HYBRID MAC PROTOCOL WITH INTRA-CLUSTER COMMUNICATIONS FOR EXTENDING WIRELESS SENSOR NETWORK LIFETIMES

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by

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LIST OF SYMBOLS

$T(n)$	Threshold
n_i	Node *i*
P	The CHs desired percentage
r	The current round
G	The set of nodes those have not been elected cluster heads probabilistic in the last *1/P* rounds
$E_{initial}$	Initial energy when the network starts
$MinPwr_i$	Minimum power level
N	Total number of nodes in network
W_1	Weight of residual energy value
Er_i	Residual energy value of node *i*
W_2	Weight of distance between node *i* and BS
D_j	Distance between node *i* and BS
$E_{ni\text{-}res}$	The residual energy of node
δ	Number of consecutive rounds during which a node has not been CH
K_{opt}	Optimum number of clusters per round
ε_{fs}	The free space factor
ε_{mp}	The multi-path factor
$M*M$	Network region
d_{bs}^2	The distance from the cluster head node to the BS
E_{ni}	Energy consumed by node n_i
E_{CT}	Total energy consumption of cluster head
E_{MT}	Total energy consumption of cluster congregation
E_{GT}	Total energy consumption of cluster member
E_{ChS}	Energy exhausted during cluster head selection process

E_{CsA}	Energy exhausted during cluster head self-advertising
E_{CrJ}	Energy exhausted during receiving joint request from cluster member nodes
E_{CR}	Energy exhausted during receiving aggregated data from congregations' nodes
E_{CS}	Energy exhausted during sending the data to the base station
E_{CGA}	Energy consumed during broadcast congregation advertising
l_c	Control packet size
α	Throughput of non-persistent CSMA
E_{ele}	Energy consumed by the electronics per bit
z	Maximum number of CH/rounds
β	Ratio of reception and idle listening
N_{cm}	Number of cluster members
k	Number of data frames per round
N_{cgs}	Number of congregation nodes who must send the data in current round
E_{GsP}	The energy exhausted during congregation self-advertising
E_{GR}	The energy exhausted during receiving sensed data from cluster member nodes.
E_{GrJ}	Energy consumed during receiving joint request from cluster member nodes
E_{GS}	The energy exhausted during sending the data to the cluster head
N_{gm}	Number of nodes per group
l_d	Data packet size.
m_{cor}	Number of correlated data-frame
E_{GaP}	Energy consumed during data aggregation process
E_{MR}	Energy exhausted receiving CHs advertisements
E_{MsJ}	Energy exhausted during sending joint request to cluster head
E_{MS}	Energy exhausted during sending sensed data to congregation

m	Number of CH per round
N_{cg}	Number of congregation nodes
E_{ni}	Energy consumption by the node per round
R_i	Total number of rounds
$E_{ni-total}$	Total energy consumed during the node lifetime

LIST OF ABBREVIATIONS

ADV	ADVertisement
AMRP	Average Minimum Reachability Power
BCDCP	Base-station Controlled Dynamic Clustering Protocol
BN	Bayesian Network
BS	Base Station
CG	ConGregation
CGs	ConGregations
CH	Cluster Head
CHs	Cluster Heads
CM	Cluster Member
CMs	Cluster Members
CSMA/CA	Carrier Sense Multiple Access/ Collision Avoidance
EECS	Energy Efficient Clustering Scheme
EESRP	Energy-Efficient Scalable Routing Protocol
ET	Energy Threshold-triggering
GB	GigaByte
ID	IDentification
IP	Internet Protocol
IT	Information Technology
LEACH	Low-Energy Adaptive Clustering Hierarchy
MAC	Multiple Access Control
MATLAB	MATrix LABoratory
RAM	Random Access Memory
SCH	Super Cluster- Head

SNR	Signal to Noise Ratio
TDMA	Time Division Multiple Access
UCS	Unequal Clustering Size
WR	Weight Relay
WSN	Wireless Sensor Network

PROTOKOL HIBRID MAC DENGAN KOMUNIKASI INTRA-KLUSTER UNTUK MEMANJANGKAN TEMPOH HAYAT RANGKAIAN SENSOR WAYARLES

ABSTRAK

Rangkaian sensor mempunyai peranti sensor kecil yang murah dengan keupayaan rangkaian tanpa wayar, tenaga bateri yang terhad dan kekangan sumber. Komunikasi Rangkaian Sensor Wayarles (WSN) dikendalikan oleh protokol penghalaan. Antara protokol penghalaan WSN, *Low-Energy Adaptive Clustering Hierarchy* (LEACH) digunakan dengan meluas sebagai kluster tanda aras berdasarkan protokol penghalaan. LEACH bergantung kepada ketua kluster (CH) untuk melakukan pengagregatan data dan penghantaran ke stesen utama. Namun, prestasi LEACH merosot dengan rangakaian yang berskala besar. Selain itu, sebahagian besar protokol berasaskan LEACH semasa menggunakan *Time Division Multiple Access Medium Access Control* (TDMA MAC). Slot bagi setiap nod kluster telah peruntukkan, walaupun beberapa nod mungkin tidak mempunyai data untuk disiarkan dan ia membazir sumber rangkaian. Selain itu, protokol ini tidak menangani masalah beban pada ketua kluster (CH). Kajian ini mencadangkan protokol penghalaan hierarki kluster ubah suai berdasarkan LEACH yang dikenali sebagai *Energy-Efficient Scalable Forwarding Protocol* (EESRP). Matlamat utama EESRP adalah untuk mengekalkan jangka hayat rangkaian melalui pengembangan rangkaian. EESRP memperkenalkan hierarki tiga lapis, iaitu sensor, kongregasi dan ketua kluster serta menggunakan komunikasi pelbagai saluran intra-kluster berdasarkan protokol MAC hibrid. EESRP dibangunkan melalui ujian simulasi menggunakan perisian MATLAB 2015a. Perbandingan prestasi EESRP dengan protokol Cell-LEACH, Multi-LEACH and BCDCP dijalankan untuk mengesahkan protokol yang dicadangkan. Pengesahan adalah berdasarkan tujuh kes kajian (100, 200, 400, 800, 1600, 3200 and 6400 nodes scenarios) melalui sepuluh percubaan simulasi. Tiga metrik penilaian dipilih untuk penilaian, iaitu kecekapan tenaga, pengimbangan penggunaan tenaga, dan pengskalaan rangkaian. Berdasarkan jangka hayat rangkaian, kes paling buruk protokol EESRP adalah 41.4%, 50.4%, 57%, 58.8%, 69.7%, 72% dan 75.4% lebih baik daripada kes terbaik protokol Cell-LEACH. Juga, kes paling buruk protokol EESRP adalah 11.7%, 26.2%, 30.3%, 33.1%, 42.1%, 46.1% dan 44.5% lebih baik daripada kes terbaik protokol Multi-LEACH. Tambahan pula, kes paling buruk protokol EESRP adalah 44.5%, 52.2%, 57.3%, 54%, 62.7%, 62.7% dan 63.3% lebih baik daripada kes terbaik protokol BCDCP. Tambahan pula, komunikasi pelbagai saluran intra-kluster dan hibrid MAC menunjukkan bahawa protokol EESRP mempunyai pengagihan muatan yang lebih baik dan mengurangkan jurang tenaga antara ketua kluster dan ahli kluster. Hasil kajian mengesahkan bahawa protokol penghalaan EESRP yang dibangunkan adalah bersesuaian untuk WSN yang besar dan kecil.

HYBRID MAC PROTOCOL WITH INTRA-CLUSTER COMMUNICATIONS FOR EXTENDING WIRELESS SENSOR NETWORK LIFETIMES

ABSTRACT

Sensor network features low-cost tiny sensor devices with wireless network capability, limited battery energy and resource constraints. The communication in Wireless Sensor Network (WSN) is handled by routing protocols. Among the WSN routing protocols, Low-Energy Adaptive Clustering Hierarchy (LEACH) is widely used benchmark cluster-based routing protocol. LEACH relies on the cluster head to perform data aggregation and transmission to the base stations. However, the performance of LEACH deteriorates with large-scale networks. Moreover, most of the current LEACH-based protocols uses Time Division Multiple Access Medium Access Control (TDMA MAC). Where slot for each cluster nodes has been assigned, even though some nodes might not have data to broadcast and that wastes the network resources. Furthermore, these protocols do not consider the cluster head (CH) overload problem. This study proposes adaptive clustering hierarchy routing protocol based on LEACH known as Energy-Efficient Scalable Routing Protocol (EESRP). The broad goal of proposing EESRP is to maintain the network-lifetime over the network expansion. EESRP introduces a three-layer hierarchy (i.e. sensors, congregations, and cluster heads) as well as applying multi-hop intra-clustering communication based on a hybrid MAC protocol. The EESRP is developed via a simulation testbed using MATLAB 2015a software. To assess the proposed protocol, a performance evaluation of EESRP with respect to Cell-LEACH, Multi-LEACH and BCDCP protocols is carried out. The validation is based on seven case studies (100, 200, 400, 800, 1600,

3200 and 6400 nodes scenarios) over ten simulation runs. Three evaluation metrics are chosen for the assessment, namely energy efficiency, energy consumption balancing and network scalability. Considering the network lifetime, the worst case of EESRP protocol is 41.4%, 50.4%, 57%, 58.8%, 69.7%, 72% and 75.4% better as compared to the best case of Cell-LEACH. Also, the worst case of EESRP protocol is 11.7%, 26.2%, 30.3%, 33.1%, 42.1%, 46.1% and 44.5% better as compared to the best case of Multi-LEACH. Further, worst case of EESRP protocol achieves 44.5%, 52.2%, 57.3%, 54%, 62.7%, 62.7% and 63.3% better than the best case of BCDCP. Moreover, the multi-hop intra cluster communication and the hybrid MAC showed that EESRP protocol has better load distribution and reduced the energy exhausting gap between cluster heads and cluster members. The obtained results confirm that the proposed EESRP protocol is suitable in both small and large WSN.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless sensor network (WSN) is a massive number of low-cost, multifunctional, low-power, and intelligent sensor nodes that sense data and transfer it to the base station (BS) (Akyildiz. *et al.*, 2002; Aslam *et al.*, 2012; Liu, 2015; Gherbi *et al.*, 2017; Mohamed *et al.*, 2018). Those tiny sensor nodes are capable of measuring, observing, and reacting to particular events in their surrounding environment (e.g. temperature, humidity, vehicular movement, pressure, soil makeup, noise levels). The sensing domain can be a military field, a healthcare system, a security observation, an information technology (IT) framework or other commercial applications (Akyildiz. *et al.*, 2002; Liu, 2012; Naeimi *et al.*, 2012; Arora *et al.*, 2016; Gherbi *et al.*, 2017).

The current trends in WSN area consider issues such as proposing and enhancing the communication protocols which related to the WSN lower physical level, introducing new applications, and investigating the resources constraints (Akyildiz. et al., 2002; Rault et al., 2014). Specifically, those issues include but not limited to the power consumption, scalability, production costs, operating environment, transmission media, fault tolerance, security, hardware constraints and sensor network topology (Akyildiz. et al., 2002). Despite the improvements in sensors technology, WSNs nodes are constrained by the limited battery power, bandwidth, computing capabilities, and memory size (Dhawan *et al.*, 2014; Kaur *et al*., 2015; Mohamed *et al*., 2018). Moreover, the study of the ability of a network to scale with increasing density of network nodes and bandwidth demands is considered critical due to the dense deployment and the rapid network expansion (e.g. periodic monitoring applications including vehicle tracking, soldier detection and tracking, forest fire detection and monitoring nuclear reactors). The adequate routing protocol must perform in an adaptive way as the network topology changes or the load increases. Thus, a network is labeled as scalable when the number of nodes is growing, while maintaining an adequate performance (Naeimi *et al.*, 2012; Sharma, 2016). Moreover, the massive number of nodes, low data rates, and resources constraint limits the usability of the protocols which are designed for ad hoc networks. Therefore, the routing protocols in WSN must be highly adaptive and resource-aware to support the network lifetime to fulfill the requirements of the applications.

WSN routing protocols are categorized into two main classes based on overall network structure to (Akkaria *et al.*, 2015; Singh *et al.*, 2017): flat or hierarchical routing protocols. Flat routing architecture allows all the sensor nodes to perform similar roles in the routing procedure. Hence, the sensor nodes are set to forward the sensed packets directly to base stations. On the other hand, hierarchal routing architecture segments the sensor nodes into clusters. Within the cluster, the nodes are separated according to their functionalities, where low-level nodes (i.e. clusters' members) are responsible for sensing and collecting the data from the surrounding environment and high-level nodes (i.e. clusters' heads) are responsible for forwarding the gathered data to the base station.

Recently, many hierarchical routing protocols have been proposed to provide efficient energy consumption (Yahiaoui *et al.*, 2018). In particular, the LEACH (Low-Energy Adaptive Clustering Hierarchy (Heinzelman *et al.*, 2000)) is considered as the first significant protocol efficiently addresses the energy consumption issue (Quynh *et al.*, 2012; Yektaparast *et al.*, 2012; Madheswaran *et al.*, 2013; Mahapatra *et al.*, 2015). However, the LEACH performance deteriorates sharply with the increase of the number of nodes in the network. Thus, scalability in WSNs is an ongoing research field, due to applications demands (Patel *et al.*, 2011; Yan *et al.*, 2011; Yueyun *et al.*, 2012; Mahapatra *et al.*, 2015; Ammar *et al.*, 2016).

This introductory chapter acts as a preface for this study and exhibits the problem formulation, motivations of study, research objectives, research contributions, scope of the study and briefly explains the research methodology of this study. Finally, this chapter presents the organization of the thesis.

1.2 Problem Statement

The increasing demand for large scale WSNs reveals a serious problem facing WSN forwarding protocols; which is how to maintain an adequate performance considering the assumption of network expansion (Lai *et al.*, 2012; Amodu *et al.*, 2016; Al-Sodairi *et al.*, 2018). The LEACH protocol lacks the ability to accommodate the network growth due to the usage of the single hop intra communication. Moreover, most of the current LEACH-based protocols dedicates TDMA slot for each cluster nodes even though some nodes might not have data to broadcast; which result in wasting network resources. In addition, these protocols suffer from a hot-spot problem due to cluster head (CH) overload. These issues motivates WSNs' research community to recognize the energy consumption (Elshrkawey *et al*., 2017; Bendjeddou *et al*., 2018), energy consumption balancing (Lee *et al.*, 2016; Randhawa *et al.*, 2019) and network scalability (Alnawafa *et al*., 2018) as the most substantial issues in WSNs.

To address the issues discussed earlier, this study proposes a new WSN forwarding protocol. The proposed protocol utilizes hybrid MAC protocol with multi-hop intra communication strategy to manage WSN energy consumption and balance the load among sensor nodes.

1.3 Motivations of the Study

Most recent studies in the WSN research area attempt to prolong the network lifetime (Amodu *et al.*, 2016; Al-Sodairi *et al.*, 2018). The extension of the network lifetime has always relied on minimizing the energy consumption. Moreover, under hazardous sensor fields and limited ability to recharge batteries or replace sensor nodes, the energy efficiency is critical for the lifetime and cost of WSN.

To cope with these challenges and to enhance the network efficiency, the developments in the WSN must consider two aspects:

- The tremendous number of nodes, random deployment, high node density and the huge amount of transmitted information (Akkaria *et al.*, 2015; Reem *et al.*, 2018).
- The imminent need for energy consumption balancing and scalable routing protocols to serve the particular application (Hani *et al.*, 2013; Mohamed *et al.*, 2018).

The combination of these aspects motivates the research community to develop new routing protocols to address the WSN power consumption and scalability issues (Li *et al.*, 2011; Xu *et al.*, 2016). The protocol developments based on LEACH structure maintain alternative cluster-head selection to accommodate continuous changes in the network topology. The rotation of the cluster head role provides a minimum level of energy consumption balancing (Liu, 2012; Yektaparast *et al.*, 2012; Tyagi *et al.*, 2013; Mahapatra *et al.*, 2015; Sabet *et al.*, 2015; Amodu *et al.*, 2016). Consequently, these developments follow certain enhancement procedures to enhance the performance: 1) algorithmic flow, 2) data communication, or 3) cluster head selection.

The discussed arrangement does not compensate further energy exhaustion during cluster head positioning. Thus, cluster heads consume more energy as compared to cluster members due to their parts in aggregating, processing and routing data. the cluster heads' energy exhaustion will result in a hot-spot problem. (Bilal, 2011; Rahman *et al.*, 2016; Singh *et al.*, 2017). Moreover, LEACH protocol follows a TDMA based scheduling scheme where dedicated slot for each cluster nodes to broadcast sensed data to cluster head even though some nodes might not have data to broadcast (Akkaria *et al.*, 2015). Further, the LEACH protocol lacks the ability to accommodate the network expansion (Patel *et al.*, 2011; Yan *et al.*, 2011; Yueyun *et al.*, 2012; M. Mehdi Afsar, 2014; Ammar *et al.*, 2016). These problems motivate the research community to investigate the energy consumption and network scalability as the most substantial issues regarding routing protocol in WSNs.

1.4 Research Objectives

The aim of the study is to propose a clustering forwarding protocol capable of efficiently managing the network tasks in large scale WSNs. The broad goal of the study can be divided into the following objectives:

1. To propose a hybrid MAC protocol to enhance WSN-LEACH energy consumption and maintaining the connectivity of WSN while the network expansions.
2. To propose intra multi-hop based forwarding protocol for efficient scalability, balancing energy consumption and prolong network lifetime.

1.5 Research Contributions

Given the increase in the node's density, the primary goal of this study is to maintain the network lifetime at an adequate measure. This goal can be further divided into the following contributions:

1. Classifying the LEACH-descendant protocols based on the enhancement techniques applied to increase the performance.
2. Implementing cross level multi-hop intra-cluster communication and a hybrid MAC Protocol to enhance the WSN connectivity due network expansion.
3. Applying a new three-layer hierarchy forwarding protocol to prolong the WSN lifetime and support network expansion.

1.6 Scope of the Study

This study proposes a forwarding protocol that maintains the WSN performance in acceptable level under the network expansion. The status of the WSN testbed consists of uniformly distributed sensor nodes in a two-dimensional space, and the intention is to continuously monitor the surrounding environment. Thus, the study states the following assumptions:

- The sensor nodes are homogeneous, and randomly distributed in a two-dimensional plane.
- All sensor nodes and base stations are stationary.
- All sensor nodes have the same resources and capabilities.
- Each node is specified with a unique identifier (ID).
- The communication is symmetric between any two sensor nodes.

1.7 Research Method

As mention earlier, the main goal of this study is to improve a clustering routing protocol that efficiently manages the networking tasks in scalable WSNs. To achieve the objective of the study the research methodology consists of several steps. Each step is linked to a tool; which used to interpret the applicability of the step. The first step includes the assessment of the existing protocols, which is done by conducting a literature review. The next step is development of simulation environment to test the various quality aspects of the WSN routing protocol, which is realized by using MATLAB simulation software. Lastly, the remaining steps include development, validation and the performance evaluation of proposed routing protocol. Figure 1.1 illustrates the key research steps in more details.

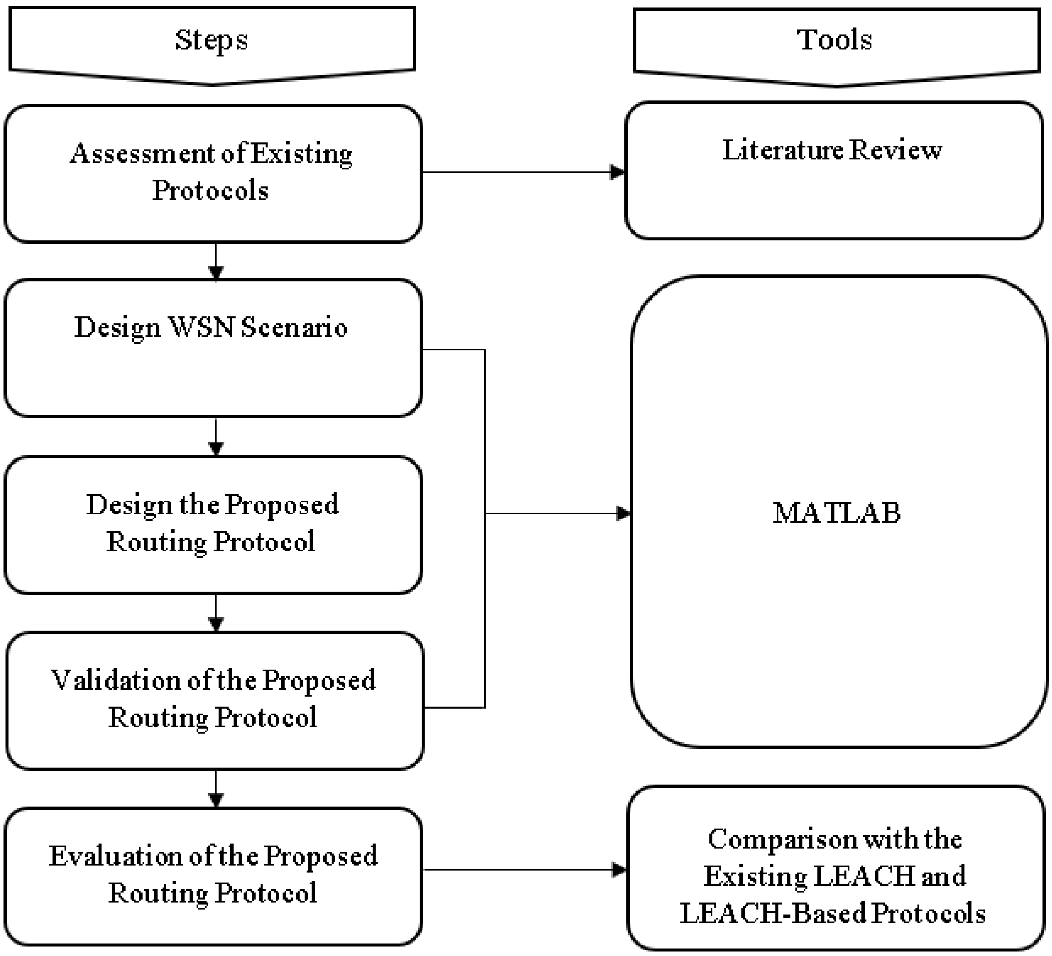

Figure 1.1 Key Research Steps

1.8 Organization of the Thesis Chapters

This thesis is composed of 6 chapters:

Chapter 2 gives intensive background about wireless sensor network and its routing protocols. Then introduces routing protocols taxonomy based on wireless sensor network architecture. Next, Chapter 2 provides related work and presents the strength and weakness of the major design concepts of the LEACH routing protocols. Moreover, the literature review chapter classifies and sums up the LEACH-descendant protocols which are proposed specifically to improve LEACH hierarchal routing protocol. Then finally the review chapter justifies the choice of LEACH for this study.

Chapter 3 introduces the methodology which is composed of three main phases: development phase, a validation phase and assessment phase. In addition, it presents the main design patterns and entire process steps of proposed protocol. The chapter elaborates how the proposed protocol’s operation will be validated. Finally, chapter 3 explains how the proposed protocol performance will be assessed in comparison to LEACH-descendant protocols.

Chapter 4 provides an in-depth detail of the improvement and implementation of the proposed routing protocol. Thereafter, chapter 4 describes the simulation models (i.e. network model and energy model) and defines the assessment metrics.

Chapter 5 presents operational validity results and performance assessment results of proposed protocol. Also, it gives exhaustive discussion of the validation for the proposed protocols and the evaluation results.

Chapter 6 presents the conclusion of the study and gives suggestions for future works regard to this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the existing works related to the LEACH and LEACH descendants routing protocols. The chapter provides in-depth analysis which facilitates the recognition of the thesis direction. The rest of this chapter is organized into six sections. Figure 2.1 shows the overall organization of this chapter.

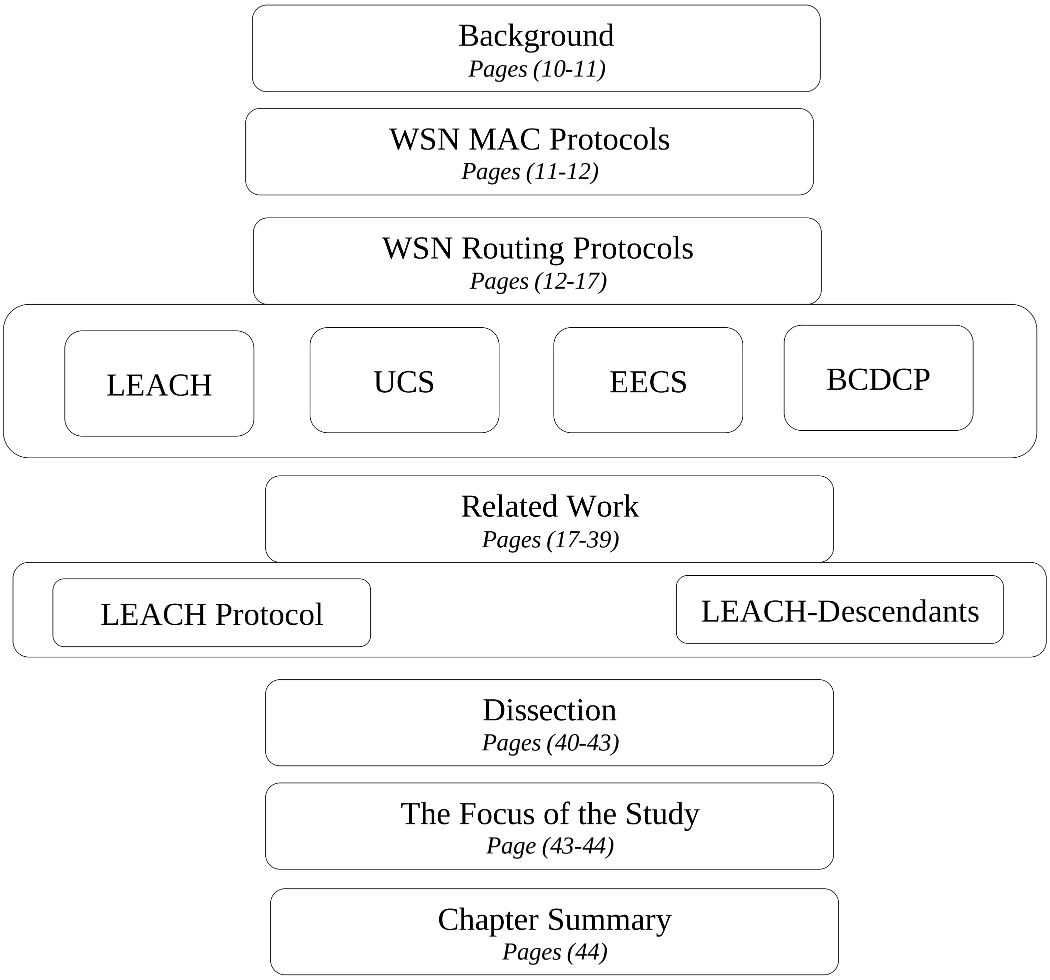

Figure 2.1 Chapter 2 Organization

Section 2.2 gives a background for wireless sensor networks. WSN MAC protocols are presented in section 2.3. Section 2.4 introduces routing protocols taxonomy based on WSN architecture. Section 2.5 provides an extensive survey of previous studies which focuses on two topics: 1) reviewing strength and weakness of the LEACH protocol, and 2) discussing the LEACH-descendant protocols which are proposed specifically to improve LEACH protocol. Discussion and justification are presented in section 2.6. Section 2.7 presents the summary of whole chapter.

2.2 Background

A wireless sensor network 'WSN' is a network of instruments denoted as nodes can sense the environment and communicate the information collected from the monitored field through wireless links (Gherbi *et al.*, 2017; Yetgin *et al.*, 2017). In WSNs the collected data is forwarded, via a single or multiple hops communication to the base station (i.e. sink). Accordingly, the sink can use the forwarded data either locally or is connected to other networks through gateways (Verdone *et al.*, 2010). The nodes can be fixed or mobile, homogeneous or heterogeneous, and they can be aware of their location or not. Figure 2.2 shows the components of the wireless sensor network in a typical scenario.

The architecture of a sensor node which is shown in Figure 2.2 includes a microprocessor controls all the running tasks and processes the information; memory is included on the board and used to store information. A radio transceiver with the antenna is also provided. All these components receive their power supplied from a non-chargeable battery (Verdone *et al.*, 2010). An energy-efficient routing technique should be implemented on the board. Moreover, all the data processing tasks must be distributed over the network. The nodes cooperate to provide the data to the sinks (Verdone *et al.*, 2010).

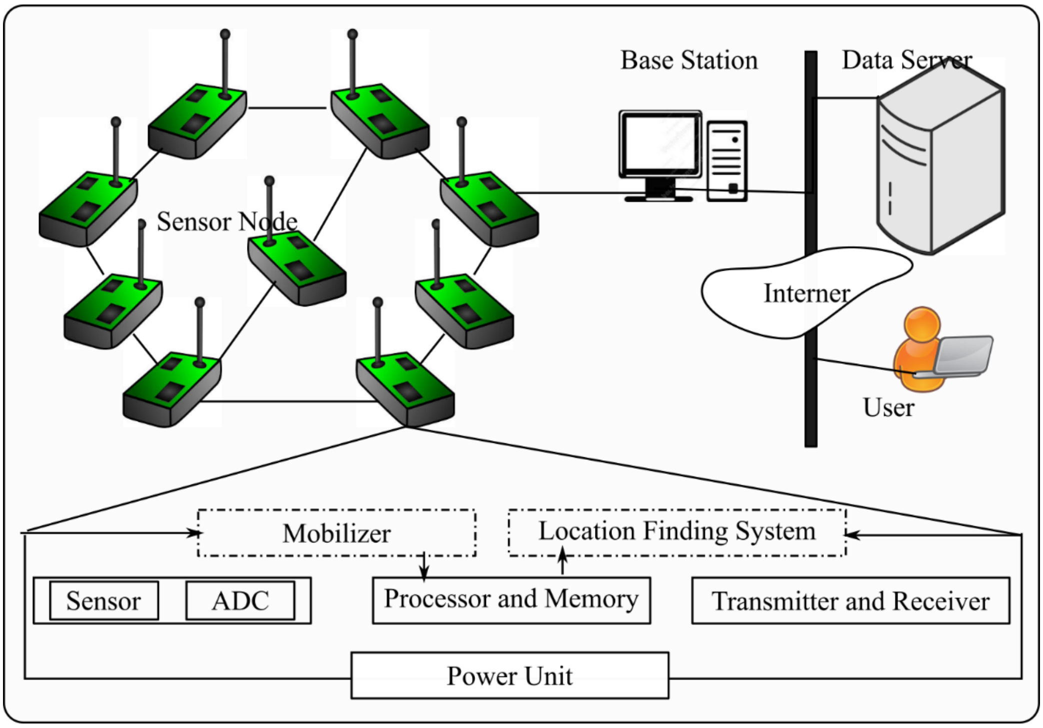

Figure 2.2 WSN and Components of Sensor Node

2.3 WSN MAC Protocols

The media access control (MAC) is a sub-layer of the data link layer. The MAC sub-layer is responsible for distributing the resource of a shared channel and regulating the various sensors activities such as data packets, data communication and idling or sleeping. Moreover, it is substantial for a WSNs to adopt a MAC technology which satisfies the requirements of communication performance (Buratti *et al.*, 2005). MAC has different classes as time division multiple access (TDMA), coding division multiple access (CDMA), frequency division multiple access (FDMA) and competition- based MAC protocol as carrier sense multiple access (CSMA) (Long, 2013). Therefore, the proper selection of the classes of MAC protocol is a critical subject for energy efficiency (Buratti *et al.*, 2005).

Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA) is an improved version of CSMA. When a node gathers a new data packet, it senses the channel and if it is idle the packet is sent. Moreover, when a collision takes place the node retransmits the crashed packet. The performance of the network is restricted by the occurrence of the collisions (Shrestha, 2013). However, in TDMA MAC protocol, each node in the network has a TDMA slot and exactly knows when will turn on its radio. Each node sends sensed packet in the assigned slot(s). The TDMA technique lacks the ability to handle the additions of new nodes, adaptation to the network topology changes, transmission delay, queuing delay and propagation delay (Gambhir *et al.*, 2014).

2.4 WSN Routing Protocols

Routing protocols in WSN vary from the traditional routing protocols in several ways such as sensor nodes have no IP addresses; therefore, IP-based routing protocols cannot be utilized in a WSN (Long, 2013). Additionally, the design of network protocols in a WSN should be energy-efficient and scalable. It should easily manage communication of all nodes to convey sensed data towards the sink. Furthermore, the routing protocol should meet network resources constraints and boost lifetime via decreasing energy consumption, reducing communication overhead, and balancing power consuming rate (Hadi *et al.*, 2015).

According to the WSN architecture, the routing protocols are categorized into two classes (Singh *et al.*, 2017): flat routing protocols, and hierarchical routing protocols. In flat routing architecture, all the sensor nodes perform the same roles in the routing procedure. Hence, they are set to forward the sensed packets to the specific base station. Hierarchal routing architecture classifies the sensor nodes per their functionalities. The typical hierarchical routing categorizes the sensor nodes into clusters and the activities within the clusters are managed by selected nodes, known as cluster-heads (CH) (Liu *et al.*, 2012; Liu, 2015). The CHs are responsible for managing the activities within and coordinating the communications with the nodes outside the cluster. On the other hand, low-level cluster member nodes are responsible for sensing and collecting the information about the event. Further, the atypical routing schemes are classified based on their logical topology and transmission methods (Liu *et al.*, 2012; Liu, 2015). Atypical routing protocols are divided into chain, area, tree and grid, based clustering routing protocols (Liu *et al.*, 2012; Liu, 2015). However, atypical hierarchical routing protocols differs from the traditional clustering protocols in their hierarchy segmentation and communication strategy. In contrast, typical hierarchical routing schemes divide the network into multiple clusters controlled by CHs. The CH of the cluster is responsible for receiving, aggregating and transmitting the sensed data to base station (BS). Usually their cluster topology falls under the block-based routing protocols. Figure 2.3 shows the routing protocols taxonomy based on network architecture.

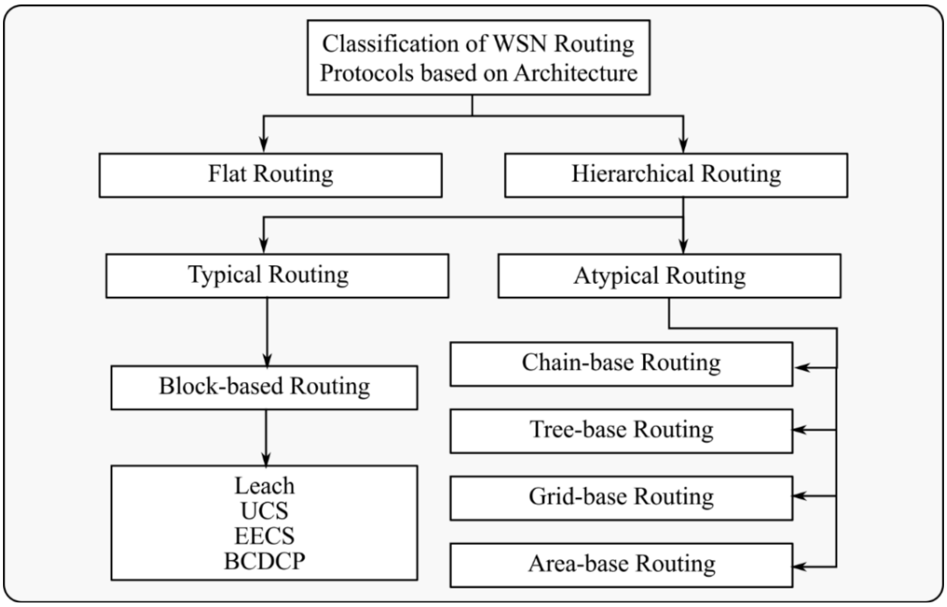

Figure 2.3 Routing Protocols Taxonomy Based on Network Architecture

2.4.1 LEACH

Heinzelman and his team have proposed the Low Energy Adaptive Clustering Hierarchy protocol, which is low-cost and self-adaption protocol (Heinzelman *et al.*, 2000). Similarly, the cluster heads have the capability to communicate with the focal point (sink). Each CH collects the data from the cluster- members and transfers it to the sink. LEACH operations consist of two main tasks: first initiating the clusters and then transmitting the sensed data. The total time of these steps is called round. Section 2.5.1 presents LEACH in- depth.

2.4.2 UCS

Unequal Clustering Size (UCS) scheme was suggested to balance the energy consumption of the CHs (Soro *et al.*, 2005). However, the sensed area is assumed to be circular and is portioned into two concentric circles: labeled layers. Supposed that all clusters in the same layer have even size and same shape. Furthermore, UCS is restricted by the presumption that the CHs have more energy and pre-determined positions. Also, regardless of residual energy, cluster heads are required to locate in the center of the cluster. Therefore, it cannot completely attain energy-consumption balancing (Liu *et al.*, 2012).

2.4.3 EECS

Energy Efficient Clustering Scheme (EECS) is a clustering protocol which suits the patrol data gathering applications (Ye *et al.*, 2005). In EECS, the network is divided into several clusters, and data communication is performed by single-hop strategy from the CH to the sink. CH election is completely based on residual energy. However, there are some shortfalls to be considered in EECS. First, single-hop communications directly from CHs to the sink can lead to more energy consumption and second, it is not appropriate for large-scale networks. (Liu *et al.*, 2012).

2.4.4 BCDCP

Base-station Controlled Dynamic Clustering Protocol (BCDCP) is a centralized clustering routing protocol where sink has the ability to do complex computation (Muruganathan *et al.*, 2005). Thus, the sink computes the average energy level and then selects some nodes which have energy levels above the mean value to act as CHs. Figure 2.4 shows BCDCP network topology (Muruganathan *et al.*, 2005). The transmit and receive energy costs for the transmission of a *k*-bit of data over distance of *r* meters is given by Equations. (2.1) and (2.2), respectively.

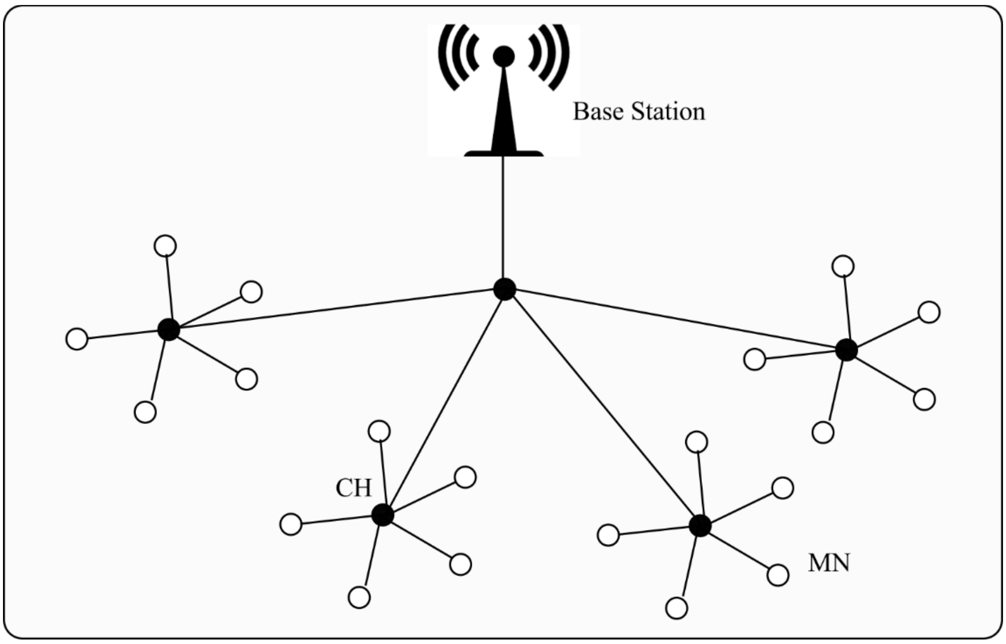

Figure 2.4 The Topology of the BCDCP Network

$$E_T(k,r) = E_{Tx}(k) + E_{amp}(r)k \tag{2.1}$$

$$\begin{cases} E_{amp} = l\varepsilon_{FS}r^2, \ \ r < r_0 \,, free\ space\ model \\ E_{amp} = l\varepsilon_{TR}r^4, \ \ r \geq r_0 \,, two - ray\ model \end{cases}$$

$$r_0 = \sqrt{\frac{\varepsilon_{FS}}{\varepsilon_{TR}}}$$

$$E_R(k) = E_{Rx}k \tag{2.2}$$

where $E_T(k,r)$ is the total energy dissipated in the transmitter of the source node, E_{Tx} is the per bit energy dissipations for transmission, E_{amp} is the energy required by the transmit amplifier to maintain an acceptable signal-to-noise ratio in order to transfer data reliably. $E_R(k)$ is the energy cost incurred in the receiver of the destination node, E_{Rx} the per bit energy dissipations for reception.

However, due to the single-hop intra-cluster transmissions, the BCDCP is not suitable for long-distance data transmission (Liu *et al.*, 2012). Moreover, the sink needs more energy to execute most of the tasks (Shafiullah *et al.*, 2008).

Table 2.1 benchmarks the main features of the various block based typical clustering routing schemes. In terms of position awareness, all are not location aware schemes. The control approach attribute determines if the protocol is distributed or centralized based routing protocol. The mobility support is not present in all protocols, rather they support stationary nodes. All the benchmarked protocols utilize single hop communication strategy in intra and inter transmission while UCS uses multi- hop as inter communication scheme.

Table 2.1 Comparison of Block Based Clustering Routing Protocols in WSNs

Protocol		LEACH	UCS	EECS	BCDCP
Merits	Position Awareness	No	No	No	No
	Control Approach	Distributed	Distributed	Distributed	Centralized
	Mobility	No	No	No	No
	Intra-Cluster Communication	Single-hop	Single-hop	Single-hop	Single-hop
	Inter-Cluster Communication	Single-hop	Multi-hop	Single-hop	Single-hop

2.5 Related works

This study investigates and categorizes the LEACH based routing protocols over the last decade. In this section an extensive survey and analysis of the previous studies which are designed to enhance the performance of LEACH have been performed.

2.5.1 LEACH Protocol: The Origin

LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol which is first proposed by (Heinzelman *et al.*, 2000) acts as a proactive, self-organizing, adaptive clustering protocol, and becomes one of the bases for routing protocol development in WSN. LEACH utilizes randomization to distribute the energy load equally between the nodes. In LEACH, the nodes regulate themselves into local clusters, with a selection of one node to be CH, acts as a local base station. The data is sent directly from any cluster node to CH. Figure 2.5 shows the basic topology of LEACH protocol. The key features of LEACH protocol are:

- Localized configuration and control for cluster organization and operation.
- Randomized rotation of the cluster-heads and the corresponding clusters.

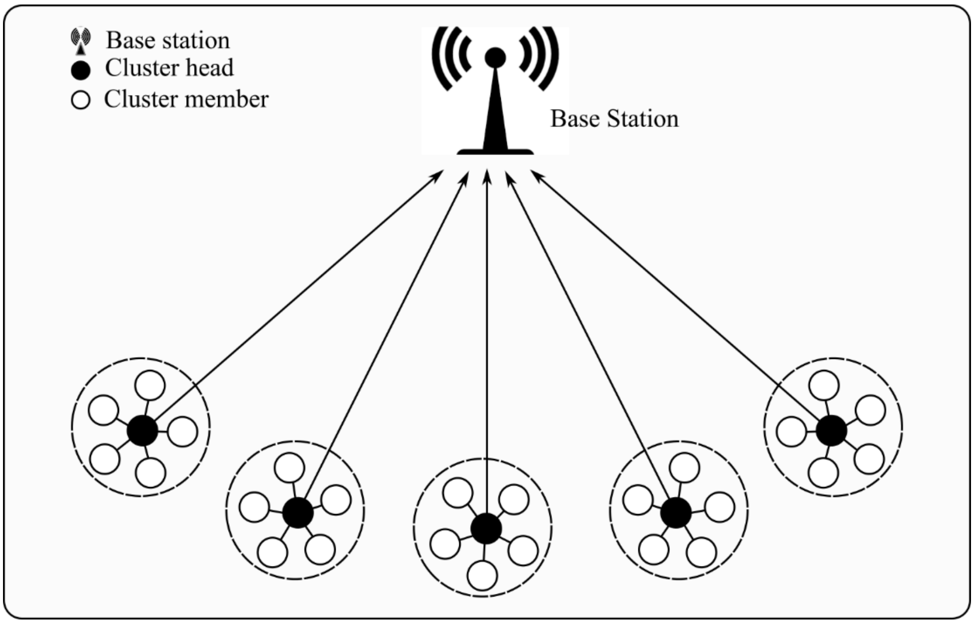

Figure 2.5 Basic Topology of LEACH

- Local compression to reduce power consumption and global communication.

LEACH routing protocol has many merits to prolong the WSNs lifetime:

- **Reduction of Energy Consumption:** the randomization of CHs selection over time leads to balance and decrease the energy consumption among all nodes which result in extending the network lifetime (Liu, 2012; Upadhyay *et al.*, 2015).

- **Less Overhead:** data aggregation process combines data from different sources and eliminates redundant data transmissions which result in reducing the overall load. While the local compression of the data, distributed nature of the network and needless global network awareness leads to minimize communications overhead. (Singh *et al.*, 2014; Upadhyay *et al.*, 2015).

Despite all the LEACH measures to prolong WSNs lifetime, still there are many disadvantages of the LEACH hierarchal routing protocol such as:

- **Less Scalability:** In LEACH protocol, the direct communication between the CH and the distant BS is restricted applying of LEACH for large coverage area applications which requires inter-cluster multi-hop communication (Patel *et al.*, 2011; Yan *et al.*, 2011; Liu, 2012; Arumugam *et al.*, 2015; Lin *et al.*, 2015; Mahapatra *et al.*, 2015; Velmani *et al.*, 2015).

- **Unbalancing Load:** Some of the clustering routing protocols including LEACH suffer from the hot-spot problem. The CHs consume their energy more quickly due to their extra duties (Bilal, 2011; Rahman *et al.*, 2016; Singh *et al.*, 2017). Thus, LEACH does not compensate sufficiently for further energy exhaustion during CH role.

2.5.1(a) LEACH Operation

The operation of LEACH consists of many rounds takes place in two phases. The first phase is the set-up phase, where the clusters for the current round are established, and then the cluster-heads are selected based on preset probability scheme. Selecting the cluster heads (CH) is followed by advertisement to all nodes about CH of the running round, then the TDMA transmission schedule is initiated. In this stage, all CHs and their receivers must be on. The potential CHs for the current round are selected by using a random number between 0 and 1, if the number is less than the threshold ($T(n)$), then the dedicated node can become a cluster-head. Equation 2.3 presents $T(n)$ value:

$$T(n) = \begin{cases} \dfrac{P}{1 - P(r \bmod \frac{1}{P})} & if\, n \in G \\ 0 & Otherwise \end{cases} \tag{2.3}$$

where P: the CHs desired percentage, r: the current round and G: the set of nodes those have not been elected as cluster head in the last $1/P$ rounds.

The second phase is known as the steady-state. In this phase, each node transfers sensed information to the respected CH at its allotted TDMA schedule. Then, the cluster head aggregates, compresses and transmits the data to the base station. When the base station receives all data, CH sends a message to the cluster members to start a new round. Figure 2.6 and Figure 2.7 consequently depict LEACH round of operation timeline and the flowchart of LEACH round.

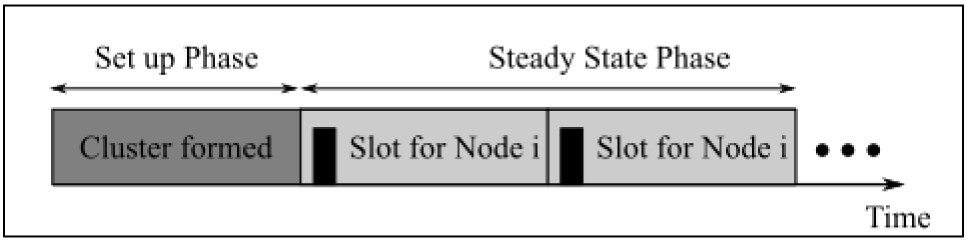

Figure 2.6 LEACH Operation’s Round Timeline.

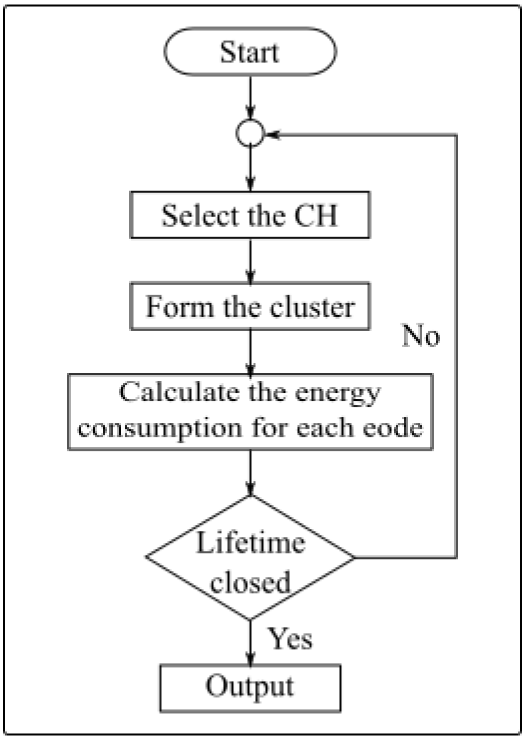

Figure 2.7 LEACH's Flowchart

2.5.1(b) LEACH Energy Model

The energy model which used in LEACH protocol (Heinzelman *et al.*, 2000), assumes that the transmission energy is composed of a propagation energy proportional to the transmitter/receiver and a constant amount of energy consumed by the internal electronics. Figure 2.8 shows the radio energy dissipation model (Heinzelman *et al.*, 2000), where the transmission energy relies on the number of transmitted bits.

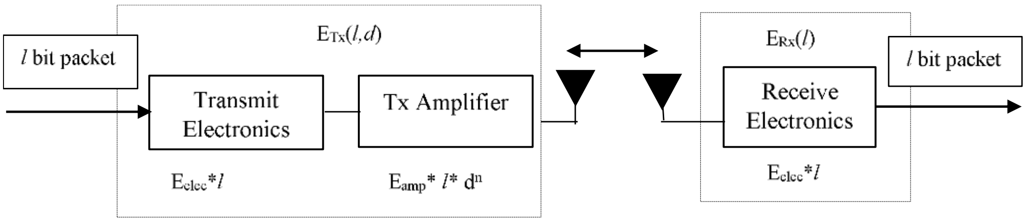

Figure 2.8 The Radio Energy Dissipation Model for LEACH

Accordingly, the cost of transmitting l-bit message over a distance d, will be calculated as follows:

$$E_{Tx}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d) = \begin{cases} l\mathrm{E}_{elec} + l\varepsilon_{fs}d^2, & d < d_0 \\ l\mathrm{E}_{elec} + l\varepsilon_{mp}d^4, & d \geq d_0 \end{cases}$$

(2.4)

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$$

where d_0 is a threshold, d, is the distance; l, is the number of bits; E_{elec}, is the energy consumed by the electronics per bit; ε_{fs} : is the free space factor; ε_{mp} : is the multi-path factor. The LEACH applies ε_{fs}= 10 pJ/bit/m2 and ε_{mp} = 0.0013 pJ/bit/m4. These factors are based on the assumption that the node transmitter operates at a bit rate of 1 Mb/s and a frequency of 914 MHz.

Based on whether the distance is larger or smaller than the d_0, d will be raised to a power of 2 or 4. On the other hand, the cost of receiving l-bit message, will be calculated as follows:

$$E_{Rx}(l) = E_{Rx-elec}(l) = lE_{elec} \tag{2.5}$$

Moreover, the energy consumed by CH (E_{CH}) and CM (E_{CM}), is given as follows:

- **The Energy Consumed by CH (E_{CH}):** Energy consumed in the cluster creation stage which mainly dissipated by a CH node includes the following:

a) Energy exhausted during cluster head selection process

b) Energy exhausted during cluster head self-advertising

c) Energy exhausted during receiving joint request from cluster member nodes

d) Energy exhausted during TDMA schedule creation and broadcasting

e) Energy exhausted during receiving sensed data from cluster member nodes

f) Energy exhausted during data aggregation

g) Energy exhausted during sending the data to the base station

Equation 2.6 shows the general form of the computation of the energy consumed by a CH:

$$E_{CH} = E_{CHsetup} + E_{CHreceive} + E_{CHsend} \tag{2.6}$$

where $E_{CHsetup}$, $E_{CHreceive}$, and E_{CHsend} are the energy dissipated in each round during setup phase, receiving and sending process, respectively.

- **The Energy Consumed by CM (E_{CM}):** Energy consumed in the sensing and sending the data by a CM node *(E_{CM})* includes:

a) Energy exhausted receiving CHs advertisements

b) Energy exhausted during sending joint request to cluster head

c) Energy exhausted during TDMA schedule receiving

d) Energy exhausted during sending sensed data to cluster head

The aggregate sum of energy dissipated by a cluster member will be calculated based on the cost of the setup and the transmission procedures as follows:

$$E_{CM} = E_{CMsetup} + E_{CMsend} \tag{2.7}$$

where $E_{CMsetup}$ and E_{CMsend} are the energy dissipated in each round during setup phase and data sending process.

2.5.2 LEACH-Protocols: The Descendants

The LEACH protocol and its descendants development is influenced by diverse factors to meet the WSNs applications requirements which include but not limited to: energy efficiency, energy consumption balancing and scalability (Tarhani *et al.*, 2014; Hadi *et al.*, 2015; Singh *et al.*, 2017).

- **Energy efficiency:** Energy efficiency is the target to provide transmission, receiving and data process in low power consuming rate. Power consuming rate is measured by the total energy of the WSN energy dissipation, where in wireless sensor network node lifecycle is substantially dependent on its limited battery power lifetime duration. Heinzelman and his team (2000) have proposed a cross-layer, low energy adaptive clustering hierarchy (LEACH) protocol, which becomes one of the basics for routing protocol development in WSN. There are some problems should be taken into consideration as LEACH protocol focuses only on clustering strategy, while clustering with multi-hop routing has less energy consumption than direct transmission approach (Long, 2013).

- **Energy consumption balancing:** Due to unequal function distribution among sensor nodes some nodes with high load show high power consumption rate and may die early which result in low network connectivity. Moreover, the energy consumption balancing issue aims to consistently distribute the workloads over the sensor nodes to achieve an even power consumption. In LEACH (Heinzelman *et al.*, 2000) clustering routing strategy, the data aggregation is carried out by cluster head reduces the number of transmitted data packets and saves energy. On the other hand, the aggregation further exhausts the cluster head power and leads to uneven power consumption among cluster heads and cluster members nodes (Bilal, 2011; Singh *et al.*, 2017).

- **Scalability:** It is the capability of a network to accommodate the network increments. The adequate routing protocol has to perform in an adaptive way to accommodate the network topology changes or the increasing load. Thus, a network is labeled as scalable, when it can handle growing number of nodes with an acceptable deterioration in network performance (Dhage *et al.*, 2015). The number of sensor nodes distributed in sensing filed to monitoring specific phenomenon may be in the order of hundreds, thousands or extreme value of millions. Depending on the application, the routing protocols must be scalable enough to be compatible with the density of the nodes. Hierarchical routing schemes are currently methods to respond to the scalability issue. However, due to direct communication in LEACH, the sensor nodes are far away from the BS, will easily fail in a high density of network (Patel *et al.*, 2011; Yan *et al.*, 2011; Liu, 2012; Arumugam *et al.*, 2015; Lin *et al.*, 2015; Mahapatra *et al.*, 2015; Velmani *et al.*, 2015).

This section considers LEACH-protocols which are developed over the last decade by focusing on two aspects: first, the LEACH enhancement avenues and second, the survey of the proposed LEACH-descendant techniques to improve shortcomings in LEACH based on enhancement avenues. As in Figure 2.9, this study has classified the methods of improving LEACH routing protocol insufficiency by the following avenues:

1. Modifying the entire algorithmic flow.
2. Modifying the data communication procedure.
3. The adjusting of the CH selection approach.

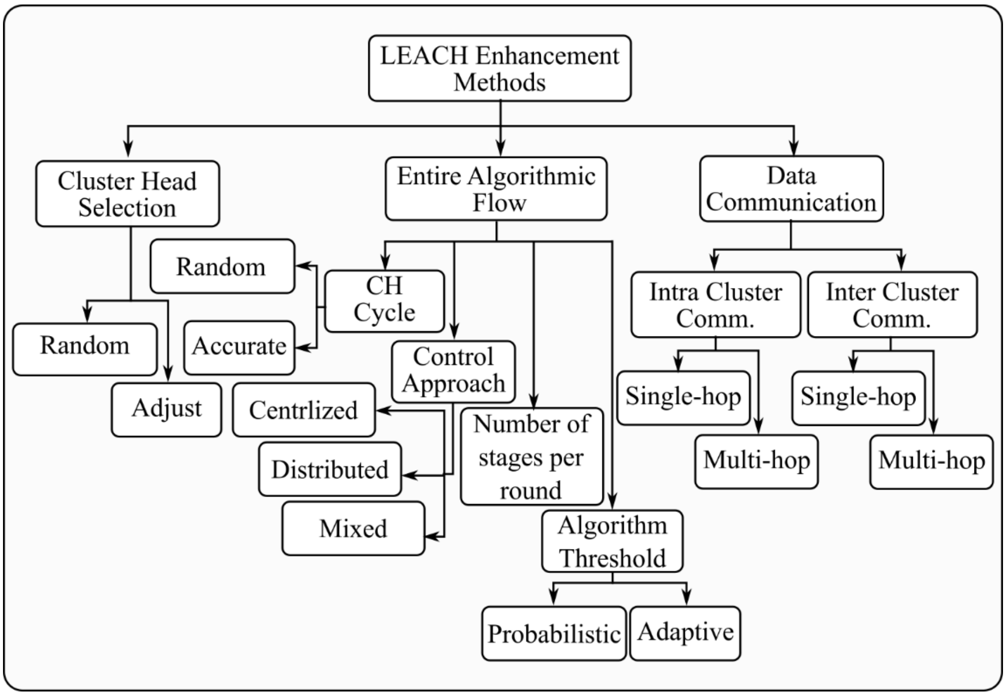

Figure 2.9 LEACH Enhancement Methods