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A Survey on Unequal-Sized Clustering Based Routing Protocols for Wireless Sensor Networks

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Abstract: Energy constraint is well known as a big issue in WSN applications since it affects their lifetime. Therefore, to increase the lifetime of WSN, a wise method has to be adopted. So far, the clustering technique has been shown to be efficient in inimizing energy dissipation and prolonging the network lifespan. This study aims to illustrate unequal-sized clustering method, show why unequal-sized clustering emerged and review a set of unequal-sized clustering routing protocols. In this survey, for each protocol studied, the attention is mainly concentrated in the manner of cluster head selection, cluster formation and data routing techniques.

Key words: WSNs, network lifetime, unequal-sized clustering, single-hop routing, multi-hop routing, concentrated

INTRODUCTION

Rapidly, WSNs have beenutilized in different applications. Many reasons lead to the adaptation of WSN applications. Some of these reasons are related to sensor technology such as low cost, small size, low power and easy deployment and others related to the applications themselves such as battlefields, unreachable regions and continuous monitoring systems. Typically, a WSN consists of many small-sized devices named sensor nodes. A single node comprises of main units with limited capabilities; these units are sensing, processing, radio communication and energy resource. Therefore with these constrained components, especially energy resource, the energy efficiency in WSN networks has become a hot area of research (Guo and Zhang, 2014).

During the last two decades, a lot of researches have been conducted to overcome the effect of energy constraint on the WSN lifetime. In that concern, regarding energyconsumption, the most expensive process in WSN networks is the data transmission. Usually, data gathered from the WSN field by individual nodes and then sent to the BS through a single or multi-hop mode. So, routing protocols can use these two models of data routing in WSN networks whether flat or hierarchical (Cheng *et al*., 2008; Ebrahimi and Assi, 2014).

Basically, in the clustering technique, the network sensor nodes join distinct sets called clusters. So, that nodes in each cluster work under the supervision of a particular node named Cluster Head (CH). Usually, the process of CH selection can be local (a distributed method), global (a centralized method) or hybrid (a mixture of previous methods) (Afsar and Tayarani, 2014).

Primarily, many hierarchical clustering protocols have been introduced and they were equal-sized such as LEACH, TEEN, HEED (Liu, 2012). In these protocols within each cluster, sensor nodes can utilize a single or multi-hop mode to convey data to CH (intra-cluster communication) whereas for clusters, each CH can transmit data of its cluster to the BS whether also using a single or multi-hop mode (inter-cluster communication). Practically, experiments prove that cluster-based routing protocols increase the lifetime, scalability, stability, even load distribution and decrease the energy dissipation in WSN networks. However, problems of unbalanced energy dissipation happen, whether implementing a single or multi-hop data routing mode (Yu *et al*., 2012; Bencan and Shouzhi, 2012; Kazerooni *et al*., 2015; Naeimi *et al*., 2012; Wajgi and Thakur, 2012).

Due to the characteristics of WSNs, using a multi-hop model for data transmission is more efficient regarding energy efficiency and scalability. However, in multi-hop routing protocols, the effect of the hot-spot problem is inevitable on the CHs located nearer to the BS. So, to deal with the unbalanced energy consumption caused by the hot-spot problem, unequal-sized clustering protocols were proposed. The idea of these protocols is to divide the network sensor nodes into clusters of different sizes so that a certain degree of balance in energy consumption assured among all CHs (Li *et al*., 2005; Jiang *et al*., 2015).

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MATERIALS AND METHODS

Equal and unequal-sized clustering techniques: The clustering technique is a hierarchical structure which has been utilized to suit WSN's requirementssuch as long lifetime, scalability and stability (Mammu *et al*., 2015; Jadidoleslamy, 2013).

For classification purpose, two types of clustering have been implemented in WSN routing protocols, an equal-sized and unequal-sized clustering. As mentioned before, data gathered in each cluster are conveyed to the BS using either a single or multi-hop model. Obviously, It is well-known that earlier established clustering-based protocols are equal-sized for example, LEACH, TEEN and HEED. Generally, in most of these protocols to equalize the rate of energy dissipation among nodes in clusters, the state of being CH frequently rotated among network's nodes. Eventually, this indeed results in to increase the network lifespan because CH rotation prevents premature death of sensor nodes (Abbasi and Younis, 2007; Maimour *et al*., 2010; Kumar *et al*., 2011; Selvi and Manoharan, 2013; Sikander *et al*., 2013).

According to Lee *et al*. (2008), Yu *et al*. (2011) and Dhanpal *et al*. (2015), an uneven energy consumption problem happens when utilizing equal-sized clustering protocols. Besides, this uneven energy consumption is found in both data routing models, single-hop and multihop. On the one hand, in the case when a single hop routingis used, CHs located distant from the BS need to expend more energy than the others due to the long distance of data dissemination and this leads to a premature death for these CHs. On the other hand, in a multi-hop routing fashion, CHs located near to the BS will die faster than the others because they are burden with heavy data traffic and this causes a problem called "hot spot" energy consumption "oenergy hole" (Mammu *et al*., 2015; Cheng *et al*., 2008; Perillo *et al*., 2005; Bagci and Yazici, 2013; Wang *et al*., 2009) Significantly, the hot-spot problem shortens the network lifetime and minimizes the sensing coverage and usually leads to network partitioning. Therefore, an unequal-sized clustering technique has been introduced as a solution to mitigate the effect of the hot-spot issue (Yu *et al*., 2011; Ren *et al*., 2010).

In an unequal-sized clustering approach for instance, when the distance to the BS is considered as a parameter for implementing the notion of unequal clustering, the scenarios would be as follows. When a multi-hop routing is utilized, the CHs near to the BS would have a small-sized cluster to help preserve some amount of energy for relaying incoming data traffic towards the BS. Whereas, in the case of a single-hop is used the CHs located farther away from the BS would have small-sized clusters to reduce their intra-cluster communication and be able to afford data transmission from a long distance. Due to the characteristics of WSN networks, experiments show that the protocols which adopt an unequal-sized clustering and multi-hop model for inter-cluster communication are more efficient concerning network lifetime, even-distributed load, scalability and stability (Ren *et al*., 2010; Pei *et al*., 2015).

RESULTS AND DISCUSSION

Unequal-clustering protocols UCS: By Soro and Heinzelman (2005), the researchers proposed the UCS protocol which was considered the first attempt that introduced an unequal-sized clustering, for WSN networks. The aim of UCS is to make energy consumption balanced among CHs and thus leads to increase the network lifetime. Researchers paid attention to the location and the role of a sensor node in WSN networks as it could play a major effect on energy consumption. So, for aclustering-based routing protocol, researchers assumed that in order toreduce energy consumption, the CH nodes should be in the center of its owncluster. Besides, the UCS protocol works according to the idea of unequal-sized clustering where CHs closer to the BS must serve fewer member nodes to preserve some amount of energy for relaying load traffic coming from other CH nodes.

In UCS protocol, several network parameters were assumed in advance such as sensor nodes are heterogeneous, network field is circular, BS is located at the center, nodes are deployed uniformly and CHs are stationary. Also, the number and size of clusters for each layer should be predefined according to the distance from the BS. Furthermore, CHs must be determined initially and stay fixed during the network lifetime. The simulation was carried out for protocols UCS and ECS (Equal Clustering Size) for different network scenarios and a comparison was made to evaluate the energy consumption and network lifespan.

The results of the simulation showed that UCS protocol achieved improvement by keeping energy consumption even among CHs, as compared to ECS protocol. However, due to the assumptionsof UCS protocol such as the selection of CHs in a predefined manner with high energy and CHs should be placed at the center of clusters during the network lifetime, the UCS protocol is consideredas not preferable for practical applications (Liu, 2012) (Table 1).

EECS: The EECS protocol aimed to stabilize energy dissipation among CHs and increased the network lifespan (Ye *et al*., 2005). To do that EECS utilizes some

Table 1: A summary of unequal clustering routing protocols

Protocol	Network type	BS location	Data gathering	CH selection	Cluster size based on CH's	CH state	Intra-cluster communication	Inter-cluster communication	Compared to protocols
UCS (Soro and Heinzelman,2000)	Homo/ hetero	Center	Periodic	Preset/probabilistic	Distance	Static/ dynamic	Single hop	Multi-hop	ECS
EECS (Ye *et al*., 2005)	Homo	Outside	Periodic	Probabilistic based on energy	Distance	Dynamic	Single hop	Single hop	LEACH
EEUC (Li *et al*., 2005)	Homo	Outside	Periodic	Probabilistic based on energy	Distance	Dynamic	Single hop	Multi-hop	LEACH, HEED
UCR (Chen *et al*., 2009)	Homo	Outside	Periodic	Probabilistic based on energy	Distance	Dynamic	Single hop	Multi-hop	HEED
EEDUC (Lee *et al*., 2008)	Homo	Outside	Periodic	Waiting time (node degree and energy)	Distance, node degree and energy	Dynamic	Single hop	Multi-hop	LEACH, EEUC
MRPUC (Gong *et al*.,2008)	Homo	Center	Periodic	Competitive based on energy	Distance and energy	Dynamic	Single hop	Multi-hop	HEED, MRPEC
PEBECS (Wang, 2009)	Homo	Outside	Periodic	Heuristic algorithm (Energy, distance and node degree)	Distance	Dynamic	Single hop	Multi-hop	LEACH, HEED, EARACM
EEMUCR (Nurhayati,2012)	Homo	Outside	Periodic	Weight function (energy, distance, node degree difference)	Distance	Dynamic	Single hop	Multi-hop	UCR, BCDCP
EB-UCP (Yang, 2009)	Homo	Center	Periodic	Probabilistic based on energy	Distance	Dynamic	Single hop	Multi-hop	LEACH, EEUC
LUCA (Lee *et al*., 2011)	Homo	Center	Periodic	Random backoff scheme	Distance and network density	Dynamic	Single hop	Multi-hop	Max-Min, CAWT
ULCA (Zhao and Wang, 2010)	Homo	Center	Periodic	Probabilistic based on energy	Distance	Dynamic	Single hop	Multi-hop	EEUC
IEEUC (Pin *et al*., 2010)	Homo	Outside	Periodic	Probabilistic based on energy	Hop-count to BS	Dynamic	Single hop	Multi-hop	EEUC
I-LEACH (Ren *et al*., 2010)	Homo	Outside	Periodic	Probabilistic based on energy	Distance	Dynamic	Single hop	Single hop	LEACH
EADUC (Yu *et al*., 2011)	Homo/ hetero	Outside	Periodic	Waiting time based on energy	Distance and energy	Dynamic	Single hop	Multi-hop	LEACH, LEACH-M, HEED,EEUC
EDUC (Yu *et al*., 2011)	Hetero	Outside	Periodic	Waiting time based on energy	Distance and energy	Dynamic	Single hop	Single hop	LEACH, HEED
EC (Wei,2011)	Hetero	Edge	Periodic	Probabilistic based on energy	Distance	Dynamic	Single hop	Multi-hop	HEED, UCR
UHEED (Ever *et al*., 2012)	Homo	Outside	Periodic	Probabilistic based on energy and intra-communication cost	Distance	Dynamic	Single hop	Multi hop	HEED, LEACH, ULEACH
MUC (Chaudhuri *et al*., 2013)	Homo	Outside	Periodic	Competitive based on energy	Distance	Dynamic	Chain-based	Chain-based	LEACH, TEEN, APTEEN, PEGASIS
EAUCF (Bagci and Yazici,2013)	Homo	Center/ outside	Periodic	Probabilistic based on energy	Distance	Dynamic	Single hop	Single hop/ Multi-hop	LEACH, CHEF,EEUC
HUCA (Baranidharan *et al*., 2014)	Homo	Outside	Periodic	Probabilistic	Distance based on energy	Dynamic	Single hop	Multi-hop	LEACH
NEEUC (Wankhade,2015)	Homo	Center	Periodic	Probabilistic based on energy and distance	Distance	Dynamic	Single hop	Multi-hop/ Multi-path	-
RUHEED (Gagliardi,2015)	Homo	Outside	Periodic	Probabilistic based on energy and intra-communication cost	Distance	Dynamic	Single hop	Multi-hop	LEACH, HEED, UHEED
EEVSCA (Dhanpal *et al*., 2015)	Homo/ hetero	Outside	Periodic	Waitingtime based on energy	Distance and energy	Dynamic	Single hop	Multi-hop	EEDU

parameters and techniques to perform CH selection and cluster formation and reduce the overhead of control messages.

In CH selection phase, nodes are exchanging messages to advertise their competition information for being CHs. So, for a particular radio range, the node with the highest remaining energy will be CH and this makes other nodes in that range give up their competition.While in cluster formation phase, the joining of member nodes to CHs occurs based on a trade off between the distance of CH-to-BS and the distance of node-to-CH so that load gets balanced among CHs. So, the cluster size gets smaller if the distance of CH to the BS gets larger and vice versa. Furthermore, to reduce the message overhead, EECS sets the probability Threshold (T) to a suitable value, so that it satisfies a tradeoff between less overhead of control messages and enough number of candidate nodes which participate in CH selection phase. With this intention, the value of the Threshold (T) should neither be so, high leading to an increase in message overhead nor too small and thus reducing the number of CH candidate nodes.

EECS achieved improvements in performance over LEACH protocol regarding a uniform distribution of CHs, balancing energy dissipation among CHs and increasing network lifetime. However, EECS does not consider multi-hop forwarding in inter-cluster communication and thus reduces its scalability. Besides, the overhead of control messages would be increased proportionally to the size of the network, since all member nodes should know about the distance between CHs and BS.

EEUC: Li *et al*. (2005) established an unequal-sized clustering routing protocol called EEUC by utilizing a novel clustering algorithm. Also, the protocol aims to mitigate the hot-spot problem and ensures that clusters distribute equally over the network.

Initially, in CH selection phase, a certain number of nodes participat to be CHs ccording to a redefined Threshold (T). Each node picks a random value in Gupta *et al*. matches it with the Threshold (T) so, that if the value is lower than the threshold the node will be a tentative CH else, it goes temporarily to a sleep mode. After that tentative CH nodes exchange with each other the message COMPETE-HEAD-MSG which includes (ID, Rcomp, RE) where ID is the Identity, Rcomp represents the competition radius and RE is the Residual Energy. Then, each tentative CH node competes with other tentative CH nodes which located within its competition radius and the final CH will be the node with highest residual energy. Eventually, CH nodes send out FINAL-CH-MESSAGE to inform other nodes for cluster formation.

In data transmission to forward data to the BS, the CH node chooses the next CH according to the distance and remaining energy, so that if there are two next-hop CH nodes with approximately equal distances, then the CH node with a higher energy will be picked as the next-hop.

EEUC out performed both LEACH and HEED protocols in reducing energy dissipation, distributing load among CHs and increasing the network lifespan and the stability. However, EEUC requires a lot of control messages which could cause extra overhead (Liu, 2012) and results in isolated nodes (Yu *et al*., 2011). Furthermore, the processes of CHs selection and cluster formation repeated for every round.

UCR: Chen *et al*. (2009), proposed the UCR protocol as a solution to mitigate the hot-spot problem. It comprises two parts, unequal-sized clustering method and an energy-aware forwarding protocol. So, in the first part, the cluster formation is similar to that of EEUC protocol (Li *et al*., 2005) where the network is divided into clusters of different-sized according to the distance between CHs and the BS.

While in the second part, data gathered in each clusterare forwarded to the BS in three manners. First, to select the next hop, two parameters are considered, the remaining energy and the path cost of the next CH to the BS where a trade-off between these two parameters is made. Second, the CHs which located next to the BS send their data packets directly using a single-hop. Third, in a case, if a CH node selected a next CH node located along to the BS with energy less than its energy, the decision will be to send data to BS directly. So, these methods of data transmission could contribute to balance energy dissipation among CHs and achieve an increase in the network lifespan.

Regarding the simulation, results showed that UCR prolongs the network lifespan more than HEED protocol considering FND and LND metrics. However, the distances between sensor nodes were calculated based on the received signal strength and this may lead to errors in case of noise presence in real applications.

EEDUC: The aim of EEDUC protocol Lee *et al*. (2008) was to solve the hot-spot problem and balance energy dissipation across the network. In EEDUC, all sensor nodes participate in the competition of being CH. In CH selection, the remaining energy and node degree are considered. Then, each elected CH node announces its advertisement message of being CH to its neighbours which locate in its competition radius. The competition range of each node is already calculated based on the distance to the BS, the energy and the node degree. Finally, in cluster construction, nodes join to the nearest CH. EEDUC outperformed LEACH and EEUC protocols in terms of balanced energy dissipation and network lifespan.

MRPUC: Gong *et al*. introduced the MRPUC protocol to enlarge lifespan of WSN. MRPUC adopts a multi-hop routing for transmitting data to the BS. Furthermore, MRPUC uses some techniques to ensure that even energy consumption across the network happened. First, in cluster head selection phase, MRPUC chooses CH with highest residual energy and makes the clusters closer to the BS small in size. Second, in cluster formation phase, the rule of joining a node to a certaincluster relies on the remaining energy of CH as well as on the distance. Third, in data transmission, each CH chooses the next CH of the highest remaining energy and the minimum energy dissipation for transmitting the data packet to the BS.

MRPUC out performed both HEED and MRPEC (a version of MRPUC adopts an equal-sized clustering style) protocols. Moreover for MRPUC, the interval between the FND and LND was small and it implicitly confirmed that the consumption of energy was even across the network.

PEBECS: Wang *et al.* (2009) proposed PEBECS protocol to tackle the problem of hot-spot and satisfy even energy dissipation across the network. For this purpose, the protocol adopts a heuristic algorithm to select the CH. This algorithm relies on a weight function which involves the remaining energy, degree difference, node degree and node's location.

The result of simulation confirmed that PEBECS outperformed LEACH, HEED and EARACM protocols concerning even energy dissipation among CHs, reducing energy dissipation and increasing the network lifespan.

EEMUCR: Nurhayati (2012) introduced the EEMUCR protocol to tackle the uneven energy dissipation and to solve the hot-spot. In this protocol, after deploying the network, the first process is to select a node of the topmost remaining energy to be the Cluster Head Leader Node (CHLN) without member nodes. Then, the whole network is partitioned into equal levels and each level is subdivided into unequal-sized clusters. Then, the selection of CH for each clusterdepends on a weight function which involves the energy, distance to BS and degree difference of the node. While in data transmission, each CH receives data, aggregates data and then aggregated data are transmitted to cluster head leader node CHLN node which directly transmits incoming data packets towards the BS. As a result, all CHs near to the BS will not be burdenedwith relaying substantial data traffic to the BS. EEMUCR achieved improvements over BCDCP and UCR protocols by 45 and 60%, respectively.

EB-UCP: The EB-UCP protocol was proposed by Yang and Zhang (2009) to mitigate the hot-spot problem. In EB-UCP, sensor nodes are distributed throughout a circular field with a particular number of layers (L1, L2, ..., Lk) around the field center where the BS is located. Apart from previous unequal-sized clustering protocols, EB-UCP protocol considers the density of nodes in all layers during the deployment of the network, so that the energy dissipation of each layer is equal to others. Also, to satisfy unequal-sized clustering, nodes in the layer close to the BS have a high probability of being CH and this probability will reduce as we move to outer layers. Upon this probability, small clusters will be in the layer close to the BS whereas large size clusters in the layer far away from the BS.

The results of the simulation showed that parameters like the count of layers, aggregation ratio and count of nodes in the first layer have a substantial effect on the network lifespan. Also, the performance of EB-UCP over LEACH and EEUC protocols for the network lifespan and with improvement by 33-54% over other protocols.

LUCA: To tackle the unfairness of energy consumption in WSN networks, the LUCA protocolin (Lee *et al.*, 2011), utilized a location-based unequal clustering algorithm. In the setup phase, to evenly distribute cluster heads across the network a back-off time wasadopted for CH election. Also, to get unequal-sized clustering, the distance of CH-to-BS was used to calculate the size of each cluster. Furthermore, the researchers conducted a theoretical analysis to compute the size of clusters according to the density and distance of CH node.

The performance of LUCA was evaluated by conducting a simulation and being compared to Max-Min and CAWT protocols and the results showed that LUCA outperformed the above protocolsin different scenarios, especially in dense networks.

ULCA: The ULCA protocol was introduced to deal with unbalanced energy consumption caused by the hot-spot problem (Zhao and Wang, 2010). ULCA runs a local implementation for CHs selection and for joining member nodes so as to reduce the overhead of control messages and hence prolonging the network lifetime. Mainly, the process of implementing ULCA consists of three phases which are initialization, cluster setup and data transfer. In the initialization phase, the field of the network is partitioned into layers of different widths around the BS which is located at the center. Besides, the nodes of each layer have its own probability of being CH. For instance, nodes at the inner layer (i.e., next to the BS) have a high probability of being CH and this probability degrades as much as the layer is located farther away from the BS. As for cluster setup phase, there are four sub-phases which are candidate announcement isolated node checking, competing for CH and member nodes joining. More, all exchanged messages in the cluster setup phase are bounded by twice of each node's radius to minimize energy dissipation.

For data transmission phase, a pair of weights was involved in selecting the next CH node. The first weight is to choose the CH node with forwarding times less than the averaged forwarding of adjacent CH nodes whereas the second weight represents the distance of next CH-to-BS.

Based on conducted simulation, results showed that ULCA protocol decreases energy dissipation across the network and balances energy among CHs more than EEUC protocol. The reason for that gain in energy efficiency for ULCA was related to well-distributed CHs, reduction in messages overhead (i.e., during clustering and joining members) and using an efficient routing manner.

IEEUC: To implement unequal clustering, IEEUC by Pin *et al*. (2010), utilized node degree to acquire node's location instead of using a GPS-like device. So, node degree represents the count of hops which are required for the node to reach the BS. Here, the count of hops is calculated by using flooding algorithm. Besides, the novelnotion in the IEEUC protocol is that the cluster's size does not only depend on the distance to the BS but also on the node degree and this makes IEEUC applicable in a network with nodes deployed unevenly. Also, the number of CHs required for covering the network entirely and the node's probability for being a CH are statistically calculated.

The comparison between IEEUC and EEUC protocols was analytically illustrated and showed that preference of the parameters adopted by IEEUC such as the reliability of calculating node's location and the communication radius of CHs. Nevertheless, there was no explicit mention about the effect caused by flooding algorithm on the delay time oronthe energy consumption due to the overhead of control messages.

Improved-LEACH: Based on the original LEACH protocol (Heinzelman *et al*., 2000), improved-LEACH by Wang *et al*. (2013) utilized a unequal-sized clustering technique for network structure to deal with unbalanced energy consumption among CHs. Also, it adopts a single hop for inter-cluster communication. In addition, the size of clusters placed far away from the BS is smaller whereas for clusters nearer to the BS is larger to guarantee even energy dissipation. In improved-LEACH, both the energy and distance are considered in CHs selection. Furthermore, the distribution of CHs in Improved-LEACH is more even than that of LEACH protocol and this leads to large-area coverage.

Both improved-LEACH and LEACH protocols were simulated. The results showed that the network lifespan was increased with Improved-LEACH more than that of LEACH. Consequently, the life time was improved by 132 and 30% over LEACH for FND and LND metrics, respectively.

However, the improved-LEACH protocol uses a single-hop routing and it is not always preferredto tackle energy efficiency in clustering-based routing protocols, especially when the networks are large-scale.

EADUC: Yu *et al*. (2011) introduced a protocol called EADUC to overcome unbalanced energy dissipation and decrease the effect of the hot-spot problem. In this protocol, to get an unequal clustering, the distance to the BS is considered. So, according to the distance consideration, the nearer CH has the smallest size and the farthest CH has the largest size. The clustering process starts by calculating the average of residual energy of neighbouring nodes for each sensor node within a predetermined radio range. Then, a waiting time for each node is calculated by dividing the averaged remaining energy of neighbours to the energy of the stated node. However, this waiting time is used for competing in CH election phase. Later on, the node of highest remaining energy succeeds to be a CH and all nodes located within its competition radius become plain nodes. After completing CHs selection phase, clustersare formed by joining plain nodes to an associated cluster based on the nearest CH. In data transmission, EADUC uses a single-hop routing for intra-cluster communication to transmit data gathered by nodes to their CHs whereas a multi-hop adopted for inter-cluster communication to convey data to the BS. More, the next-hop node will be selected from the neighboring CH nodes according to the highest remaining energy as well as the least cost path to the BS.

In simulation experiments, EADUC was evaluated in both homogeneous and heterogeneous scenarios to see its efficiency in energy dissipation and network lifespan. Results showed that the performance of EADUC over LEACH, LEACH-M, HEED and EEUC protocols.

EDUC: The EDUC protocol by Yu *et al*. (2011), Ren *et al*. (2010), aimed to prolong the network lifetime. EDUC adopts an unequal-sized clustering to balance energy dissipation among CHs whereas a CHs rotation was employed to balance energy dissipation among nodes. Also, EDUC utilized a single-hop routing to transmit data gathered by CHs towards the BS. So, the CHs close to the BS serve large size clusters while the distant CHs serve small size clusters so as to reserve enough energy for long distant transmissions. Besides in EDUC, the maintenance of network topology does not need to include the entire network since the changes would be limited to wherever is required. So, the process of CHs rotation would include only the CHs whose residual energy reached a certain threshold so that the overhead of re-clustering the entire network would be avoided. Furthermore, each node takes the role as CHs just once during the network lifespan and this also reduces the energy dissipation of regular CHs rotations.

EDUC increased the network lifetime more than that of LEACH and HEED protocols. However, utilizing a single hop fashion for inter-cluster transmission is not preferred in WSN networks as it mostly reduces scalability.

EC: The EC protocol by Wei (2011), involved a localized unequal-sized clustering algorithm and a multi-hop routing. Also, the nodes in EC are heterogeneous with BS placed on the edge of the network field. Besides, the network area is subdivided into regions where each region accommodates a certain number of clusters. More, the size of a cluster is indicated by hop-count to the BS, so that the effect of the hot-spot problem can be reduced. So,the probability of a node to work as a CH relies on the hop-count from the BS so that the nodes next to the BS have a higher probability.

Mainly, the implementation of EC includes CH selection, cluster construction and data transmission phases. In CH selection, every node picks a value randomly by Gupta *et al.* and if it is fewer than the probability threshold it becomes a candidate CH otherwise, it will be a non-CH node. For each region, the candidate CHs within a common radius compete based on the remaining energy; the winner will be a final CH. Then, the non-CH nodes are asking the associated CH for joining based on the distance. Eventually, in data transmission phase, the protocol tries to achieve less overhead and equalize energy consumption among CHs. Simply, to select the next-hop the CH sends a request for route discovery to the CH nodes in the next region along to the BS. So, each asked CH node establishes a route reply timer inversely to its residual energy and thus the more residual energy CH node will respond firstly and be the next-hop CH node.

Based on the simulation conducted for HEED, UCR and EC protocols, results showed that EC outperformed others in balancing energy dissipation among CHs and in increasing the network lifespan.

UHEED: Ever *et al.* (2012) proposed UHEED as an improved version of the well-known HEED protocol (Younis and Fahmy, 2004). The aim of UHEED protocol was to increase the network lifespan and evenly distribute energy dissipation by adopting unequal-sized clustering. In UHEED to select a node as a final CH, the remaining energy and node degree are considered. Also, the size of each cluster relies on the distance, so that more clusters with small size are near to the BS and fewer clusters with the large size in distant regions.

The simulation for the LEACH, unequal-LEACH, HEED and UHEED protocols was conducted and the results confirmed that the network lifespan of UHEED was over other protocols especially when the LND metric is considered. However, the protocol needs to improve the network lifespan by considering the FND metric since, it clearly expresses how long the period of the network stability was instead of using LND metric.

MUC: To overcome the problem of energy constraint, the researchers by Chaudhuri *et al.* (2013), introduced a protocol called MUC. Nodes in this protocol presumed to be deployed randomly over the network's regions. The MUC protocol consists of two phases; they are setup and data transmission. In the setup phase, there are two sub-phases, the CH selection and cluster construction. In CH selection sub-phase, depending on the received signal strength, a certain number of tentative CH nodes are chosen. Then, a competition process will be run between tentative CH nodes located within each other range and the selection of the final CH nodes would be based on the residual energy. While in the cluster construction, each non-CH node will join the nearest CH. Finally, in the data transmission phase, a PEGASIS-based method is utilized to construct a data chain to transmit and receive until the BS is reached.

EAUCF: The goal of EAUCF protocol was to increase the network lifespan by avoiding the CH from being dead due to its location next to the BS (i.e., the hot-spot problem) or because its battery tends to run out (Bagci and Yazici, 2013). To tackle this situation, EAUCF used fuzzy logic to select the appropriate competition radius for each CH.

Initially, EAUCF selects a set of nodes to be candidate CH nodes according to a predefined probability, so that each node can participate in CH election. So, to take part in the CH selection, each node randomly picks a value by Gupta *et al.* and if it is under the probability threshold then the node will be a candidate CH node. After that each candidate CH node passes its distance from the BS as well as its remaining energy to a Fuzzy algorithm in order to estimate the appropriate competition radius. Then, competitionis runbetween candidates located within each other competition radius and the candidate with the highest remaining energy would become a final CH. Later, the non-CH nodes join their associated CH according to the nearest distance.

Different scenarios of the simulation were conducted. These scenarios were a single-hop routing, multi-hop routing, dense network and outside-located BS for LEACH, EEUC, CHEF and EAUCF protocols. In all scenarios of simulation, the performance of EAUCF was higher than other simulated protocols considering FND and HNA metrics except in a single case where the network was dense the performance of EEUC was a little bit better than EAUCF in terms of FND.

HUCA: Baranidharan *et al.* (2014) introduced the HUCA protocol which is anunequal clustering and a multi-hop routing protocol. In HUCA, the network field is divided into three equal regions and for each region, a different number of CHs are assigned so that the idea of unequal clustering satisfied. So, the region near the BS owns more CHs than others. Besides, the process of CH selection is random upon probability. So, the CH node of the highest remaining energy among its neighbours will be chosen as a final CH. Finally, the elected CH nodes send out an advertising message to its neighbouring nodes to ask them for cluster formation.

NEEUC: Wankhade (2015) introduced a multi-hop protocol called NEEUC to deal with the energy hot-spot. Initially, the fieldis partitioned into unequal layers around the BS which is locatedat the center. Next, each node calculates its competitive radius by considering the distance to the BS (based on RSSI). Then, clusters are constructed by joining the plain nodes to the associated CH. After completing the setup phase, data are transmitted from clusters of out-layer to CHs at inner-layer and then towards the BS (by using a multi-hop route selected from multi-path routes). Unfortunately, the researchers neither showed any analysis about the performance of NEEUC protocol nor made a comparison with other protocols.

RUHEED: The rotation of CH technique was suggested by the researcher derive a new version of the UHEED protocol. RUHEED is a multi-hop routing protocol of three phases; CH election, cluster construction and CH rotation. The algorithm of CH election is similar to that of HEED (using energy-based probability). While to form clusters, each node joins to the nearest CH so thatclusters (of the size that corresponds to the competitive radius of each CH) are formed. Besides, the competitive range for each CH is calculated in a similar way to that of EEUC protocol and bounded by the distance from BS. Furthermore, to reduce messages overhead which caused by re-running CH election phase, the next CH node for each cluster is chosen from the same cluster with the highest remaining energy. However, the process of CH election will be re-run only in case the energy of any node runs out completely.

According to the researcher analysis, RUHEED out performed LEACH, HEED and UHEED protocols in terms of the network lifespan, especially for both metrics, FND and HNA, the performance of RUHEED was the highest.

EEVSCA: Wang *et al.* (2013) introduced the EEVSCA protocol with features of unequal-sized clustering and multi-hop forwarding. Mainly, EEVSCA targets to balance energy dissipation and prolong the network lifespan. In this protocol, the algorithm of clustering includes two phases. The first phase works within the intervals (T1& T2) and involves the calculation of waiting time for each node by considering their remaining energy. So, the calculation must ensure that the waiting time must be >T2 which is the deadline to finish the CH selection phase. Besides, each node in the network field must calculate its competitive radius using the distance and remaining energy. So, the clusters will be in different sizes to achieve a certain balance of load distribution across the network. Hence, more clusters with small size near the BS and fewer clusters with large-size as we move away from the BS. Whereas, the second phase includes joining plain nodes to their associated clusters based on the distance.

The characteristics of EEVSCA such as even distributed CHs, no isolated nodes and using distance and energy parameters to compute CH radius make the protocol efficientin terms of energy efficiency. However, there was not clear statistics that clearly show the performance of this protocol.

CONCLUSION

The study examined the problem behind the adoption of unequal-sized clustering which is the hot spot. The hot spot problem happens when a multi-hop style of routing is applied. In this study, several parameters are used by the protocols to implement the notion of unequal clustering. Some of these parameters are the distance to the base station, the density of node, the residual energy, the node degree and so on. Importantly, the primary goal of unequal-sized clustering protocols is to tackle the hot spot problem in WSNs but by achieving this aim, the network lifetime would be eventually increased. Also, during this study, the performances of the unequal-sized clustering protocols are more than that of equal-sized clustering protocols regarding the network lifetime, through put, stability and scalability. Finally, the study has presented a summary in Table 1 for the unequal-sized protocols which are reviewed here in based on some selected characteristics to give a quick glance on each protocol.

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