanced load and decreased energy dissipation, caused by local computation within each cluster and randomized node death. Therefore, this algorithm represents a dynamic and self-organizing clustering method. Nodes are self-organized within the local clusters, a sensor is allocated as CH and the nodes are distributed randomly on a grid-like area. This algorithm divides the lifetime of the networks to a number of rounds, each including set-up and steady phase. During the set-up phase CHs are selected and the clusters are organized. Data transmission to the sink occurs during the steady phase via the CHs. In order to minimize the load, the steady phase is made longer than the initial set-up phase and there is no limit accounted for the number of nodes in a cluster. Following the clustering, CHs send timing to each node resulting in an off mode in each node when no data is transmitted by the node. The optimum number of CHs depends on a number of factors such as the WSN topology and the computation cost as well as the data transmission cost.

3.2. Threshold Sensitive Energy Efficient Sensor Network (TEEN)

TEEN is a hierarchical communication protocol which mainly focuses on the time and dynamics of the responses to the sensed attributes as well as the trade-off between energy consumption and accuracy [25]. TEEN considers the nodes to be homogenous with equal initial energy. The BS also has a limitless energy as there is a constant energy supply. Member nodes send their data to the CHs to be able to transmit the aggregated data to the BS or a higher-level CH. Also, to minimize and distribute the energy consumption among the nodes, all nodes take turn in becoming a CH during the time called “cluster period”. This protocol introduces a hard threshold (HT) and soft threshold (ST) for the nodes to switch the transmitter and reporter of each node on at the time of message transmission, and therefore, saves energy.

3.3. Power-Efficient Gathering Sensor Information Systems (PEGASIS)

PEGASIS algorithm considers the BS to be fixed and the nodes to be non-mobile and homogeneous with equal and limited energy [26]. This algorithm constructs a chain among the nodes towards the BS instead of performing the CH selection. Therefore, PEGASIS collects and fuses the data from the node to node communication and transmit it to the BS using long-distance transmission. Nodes send data to the BS in a periodic manner in order to reduce the energy expenditure for data transmission during each round and to have as minimum number of transmissions to the BS as possible.

3.4. Hybrid Energy Efficient Distributed Clustering (HEED)

HEED is a single-hop clustering protocol and considers the nodes to be quasi-stationary, not rechargeable and location-unaware and have equal significance [27]. This algorithm aims in increasing network lifetime by distributing the energy consumption and propagating the residual energy information. The clustering process terminates in O(1) iterations. The CHs are selected in a probabilistic manner depending on the estimated residual energy of each node and intra-cluster communication cost, which depends on the closeness of the neighbor node, cluster density and range proximity. Therefore, those nodes become cluster heads that have less communication cost and each node joins a single cluster that is in its closest proximity.

3.5. Stable Election Protocol (SEP)

SEP is a clustering algorithm that considers the nodes to have heterogeneous energy within a network but are distributed in a two-level hierarchical network uniformly. In SEP a proportion of the nodes have higher energy levels compared to the others [28]. This algorithm also assumes the BS to have limitless energy and the coordinates of the BS and the size of the network is defined. By introducing heterogeneity to the nodes, this algorithm is able to re-energize the sensor network and add some nodes with higher energy than the existing nodes. The CH selection is performed based on the initial energy of the nodes. SEP increases the time interval before the first node death (called stability period) and thus, enhances the reliability of the clustering method while creating a trade-off between the network lifetime and reliability of the clustering.

3.6. Distributed Weight-based Energy-efficient Hierarchical Clustering (DWEHC)

This Hierarchical clustering algorithm applies no limit on the network diameter and topology as well as the number of nodes and clustering levels [29]. In DWEHC, the nodes are quasi-stationary, distributed in a two dimensional space, are not rechargeable, are location-aware and have non-uniform energy consumption. The number of clustering levels depends on the radio range and the minimum energy required to send data to the corresponding CHs. The weight factor is computed based on the node energy, the distance to the corresponding CH and the radio range. The nodes that have higher weights are selected as the temporary CHs. Each temporary CH becomes the final CH only when a certain percentage of the neighboring nodes have selected it as a temporary CH. Each node sends the information to the CH and the CH utilizes a TDMA method for time scheduling for its nodes in order to send the data in a scheduled manner. To inhibit collision and inter-cluster interference this algorithm uses the direct-sequence spread spectrum (DSSS) [30].

3.7. Maximum Energy Cluster Head (MECH)

MECH executes the clustering based on the radio range and the number of nodes within each cluster [31]. Optimum CHs are selected based on the number of steps and energy level. Each round consists of set-up phase, steady phase and transmission phase. At first, each node transmits information to recognize neighboring nodes within its radio range and then counts the number of neighboring nodes. If this number reaches the cluster number (CN), it introduces itself as a CH. Each node receives this information and its timer starts to count down. When the timer becomes zero, each node joins the closest CH. Each CH computes the number of nodes and sends the information to the BS. BS computes the optimum time slot and sends the information to the CH using TDMA method. In the set-up phase, each node is informed with its schedule sent by BS using TDMA and each node sends residual energy information of its own and the neighboring nodes to the BS. In the steady phase, data transmission occurs and the nodes become active only at the time of data transmission in order to reduce the energy consumption. Finally, in transmission phase, CHs send data packed to the BS.

3.8. Multiple Routing Protocol with Unequal Clustering (MRPUC)

In MRPUC, CHs are selected based on the energy levels and the closeness [32]. The nodes and the BS are considered to be stationary. Each node estimates the distance to the BS according to the initial data that BS sends throughout the network. Subsequently, each node computes its radio range. The unknown nodes that are not either the CHs or member nodes, joins a CH with low joining cost. The nodes that are not located in any other nodes' radio range and are considered to be unknown become a CH. In This algorithm, TDMA method is used for sending the data to the CHs by the nodes. CH selects an intermediate node with higher energy level and less energy cost to send data to the BS. Therefore, nodes are able to adjust the energy required for sending data.

3.9. Adaptive Routing Protocol with Energy Efficiency in Wireless Sensor Networks (ARPEES)

ARPEES is one of the adaptive dynamic event clustering algorithms [33]. The CH selection in ARPEES is based on the event occurrence. Thus, the nodes are switched on when they sense an event. Active nodes send “request cluster” message for an on-demand clustering to be performed. Hence, only activated nodes are taken part in clustering during the event occurrence [34]. All member nodes send data to their CHs and the CHs transmit the data packet to the relay nodes, which have maximum residual energy and distance from the CH and minimum distance from the BS. The data is then transmitted using a multi-hop routing protocol. In this algorithm, the nodes are homogenous and quasi-stationary and have fixed transmission power levels. Whereas the BS is fixed and has limitless energy. To make adjustments against the changes in the network topology, this algorithm performs optimal relay path selection dynamically in each round. This algorithm aims to create a trade-off between the energy efficacy and minimum number of hops by considering an optimal path for the relay nodes for data transmission to the BS.

3.10. Unequal Cluster-based Routing (UCR)

UCR is an unequal cluster-based protocol and adopts cluster rotation [35]. It includes two parts as Energy-Efficient Unequal Clustering (EEUC) and a greedy geographic and energy-aware routing protocol. Topology management and cluster head selection based on node information and competition are done by using distributed EEUC algorithm, which is a self-organized algorithm. For inter-cluster communication, the proposed multi-hop routing protocol is used. It considers the balance between the energy of symmetric relay links and relay nodes. The nodes are considered to be homogenous, active only when they send data, capable to modify the transmission power based on the distance and able to compute the distance to the other nodes. This protocol considers a threshold for the distance. If the CH distance from the BS is less than the threshold value, the CH sends data directly to the BS. Otherwise, the CH sends data to a closer CH and then to the BS with higher energy level. Synchronism is an important factor in this algorithm since it is assumed that the nodes start clustering simultaneously. The main goal of this routing protocol is to solve the hotspot problem in WSNs, caused by unbalanced load in CHs, thorough considering the impacts of both intra-cluster and inter-cluster commination simultaneously and thus, improves the network lifetime and energy consumption uniformity by reducing the number of nodes close to the BS with a higher relay load.

3.11. K-hop Overlapping Clustering Algorithm (KOCA)

KOCA is a randomized multi-hop heuristic K-clustering algorithm which mainly focuses on the overlapping multi-hop clustering problem (NP-hard) [36]. KOCA considers the nodes to be homogenous, fixed and location-unaware with equal energy. KOCA assumes that all nodes cooperatively make decision and incorporate the cluster radius (K parameter) to the clustering process and the CH probability to compute an optimum number of boundary nodes within the overlapping clusters. This performance leads to the scalable localization and global synchronization of the network. KOCA considers the nodes to be either of these three node subtypes: CH, boundary nodes (BNs) and member nodes. BNs are the nodes that belong to two adjacent clusters. While member nodes belong to one cluster. The clustering is performed by the nodes in an autonomous decision making manner. The initial CHs send an advertisement, which includes SID (sensor node ID), CHID and HC (hops count) message to the nodes within the K-hop. Therefore, if a node does not receive any advertisement message within a specified time-period it becomes a CH.

3.12. Virtual Multiple Input Multiple Output Communication Protocol (Virtual- MIMO)

In this algorithm, in order to increase the network lifetime, the first node death is delayed [37]. CHs are selected based on their residual energy. Nodes are classified either or both as a receiver node or sender node and join a cluster based on the distance from the CH. CHs select the receiver and sender nodes within each cluster based on the energy required by each node to send the data. Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol is used for data transmission by the nodes.

3.13. Wireless Sensor Networks Powered by Ambient Energy Harvesting (WSN-HEAP)

HEAP is another algorithm that is designed for the nodes having heterogeneous energy and consists of the relay nodes, source nodes and the BS [38]. The relay nodes send data packet collected from the sensor nodes to the BS using a multi-hop routing method. Sensor nodes send their own data if they do not receive any data from the other sensor nodes during the transmission period. Therefore, sensor nodes are unlikely to be selected as CHs and the relay nodes are the ones that are selected as CHs. HEAP considers some of the nodes to be more powerful than others and all nodes to be location-aware. Eu et al. [38] investigated three different routing protocols and considered a few parameters including sending rate, throughput, efficiency, data delivery ratio and hop count. They also considered a long-term network deployment by considering the harvested energy as the only energy resource rather than battery supply.

3.14. Density and Distance based Cluster Head Selection (DDCHS)

DDCHS algorithm considers the nodes to be quasi-stationary and location-aware with equal capability for data transmission [39]. During the clustering period, the area is divided into a number of hexagons in order to inhibit circular cluster overlapping and a CH is selected for each hexagon. Subsequently, a number of sub-circles are considered within each virtual hexagon based on the average node distance to the CH. This algorithm consists of three steps; first step is the local grouping which divides each hexagon to four equal parts depending on the average length and width. During the second step, the node density is calculated and one of the four parts is nominated as candidate quarter. During the last step, CHs are selected based on the least distance to the candidate quarter. Thereafter, nodes join the closest CHs within the network.

3.15. Region-based Energy-aware Cluster (REC)

REC algorithm is proposed to reduce energy expenditure through optimum clustering and data transmission as well as intra-cluster communication [40]. The CH selection is based on the balance between the residual energy and node sensing range. Thus, the nodes with higher residual energy and Overlap Coverage percentage (OCp) are more likely to become a CH.

3.16. Clustering Routing for Selfish Sensors (CROSS)

CROSS is a game theory-based algorithm proposed in 2011 [41]. Two strategies are introduced for nodes, each having a utility function (U): D strategy when a node decides to become a CH and ND strategy is for nodes that declare to be a non-CH node. This algorithm applies a mixed Nash equilibrium of the game strategy to compute the probability of becoming a CH for each node and therefore, p is the probability of following D strategy and "q= 1 – p" is the probability of ND strategy. The probability of becoming a CH or D strategy has reverse correlation with the number of players (nodes), the cost of becoming a CH and sending data to the BS.

3.17. Energy Aware Clustering Approach (EACA)

EACA is a communication protocol proposed by Barati et al. in 2012 and is a modified hierarchical LEACH protocol [42]. In this clustering protocol, the energy efficient clustering is performed based on the residual energy, the distance of each node to the CH and the communication cost. This protocol achieved a 23% increase in network lifetime compared to the LEACH protocol by applying a step-based protocol and therefore, terminates the clustering process quicker and does not need any information about the number of required CHs, network congestion and time synchronization.

3.18. Energy-aware Distributed Dynamic Clustering Protocol using Fuzzy logic (ECPF)

ECPF follows three main techniques including non-probabilistic, fuzzy logic and on-demand clustering and CH selection [43]. Each round in ECPF has set-up and steady phase. During the set-up phase, the CH selection and clustering are performed and nodes are synchronized to send data. In the second phase, the data is transmitted to the BS using TDMA method and each node is allocated a specific time for data transmission in order to minimize the network interference. The main goal of this algorithm is to run the set-up phase on demand rather than doing it during each round. Therefore, CH selection is only done when it's required based on their residual energy to reduce the overload. Data transmission to the BS is done by a multi-hop method and the tentative CHs are selected based on the residual energy and the fuzzy cost, which is computed by fuzzy logic. Other nodes join the CHs which has less fuzzy cost. Fuzzy logic considers two parameters including node degree and node centrality to perform the CH selection.

3.19. Distributed Self-organization Balanced Clustering Algorithm (DSBCA)

DSBCA is a balanced clustering algorithm for inconsistently distributed WSNs which performs the clustering based on the node distribution, distance, connection density and residual energy [44]. To create the balanced and stable clusters and reduce the overhead, DSBCA incorporates the connection density and distance to the BS into the node weight and cluster radius. Furthermore, additional factors such as residual energy and the number of rounds of being a CH are incorporated into the node weight calculation in order to minimize the cluster change. The nodes are considered to be fixed during a certain time period, location-unaware, self-organized and randomly distributed with equal transmission capacity. BSBCA consists of CH selection, cluster built-up and cycle phases. The CH selection is a self-organizing step and selects random nodes at first. Consequently, the selected nodes compute their cluster radius without a central control. Finally, the nodes with higher node weight become the CHs. In cluster building phase, BSBCA computes a threshold for the cluster configuration and size to optimize the overhead. Therefore, it periodically performs the clustering during the cycle phase to create the energy-balanced clusters.

3.20. Improvements on LEACH Algorithm

Handy et al. [45] proposed an extended LEACH algorithm by replacing the stochastic CH selection in LEACH algorithm with a deterministic component. Their proposed algorithm also increases the network lifetime by considering the number of dead nodes and defining three factors including FND (First Node Dies), HNA (Half of the Nodes Alive), and LND (Last Node Dies).

Wang et al. [46] proposed another improvement for LEACH algorithm in which the number of CHs is not definite and the optimum number of CHs depends on the total number of nodes. This algorithm has two phases including the set-up and steady phase and computes the optimum number of the clusters before each round. As the number of live nodes decreases, the number of clusters and CHs changes and is not constant. The optimum number of clusters is computed based on background scheduling process and real-time executive process. During the background scheduling process, some parameters are considered such as the number of nodes and the distance to the BS. During the real-time executive process, each node computes its probability to become a CH.

U-LEACH is a hierarchical clustering algorithm proposed in 2012 and forms a chain similar to PEGASIS algorithm [47]. This protocol considers the initial energy level of the nodes to be heterogeneous and the clustering differs from LEACH by considering the node initial and residual energy. The data is sent by the CHs to a higher level node called Master Cluster Head (MCH), which transmits the aggregated data to the BS.

Threshold-based LEACH (T-LEACH) [48] was proposed by Hong et al. in 2009. In T-LEACH algorithm, CH exchange is performed based on a predefined threshold for the residual energy of the nodes. The threshold is based on the total energy of the CHs and number of the rounds that each node could be an active member node within a cluster. If the computed total energy is less than the defined threshold, the CH selection is performed again in a new round. Each CH consumes energy twice, first for collecting the information from the member nodes and second, for sending the data packet to the BS which depends on the distance from the BS.

Shaw proposed an improved LEACH called Z-LEACH in 2011 [49]. This algorithm considers the remaining energy of the existing CHs for the new CH selection and adds a level of data aggregation by using the least overloaded CH.

4. Hybrid Clustering Protocols

Hybrid clustering is the combination of both centralized and distributed clustering protocols. In hybrid protocols, the information about the location of each node is collected by the BS and the consequent clustering and communications are carried out by the nodes. Thus, these protocols possibly result in reduced overhead and improved network lifetime (Table 1).

4.1. Transmission-Efficient Clustering Method (TECM)

Xie and Jia proposed the TECM protocol, which utilizes a hybrid comprehensive sensing (CS) method for clustering in 2014 [50]. In this protocol, the nodes are considered to be distributed uniformly throughout the network and to be location-aware with equal capability for data transmission. The sink is assumed to have information about the sensor filed but not to be aware of the location of the nodes. The member nodes send data to the CH without utilizing the CS method (intra-cluster communication). The data transmission from the CHs to the BS utilizes a data gathering backbone tree with a CS method. The CH selection is performed by the sink through dividing the sensor filed into C cluster areas, computing the central point of each cluster, sending the information to all sensor nodes and finally, selecting the nodes as CHs that are the closest nodes to the central point of the clusters. This hybrid clustering method aims to optimize the cluster size in order to minimize the transmission frequency by using a centralized clustering and distributed implementation of the clustering. Therefore, it establishes a balance between the cluster size and number of the clusters. As the size of the transmitted data during the intra-cluster and inter-cluster communication is reduced, this protocol effectively reduces the number of transmissions and consequently, the energy consumption.

4.2. Optimized Zone based Energy Efficient routing Protocol for Mobile Sensor Networks (OZEEP)

OZEEP is an optimized ZEEP which improves the network energy and lifetime as well as the packet drop ratio [51, 52]. Using a two-tier communication model, OZEEP consists of the implementation of a multi- and single-hop routing for inter- and intra-cluster communication, respectively. The clustering is performed in two steps. The first step, which is the screening step, recognizes capable nodes for becoming a CH by using a fuzzy module within the nodes. The fuzzy module collects the information about the energy, density, mobility and distance of the nodes and generates an output to nominate the CHs. The candidate CHs are declared to the BS. The BS elects the final CHs and the balanced clusters using a genetic algorithm by converting the information into chromosomes. Finally, the nodes join the clusters with minimum communication cost. This protocol aims to alleviate the collision by reducing the number of communications to the sink and thorough network coverage by forming the stable and balanced clusters. OZEEP considers the nodes to be mobile with variable speeds. In OZEEP, the nodes with the least mobility have the highest chance to become CH and to form more stable clusters with less routing disturbance. Due to the high mobility of the member nodes, these nodes might move out of the cluster region. Consequently, these nodes send their data directly to the BS until they are involved in the re-clustering process.

4.3. Mobile Sink Based Routing Protocol (MSRP)

This protocol aims to alleviate the hotspot and the energy hole problem caused by static and multiple sinks via considering a dynamic mobile sink. Therefore, MSRP prolongs the network lifetime [53]. In MSRP, the mobile sink collects the information about the residual energies from the CHs and works out the best moving route based on the residual energies in order to be in the vicinity of those nodes with higher energy. This ultimately leads to a balanced energy consumption. MSRP divides the whole sensor field into the small clusters and assigns a CH for each cluster, which aggregates transmits the data to the BS or a higher CH and finally, forwards them to the sink only when it's close to the mobile sink. The data gathering consists of two set-up phase, including initialization, mobile sink advertisement and CH registration, and the steady phase, including TDMA scheduling, forwarding to the sink and sink movement.

5. Conclusions

Wireless Sensor Networks have broad range of applications ranging from health to military. Clustering of sensor into manageable clusters in order to build scalable networks. This paper, recent clustering methods for WSNs have been summarized. These methods are classified as centralized, distributed and hybrid clustering algorithms and the main characteristics of these methods have been discussed. The main goal of these algorithms is to optimize the energy consumption in WSNs and prolong their lifetime. This paper focused on the advantages and the limitations of the protocols and classified them in tabular form. Although distributed clustering protocols have some advantages including the scalability, deployment and elimination of the nodes and self-organization, centralized methods benefits from their low transmission and reception interference. Furthermore, hybrid methods have been proposed taking the advantages of both distributed and centralized methods. Therefore, this paper surveyed the status of research based on different WSN metrics including control method, network architecture, communication method, clustering features and protocol operation with the aim of improving and giving a support of the weaknesses and strength of the algorithms. Therefore, this review will be useful for researchers and developers in order to develop, modify, optimize and improve the performance of WSN to design optimal clusters and prolong network lifetime for specific applications. Furthermore, we hope that this survey will reduce the gap between the developed algorithms and required applications of WSNs.

Table 1. Summary of advantages and disadvantages of clustering protocols and their clustering properties

Protocols	Merits	Demerits	Clustering properties	Ref
Centralized Clustering Protocols				
LEACH-C	• Uniform and optimum distribution of CHs • Less data transmission energy	• Single-hop data transmission which results in overhead	• Average node energy • Distance	[8]
ACGHT	• Suitable for the static distributed networks. • Reduced energy consumption and prolonged network partitions	• Not suitable for dynamic networks	• Residual node energy • Node weight	[9]
BCDCP	• Uniform cluster size	• Decreased performance gain when the sensor filed area decreased	• Node energy	[10]
PEACH	• Scalability • Suitable for both location-aware and un-aware applications • Adaptive multi-level clustering	• Overhead • Direct communication • Possible clustering overlapping	• Node energy	[11]
OLE	• Uniform distribution of CHs • Prolonged networks lifetime in comparison with PEGASIS	• Small Variation in nodes' energy consumption and residual energy	• Residual energy • Node location	[14]
CCGA	• Reduced search space • Increased clustering rate	• Neglecting the balance of residual energy in sensor nodes • Not considering mobility	• • Distance to the CHs • Node density • Distance between the CHs	[15]
CFGA	• Utilizing combination of fuzzy rules and node characteristics	• Neglected distance for the fitness function	• Distance from the sink • Node energy • Node density	[16]
PSO-MBS	• Improved delayed delivery • Considering the distance to sink in fitness function	• Needs location information • Increased packet delay	• Coverage of the network • link quality a • Power consumption	[17]
GABEEC	• Facilitated clustering • Increased number of live nodes	• Non-uniform distribution of CHs • Fixed number of CHs and member nodes • Decreased convergence in large scale systems and non-scalable • Disregarded the remaining energy in fitness function and non-balanced node power	• Pre-defined number of sensors • Distance to the CHs • Residual energy	[18]
MIEEPB	• Inhibiting the formation of long links	• Hotspot problem caused by fixed sojourn locations of the sink • Needs location information	• Distance to the CHs • Weight Q (residual energy and distance to the BS)	[20]
ECBR-MWSN	• Balanced energy consumption	• Limited scalability • High overhead	• Residual energy • Node mobility • Distance to the BS	[22]
EMMS	• Balanced load by introducing multiple sinks • Suitable for time-driven applications	• Time complexity • High overhead caused by sink control	• Residual energy • Sojourn time	[24]

Distributed Clustering Protocols				
LEACH	• Reduced control message overhead • Low complexity • Shared load between the nodes • Inhibits unnecessary collision by using TDM	• May lead to non-uniform distribution of the CHs and un-balanced load • Single-hop data transmission which results in overhead • Not considering the residual energy • Not suitable for large scale networks • Using random method in CH selection based on priori probability regardless of the network structure and the actual nodes energy	• Prior node probability	[5]
TEEN	• Suitable for event-based applications • Suitable for time-critical applications • Controlled data transmission •	• Unsuitable for common data gathering and periodic report-based applications • Wasting time slot • CH lost when the communication thresholds are not met	• Residual energy	[25]
PEGASIS	• Preventing clustering overhead • Distributed energy • Dynamic cluster formation • Decreased data transmission quantity	• Chain overhead • Transformation of the node to the bottleneck caused by the long delay • Low scalability • Not suitable for networks with varying times	• Distance to the CHs • Weight Q (residual energy and distance to the BS)	[26]
HEED	• Uniform distribution of the CHs • Balanced load • High scalability •	• High overhead during the set-up phase • Unbalanced energy consumption	• Node proximity to its neighbor • Residual energy • Node density	[27]
SEP	• Suitable for heterogeneous systems	• Unsuitable for homogenous systems • Using random method in CH selection based on priori probability regardless of the network structure and the actual nodes energy	• Initial node energy	[28]
DWEHC	• Balanced cluster size • Inhibits unnecessary collision by using TDM for inter-cluster communication	• Hard to compute node weight • The implementation of the algorithm by each node • The number of iteration required for the protocol	• Residual energy • Distance • Radio range3	[29]
MECH	• Self-configuration • Localized coordination • Balanced load	• The synchronization might be expensive • High control messages	• Residual energy • Node density	[31]
MRPUC	• Preventing the early death of the CHs	• High overhead • Unbalanced load • Additional overhead caused by inter-cluster multi-hop communication	• Residual energy • Distance between sensor nodes • Distance to the BS	[32]
ARPEES	• Dynamic event clustering • Balanced energy consumption (compared to LEACH) • Balanced load • Alleviating the hotspot problem • On-demand clustering	• Unsuitable for large-scale scenario • The energy exhaustion is not handled as the CH has to keep the transceiver active all the time	• Residual energy • Distance • Event occurrence	[33, 34]

UCR	• Mitigating hotspot problem	• Error that might arise in computing the distance to the other node due to the noise in the network environment	• Residual energy	[35]
KOCA	• Forming optimum k-hop and non-overlapping clusters with partial network topology	• Not considering the cluster size and the residual energy of the nodes • May form unbalanced clusters	• Coverage • Residual energy	[36]
Virtual-MIMO	• Decreased bit errors	• Not specific routing protocol is considered	• Residual energy • Node density	[37]
HEAP	• Relay node placement scheme • Energy harvested from the environment perpetually	• Unsuitable for homogenous systems	• NA	[38]
DDCHS	• Suitable for systems with mobile nodes	• Node interactions result in energy loss	• Node density • Distance	[39]
REC	• Utilization of two thresholds for energy and delay in cluster formation • Reduced power between the CHs by using the relay node	• High overhead • The nodes are assumed to be able to directly connect to the BS	• Coverage area • Residual energy	[40]
CROSS	• Non-cooperative game approach • Nash Equilibria of the game for pure and mixed strategies • Suitable for energy-aware ad-hoc networks	• Having no assumption on the nodes cooperation • No guarantee that all nodes will become a CH for exactly one time.	• Cost of being a CH	[41]
EACA	• Quick termination of the clustering	• Having no assumption on the node densities and synchronization of the nodes	• Residual energy • Distance from the neighbors and other CHs • Communication cost	[42]
ECPF	• Non-probabilistic CH selection • On-demand CH selection	• Unbalanced energy consumption • Required more time and energy for CH selection as the nodes have limited computing capacity	• Delay time • Initial energy • Node centrality • Residual energy	[43]
DSBCA	• Decreased communication costs	• Initial random CH selection • May form energy holes	• Residual energy • Distance • Density	[44]
Hybrid Clustering Protocols				
TECM	• Reduced redundancy by implementing optimal cluster size	• Inefficient network coverage	• Distance to the center of the cluster	[50]
OZEEP	• GFS utilization for CH selection	• Not considering the packet delay • Waiting period for the disconnected nodes to be re-clustered	• Residual energy • Density • Mobility • Distance	[51]
MSRP	• Alleviating the hotspot problem • Controlled sink movement	• High overhead in CH registration • Communication loss of some CHs to the sink	• Residual energy • Distance	[53]

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