LEACH inspired hierarchical routing protocols for wireless sensor networks

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Abstract: A wireless sensor network is a collection of various sensor nodes which are organised into a complex and cooperative network. These sensor nodes, which are used not only for monitoring but also for capturing the required data from the environment. Most of the research work on WSNs is done keeping in view the energy efficiency, scalability and efficient routing. In WSNs, the most of energy efficient and scalable routing protocols are hierarchical (cluster-based) routing protocols. Among all the clustering techniques low energy adaptive clustering hierarchy (LEACH) is one of the fundamental protocols. We have surveyed and analysed different hierarchical routing protocols that are being modified from LEACH. The main focus of our research is to study how these variant routing protocols work in order to enhance the network life time and how the quality of routing protocols are improved for the wireless sensor network. This paper explains some of the major issues faced by LEACH and suggest the way how these are tackled by variant versions of LEACH. A comprehensive discussion is provided in the table highlighting the relative advantages and disadvantages of some of the prominent protocols.

Keywords: wireless sensor networks; WSNs; clustering protocol; cluster head selection; energy efficiency; scalability; LEACH protocol.

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1 Introduction

A wireless sensor network (WSNs) is composed of a large number of sensor nodes with sensing, processing and communication facilities which are deployed either inside the phenomenon or very close to it. A node collects data from its vicinity and then transmits it to base stations (BS) for further analysis and processing. Since WSN consists of a large number of energy limited sensors, an energy-efficient and scalable network protocol is an important consideration in WSN applications. In order to address the constraints related to WSN many routing protocols are proposed in literature. Some of the proposed routing protocols consider direct transmission for which sensor nodes directly transmit their sensed data to a BS. In direct transmission, the nodes located far from the BS get their energy drain off rapidly and will die quickly since they dissipate more energy in transmitting the sensed data. This energy hole creations make the direct transmission protocols inefficient for data routing. On considering other routing protocols, minimum transmission energy protocols transmit sensed data packets to BS by using multi-hop relay. As a result, nodes located near to the BS will die quickly since they act as ending relay nodes to send the sensed data on behalf of other remote nodes. Hence, direct transmission and minimum transmission energy protocol (Tan and Körpeoglu, 2003) result in a poor energy distribution among nodes. By which, some of the sensor nodes are still active and on the other side some have died out. As a result network gets portioned and partial network may not efficiently communicate the sensed data. Thus, there is a need to optimise the network architecture in order to minimise resource consumption and make efficient use of it. These requirements and constraints with WSNs make their architecture and protocols both challenging and divergent from the other traditional internet-based architectures.

In general, depending upon network structure, routing in WSNs can be divided into flat-based routing (data-centric routing), hierarchical (cluster-based) routing and location-based routing. Here just a brief introduction is given about all the routing techniques. But while talking about energy consumption and scalability, clustering communication protocols are superior approach amongst all.

1.1 Flat routing

In flat routing protocols each sensor node play the same role and have the same functionality while transmitting and receiving the sensed data. However, due to large number of nodes it is not possible to specify and assign a global identifier to each node.

Therefore, the BS generates and sends queries to different parts of the network and waits for the reply in form of sensed data from other remote sensors in selected parts of the network. This query-based approach is called as data centric routing. Sensor protocols for information via negotiation (SPIN) and direct diffusion (DD) (Zabin et al., 2007) are two such examples which act as energy savers by data negotiation and discard the redundant sensed data.

1.2 Hierarchical (cluster-based) routing

In this type of routing, sensor nodes play different roles while transmitting and receiving the sensed data. Some of the nodes act as a processing and communicating unit, while other acts as a sensing unit for the target area. Hierarchical routing is a two layered architecture where one layer corresponds to cluster head (CH) and its member nodes while other is responsible for routing between nodes and sink as BS. The main aim of hierarchical routing is to make efficient use of energy consumption of sensor nodes by confining them within a particular cluster. To reduce the number of transmitted data packets to the sink, data aggregation and fusion is performed. CH is the node which collects sensed data from other cluster member nodes, aggregating all sensed data and transmitting the aggregated data to the sink as BS. Creating clusters and assigning communication task to CHs contribute a network to be more energy efficient and scalable. The main goal of all the hierarchical routing protocols is to appropriately create clusters; elect CHs and establish routing between nodes or clusters in order to reduce the energy consumption.

1.3 Location-based routing

The location information-based routing algorithm works on the nodes location to discover the route, forward data, enables directional transmission of the information and avoids information flooding in the entire network. Here, the main aim is to optimise the routing and can be achieved by reducing the control overhead. Moreover, with location-based network topology, network management becomes simple and optimised global network can be easily achieved.

Hierarchical model is basically in demand for applications that require scalability to hundreds or thousands of nodes as other conventional protocols of direct transmission, minimum-transmission-energy and multi hop routing are not embedded with scalability as additional feature. Hierarchical techniques perform data aggregation and fusion in order to decrease the number of messages transmitted directly to the sink as BS and thus leads to energy optimisation. In hierarchical technique, CH nodes are selected from the set of nodes in the network and then remaining nodes get associated with these heads. After cluster formation the CHs are perform intra cluster, inter cluster coordination and communications. In this paper, we have proposed LEACH (Heinzelman et al., 2000) which is most popular hierarchical routing protocol for WSNs. This paper aims to describe the LEACH-based routing protocols in such a way that different modifications and extensions of the said protocol could be understood and are distinguishable and this would be beneficial for researchers in future to develop new hierarchical protocols.

Rest of the paper is organised as follows. Section 2 provides the complete explanation of LEACH, a most popular hierarchical (cluster-based) routing protocol and its advantages and disadvantages. Section 3 provides the comparison of modified variants of

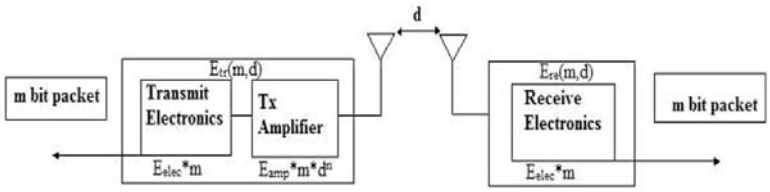
low energy adaptive clustering hierarchy (LEACH)-based clustering protocols considering various parameters. Finally Section 4 concludes the article.

2 Hierarchical (cluster-based) routing protocol

In WSNs, clustering is widely used for designing various energy efficient protocols. One of the most common protocols used in this category is LEACH (Heinzelman et al., 2000). LEACH is a first hierarchical (cluster-based), self-organising, ability to perform re-clustering and dynamic routing protocol for WSNs. In the case of static clustering a fixed cluster-head is assigned at the time of network initialisation. As CH is responsible for collecting data from all the neighbour nodes, aggregating data, finally transmitting the aggregated data to base station and synchronisation between member nodes, CH dissipates more energy and die quickly. To tackle this problem LEACH uses randomised allocation of cluster-head by which battery of individual node is saved. In this way LEACH enhances the network lifetime and also reduces the energy dissipation by compressing the data before transmitting to cluster-head.

In LEACH protocol it is assumed that the deployed network has homogeneous characteristics such as all nodes start with equal initial energy level and have same computing and communication capabilities. Each sensor node is location aware. Base station and sensor nodes are considered to be stationary and time synchronised with respect to a global clock. Transmission range of sensor nodes is adjustable and any node can transmit data directly to any other node or sink. Further it is assumed that data collected by sensor nodes present in a cluster is correlated and can be perfectly aggregated into a single packet. Figure 1 presents the energy model adopted in LEACH protocol for data communications.

Figure 1 Energy radio model of LEACH protocol



According to the model transmission and reception radio equations (1) and (2) are defined as:

$$\begin{aligned} E_{tr}(m,d) &= E_{elec}(m) + E_{amp}(m,d) \\ E_{tr}(m,d) &= \left(E_{elec} + E_{amp} * d\right) * m \end{aligned} \tag{1}$$

$$\begin{aligned} E_{re}(m) &= E_{elec}(m) \\ E_{re}(m) &= E_{elec} * m \end{aligned} \tag{2}$$

where E_{elec} is distance-independent energy consumed in running transmitter or receiver circuitry, E_{amp} denotes the energy consumed by the transmitter's amplifier.

LEACH protocol operates in rounds, where each round basically consists of two phases. First is a setup phase and second is steady state phase.

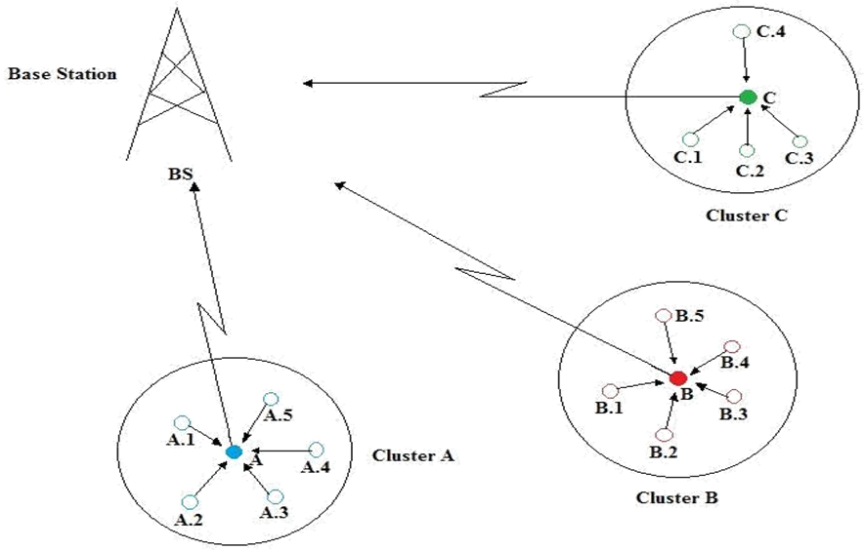
In setup phase whole network nodes are divided into multiple clusters. On basis of proposed desired percentage P of CHs and the last record of CHs, some nodes elect themselves as CHs independently from other nodes. Nodes which have not been CHs in last $1/p$ rounds generate a random number between 0 to 1 and if it is less then threshold $T(n)$ then nodes become CHs. Threshold value is set through the given formula in equation (3).

$$T(n) = \begin{cases} \dfrac{P}{1 - P * \left(r \bmod 1/P\right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

where G is the set of nodes which have not been elected as cluster-head in previous $1/p$ rounds, P is the proposed percentage of CH, r is the current clustering round.

When node becomes CH in current round, it can again be selected as CH after next $1/p$ rounds. In this way LEACH ensures that every node will serve as a CH equally and perform uniformly distributed energy dissipation throughout the entire network. A cluster-based model is depicted in Figure 2. Elected CH broadcasts its current status using CSMA MAC protocol to BS and to other cluster member nodes. Nodes other than CH will select its CH on comparing RSSI from multiple CHs from which they have received broadcasted advertisements. CH establishes TDMA schedule for its associated cluster members for make collision free data communication.

Figure 2 Cluster-based model (see online version for colours)



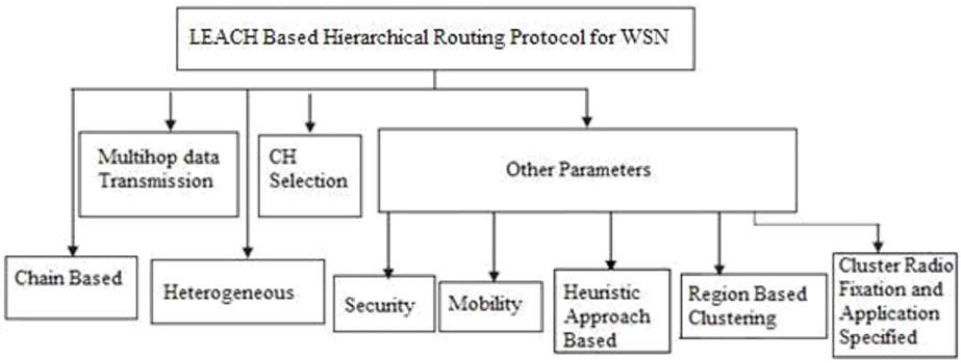
As soon as clusters formation is done, Steady State phase starts. In this phase nodes communicate to CH within the allocated TDMA time slots else they remains in sleeping mode. Due to this impute LEACH reduces energy consumption and enhances battery life of all individual nodes. When data from all nodes of cluster have been accumulating to

CH, it aggregates, compress and transmit to sink as BS. The steady state phase is longer than setup phase.

LEACH protocol outperforms in energy consumption through dynamic clustering. Data transmission is confined within the cluster which reduces the energy consumption by communicating CH directly to the nodes and the base station. The LEACH protocol uses the mechanism of cluster-head rotation, elects cluster-head randomly and aggregates the information that is been collected by the sensor nodes and this helps in to limit high amount of traffic generated within the network. In this way, a large-scalable network without traffic overload can be deployed and will also result in energy efficient network topology as compared to others. Also, LEACH is entirely a distributed protocol and need not require global knowledge of network.

Though having many advantages, LEACH has some limitations which have been addressed in its modified and extended versions. LEACH works on single-hop communication where each node can transmit directly to the CH and further to sink, which further makes LEACH not applicable for large region networks. Furthermore, the concept of dynamic clustering results in extra overhead, like CH changes, advertisements etc., which leads to increase in energy consumption. LEACH protocol significantly relies on CHs rather than cluster members for communication and leads to incur robustness issues like failure of the CHs. As CHs directly communicate with sink so, no inter-cluster communication is possible and to make it possible high range of transmission power is required. By this only, LEACH is not best suited for large-scale networks that interns require single hop communication. In LEACH, CHs are not uniformly distributed within the cluster which means CHs can be located at the edges of the cluster that sometimes leads to the collision. It will not work well with the applications that require large area coverage along with multi-hop inter-cluster communication. These all issues and advantages related to LEACH and other characteristics and constraints related with WSNs like deployment strategy, optimal energy consumption, computation and storage, scalability, security, fault tolerance, reliability, quality of service (QOS), adaptability and bandwidth utilisation leads to modifications & extensions and improvements proposed for hierarchical routing protocols. Most of these proposals are the modified variants of LEACH protocol (Tyagi and Kumar, 2013). Figure 3 describes various parameters based upon which various categories of LEACH-based protocols have been developed. The purpose of this paper is to provide the detailed description of all those modified LEACH-based protocols according to the categorisation shown in Figure 3.

Figure 3 Categorisation of LEACH related routing protocols for WSNs



3 Comparison and discussion of existing protocols

On the basis of below parameters the comparison of variant protocols of LEACH is done.

3.1 Chain-based routing protocols

Chain-based routing protocols work on the chain formation within the nodes for data transmission. Such protocols result in energy saving as each single node is communicating with two neighbouring nodes for the chain formation. But here the problem arises is delay which somehow effects the network lifetime. Some of the chain-based routing protocol are PEGASIS (Lindsey and Raghavendra, 2002), EB-PEGASIS (Yueyang et al., 2006), CCBRP (Ali and Refaay, 2011), IEEBP, WEP (Rashed et al., 2012), EHE-LEACH (Tyagi et al., 2013), SEP-MS (Javaid et al., 2013b), U-LEACH (Kumar et al., 2012) and many more.

3.2 Multi-hop data transmission

In cluster-based routing, once the cluster is formed then the next step is to elect CH as CH is only responsible for the data transmission between CHs and BS. Location of BS plays an important role in transmission of data. If BS is located away from the vicinity area then the distance between CH and BS will be more which further increases the transmission cost and leads corresponding CH to die soon. This condition arises in single-hop transmission, but to deal with above cited problem multi-hop data transmission is practiced. This results in parallel transmission to reduce delay and energy consumption. Considering various performance metric such as reliability, load balancing, lifetime enhancement, stability and high data level transmission many multi-hop data transmission routing protocol are studied. Some of the multi-hop data transmission routing protocol are LEACH-ER, LEACH-TM (Weichao et al., 2009), Energy-LEACH, Multi-hop LEACH (Xiangning and Yulin, 2007), BCDCP (Muruganathan et al., 2005), HIT (Culpepper et al., 2004), MCR (Kumar et al., 2011), VIBE (Papadopoulos et al., 2012), ECCRA (Jin et al., 2008), DEECIC (Liu et al., 2012), MLCRA (Liu et al., 2010b), LEACH-D (Liu et al., 2010a), ACT, SHRP, CCRP (Bian et al., 2008), MR-LEACH (Farooq et al., 2010), BCEE (Cui and Liu, 2009), DE-LEACH, KMMDA (Peng and Edwards, 2010), DAO-LEACH (Saminathan et al., 2013), DREEM-ME (Amjad et al., 2013), HEER (Javaid et al., 2013a), TREE-CR (Sahoo et al., 2013), LEACH-HPR (Han, 2010), LEACH-ECD (Wang et al., 2010) etc.

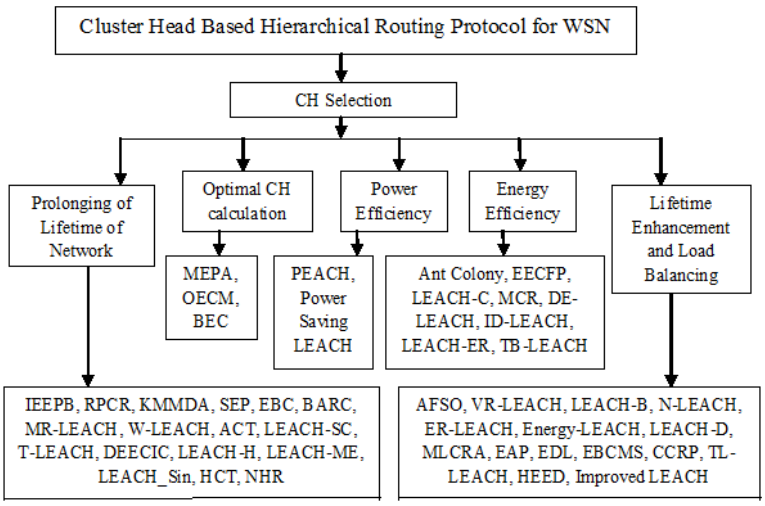
3.3 Heterogeneous routing protocol

Most of the clustered protocols assume that all SNs have equal initial energy which results in homogeneous network. But few protocols avoid this assumption and result in heterogeneity of the network. Various routing protocol which are used for heterogeneous WSNs are SRMCF (Derogarian et al., 2011), EAP (Liu et al., 2009), HEED (Younis and Fahmy, 2004), EHEED, SEP (Smaragdakis et al., 2004), EEFS (Shih et al., 2009), REFS, EDL (Hou et al., 2009), EECHE (Kumar et al., 2009), RMCF, modified HEED (Lin and Tsai, 2006), DAO-LEACH, ESRP (Pramanick and Das, 2014), HEER, Ad-LEACH (Iqbal et al., 2013), LEACH-E etc.

3.4 CH selection routing protocol

In WSNs complexity and energy is the main constraint, to deal with the both clustering of SNs has been widely used. For clustering selection of CH is an important task. Based on the different parameters like power efficiency, lifetime, load balancing, optimal CH calculation and power efficient, the protocols are further classified. Some of the CH selection-based protocols are LEACH-TLCH (Fu et al., 2013), EESAA (Shah et al., 2012), EH-LEACH, EE-LEACH, BCDCP, EECS (Ye et al., 2005), PEACH (Yi et al., 2007), EFSO (Song et al., 2010), ER-LEACH (Al-Refai et al., 2011), EBCMS (Ding et al., 2009), CCRP, TL-LEACH (Loscri et al., 2005), MEPA (Ngo et al., 2007), BARC (Watfa et al., 2009), ID-LEACH (Torkzaban et al., 2009), W-LEACH (Abdulsalam and Kamel, 2010), OECM (Yang et al., 2010), TB-LEACH (Junping et al., 2008), LEACH-H (Wang et al., 2009), T-LEACH (Hong et al., 2009) and others are classified below and shown in Figure 4.

Figure 4 Protocol based on CH selection



3.5 Other parameters-based protocols

Some of the other parameters based upon which selection of CH is made are described below:

- Mobility

  In WSNs the deployment of SNs and BS is random. But with random deployment sometimes the SNs or BS becomes mobile. In such cases clustering protocol which can handle the mobility are considered. Some of the protocols are VIBE, MBC (Deng et al., 2011), ER-LEACH, LEACH-ME (Kumar et al., 2008), LEACH-EM, and RPA.

- Security

  To make the route secure, some of clustering protocols are proposed. HIT, Sec-LEACH and key management schemes are some of the security-based clustering protocol.

- Heuristic approach-based

  Based on artificial intelligence like particle swarm optimisation (PSO), fish swarm optimisation (FSO), ant colony optimisation (ACO), fuzzy logic, genetic measure and Gaussian distribution, the protocols are proposed which optimises the system in terms of both lifetime and energy consumption. Some of them are BCEE, ASFO, LEACH-FL (Ran et al., 2010), LEACH-GA (Liu et al., 2011), FSEP-F (Pal and Sharma, 2013), hybrid PSO LEACH (Raina and Bansal, 2014), K-LEACH (Bakaraniya and Mehta, 2013), etc.

- Clusters radio fixation and application specified

  LSN, LEACH-SM (Bakr and Lilien, 2011), CCCR, ECHR, FTTT (Bhatti et al., 2011), O-LEACH (Suharjono and Hendrantoro, 2011), ACT, MLCRA, LEACH-D, MR-LEACH, LEACH-F are some of the protocols which are application specified and having fixed radio vicinity of the CHs.

- Region-based clustering

  Both the concept direct transmission and clustering are practiced by these types of protocol. The SNs which come in the vicinity of BS use direct transmission but the SNs which are far away from BS, a CH is elected among all nodes and the communication is made possible by clustering routing. So the zonal wise clustering is used for data transmission. Some of the protocols are REECH-ME (Haider et al., 2014), M-GEAR (Nadeem et al., 2013), Z-SEP (Faisal et al., 2013), TSEP, EEE-LEACH (Sharma and Sharma, 2012), CEEC (Aslam et al., 2012), AZR-LEACH (Khan, 2012), FMCDA (Mishra et al., 2012), TLHCLP (Taneja and Bhalla, 2013), EEMHR (Tanwar et al., 2014), LEACH-SC, ER-LEACH, LEACH-A, RPCR (Duan et al., 2009) etc.

Tyagi and Kumar (2013) introduced many LEACH-based variants protocol on the basis of deployment strategy, optimal energy consumption, scalability and mobility. Besides all these there are some more parameters which are required to be considered. In this paper we have additionally considered some of the new and widely accepted approaches such as heuristic-based and zonal section-based approaches. In a way in this paper we have presented an exhaustive and complete survey of LEACH inspired Hierarchical Routing for WSNs.

Table 1 provides a comparison of all the above protocols with respect to various parameters. As WSNs are applications specific, so we have selected various parameters depending upon applications where these can be applied. The detailed analysis of all the variants of LEACH-based routing and clustering protocols with respect to various parameters are listed in Table 1. Various parameters selected for discussion are data transmission, network type, routing type, deployment strategy, energy efficiency, load balancing, scalability and mobility.

Table 1 Comparison table for various LEACH-based protocols

Protocols	*Year*	*Data transmission*	*Network type*	*Routing type*	*Deployment strategy*	*Energy efficiency*	*Load balancing*	*Scalability*	*Mobility of nodes*
LEACH	2000	Single hop	Homogeneous	Probabilistic cluster-based	Random	Good	….	Low	Stationary nodes
LEACH-C	2002	Single hop	Homogeneous	Probabilistic cluster-based	Random	Good	….	Low	Stationary nodes
LEACH-EM	2002	Single hop	Homogeneous	Cluster-based	Random	….	….	Low	Mobile nodes
PEGASIS	2002	Single hop	Homogeneous	Chain-based	Random	Very good	….	Low	Stationary nodes
Binary schemes with and without CDMA	2002	Single hop	Homogeneous	Chain-based	Random	Very good	….	Low	Stationary nodes
HIT	2004	Multi hop	Homogeneous	Multiple clustering	Random	Good	….	….	Stationary nodes
HEED	2004	Multi hop	Heterogeneous	Residual energy and node degree-based cluster	Random	Good	Yes	Medium	Stationary nodes
SEP	2004	Single hop	Heterogeneous	Cluster based on weighted probability	Random	Good	Yes	….	Stationary nodes
TL-LEACH	2005	Two level	Homogeneous	Two level hierarchy based on primary and secondary cluster	Random	Good	Yes	Low	Stationary nodes
BCDCP	2005	Multi hop	Homogeneous	Random clustering	Random	Good	….	Low	Stationary nodes
EECS	2005	Single hop	Homogeneous	Cluster-based	Random	Good	Yes	High	Stationary nodes
LEACH-L	2005	Multi hop	Homogeneous	Cluster-based	Random	Very good	Yes	Very high	Stationary nodes
EB-PEGASIS	2006	Single hop	Homogeneous	Chain-based	Random	Very good	….	Low	Stationary nodes
Modified HEED	2006	Multi hop	Heterogeneous	Cluster-based	Random	Good	Yes	Medium	Stationary nodes
Energy LEACH	2007	Single hop	Homogeneous	Residual energy of SN-based cluster	Random	Good	….	….	Stationary nodes
PEACH	2007	Single hop	Homogeneous	Multi-level clustering	Random	Good	Yes	Medium	Stationary nodes
MEPA	2007	….	Homogeneous	Cluster formation based on network topology and node residual energy	Random	Very good	….	Very high	Nodes are quasi-stationary
Multi-hop-LEACH	2007	Multi hop	Homogeneous	Cluster-based	Random	Good	….	Medium	Stationary nodes
Sec-LEACH	2007	Single hop	Homogeneous	Cluster-based	Random	Poor	….	….	Stationary nodes

Table 1 Comparison table for various LEACH-based protocols (continued)

Protocols	*Year*	*Data transmission*	*Network type*	*Routing type*	*Deployment strategy*	*Energy efficiency*	*Load balancing*	*Scalability*	*Mobility of nodes*
LEACH-ME	2008	Single hop	Homogeneous	Cluster based on minimum mobility	Random	Depends upon mobility of SNs	….	….	Mobile nodes
TB-LEACH	2008	Single hop	Homogeneous	Cluster formation based on shortest time interval	Random	Good	Yes	….	Stationary nodes
ECCRA	2008	Multi hop	Homogeneous	Cluster-based	Random	Good	….	….	Stationary nodes
CCRP	2008	Multi hop	Homogeneous	Cluster-chained formation based on residual energy and number of neighbours	Random	Very good	Yes	….	Stationary nodes
EBCMS	2009	Single hop	Homogeneous	Master and slave-based cluster formation	Random	Good	Yes	….	Stationary nodes
EBC	2009	Single hop	Homogeneous	Cluster-based on more remaining energy of SNs	Random	Good	Yes	….	Stationary nodes
T-LEACH	2009	Single hop	Homogeneous	Residual energy threshold-based clustering	Random	Good	Yes	….	Stationary nodes
RPCR	2009	Single hop	Homogeneous	Time and region based-cluster formation	Random	Good	Yes	….	Stationary nodes
LEACH-H	2009	Single hop	Homogeneous	Cluster based on stimulated annealing algorithm	Random	Good	Yes	….	Stationary nodes
EECFP	2009	Single hop	Homogeneous	Cluster-based	Random	Good	….	….	Stationary nodes
ID-LEACH	2009	Single hop	Homogeneous	Cluster-based	Random	Very good	….	….	Stationary nodes
BCEE	2009	Multi hop	Homogeneous	K-means clustering strategy and ACO-based routing	Random	Good	Yes	High	Stationary nodes
LEACH-TM	2009	Multi hop	Homogeneous	Initial energy-based threshold clustering	Random	Good	Yes	….	Stationary nodes
SHRP	2009	Multi hop	Homogeneous	Cluster-based	Random	Good	Yes	High	Stationary nodes
EAP	2009	Single hop	Heterogeneous	Cluster-based	Random	Good	Yes	….	Stationary nodes
EDL	2009	Single hop	Heterogeneous	Cluster-based	Random	Good	Yes	….	Stationary nodes
EECHE	2009	Single hop	Heterogeneous	Cluster-based	Random	Very good	….	….	Stationary nodes
REFS,EEFS	2009	Multi hop	Heterogeneous	Cluster-based	Random	Good	Yes	….	Stationary nodes

Table 1 Comparison table for various LEACH-based protocols (continued)

Protocols	*Year*	*Data transmission*	*Network type*	*Routing type*	*Deployment strategy*	*Energy efficiency*	*Load balancing*	*Scalability*	*Mobility of nodes*
BARC	2009	Multi hop	Homogeneous	Cluster-based on trust factor and battery recovery scheme	Random	Good	Yes	High	Stationary nodes
ASFO	2010	Single hop	Homogeneous	Fish swarm optimisation-based cluster	Random	Very good	….	….	Stationary nodes
VR-LEACH	2010	Single hop	Homogeneous	Cluster-based SN situation	Random	Very good	Yes	….	Stationary nodes
LEACH-B	2010	Single hop	Homogeneous	SN residual energy-based cluster	Random	Very good	….	….	Stationary nodes
N-LEACH	2010	Single hop	Homogeneous	SN residual energy and distance from BS-based cluster	Random	Very good	Yes	….	Stationary nodes
LEACH_Sin	2010	Single hop	Homogeneous	Cluster-based	Random	Very good	….	….	Stationary nodes
KMMDA	2010	Single hop	Homogeneous	Cluster based on the minimum mean distance between SNs	Random	Good	….	….	Stationary nodes
W-LEACH	2010	Single hop	Homogeneous	Cluster based on sensor weights	Uniform and non-uniform	Very good	….	….	Stationary nodes
DE-LEACH	2010	Single hop	Homogeneous	Cluster-based	Random	Very good	Yes	….	Stationary nodes
LEACH-ER	2010	Single hop	Homogeneous	Energy-based cluster	Random	Good	….	….	Stationary nodes
BEC	2010	Single hop	Homogeneous	Energy threshold-based cluster	Random	Very good	….	….	Stationary nodes
OECM	2010	Single hop	Homogeneous	Cluster-based	Random	Good	….	….	Stationary nodes
LEACH-D	2010	Multi hop	Homogeneous	Degree of connectivity and distance-based cluster	Random	Very good	Yes	….	Mobile nodes
MLCRA	2010	Multi hop	Homogeneous	Cluster-based	Random	Very good	Yes	….	Stationary nodes
MR-LEACH	2010	Multi hop	Homogeneous	Multi-level clustering resulted by BS	Random	Very good	Yes	….	Stationary nodes
C3R	2010	Single hop	Homogeneous	Cluster-based	Random	Very good	Yes	….	Stationary nodes
LEACH-FL	2010	Single hop	Homogeneous	Fuzzy-based clustering approach	Random	Very good	Yes	Low	Stationary nodes
LEACH-HPR	2010	Multi hop	Heterogeneous	Cluster-based	Random	Very good	Yes	High	Stationary nodes
LEACH-ECD	2010	Multi hop	Homogeneous	Cluster-based	Random	Good	Yes	High	Stationary nodes
LEACH-A	2010	Single hop	Heterogeneous	Cluster as gateway based	Random	Poor	….	Medium	Stationary nodes
LEACH-SC	2011	Single hop	Homogeneous	Distance-based clustering	Random	Good	Yes	….	Stationary nodes
ER-LEACH	2011	Single hop	Homogeneous	Zone and alternative CH-based cluster formation	Random	Very good	Yes	….	Mobile nodes

Table 1 Comparison table for various LEACH-based protocols (continued)

Protocols	*Year*	*Data transmission*	*Network type*	*Routing type*	*Deployment strategy*	*Energy efficiency*	*Load balancing*	*Scalability*	*Mobility of nodes*
MBC	2011	Single hop	Homogeneous	Cluster based on residual energy and mobility	Random	Good	Yes	….	Mobile nodes
FTTT	2011	Single hop	Homogeneous	Cluster-based	Random	Very good	Yes	….	Stationary nodes
O-LEACH	2011	Single hop	Homogeneous	Cluster-based	Random	Very good	Yes	….	Stationary nodes
ECHR	2011	Single hop	Homogeneous	Cluster-based	Random	Good	Yes	….	Stationary nodes
LEACH-SM	2011	Single hop	Homogeneous	Cluster-based	Random	Good	….	High	Stationary nodes
CCBRP	2011	Single hop	Homogeneous	Chain-based	Random	Very good	Yes	….	Stationary nodes
IEEPB	2011	Single hop	Homogeneous	Chain-based	Random	Good	Yes	….	Stationary nodes
SRMCF	2011	Single hop	Heterogeneous	Cluster-based	Random	Good	Yes	….	Stationary nodes
LSN	2011	Single hop	Homogeneous	Cluster-based	Random	Good	Yes	High	Stationary nodes
EE-LEACH	2011	Single hop	Homogeneous	Cluster-based	Random	Good	….	Low	Stationary nodes
LEACH-GA	2011	Single hop	Homogeneous	Genetic-based cluster approach	Random	Very good	Yes	High	Stationary nodes
LEACH-F	2011	Single hop	Homogeneous	Cluster-based	Random	Good	Yes	Low	Stationary nodes
ACT	2012	Multi hop	Homogeneous	Multi-level clustering	Random	Good	Yes	….	Stationary nodes
DEECIC	2012	Multi hop	Homogeneous	Cluster based on node degree	Random	Good	Yes	….	Stationary nodes
EBRAMS	2012	Single hop	Homogeneous	Chain-based	Random	Good	Yes	….	Sink is mobile
EHEED	2012	Multi hop	Heterogeneous	Cluster-based	Random	Good	Yes	….	Stationary nodes
VIBE	2012	Multi hop	Homogeneous	Cluster-based	Random	Good	Yes	….	Mobile nodes
AZR-LEACH	2012	Multi hop	Heterogeneous	Rectangular static cluster-based	Random	Very good	Yes	Medium	Stationary nodes
EH-LEACH	2012	Single hop	Heterogeneous	Cluster-based	Random	Very good	….	….	Stationary nodes
U-LEACH	2012	Multi hop	Heterogeneous	Both	Random	Good	Yes	High	Stationary nodes
WEP	2012	Multi hop	Heterogeneous	Both but preferably cluster-based	Random	Good	Yes	Medium	Stationary nodes
EESAA	2012	Multi hop	Homogeneous	Cluster based on remaining energy of nodes	Random	Good	Yes	Medium	Stationary nodes
CEEC	2012	Multi hop	Heterogeneous	Three level clustering	Random	Very good	….	Medium	Stationary nodes
TSEP	2012	Multi hop	Heterogeneous	Three level clustering	Random	Good	….	Medium	Stationary nodes
FMCDA	2012	Multi hop	Homogeneous	Secondary and primary clustering	Random	Good	….	High	Stationary nodes

Table 1 Comparison table for various LEACH-based protocols (continued)

Protocols	*Year*	*Data transmission*	*Network type*	*Routing type*	*Deployment strategy*	*Energy efficiency*	*Load balancing*	*Scalability*	*Mobility of nodes*
LEACH-E	2012	Single hop	Heterogeneous	Cluster-based	Random	Very good	Yes	Very high	Stationary nodes
K-LEACH	2013	Single hop	Homogeneous	Cluster-based	Random	Very good	Yes	Medium	Stationary nodes
Ad-LEACH	2013	Single hop	Heterogeneous	Static cluster-based	Random	Good	….	High	Stationary nodes
EHE-LEACH	2013	Multi hop	Heterogeneous	Both	Random	Very good	….	High	Stationary nodes
EEE-LEACH	2013	Multi hop	Homogeneous	Multi level clustering approach	Random	Very good	Yes	High	Stationary nodes
TREE-CR	2013	Multi-hop	Heterogeneous	Cluster-based	Random	Very good	Yes	High	Stationary nodes
FSEP-E	2013	Multi-hop	Heterogeneous	Fuzzy-based clustering approach	Random	Very good	Yes	Medium	Sink is mobile
HEER	2013	Multi hop	Both	Cluster-based on initial and residual energy of nodes	Random	Very good	Yes	High	Stationary nodes
Z-SEP	2013	Single hop	Heterogeneous	Cluster-based and direct communication	Random	Good	….	Medium	Stationary nodes
SEP-MS	2013	Single hop	Heterogeneous	Cluster less	Random	Good	Yes	Medium	Sink is mobile
TLHCLP	2013	Multi hop	Homogeneous	Three level clustering	Random	Very good	Yes	High	Stationary nodes
DAO-LEACH	2013	Multi hop	Heterogeneous	Cluster-based	Gaussian random distributed nodes	Good	Yes	Very high	Nodes are mobile
DREEM-ME	2013	Multi hop	Homogeneous	Cluster based on maximum energy	Random	Good	Yes	High	Stationary nodes
M-GEAR	2013	Multi hop with gateway	Homogeneous	Region wise cluster-based and chain-based	Random	Very good	Yes	….	Stationary nodes with gateway in centre and sink outside the network
REECH-ME	2013	Single hop	Homogeneous	Region wise energy-based clustering	random	Very good	Yes	High	Sink is mobile
LEACH-TLCH	2013	Both	Homogeneous	Randomly and probability-based two level Clustering	Random	Very good	Yes	High	Stationary nodes
Hybrid PSO LEACH	2014	Multi hop	Homogeneous	PSO-based cluster approach	Random	Good	….	High	Stationary nodes
ESRP	2014	Single hop	Heterogeneous	Cluster head selection is from the group of highest energy level	Random	Good	….	High	Stationary nodes
EEMHR	2014	Multi hop	Heterogeneous	Multi level clustering approach	Random	Good	….	Medium	Stationary nodes

4 Conclusions

Hierarchical (cluster-based) routing techniques play an important role in the efficiency of WSNs as they contribute to the reduction of energy consumption and latency and also provide high data throughput, network lifetime and QoS. LEACH protocol is the fundamental clustering-based routing protocol for WSNs. Considering LEACH as a base protocol, various protocols have been developed. Each new protocol of LEACH was implemented to solve some limitations of original LEACH algorithm. In this paper, we have described various routing protocols based upon the standard LEACH protocol and their comparison to other protocol. Various parameters such as CH selection, load balancing, routing, deployment etc. are selected for comparison of the LEACH-based protocols. The parameters selected are based upon the applications and environment on which the WSN is operating.

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