A Survey on Multi Hop LEACH Protocol

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ABSTRACT

Low energy adaptive clustering hierarchy (LEACH) protocol is still gaining the attention of the research community working in the area of wireless sensor network (WSN).This itself shows the importance of this protocol. LEACH is a hierarchical protocol in which most nodes transmit to cluster heads, and the cluster heads aggregate and compress the data and forward it to the base station (sink). Researchers have come up with various and diverse modifications of the LEACH protocol. Successors of LEACH protocol are now available from single hop to multi-hop scenarios. Extensive work has already been done related to LEACH and it is a good idea for a new research in the field of WSN to go through LEACH and its variants over the years. This paper surveys the variants of LEACH routing protocols proposed so far and discusses the enhancement and working of them. This survey classifies all the protocols in two sections, namely, single hop communication and multi-hop communication based on data transmission from the cluster head to the base station. A comparative analysis using nine different parameters, such as energy efficiency, overhead, scalability complexity, and so on, has been provided in a chronological fashion. The article also discusses the strong and the weak points of each and every variants of LEACH. Finally the paper concludes with suggestions on future research domains in the area of WSN.

KEY TERMS : LEACH, Wireless Sensor Networks, Clustering Protocol, Cluster Head, Routing.

I. INTRODUCTION

A Wireless Sensor Network (WSN) is a collection of large numbers of sensor nodes with limited sensing, computing and communication capabilities. These sensors are deployed over a large area with one or more than one Base Station (BS). WSN has wide application possibilities, such as temperature, pressure, humidity and habitat monitoring, disaster management, military reconnaissance, forest re-tracking, security surveillance and many more. In most scenarios, sensor nodes are randomly deployed with limited battery power. The selection of routing techniques is an important issue for the efficient delivery of sensed data from its source to the destination. The routing strategy used in these type of networks should ensure minimum energy consumption as battery replacement in sensors are often not possible. A lot of energy-efficient routing protocols have been proposed and developed for WSN, depending on their application and network architecture. Designing a routing protocol is full of challenges, mainly due to limited power, low bandwidth, low computational power, no conventional addressing scheme, computational overheads and self-organization of the sensor nodes

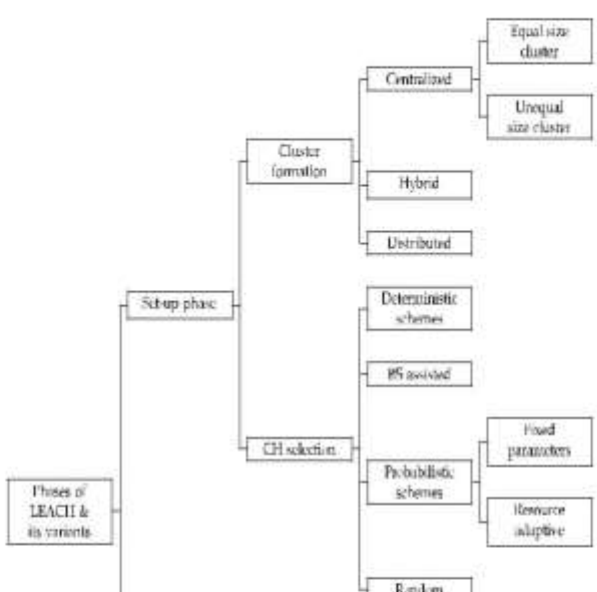
Routing protocols can be classified in four schemes: Network Structure Scheme, Topology Based Scheme, Communication Model Scheme, and Reliable Routing Scheme. The network structure schemes can be divided into two types: Flat routing and Hierarchical routing.

Flat and hierarchical routing are two most typical routing protocols in wireless ad hoc networks. There have been many researches working on studying different flat or hierarchical routing protocols separately. However, there are little works about a comprehensive comparison study between these two kinds of routing protocols. As there are many protocols for both flat and hierarchical routing protocol, it is necessary to study their advantages and disadvantages, so that we could provide guidance for the deployment of different protocols in different networks configuration. This paper will study the performance of hierarchical routing protocols as compare to flat routing protocols.

1.List of the previous surveys on LEACH variants

Year	Contributions	Limitations	References
2010	Compared six hierarchical routing protocols (HRPs) with a comparision graph in terms of energy consumption and network lifetime.	Only six protocols are compared and only one parameter, namely network lifetime, is used.	Lotf et al. [17]
2011	Six HRPs with 12 parameters were compared.	Proper parameters are not used and discussed protocol are outdated.	Xu et al. [18]
2012	LEACH was compared with M-LEACH, MH-LEACH and sLEACH in terms of energy consumption.	Only four HRPs are analysed under energy consumption parameters.	Aslam et al. [19]
2013	Various LEACH-related protocols are discussed and their basic techniques comapred CH selection, improvement over LEACH and their disadvantages.	Limited number of comparision parameters are taken.	Hani et al. [20]
2013	Classified all LEACH variants into three categories: modified CH selection algorithms, energy aware algorithms and optimization in CH selection.	Smaller number of HRPs compared with some selected parameters.	Madheswaran et al. [21]
2014	Security-related LEACH variants are presented.	Only security-related protocols and issues are discussed.	Rahayu et al. [22]
2015	Successors of LEACH protocols in alphabetical order are discussed and compared.	Only four parameters are considered and analysed without considering the energy consumption parameters.	Mahapatra et al. [23]
2016	Variants of LEACH and other HRP protocols are discussed with four parameters.	Only four parameters and few HRPs are considered and analysed.	Arora et al. [24]

2.LEACH protocol architecture



II.LEACH (LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY) PROTOCOL

LEACH is a pioneer clustering routing protocol for WSN. The main objective of LEACH is to increase the energy effciency by rotation-based CH selection using a random number. The LEACH protocol architecture is shown in Figure 3.

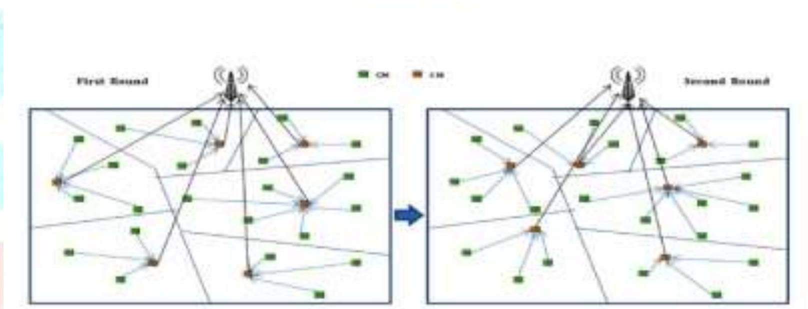
The operation of LEACH consists of several rounds where each round is divided into two phases: the set-up phase and the steady state phase as shown in Figure 4. During the set-up phase, CH selection, cluster formation and assignment of a TDMA (Time Division Multiple Access) schedule by the CH for member nodes are performed. In CH selection, each node participates in a CH election process by generating a random priority value between 0 and 1. If the generated random number of a sensor node is less than a threshold value $T(n)$ then that node becomes CH. The value of $T(n)$ is calculated using Equation 1.

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

Where P denotes the desired percentage of sensor nodes to become CHs among all sensor nodes, r denotes the current round and G is the set of sensor nodes that have not partic-ipated in CH election in previous $1=P$ rounds. A node that becomes the CH in round r cannot participate in the next $1=P$ rounds. In this way every node gets equal chance to become the CH and energy dissipation among the sensor nodes is distributed uniformly. Once a node is selected as the CH, it broadcasts an advertisement message to all other nodes. Depending on the received signal strength of the advertisement message, sensor nodes decide to join a CH for the current round and send a join message to this CH. By generating a new advertisement message based on Equation 1, CHs rotate in each round in order to evenly distribute the energy load in the sensor nodes. After the formation of the cluster, each CH creates a TDMA schedule and transmits these schedules to their members within the cluster. The TDMA schedule avoids the collision of data sent by member nodes and permits the member nodes to go into sleep mode. The set-up phase is completed if every sensor node knows its TDMA schedule. The steady state phase follows the set-up phase.

In the steady state phase, transmission of sensed data from member nodes to the CH and CH to the BS are performed using the TDMA schedule. Member nodes send data to the CH only during their allocated time slot. When any one member node sends data to the CH during its allocated time slot, another member node of that cluster remains in the sleep state. This property of LEACH reduces intra cluster collision and energy dissipation which increases the battery life of all member nodes. Additionally, CHs aggregate data received from their cluster members and send it directly to the BS. Transmission of data from the CH to the BS is also performed with the help of the allotted TDMA schedule. The CH senses the states of the channel for sending its data. If the channel is busy i.e. it is being used by any other CH then it waits; otherwise it uses the channel to transmit the data to the BS.

3. Illustration of the LEACH protocol with two different rounds with different CH.



A. ADVANTAGES OF LEACH

LEACH is a complete distributed routing protocol in nature. Hence, it does not require global information. The main advantages of LEACH include the following:

1) Concept of clustering used by LEACH protocol enforces less communication between sensor nodes and the BS, which increases the network lifetime.
2) CH reduces correlated data locally by applying data aggregation technique which reduces the signi cant amount of energy consumption.
3) Allocation of TDMA schedule by the CH to member nodes allows the member nodes to go into sleep mode. This prevents intra cluster collisions and enhances the battery lifetime of sensor nodes.
4) LEACH protocol gives equal chance to every sensor node to become the CH at least once and to become a member node many times throughout its lifetime. This randomized rotation of the CH enhances the network lifetime.

B. DISADVANTAGES OF LEACH

However, there exist some disadvantages in LEACH which are as follows:

1) In each round the CH is chosen randomly and the prob-ability of becoming the CH is the same for each sensor node. After completion of some rounds, the probability of sensor nodes with high energy as well as low energy becoming the CH is the same. If the sensor node with less energy is chosen as the CH, then it dies quickly. Therefore, robustness of the network is affected and lifetime of the network degrades.

2) LEACH does not guarantee the position and number of CHs in each round. Formation of clusters in basic LEACH is random and leads to unequal distribution of clusters in the network. Further, in some clusters the position of the CH may be in the middle of the clusters, and in some clusters the position of the CH may be near the boundaries of the clusters. As a result, intra cluster communication in such a scenario leads to higher energy dissipation and decreases the overall performance of the sensor network.

3) LEACH follows single hop communication between the CH and the BS. When the sensing area is beyond a certain distance, CHs which are far away from the BS spend more energy compared to CHs which are near to the BS. This leads to uneven energy dissipation which ultimately degrades the lifetime of the sensor network.

III.SUCCESSORS OF LEACH WITH MULTI-HOP COMMUNICATION

B

In multi-hop communication, the CH sends its data via some intermediate nodes to the BS. Intermediate nodes are either some relay nodes or other CHs which forward received data towards the BS. According to the radio model, the energy dissipation by a transceiver is directly propotional to the distance between the source and destination. If the distance goes beyond a threshold distance, the energy consumption increases in distance to the power four: d^4. So, the main purpose of multi-hop communication is to keep the distance at a minimum or less than the threshold distance. In succes-sors of LEACH with multi-hop communication, researchers have mainly focused on inter and intra cluster communica-tion, CH selection, cluster formation and scalability. These improvements achieve energy ef ciency and scalability in WSN. This section discusses about all the multi-hop LEACH successors and their merits and demerits in detail.

1) **MH-LEACH (Multi-hop-LEACH)**

According to the radio energy model, if the distance between the CH and the BS is greater than a certain threshold distance, energy dissipation of the CH is directly proportional to distance to the power four: d^4. So in large sensing regions and far distance between CHs and the BS, CHs dissipate their large amount of energy and die quickly. The basic LEACH protocol is not appropriate for this type of situation. Multi-hop LEACH routing protocol [74] solves this problem. Multi-hop LEACH routing protocols improve the per-formance in terms of energy ef ciency by adopting multi-hop communication between CHs and the BS. The set-up phase of multi-hop LEACH protocol is sim-ilar to the basic LEACH protocol in that it is completely distributed in nature. In the steady state phase, CHs which are far away from the BS are chosen as inter-mediate nodes to transmit data to the BS (multi-hop communication) and the CHs which are near to the BS transmit data directly (single hop communication) to the BS. The inter-cluster communication and the intra-cluster communication are two types of communication used in multi-hop LEACH. In intra-cluster communi-cation, member nodes communicate with the CH and in inter-cluster communication one CH communicates with the other CH to send information to the BS. The CHs that are far away from the BS choose a best route with the minimum hop count in order to deliver the information to the BS ef ciently.

MH-LEACH is more energy efficient and highly scalable than basic LEACH but due to multi-hop transmission via relay nodes it became more complex and increases network overheads.

2) **TL-LEACH (Two Level-LEACH)**

For ef cient energy consumption and even distribu-tion of energy load in large area networks, Loscri et al. [75] have proposed a two-level hierarchy of clusters. Information sensed by sensor nodes is trans-mitted to the BS over two different hierarchies. Two levels of clustering facilitates more sensor nodes to use shorter distances and far fewer sensor nodes to use longer distances for transmitting data to the BS. In TL-LEACH protocol, upper level CHs are known as primary CHs and lower level CHs are known as the secondary CH. Each CH at the secondary level performs partial local computation of data and each CH at the primary level performs complete local computa-tion, from where data is transmitted directly to the BS. TL-LEACH extends the lifetime of a sensor network by even distribution of energy among sensor nodes. For high density nodes and large area networks this protocol performs better compared to LEACH and LEACH-C. The primary level CHs which are near to the BS suffered from a hotspot problem.

3) **E-LEACH (Energy-LEACH)**

The CH selection and data transmission between the CH and the BS have been improved in Energy-LEACH (E-LEACH) [76] over the LEACH protocol. The main selection criteria of the CH in Energy-LEACH is resid-ual energy of the sensor nodes. The working operation of Energy-LEACH is similar to basic LEACH. The probability of becoming a CH in the rst round is same for all sensor nodes. So randomly n D p N number of sensor nodes are selected as the CH. Where n is the number of CHs in the rst round, p is the probability of becoming CH and N represents the total number of sensor nodes in the network. After completion of the rst round, the residual energy of every sensor node is not the same. So, sensor nodes with higher residual energy are chosen as CHs and sensor nodes with less energy act as member nodes. In multi-hop LEACH, CHs select the nearest node as an aim node which is energy ef- cient and situated in one hop range. CH transfers the aggregated data to the aim node. This process is repeated until the CH which is nearest to the BS receives the data. Finally, this CH sends data to the BS. Selecting the high energy nodes as a CH in each round provides better lifetime of the WSN. Data is transmitted in a multi-hop optimal path which reduces the energy consumption and enhances the network lifetime. This protocol selects the CH based on residual energy only, which results in uneven cluster sizes and load balances in the network.

4) **LEACH-L (Advance Multi-hop Low Energy Adap-tive Clustering Hierarchy)**

LEACH-L [74] is an advanced multi-hop routing pro-tocol in which the CH away from the BS selects other CH as a relay node. The selection critera for the relay node is distance to the BS and energy. So a CH which is closer to the BS and has more energy is selected as the relay node. The CH near to the BS transmits data directly. Selection of clusters and formation of clusters is similar to the basic LEACH. LEACH-L bal-ances energy load in the network and decreases energy dissipation of the network, which in turn increases the lifetime of the network. The authors show that LEACH-L performs better than basic LEACH protocol when the target area of the sensing network is large.

The selection of the most suitable relay node, in terms of energy and distance from the BS for multi-hop transmission, results in equal energy distribution in the network. It enhances the lifetime of large WSN, where the BS is far away from the network. In this protocol, each node requires location information which is a complex process and also costly.

5) **MR-LEACH (Multi-hop Routing-LEACH)**

In order to minimize consumption of energy and prolong the network lifetime, MR-LEACH [82] is proposed by Farooq et al. It divides the entire area into various layers and forms the hierarchy of different layers of clusters. MR-LEACH produces the same size of clusters in each layer that means any normal node sends data to the BS in an equal number of hops. For this the BS allocates a time slice for each CH by using TDMA scheduling. Based on the TDMA schedule received from the BS, every CH allocates its own TDMA schedule for its member nodes. The CH in MR-LEACH is selected based on maximum residual energy. Each adjacent upper layer CH assists the lower layer CH during the data transmission to the BS.

MR-LEACH protocol increases the network lifetime by adopting multi-hop transmission from lower layers to the upper layer. It is highly scalable compare to basic LEACH. Hotspot is the main problem in this protocol.

6) **MS-LEACH (Multi-hop And Single Hop Routing LEACH)**

Based on the analysis of energy consumption of single hop transmission and multi-hop transmission within a single cluster, Qiang *et al.* [80] presented the con-cept of the critical value for cluster size. MS-LEACH proposes a combination of single-hop and multi-hop communication within the clusters based on the critical value of cluster size. The set-up phase of MS-LEACH protocol is similar to the basic LEACH protocol. In the steady state phase, the critical value of the cluster area is determined. Based on critical value, it is decided whether data will transmit through single-hop commu-nication or multi-hop communication between CH and member nodes within the cluster. With the knowledge of the total number of nodes and their position within the cluster, the CH computes the critical value of a cluster size. Suppose a critical and approximate value of a cluster size is A. If the value of A is less than the value of a critical value then the CH does nothing and receives information from member nodes; otherwise the CH determines a routing path tree using a Dijkstra algorithm and broadcasts this information within the cluster. Simultaneously each member node sets a timer value and waits for the routing path tree. If the value of the timer is positive, then the CH determines the next hop with the help of the routing path tree; otherwise it sends data directly to the BS.

MS-LEACH adopts single-hop transmission as well as multi-hop transmission within the cluster which gives better performance in terms of network lifetime and scalability compare to LEACH. It suffers from a hotspot problem and network overheads in the cluster as well as in the network.

4. Comparative analysis of Single-hop LEACH and its successors

Leach & its successor	Year	Clustering	Overhead	Scalability	Energy efficiency	Loc. Req.[1]	Load Bal.[2]	Complexity	Delay
LEACH	May 2000	Distributed	high	low	moderate	no	bad	low	small
LEACH-C	Oct 2002	Centralized	low	low	high	yes	moderate	moderate	small
LEACH-DCHS	Sept 2002	Distributed	high	low	high	yes	good	moderate	small
Solar-LEACH	June 2004	Hybrid	high	moderate	very high	yes/no	moderate	high	small
SLEACH	April 2005	Distributed	high	moderate	very high	yes	moderate	high	small
LEACH-Mobile	June 2006	Distributed	very high	low	low	yes	bad	high	small
Sec-LEACH	July 2006	Distributed	very high	high	low	no	moderate	very high	small
A-sLEACH	April 2007	Distributed	high	moderate	high	no	good	high	high
Q-LEACH	May 2007	Distributed	high	high	high	yes	good	high	small
Energy LEACH	Oct 2007	Distributed	high	moderate	high	no	good	high	high
LEACH-L(UWSN)	Dec. 2007	Distributed	moderate	high	moderate	yes	good	low	small
ME-LEACH	July 2008	Distributed	low	low	moderate	yes	bad	high	small
Armor-LEACH	Aug 2008	Distributed	very high	low	low	no	good	very high	small
TB-LEACH	Sept. 2008	Distributed	high	moderate	moderate	no	good	high	small
LEACH-ME	Dec 2008	Distributed	very high	low	moderate	no	bad	high	small
ALEACH	Dec 2008	Distributed	high	moderate	high	no	good	very high	small
T-LEACH	June 2009	Distributed	moderate	high	high	yes	good	high	small
LEACH-H	Nov 2009	Hybrid	high	moderate	high	yes	moderate	high	high
U-LEACH	March 2010	Distributed	low	low	high	yes	good	high	small
LEACH-B	Aug 2010	Distributed	high	low	high	yes	good	high	high
LEACH-GA	April 2011	Distributed	high	low	high	yes	low	high	small
MS-LEACH [34]	June 2011	Distributed	very high	high	low	no	bad	low	small
FL-LEACH	April 2012	Distributed	low	high	low	yes	good	high	small
LEACH-SWDN	May 2012	Distributed	moderate	high	low	yes	moderate	high	small
EP-LEACH	April 2013	Distributed	high	low	very high	no	good	high	small
I-LEACH	May 2013	Distributed	moderate	high	high	yes	good	high	small
MOD-LEACH	June 2013	Distributed	low	moderate	high	yes	good	high	small
Weighted-LEACH	Aug 2013	Distributed	high	high	high	yes	good	high	small
LEACH-G	Oct 2013	Hybrid	low	high	high	yes	good	high	small
EC-LEACH	Nov 2013	Centralized	low	high	high	yes	good	high	small
LEACH-CE	Dec 2013	Centralized	low	low	very high	no	good	moderate	small
FT-LEACH	March 2014	Distributed	high	low	moderate	yes	bad	high	small
IB-LEACH	Aug 2014	Distributed	high	low	high	no	good	high	small
CogLEACH	Oct 2014	Distributed	high	high	moderate	no	bad	moderate	small
V-LEACH	June 2015	Distributed	high	low	very high	no	good	very high	high
CogLEACH-C	Aug 2015	Centralized	high	low	high	yes	good	moderate	small
EMOD-LEACH	Sept 2015	Distributed	high	low	high	yes	good	moderate	small
EHA-LEACH	Feb 2016	Distributed	high	high	very high	yes	good	high	small
LEACH-MAC	July 2016	Distributed	high	moderate	high	yes	good	high	small

Loc. Req.-Location Required and Load Bal-Load Balance

IV. SECURITY

Incorporating security in LEACH-based protocols is a dif - cult task due to the lack of resources in a sensor node. Exist-ing solutions for wireless ad hoc networks are not relevent here. Like other protocols, LEACH is at high risk of secu-rity attacks including spoo ng, replay, hello ood, sybil etc. Since it is a cluster-based protocol, CHs are the rst target for attackers due to the potential for most damage. The CHs should perform the security protocols and data acquisition and at the design level data link-layer encryption and authen-tication should be considered. SPINs [33], SLEACH [32] and SecLEACH [36] protocols are based on LEACH and they have contributed different light-weight security approaches in hierarchical clustering protocols. The major open research challenges in this domain are designing light-weight cryp-tographic algorithms, thereby minimizing the message over-heads and reducing energy consumption.

V. FAULT TOLERANCE MANAGEMENT

Fault tolerance is one of the most important issues in LEACH and its variants due to temporal link failures. Since, in WSN, sensor nodes are deployed in an inhospitable environment and remain unattended, the failure of a node's components is practically unavoidable. In cluster-based protocols, fail-ure of the CH causes more damage in the network because it directly affects their member nodes. This issue is dis-cussed and an attempt at resolution is made by an ef cient re-clustering method in [106]. LEACH-FT [64] has been developed to increase the network's dependability and fault-tolerance capacity and also reduces energy consumption. In fault tolerance management, the major challenges are fault detection and its recovery. Implementing fault-tolerance schemes in LEACH and its associated protocols have several issues that need to be considered such as managing frequent link breaks, re-clustering, selection of new CH incase of CH failure and minimizing the message overhead

VI.QUALITY OF SERVICE (QoS) BASED COMMUNICATION

QoS pertains to several WSN performance issues such as end-to-end delay, bandwidth, throughput and latency [107]. In most of the WSN protocols, energy ef ciency is con-sidered a key design issue to improve the network lifetime. However, due to the emergence of the latest multimedia and imagining sensors that are used in new WSN applications, QoS-aware energy-ef cient protocols need to be developed. [108] and [109] provide some better QoS schemes in cluster-ing routing protocols to ensure minimum delay and path loss.

VII.CONCLUSIONS

The paper presents a comprehensive and state-of-the-art sur-vey of LEACH and its successors. We have discussed and compared more than 60 LEACH related protocols cover-ing both single hop and multi-hop communication. Further, these protocols have been comparatively analysed on vari-ous parameters like energy ef ciency, overheads, scalabil-ity etc. These analyses have also been presented in tabular formats for easy reference. It is evident that the different successors of LEACH are an improvement over the basic LEACH protocol. A major goal of any newly designed pro-tocol in WSN is energy ef ciency apart from performance factors.

The ndings of this survey show that most of the dis-cussed protocols are distributed in nature and require location information. Finding location coordinates through either GPS device or localization techniques is expensive and it con-sumes a signi cant amount of energy. Multi-hop clustering routing protocols suffer from more overheads and delay due to path set-up and relay nodes as compared to single hop clustering routing protocols. Only few protocols have consid-ered the consumption of energy during the CH selection and cluster formation in their simulation. In CH selection, energy is an important parameter but apart from this, researchers have considered many other parameters for it such as location of the node, node density, distance from the BS, mobility, energy harvesting nodes, optimal number of CHs etc. Secu-rity is a major concern as WSN is also used in military and hostile scenarios. Most of the proposed protocols for security in WSN are doing so at the expense of energy ef ciency as there is a trade-off between security and energy efficiency. Hence, it is challenging to improve both energy ef ciency and security at the same time.

In recent years deterministic clustering approaches have gained more popularity in WSN as they are more reliable than probabilistic clustering approaches. However, the determin-istic clustering methods increase the complexity and energy consumption, as they use different approaches like fuzzy-logic based, weight-based, heuristic-based, and compound based approaches. The most important design objectives are detailed with priority in Figure 2 to help the reader eval-uate the different design parameters used by researchers in developing LEACH. We have highlighted some research domains based on discussed protocols, which is mentioned in Table 4.

LEACH has been a creative eld of research over the years. All LEACH-related protocols discussed in this paper offer a promising improvement over conventional LEACH; how-ever, there is still much room for developing convenient and ef cient LEACH variants. This paper proposes some open issues in Section VI, which can be considered as important areas in the future for designing a new LEACH-related pro-tocol. Among the proposed open issues, QoS-based LEACH-inspired routing needs to be addressed more in the near future, mainly in multimedia and real-time applications in WSN.

Another interesting area is EHWSN which will require more attention in LEACH-based protocols by the researchers in the near future. Furthermore, the cluster formation in heteroge-neous network should be considered as an important problem due to different communication and processing capabilities. Based on the reviewed literature, presented tables and discus-sions, it is clear that the design of a suitable LEACH variant depends on the speci c application and user's requirements. We believe that this comprehensive survey will pave the way for the researchers to have an in-depth understanding of WSN routing protocols and help them in designing more effective routing algorithms in WSN.