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In Sciences

Theme

Hierarchical Routing Optimization in Wireless Sensor Networks

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Presented by

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Abstract

Wireless Sensor Networks (WSNs) are composed of hundreds of tiny sensor nodes with limited resources communicating with each other to monitor the environment. Sensor nodes are usually powered by a battery. Consequently, energy efficiency is critical for the lifetime of the Wireless Sensor Network. Routing protocols are the most important issue for WSNs. LEACH (Low Energy Adaptive Clustering Hierarchy) is one of the first hierarchical routing algorithms for WSNs. LEACH uses Cluster Heads (CHs) to mediate data transmission.

This thesis contains a new formula for the Cluster Head selection process and two new routing protocols. The new formula introduces the residual energy of the node in the CH selection process. The first improved protocol uses a Vice-Cluster head (VCH) for each cluster to replace the CH when it dies. The second new protocol is an improved LEACH-C protocol in which, the Sink uses a Consumption Model for each Sensor Node (CMSN) to estimate the amount of energy needed for the next rounds ,so sensor nodes don’t have to send the value of current energy to the base station at the beginning of each round like it does in LEACH-C. Simulation results show that these improvements extended the network lifetime compared to previous works.

Keywords: Wireless Sensor Networks, Energy Efficiency, LEACH, LEACH-C.

Résumé

Les Réseaux de Capteurs Sans Fil (RCSF) sont composés de centaines de minuscules nœuds capteurs avec des ressources limitées, communiquant entre eux pour surveiller l'environnement. Les nœuds capteurs sont généralement alimentés par une batterie. Par conséquent, l'efficacité énergétique est essentielle pour la durée de vie du RCSF. Les protocoles de routage sont le problème le plus important pour les RCSF. LEACH (Low Energy Adaptive Clustering Hierarchy) est l'un des premiers algorithmes de routage hiérarchique pour les RCSF. LEACH utilise des Chefs de Grappe (CG) pour arbitrer la transmission de données.

Cette thèse contient une nouvelle formule pour le processus de sélection des CG et deux nouveaux protocoles de routage. La nouvelle formule introduit l'énergie résiduelle du nœud dans le processus de sélection du CG. Le premier protocole amélioré utilise un Vice Chef de Grappe (VCG) pour chaque Grappe pour remplacer le CG quand il meurt. Le deuxième nouveau protocole est un protocole LEACH-C amélioré dans lequel le la Station de Base utilise un Modèle de Consommation pour chaque Nœud Capteur (MCNC) pour estimer la quantité d'énergie nécessaire pour les prochains tours afin que les nœuds capteur n'aient pas à envoyer la valeur de l'énergie actuelle à la Station de Base au début de chaque tour comme dans LEACH-C. Les résultats de simulation montrent que ces améliorations ont prolongé la durée de vie du réseau par rapport aux travaux précédents.

Mots clés : Réseaux de capteurs sans fil, efficacité énergétique, LEACH, LEACH-C.

الملخص

تتكون شبكات الاستشعار اللاسلكية من مئات من عقد الاستشعار الصغيرة بموارد محدودة، وتتواصل مع بعضها البعض لمراقبة البيئة. عادة ما يتم تشغيل عقد الاستشعار بواسطة بطارية. وبالتالي، فإن كفاءة الطاقة أمر بالغ الأهمية طوال عمر شبكة المستشعرات اللاسلكية. بروتوكولات التوجيه هي أهم مسألة لشبكات الاستشعار اللاسلكية . يعد LEACH (Low Energy Adaptive Clustering Hierarchy) أحد أول خوارزميات التوجيه الهرمي لشبكات الاستشعار اللاسلكية .يستخدم LEACH رؤوس الكتل للتوسط في نقل البيانات.

تحتوي هذه أطروحة على صيغة جديدة لعملية اختيار رئيس الكتلة وبروتوكولين جديدين للتوجيه. تستعمل الصيغة الجديدة الطاقة المتبقية للعقدة في عملية اختيار رئيس العقدة. يستخدم البروتوكول المحسن الأول نائب رئيس العقدة لكل مجموعة ليحل محل رئيس العقدة عندما يموت. البروتوكول الثاني هو تحسين للبروتوكول LEACH-C حيث يستخدم نموذج استهلاك لكل مستشعر لتقدير كمية الطاقة اللازمة للجولات التالية حتى لا تضطر المستشعرات إلى إرسال قيمة الطاقة الحالية إلى المحطة الأساسية في بداية كل جولة كما هو الحال في البروتوكول LEACH-C . تظهر نتائج المحاكاة أن هذه التحسينات أدت إلى إطالة عمر الشبكة مقارنة بالأعمال السابقة.

الكلمات الرئيسية: شبكات الاستشعار اللاسلكية، كفاءة الطاقة، LEACH، LEACH-C.

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Above all, a big and true thank you to Allah who gave me the strength and the life to accomplish this task, which at the beginning seemed a difficult one.

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I address my warmest thanks to all my family and friends.

Contents

Acronyms

WSN: Wireless Sensor Network

LEACH: Low Energy Adaptive Clustering Hierarchy

CH: Cluster Head

VLEACH: Vice LEACH

VCH: Vice Cluster Head

LEACH-C: LEACH-Centralized

LEACH-CCMSN: LEACH-Consumption Mode for each Sensor Node

CMSN: Consumption Mode for each Sensor Node

BS: Base Station

.NOW : DotNOW

TinyOS Tiny Operating System

nesC: Network Embedded Systems C

QoS: Quality of Service

SPIN: Sensor Protocols for Information via Negotiation

GEAR: Geographical and Energy Aware Routing

SAR: Sequential Assignment Routing

CSMA: Consumption Mode for each Sensor Node

TDMA: Time Division Multiple Access

MECH: Maximum Energy Consumed by sensor node as Cluster Head

ETX: Transmitter Energy

ERX: Receiver Energy

Efs: Amplification Energy for short distance

Emp Amplification Energy for long distance

Eda: Data Aggregation Energy

P: Cluster Head probability,

TRV-LEACH: Two Rules for Vice cluster head selection- LEACH

TV-LEACH: Two Vice-cluster head LEACH

MMR-LEACH: Multi-hop Routing in LEACH

PSO: Particle Swarm Optimization

DARPA : Defense Advanced Research Projects Agency

NSF: National Science Foundation

SA: Simulated Annealing

BCDCP: Base Station Controlled Dynamic Clustering Protocol

DMSTRP: Dynamic Minimum Spanning Tree Routing Protocol

EC-LEACH: Enhanced Centralized-LEACH

LEACH-CE: LEACH-Centralized Efficient

EELEACH-C: Energy Efficient LEACH-C

ISNEL: Information about Sensor Node Energy Level

MECCH: Maximum Energy Consumed by sensor node as Cluster Head

MECCN: Maximum Energy Consumed by sensor node as Common Node

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General introduction

A Wireless Sensor Network (WSN) consists of densely distributed nodes with limited sensing, computing and communication capabilities that calculate local parameters, and send such information to a Sink (Base Station) for a suitable handling. WSNs support a broad spectrum of applications, like environmental sensing, vehicle tracking, perimeter security, inventory management, habitat monitoring, and battlefield management. For example, WSNs may be used in sensor fields to detect the spread of wildfires, or to assist environmental monitoring, including precision agriculture [1].

Routing in WSNs is a main challenge due to the fundamental features that differentiate such networks from other wireless networks. The limited battery is the most important constraint in WSN. The need for less energy consumption limits the sensor node to use a smaller memory capacity, a short transmit rang, and less calculations. Several routing protocols exist for WSN. These protocols are categorized into hierarchical, flat, and location-based network routing protocols [2].

One of the first hierarchical-based protocols is LEACH [3] with advantages such as simplicity, energy efficiency, and data aggregation abilities [4]. LEACH divides the network into clusters, and for each cluster there is a Cluster Head (CH) that receives data from all member nodes, and then transfers them to the Sink (Base Station). However, the CHs selecting formula ignores the residual energy of the nodes which may lead to the death of the CHs that have low residual energy. The first contribution of this research is to present a new formula for the CH selection process that takes residual energy into consideration.

VLEACH [5, 6] is a descendant of the LEACH protocol that considers a Vice Cluster Head (VCH) for each cluster that takes the place of the CH when it dies. The second contribution of this work is to present a new improvement of VLEACH protocol called TRV-LEACH that uses a new algorithm for the VCH selection process to ensure a longer network lifetime.

LEACH-C [7] protocol is a solution that was proposed to overcome the irregular distribution of CHs in LEACH. LEACH-C is a centralized protocol that uses a simulated annealing algorithm [8] to balance CHs distribution in the network. In LEACH-C, at the beginning of each round all sensors nodes send messages about their residual energy to the Sink for the CHs selection process. These messages cost sensor nodes a lot of energy. The third contribution of this study is to present a new improved protocol named LEACH-CCMSN that uses a Consumption Mode for each Sensor Node (CMSN) to reduce the number of rounds where sensor nodes have to send messages about their residual energy to the Sink, which will extend the network lifetime.

In addition to this general introduction, this thesis consists of four chapters. Chapter 1 provides background information about Wireless Sensor Networks, in which an overview of the main problems in this research area is discussed. Chapter 1 also includes a brief description of Wireless Sensor Networks: Applications, services, operating systems, and routing techniques.

Chapter 2 details the LEACH protocol, related works, and presents the new CH selection formula.

Chapter 3 provides the VLEACH protocol, followed by the first proposed protocol that uses a vice cluster head as well as V-LEACH protocol and talks over the simulation results.

Chapter 4 describes the LEACH-C protocol, then the second proposed protocol, and it discusses the simulation results.

Finally, we end this thesis with a general conclusion.

Chapter 1:

Introduction to Wireless Sensor Networks

1.1 Introduction

Wireless Sensor Networks (WSNs) show promising results for their capability to provide a multitude of applications such as fire detection, and vehicle traffic [9]. The applications provided by WSNs are based on small sensor nodes. These devices have the task of collecting data and transmitting them to a specific node called a “Sink”. This chapter presents the characteristics and architecture of the network, the applications and services offered by Wireless Sensor Networks, and finally the operating systems and routing protocols of these networks.

1.2 Background of Wireless Sensor Networks

Technological advances in microelectronics, micromechanics, and wireless communications have given rise to a new generation of networks called Wireless Sensor Networks (WSNs).

1.2.1 Wireless Sensor Networks

A WSN contains a large number of wireless devices able to take environmental measurements such as sound, temperature, movements, or chemicals. Sensors are usually equipped with data processing and communication capabilities. The sensor sends sensed data, typically via a radio transmitter, to a command center, either directly or through a Sink as shown in figure 1.3. To reduce power consumption, sensed data are normally sent via other sensors in a multi-hop approach. Retransmitting sensors and the Sink can perform fusion of the sensed data in order to filter out erroneous data and anomalies.

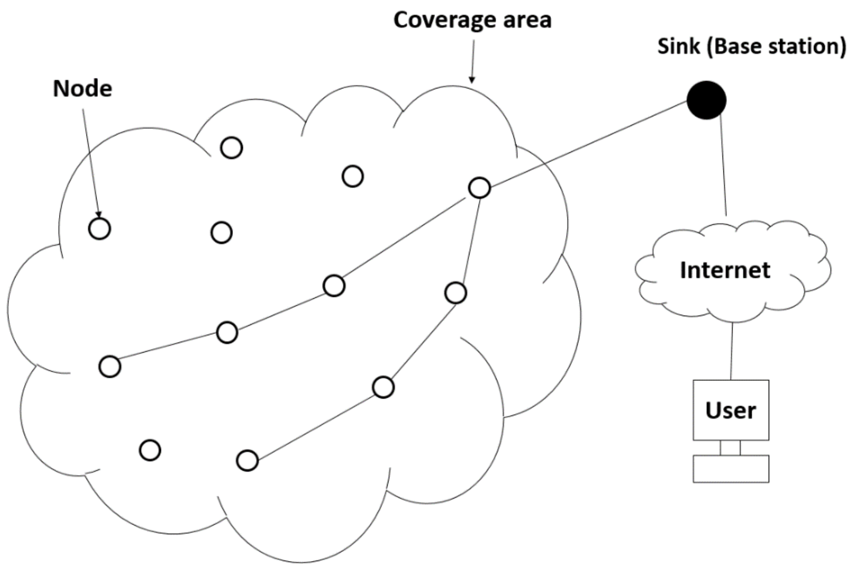

Fig. 1.1 General architecture of a WSN

Many applications have been proposed for WSNs, and many of these applications have specific requirements that offer additional challenges to the application designer.

1.2.2 Sensor node

A sensor node (mote) is a small electronic device capable of measuring physical environmental (temperature, light, pressure, etc.) or physiological (blood sugar, blood pressure, etc.) values, and of communicating it to a control center via a Sink [10].

The structure of a sensor node is shown in Figure. 1.1. A sensor node is generally composed of a sensor module, a communication module, a processing module, and an energy supply module.

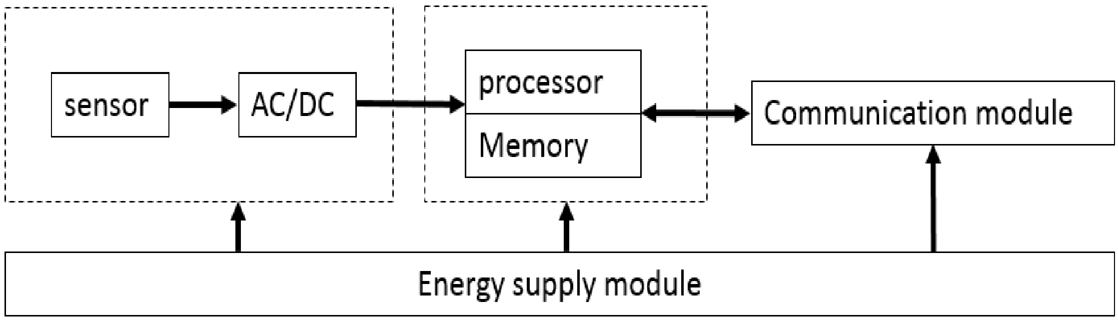

Fig. 1.2 Sensor node structure

The sensing module is composed of a sensor responsible of collecting environment data and an analog-to-digital converter (AC/DC), which converts these data from an analog signal into a digital signal, and then transmits the signal to the processing module [10].

The processing module contains a processor and a memory. The main operations of the processing module are processing and storing sensed and received data. The task of the communication module is to achieve communication with other sensor nodes. The energy supply module uses batteries with limited energy to provide all the energy required for the node to work [10].

Figure 1.2 shows the latest-generation DotNOW (.NOW) sensor node. DotNOW motes are equipped with an ARM 32 bit Cortex M3 processor capable of maximum throughput of 45 millions of instructions per second when operating at 45 MHz. The DotNOW runs on eMoteMicro Framework with real-time extensions, which contain libraries for networking, security and analysis[11].

Fig 1.3 DotNOW 1.0 mote hardware [11].

1.2.3 WSNs architecture

Generally, in WSNs architecture, we need five layers (OSI Model): application layer, transport layer, network layer, data link layer, and physical layer as shown in Figure1.4. In addition to these five layers, we have three cross-layers, which are power management cross-layer, mobility management cross-layer, and task management cross-layer. These cross-layers are used to manage the network [12].

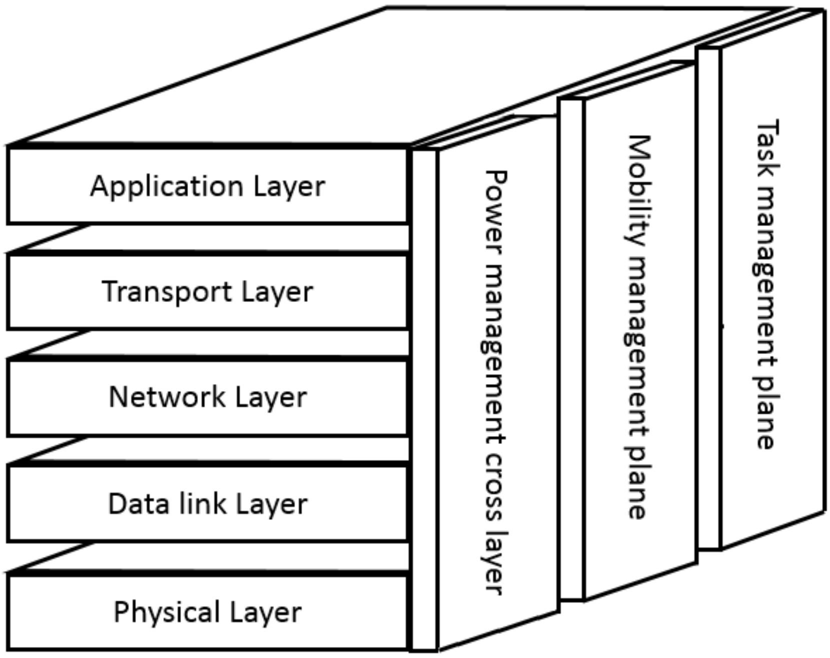

Fig. 1.4 OSI Model of WSN

1.2.4 WSNs Topology

WSNs include different topologies for radio communications. Network topologies applied to WSNs are shortly discussed below:

1.2.4.1 Star network

In star topology, sensor nodes cannot send data to each other, they send them only to the Sink. The power consumption of sensor nodes in this type of network is low because of its simplicity. On the other hand, the Sink must be inside the radio transmission range of all sensor nodes.

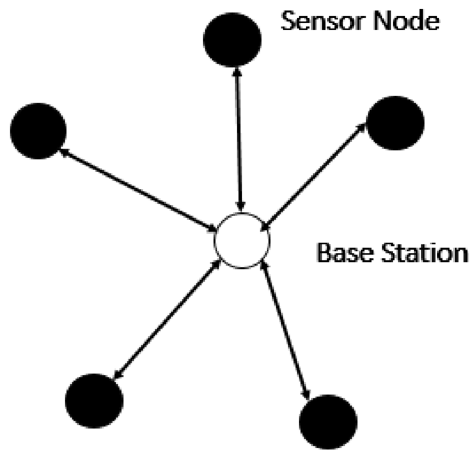

Fig. 1.5 a Star network topology

1.2.4.2 Mesh network

In mesh topology, sensor nodes can send data to each other (within radio transmission range), so a node can send a message to the Sink, even if it is out of radio communications range, by using an intermediate node to forward the message.This type of communication is called multi-hop. The main drawback of the mesh topology is in the power consumption of the intermediate sensor node, which is higher than non intermediate sensor node.

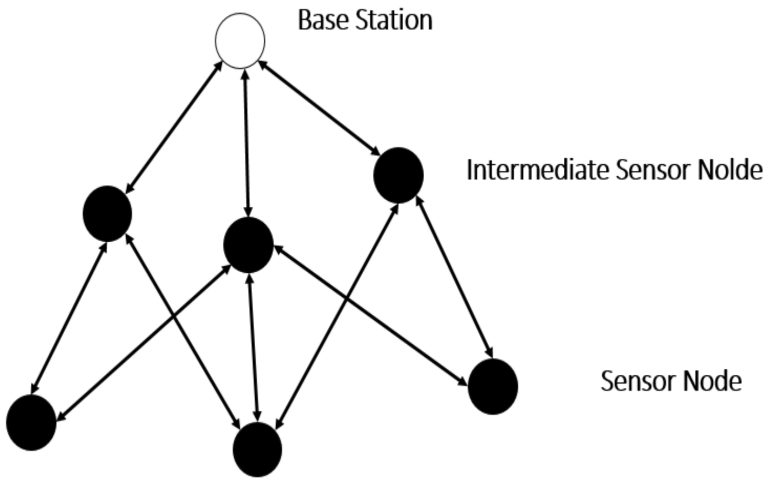

Fig. 1.6 a Mesh network topology

1.2.4.3 Hybrid star–Mesh network

A hybrid star-mesh network offers a strong and useful communications network while keeping the sensor node's power consumption to a minimum. In this type of network, only a few sensor nodes are allowed to act as intermediate nodes to forward messages.

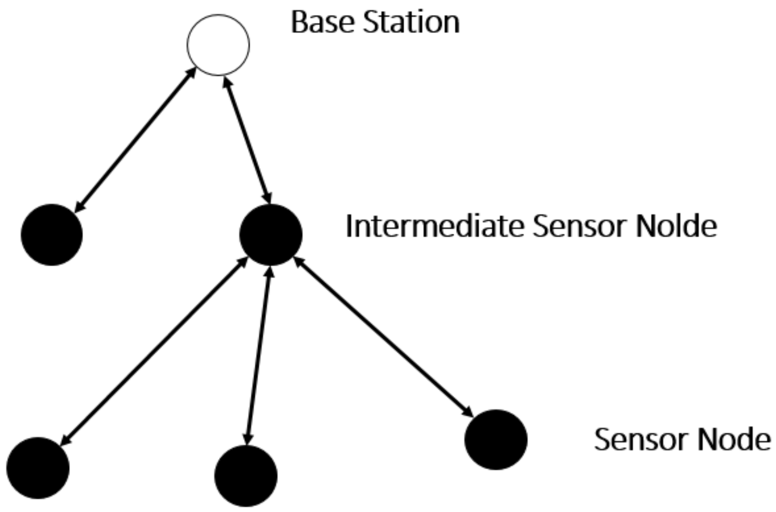

Fig. 1.7 A Hybrid Star–Mesh network topology

1.2.5 Advantages of WSNs

Several advantages exist for using Wireless Sensor Network [13]:

- A higher level of fault tolerance is achievable, because of the dense deployment of a larger number of nodes.
- Coverage of a large area is possible through several sensors.
- It is possible to add additional sensor nodes within the region of interest.
- An improvement in sensing quality is achieved by merging multiple, independent sensor measurements.

1.3 Applications of WSNs

Several applications have been intended for WSNs.

1.3.1 Military applications

WSNs can be a critical part of a military facility. For example, by deploying Wireless Sensor Networks in critical areas, enemy troops can be tracked. Sensor nodes can send notifications whenever movement through a specific region is sensed as shown in figure 1.8. Distinct from other surveillance techniques, WSN can be entirely passive until a particular phenomenon is detected [14].

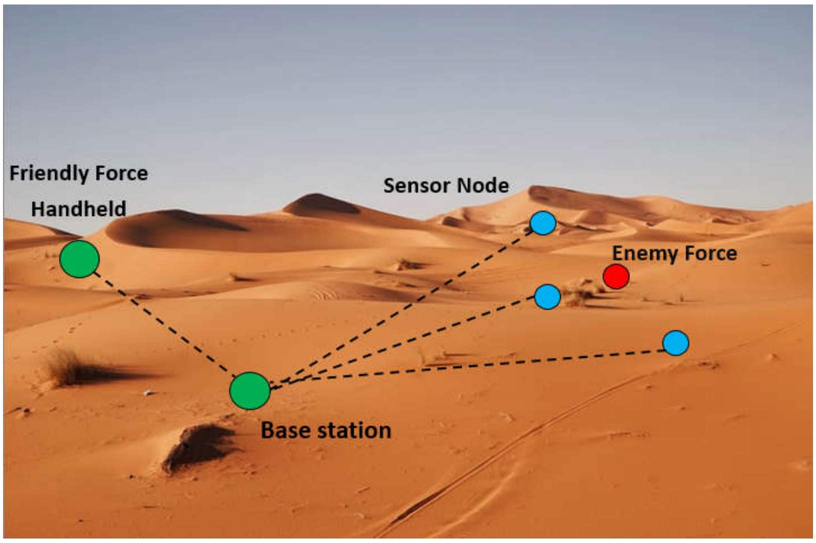

Fig. 1.8 Application of WSN: enemy force detection

1.3.2 Environmental applications

By using a WSN within a natural environment, collection of long-term data becomes possible. Wireless Sensor Network applications are able to get measurements that are else ways more difficult to collect. As a result, numerous environmental applications have been proposed for Wireless Sensor Networks

[13, 14].Few of them include animal tracking, forest-fire detection, and disaster assistance applications.

Consider a situation where a fire starts in a forest. A WSN deployed in the forest could immediately inform authorities as soon as possible.

Fig. 1.9 Environmental application: ZebraNet[7]

ZebraNet system shown in Figure 1.9 is a mobile WSN used to track animal migrations [15].

1.3.3 Health Applications

Numerous health applications can use WSN. For example, hospital patients could be equipped with wireless sensor nodes that monitor the patient's vital signs and track their location. Patients could move about more freely while still being under constant supervision.

Figure 1.10 shows an example of the healthcare application, formed by a number of medical sensors; these sensors are connected to a coordinator. The coordinator collects data and forwards them to the Sink. The Sink is a medical server that receives all the medical data gathered by the coordinator.

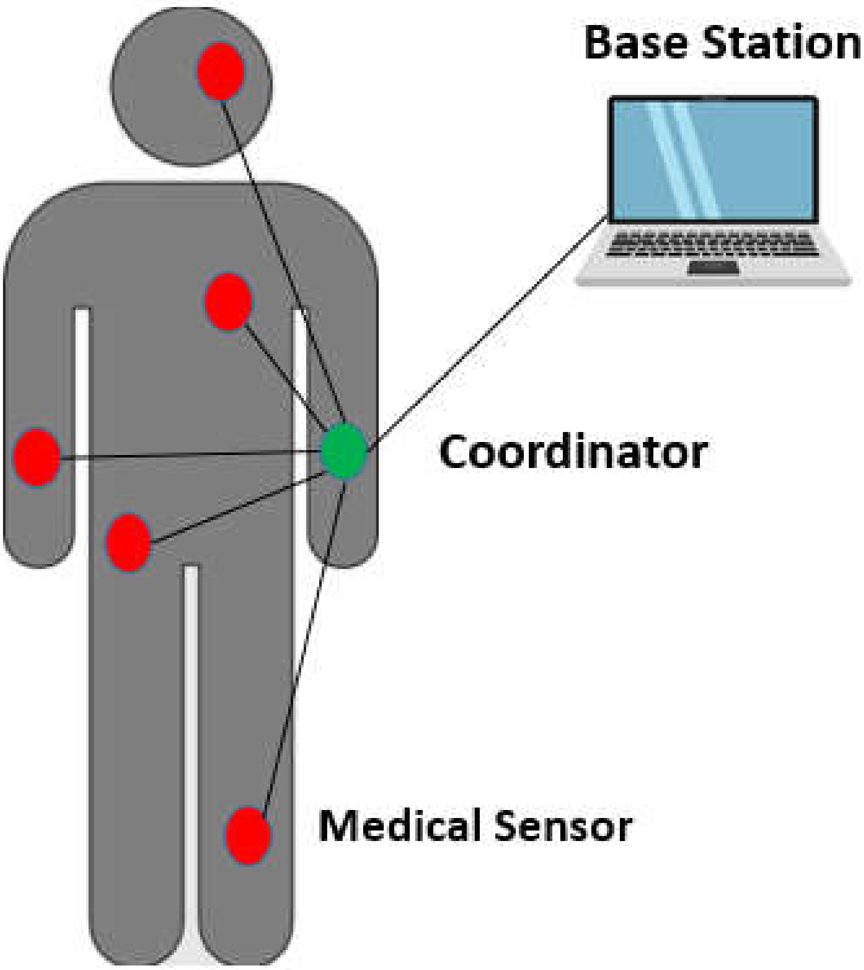

Fig. 1.10 Framework of the healthcare application

1.3.4 Home applications

WSNs can be used to create a smart environment by interconnecting different devices at home. An example of WSN Home applications is the smart kindergarten project [16], which create a smart environment for early childhood learning.

1.4 Design issues of a WSN

The deployment of Wireless Sensor Networks poses many challenges, which are discussed in the following.

1.4 .1 Fault Tolerance

Node failures in WSNs are much higher than other networks, because of hardware issues or physical damage or by depleting their power supply. Protocols deployed in a sensor network must ensure that alternative paths are available for forwarding packets.

1.4.2 Scalability

In WSNs, the numbers of nodes goes from a few to thousands, and in terms of density, a node can have thousands of nodes in its transmission area. Routing protocols in WSN must maintain adequate performance in these situations.

1.4.3 Production Costs

Since most WSN approaches consider the sensor nodes disposable devices, WSN cannot compete with traditional approaches of collecting data if sensor nodes cannot be produced very cheaply. The expected price of a sensor node should be less than $1[**17**].

1.4 .4 Hardware Constraints

Mainly, a sensor node is made up of four units, a sensing unit, a transmission unit, a processing unit, and a power supply. Additionally, the nodes may have more units such as a localization system. However, every additional unit comes with additional power consumption and increases the size of the node. Therefore, additional functionality needs to be balanced against low-power and cost requirements.

1.4 .5 Topology

Topology control in WSNs is a technique of defining the connections between nodes. It is one of the main issues researched to reduce power consumption in WSNs.

1.4 .6 Power Consumption

Most of the WSN challenges arise from the limited energy resources of the sensors. Software and hardware design for WSNs must take into account energy resources. Some solutions are to aggregate sensed information and to turn off some nodes to conserve energy.

1.5 Services of WSNs

Most Wireless Sensor Network applications share common services; for-instance, time synchronization, data aggregation, location detection, topology management, data storage, and message routing.

1.5.1 Time Synchronization

Time synchronization is acrucial service in WSNs [18]. So as to properly coordinate their operations to achieve complex sensing tasks, sensor nodes must be synchronized. Time synchronization allows sensor nodes to correctly time-stamp sensed events. Incorrect timestamps, due to factors; for-example, hardware clock drift which can cause incorrect chronological order of sensed data to be sent to the Sink.

Time synchronization is crucial for low-duty power cycles. Synchronized sensor nodes can send messages to the Sink and subsequently power down to conserve energy.

1.5.2 Data Aggregation

Data aggregation is an important issue in WSNs. Sensor nodes power is limited. Therefore, it is important to minimize the number of messages transmitted. Sensor nodes within the same area often detect the same, shared phenomenon; it is possible for some sensors to have the same readings. Local collaboration allows nearby sensor nodes to filter and aggregate sensor readings before transmitting them to a Sink. As a result, this process can reduce the number of transmitted messages.

1.5.3 Location detection

Location detection of a sensor node can be expressed as global coordinates or inside an application-defined local coordinate system. It serves as additional WSN services where location awareness is required; for example, message routing. Besides that, in applications like fire detection, it is usually not sufficient to determine if a fire is happening, but more importantly, where.

1.5.4 Message Routing

In WSNs, routing protocols must minimize energy consumption and achieve an acceptable degree of fault tolerance if some of the sensor nodes died.

1.5.5 Data Storage

Data collected by individual nodes should be stored at some place, either internally or externally. In some cases, where an off-line storage area is not available, data must be stored within the WSN [19].

1.6 Operating Systems for WSNs

The design of operating system for WSNs diverges from the traditional operating system design due to their particular features like limited resources and inaccessible deployment environments. Some of the WSN operating systems are described in what follows.

1.6.1 TinyOS

TinyOS[20] is an open source operating system designed for sensor networks. It supports multithreading, and asynchronous *events*. It is written in nesC language with a footprint of 400 bytes. It started as a collaboration between the University of California and Intel Research. TinyOS has been under development for several years and is now in its 2.1.2 version.

1.6.2Contiki

Contiki [21], is an open source operating system written in C language for sensor nodes. It is portable and built around an event driven kernel. A typical Contiki configuration needs about 40 kilobytes of ROM. It includes multitasking, multithreading, TCP/IP, Graphical User Interface, personal web server, and other features.

1.6.3 MANTIS

MANTIS [22], is an open source multithreaded operating system for WSN. The MANIS Operating System (MOS) is written in C with a footprint that needs less than 500 bytes. The sleep() function in MOS provides more energy conservation, such as sleeping redundant sensor nodes. A basic part in MOS design characteristics is its flexibility in the form of cross platform support and capabilityto test on PCs, PDAs, and different WSN platforms.

1.7 **Routing in WSNs**

In most situations, sensor nodes are deployed with limited battery power. The routing technique used in Wireless Sensor Networks must ensure minimum energy consumption. Many energy-efficient routing protocols have been proposed for Wireless Sensor Networks.

1.7.1 **Routing challenges in WSNs**

Routing in WSNs is very challenging due to the inherent characteristics that distinguish these networks from other wireless networks. Some of these challenges are discussed below: [23]

• IP-based protocols cannot be used in wireless sensor nodes. Because, it is difficult to allocate a universal identifiers scheme for a big number of sensor nodes.

•The detected data is sent from a number of sources to a specific Sink. Which does not happen in typical communication networks.

•In most cases, many sensor nodes send the same sensed data. Therefore, it is important to exploit such redundancy by the routing protocols

•Furthermore, wireless sensor nodes are limited in transmission energy, bandwidth, capacity and storage.

1.7.2 Classification of routing protocols

Various routing protocols have been proposed for WSNs. Based on network structure, routing protocols for WSNs can be classified as data-centric protocols, hierarchical protocols, location-based protocols and QoS aware protocols [24].

1.7.2.1 Data-centric protocols

In the data centric routing, the Sink sends requests to specific sensors of specific areas. Attribute-based naming is necessary to define characteristics of the requested data [25].One of these Data-centric protocols is SPIN.

The idea behind SPIN is to exchange information about the data to be sent using special signaling packets called meta-DATA. This avoids the problem of redundant data. Each node, interested in the data referenced by this meta-DATA packet, can retrieve them by sending a request packet [26].

1.7.2.2 Hierarchical protocols

The main objective of hierarchical routing is to reduce the energy consumption of the sensor nodes by involving them in the multi-hop communication in a group of particular nodes, called a cluster, and by performing the aggregation data in order to decrease the number of messages transmitted to the Sink (see Figure 1.11). The formation of clusters is generally based on the energy reserve of the sensors and the proximity of the sensor to the cluster head .LEACH (Low Energy Adaptive Clustering Hierarchy) is one of the first hierarchical routing algorithms for WSNs [27].

LEACH is a distributed clustering protocol that uses single-hop inter-cluster communication towards the Sink. LEACH operation is divided into rounds. Each round contains two phases: the set-up phase and the steady state phase [28].

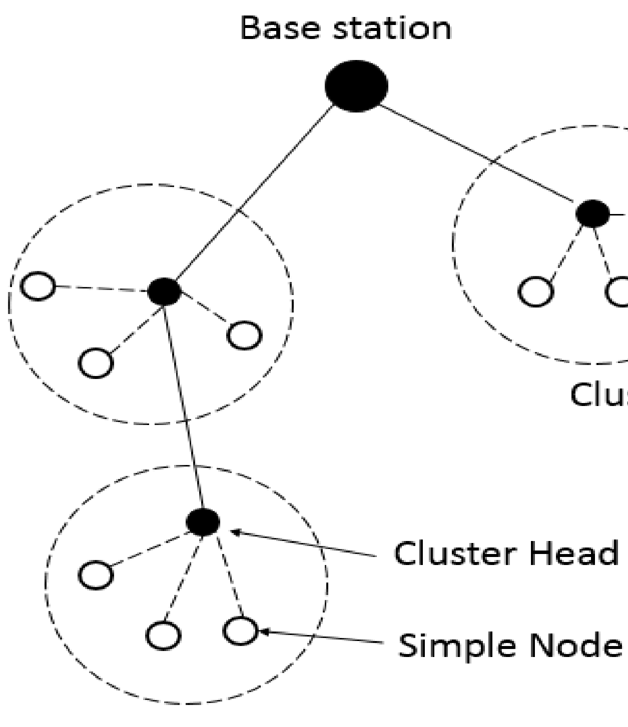

Fig. 1.11 Hierarchical based routing

1.7.2.3 Location-based protocols

In this type of routing protocols, each node knows its geographic coordinates and uses those of the Sink for routing decisions. Geographical and Energy Aware Routing (GEAR) protocol is an example of location based routing protocols [29].

The GEAR protocol uses energy and geographically informed neighbor selection heuristics to route a packet to the target region[30].

1.7.2.4 QoS aware protocols

In QoS based routing protocols, the network must balance between power consumption and data quality. In particular, the network must satisfy a certain QoS metric, for example: bandwidth width. One of these QoS routing protocols is Sequential Assignment Routing (SAR) [31].

SAR protocol creates multi-path trees taking into account the following metrics: QoS, the priority level of each packet, and the energy reserves on each path. Using these trees, multiple routes from the Sink to the sensors are formed. One or more of these routes can be used [32].

1.8 Conclusion

In this chapter, we have given a brief overview on Wireless Sensor Networks, where we have shown that routing protocols in them is different from other networks. In chapter 2, we shall show an improvement on one of the most known routing protocols for WSNs.

Chapter 2

The Cluster Head selection formula

2.1 Introduction

LEACH is a distributed clustering protocol that uses single-hop inter-cluster communication towards the Sink. The Cluster Head (CH) node consumes additional energy compared to ordinary nodes since it receives data from all member nodes, and then transfers them to the Sink. In LEACH, the CH selection process does not take into consideration the residual energy of the nodes, which may lead to the death of some CHs and reduces the network performances.

Many protocols have been extracted from LEACH with some improvements in the basic routing method. In this section, we present the description of LEACH protocol, followed by its derived protocols that use a different threshold equation for the CH selection process, then our new threshold equations and the experimental results.

2.2 LEACH

The LEACH (Low Energy Aware Cluster Hierarchy) protocol proposed by Heinzelman et al. [33] is one of the most known hierarchical routing protocols for WSNs.

LEACH divides the network into clusters in a distributed manner, in each cluster there is a Cluster Head (CH) responsible of receiving, processing, and transmitting data from cluster members to the Sink in a single hop communication.

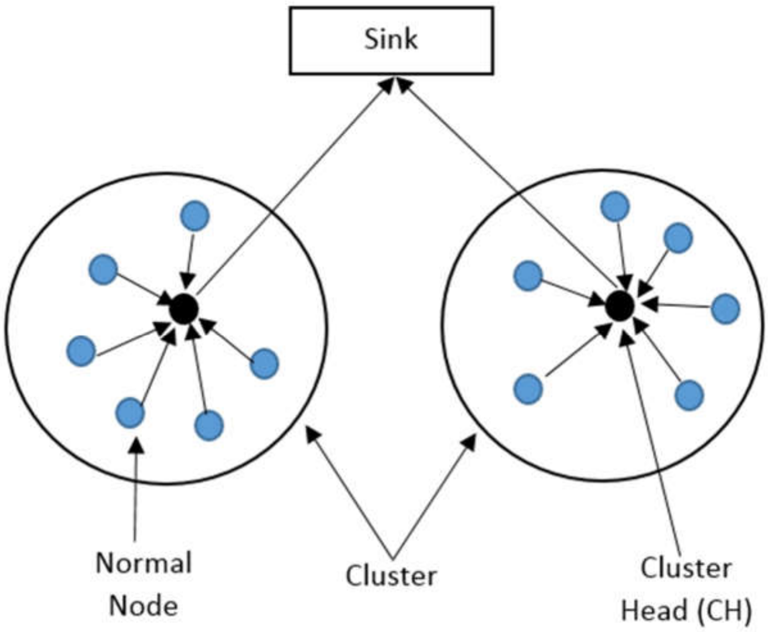

Fig. 2.1. LEACH network model

The LEACH algorithm runs in rounds, where each round begins with a setup phase followed by a steady-state phase.

2.2.1 Setup phase

In the setup phase, the election of CHs and the formation of clusters takes place. The Setup phase can be divided into three sub-phases (figure 2.2): the announcement phase, the cluster organization phase and the scheduling phase. [b9]

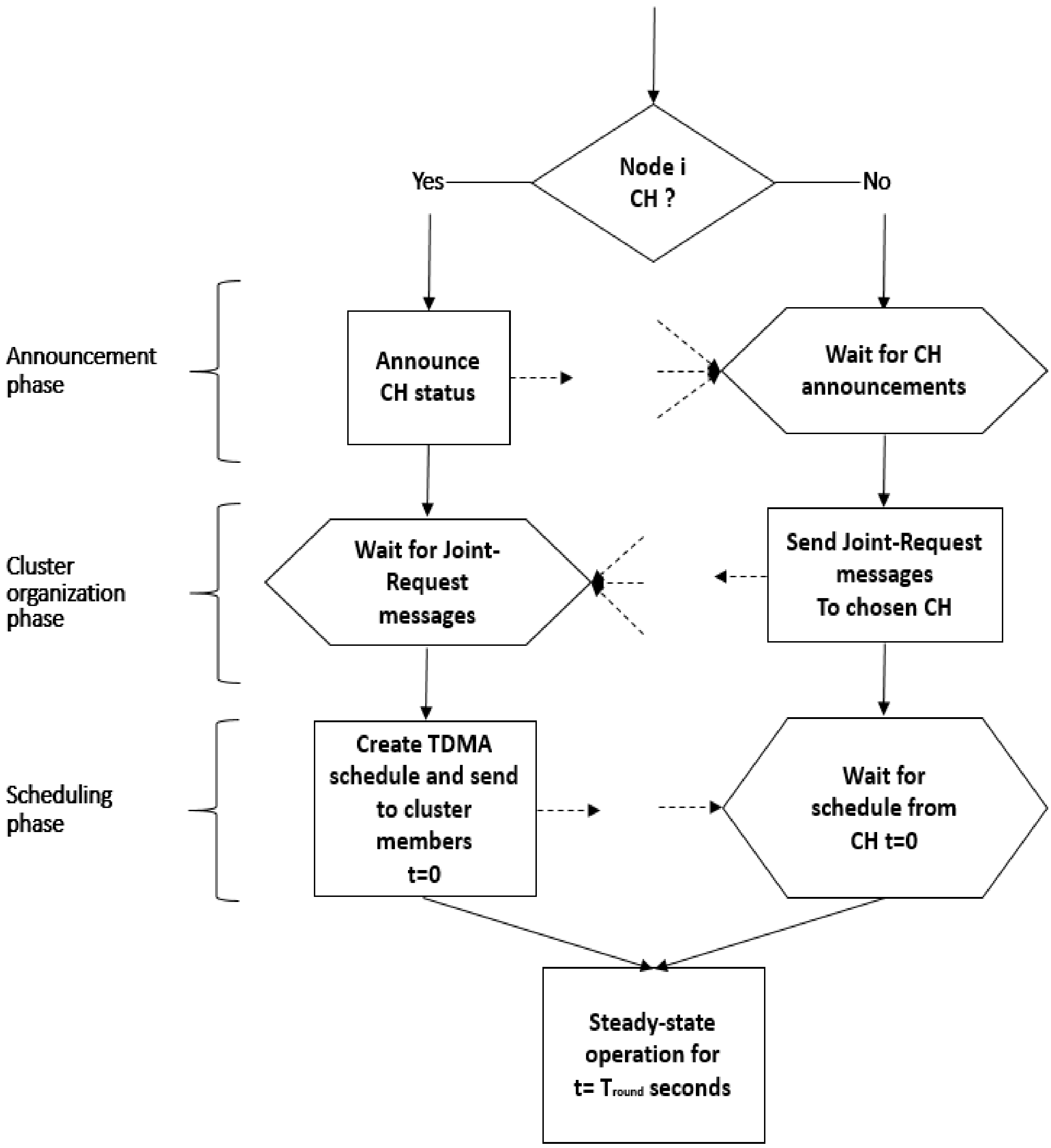

Fig. 2.2 Flowchart of the distributed cluster formation algorithm for LEACH [3]

2.2.1.1 Announcement phase

In the setup phase, a round of CH election begins. The CH selection method guarantees that this role rotates between nodes, to make sure that the energy consumption is distributed evenly across all the sensor nodes.

To determine cluster heads, each node n produces a random number, v, between 0 and 1 and compares it to a threshold T(n). The node turns into a cluster head if its v, is less than the threshold. Equation 1 calculates the threshold:

$$\mathrm{T(n)} = \begin{cases} 0 & \forall n \notin G \\ \dfrac{P}{1 - P\left(r \bmod \left(1/P\right)\right)} & \forall n \in G \end{cases} \tag{1}$$

P denotes the CH probability, r represents the present round, and G characterizes the set of nodes that was not chosen as CH in the last 1/P rounds.

2.2.1.2 Cluster organization phase

After the CH election process, each CH broadcasts a message containing the CH identifier to its surround nodes using the MAC CSMA protocol to avoid collisions between the CHs.

Based on the received signal strength, all the remaining nodes select the CH with the strongest signal (i.e. the closest one) to join, to ensure minimum energy for communication between cluster-members and CH.

After that, the nodes notify their designated CH of their choice to be a member of the cluster by sending a join request message.

2.2.1.3 Scheduling phase

Based on the cluster construction, every CH builds a TDMA schedule and assigns to each member node a time slot during which it can transmit its data. Then the CH sends the TDMA schedule to its members [7].

2.2.2 steady-state phase

This phase is longer than the setup phase. In this phase, all the nodes gather data and use their assigned slots to transmit them to the CH (figure 2.3). The CH aggregates the data and sends them to the Sink.

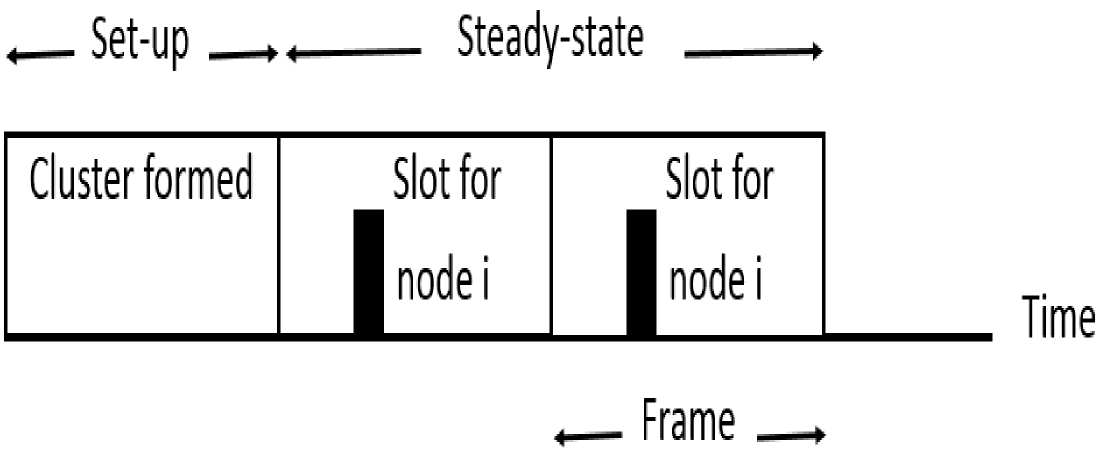

Fig. 2.3 Timeline showing LEACH operation

After a predetermined period of time, a new round begins. This process is repeated until all nodes in the network are selected only once as CH in all previous rounds. If so, all nodes can participate again in the CH selection process.

2.3 Related Work

In each round of LEACH protocol and based on its threshold equation, the CHs are selected randomly. After some rounds, there will be some nodes with high energy and other with low energy. If the node with low energy is selected as the CH, then it dies rapidly. Consequently, the network performances are influenced.

In what follows, we present the threshold equations for the CH selection process of LEACH successors.

2.3.1 Modified-LEACH

Handy *et al.* [34] and Abuhelaleh *et al.* [35] both proposed to introduce the current energy (Encurrent) and the initial energy (Emax) in the threshold *T*(*n*) calculation, as shown in Equation 2:

$$\mathrm{T(n)} = \begin{cases} 0 & \forall n \notin G \\ \frac{P}{1-P\left(r \bmod \left(1/P\right)\right)} * \frac{En_{current}}{En_{max}} & \forall n \in G \end{cases} \qquad (2)$$

However, after unquestionable number of rounds, the network is stuck. Some nodes with enough energy still exist. So, Handy *et al.* added a factor to increase the threshold. The new T(n) is given in Equation 3:

$$\mathrm{T(n)} = \begin{cases} 0 & \forall n \notin G \\ \frac{P}{1-P\left(r \bmod \left(1/P\right)\right)} * \left[\frac{En_{current}}{En_{max}} + \left(r_s \; div \; \frac{1}{P}\right)\left(1 - \frac{En_{current}}{En_{max}}\right)\right] & \forall n \in G \end{cases} \qquad (3)$$

Where $r_s$is the number of successive rounds where the node was not elected as the CH. r_s is set to zero once the node becomes a cluster head. In some cases, the r_s value will have greater influence on the T(n) value than the current energy value of a node.

2.3.2 ALEACH

In ALEACH [36], M. S. Ali *et al*. introduced a new term called the Current State probability (CSp), to certify that all nodes die at nearly the same time. The value of *CSp* is calculated as shown in Equations 4:

$$CS_P = \frac{E_{current}}{E_{n-max}} * \frac{k}{N} \qquad (4)$$

Equation 5 represents the final threshold value:

$$\mathrm{T(n)} = \begin{cases} 0 & \forall n \notin G \\ \dfrac{k}{N - k\left(r \bmod \left(N/_k\right)\right)} + \dfrac{E_{current}}{E_{n-max}} * \dfrac{k}{N} & \forall n \in G \end{cases} \qquad (5)$$

Where $E_{current}$ is the node current energy, $E_{n\text{-}max}$ is the network primary energy, *K* is the expected number of CHs in a round, *N* is the entire number of nodes and *r* represents the present round. The *CSp* value will not have much influence on the T(n) value, especially when the node starts losing energy.

2.3.3 LEACH-N

LEACH-N [37] added the residual energy in the calculation of the nodes' threshold as shown in the Equation 6:

$$\mathrm{T(n)} = \begin{cases} 0 & \forall n \notin G \\ \dfrac{P}{1-P\left(r \bmod \left(1/_P\right)\right)} * \dfrac{E_{in\,it} - E_{current}}{E_{in\,it}} & \forall n \in G \end{cases} \qquad (6)$$

Here, E_{init} and $E_{current}$ are the initial energy and the current energy of a node, respectively. The problem of such equation is that the threshold of nodes with the lowest current energy will be higher than the threshold of nodes with the highest current energy.

2.3.4 I-LEACH

In I-LEACH [38], the CH is chosen by considering in addition to the residual energy, the number of neighboring nodes and the location of the node from the Sink. The number of neighbors of each node can be calculated by the Equation7:

$$R_{CH} = \sqrt{(M \times M)/(\pi \times k)} \tag{7}$$

Where, *M x M* is the zone of the deployed nodes and *K* represents the number of clusters. In I-LEACH, a sensor node with more neighbors has a higher chance to be selected as a CH. The ameliorated threshold *T*(*n*) has been obtained as appears in Equation 8:

$$\mathrm{T(n)} = \begin{cases} 0 & \forall n \notin G \\ \frac{P}{1-P\left(r \bmod \left(1/P\right)\right)} \times \frac{E_{cur}}{E_{avg}} \times \frac{Nbr_n}{Nbr_{avg}} \times \frac{dtoBS_{avg}}{dtoBS_n} & \forall n \in G \end{cases} \tag{8}$$

Where E_{cur} is the current energy of a node ,and E_{avg} is the average energy of the network. Nbr_n and Nbr_{avg} are the number of neighbors for *n* and the average number of neighboring nodes in the network, respectively. $dtoBS_{avg}$ is the average distance between the sensor nodes and the Sink and, $dtoBS_n$ is the distance of the sensor nodes from the Sink.

The major problem of such equation is that all nodes must update the value of E_{avg}, Nbr_{avg} and $dtoBS_{avg}$ at the beginning of each round, which consumes more energy.

2.4 The new threshold equation

An experimental test on the previous equations allowed us to propose two new threshold equations. The first equation (equations 9) is used when the node has enough power to act as CH, this equation always favors the node with the utmost value of the remaining energy to be a CH, and doesn't make the network stuck after some rounds. The second equation (equation 10) is used when the node may not be able to act as CH, this equation decreases the chance of the node to be elected as CH to the minimum.

To determine which equation is used for the current round each node $n_{(i)}$ compares its remaining energy $n_{(i)}E$ to the Maximum value of Energy consumed by this node *i* when it was elected as CH ($n_{(i)}$ *MECH*) in the previous rounds (if not $n_{(i)}$ *MECH =0*). If $n_{(i)}E$ is greater than $n_{(i)}$ *MECH* the node $n_{(i)}$ will use equation 9 in the current round for the CH selection process, otherwise it will use equation 10.

The new threshold equations are as follow.

$$\mathrm{T(n)} = \begin{cases} 0 & \forall n \notin G \\ \left(\left(\frac{P}{1-P\left(r \bmod \left(1/_P\right)\right)}\right) * \left(1 + \frac{E_{residual}}{E_{initial}}\right)\right) & \forall n \in G \end{cases} \quad (9)$$

$$\mathrm{T(n)} = \begin{cases} 0 & \forall n \notin G \\ \left(\left(\frac{P}{1-P\left(r \bmod \left(1/_P\right)\right)}\right) * \left(1 + \frac{E_{residual}}{E_{initial}}\right) * p\right) & \forall n \in G \end{cases} \quad (10)$$

Where: *p* is the percentage of CHs in the network, *r* is the present rounds, *G* is the set of nodes that was not elected as the CH in the round *1/p*, $E_{residual}$ is the residual energy and $E_{initial}$ is the initial energy.

2.5 Simulation results

In this part, the performance of LEACH protocol using the new threshold equations is evaluated against the other threshold equations in MATLAB.

We are going to compare four versions of LEACH protocol. We have named LEACH1 the version that uses equation 3, LEACH2 the version that uses equation 5, LEACH3 the version that uses equation 8, and LEACH4 the version that uses equations 9, and 10.

The protocol LEACH-N that uses equation 6 to calculate the threshold will not be compared with the other four LEACH protocols. Simulation results of LEACH-N protocol showed that in the first rounds, when most nodes are at their high energy level, the network stuck because the threshold value is too small, which ended to no election of CHs, or at maximum one or two CHs in the whole network.

Table 2.1 resumes the different LEACH protocol versions based on the threshold equations used in the simulation.

In what follows, the basic assumptions are considered:

- All sensor nodes have the same initial energy.
- They are randomly distributed.
- They have location information.

- Sensor nodes and Sink are static.

- All sensor nodes know the location of the Sink.

- The Sink has unlimited energy.

Table 2.1 the threshold equations for the simulation

LEACH1	$T(n) = \begin{cases} 0 & \forall n \notin G \\ \frac{P}{1-P\left(r \bmod \left(1/P\right)\right)} * \left[\frac{En_{current}}{En_{max}} + \left(r_s \, div \, \frac{1}{P}\right)\left(1-\frac{En_{current}}{En_{max}}\right)\right] & \forall n \end{cases}$
LEACH2	$T(n) = \begin{cases} 0 & \forall n \notin G \\ \frac{k}{N-k\left(r \bmod \left(N/k\right)\right)} + \frac{E_{current}}{E_{n-max}} * \frac{k}{N} & \forall n \in G \end{cases}$
LEACH3	$T(n) = \begin{cases} 0 & \forall n \notin G \\ \frac{P}{1-P\left(r \bmod \left(1/P\right)\right)} \times \frac{E_{cur}}{E_{avg}} \times \frac{Nbr_n}{Nbr_{avg}} \times \frac{dtoBS_{avg}}{dtoBS_n} & \forall n \in G \end{cases}$
LEACH4	$T(n) = \begin{cases} 0 & \forall n \notin G \\ \left(\left(\frac{P}{1-P\left(r \bmod \left(1/P\right)\right)}\right) * \left(1+\frac{E_{residual}}{E_{initial}}\right)\right) & \forall n \in G \end{cases}$ $T(n) = \begin{cases} 0 & \forall n \notin G \\ \left(\left(\frac{P}{1-P\left(r \bmod \left(1/P\right)\right)}\right) * \left(1+\frac{E_{residual}}{E_{initial}}\right) * p\right) & \forall n \in G \end{cases}$

3.5.1 Simulation parameters

The simulations are performed under Windows 7 environment, using MATLAB R2010a simulator. Table 2.2 resumes the different parameters used in the simulation.

Table 2.2 Simulation parameters

Network Parameters	**Values**
Network Size	100 x100 m
Sink position	150 x50 m
Number of nodes	100
Initial Energy, $E_{initial}$	1 Joule
Transmitter Energy, ETX	50nJ/bit
Receiver Energy, ERX	50nJ/bit
Amplification Energy for short distance, Efs	10pJ/bit/m2
Amplification Energy for long distance, Emp	0.0013pJ/bit/m2
Data Aggregation Energy, Eda	5nJ/bit
Cluster Head probability, p	0.05

3.5.2 Simulation Results

The comparison of LEACH1, LEACH2, LEACH3, and LEACH4is in terms of the Total number of alive nodes, and the Total number of dead nodes as Cluster Heads. Figure 2.4 shows the network configuration.

In Figure 2.5 LEACH3 showed the lowest network lifetime compared to the other three protocols, due to the needed formations about neighbors at the beginning of each round, which consumes additional power.

The network lifetime of LEACH4 protocol is extended a least 20 % than the other protocols, because LEACH4 favors, more than the other protocols, the node with the higher residual energy to be elected as a CH.

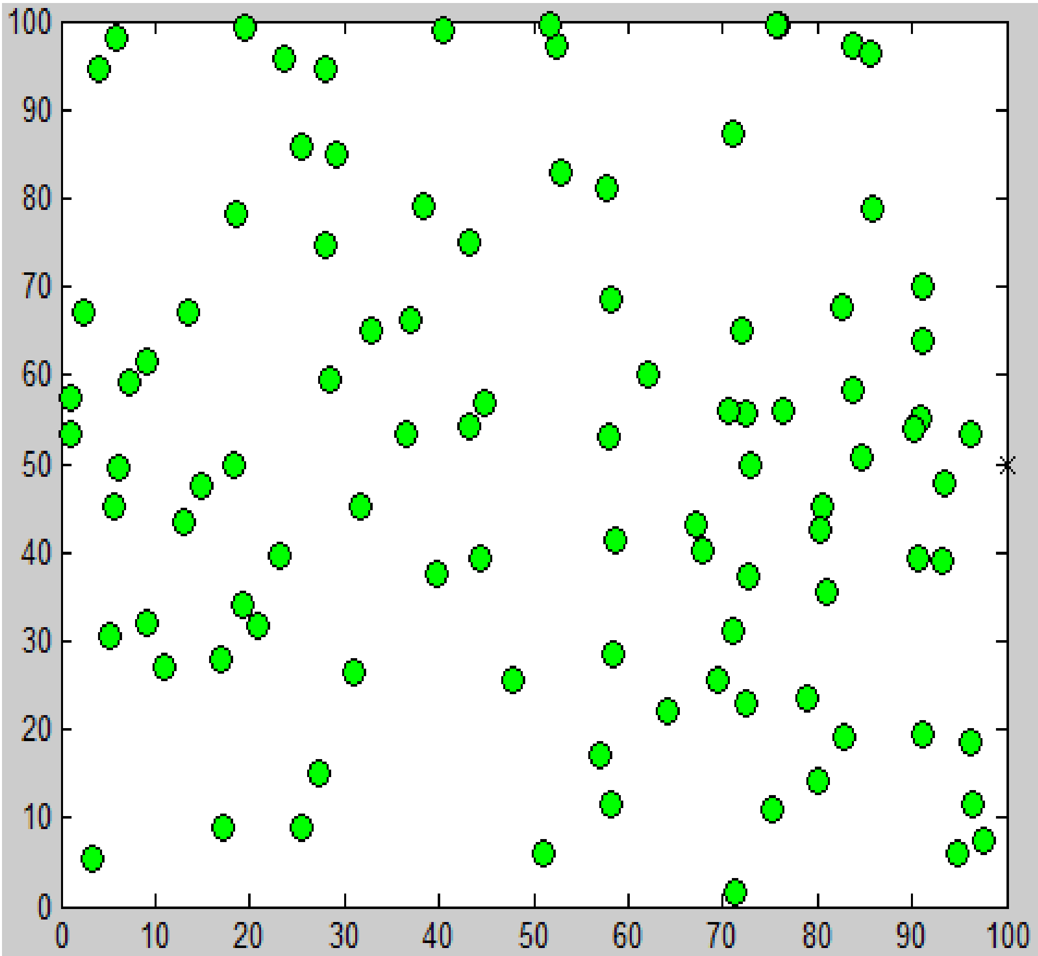

Fig. 2.4 The network configuration

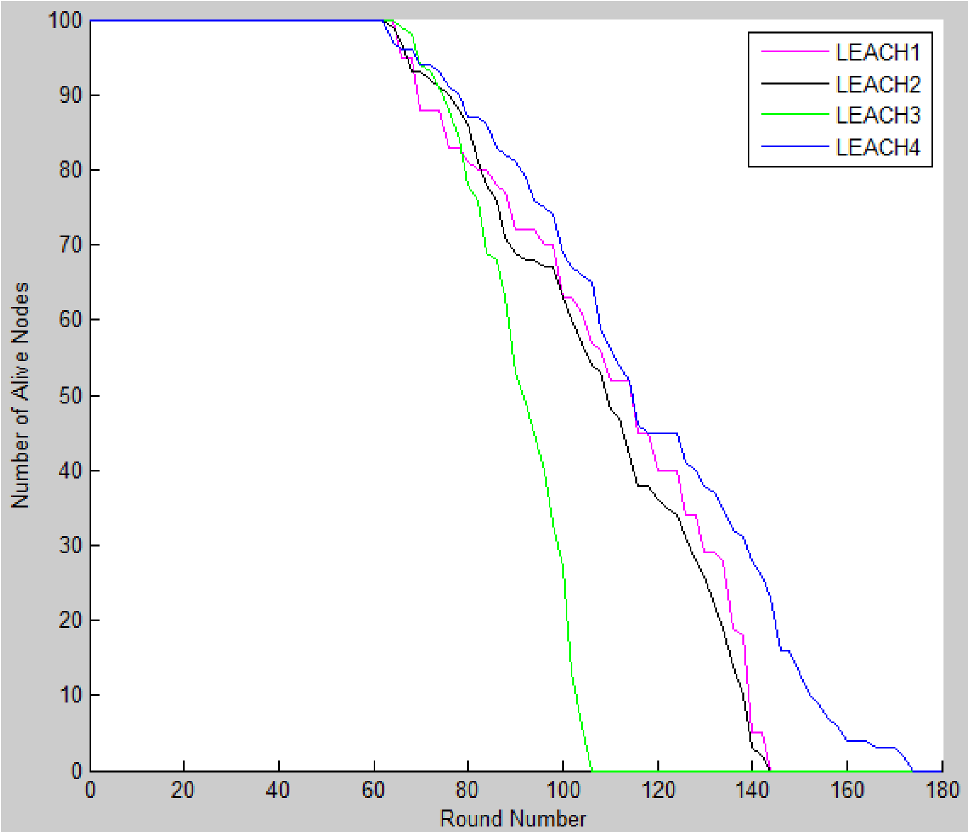

Fig. 2.5 Total number of alive nodes

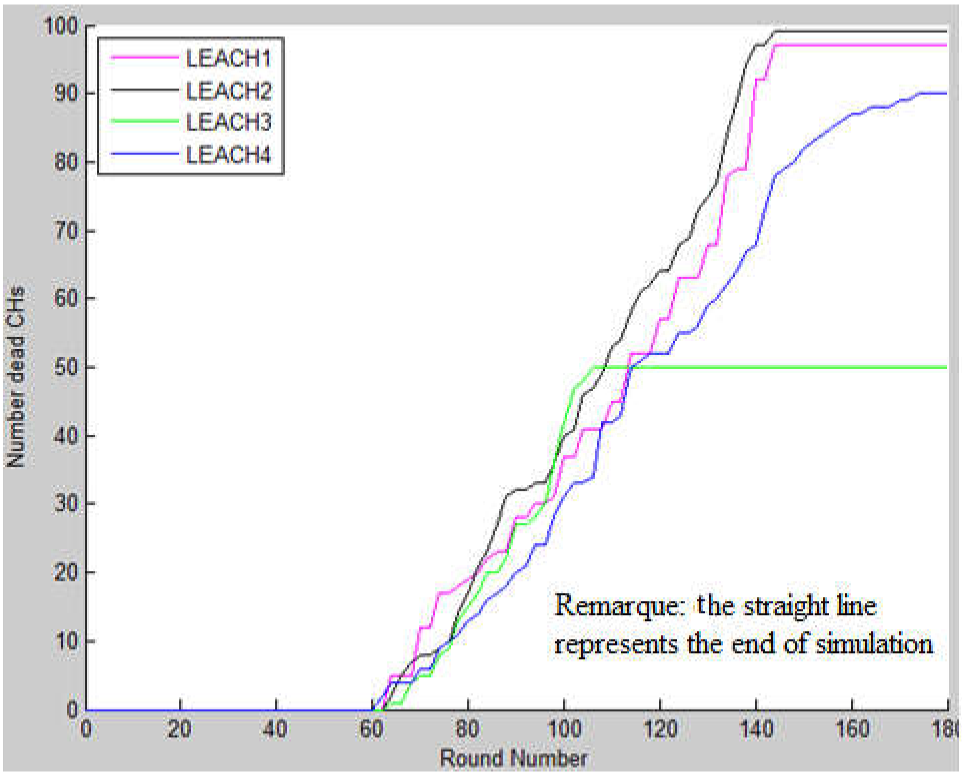

Fig. 2.6 Total number of dead Cluster Heads

Figure 2.6 reports the influence of the different Threshold equations on the LEACH protocol. As we can note from this figure, the total number of dead nodes as Cluster Heads in LEACH4 is less than the other protocols during their lifetime. Cluster Head nodes consume much more power than common nodes due to their heavy-duty, so electing Cluster Head nodes with low energy led to having more dead nodes as Cluster Heads in LEACH1, LEACH2, and LEACH3 than in LEACH4.

3.5 Conclusion

The LEACH protocol and its successors that use a different threshold equation for the CH selection process are introduced in this chapter and the proposed threshold equations are detailed as well. The experimental results prove the efficiency of the proposed threshold equations, by favoring nodes with high energy reserves to be elected as CH. As a result, the life of the network lifetime is extended.

Chapter 3

TRV-LEACH protocol

3.1 Introduction

In LEACH, the Cluster Head (CH) node consumes additional energy compared to ordinary nodes since it receives data from all member nodes, and then transfers them to the Sink. The main disadvantages of the LEACH protocol are the irregular distribution of CHs, and the data loss caused when the CH die.

In this chapter, we present a new protocol called: Two Rules for Vice cluster head selection- LEACH (TRV-LEACH). In the TRV-LEACH protocol, we use the threshold equations proposed earlier in chapter two for the CH selection process, and a Vice Cluster Head (VCH) for each cluster to replace the CH when it dies.

The rest of this section is organized as follows: we start by presenting related works, followed by our improved routing protocol, and then, as a final point, the performance evaluation and the simulation results.

3.2 Related Work

The main goal of routing protocols for WSNs is to reduce the energy consumption. Many protocols have been extracted from LEACH with some enhancements in the basic routing method. In what follows, the descriptions of LEACH derived protocols based on the Vice Cluster Head (VCH) are discussed.

3.2.1 VLEACH

The extended LEACH (VLEACH) [5] protocol uses the node's energy level in the CH election process and considers a Vice Cluster Head (VCH) (Figure 3.1). The VCH is an alternate head that will take the role of the CH when it dies. The VCH selection process is based on three factors: the minimum distance, the maximum residual energy, and the minimum energy. Simulation shows that VLEACH extends the network lifetime better than LEACH protocol.

However, VLEACH suffers from some drawbacks. In the last rounds of the network lifetime where the nodes consumed most of their energy and when the CH is dead, the VCH inherits the heavy tasks of the CH. Such a VCH has a lower probability to deliver data to the Sink because it may not be the node that has the utmost energy level in the cluster.

Manjusha *et al* [6] presented a new version of VLEACH. They used a modified selection formula by considering nodes energy and selected the node with the utmost energy as a VCH. The VCH will be the CH in the later steady-state phase of the present round. So the CH will become an ordinary member and the time of being in a steady-state phase is prolonged. This will reduce the reclustering frequency to extend the lifetime of the network.

Simulations show that *VLEACH* [6] is better than LEACH, but it has some drawbacks. In the later steady-state phase of the present round, the CH must inform the cluster nodes to send their data to the new cluster head (VCH). This needs an additional slot of time and consumes more energy. Furthermore, the ordinary nodes use significantly more energy to reach the new cluster head if it is situated at the border of the cluster.

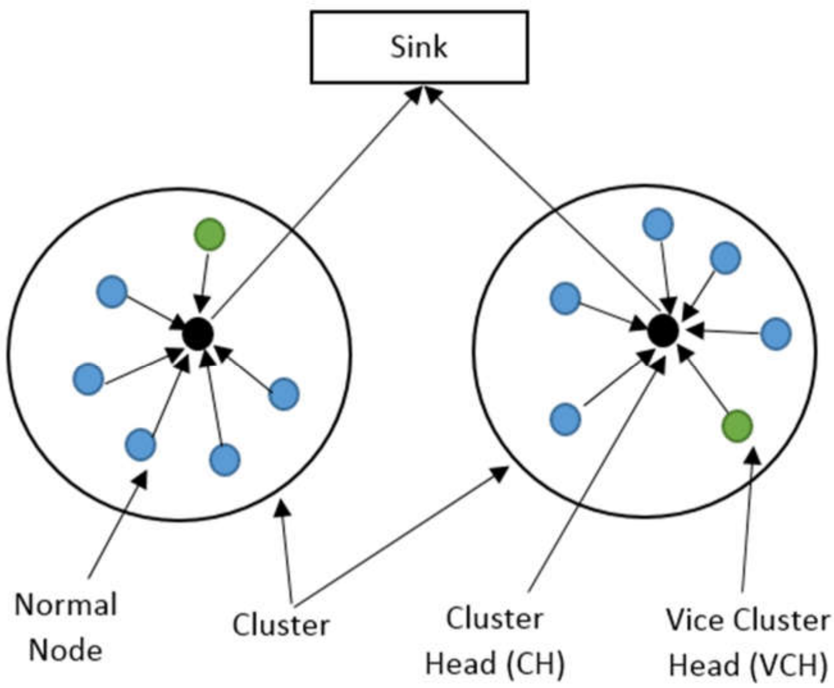

Fig.3.1 VLEACH network model

A recent improvement of LEACH was proposed. TV-LEACH [40] (Two Vice-cluster head LEACH) uses two VCH (Figure 3.2). The first VCH will be the node with a higher value of residual energy divided by the distance, while the second one will be the node with the maximum of residual energy.

The simulation results demonstrate that TV-LEACH extends the network lifetime. However, TV-LEACH has some weaknesses; when the CH dies, the common nodes of the cluster will send their data to the new CH (the first VCH). If this last one dies too, the common nodes will send their data to the second VCH acting as a new cluster head. This causes more energy consumptions for the common nodes.

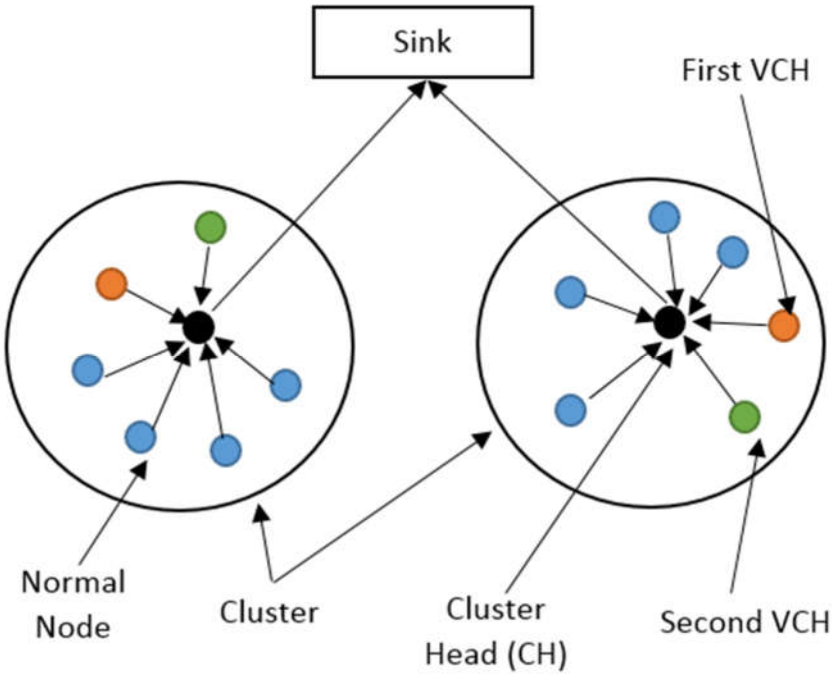

Fig. 3.2 TV-LEACH network model

3.2.2 YA-LEACH

W.T. Gwavava *et al*. [41] exploit the advantage of VLEACH [c3,c4] and LEACH-C (LEACH-Centralized) [7] algorithms to propose a new one named YA-LEACH (Yet Another LEACH). This new protocol uses a centralized cluster formation to ensure optimal clusters with an addition of an alternative VCH. The VCH replaces the CH when its energy is under the threshold.

One major drawback of YA-LEACH can be shown at the new clustering creation phase when all the CHs have to send cluster information to the Sink. If some CHs die before sending such information, the common nodes that belong to the CHs will never participate in the next clustering process.

3.2.3 P-LEACH

Abdul Razaque *et al.* [42] extended LEACH by combining the hierarchical chain formation technique of the PEGASIS within the clusters for the data sending process to exceed the disadvantages of LEACH and PEGASIS. Abdul Razaque *et al.* said that if the CH fails to keep the same maximum energy, then the node with the second maximum energy is chosen as a CH. However, they did not explain how the node with the second maximum energy is designated and how the other CHs are informed about this selection. We think that these operations could reduce the network lifetime.

3.2.4 MMR-LEACH

KausaAghera *et al.* [43] proposed Multi-tier Multi-hop Routing in LEACH protocol (MMR-LEACH) that uses multi-tier concept to divide the whole sensor network into several layers of clusters. MMR-LEACH added a VCH to ensure data transmission from a lower layer to an upper layer and so on until it reaches the Sink.

The main issues that must be addressed in this protocol are how to consider the residual energy in the CH selection formula, how to reduce the number of parameters to select the VCH, and how to ensure data transmission between the lower layer and the upper one when the VCH is dead.

Singh *et al*. [44] proposed a new multi-hop LEACH for prolonging the network lifetime. This is achieved by combining a Particle Swarm Optimization (PSO) technique and V-LEACH protocol. The proposed model uses a PSO technique to avoid having more nodes in some clusters than the others. Further, they use a VCH to ensure data transmission between the common nodes and the Sink after the death of the CH. The authors did not present any details on the VCH selection process.

3.3 Proposed routing protocol TRV-LEACH

In this part, we present the different phases of a new protocol that we call: Two Rules for Vice cluster head selection-LEACH (TRV-LEACH). In TRV-LEACH, CH selection and cluster formation is similar to LEACH. The operation of TRV-LEACH is divided into rounds. Each round consists of two phases, the set-up phase and the steady-state phase. In what follows, the basic assumptions are considered:

- All sensor nodes have the same initial energy.
- They are randomly distributed.
- They have location information.
- Sensor nodes and the Sink are static.
- All sensor nodes know the location of the Sink.
- The Sink has unlimited energy.

3.3.1 Set-up phase

3.3.1.1 Cluster Formation

The first operation in the set-up phase is the creation of the clusters. Each node chooses either to become a CH for the current round or not. This choice is based on a random number between 0 and 1. If this number is lower than the threshold value given by Equations 9 and 10, the node becomes a CH for the current round.

Each node electing itself CH for the present round broadcasts an advertisement message to the rest of the nodes in the network.

All the non-cluster head nodes, decide to which cluster they will belong for this round. This decision is based on the distance of the node from the CH, and it depends on the signal strength of the advertisement messages.

The CH will receive a join message from the nodes that want to be a part of the cluster. The join message contains information about cluster nodes such as the residual energy ($E_{residual}$) and the distance from the cluster head (*dtoCH*). The CH will use this information to calculate its Vice Cluster Head (VCH).

3.3.1.2 Selection of Vice Cluster Head (VCH)

To overcome the VCH selection problems recalled in Section 2 for the existing protocols [5, 6 and 33], the selection of the VCH is based on one of the following two rules. In the first rule, the VCH will be the node with the higher value of the remaining energy divided by the distance from the CH ($E_{residual}$/ *dtoCH*) to reduce the energy spent in the intra-cluster communication. In the second rule, the VCH will be the node with the higher value of remaining energy ($E_{residual}$) to increase the data transfer probability to the Sink.

Considering $E_{start\text{AsCH}}$ and $E_{end\text{AsCH}}$ respectively, the node energy at the beginning and at the end of the last time it was CH, $E_{\text{consumedAsCH}}$ the amount of energy consumed by the CH node per round ($E_{start\text{AsCH}}$-$E_{end\text{AsCH}}$).

Each CH decides which rule is applied to elect the VCH based on the amount of energy consumed per round ($E_{\text{consumedAsCH}}$). If the CH residual energy is bigger than its $E_{\text{consumedAsCH}}$, then the VCH will be the node with the utmost value of remaining energy divided by the distance from the CH. Otherwise, the VCH will be the node with the utmost value of remaining energy.

The process of the VCH selection is as follows:

- *$E_{startAsCH}$=0, $E_{endAsCH}$=0*
- *from round one to the Last round*
  - *for each CH node*
    - *if ($E_{startAsCH}$==0) then*

      $E_{consumedAsCH}$=0;

      $E_{startAsCH}$=$E_{residual}$;
    - *else*

      $E_{consumedAsCH}$ = $E_{startAsCH}$ - $E_{endAsCH}$

      end if
    - *if ($E_{residual}$>$E_{consumedAsCH}$)*

      The VCH is the cluster nodes' member with the greatest value of ($E_{residual}$ / dtoCH).
    - *else*

The VCH is the cluster nodes' member with the greatest value of $E_{residual}$

end if

- *at the end of the current round $E_{endAsCH} = E_{residual}$*

- *end for*

The CH creates a TDMA schedule. The CH broadcasts the *id* of the VCH with the TDMA schedule message to all the cluster nodes.

3.3.2 Steady-state phase

In this phase, the common nodes start sending their data to the CH. The last aggregates the data and sends them to the Sink. If the CH dies, it will be replaced with the VCH and the common nodes proceed to transmit the collected data to the new CH.

3.4 Simulation and discussion

In this part, the performance of TRV-LEACH protocol was evaluated against LEACH and VLEACH [6] considering the same basic assumptions of network and simulation parameters using Network Simulator (Version 2), widely known as NS2.

3.4.1 Network Simulator

NS2 is an event-driven simulation tool used for wired as well as wireless network. Due to its flexibility and modular nature, NS2 has gained a great place in the field of network research since its beginning in 1989. Afterward, several revolutions and revisions have marked the growing maturity of the tool, thanks to the University of California, Cornell University, the Defense Advanced

Research Projects Agency (DARPA), and the National Science Foundation (NSF) [46].

Figure **3.3** shows the basic architecture of NS2. NS2 consists of two languages: C++ and OTcl (Object-oriented Tool Command Language). C++ is used to define the internal mechanism of the simulation, and OTcl configures objects and schedules discrete events. TclCL(Tcl with classes) provides the linkage between C++ and OTCL[c11].

NS2 takes as an input a TCL (Tool Command Language)simulation script file. After simulation, tools like NAM (Network AniMator) and XGraphare used to create animation and plot graphs.

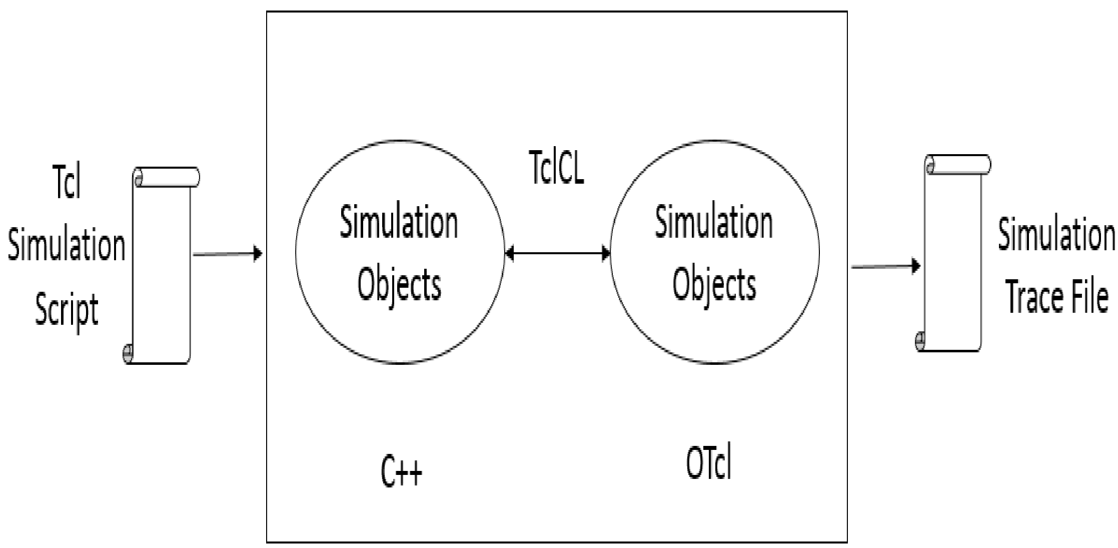

Fig. 3.3 Basic architecture of NS

3.4.2 Simulation parameters

The simulations are performed under Ubuntu 14.04 LTS environment, using Network Simulator (Version 2.34). Table 3.1 resumes the different parameters used in the simulation.

Table 3.1 Simulation parameters

Network Parameters	**Values**
Network Size	100 x 100 m^2
Sink location	150 x 50 m
Number of nodes	200
Packet Size	4200 bits
Initial Energy, $E_{initial}$	5 Joule
Transmitter Energy, ETX	50nJ/bit
Receiver Energy, ERX	50nJ/bit
Amplification Energy for short distance, Efs	10pJ/bit/m2
Amplification Energy for long distance, Emp	0.0013pJ/bit/m2
Data Aggregation Energy, Eda	5nJ/bit
Cluster Head probability, p	0.05

3.4.3 Simulation Results

The comparison of TRV-LEACH, LEACH, and VLEACH is in terms of the Total Energy consumed by all the nodes, and the Total number of alive nodes. Figure 3.4 shows the network configuration

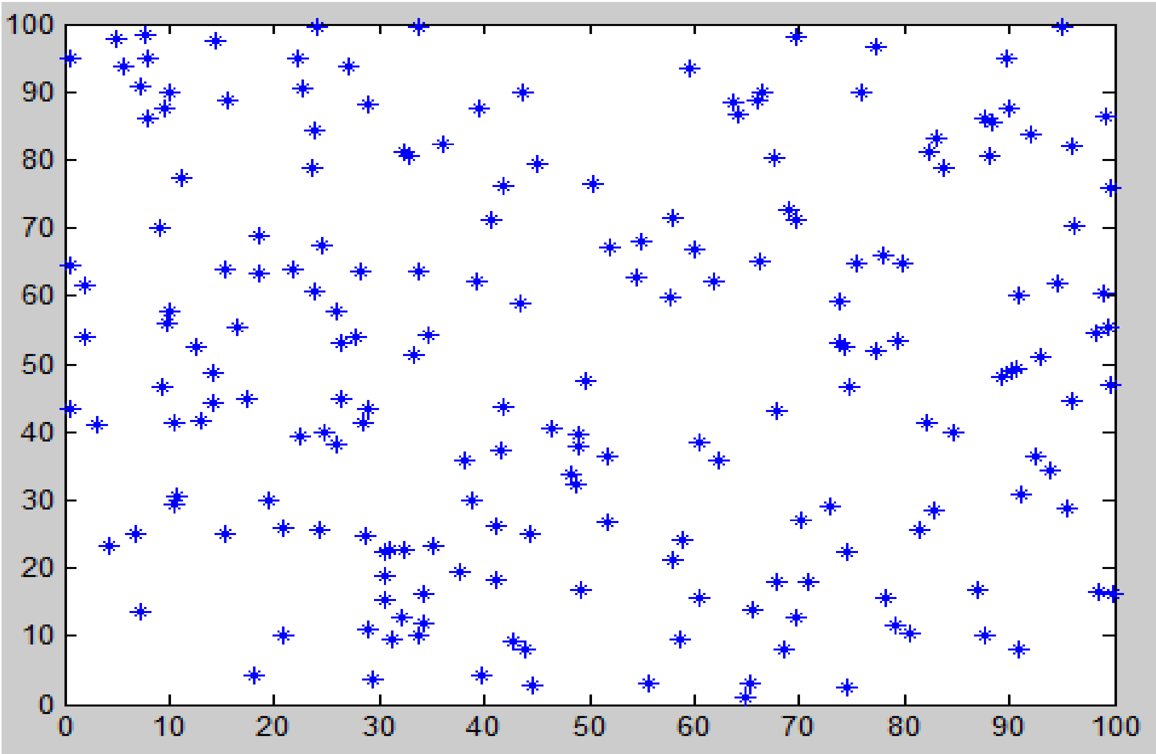

Fig. 3.4 The network configuration

Figure 3.5 clearly shows that the total energy consumed in TVR-LEACH is better than that in LEACH and VLEACH. In LEACH protocol, the CH selection is done randomly. So a node with a smaller amount of energy may be selected as a CH, and it could quickly die. Consequently, the frequency of reclustering increases, which consumes more energy and decreases the network lifetime.

In VLEACH, the VCH is always the node that has the upper most remaining energy in the cluster. The positions of the VCHs vary from the middle of the clusters to the borders. As a result, intra-cluster communications lead to increase the energy consumption and decrease the network lifetime.

In TRV-LEACH, if the remaining energy of the cluster head is bigger than the amount of energy consumed by the CH node per round ($E_{consumedAsCH}$), then the VCHs selection method will be based on the first rule (highest value of $E_{residual}/d_{toCH}$ *of cluster members*) to ensure the minimum energy consumption of intra-cluster communication. Elsewhere, the VCHs selection method will be based on the second rule (highest value of $E_{residual}$ *of cluster members*) to increase the data transfer probability to the Sink. At this stage, if the CH remaining energy is low, the remaining energy of the most cluster members is low too.

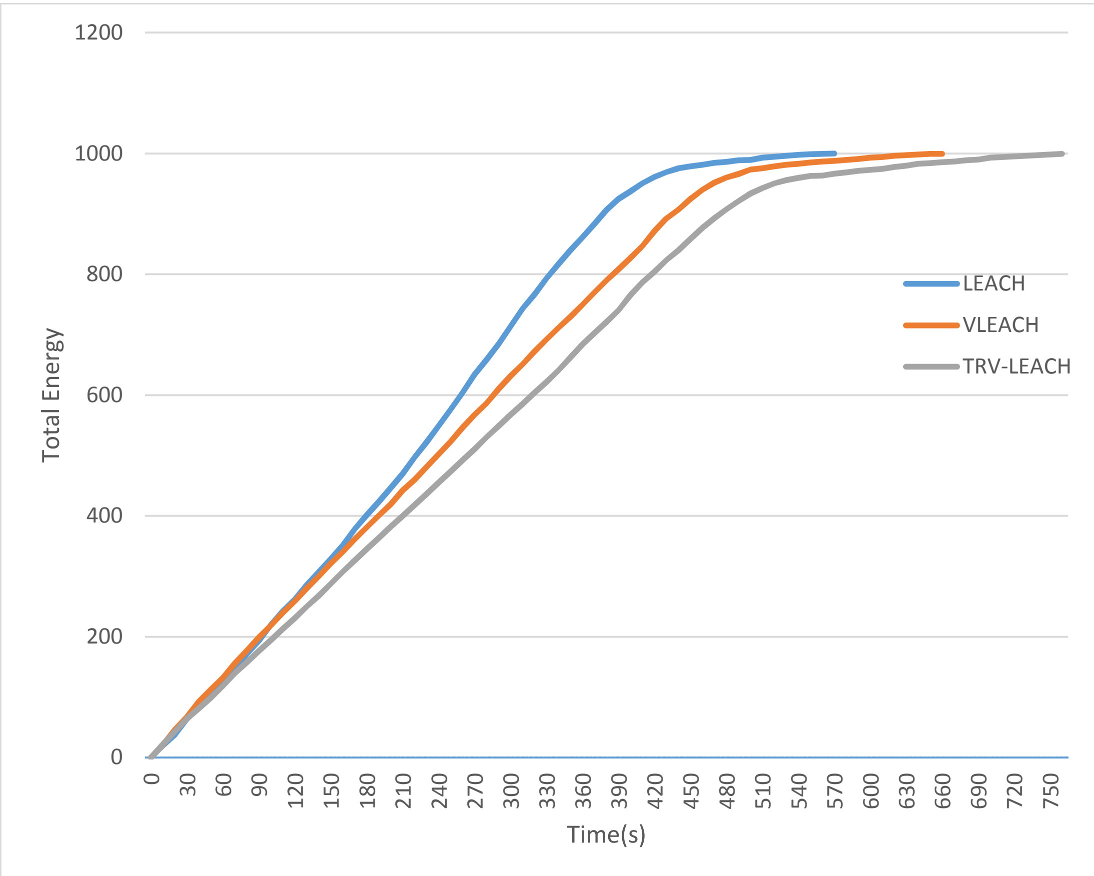

Fig.3.5 Total Energy consumed by all the nodes over time

Figure 3.6 shows that the total number of alive nodes in TRV-LEACH is higher than LEACH and VLEACH. In LEACH, the threshold equation doesn't take into consideration the sensor nodes' residual energy where a node with a low residual energy could be selected as a CH instead of another one with a high residual energy. If the node with a low energy is selected as the cluster head, then it quickly dies. Although this limit is addressed in V-LEACH, TRV-LEACH gives better results. V-LEACH considers, in addition to the node's residual energy, two factors (CH_{times} and VCH_{times}) in the threshold equation. So a sensor node with a low energy could be a CH. However, TRV-LEACH always selects the node with the highest remaining energy as a cluster head.

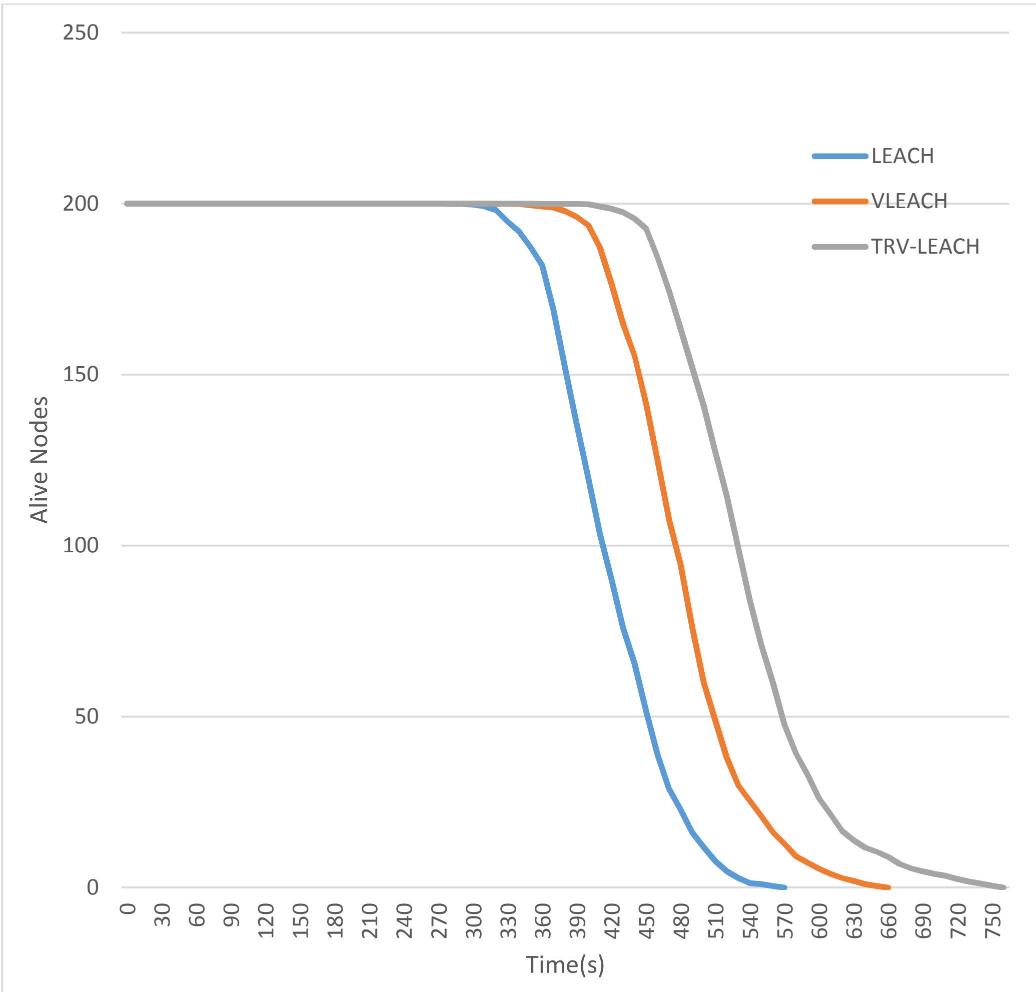

Fig. 3.6 Total number of alive nodes over time

3.5 Conclusion

In this section, we have presented our new improved routing protocol called TRV-LEACH to minimize the energy consumption in Wireless Sensor Network.

The simulation results show that the proposed protocol ensures low energy consumption and improves the network lifetime up to 33% compared to LEACH and up to 16% compared to VLEACH. The following chapter presents another improvement on the LEACH protocol.

Chapter 4

LEACH-CCMSN

4.1 Introduction

Cluster-based algorithms [46, 47] have been proposed for WSN for various reasons including scalability and energy efficiency. Sensor nodes in cluster-based algorithms are organized into clusters with cluster heads (CHs) transmitting messages from the cluster nodes to the Sink.

This chapter provides a new cluster-based protocol named LEACH-CCMSN (LEACH-Centralized Consumption Mode for each Sensor Node) [48]. We start by discussing the energy efficiency issue, then related work, followed by presenting the new proposed protocol, and finally discussing the simulation results.

4.2. Issue of energy efficiency

In WSNs, usually sensor nodes have low and limited resources of energy. This makes energy consumption the most important factor in WSNs. Reducing the energy consumption by having energy awareness in every aspect of design and operation will extend network lifetime. The major goal of any Energy Efficient Routing protocol for WSN is to prolong the life of the network as much as possible by minimizing energy consumption. [49].

4.3 Related work

4.3.1LEACH-C (LEACH-Centralized)

LEACH-C is a centralized protocol [7] where the Sink performs all the decisions such as the CH selection and the cluster formation, which produces better clusters. LEACH-C operation can be divided like LEACH into two phases, the setup phase that uses a centralized clustering algorithm and a steady-state phase, that is the same as LEACH protocol.

4.3.1.1 CH candidates list

In the setup phase, at the beginning of each round, all the sensor nodes transmit their position (determined by GPS receiver) and their residual energy to the Sink. In order to form better clusters, the Sink calculates the average energy of sensor nodes; the sensor nodes with energy level above the average energy are chosen to participate in the CH selection process for the current round.

The average energy E_{avg} of all the sensor nodes in the network can be calculated by using Equation 11.

$$E_{avg} = \frac{\sum_{i=1}^{N} E_i}{N} \quad (11)$$

Where *Ei* is residual energy of the *i^th^* node and *N* represents the number of sensor nodes.

4.3.1.2 CH selection process

First, the Sink calculates the optimal number of clusters (*K*) in the network using Equation 12. Where $\epsilon_{fs}$and $\epsilon_{mp}$are parameters of the transmission/reception circuit in free space and the multi path fading respectively. *M* is the sensing area and $d_{toBS}$is the average distance between the CHs and the Sink.

$$K = \sqrt{\frac{N}{2\pi} \frac{\epsilon_{fs}}{\epsilon_{mp}} \frac{M}{d_{toBS}^2}} \quad (12)$$

Next, the Sink selects *K* CHs from the set of nodes with energy level above the average energy using a Simulated Annealing algorithm, which will be discussed next. Then, for each normal node, the Sink decides to which cluster it will belong based on the minimum distance of the node to the CHs.

4.3.1.3 Simulated Annealing

4.3.1.3.1 Definition

Simulated Annealing (SA) is a local search metaheuristic technic. Metaheuristic is a term used to describe technics and algorithms that employ some degree of randomness to find the optimal solution for NP-hard problems, and it can be classified into two categories :local and global. This technic deals with highly complex and nonlinear problems; its main feature is that it, by allowing hill climbing moves, provides a mechanism to escape local optima.

SA’s name and inspiration came from annealing in metallurgy where a material ,in order to increase the size of its crystals and reduce its defects, is heated up to a high temperature, followed by a controlled cooling ,and then to reach thermal equilibrium it spends enough time at each temperature[8].

4.3.1.3.2 SA algorithm of the LEACH-C protocol

SA is used in LEACH-C to find the set of CHs which guarantees a minimum value of the sum of the distances between normal nodes and the nearest CH.

We start from an initial random solution S0. To this solution corresponds a distance $D(S0)$, which is the sum of the distances between the nodes and the nearest CH.

An initial temperature *T0* is also defined at the start. The value of this temperature decreases as a function of the initial temperature *T0* and of the cooling coefficient α ($\alpha \in [0,1]$). The adjustment of these parameters will be carried out via an experimental study allowing their values to be determined empirically. The algorithm stops when the temperature reaches almost zero.

For a certain number of iterations (N_{iter}) at each temperature *T* of the algorithm, a random solution *S’* with a distance *D (S’)* is directly accepted if it improves the objective function $(\Delta D \leq 0)$. Otherwise, if $(\Delta D > 0)$,i.e. the new solution, is less good than the current solution, then it is accepted with a probability *P*, calculated as a function of the temperature *T* and distance ΔD .

$$P = e^{(-\frac{\Delta D}{T})} \qquad (13)$$

This rule of acceptance is called the Metropolis criterion. A number *r* is randomly generated $r \in [0,1]$. If $P< r$ then the new solution is accepted; otherwise, it will be refused.

We note that the temperature is a parameter controlling this acceptance criterion. Indeed, when *T* is high then $P \cong 1$, so any solution will necessarily be accepted, but when *T* is small, we will have $P \cong 0$, then the transformations degrading the objective function will have less chance of being accepted.

The following Algorithm illustrates all of the above steps.

Data:

List: list of nodes

T0: Initial temperature

N_{iter}*: number of iterations for which the temperature is constant*

α*: The cooling coefficient,* $\alpha \in [0,1]$

Initialization:

T = T0;

S = getCHs(List); // Random initial set of CHs

While *T >0* ***Do***

For*ifrom 1 to*N_{iter}***Do***

S' = getCHs(List); // Random set of CHs

Calculate $\Delta D = D(S') - D(S)$

// Apply the Metropolis rule

If$\Delta D < 0$***then***

S = S' ;// Accept S' ;

elseif**e(-ΔD/T)> random[0,1]* ***then

S = S'; // Accept S'

else

rejectS' ;

end if

end for

*T= α*T// Decrease the temperature*

end while

4.3.1.4 Nodes notifications

The Sink broadcasts its decision of which nodes could act as CHs back to the nodes. The steady state phase of the LEACH-C protocol is the same as LEACH protocol.

4.3.2 BCDCP (Base Station Controlled Dynamic Clustering Protocol)

BCDCP [50] also relies on the Sink for election of cluster heads from a set of nodes based on residual energy and predetermined energy threshold (the average energy level of all the nodes) BCDCP uses an iterative cluster-splitting algorithm. This algorithm commences by splitting the network into two sub clusters, and continues the splitting process on the sub clusters into smaller clusters until the desired number of clusters is reached.

BCDCP uses inter-CH communication to transfer the sensed data to the Sink. After identifying the clusters, the Sink chooses the lowest energy routing path by introducing a Minimal Spanning Tree (MST) [51] to connect CHs, and send it to the sensor nodes. Using a TDMA schedule, each node transmits the sensed data to its cluster head (CH). Once data is received from all sensor nodes, the CH performs data aggregation and sends them to the Sink through the inter-CH routing path created by the Sink.

4.3.3 DMSTRP (Dynamic Minimum Spanning Tree Routing Protocol)

DMSTRP [52] attempts to improve the behavior of BCDCP by retaining many of its other characteristics. It applies Minimal Spanning Tree (MST) to make optimal decisions in inter-clusters and intra-clusters communications.

4.3.4 LEACH-G

In order to improve LEACH, where the number of CHs is uncertain, Chen *et al.* [53] have proposed a protocol called LEACH-G, which provides the optimal number of CHs and their positions. According to Equation 4.3.

$$K = \sqrt{\frac{N}{2\pi}} \sqrt{\frac{\epsilon_{fs}}{\epsilon_{fs} - d_{toBS}^{4}} M} \qquad (4.3)$$

LEACH-G uses a centralized and distributed approach for the selection of CHs and for the clusters formation.

4.3.5 EC-LEACH (Enhanced Centralized-LEACH)

EC-LEACH [54] uses a centralized and multi-hop clustering approach. The main adjustment of this protocol is in CH selection. In EC-LEACH the Sink calculates the threshold $T(n)$ through Equation 4.4.

$$T(n) = \frac{R_E(n)}{\sum_{i=1}^{m} \frac{d(i,n)}{R_E(i)}} \qquad (4.4)$$

Where, $R_E(n)$ and $R_E(i)$ are the residual energy of the sensor nodes *n* and *I* respectively, *m* denotes the number of nodes in the network and $d(i; n)$ is the distance between node *I* and node *n* .

After calculating all sensor nodes thresholds $T(n)$, the Sink picks the highest threshold node as the first CH and checks the distance to the second highest threshold node. If the distance between them is greater than or equal to the Minimum Distance Between Every CH (MDBECH), then the second highest $T(n)$ node becomes the second CH. Otherwise, it checks the distance to the third highest threshold node in the same way. After selecting all the CHs, the Sink broadcasts to all sensor nodes the CHs list. The steady state phase of EC-LEACH protocol is the same as LEACH protocol

4.3.6 LEACH-CE (LEACH-Centralized Efficient)

LEACH-CE [55] is a modified version of LEACH-C protocol. There may be a chance in LEACH-C where some nodes with higher energy are not selected as CHs, which lead to uneven energy consumption and the early death of low-energy CHs. LEACH-CE selects higher energy nodes as CHs in every round. In the first round, CHs election and clusters formation are made in the same way as in LEACH-C. Then the Sink selects the final CH for each cluster by choosing the node with the highest energy among the initial CHs candidates in the cluster. When all final CHs are selected, the Sink sends this information to all sensor nodes and the steady state phase starts which is similar to LEACH.

4.3.7EELEACH-C(Energy Efficient LEACH-C)

EELEACH-C [56] is a centralized protocol, where the Sink takes only the nodes with the highest value of residual energy as cluster heads ,and then builds clusters based on the quadratic sum of the distances from each cluster head to its member nodes.

4.4 The proposed protocol

In LEACH-C, at the beginning of each round all sensors nodes send Information about Sensor Node Energy Level (ISNEL) to the Sink. These ISNEL messages cost a lot of sensor node energy. The proposed protocol named LEACH-CCMSN for LEACH- Centralized Consumption Mode for each Sensor Node aim to reduce the number of rounds where sensor nodes have to send ISNEL messages to the Sink, which will extend the network lifetime.

LEACH-CCMSN protocol can be divided into two phases. The first phase represents the rounds where all sensor nodes must send ISNEL messages to the Sink at the beginning of each round like in LEACH-C protocol, but in the second phase sensor nodes do not have to send these ISNEL messages each round.

Our protocol will use the ISNEL messages sent in the first phase to create the Consumption Mode for each Sensor Node (CMSN), which will be used in the second phase to estimate sensor nodes energy level.

Based on several simulation results of the LEACH-C protocol we have found that in the round where the first node is dead ($R_{First\_Dead\_Node}$), most sensor nodes with residual energy above the mean have been elected as CH. So we will take this round as the round where the first phase ends.

4.4.1 The Consumption Mode for each Sensor Node (CMSN)

Considering N the number of all sensor nodes, $E_{curr(i)}$ the sensor node i energy level for the current round, $E_{prev(i)}$ the sensor node i energy level for the previous round ,and K is the expected number of clusters. $MECCH_{(i)}$ Maximum Energy Consumed by sensor node i as Cluster Head per round and $MECCN_{(i)}$ Maximum Energy Consumed by sensor node i as Common Node per round. $was_{CH(i)}$ indicates if the node i was cluster head($was_{CH(i)}$ =1) or not($was_{CH(i)}$ =0) in the previous round.

The algorithm of CMSN can be divided into two phases as follow:

Phase one: from *round one* ***to round*** $R_{First\_Dead\_Node}$

1. The Sink creates a list of all sensor node and initializes $MECCH_{(i)}$, $MECCN_{(i)}$,and $was_{CH(i)}$ for each one of them to zero.

2. At the beginning of the rounds all sensor nodes transmit their $E_{curr(i)}$ to the Sink. The Sink starts calculating $MECCH_{(i)}$ and $MECCN_{(i)}$ as follow:

If (current round <>1) then { *// to skip the first round because we don't have the value of* $E_{prev(i)}$

For i =1 to N {
  temp= $E_{curr(i)}$- $E_{prev(i)}$
  if ($was_{CH(i)}$ == 1) and ($MECCH_{(i)}$< temp) **then**
    $MECCH_{(i)}$ = temp

else if ($MECCN_{(i)} <$ temp) **then**

$MECCN_{(i)}$ = temp

$was_{CH(i)}$ == 0

end if

end for

3. CHs election and clusters formation are made in the same way as in LEACH-C.

4. The Sink copies $E_{curr(i)}$ value for each node in $E_{prev(i)}$ and updates $was_{CH(i)}$ to 1 for all the nodes that were elected as cluster heads.

5. At the round $R_{First\_Dead\_Node}$, most nodes have been elected as CH. For those that have not been elected as CH their $MECCH_{(i)}$ will be the average of *MECCH* of the nodes that have been CH.

Phase two: from round $R_{First\_Dead\_Node}$ *+1* ***to the*** *last round*

1. Sensor nodes will send $E_{curr(i)}$ only in $j*R_{First\_Dead\_Node}$ rounds (where *j* is a natural number that goes from 2 to *last round*/($R_{First\_Dead\_Node}$)) to reduce the gap between the estimated and the actual value of $E_{curr(i)}$.

2. For the rest of rounds $E_{curr(i)}$ will be estimated based on *MECCH* and *MECCN* as follow:

For i =1 to N **do**

if ($was_{CH(i)}$ == 1) **then**

$E_{curr(i)} = E_{prev(i)} - MECCH_{(i)}$

else

$E_{curr(i)} = E_{prev(i)} - MECCN_{(i)}$

$was_{CH(i)}$ == 0

end if

end for

3. CHs election and clusters formation are made in the same way as in phase one.

4. The Sink updates the value of $E_{prev(i)}$ and $was_{CH(i)}$.

4.5 Simulation tests

The routing protocols LEACH-C and LEACH-CCMSN have been simulated accurately in MATLAB; it is assumed that there are *100* nodes in an area of *100x100*meters, and the location of the nodes is generated randomly. We assume that all nodes have no mobility. The parameters involved in the simulation are described in table 4.1.

TABLE 4.1 Simulation Parameter

Parameters	**Values**
Routing Protocols	LEACH-C and LEACH-CCMSN
Environment Size	100 x 100m^2
Sink location	150x50m
Number of nodes	100 nodes
Packet Size	2000 bits
Number of rounds	2000 rounds
Initial energy per node	1 J
E_{elec}	50 nJ / bit
E_{fs}	10 pJ / bit / m^2

E_{mp}	0.0015 pJ / bit / m^4
E_{DA}	5 nJ / bit
E_{MDA}	3 nJ / bit
$T0$	100
N_{iter}	200
α	0.8

Figure 4.1 shows the network configuration.

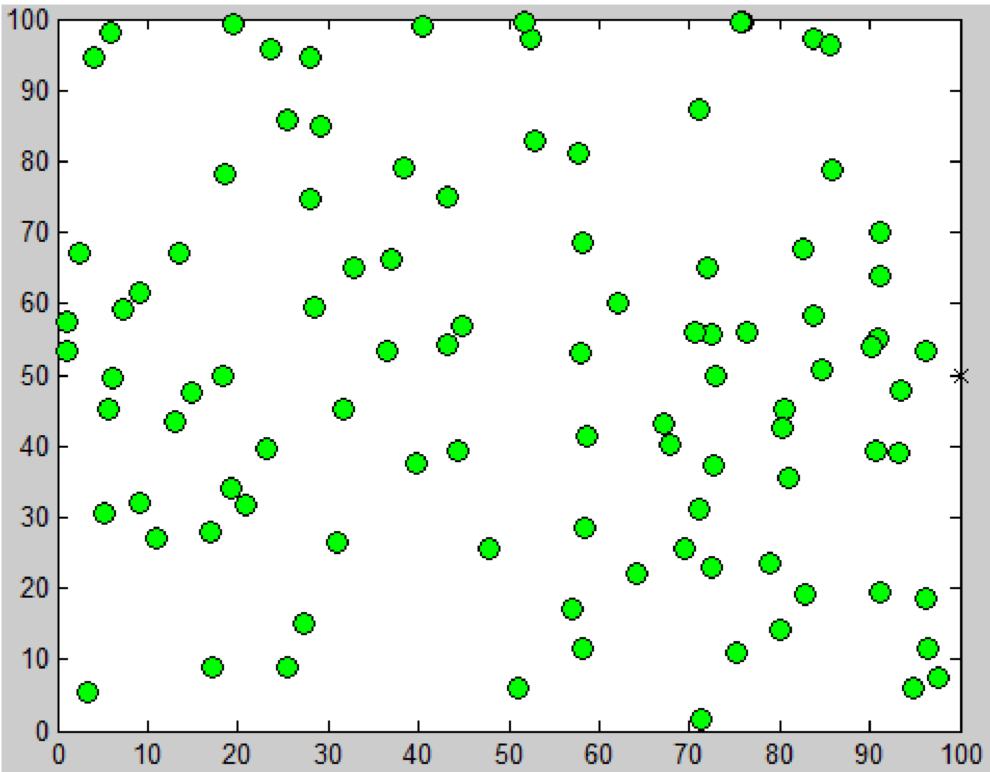

Fig. 4.1 The network configuration

The number of ISNEL messages and the network lifetime of LEACH-C and LEACH-CCMSN have been compared and shown in Figure 4.2 and 4.3.

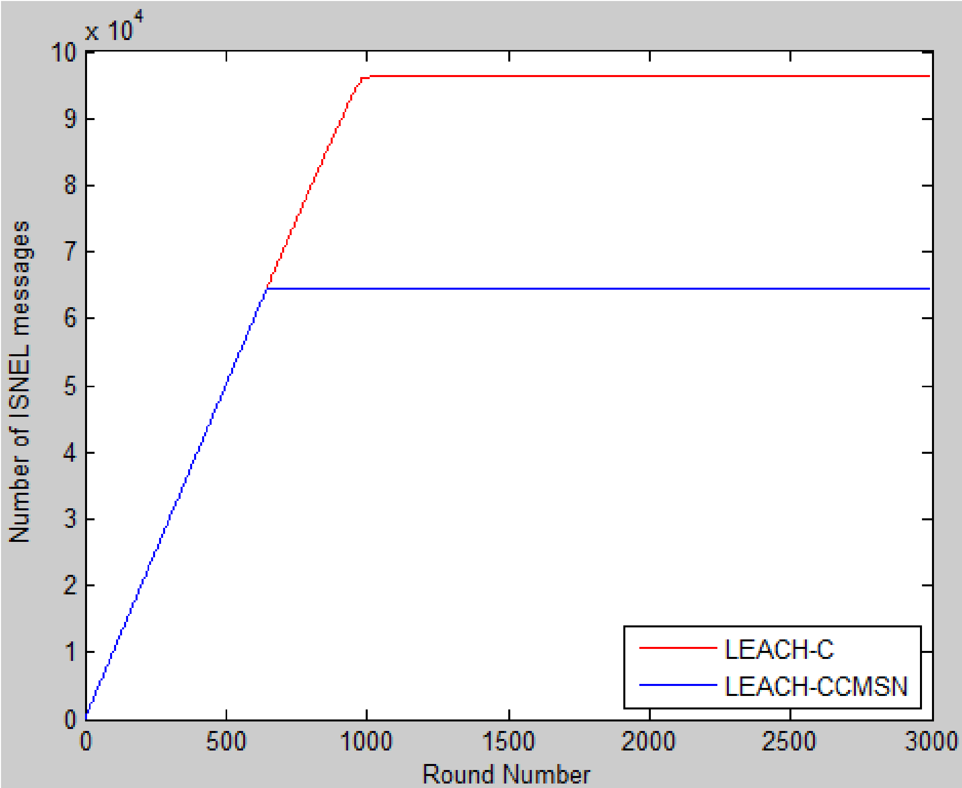

Fig. 4.2 Number of ISNEL messages of LEACH-C and LEACH-CCMSN

Figure 4.2 shows the comparison graph between LEACH-C and LEACH-CCMSN in terms of the number of ISNEL (Information about Sensor Node Energy Level) messages. Before round 620 (First dead node) both protocols have the same number of ISNEL messages because they were sending these messages each round. After that LEACH-C continues sending ISNEL messages for the rest of rounds, on the contrary, LEACH-CCMSN will stop sending ISNEL messages, and start using the CMSN (Consumption Mode for each Sensor Node) created in the first 620 rounds to estimate the current energy for each sensor nodes. LEACH –C protocol generates 50% more ISNEL messages than LEACH-CCMSN protocol. From that, it is clearly understood that LEACH-CCMSN is better than LEACH-C.

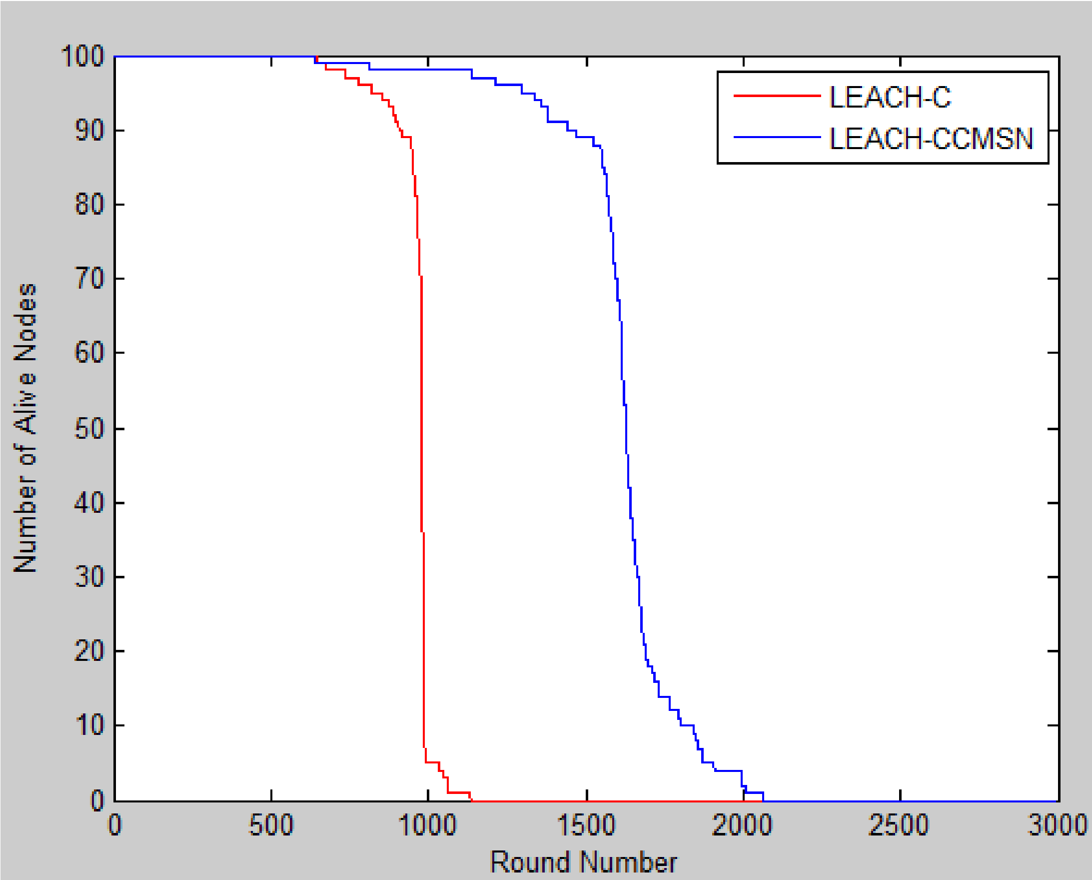

Fig. 4.3 Network lifetime of LEACH-C and LEACH-CCMSN

Figure 4.3 shows the network lifetime of LEACH-C and LEACH-CCMSN. Seen from figure 4.3,the death time of the first node in LEACH-CCMSN and LEACH-C is the same. After that, each protocol takes a different path. Sensor nodes die more rapidly in LEACH-C than LEACH- CCMSN. Because LEACH-CCMSN uses a Consumption Mode for each Sensor Node (CMSN), which leads to reduce the number of ISNEL messages sent from sensor nodes to the Sink at the beginning of each round. The energy consumption of the sensor nodes in LEACH-CCMSN protocol is less than the energy consumption of the sensor nodes in LEACH-C protocol.

4.6 conclusion

We proposed an energy-efficient protocol denoted LEACH-CCMSN, a new variant of the standard LEACH-C protocol. Simulation results show that LEACH-CCMSN can considerably prolong the network lifetime compared to LEACH-C protocol.

General conclusion

This thesis work provides three contributions to the area of energy-efficient protocols based on Wireless Sensor Networks. The first contribution is a new formula for the CH selection process that takes into consideration residual energy of the nodes to extend the network lifetime. The second contribution called TRV-LEACH protocol considers a Vice CH to replace the CH once it dies. If the CH's remaining energy is high, the Vice CH will be elected based on the cluster members' residual energy and its distance from the CH to reduce the energy spent in intra-cluster communication. Otherwise, the Vice CH will be elected based only on the cluster members' residual energy to increase the data transfer probability to the Sink.The third contribution denotes LEACH-CCMSN, which is new variant of the standard LEACH-C protocol, and that uses a Consumption Mode for each Sensor Node (**CMSN**) to reduce the number of ISNEL messages (Information about Sensor Node Energy Level) sent from the sensor nodes to the Sink at the beginning of each round.

Simulation results showed that the new CH selection formula has extended the network lifetime and decreased the number of dead nodes acting as CH. In addition, simulation results also revealed that both of the proposed protocols LEACH-CCMSN and TRV-LEACH have considerably decreased the total energy consumed by the sensor nodes compared to the previous protocols which has extended the network lifetime.

Besides the described contributions, we believe that this thesis provides the foundation for many future works that can enhance and extend what was proposed, and provide more energy-efficient solutions for Wireless Sensor Networks.

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