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Title

Energy Efficient Mobility Management in Wireless Sensor Networks

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Abstract

Mobile Wireless Sensor Network (MWSN) has mobile sensor nodes which sense the data and communicate with the base station via other nodes. Both sensor nodes and sinks can be mobile and can operate with static sensor nodes in the network based on the application requirements. However, mobility poses new challenges for the researchers particularly in energy consumption and packets loss in addition to routing protocols are responsible for discovering and maintaining the routes in the network. In this thesis, a new routing protocol is proposed for mobile wireless sensors, which was invented after a thorough study of various protocols in the literature that try to resolve the typical routing issues for both technologies of WSNs and MWSNs. Our proposed protocol, called FF-LEACH, takes the advantages of the MH-LEACH-1R protocol, as well as properties of the firefly optimization. In order to show the performance of the proposed protocol, we have performed some simulations, comparisons and analysis using MATLAB environment. These routing protocols (LEACH-M, MH-LEACH-1R, and FF-LEACH) are compared based on different factors such as residual energy, data delivery to the base station, number of rounds, nodes alive, and packets loss. Experimental results show that our proposed protocol FF-LEACH has the best performance in almost all metrics especially in terms of lifetime and lost packets.

Key words: MWSNs, energy consumption, LEACH-M, MH-LEACH-1R, FF-LEACH, mobility.

Dedicates

Every challenging work needs self efforts as well as guidance of elders especially those who were very close to our heart.

My humble effort is dedicated to the ones who gave me life and grew me up, those who were always supportive.

Dedicated to:

The most holy person, My ***Mother***

&

The dearest person, My ***Father.***

Whose affection, love, encouragement and prays of day and night make me able to get such success and honor.

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"In The Name Of Allah the Most Gracious the Most Merciful"

First and foremost, all praises go to Almighty Allah (SWT), the Most Gracious the Most Merciful and Peace upon his prophet Mohammed S.A.W. Alhamdulillah, a foremost praise and thankful to Allah for his blessing, giving me opportunity, perseverance, wisdom to have this work done on time and strength in completing this study.

*My deep gratitude goes first to my ideal supervisor: **Dr. Mohammed OMARI** who expertly guided me through my bachelor's and master's degree, also for his patience, advice, and encouragement.*

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Soumia

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The advances in mobile robotics, the need for real time and reliable communication applications today allowed to adding the mobility concept into many different classes of Wireless Sensor Networks (WSN). The deployment of mobile sensors is possible and useful in many application scenarios, ranging from the environmental monitoring to track the dispersion of pollutants, gas plumes or fires, and public safety applications to the industry, healthcare, and military applications. This gives birth to Mobile Wireless Sensor Networks (MWSNs).

Mobile wireless sensor network (MWSN) is becoming popular because of the advantages over the static network such as the locomotive capability of sensor nodes which can improve the lifetime of the network. In fact, MWSNs pose many challenges for newly designed applications, the sensor nodes can move out of the region in which they are present and cause many problems. For that, routing process in a mobile network is very complex and it becomes even more complicated in MWSN as the sensor nodes are low power, cost effective mobile devices with minimum resources.

Our objective in this thesis is motivated to focus on the design of an efficient routing protocol for MWSNs to resolve many problems like retaining the network connectivity, reducing the energy cost etc.

This thesis consists of four chapters:

❖ The first chapter **"Introduction and Overview of Mobile Wireless Sensor Networks"** introduces and defines basic terminology used in MWSNs.

❖ The second chapter **"Routing Protocols in Mobile Wireless Sensor Networks"** examines the sections that cover classification of MWSNs routing protocols and gives the principle details of these protocols like LEACH, LEACH-M and MH-LEACH- 1R.

❖ The third chapter **"FF-LEACH: A multihop MWSN protocol based on MH-LEACH-1R and Firefly Algorithm"** is divided into two parts. In the first part, we illustrate the algorithm of firefly optimization. Then, we explain our proposed protocol FF-LEACH.

❖ The fourth chapter **"Simulation, Results, and Analysis"** gives an overview of simulation and MATLAB environment, the simulation results of the selected protocols and our proposed protocol as well as comparison and analysis of different metrics such as throughput to the base station, number of rounds, lost packets, and residual energy.

At the end of each chapter are drawn a series of conclusions, concerning the investigations performed and the obtained results. The general conclusion is given at the end of this thesis, where possible future investigations are also indicated.

Introduction and Overview of Mobile Wireless Sensor Networks

1.1. Background:

The limitation of wireless sensor networks (WSNs) coverage, localization and energy consumption create problems as well as weaken security. So, a complementary wireless technology, MWSNs, is required.

Today, Mobile wireless sensor networks (MWSNs) are one of very important technology that is used for communications due to their characteristics and to their great number of real-life applications.

In this chapter, we discussed in deep for general understanding of the concept of this study. First, we present the concepts of different types of networks from static to dynamic. Second, identify the benefit of using mobility in WSNs, the biggest challenges of MWSNs and its applications areas. Third, review the different mobility models.

1.2. Wireless network:

Wireless network refers to any type of computer network that is not connected by cables of any kind. It is a method by which homes, telecommunications networks and enterprise (business) installations avoid the costly process of introducing cables into a building, or as a connection between various equipment locations. Wireless telecommunications networks are generally implemented and administered using a transmission system called radio waves. AM radio, FM radio, satellite radio, satellite TV, satellite Internet access and broadcast TV is also, in fact, wireless networks. Wireless technology is very convenient [1].

1.3. Sensor node structure [2]:

A sensor node made up of five basic components, as show in Figure 1.1.

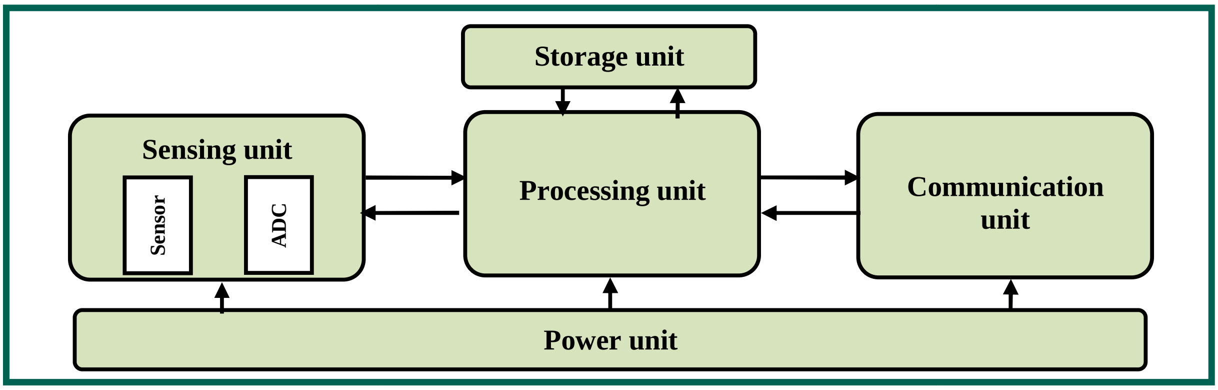

Figure 1.1: Sensor node structure [2].

1.3.1. The sensing unit: usually consists of one or more sensors and analog - to – digital converters (ADCs). The sensors observe the physical phenomenon and generate analog signals based on the observed phenomenon. The ADCs convert the analog signals into digital signals, which are then fed to the processing unit.

1.3.2. The processing unit: usually consists of a microcontroller or microprocessor with memory (e.g., Intel's Strong ARM microprocessor and Atmel's AVR microprocessor), which provides intelligent control to the sensor node.

1.3.3. The communication unit: consists of a short - range radio for performing data transmission and reception over a radio channel.

1.3.4. The power unit: consists of a battery for supplying power to drive all other components in the system.

1.3.5. The Memory/storage unit: Storage in the form of random access and read-only memory includes both program memory (from which instructions are executed by the processor), and data memory (for storing raw and processed sensor measurements and other local information). The quantities of memory and storage on board a WSN device are often limited primarily by economic considerations, and are also likely to improve over time.

In addition, a sensor node can also be equipped with some other units, depending on specific applications. For example, a global positioning system (GPS) may be needed in some applications that require location information for network operation. A motor may be needed to move sensor nodes in some sensing tasks. All these units should be built into a small module with low power consumption and low production cost.

1.4. Wireless Sensor Network:

A wireless sensor network (WSN) in its simplest form can be defined as a network of (possibly low size and low-complex) devices denoted as nodes that can sense the environment and communicate the information gathered from the monitored field through wireless links; the data is forwarded, possibly via multiple hops relaying, to a sink that can use it locally, or is connected to other networks (e.g., the Internet) through a gateway [3, 4].

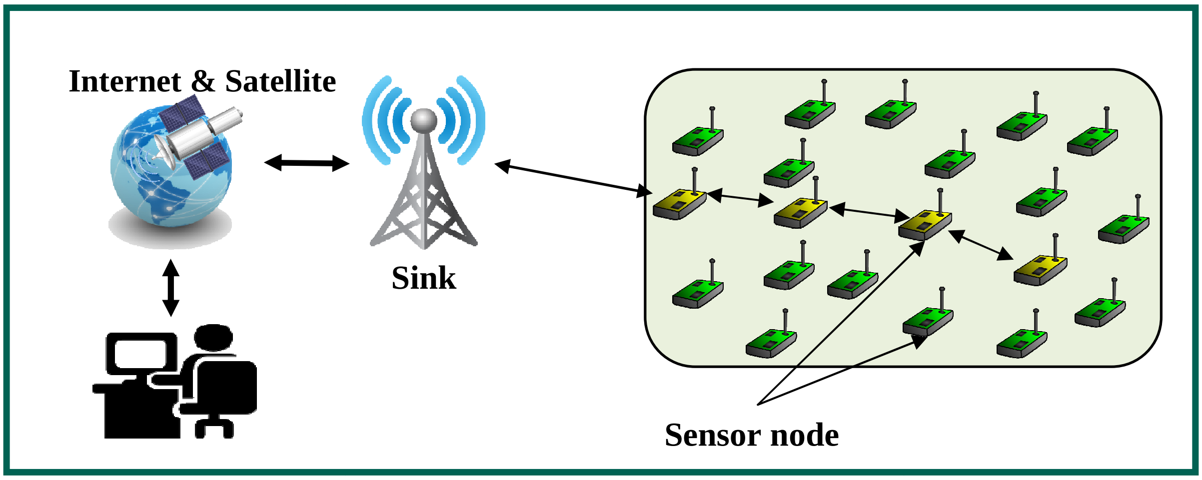

Figure 1.2: Wireless sensor networks.

1.5. Mobile Wireless Sensor Network:

1.5.1. Definition: Mobile wireless sensor networks (MWSNs) can simply be defined as a wireless sensor network (WSN) in which the sensor nodes are mobile [5]. MWSNs are a smaller, emerging field of research in contrast to their well-established predecessor [6]. MWSNs are much more versatile than static sensor networks as they can be deployed in any scenario and cope with rapid topology changes [7]. However, many of their applications are similar, such as environment monitoring or surveillance commonly the nodes consist of a radio transceiver and a microcontroller powered by a battery [6][8].

1.5.2. Advantages of adding mobility:

In many sensor network deployments, an optimal distribution is unknown until the sensor nodes start collecting and processing data. This optimal deployment is generally infeasible without adding mobility. These some advantages of adding mobility into WSNs.

- **Long Network Lifetime:** Because sensors can move, they will make the transmission more disperse and energy dissipation more efficient. In networks that are sparse or disjoint, or when stationary nodes die, mobile nodes can maneuver to connect the lost or weak communication pathways [9].

- **More Channel Capacity:** Experiments have demonstrated that the capacity gains can be 3–5 times more than static WSNs, if the number of mobile sinks increases linearly with the number of sensors. Mobility also enables greater channel capacity and maintains data integrity by creating multiple communication pathways, and reducing the number of hops messages must travel before reaching their destination [9].

- **Enhance Coverage and Targeting:** Because sensors are mostly deployed randomly instead of precisely, they are generally required to move for better sight or for close proximity which is favorable for targeting. Sensor network deployments are often determined by the application. Nodes can be placed in a grid, randomly, surrounding an object of interest, or in countless other arrangements. In many situations, an optimal deployment is unknown until the sensor nodes start collecting and processing data. For deployments in remote or wide areas, rearranging node positions is generally infeasible. However, when nodes are mobile, redeployment is possible. In [10] the integration of mobile entities into WSNs improves coverage, and hence, utility of the sensor network deployment. For example, an application that monitors wildfires, the mobile sensors are able to maintain a safe distance from the fire perimeter, as well as provide updates to fire fighters that indicate where that perimeter currently is.

- **Improve Performance:** Most networks can be gained improved quality of communications, reduction in overall cost and time to complete task, better security in ad-hoc networks [11], and increase of network capacity [12]. The aspect of wireless communication is getting more and more important in multi-robot systems to improve their overall performance. To decide its next movement efficiently, a mobile robot may need input data from other robots through wireless interaction. Communication module not only enables data fusion through the sharing of sensor data gathered by mobile robots, but also helps expand an individual view of the network and the physical environment.

- **Better data fidelity:** The last benefit can be attained by utilizing a mobile node to carry data to a destined point. It is useful when wireless channel is in poor condition, or if the premature energy depletion is possible (also called **funnelling effect**). The reduced number of hops due to mobility will increase the probability of successful transmissions [9].

1.5.3. Mobile WSNs challenges:

In order to focus on the mobility aspect of wireless sensor networks, it is important to first understand how the common assumptions regarding statically deployed WSNs change when mobile entities are introduced.

- **Localization:** In statically deployed networks, node position can be determined once during initialization. However, those nodes that are mobile must continuously obtain their position as they traverse the sensing region [13]. This requires additional time and energy, as well as the availability of a rapid localization service [9].

- **Dynamic Network Topology:** Because nodes generally are mobile in MWSNs, the topology is dynamic. New routing and Medium access control (MAC) protocols are needed in MWSNs. Traditional WSN routing protocols, which describe how to pass messages through the network so they will most likely reach their destination, typically rely on routing tables or recent route histories. In dynamic topologies, table data become outdated quickly, and route discovery must repeatedly be performed at a substantial cost in terms of power, time, and bandwidth [9].

- **Power Consumption:** Power consumption models differ greatly between WSNs and MWSNs. For both types of networks, wireless communication incurs a significant energy cost and must be used efficiently. However, mobile entities require additional power for mobility, and are often equipped with a much larger energy reserve, or have self-charging capability that enables them to plug into the power grid to recharge their batteries [9].

- **Mobility of Sink:** In centralized WSN applications, sensor data is forwarded to a base station, where it can be processed using resource-intensive methods. Data routing and aggregation can incur significant overhead. Some MWSNs use mobile base stations, which traverse the sensing region to collect data, or position themselves so that the number of transmission hops is minimized for the sensor nodes [9].

1.5.4. The applications of mobile wireless sensor networks [14]:

Mobile wireless sensor networks are currently being employed in a variety of applications in which localization plays an integral part. These applications fall under four main categories: commercial, environmental, civil, and military.

Figure 1.3: Applications of mobile wireless sensor networks.

1.5.4.1. Commercial:

As MWSNs grow in popularity, we expect to see a burst of applications in the commercial sector that require some kind of position data.

➢ **Service Industry:** One such area is the service industry. Companies such as Skilligent are developing software protocols for service robots that perform tasks such as basic patient care in nursing homes, maintenance and security in office buildings, and food and concierge service in restaurants and hotels. All of these applications require a mechanism for position estimation.

➢ **Housekeeping:** Such an automated vacuum cleaning robot for domestic use. This robot creates a map of the room as it moves by using feedback from a variety of bumper and optical sensors. Wheel encoders provide run-time position information that enable it to cover the entire room.

1.5.4.2. Environmental:

MWSNs have become a valuable asset for environmental monitoring. This is thanks in part to their ability to be deployed in remote areas and for their ability to gather data of wide areas of interest.

➢ **Wildlife Tracking:** ZebraNet [15] is an early MWSN, in which mote-scale wireless devices were fitted to zebras for the purpose of tracking their movement. Due to the remote region, there was no cellphone coverage, so data was routed through the peer-to-peer network to mobile base stations. The zebras were not constrained to certain areas, and other than the small devices attached to their bodies, left undisturbed. To accomplish this level of tracking without the use of MWSNs would not be possible.

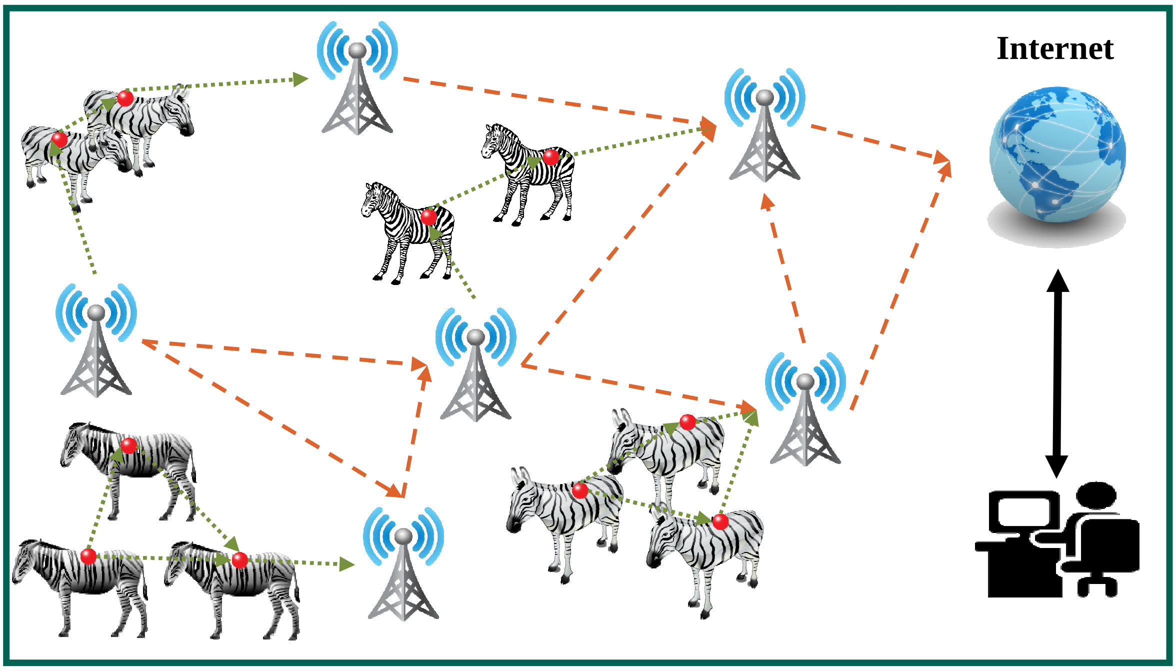

Figure 1.4: Wildlife tracking applications.

➢ **Pollution Monitoring:** MAQUMON [16] is one of a mobile air quality monitoring system. Sensor nodes that measure specific pollutants in the air are mounted on vehicles. As the vehicles move along the roadways, the sensors sample the air, and record the concentration of various pollutants along with location and time. When the sensors are in the proximity of access points, the data are uploaded to a server and published on the web.

1.5.4.3. Civil:

The civil services are one of areas that need MWSN utility. This includes applications that keep society running efficiently and safely.

➢ **Pothole Detection**: In [17], a system is developed to detect potholes on city streets. Deployed on taxi cabs, the sensor nodes contain an accelerometer, and can communicate using either opportunistic WiFi or cellular networks.

1.5.4.4. Military:

Mobile wireless sensor networks will play more important roles in future military systems and make future wars more intelligent with less human involvement.

➢ **Shooter Detection / Weapon Classification.** In [18], a soldier-wearable sensor system is developed that not only identifies the location of an enemy sniper, but also identifies the weapon being fired. Each sensor consists of an array of microphones mounted on the helmet of a soldier. The sensor observes both the shock wave of the projectile, as well as the muzzle blast from the weapon, and based on TDOA, as well as properties of the acoustic signal, is able to triangulate the enemy position and classify the weapon type.

Figure 1.5: Sensor prototypes mounted on a Kevlar helmet.

➢ **Autonomous Deployment.** In [19] an unattended aerial vehicle is used for sensor network deployment and repair. Such deployments aid the military in battlefield surveillance and command and control field operations.

1.6. Mobility Model:

1.6.1. Entity/Individual mobility models: also called (memory-less models) [20] nodes movements are independent of each other and doesn't spend any memory to change their location, such as Random Waypoint, Random direction, and Random Walk.

➢ **Random Waypoint model:** The Random Waypoint model is the most commonly used mobility model in research community. At every instant, a node randomly chooses a destination and moves towards it with a velocity chosen randomly from a uniform distribution [0, V_max], where V_max is the maximum allowable velocity for every mobile node. After reaching the destination, the node stops for a duration defined by the 'pause time' parameter. After this duration, it again chooses a random destination and repeats the whole process until the simulation ends [21].

➢ **Random Walk model:** In the Random Walk Mobility Model, a mobile node moves from its current location to a new location by randomly choosing a direction and speed in which to travel. The new speed and direction are both chosen from pre-defined ranges, [V_min, V_max] and [0, 2π] respectively.

So, The Random Waypoint Mobility Model is similar to the Random Walk Mobility Model if pause time is zero and [0, V_max] = [V_min, V_max] [20].

➢ **Random Direction Model:** In the Random Direction Mobility Model**,** mobile node chooses a random direction in which to travel instead of a random destination. After choosing a random direction, the node travels to the boundary. As soon as the boundary is reached the node stops for a certain period of time, chooses another angular direction (between 0 and 180 degrees) and continues the process [20].

1.6.2. Group mobility models: also called (memory based models) [20], where the mobile nodes move dependent of one another and use its previously stored database for its movement.

1.6.2.1. Geographic Based Models:

➢ **Manhattan model:** The Manhattan mobility model uses a grid road topology. This model is mainly proposed for the movement in urban area, where the streets are in an organized manner and the mobile nodes are allowed to move only in horizontal or vertical direction. At each intersection of a horizontal and a vertical street, the mobile node can turn left, right or go straight with certain probability [22].

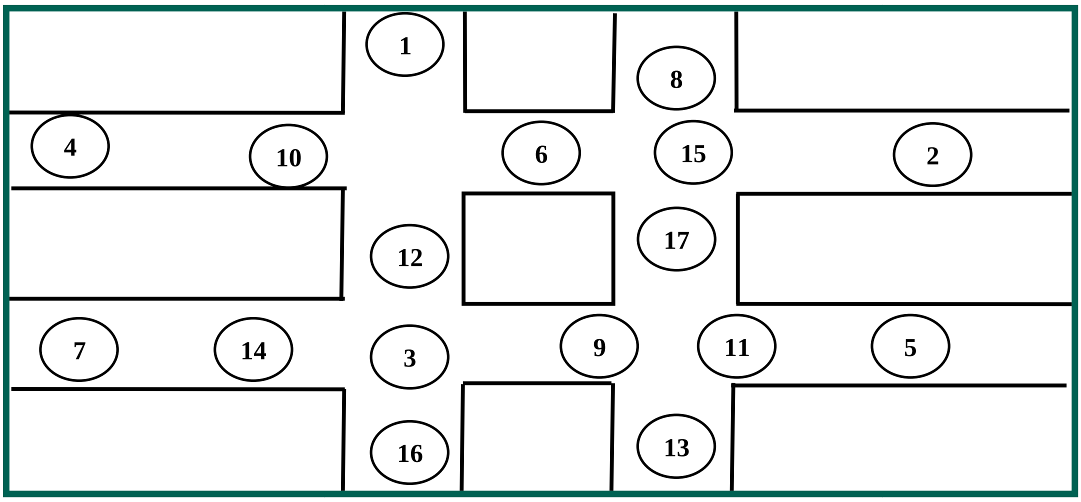

Figure 1.6: Manhattan mobility model movement.

➢ **Pathway model:** One simple way to integrate geographic constraints into the mobility model is to restrict the node movement to the pathways in the map. The map is predefined in the simulation field. Tian, Hahner and Becker et al [23] utilize a random graph to model the map of city. This graph can be either randomly generated or carefully defined based on certain map of a real city. The vertices of the graph represent the buildings of the city, and the edges model the streets and freeways between those buildings. Initially, the nodes are placed randomly on the edge. Then for each node a destination is randomly chosen and the node moves towards this destination through the shortest path along the edges.

Upon arrival, the node pauses for **T** pause time and again chooses a new destination for the next movement. This procedure is repeated until the end of simulation.

➢ **Obstacle model:** The Obstacle Mobility Model is based on the following real-life observations. First, people move towards specific destinations rather than randomly choosing some destinations. Second, there are obstacles in the real world. These obstacles, most commonly the buildings, block people's movements as well hinder signal-propagation. Third, people do not walk along random trajectories; they usually move along pathways and select shortest paths [24].

➢ **Freeway model:** This model emulates the motion behavior of mobile nodes on a freeway. It can be used in exchanging traffic status or tracking a vehicle on a freeway. This model use maps and there are several freeways on the map and each freeway has lanes in both directions [22].

1- Each mobile node is restricted to its lane on the freeway.

2- The velocity of mobile node is temporally dependent on its previous velocity.

3- If two mobile nodes on the same freeway lane are within the safety distance (SD), the velocity of the following node cannot exceed the velocity of preceding node.

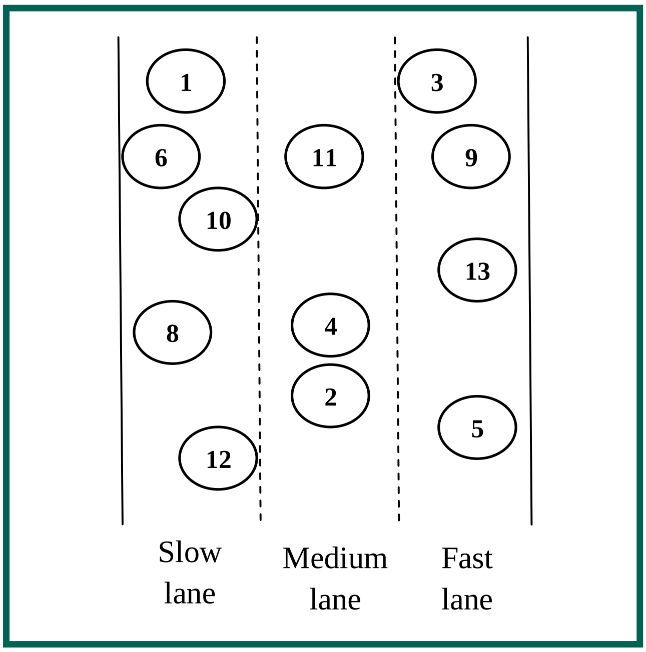

Figure 1.7: Freeway mobility model movement.

1.6.2.2. Temporal Based Models:

➢ **Gauss Markov model:** In the Gauss-Markov Mobility Model each mobile node is initialized with a speed and direction. By fixed intervals of time movement occurs to updating the speed and direction of each node. To be specific, the value of speed and direction at the n^{th} instance of time is calculated based upon the value of speed and direction at the $n - 1^{st}$ instance and a random variable [22].

➢ **City Section model:** The City Section mobility model puts constraints on the movement of a node on a city street grid, constructed of horizontal and vertical streets. Each street on the grid is assigned a speed limit. A mobile node moves along the streets according to the speed limit set for that particular street [20].

1.6.2.3. Spatial Based Models:

➢ **Reference Point Group model:** Random point group mobility can be used in military battlefield communication. Here each group has a logical centre (group leader) that determines the group’s motion behavior. Initially each member of the group is uniformly distributed in the neighborhood of the group leader. Subsequently, at each instant, every node has speed and direction that is derived by randomly deviating from that of the group leader. Given below is example topography showing the movement of nodes for Random Point Group Mobility Model [21]. The scenario contains sixteen nodes with Node 1 and Node 9 as group leaders.

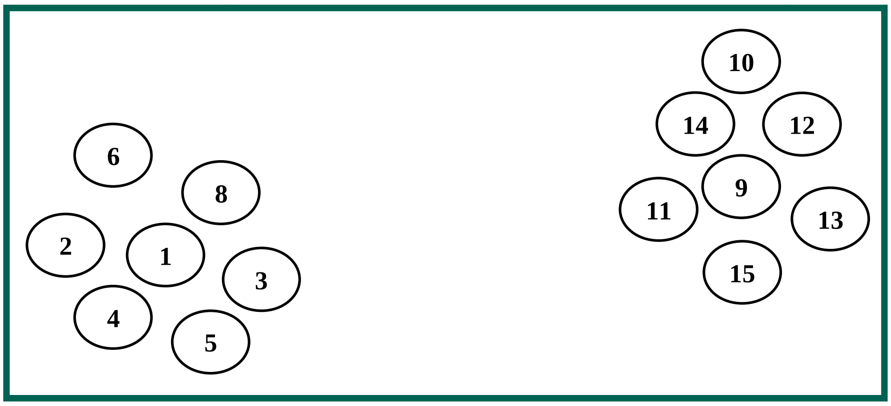

Figure 1.8: Reference point group model movement.

Important Characteristics: Each node deviates from its velocity (both speed and direction) randomly from that of the leader. The movement in group mobility can be characterized as follows:

$$|\mathbf{V}_{\text{member}}(\mathbf{t})| = |\mathbf{V}_{\text{leader}}(\mathbf{t})| + \textbf{random () * SDR * max\_speed}$$

$$|\theta_{member}(\mathbf{t})| = |\theta_{leader}(\mathbf{t})| + \textbf{random () * ADR * max\_angle}$$

Where: 0 <<ADR, SDR<< 1. SDR is the Speed Deviation Ratio and ADR is the Angle Deviation Ratio. SDR and ADR are used to control the deviation of the velocity (magnitude and direction) of group members from that of the leader. Since the group leader mainly decides the mobility of group members, group mobility pattern is expected to have high spatial dependence for small values of SDR and ADR [21].

➢ **Column model:** The Column Mobility Model represents a set of mobile nodes (e.g., robots) that move in a certain fixed direction. This mobility model can be used in searching and scanning activity, such as destroying mines by military robots. When the mobile node is about to travel beyond the boundary of a simulation field, the movement direction is then flipped 180 degree. Thus, the mobile node is able to move towards the center of simulation field in the new direction [22].

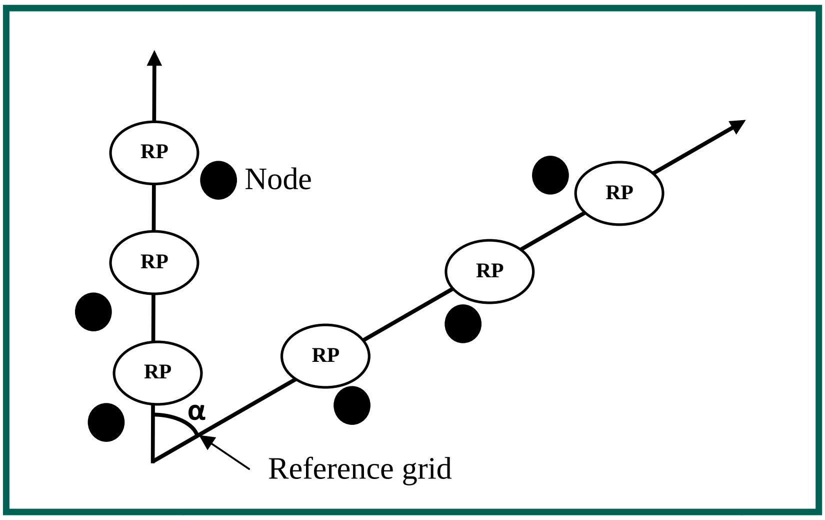

Figure 1.9: The Column mobility model movement.

In this mobility model, each node (black dots) has a single reference point (RP) and moves around its reference point via an entity mobility model. The reference point is chosen periodically based on an advance vector, where the new reference point is the sum between the old reference point (the node's previous reference point) and the advance vector (a predefined offset that moves the reference grid) [25].

➢ **Pursue model:** The Pursue Mobility Model emulates scenarios where several nodes attempt to capture single mobile node ahead. This mobility model can be used in target tracking and law enforcement. The node being pursued (target node) moves freely according to the Random Waypoint model by directing the velocity towards the position of the targeted node, the pursuer nodes (seeker nodes) try to intercept the target node [22].

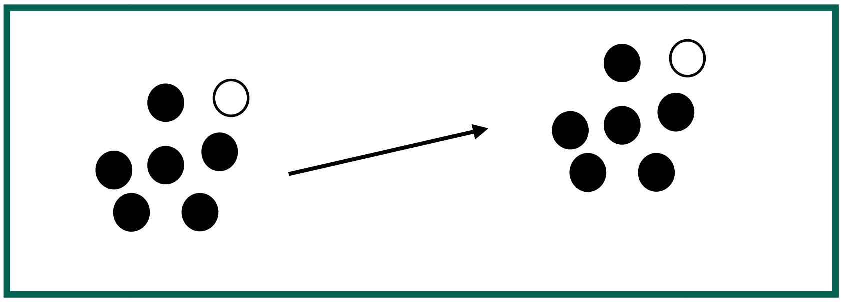

Figure 1.10: The Pursue mobility model movement.

➢ **Normadic model:** The Nomadic Mobility Model is to represent the mobility scenarios where a group of nodes move together. This model could be applied in mobile communication in a conference or military application. The whole group of mobile nodes moves randomly from one location to another. Then, the reference point of each node is determined based on the general movement of this group. Inside of this group, each node can offset some random vector to its predefined reference point. The movement in the Nomadic Community Model is sporadic while the movement is more or less constant in Column Mobility Model [22].

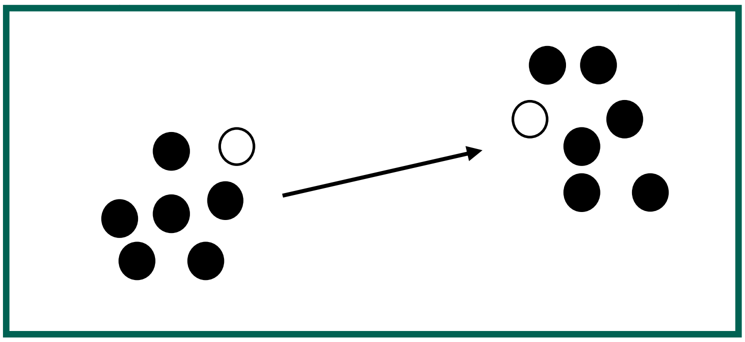

Figure 1.11: The nomadic mobility model movement.

➢ **Exponential Correlated model:** One of the first examples of group mobility is the Exponential Correlated Random (ECR) model. The model reproduces all possible movements, including individual and group, by adjusting the parameters of a motion function. The new position $\vec{\mathbf{b}}\ (\mathbf{t+1})$ is a function of the previous position $\vec{\mathbf{b}}$, to which a random deviation $\vec{\mathbf{r}}$ is added.

$$\boldsymbol{b}\ (\boldsymbol{t}+\mathbf{1}) = \boldsymbol{b}(\boldsymbol{t})\boldsymbol{e}^{\frac{-1}{\tau}} + \boldsymbol{\sigma}\sqrt{(\mathbf{1}-\boldsymbol{e}^{\frac{-1}{\tau}})}\ \boldsymbol{r}$$

Where: $\boldsymbol{b}(\boldsymbol{t}) = (\boldsymbol{r_t}, \boldsymbol{\tau_t})$is defined for a group or a node at time **t**; $\boldsymbol{\tau}$ adjusts the rate of change from old to new (small $\boldsymbol{\tau}$ causes large change); $\boldsymbol{r}$ is a random Gaussian variable with a variance $\boldsymbol{\sigma}$.

The parameters $\boldsymbol{\tau}$ and $\boldsymbol{\sigma}$ vary from group to group. They drive the groups into different moving patterns. The ECR mobility model requires a complete set of ($\boldsymbol{\tau}$; $\boldsymbol{\sigma}$) (one per group) to define the motion of the entire network.

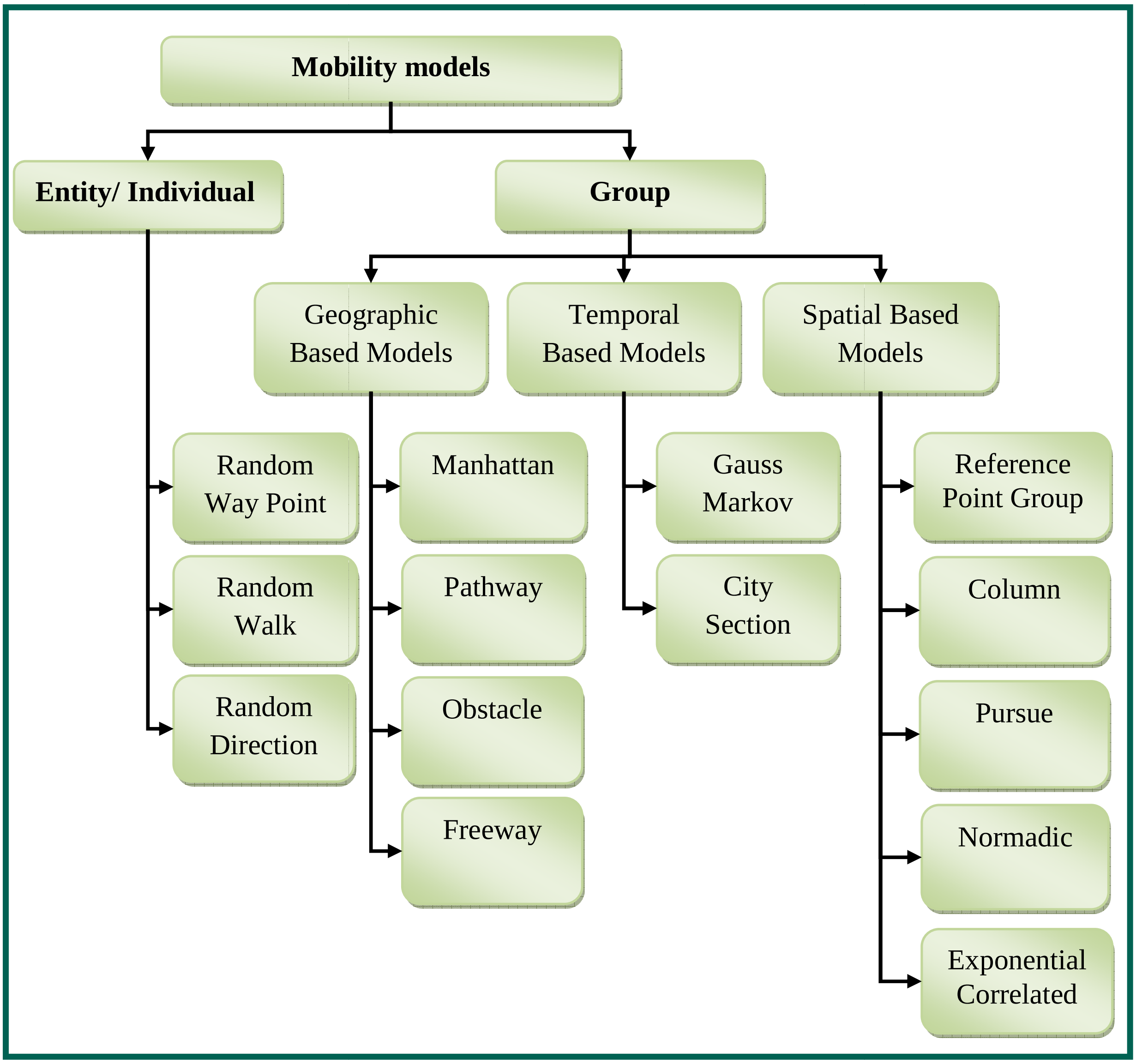

Figure 1.12: Classification of mobility model.

1.7. Conclusion:

Mobility of WSN is a new concept which received increasing attention due to the advantages over static WSNs such as the network lifetime prolongation. But, the dynamic nature of MWSNs still introduces various challenges like data management, accuracy, coverage and localization. However, depending on the applications, there are multiple mobility models.

In the next chapter, we make a study of the major routing protocols that manage the mobility in these networks.

Routing Protocols
in
Mobile Wireless Sensor Networks

2.1. Background:

Mobility management is one of the important functions of routing protocols in mobile wireless sensor networks (MWSNs) as well as energy consumption. For that, this chapter defines the routing protocols in MWSNs and their classification .Then, gives a brief description related to the routing protocols used in our study.

2.2. Routing protocols for MWSNs:

Routing is the process in which the data packets are forwarded to the base station. The data are routed to the destination in an efficient manner without delay and packet loss. Usually the network layer handles the process of routing the data. The best routing protocol is the one that covers all states of a specified network and will not consume too much network resources. In a mobile based wireless sensor network, minimizing the power consumption is very important [27].

2.3. Classification of routing protocol for MWSNs :

The routing protocols of MWSN can be mainly classified based on their network structure, state of information, mobility and biologically cooperative routing.

2.3.1. Network structure: they are further cataloged as Direct Communication Routing, Flat based Routing, and Hierarchical routing.

➢ **Direct communication routing:** a sensor node sends data directly to sink. The power of the sensor node drains very quickly here if the network area is large and the number of collision too increases [28].

➢ **The flat based routing:** protocol assign the same functionality to all nodes [29]. It is very simple and efficient for small networks. It is further categorized into[28]:

- **Opportunistic Routing (OR):** The idea behind opportunistic routing is that for each destination, a set of next hop candidates are selected and each of them is assigned a priority according to its closeness to the destination When a packet needs to be forwarded, the highest priority node is chosen as the next hop.

- **Best Path routing:** The best path routing scheme attempts to find the best path and forwards packets to the corresponding next hop.

➢ **Hierarchical routing protocols:** dynamically organize the nodes in the network into partitions called clusters and the clusters are further aggregated into larger partitions called super clusters and so on. The cluster heads aggregate the data; thereby reducing the data and saving energy [30]. They are further categorized as flat hierarchy, cluster based hierarchy and zone based hierarchy.

- **Flat based hierarchy:** all nodes have same capabilities but different responsibilities.
- **Cluster based hierarchy:** the physical network is transformed into a virtual network of interconnected clusters. Each cluster has cluster heads which make control decisions for cluster members.
- **Zone based hierarchy:** increases the scalability by shrinking the topology reorganization scope. Zones are created and the flat scheme is applied to each zone [31].

2.3.2. State of information: the routing protocols are grouped into topology based routing and location based routing.

➢ **The topology based routing protocols:** use the principle that every node in the network maintains large scale topology information. They can be again classified as proactive routing, reactive and hybrid routing [28].

- **Proactive routing:** also known as pre-computed routing or table driven routing, calculates the route to all destinations apriori and stores the information about the links and network topology changes in a routing table. The nodes here periodically update their routing tables.
- **Reactive routing:** or on demand routing computes the route to a destination only when it is needed using route discovery process and route maintenance.
- **Hybrid routing**: utilizes the functionality of both proactive and reactive routing.

➢ **Location based routing protocols:** make use of position information of nodes to route data.

They are yet again ordered under the location updates as time, distance, and predictive distance based location update routing protocol [31].

- **Time based location update scheme:** each node periodically sends a location update to a location server.
- **Distance based update scheme:** each node tracks the distance it has moved since its last update and sends its location update whenever the distance exceeds a certain threshold.
- **Predictive distance based update scheme:** also called as dead reckoning, the node reports to the location server both its position and velocity. Based on this information and the mobility pattern, the location of the node can be predicted.

2.3.3. Depending on the applications: the nodes that have to be mobile are decided. The routing protocols should support the mobility management accordingly. Based on the impact of mobility on nodes in the network [28], the routing algorithms are cataloged as:

- Routing only when the sink is mobile.
- Routing when a few nodes act as mobile relays.
- Routing when all the nodes are mobile.
- Routing when a few nodes are stationary.

2.3.4. Biologically cooperative routing: is nowadays being widely tested on MWSN and found to have remarkable adaptively, reliability and robustness in Mobile Wireless Sensor Network. These include nature inspired techniques like Ant Colony Optimization, Bee Colony Optimization, Genetic algorithms etc. to find the optimal path for routing [28].

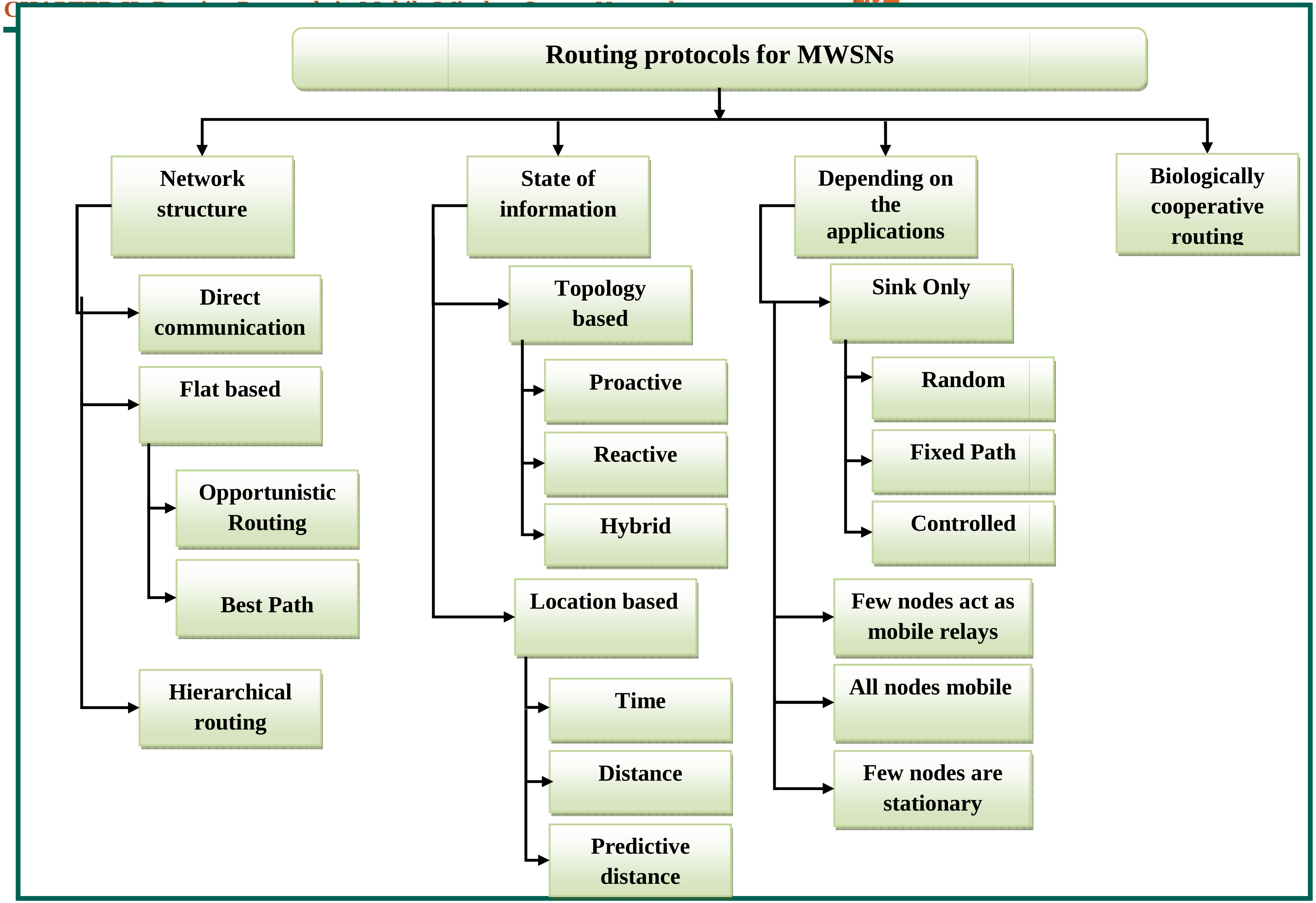

Figure 2.1: Classification of MWSNs protocols.

2.4. Description of protocols:

2.4.1. Low Energy Adaptive Clustering Hierarchy (LEACH) Protocol:

Low Energy Adaptive Clustering Hierarchy (LEACH) proposed by Wendi B. Heinzelman, *et al*. [32] is the first hierarchical, self-organizing, adaptive cluster-based routing protocol for wireless sensor networks which partitions the nodes into clusters.

LEACH [32] is a hierarchical protocol in which most nodes transmits the data to cluster heads, and the cluster heads aggregate and compress the data and forward it to the base station. Node first senses its target and then sends the relevant information to its cluster head. Then the cluster head aggregates and compresses the information received from all the nodes and sends it to the base station. Nodes that have been cluster heads cannot become cluster heads again for P rounds, where P is the desired percentage of cluster heads. Thereafter, each node has a 1/P probability of becoming a cluster head in each round. At the end of each round, each node that is not a cluster head selects the closest cluster head and joins that cluster. The cluster head then creates a schedule for each node in its cluster to transmit its data. Each sensor node n generates a random number such that 0< random < 1 and compares it to a pre-defined threshold T (n). If random < T (n), the sensor node becomes cluster head in that round, otherwise it is cluster member.

The threshold is set

$$\mathbf{T(n)} = \begin{cases} \dfrac{\mathbf{P}}{\mathbf{1-P} \times \left[r\ mod \left(\frac{1}{P}\right)\right]}, & n \in G \\ \mathbf{0}, & \textbf{Otherwise} \end{cases} \qquad \textbf{(2.1)}$$

Where P is the desired percentage of cluster heads, r is the current round, and G is the set of nodes that have not been cluster head in the last 1/P rounds. After the cluster heads are selected, the cluster heads advertise to all sensor nodes in them network that they are the new cluster heads. Then, the other nodes organize themselves into local clusters by choosing the most appropriate cluster head (normally the closest cluster head). During the steady-state phase the cluster heads receive sensed data from cluster members, and transfer the aggregated data to the BS [33]. This protocol is divided into rounds each round consists of two phases:

1. Set up phase:

Initially, when clusters are being created, each node decides whether or not to become a cluster-head for the current round. This decision is made by the node n choosing a random number between 0 and 1. If the number is less than a threshold, the node becomes a cluster-head for the current round. Each node that has elected itself a cluster-head for the current round broadcasts an advertisement message to the rest of the nodes. For this "cluster-head-advertisement" phase, the cluster-heads use a CSMA MAC protocol, and all cluster-heads transmit their advertisement using the same transmit energy. The non-cluster-head nodes must keep their receivers on during this phase of set-up to hear the advertisements of all the cluster-head nodes. After this phase is complete, each non-cluster-head node decides the cluster to which it will belong for this round. This decision is based on the received signal strength of the advertisement [33].

2. Steady state phase:

The process of transferring aggregated data or sensed data from all the sensor nodes to the sink or base station is done under steady state phase. During this phase, nodes in each cluster sends data based on the allocated transmission time to their local cluster heads. To reduce the energy dissipation, the receiver of all non-cluster head nodes would be turned off until the nodes" defined allocated time. After receiving all the data from the nodes, the cluster head aggregates all the data sent from the member nodes into a single signal and transfers it to the base station. The duration of the steady state phase is longer than the duration of the set-up phase in order to minimize overhead [33].

The flowchart of LEACH algorithm is presented in Figure 2.2.

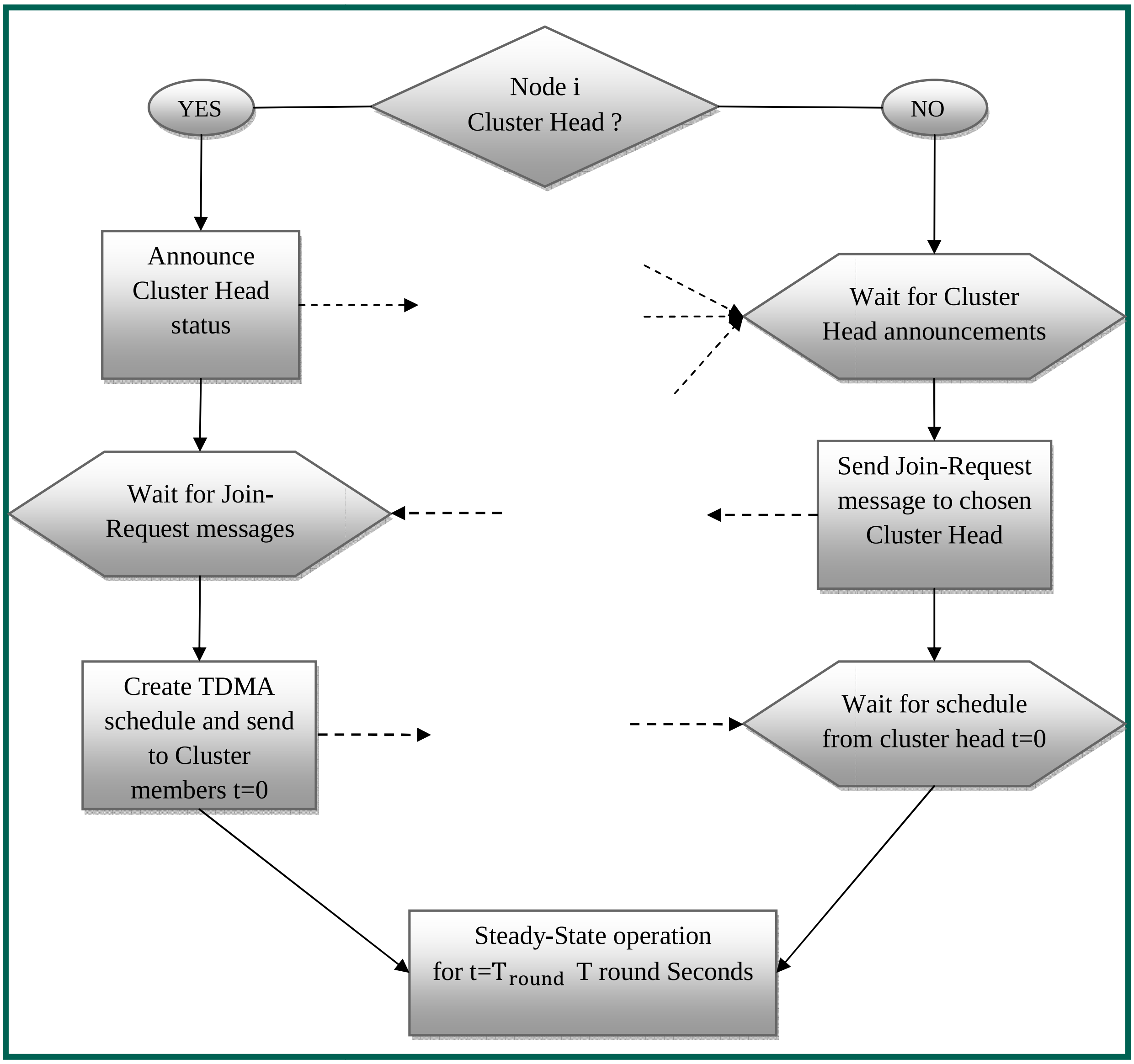

Figure 2.2: LEACH flow chart diagram.

To complete the set-up phase, each node sends a join-request message after they receive a broadcast from the elected cluster-heads using a non-persistent CSMA MAC protocol. The cluster-head creates a TDMA as shown in the LEACH flow chart and finally the nodes forming each cluster wait for their schedule before transmission. The steady phase starts immediately after the set-up phase. The cluster-heads gather all data from their respective cluster members and send the respected data to the base station. Figure 2.3 shows the Set up phase and Steady state phase [34].

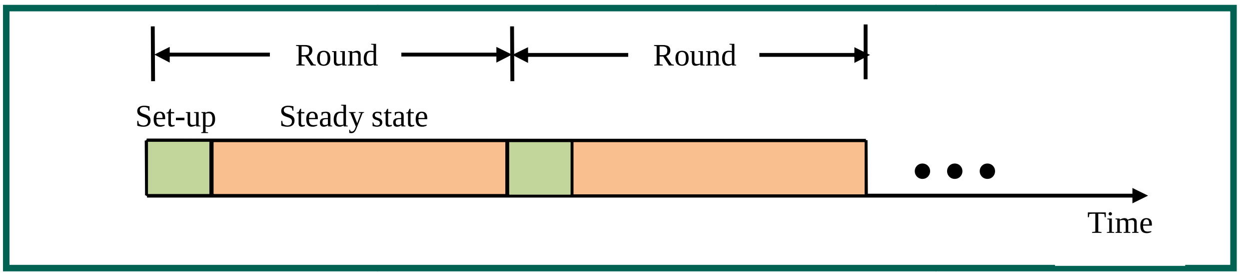

Figure 2.3: Set up and Steady state phase of LEACH.

2.4.2. ONE ROUND LEACH (LEACH-1R) protocol:

In order to achieve the goal of enhancing the WSNs clustering, that need to perform more control of the clustering process, i.e., detecting CHs and their members. In fact, such operation is based on two phases. In the first phase Figure 2.4, CHs are selected upon the first round of LEACH mechanism. In fact, can use any of the first rounds since the percentage P is more or less respected.

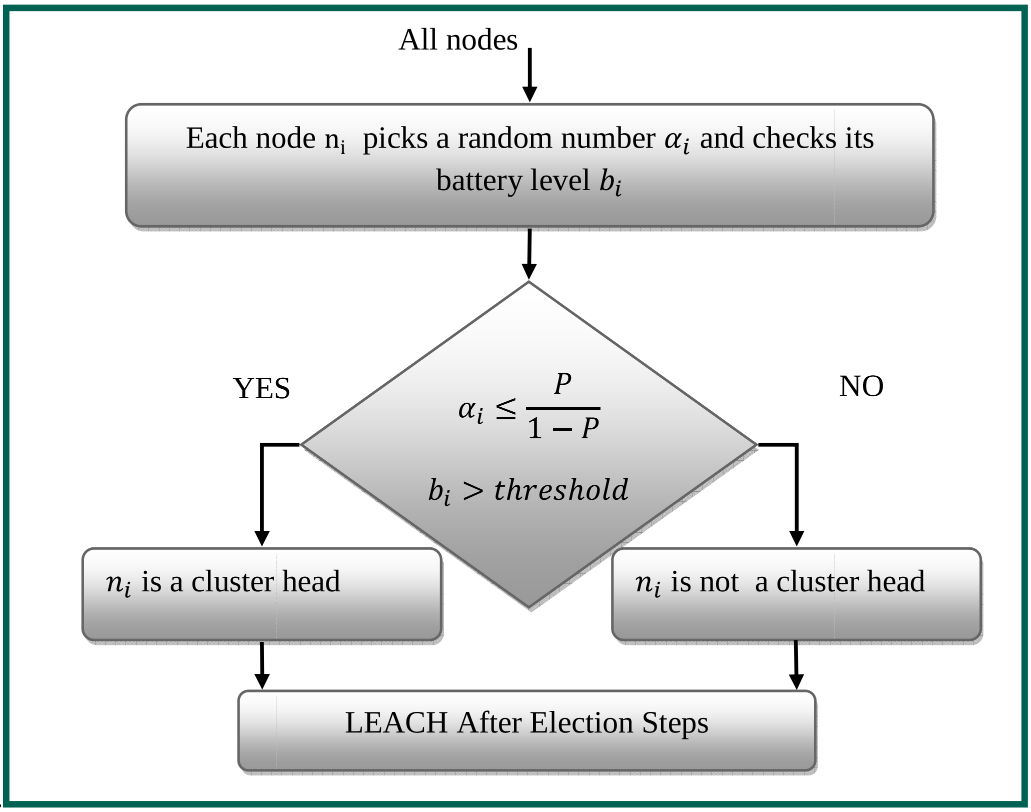

Figure 2.4: The first clustering round in LEACH-1R.

In the second phase Figure 2.5, the clusters are preserved and a new CH is selected only if the current one ran out of energy, (i.e., the battery level beyond certain threshold). In this case, a new CH is selected among the cluster members only taking in consideration the strength of the last received signal [34].

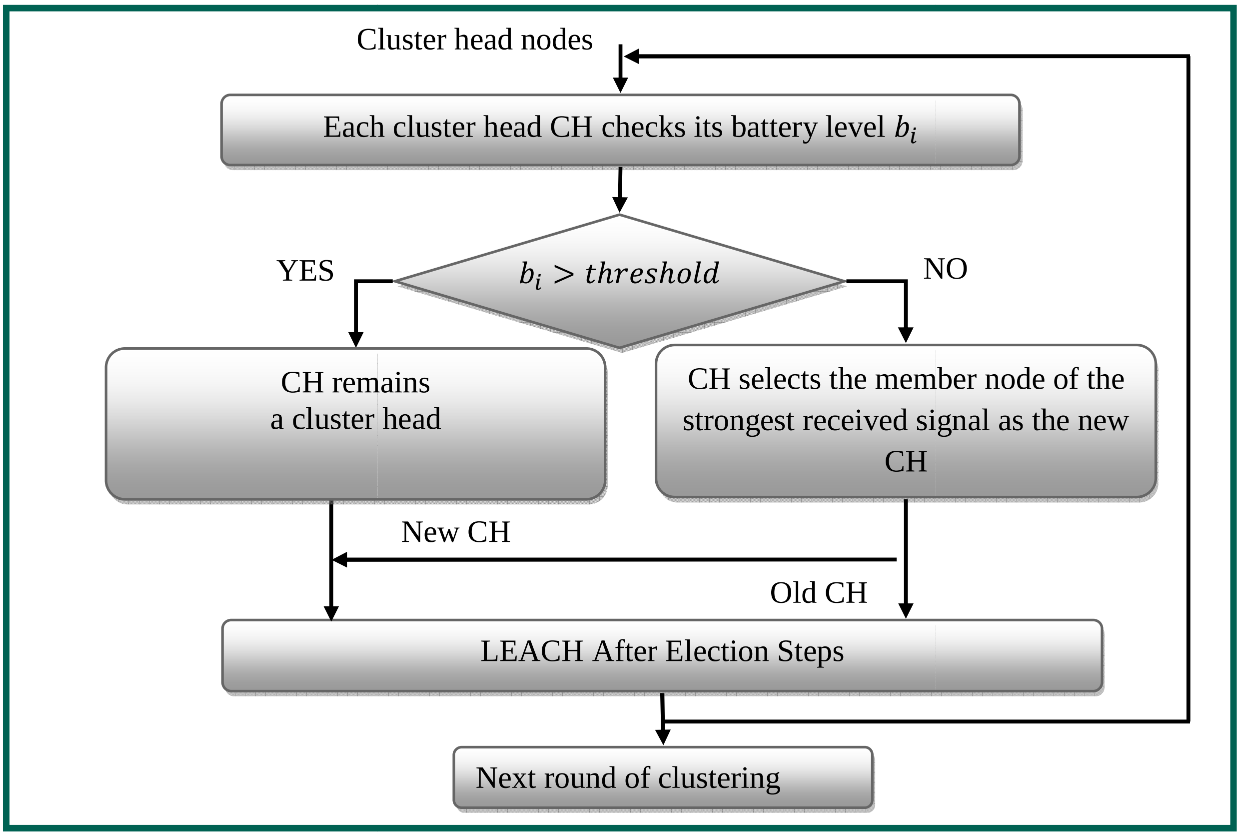

Figure 2.5: The other rounds in LEACH-1R.

2.4.3. MH-LEACH-1R (MULTI-Hop LEACH One Round) protocol[35]: consist of 2 phases:

- **Setup phase:** MH-LEACH-1R forms clusters like LEACH-1R protocol.
- **Steady state phase:** a CH collects data from all nodes in its cluster and transmits data directly or through other CHs (closest with strong signal and closer to BS) after aggregation. Multi-Hop LEACH allows two types of communication operations. First one is intra-cluster communication, when the whole network is divided into multiple clusters. CH receives data from member nodes at a single hop distance and aggregates and transmits the data directly to the BS, or through intermediate CH(s). The second one is inter-cluster communication, when the distance between the CH and the BS is large; the CH uses intermediate CH(s) to communicate to the BS.

Though MH-LEACH-1R protocol has its advantages over LEACH protocol in static network, but still not supports the mobility. The following points present some of deficiencies or limits due to the mobility:

- The clusters loss his members and the sensors become isolated.
- The network loss his connectivity, so the lifetime ends though there are a number of sensors alive.
- In inter-cluster communication, the relay CHs is selected without taking the current energy in consideration.

2.4.4. LEACH-M (Low-Energy Adaptive Clustering Hierarchy-Mobile) protocol [36]:

Although the hierarchical clustering protocol of LEACH that includes distributed cluster formation algorithm has the advantages of high energy efficiency and dynamic self-organization of the cluster, this protocol offers no guarantee of the success of data transfer in the typical mobility-centric environment of wireless sensor nodes.

In the set-up phase of LEACH, the clusters are organized and cluster heads are selected. Because the actual data transfer to the base station takes place and it maintains the configuration of clusters during the steady state phase, it cannot accommodate the alteration of cluster by mobile sensor nodes during the steady-state phase. It is possible to resolve such problem by simple and traditional method that adds membership declaration of mobile nodes to typical LEACH protocol. In LEACH-Mobile protocol scheme, it assumes that all the non-cluster head nodes of sensor network has to have data to send to cluster head necessarily at its time slot allocated in TDMA schedule.

While the cluster-head in LEACH protocol waits to receive sensed data according to TDMA schedule during steady-state phase, the cluster head in LEACH-Mobile transmits the request message for data transmission to non-cluster head node for gathering sensed data according to TDMA schedule at each time slot. As the data transfer takes place, the cluster head confirms with a time slot list of nodes whether the sensed data is received accordingly at an allocated TDMA time slot at every time when a frame ends, then marks the node on the list of non-receiving. If the sensed data is not received again from the node marked previously when the next frame ends, it removes the node and it may also assign this time slot to the newly joined node in TDMA schedule. It assumes for the cluster head that the nodes not responding to data-request message are moved and are located out of its cluster region. Then, TDMA schedule created by rescheduling is transmitted to all cluster members of nodes.

While cluster-head declares the membership of node within its own cluster region by data-request message, each mobile node confirms the cluster to which it will belong. After the clusters are organized and cluster heads are selected, the non-cluster head nodes transmit data to cluster head upon receiving data-request message. If data request message are not received until the frame ends with time slot allocated by TDMA schedule, the procedure of protocol operation goes to next frame. If mobile node does not receive data-request message even when next frame ends, it broadcasts cluster join-request message. Then the cluster-head upon receiving cluster join request message transmits cluster head advertisement message like a set-up phase to that node. Figure2.6, 2.7 and Figure 2.8, 2.9 shows the time line and message exchange process for one round of LEACH-Mobile respectively.

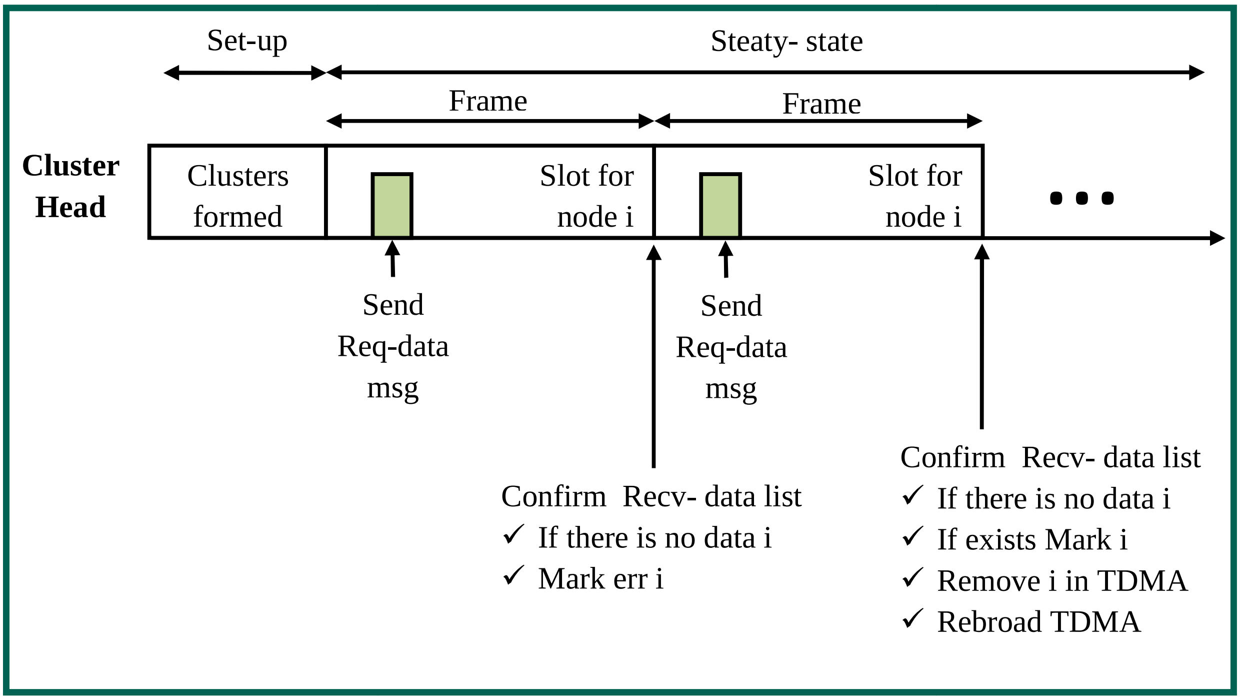

Figure 2.6: TDMA time slot for CH.

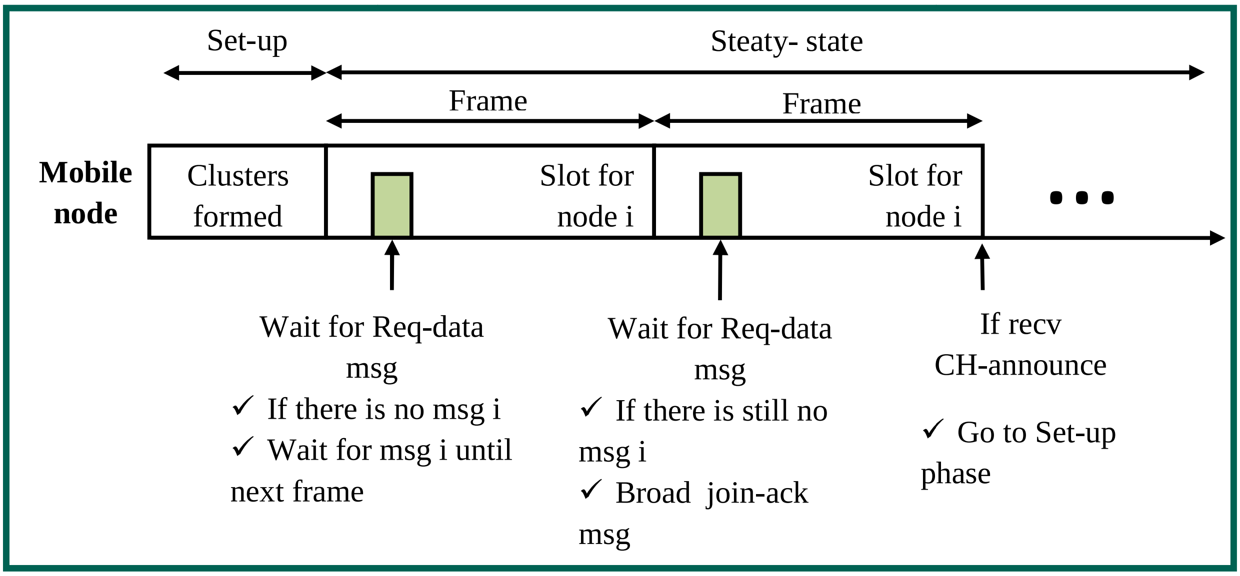

Figure 2.7: Time line of at allocated TDMA time slot for each node.

After this phase is completed, the mobile node decides the new cluster to which it will belong for this round as the mobile node moves. This decision is based on the received signal strength of the advertisement message.

After mobile node has decided its membership of a cluster to which it belongs, it must inform the cluster-head that it will be a member of the cluster. The head of the cluster in which mobile node are newly participated, updates the cluster membership list and TDMA schedule, and then broadcasts updated TDMA schedule to its own cluster member nodes. The nodes of a cluster including newly joined mobile nodes are operating according to updated schedule from next frame.

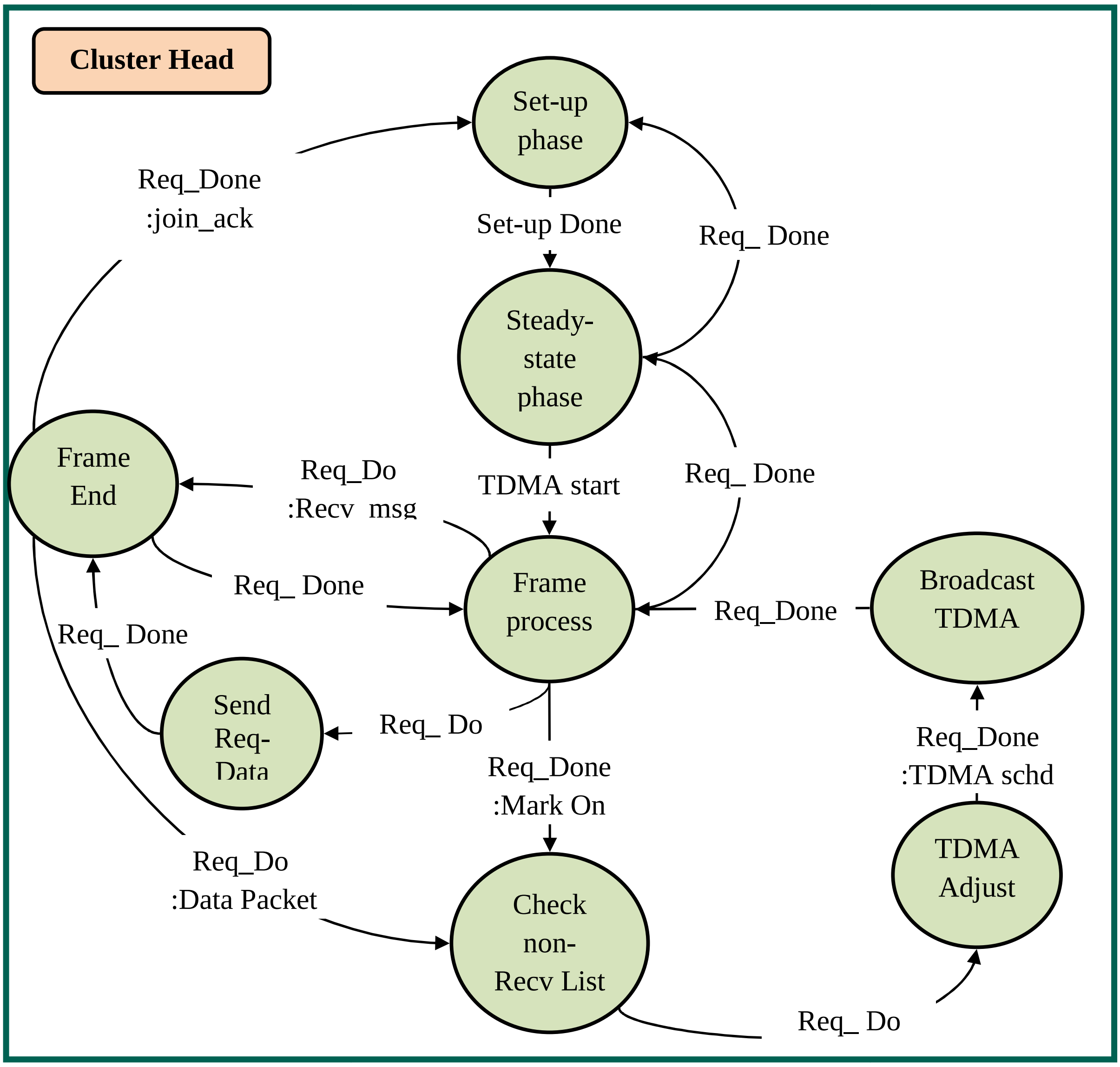

Figure 2.8: Message exchange process of at allocated TDMA time slot CH.

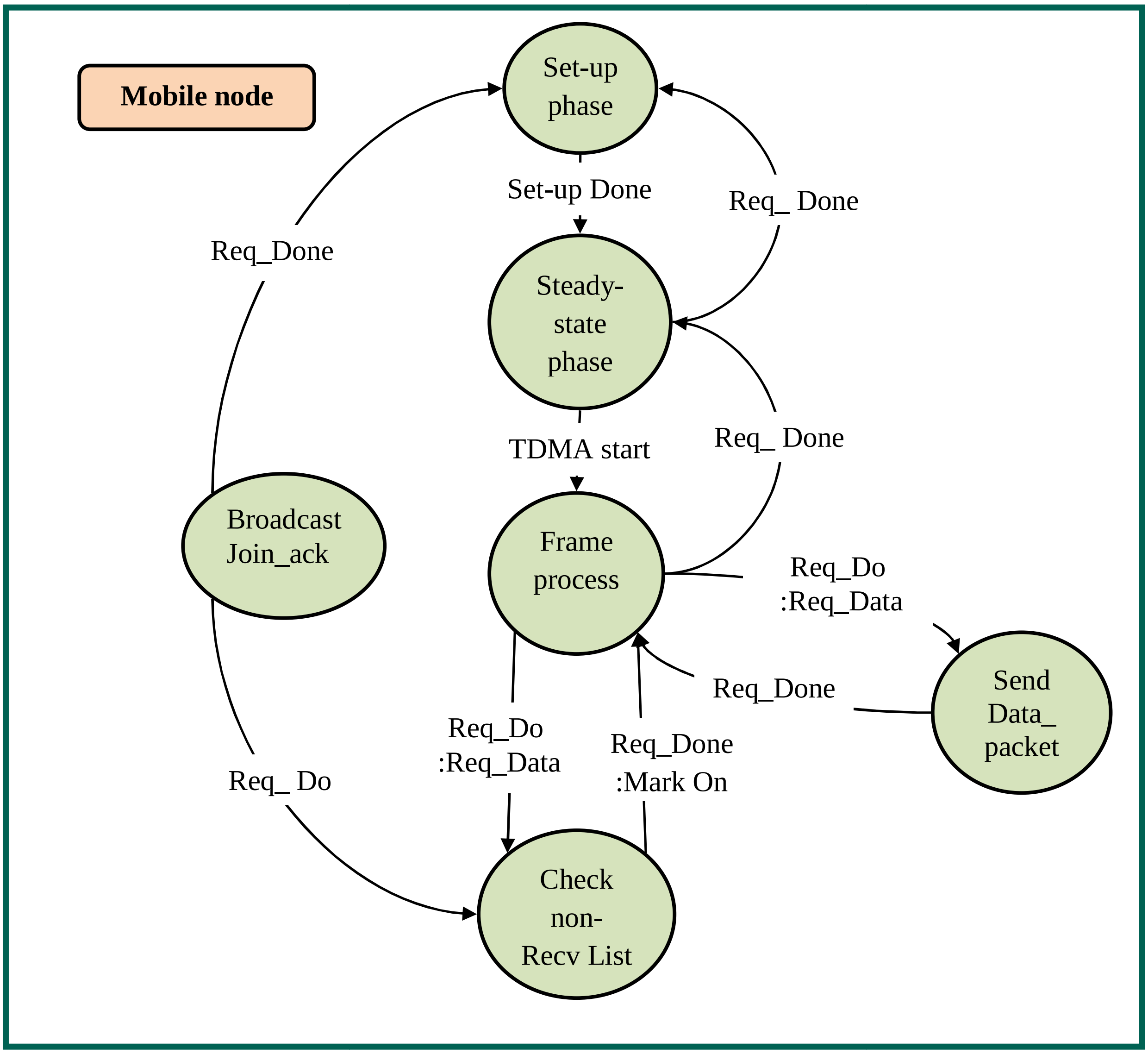

Figure 2.9: Message exchange process of at allocated TDMA time slot for each node.

The main drawback of LEACH-M protocol are as follows:

- LEACH-M suffers from consequent control packets due to the clustering in each round, so more energy consumptions.
- Also, LEACH-M is not effective in terms of energy consumptions because a large number of packets are lost if the CH keeps moving before selecting a new CH for the next round.
- LEACH-M is a single hop protocol, so more energy are consumed and more packets are lost if the distance between CHs and BS is greater than the coverage radius.
- The moved sensor node sends new join Req after 2 consecutive frames.

2.4.5. LEACH-ME (Low-Energy Adaptive Clustering Hierarchy-Mobile Enhanced):

2.4.5.1. Cluster Head Election and Maintenance in LEACH-ME [37]:

In LEACH the election and cluster head rotation makes sure that the cluster heads do not die due to prolonged extra work. This is done by the random rotation of the cluster head duty across the nodes in the cluster by considering the energy level of the nodes. In view of mobility centric environment, the election of a cluster or the job rotation of the cluster head on purely energy level, without considering the node mobility can cause serious problem. A node with sufficiently rich energy level, taking over the duty of cluster head possessing high mobility, may move out of the cluster, causing the cluster to become headless. The situation causes the cluster to go for a new cluster head. But again the mobility of the nodes is not considered causing the same process to repeat. To cope with the situation of cluster head going out of reach due to mobility, the head rotation process needs to consider the node's mobility. The nodes need to maintain certain additional information to make room for handling mobility. Following are some of the information the node should maintain:

• ***Role***: to indicate if the sensor is acting as a Cluster head CH (value=1) or as a participating node (value=0) in the zone

• ***Mobility Factor***: calculated based on the number of times a node changes from one cluster to another or on the basis of remoteness.

• ***Members List***: if the node is a cluster head, a list which contains references to the nodes associated with its Cluster.

• ***TDMA Schedule***: Time slot information, when data need to be collected from the sensor nodes by the cluster head.

The node needs to maintain all these four information, in which the mobility factor is the one with prime importance for the election of cluster head. There are different approaches to calculate mobility factor. One approach is to calculate the transitions the node makes across the cluster and the other one is through the concept of remoteness introduced in [38].

In LEACH-ME protocol, the second method for the cluster head election it used.

1. Mobility factor based on transition count:

The node associated to a cluster in motion may break its association to the cluster head and create a new association with a new cluster head in its new territory. The mobility factor is calculated based on the number of times the node moves from one cluster to another.

2. Mobility factor through the Concept of Remoteness:

Mobility measure should have a linear relationship with link change rate. If all the nodes in the cluster are in group motion like in RPGM, even though the nodes are in motion, the average link change is minimal, maintaining high spatial dependency. The node movement in such scenarios does not make any breakage of association with the cluster head. So remoteness can be treated as a measure of mobility factor.

Let $n_i\ (t), i = 0,1,2,3,...N-1$, where **N** is the number of nodes, represents the location vector of node i at time t and $d_{ij}\ (t) = |\ n_j\ (t) - n_i\ (t)\ |$, the distance from node i to j at time t. Then the remoteness from node i to node j at time t is $R_{ij}\ (t) = F(d_{ij}\ (t))$, where **F** is the function of remoteness. For a simple choice of **F** as identity function, the remoteness is just the distance between the nodes.

As a node moves relative to the other nodes, remoteness remains proportionate to its previous values. But as the node moves in a manner, in which its speed and angular deviation from the current state are not predictable, remoteness changes in time. Thus the definition of relative mobility measure in terms of remoteness of a node as a function of time with respect to its immediate neighbors is

$$M_i(t) = \frac{1}{N-1}\sum_{j=0}^{N-1} |d_{ij}\ (t)| \qquad (2.2)$$

In order to calculate $d_{ij}(t)$, from i^{th} node to all its j^{th} neighboring nodes, the broadcast medium may be used. In LEACH protocol all nodes in a cluster are time synchronized with the cluster head. The TDMA schedule issued by the cluster head are complied by the nodes. Each node uses its time slot given by the schedule to communicate to the cluster head. To reduce energy consumption during the other time slots not intended for a node, the node goes to sleep mode.

Therefore even though a node is in the radio range of its neighboring nodes, it can not hear the information sent by its immediate neighbors. In order for nodes to hear simultaneously, the cluster head gives an extra time slot as shown in Figure 2.10.During the period of extra time slot, called ACTIVE slot, all nodes need to send their broadcast IDs. As all nodes are time synchronized with cluster head and use radio propagation, the node *i* can make use of the ID broadcast of all the nodes it hears and calculate d_{ij} (t).

Slot 0	**Slot 1**	**Slot 2**	**…**	**Slot N-1**	**Active**

Figure 2.10: TDMA time slots in LEACH-ME protocol.

Let beacon sent by a neighboring node was at the start of ACTIVE time slot t1 and received at time t2. The distance **d_{ij}(t) = Radio velocity * |t2-t1|** .

Upon receiving the information from all the nodes, it's possible to calculate the mobility factor for N neighbors through equation (2.2). The node with least mobility factor is considered for the next cluster head, provided the energy level of that node is not below the threshold. Also the transition count for the node is checked to be minimal among all of its neighbors.

The method is explained in steps as given below. Denote {a} as the normal node, *c* as the cluster head. The following steps illustrate cluster head election process.

1. Cluster head c sends ACTIVE message to all its cluster members to wake up simultaneously.

ACTIVE: c → {a}: wake up

2. Upon receiving the ACTIVE message, all cluster members broadcast their IDs with time-stamp. All cluster member nodes set time-out to receive broadcast of their entire neighboring node IDs. The ID_broadcast helps individual node to know its neighbors.

ID_broadcast: {a}→ NEIGHBORS: know_neighbors

3. Once the broadcast ID timer expires, each node calculates the remoteness based on the IDs received and the time at which the IDs are received. The calculated remoteness information is broadcast by each node. The process helps to know the remoteness of neighbors of each other.

remoteness:{a}→NEIGHBORS: know_remoteness

4. Once all the remoteness values of neighbors are received nodes can go for cluster head election, where the node with minimal mobility factor is elected as cluster head, provided its energy level is not below the threshold.

Initial creation of clusters is based on certain random selection. The number of cluster heads is based on a suggested percentage of cluster heads for the network. Normal figure is 5% of the total number of nodes. In view of mobility, the figure can go high depending on the spatial dependency factor and the speed with which the node moves. A probable figure is of the order of 5 -15 % of the total number of nodes. It should be noted that the cluster head election need not be done at every TDMA time slot. ACTIVE time slot can be introduced periodically after a certain number of regular TDMA periods. The periodicity can be decided based on the active mobility of the nodes.

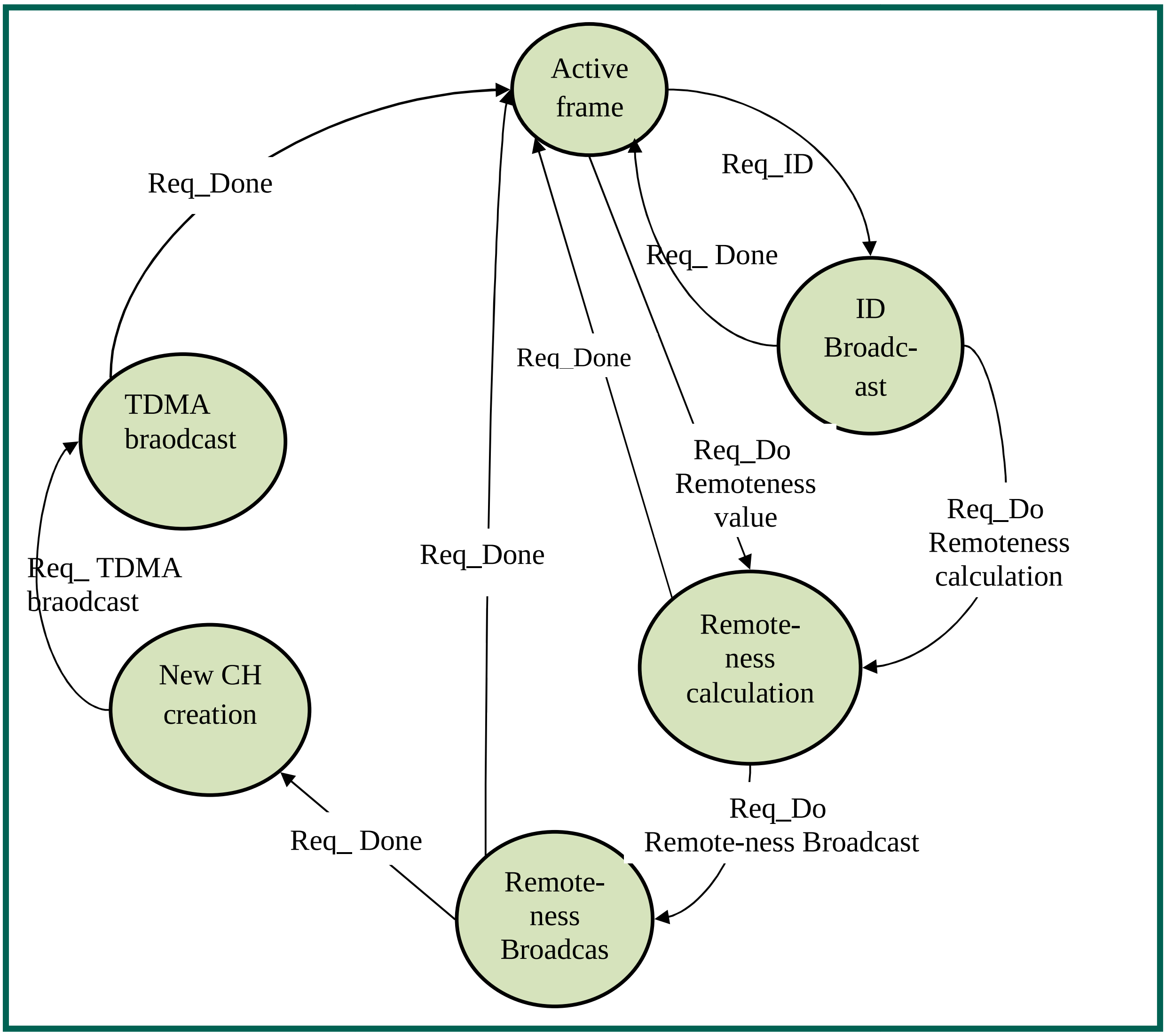

Figure 2.11: CH election in LEACH-ME.

2.4.5.2. ACTIVE slot deciding phase [38]:

Calling ACTIVE slot in regular basis without considering the nature of the mobility of the nodes can cause extra loss of energy to the nodes and hence cause threat to the life of nodes. So the selection of periodicity of ACTIVE slot in TDMA schedule should be flexible based on the mobility nature of the nodes. It is desirable to have a measure to decide the periodicity of the ACTIVE slot. The approach followed is the transition count as measure to periodicity decision. For a specific cluster the average transition count of members decide the slot frequency.

The node which migrates from one cluster to the other cluster during steady state phase need to have a count of number of such transition it made. The concept is stated earlier as mobility factor based on transition count.

In order to have the average transition count of the cluster there should be certain information with the cluster head regarding the individual transition count of the node members. But there is no additional time slot available to communicate the transition count of the nodes to the cluster head. So, each node get a data request from the cluster head need to sent back data along with transition count information to the cluster head. Cluster head need to process the transition count information separately. The decision of including ACTIVE slot in the next TDMA cycle is taken based on the average transition count calculated for the last few cycles. Transition count beyond the threshold decides the ACTIVE slot induction.

The method explained is put in steps as given below.

1. Cluster head sends data request to the respective nodes in their TDMA time slot. If the TDMA cycle does not contain ACTIVE slot, then the data request is sent with the active flag as zero.

REQ_Data/active = 0: c → {a}: get data

2. Upon receiving the data request from cluster head, the cluster member sent its data along with transition count for the last few cycles to the cluster head.

DATA: {a} → c: sent data and transition count

3. Once all the cluster member data available, the cluster head calculate the average transition count for the last few cycles and decide whether it is above the threshold decided earlier. If the value is above the threshold, then all the cluster members are intimated about the inclusion of ACTIVE slot in the next TDMA cycle by setting active flag in the REQ_Data.

REQ_Data/active=1: c → {a}: get data and reschedule

4. Upon receiving the data request with active flag set, the cluster members need to reschedule the TDMA time slot accordingly to include the ACTIVE frame.

2.4.5.3. Steady State phase in LEACH-ME [38]:

The steady state phase of LEACH-ME protocol is the same with LEACH-M protocol where, the non-cluster head nodes instead of sending the data to the cluster head in their allotted time slot in the TDMA schedule wait for a request (REQ_Data) from the cluster head to send data.

In the vicinity of mobility it may happen that the REQ_Data sent to a particular node by the cluster head is not received by the node, since it is moved to a new location which is not in the radio range of its current cluster head.

After sending the REQ_Data, if no response is obtained from the node before the time slot allotted for that node, the node will be marked as mobile-suspect. If the same thing repeats for the next time slot allotted for the same node, then the suspect node is declared as mobile and the time slot for that node is deleted from the TDMA schedule.

On the other hand, if the node doesn't receive any REQ_Data from the cluster head when it is awake, it marks itself as suspect of non-member of cluster. During the next frame slot allotted to this node, if the same thing repeats, then it takes the decision that it is not a member of the cluster.

Once a node becomes a non-member in any of the cluster, it looks for a cluster to join by sending a broadcast JOIN_REQ. The cluster head hearing the JOIN_REQ allots a time slot in its TDMA schedule and broadcasts it to all the member nodes including the new member. Upon receiving the new TDMA schedule the mobile node now becomes part of the cluster and uses the new cluster schedule. The sequences of messages are shown in Figure 2.12:

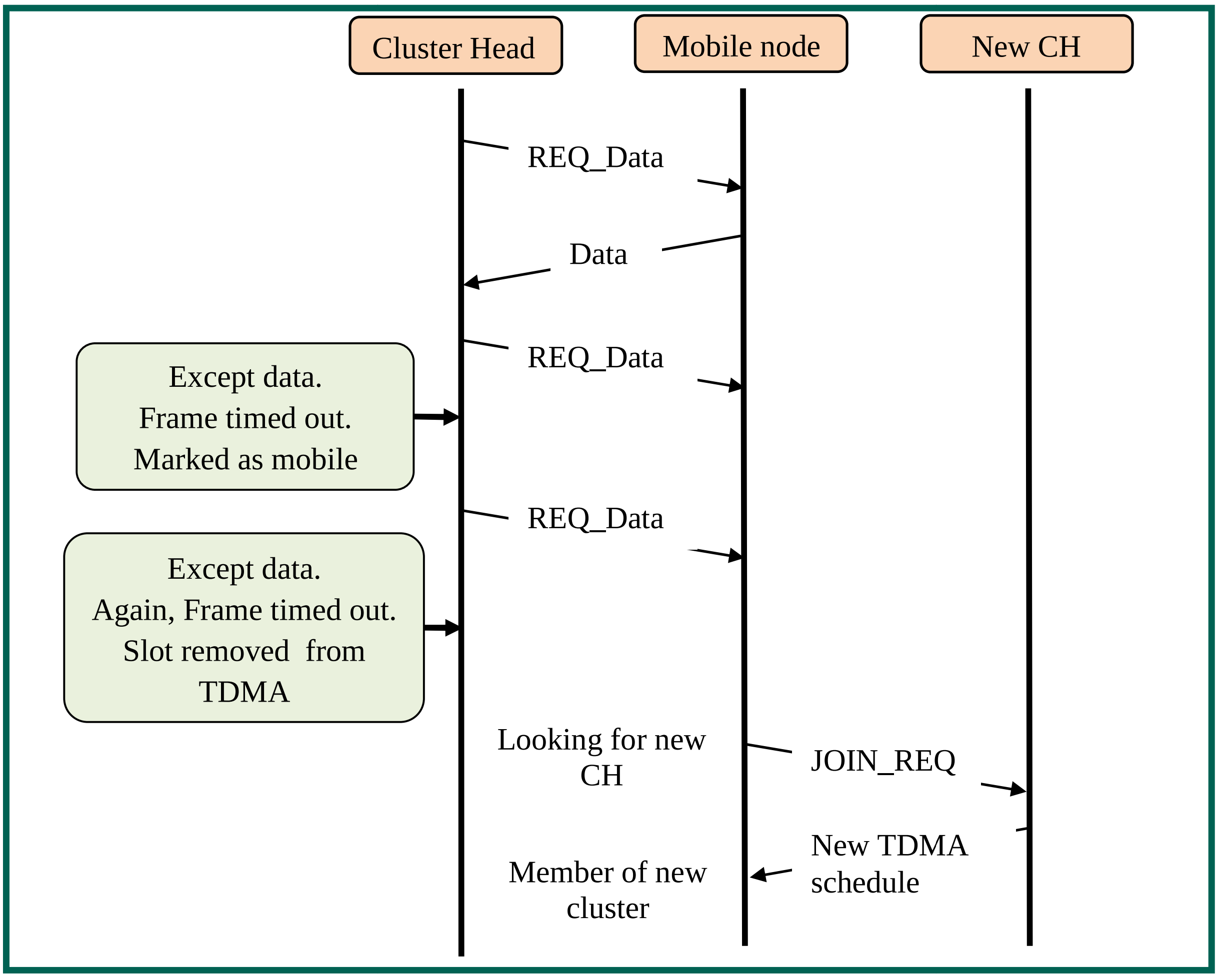

Figure 2.12: Message exchange process of at allocated TDMA time slot for each node.

2.4.6. Fault Tolerant Routing Protocol(FTCP –MWSN):

The FTCP-MWSN protocol works into the following phases.

2.4.6.1. Cluster Formation and Cluster Head Selection [39]:

Base station (BS) forms clusters based on the geographical locations of sensors and selects cluster heads (CHs) based on the residual energy and position of the sensors. Since all nodes have the same initial energy CH is selected based on a random number (between 0 and 1) and CH probability, which is similar to the method used in the LEACH protocol [32]. Once CHs are selected they broadcast their positions and IDs. A node *x* is assigned to a cluster if the CH of that cluster is at the minimum distance with *x*. The node *x* then sends a registration message to the CH with its ID and current location. CHs send cluster information to BS for centralized control and operations. Each CH that is selected at the beginning of a round is static until a new CH is selected in the next round based on the mobility factor of nodes. After a number of rounds a new cluster formation and CH selection phase is initiated to balance the network energy consumptions. Once the network operation starts and nodes move at a fixed (low) velocity, each node keeps track of the number of movements inside and outside of its current cluster based on which node's mobility is calculated at each round.

2.4.6.2. Steady Phase [39]:

In the steady phase, CHs assign timeslots to the member nodes using TDMA scheme. Member nodes of a cluster transmit data, receive acknowledgements from the CH, and count their movements inside and outside of the cluster at their allocated timeslot. Thus, no extra timeslot is required to calculate nodes mobility. All nodes are homogeneous in terms of mobility and so, while a node moves out of a cluster there is a high probability of another node entering into that cluster. However, if a node moves into a new cluster and sends JOIN-REQUEST message to CH, the CH does not allocate the node a timeslot until any timeslot becomes free for moving a node out of this cluster. CH subscribes to each node *x* for some events of interest. Whenever the node *x* sense the subscribed events at its allocated timeslot, the node *x* sends data packet to CH. In case of no such sensed event of interest, the node *x* sends a small sized special packet to notify CH that it is still alive or within the communication range of CH (i.e., it has not moved). After receiving the data or special packet CH replies to *x* with an ACK packet. If a CH does not receive any data or special packet from *x* at its allocated timeslot the CH assumes that the node *x* either has moved out of the cluster or failed. Then CH deletes the node *x from* its members list and also the timeslot allocated to *x*. CH also notifies BS the ID of *x*. On the other hand, whenever *x* does not receive any ACK packet from CH, *x* assumes that it is no longer attached to its CH due to mobility. Then *x* broadcasts a JOIN-REQUEST packet and the CHs that are within the communication range of *x* and also have free timeslot replies *x* with an ACK-JOIN packet. Then *x* registers to the cluster of the CH from which *x* receives the ACK-JOIN packet with the highest signal strength (i.e., the CH which is at the shortest distance). This new CH of *x* then allocates a timeslot for *x* and notifies BS. If the ID of this new cluster member *x* does not match with the ID of the sensor node which was reported to BS either as moved or died at the previous frame, BS identifies the node *x* as failed because if it is not dead it obviously sends JOIN-REQUEST and later, BS knows the ID of this node. Figure 2.13 illustrates the working principle of different phases of FTCP-MWSN protocol.

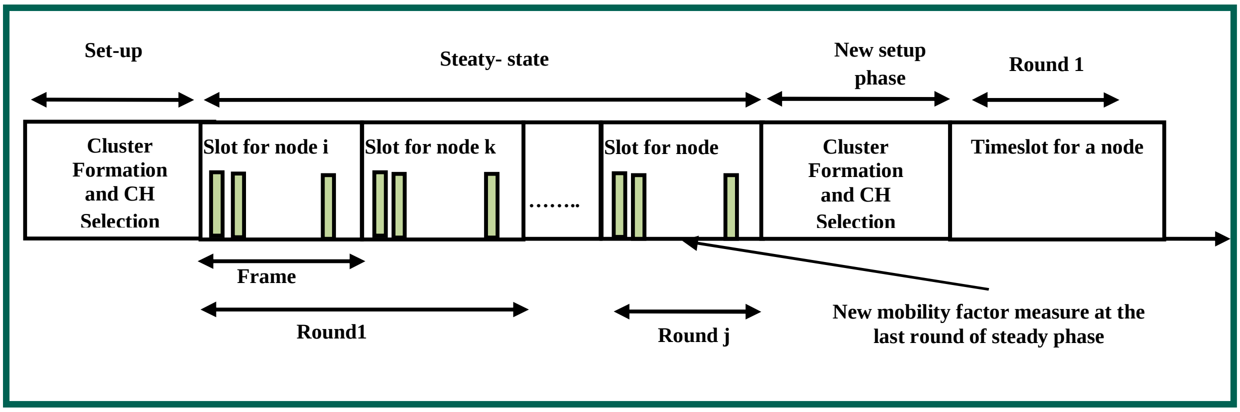

Figure 2.13: Different Phases of FTCP-MWSN protocol.

2.4.6.3. Nodes Mobility Determination [39]:

The node with the lowest mobility factor in a cluster is selected as a CH if its residual energy is above a threshold value. The mobility factor is determined as the probability of a node to move into a different cluster during the steady period and is calculated as the ratio of the number of times a node enters different clusters to the number of times a node changes positions within a cluster. Hence, the least number of times a node enters other clusters it will have the least mobility factor.

Each node keeps track of the current time of the beginning of its allocated timeslot in two consecutive frames. Let the current time at the beginning of a timeslot is **t1**. Since the node can move, it estimates the distance d it has travelled at the beginning of time slot **t2** in the next frame as

$$\mathbf{d = t2 - t1 \times velocity} \qquad \mathbf{(2.3)}$$

If d > 0 and the node does not receive any ACK from its CH then it broadcasts a JOIN-REQUEST message that represents nodes mobility into a different cluster. Otherwise, the node counts its movement as within its own cluster. Then each node x measures its mobility as

$$\boldsymbol{mobility_x = \frac{CountMoveOutOfCluster\ x}{CountMoveInsideCluster\ x}} \qquad \mathbf{(2.4)}$$

2.4.6.4. FTCP-MWSN Algorithms:

Initial State (Cluster formation, Initial CH selection)

```
BS broadcasts ID, Position, Initial Energy and CH probability of each node to the network
BS assigns ClusterArea, NoOfClusters and ClusterID
for i ← 1 to NoOfNodes do //Assign node to a cluster
        for each cluster j do
                if Position[Node[i]] ∈ ClusterArea[ClusterID[j]] then
                Node[i] ← ClusterID[j]
                end if
        end for
end for
for each node j in a cluster i do //initial CH selection
        CHProbNode[i][j] ← random(0,1)
        if CHProbNode[i][j] <= CH Probability then
                CH[i] ← Node [j]
                CH[i]subscribes events to Nodes[j] of Cluster[ i]
        end if
end for
```

Steady State (TDMA, Mobility Calculation, new CH selection, Data/Special packet sending)

for each *frame f* in each *round r* **do**
    for each *node j* of a *Cluster k* ← *t* (a time slot) **do**
        if (*node*[*k*][*j*] has an sensed event) **then**
            node[*k*][*j*] sends data to CH
            Calculates *DataEnergyConsumption*[*k*][*j*]
            Calculate *ReceiveEnergy* of *CH*[*k*]
            CH sends ACK to node[*k*][*j*]
        else //send special packet for mobility & fault tolerance
            node[*k*][*j*] sends a *special* packet to CH
            Calculate *SpecialEnergyConsumption*[*k*][*j*]
            Calculate *ReceiveEnergy* of *CH*[*k*]
            CH sends ACK to node[*k*][*j*]
        end if
        if *node*[*k*][*j*]] moves inside *Cluster k* ***then***
            ++*CountMoveInsideCluster*[*node*[*k*][*j*]]
        end if
        if CH not receive data/special from *node*[*k*][*j*] **then**
            delete *node*[*k*][*j*] & timeslot of *node*[*k*][*j*]
            notify BS about *node*[*k*][*j*] sending MOVED-NODE
        else if *node*[*k*][*j*] not receive ACK from CH **then**
            Broadcast JOIN-REQUEST
            CH within shortest communication range replies with
            ACK-JOIN & notify BS the ID of *node*[*k*][*j*] using
            NEW-NODE
        end if
        if BS receives NEW-NODE & MOVED-NODE for
            node[*k*][*j*] in two consecutive frames **then**
            mark *node*[*k*][*j*] as a moved-node
            ++*CountMoveOutsideCluster*[*node*[*k*][*j*]]
        else if CH receives NEW-NODE or MOVED-NODE
            mark *node*[*k*][*j*] as failed **//fault tolerance**
        end if
    end for //each node
        CH[*k*]aggregates Data and Sends to BS
        CHEnergyConsumption[*k*] for aggregating, sending to BS
end frame
CH[*k*] selects new CH with least mobility calculated as

$$\boldsymbol{mobility}\ [node[k][j]] = \frac{\boldsymbol{CountOutsideOfCluster}\ [node[k][j]]}{\boldsymbol{CountMoveInsideCluster}\ [node[k][j]]}$$

Calculate *CHEnergyConsumption*[*k*] for new CH Selection
Calculate number of frames for the next round as

$$\boldsymbol{NoOfFrames} = \frac{\boldsymbol{PreNoFrames}}{\boldsymbol{PreNetEnergy}} \times \boldsymbol{CurentNetEnergy}$$

end for //round

2.5. Conclusion:

Routing protocols in MWSNs are still an area of research which must adjust to topology changes and should determine the path with minimum overheads. In this chapter we presented in detail the major routing protocols for both WSNs and MWSNs. It is worth emphasizing that it is important and strongly recommended to work on both technologies in order to enhance the efficiency of the mobile network.

In the next chapter, and depending on existing protocols such as MH-LEACH-1R or LEACH-M, we will propose a study as well as a newly designed protocol to overcome the discussed limitations.

FF-LEACH: A multihop MWSN protocol based on MH-LEACH-1R and Firefly Algorithm

3.1.Background:

There are no doubts that mobility is an interesting area in MWSN field. So, enhancement of the network performance by routing protocol lead to present attractive and compelling protocols with both MWSNs and WSNs features and gets the advantage of protocol cost savings enabled by merging the two technologies.

In this chapter, we highlight the meta-heuristic algorithm (Firefly Algorithm) which nowadays being widely tested on MWSN and found to have remarkable adaptively, reliability and robustness in MWSNs. Then, we present our proposed protocol FF-LEACH.

3.2. Firefly overview[40,41]:

The flashing light of fireflies is an amazing sight in the summer sky in the tropical and temperate regions. There are about two thousand firefly species, and most fireflies produce short and rhythmic flashes. The pattern of flashes has been often unique to a particular species. The flashing light is produced by a process of bioluminescence, and the true functions of such signaling systems are still being debated. However, two fundamental functions of such flashes are to attract mating partners (communication), and to attract potential prey. In addition, flashing may also serve as a protective warning mechanism to remind potential predators of the bitter taste of fireflies.

3.2.1. Firefly Algorithm (FA):

Firefly Algorithm (FA) was developed by Xin-She Yang at Cambridge University in 2007; use the following three idealized rules:

- All fireflies are unisex so that one firefly will be attracted to other fireflies regardless of their sex;
- Attractiveness is proportional to their brightness, thus for any two flashing fireflies, the less brighter one will move towards the brighter one. The attractiveness is proportional to the brightness and they both decrease as their distance increases. If there is no brighter one than a particular firefly, it will move randomly;
- The brightness of a firefly are affected or determined by the landscape of the objective function.

For a maximization problem, the brightness can simply be proportional to the value of the objective function. Other forms of brightness can be defined in a similar way to the fitness function in genetic algorithms.

Based on these three rules, the basic steps of the firefly algorithm (FA) can be summarized as the pseudo code shown in Figure 3.1.

Objective function f(x), $x = (x1, .., x_d)^T$

$Generate\ initial\ population\ of\ fireflies,\quad x_i (i = 1;\ 2, .., n)$

$Light\ intensity\ I_i at\ x_i\ is\ determined\ by\ f(x_i)$

$Define\ light\ absorption\ coefficient\ \gamma$

$while(t < MaxGeneration)$

$for\ i = 1{:}\ n\ all\ n\ fireflies$

$\quad for\ j = 1{:}\ n\ all\ n\ fireflies$

$\qquad if\ (\boldsymbol{I_i} < \boldsymbol{I_j}), Move\ firefly\ i\ towards\ j;\ end\ if$

$\qquad Vary\ attractiveness\ with\ distance\ r\ via\ exp[-\gamma r]$

$\qquad Evaluate\ new\ solutions\ and\ update\ light\ intensity.$

$end\ for\ j$

$end\ for\ i$

$Rank\ the\ fireflies\ and\ find\ the\ current\ global\ best\ g_*$

$end\ while$

$Postprocess\ results\ and\ visualization$

Figure 3.1: Fire Fly Algorithm.

3.2.2. Light intensity and attractiveness[41]:

In the firefly algorithm, there are two important issues: the variation of light intensity and formulation of the attractiveness. For simplicity, can always assume that the attractiveness of a firefly is determined by its brightness which in turn is associated with the encoded objective function.

In the simplest case for maximum optimization problems, the brightness ***I*** of a firefly at a particular location ***x*** can be chosen as ***I(x)*** ∝ ***f(x)***.However, the attractiveness **β** is relative, it should be seen in the eyes of the beholder or judged by the other fireflies. Thus, it will vary with the distance $\boldsymbol{r_{ij}}$ between firefly ***i*** and firefly ***j***. In addition, light intensity decreases with the distance from its source, and light is also absorbed in the media, so we should allow the attractiveness to vary with the degree of absorption.

In the simplest form, the light intensity I(r) varies according to the inverse square law

$$I(r) = \frac{I(s)}{r^2} \qquad (3.1)$$

Where: $I(s)$ is the intensity of the source. For a given medium with a fixed light absorption coefficient γ, the light intensity Ivaries with the distance r. That is:

$$I = I_0\, e^{-\gamma r} \qquad (3.2)$$

Where: I_0 is the original light intensity. In order to avoid the singularity at $r = 0$ in the expression $\frac{I(s)}{r^2}$, the combined effect of both the inverse square law and absorption can be approximated as the following Gaussian form:

$$I(r) = I_0\, e^{-\gamma r^2} \qquad (3.3)$$

As a firefly's attractiveness is proportional to the light intensity seen by adjacent fireflies, we can now define the attractiveness β of a firefly by:

$$\beta = \beta_0\, e^{-\gamma r^2} \qquad (3.4)$$

Where:β_0 is the attractiveness at r = 0. As it is often faster to calculate $1/(1 + r^2)$ than an exponential function, the above function, if necessary, can conveniently be approximated as:

$$\beta = \frac{\beta_0}{1+\gamma r^2} \qquad (3.5)$$

Both $\beta = \beta_0\, e^{-\gamma r^2}$ and $\beta = \frac{\beta_0}{1+\gamma r^2}$ define a characteristic distance $\Gamma = 1/\sqrt{\gamma}$ over which the attractiveness changes significantly from β_0 to $\beta_0\, e^{-1}$for equation $\beta = \beta_0\, e^{-\gamma r^2}$or β_0 /2 for equation $\beta = \frac{\beta_0}{1+\gamma r^2}$

The distance between any two fireflies i and j at x_i andx_j , respectively, is the Cartesian distance

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})}^{\,2} \qquad (3.6)$$

Where:$x_{i,k}$ is the k^th component of the spatial coordinate x_i of i^th firefly. In 2-D case, we have:

$$r_{ij} = \sqrt{(y_i - y_j)^2 + (x_i - x_j)}^{\,2} \qquad (3.7)$$

The movement of a firefly i is attracted to another more attractive (brighter) firefly j is determined by:

$$x_i = x_i + \beta_0 e^{-\gamma r^2} (x_j - x_i) + \alpha\, (rand - 1/2) \qquad (3.8)$$

Where: the second term is due to the attraction. The third term is randomization with α being the randomization parameter, and $(rand - 1/2)$ is a vector of random numbers drawn from a Gaussian distribution or uniform distribution. ***rand*** is a random number generator uniformly distributed in [0; 1].

3.3. Our proposed protocol FF-LEACH:

The main idea of our proposed protocol is to divided the sensor network into clusters and determinate the cluster heads using the MH-LEACH-1R clustering methodology.

Once the clusters are determined and the cluster heads are elected, The steady state phase start where FF-LEACH confirm whether a mobile sensor node is able to communicate with a specific cluster head, as it transmits a message which requests for data transmission back to mobile sensor node from the cluster head within a time slot allocated in TDMA schedule of a wireless sensor cluster. If the mobile sensor node does not receive the data transmission from the cluster head within an allocated time slot according to TDMA procedure from one frame, it sends join-request message at next TDMA time slot allocated. Then it decides the cluster to which it will belong to by receiving cluster join-ack messages back from specific cluster heads. Then, inter-cluster communication starts when the distance between the CH and the BS is large; the CH uses intermediate CH(s) to communicate to the BS, so the CH choose relay CH (s) in consideration of their residual energy as well as the shortest distance. Hence, the firefly algorithm is applied.

There are two phases in our proposed protocol:

1. Setup phase,

2. Steady state phase.

1. Setup phase: Consist of 2 phase:

➢ **Cluster formation phase:**

In our proposed protocol the clusters are formed depending on Leach topology for the first round. Each node chooses a random number P between 0 and 1, if P < threshold the node is a cluster head. After the election of cluster heads each CH sends an announcement of cluster head status. Ordinary nodes reply to the cluster heads with a join-request message. The next round of re-clustering is performed after a certain period, with the following conditions:

```
if the AVG(Cluser_head_reachability) > Threshold1 then
  if Reclustering_period < Threshold2 then
      Reclustering_period = Reclustering_period * 2
  end if
end if
```

Figure 3.2: The re-clustering conditions in FF-LEACH.

Where:

- $\textbf{Cluser\_head\_reachability} = \frac{\textbf{Loyal members}}{\textbf{Last clustering members}}$ **(3.9)**
- $\textbf{Reclustering\_period} == \textbf{1}$, for the first round.

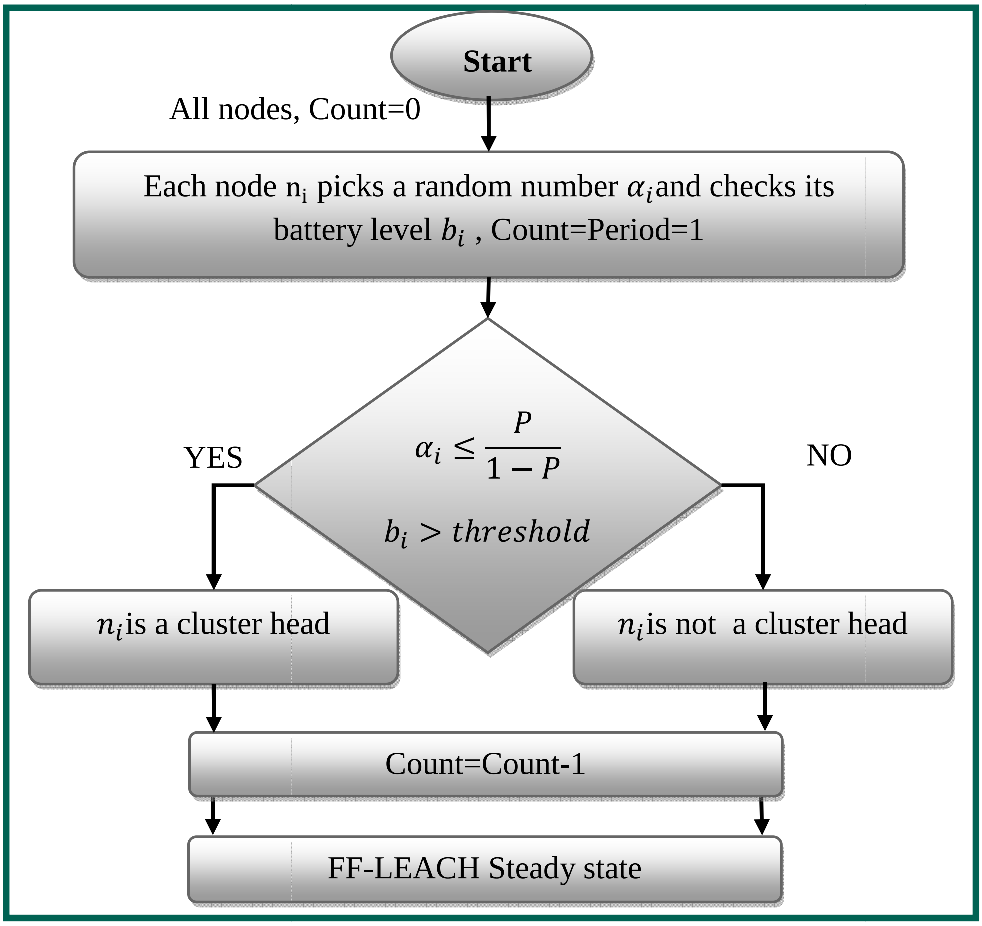

Figure 3.3: The first round in FF-LEACH.

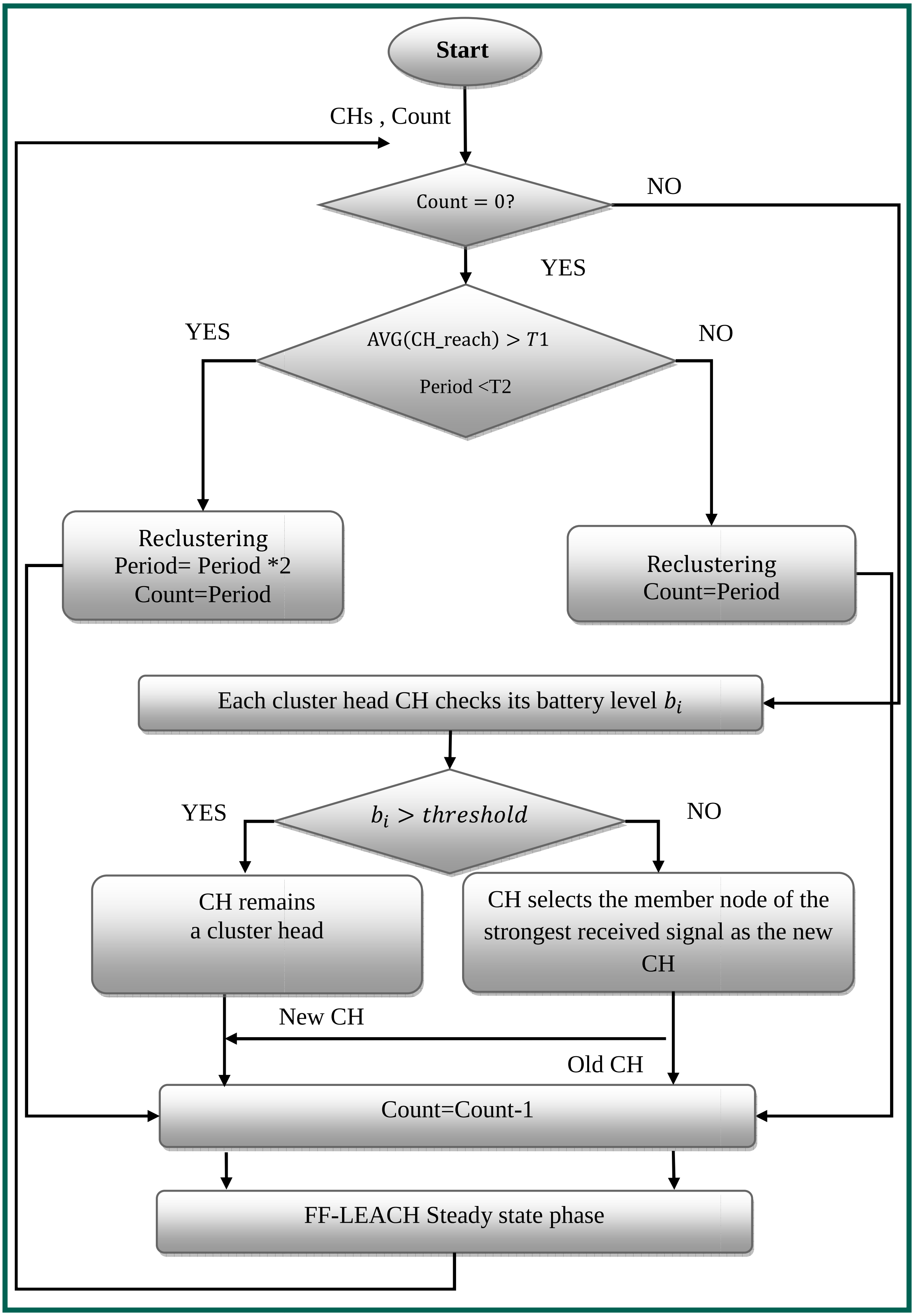

Figure 3.4: The next round in FF-LEACH.

- **Multi-hop phase:** An inter-cluster communication starts when the distance between the CH and the BS is large; the CH uses intermediate CH(s) to communicate to the BS, and the CH choose relay CH (s) in consideration to the residual energy and the shortest distance based on the firefly algorithm. The brightness (the objective function) is set as follows:

- $\text{Clusterhead light} = \max\left(\alpha * \text{residual energy} + (1 - \alpha) * \left(\frac{1}{\text{BS}-\text{RSSI}}\right)\right)$

In this case, the brightness can simply be proportional to the value of the objective function. Also for simplicity the attractiveness of a firefly is determined by its brightness which in turn is associated with the encoded objective function.

Where**:**

- **RSSI:** Received Signal Strength Indicator.

2. Steady state phase: CH transmits a message which requests for data transmission back to mobile sensor node from the cluster head within a time slot allocated in TDMA schedule of a wireless sensor cluster. If the mobile sensor node does not receive data from the cluster head within an allocated time slot according to TDMA procedure from one frame, it sends join-request message at next TDMA time slot allocated. Then it decides the cluster to which it will belong to by receiving cluster join-ack messages back from specific cluster heads.

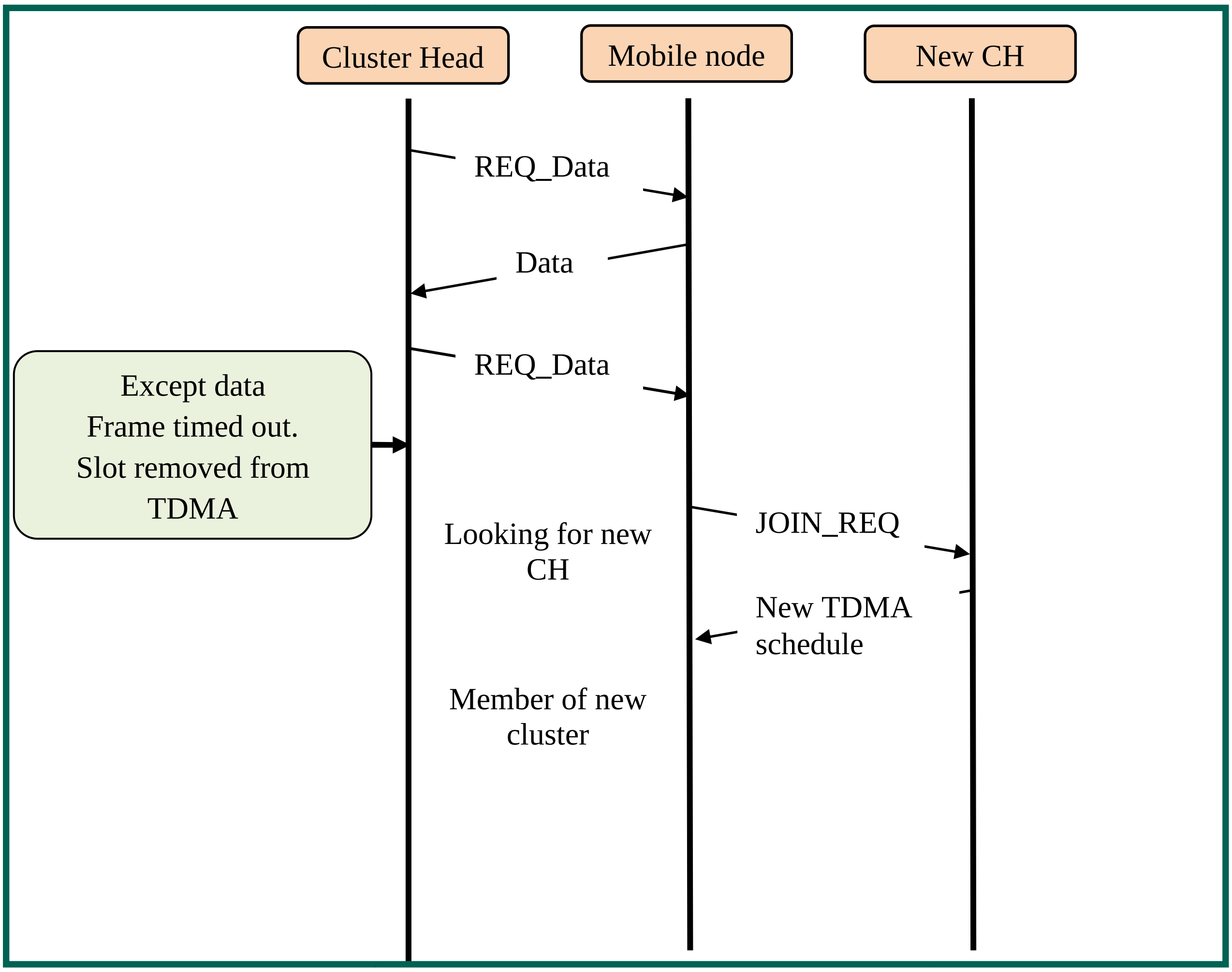

Figure 3.5: The Steady state phase in FF-LEACH.

3.4. Conclusion:

Firefly algorithm is a nature inspired optimization technique that has remarkable adaptively, reliability and robustness in MWSNs.

Our proposed protocol is based on MH-LEACH-1R protocol with some enhancement using the Firefly algorithm, in order to maintain the connectivity of the network and reduce the energy consumption.

To find which factors are most important, the network performance needs to be tested through a simulator. In the next chapter, the three protocols (MH-LEACH-1R, LEACH-M, and FF-LEACH) are implemented and tested using MATLAB environment.

Simulation, Results, and Analysis

4.1. Background:

Researcher and developers usually select simulation applications in order to implement their proposed protocols. Due to many reasons, such simulation provides acceptable level in terms of measurement. In fact, it gives a convenient way to predict performance, even in the presence of network hardware.

In the literature, we found many simulation environments and network simulators that are available for network performance measurement. In our study, we selected the MATLAB environment because it very simple and has easy ways to create GUIs (Graphical User Interface).

In this chapter, first, we show the reasons to use simulation with the indication to the major advantages and drawbacks of simulation. Second, we present the MATLAB environment as well as the developed interface that we used for this simulation. Third, we present the different simulation scenarios and their corresponding results. At the end, we present the analyses and comparison of the simulated protocols in order to extract the best protocol in terms of each used metric.

4.2. Why Simulation?

- Real-system is complex/costly or dangerous (e.g: space simulations, flight simulations)[42].
- Quickly evaluate design alternatives (e.g. different system configurations)[43].
- Evaluate complex functions for which closed form formulas or numerical techniques are not available.

➢ **<u>Advantages</u>**:

- Sometimes cheaper.
- Find bugs (in design) in advance.
- Generality: over analytic/numerical techniques.
- Detail: can simulate system details at arbitrary level.

➢ **<u>Drawbacks</u>**:

- Caution: does model reflect reality?
- Large scale systems: lots of resources to simulate (especially accurate simulation)

- May be slow (computationally expensive – 1 min real time could be hours of simulated time)
- Statistical uncertainty in results.

4.3. MATLAB environment:

MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. Using the MATLAB product, we can solve technical computing problems faster than with traditional programming languages, such as C, C++, and FORTRAN [44].

We can use MATLAB in a wide range of applications, including signal and image processing, communications, control design, test and measurement, financial modeling and analysis, and computational biology. Add-on toolboxes (collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas.

MATLAB provides a number of features for documenting and sharing work. We can integrate MATLAB code with other languages and applications [44].

MATLAB Features include:

- High-level language for technical computing,
- Development environment for managing code, files, and data,
- Interactive tools for iterative exploration, design, and problem solving,
- Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, and numerical integration,
- 2-D and 3-D graphics functions for visualizing data,
- Tools for building custom graphical user interfaces,
- Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, FORTRAN, Java™, COM, and Microsoft® Excel®.

MATLAB is widely used as a computational tool in science and engineering encompassing the fields of physics, chemistry, math and all engineering streams. It is used in a range of applications including:

- Signal processing and Communications.

- Image and video Processing.
- Control systems.
- Test and measurement.
- Computational finance.
- Computational biology.

4.4. System model:

4.4.1. Network model:

1- Nodes in the network are mobile and the Base station is stationary.

2- Nodes are dispersed in a 2-dimensional space and cannot be recharged after deployment.

3- Nodes have similar processing and communication capabilities and equal initial energy.

4- Nodes are homogeneous deployment in the sensor field, and random distribution in the network.

4.4.2. Energy dissipation model:

The radio hardware dissipation model is a simple radio model. In this model, when the distance of a node transmitting data to other nodes or the base station is greater than the threshold (*Tn*) , the multipath ($\boldsymbol{\varepsilon_{mp}}$) fading channel model is used. When the distance between a node transmitting data to other nodes or the base station is less than threshold the free space ($\boldsymbol{\varepsilon_{fs}}$) channel model is used (power loss). Thus, to transmit a L-bit message at distance d, the radio transmission energy is given by:

$$\boldsymbol{E_{TX}} = \begin{cases} \boldsymbol{L * E_{elec} + L * \varepsilon_{fs} * d^2}, & \boldsymbol{d < d_0} \\ \boldsymbol{L * E_{elec} + L * \varepsilon_{mp} * d^4}, & \boldsymbol{d \geq d_0} \end{cases} \quad \textbf{(4.1)}$$

- E_{elec} represents the energy consumption in the for sending or receiving one bit.
- $\varepsilon_{fs} * d^2$ and $\varepsilon_{mp} * d^4$ is the amplifier energy that depends on the transmitter amplifier model.
- E_{da} is data aggregation energy.

The energy consumption of receiving L-bit data is:

$$\boldsymbol{E_{RX}}\ \textbf{(L)} = \boldsymbol{L * E_{elec}} \qquad \textbf{(4.2)}$$

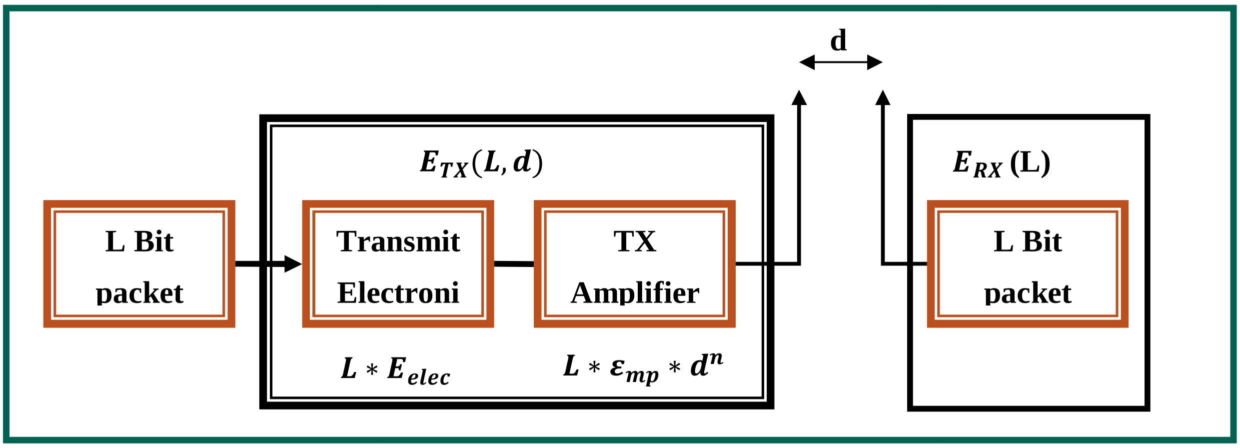

Figure 4.1: Energy dissipation model.

4.4.3. Hardware characteristics for MATLAB environment:

In our simulation, we use the same machine characteristics in all experimentations as shown in the table below.

Table 4.1: Hardware characteristics.

Hardware	*Characteristics*
Processor	Intel(R) Core(TM) i3-2348M CPU @ 2.30GHz, 2300 MHz.
Memory (RAM)	4.00Go.
Operation system	Microsoft Windows7 Professional 64bits.

4.5. Description of “WSN Simulation” interface:

In our simulation, we used MATLAB environment to implement and simulate the routing protocols, which is initially created by Omari [34].

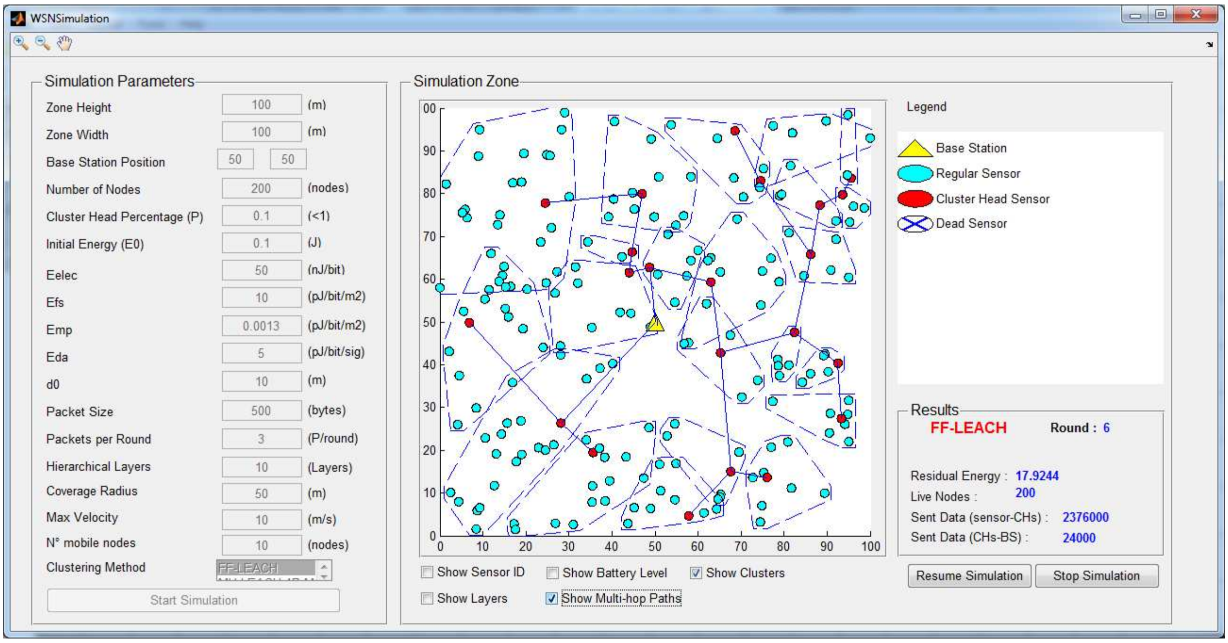

Figure 4.2: The interface of WSNSimulation.

WSNSimulation is composed of two principal parts:

1- Simulation parameters.

Before starting a simulation in the WSNSimulation interface, we need to fill the simulation parameters that are required to simulate each protocol. In general, we need to specify the simulation area and the location of the base station, which are important parameters in any simulation. Then, we introduce the number of deployed sensors, the different consumed energies (Eelct, Efs, Emp, Eda), the packets size, and the mobility paramaters (Max velocity, Number of mobile nodes). Finally, we press the Start button in order to launch the simulation.

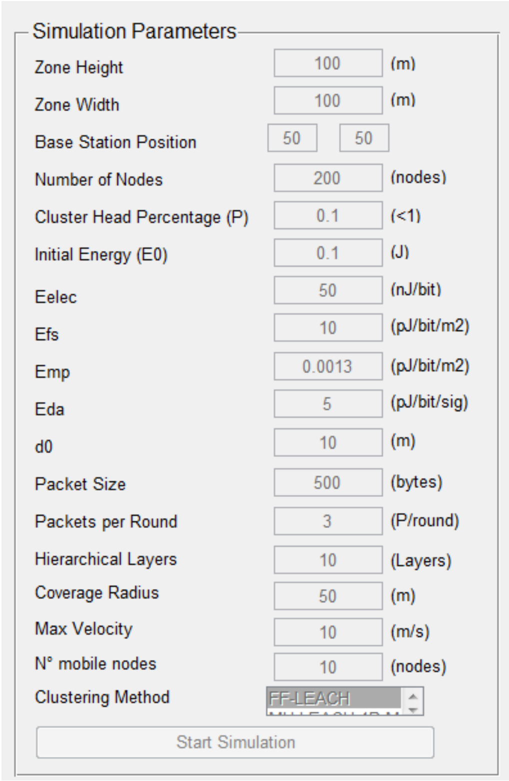

Figure 4.3: The Simulation parameters.

2- Simulation zone:

After pressing the “Start Simulation” button, the second part of our simulator is shown which consists of the “simulation zone”. This zone is divided into four sections:

➢ The first section is the important section which represents the simulation area with the deployed sensors and the base station.

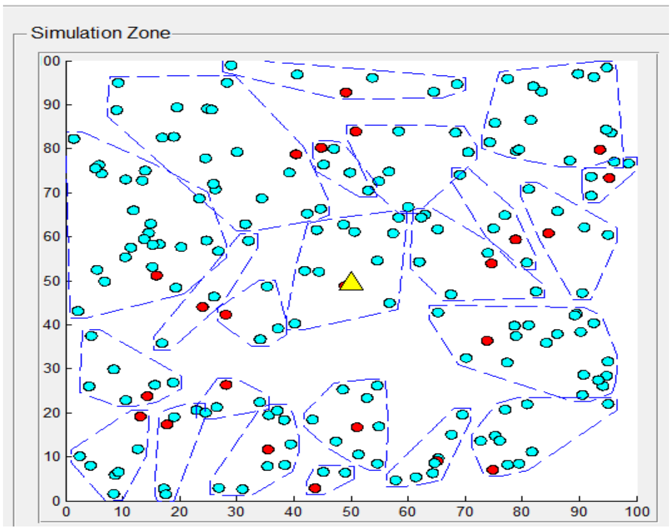

Figure 4.4: The area of simulation.

- The second section is the "Legend" which defines the different shapes that are shown on the area of simulation: The base station as a yellow triangle, CHs as a red circle, regular sensor as a blue circle and dead sensors as a circle containing two intersecting lines.

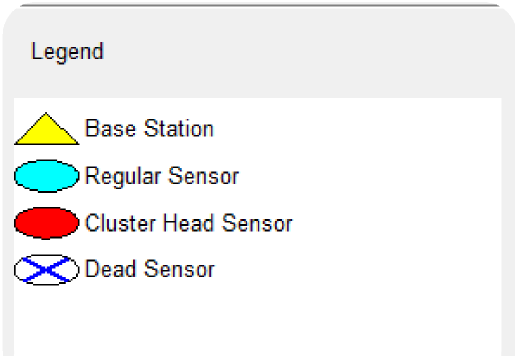

Figure 4.5: The legend of the WSNSimulation environment

- The third section is the "Results Box" which presents the current results of the ongoing simulations with step by step update (each round): the number of rounds, the residual energy, the number of alive nodes, data sent to CHs, at the end the data sent to BS, as we show in the Figure 4.6

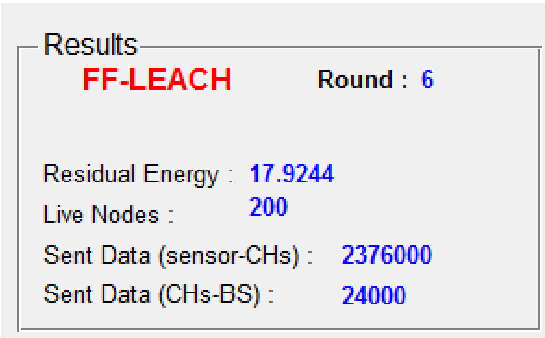

Figure 4.6: The results of simulation

- As shown in Figure 4.7, the fourth and the last section is a set of checkboxes "Show parameters" which are located under the simulation area: show SensorID, show Battery Level…

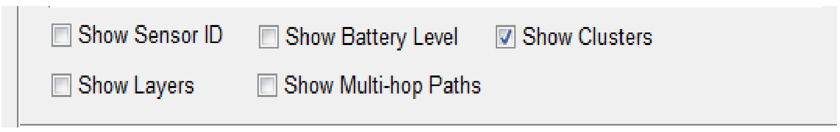

Figure 4.7: The Show parameters.

4.6. Simulation of the routing protocols:

In this section, we will evaluate the performance of each of the following protocols: MH-LEACH-1R, LEACH-M, and our proposed protocol FF-LEACH.

Our simulation is divided into 3 parts: First, we make a scenario which shows the main problem of mobility. Then, the two other scenarios investigate the performance of the three protocols with different parameters.

In our simulation, we take the average of three experimentations due to the random factors that are used such as max velocity, the random distribution, random direction …

Table 4.2: Simulation parameters

Parameters	***1st scenario***	***2nd scenario***	***3rd scenario***	
Protocols	MH-LEACH-1R Static, MH-LEACH-1R Mobile	LEACH-M, FF-LEACH, MH-LEACH-1R Mobile	LEACH-M, FF-LEACH, MH-LEACH-1R Mobile	
Number of nodes	200	200	200	200
Location of BS	(50, 50)	(50, 50)	(50, 50)	(50, 50)
Simulation area	100mX100m	100mX100m	100mX100m	100mX100m
Node deployment	Random	Random	Random	Random
Packet size	500 Bytes	500 Bytes	500 Bytes	500 Bytes
Initial energy	0.1J	0.1J	0.1J	0.1J
E_{elec}	50nJ/bit	50nJ/bit	50nJ/bit	50nJ/bit
ε_{fs}	10pJ/bit/m²	10pJ/bit/m²	10pJ/bit/m²	10pJ/bit/m²
E_{da}	5pJ/bit/sig	5pJ/bit/sig	5pJ/bit/sig	5pJ/bit/sig
P	0.1	0.1	0.1	0.1
Coverage radius	50	50	50	50
Max velocity	20m/s	20m/s	10,30,50 m/s	20 m/s
Nb of mobile nodes	100	100	100	50,100,150
Mobility Model	Random Waypoint	Random Waypoint	Random Waypoint	Random Waypoint
α	0.6	0.6	0.6	0.6
Threshold1	0.6	0.6	0.6	0.6
Threshold2	32	32	32	32

4.6.1. The 1st scenario:

4.6.1.1. Number of rounds:

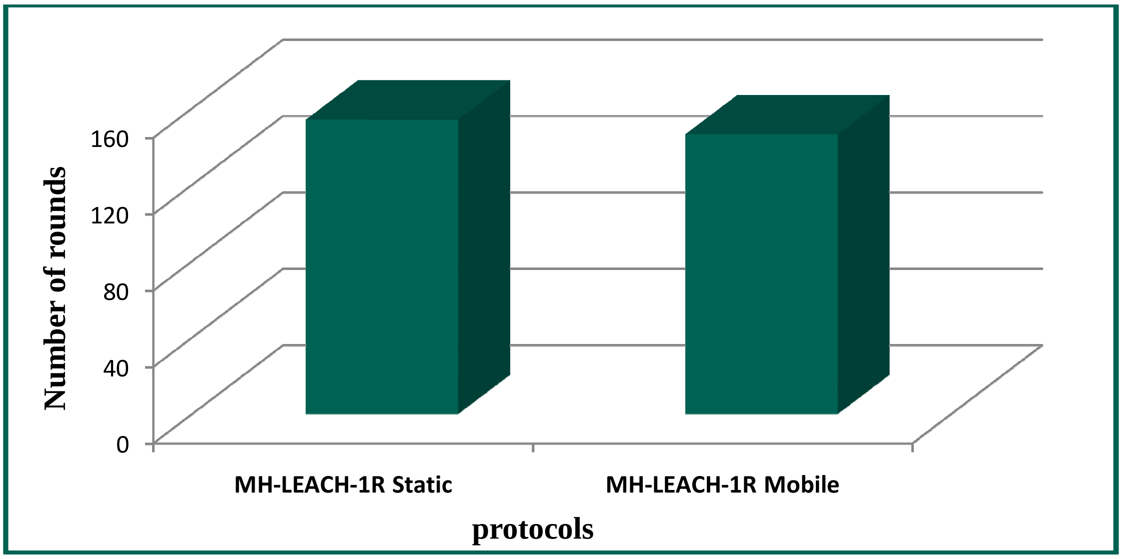

Figure 4.8: Comparison of the lifetime of MH-LEACH-1R protocol in the two states.

Figure 4.8 presents the number of rounds of MH-LEACH-1R protocol in each state (static and mobile) after the last cluster head dies with radius of 50m. We observed that MH-LEACH-1R in the static state has higher number of rounds as compared to the mobile one. This is due to the stability of sensors in the clusters which give more chance to regular sensors to become CH, because in this protocol if all CHs are dead this means that the life time of network is expired even if there are regular sensors still alive (isolated).

As a result, this metric does not reflect the reality because in the static case, the protocol receives and sends more data which leads to consume more energy.

4.6.1.2. Data delivery to BS:

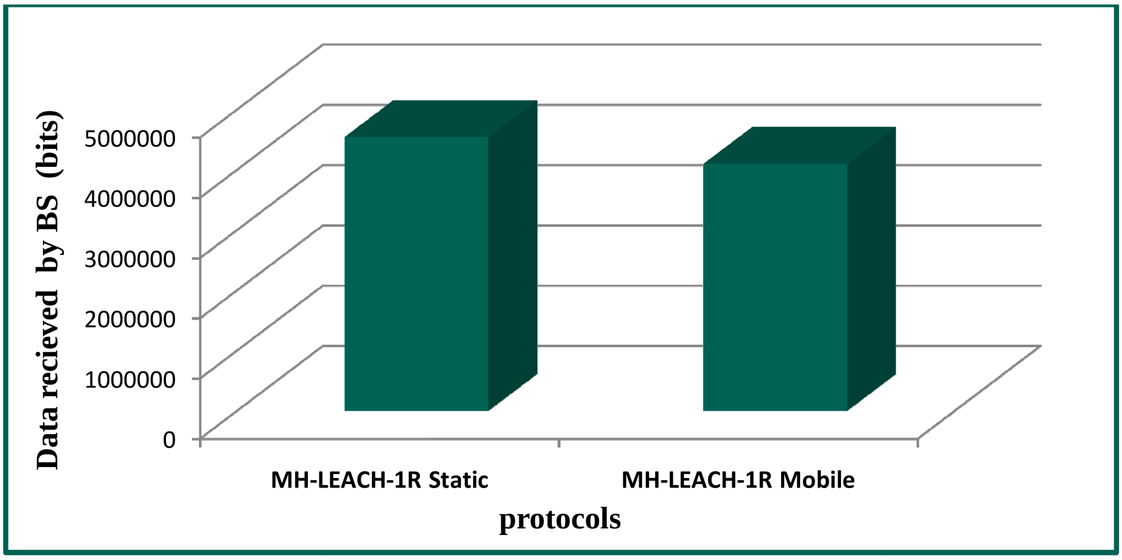

Figure 4.9: Comparison of the data received by BS for the two cases.

Figure 4.9 presents the amount of data received to the base station while the CHs still alive for the two states. The simulations show that in the two cases CHs deliver almost the same amount of data to the base station because usually they use the same numbers of clusters, so the same data delivery was recorded in the two states.

4.6.1.3. Data delivery to CHs:

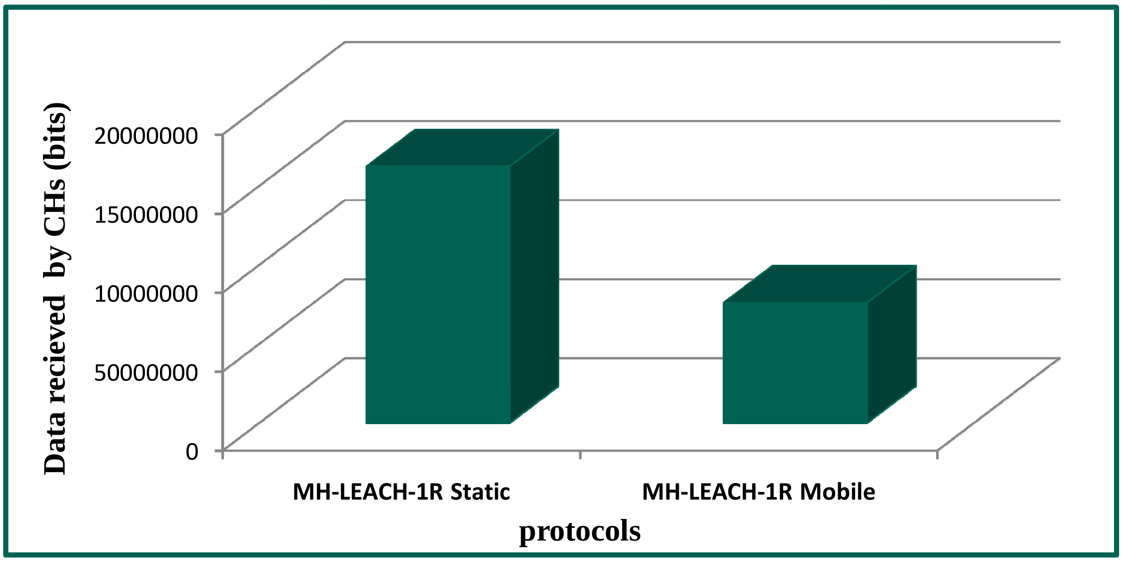

Figure 4.10: Comparison of the data received by CHs for the two cases.

Figure 4.10 presents the amount of data received to the CHs until the last CH dies for the two states. The results show that MH-LEACH-1R-Static protocol has more data delivery to CHs (twice), because of the best clustering which maintain the same clusters until the CH runs out of energy. Unlike MH-LEACH-1R-Mobile protocol which loses its members due to the mobility that makes them isolated.

So, the mobility affects the MH-LEACH-1R protocol in terms of data delivery to CHs, especially if the coverage radius becomes small.

4.6.1.4. Lost packets:

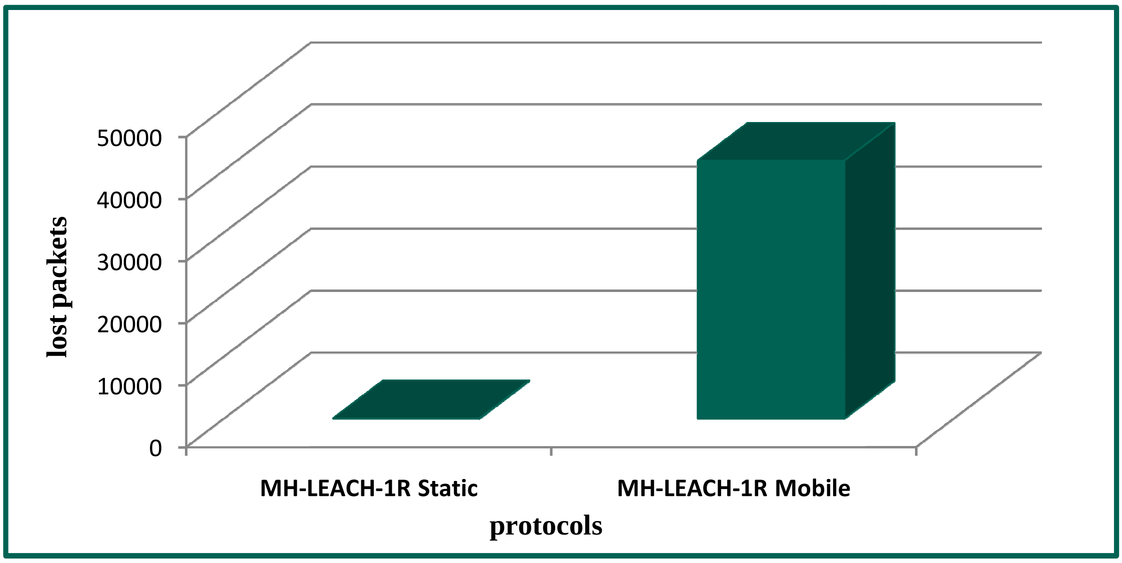

Figure 4.11: Comparison of No. of lost packets for the two cases.

Figure 4.11 presents the number of lost packets until the last CH dies for the two states of protocol, static and mobile. Results show that the number of lost packets for the MH-LEACH-1R Mobile is higher, while it is very low for MH-LEACH-1R Static, because of the mobility and the coverage radius parameters, which results in two cases: Firstly, the regular sensor node can move and go out of the cluster which becomes isolated. Secondly, the CHs also can move and loses the majority of its members and make them isolated.

4.6.1.5. Control packets:

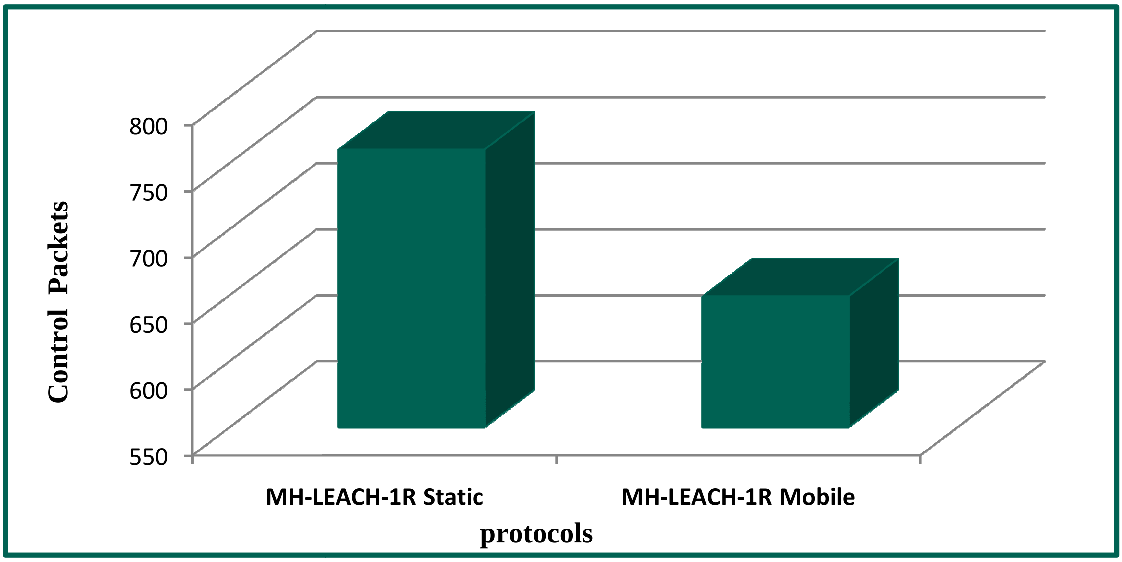

Figure 4.12: Comparison of No. of control packets for the two cases.

Figure 4.12 presents the number of control packets until the last CH dies for the two states of MH-LEACH-1R protocol. It is clearly seen that after the application of the mobility, the MH-LEACH-1R protocol has less control packets because the CHs lose their members. Unlike the MH-LEACH-1R Static protocol suffers from a consequent overhead, due to the connectivity of the network.

4.6.1.6. Live nodes:

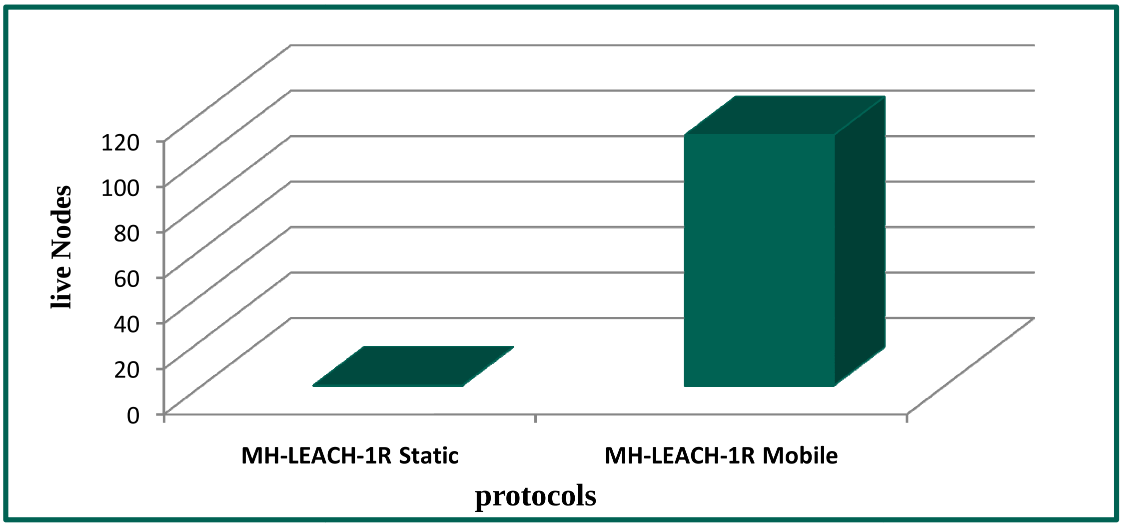

Figure 4.13: Comparison of No. of alive nodes for the two cases.

Figure 4.13 presents the number of the nodes that remain alive after the last CH dies through the simulation rounds for the MH-LEACH-1R protocol. As we show that MH-LEACH-1R Static has less number of isolated sensors because of the connectivity of the network. Therefore, the majority of sensors have high chance to become CH. The MH-LEACH-1R Static loses a member just if the new chosen CH has coverage greater than the radius with another member. Whereas, the MH-LEACH-1R Mobile has less connectivity which produces a lot number of isolated sensors.

Conclusion of the 1st scenario:

Finally, After showing the results of this scenario that compares the MH-LEACH-1R protocol in both cases static and mobile, we conclude that the mobility affects the performance of this protocol in different terms. So, our objective is to enhance this protocol in order to adapt with the mobility and obtain good results.

4.6.2. The 2nd scenario:

4.6.2.1. Number of rounds:

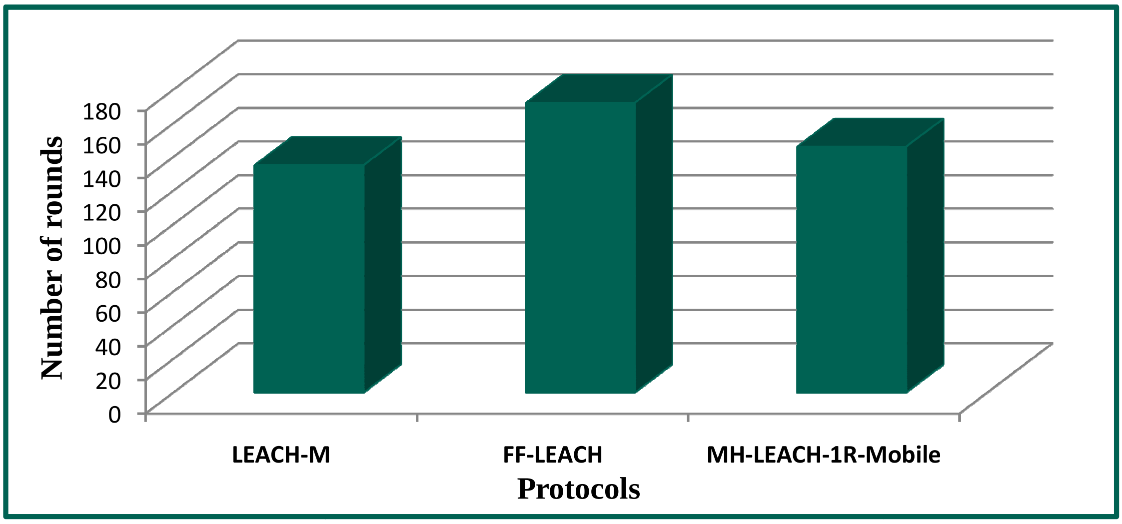

Figure 4.14: Comparison of the lifetime of each protocol.

We observed in Figure 4.14 that the FF-LEACH protocol has higher number of rounds as compared to the others protocols. This is due the best clustering which does not change the CH only after running out of energy for certain period which lead to less control packets and the isolated sensor can join new CH just after one frame, unlike LEACH-M which makes clustering at each round so consuming more energy. On the other hand, MH-LEACH-1R has more rounds than LEACH-M because this protocol loses its members so the CHs consume less energy.

4.6.2.2. Lost packets:

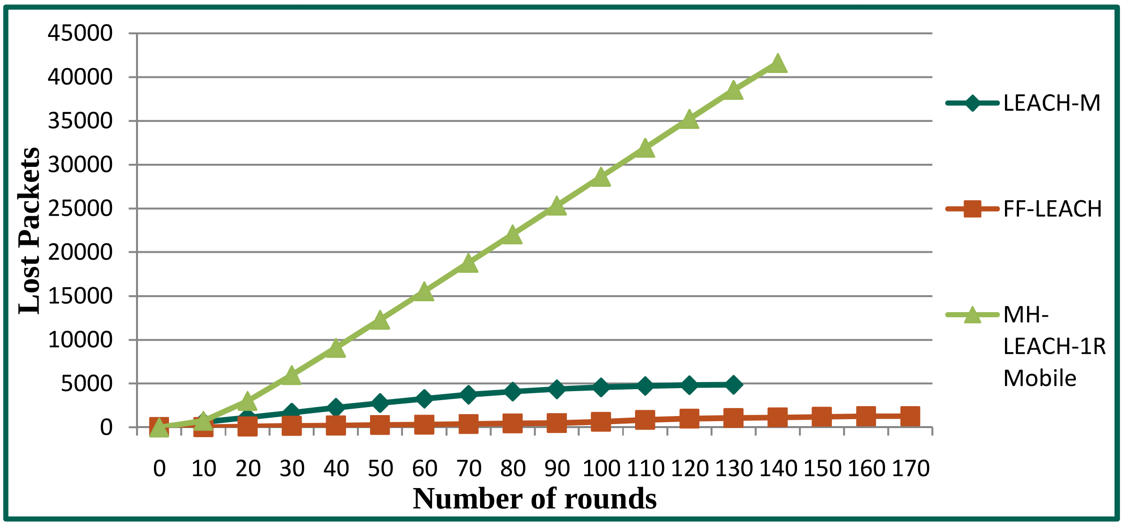

Figure 4.15: Comparison of No. of lost packets versus No. of rounds.

Figure 4.15 presents the amount of lost packets versus the number of rounds for the three protocols. We observed that the FF-LEACH protocol has less number of lost packets when compared to the two other protocols. This is due to the best clustering which maintain the same members when the sensors moved within the range of the same cluster, the protocol loses just one packet when the sensor moved out of cluster and its location is near to other CHs, also the strategy of multi-hop make this protocol more efficient. However, it is clearly seen that MH-LEACH-1R Mobile has more lost packets than LEACH-M because MH-LEACH-1R Mobile does not send any new join Req to other CHs if the sensor moved out of cluster.

4.6.2.3. Control packets:

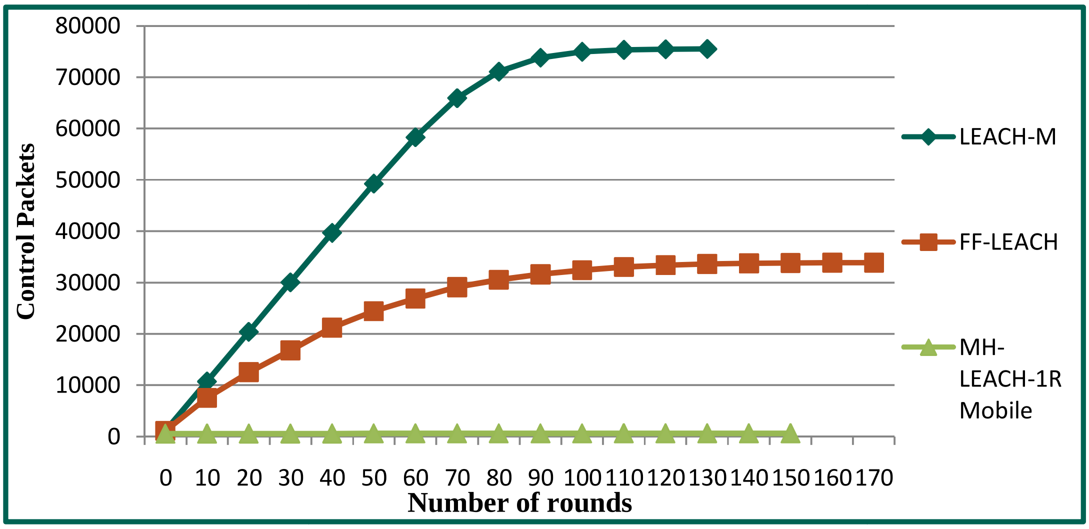

Figure 4.16: Comparison of No. of control packets versus No. of rounds.

Figure 4.16 presents the number of control packets against the number of rounds for the three protocols. The simulations show that LEACH-M has a large amount of control packets because of the clustering in each round and the isolated sensors which send join Req after each two consequent frame. FF-LEACH protocol stands between the two other protocols, MH-LEACH-1RMobile and LEACH-M which maintain the same members in each cluster for a certain period and send join Req if the sensor is isolated.

4.6.2.4. Data delivery to CHs:

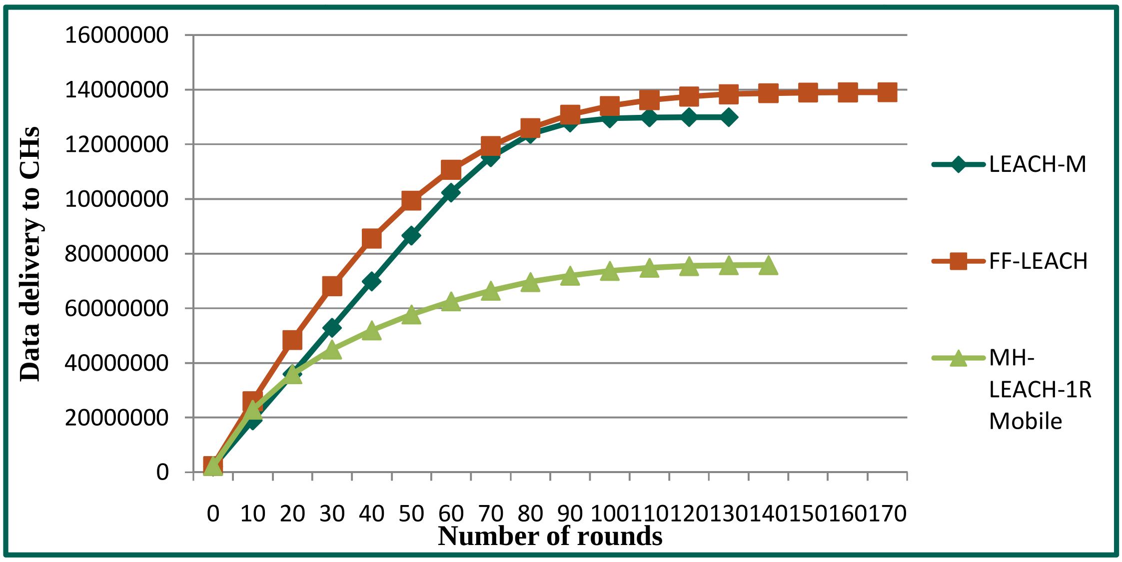

Figure 4.17: Comparison of the data received by CHs versus No. of rounds.

Figure 4.17 presents the amount of data delivery to CHs versus the number of rounds for the three protocols. As we show the FF-LEACH protocol has more data delivery to CHs. This is due to the period which maintains the same CH which means the same members, and the isolated sensor can join the cluster just after one frame without receiving Req to send data.MH-LEACH-1R Mobile has less data because the cluster loses its members.

4.6.2.5. Data delivery to BS:

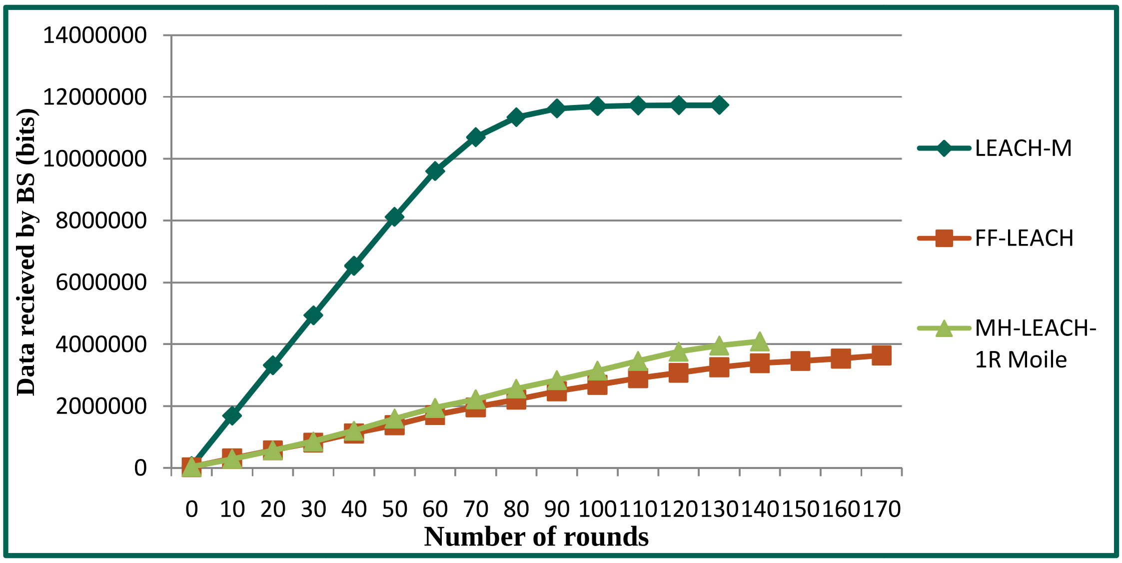

Figure 4.18: Comparison of the data received by BS versus No. of rounds.

Figure 4.18 presents the amount of data delivery to CHs versus the number of rounds for the three protocols. Results show that LEACH-M has more data delivery to BS because of the clustering in each round. So, the isolated sensors have chance to be CHs and due to the mobility the nodes become very near to BS. Unlike the FF-LEACH and MH-LEACH-1R-Mobile protocols which maintains the same members especially when the sensors moved in the same cluster and aggregate the data.

So, the delivery of more data to the sink does not mean that this protocol is better .That is why, the FF-LEACH protocol is better than LEACH-M and MH-LEACH-1R-Mobile protocols.

4.6.2.6. Residual energy:

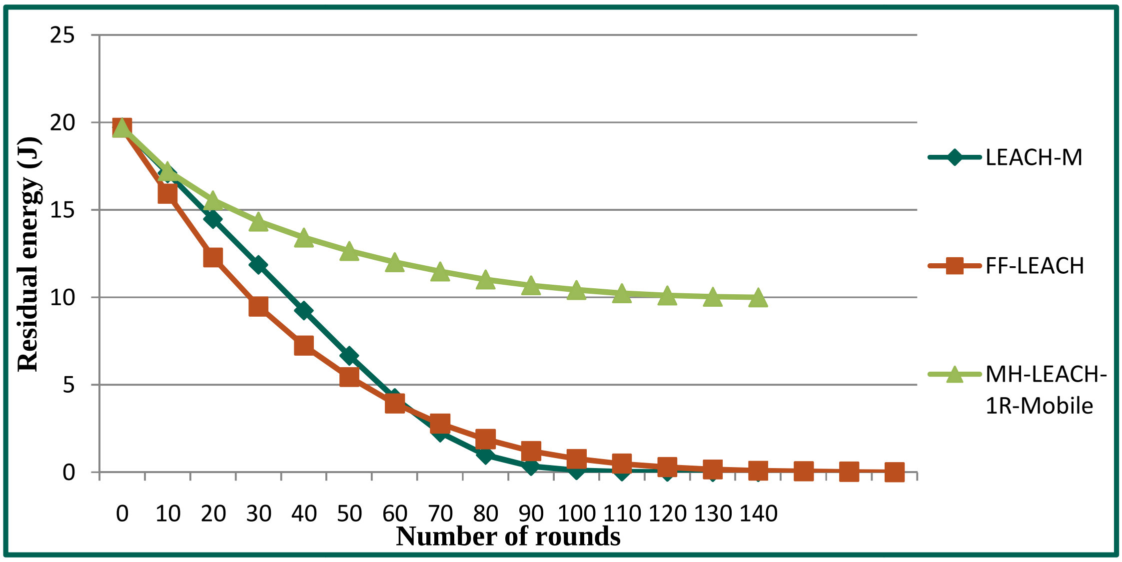

Figure 4.19: Comparison of the residual energy versus No. of rounds.

Figure 4.19 presents the residual energy versus number of rounds for the three protocols. All protocols showed a gradual decrease of energy, but FF-LEACH protocol has a regular decrease with the number of rounds until round 172 because it maintains the same members in each cluster for a certain period and a new CH is selected only if the current one ran out of energy, unlike the LEACH-M protocol which usually changes the clusters. This change leads to more control packets, so more energy is consumed. The MH-LEACH-1R-Mobile protocol has half the initial energy after the 146 round because the network has no CHs, so the life time of the network is expired.

4.6.2.7. Live Nodes:

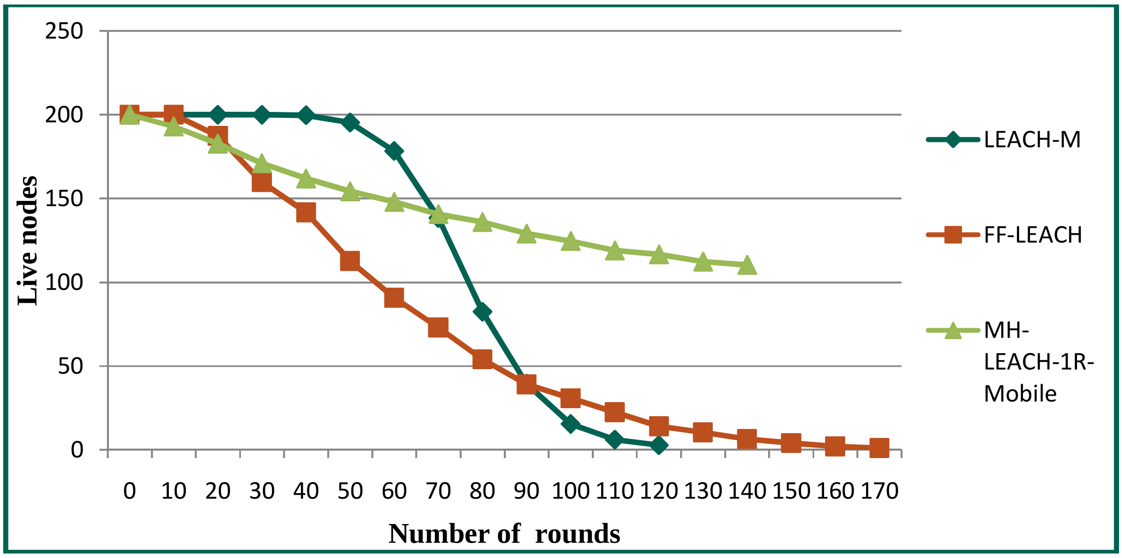

Figure 4.20: Comparison of the alive nodes versus No. of rounds.

Figure 4.20 presents the number of nodes that remain alive over the simulation round for the three protocols. We observed that after the first 10 rounds the number of live nodes for MH-LEACH-1R-Mobile protocol decreases because it has not changed the CH only after it runs out of energy. Due the mechanism of selection of CHs and the amount of data delivery to CHs, FF-LEACH protocol shows an early decrease after 20 rounds as compared to LEACH-M protocol. As illustrated in this figure, the nodes died rapidly for LEACH-M protocol after the round 80 because of the equal chance for all nodes to become CHs.

4.6.2.8. First dead node:

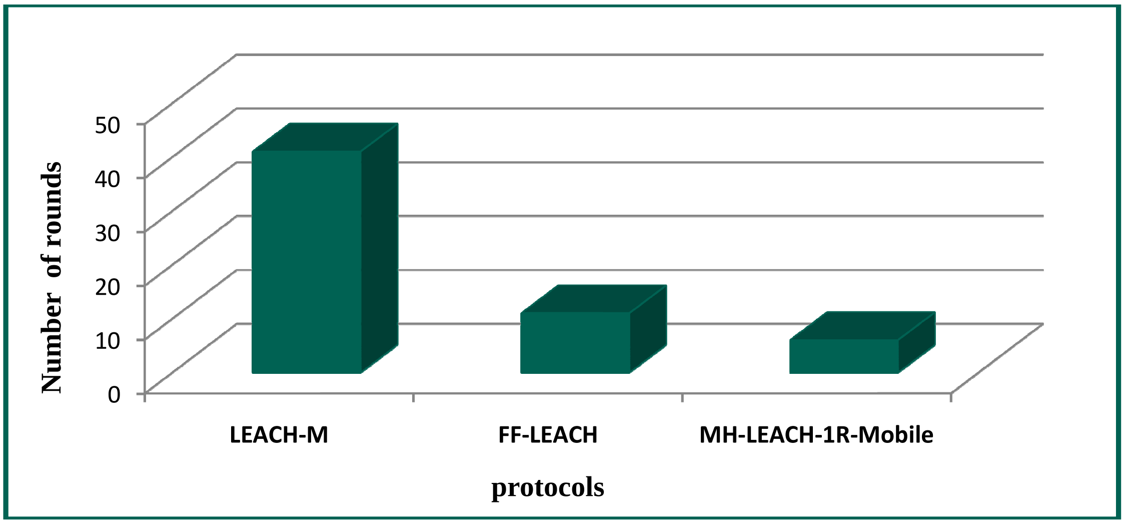

Figure 4.21: The first dead node though the simulation rounds.

Figure 4.21 presents the first dead node dies through the simulation rounds for the three protocols. Results show that MH-LEACH-1R Mobile is the first protocol losing the first node because this protocol does not change the CH only after running out of energy, so the first dead node is the cluster head itself. However, FF-LEACH protocol is twice better than MH-LEACH-1R Mobile due re-clustering method after certain period. On the other hand, LEACH-M is four-tiles better than FF-LEACH relative to this metric because of LEACH-M re-clustering in each round.

All this does not reflect the reality of the performance of protocols, because at the end of simulation (Figure 4.14), FF-LEACH and MH-LEACH-1R protocols have more lifetime than LEACH-M.

<u>Conclusion of the 2nd scenario:</u>

After this simulation, we conclude that:

- The number of round does not reflect the reality of the lifetime of the network if the application is of real time type, because there is a protocol that has large lifetime, but it suffers from rounds without any information, i.e., all packets loss due to the mobility.
- The protocol with less lost packets is better because the mobile wireless sensor networks (MWSNs) are one of the very important technology that is used for communications due to their characteristics and to their great number of real-time applications. So, we need the information in time.

4.6.3. The 3rd scenario:

✓ **Part one:**

4.6.3.1. Number of rounds:

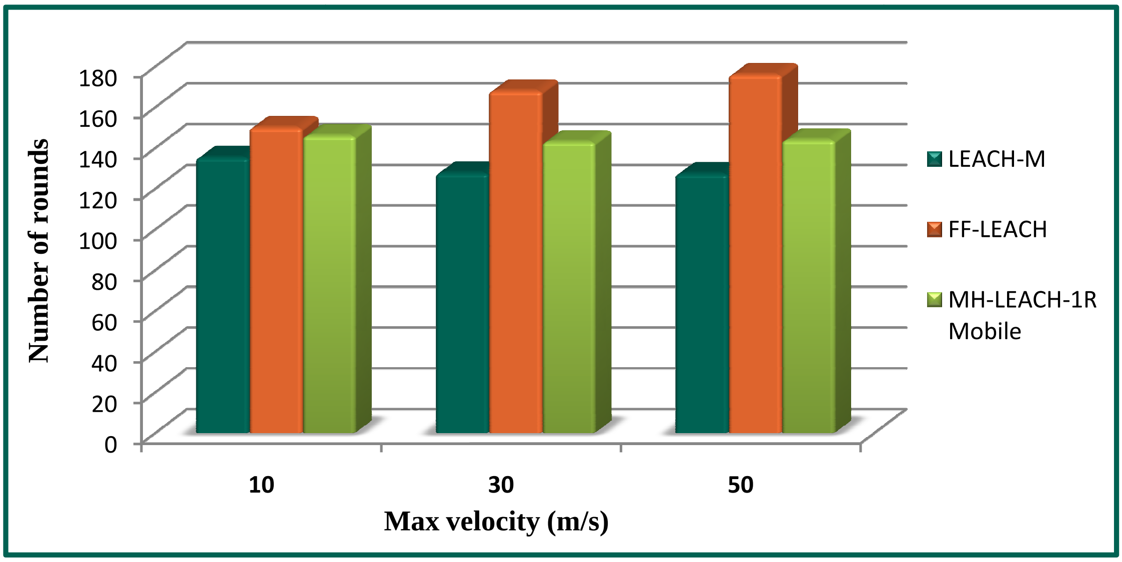

Figure 4.22: Comparison of the lifetime of each protocol.

Figure 4.22 presents the number of rounds of each protocol against the increase of velocity. We observed that FF-LEACH protocol has higher number of rounds as compared to the others protocols, and MH-LEACH-1R Mobile protocol has more lifetime than LEACH-M protocol because when the velocity increases, MH-LEACH-1R Mobile protocol loses its members quickly so the cluster maintains just few members which consume less energy. The number of rounds in LEACH-M protocol decreases with the increase of velocity due to the large amount of control packets (sensors located far from the CHs).

4.6.3.2. Control packets:

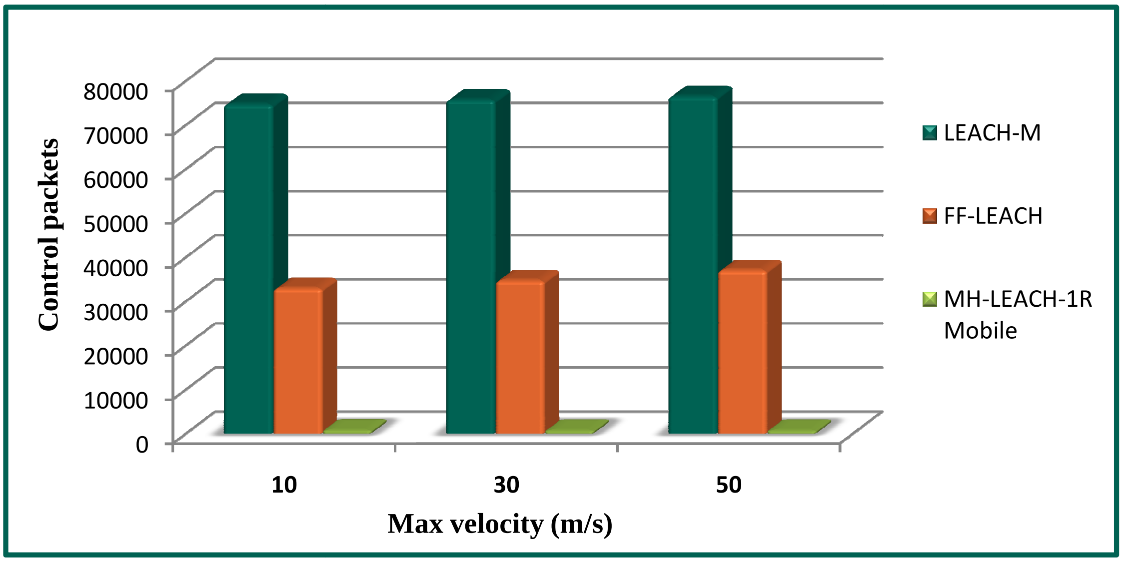

Figure 4.23: Comparison of No. of control packets against the max velocity.

Figure 4.23 presents the number of control packets versus the velocity for the three protocols. It is clearly seen that the LEACH-M protocols has more control packets due to the clustering method and the isolated nodes which try to join CHs after two consecutive frames. However, FF-LEACH protocol has more control packets when compared to MH-LEACH-1R Mobile because of the new joins to new CHs and re-clustering after certain period.

4.6.3.3. Lost packets:

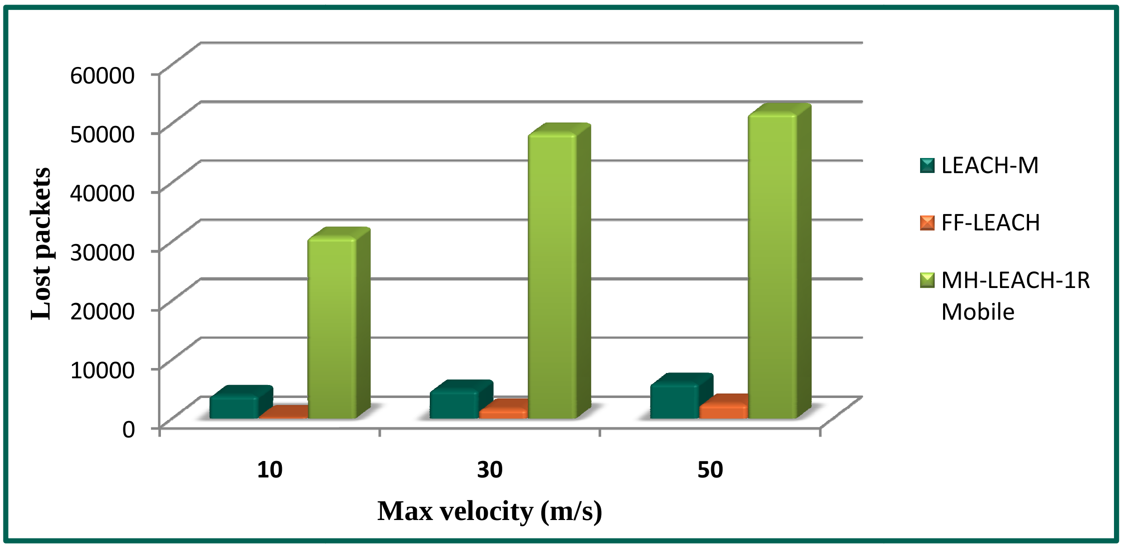

Figure 4.24: Comparison of No. of lost packets against Max velocity.

Figure 4.24 presents the amount of lost packets versus the increase of velocity for the three protocols. The results show that FF-LEACH protocol has less lost packets than LEACH-M and MH-LEACH-1R Mobile protocols. This is due to the Multi-hop and the best clustering which maintains and allows the isolated sensor to join CHs just after one frame. In addition, the number of lost packets increases with the increase of velocity for the three protocols especially for MH-LEACH-1R Mobile because the members quickly leave their clusters and stay far from them.

- ✓ **Part two:**

4.6.3.4. Number of rounds:

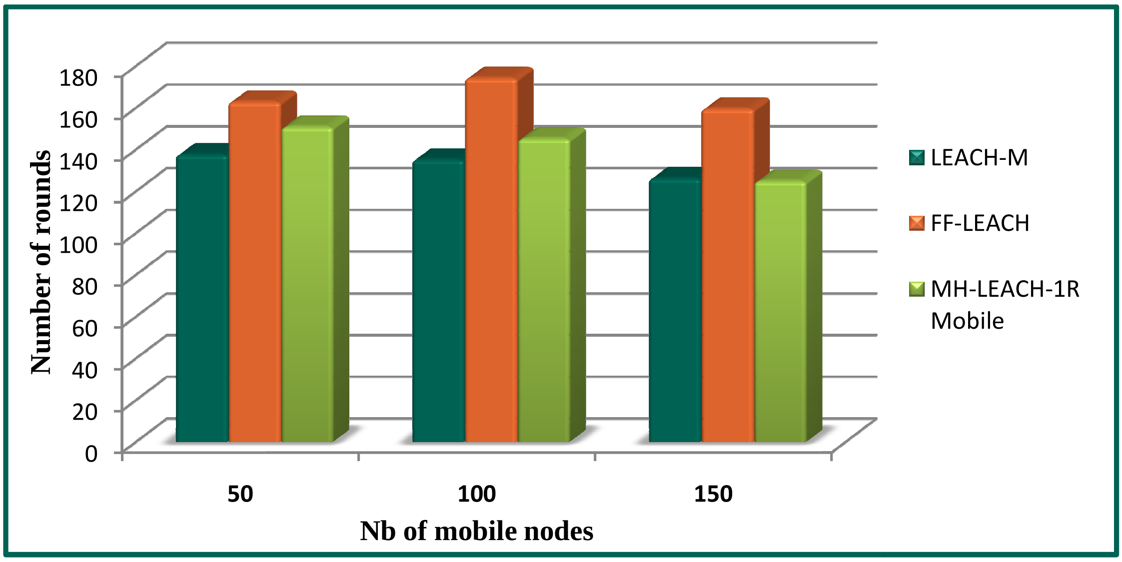

Figure 4.25: Comparison of the lifetime of each protocol.

Figure 4.25 presents the number of rounds of each protocol against the number of mobile nodes. We observed that FF-LEACH protocol has higher number of rounds as compared to the others protocols, but the increase of mobile nodes can either increase the lifetime or decrease it based on members being still in the range of cluster or located far away. The lifetime of MH-LEACH-1R Mobile protocol decreases with the increase of mobile nodes due to the large ratio of nodes that leaves the cluster.

4.6.3.5. Control packets:

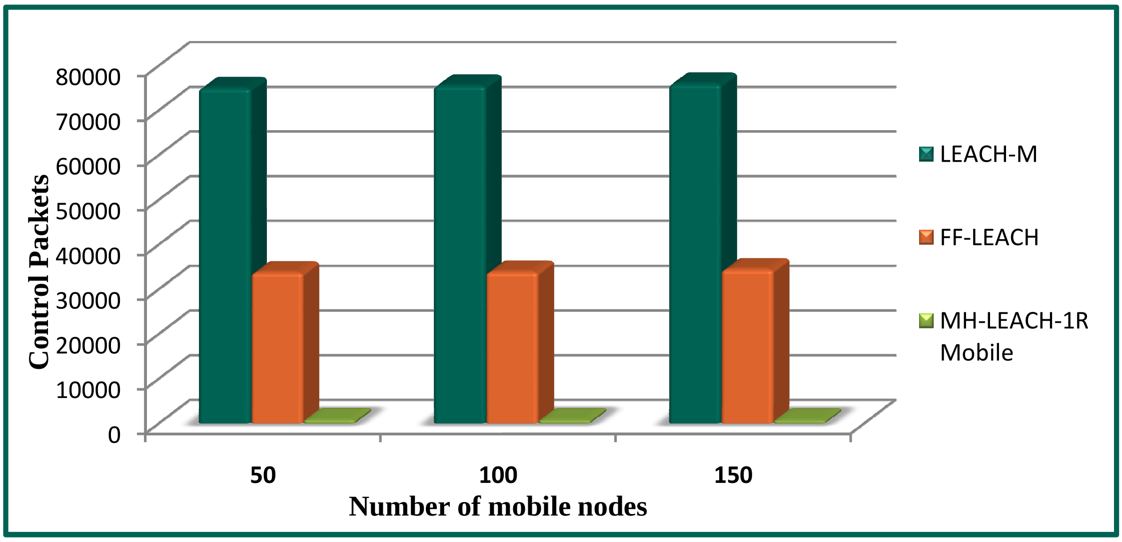

Figure 4.26: Comparison of No. of control packets against Nb. of mobile nodes.

Figure 4.26 presents the number of control packets versus the increase of the number of mobile nodes for the three protocols. Results show that MH-LEACH-1R Mobile has less control packets because the sensors quickly leave the cluster especially if the coverage radius is small. However, FF-LEACH and LEACH-M have almost the same number of control packets with the increase of the number of mobile nodes due to the clustering method in each round for LEACH-M and the re-clustering after certain period for FF-LEACH.

4.6.3.6. Lost packets:

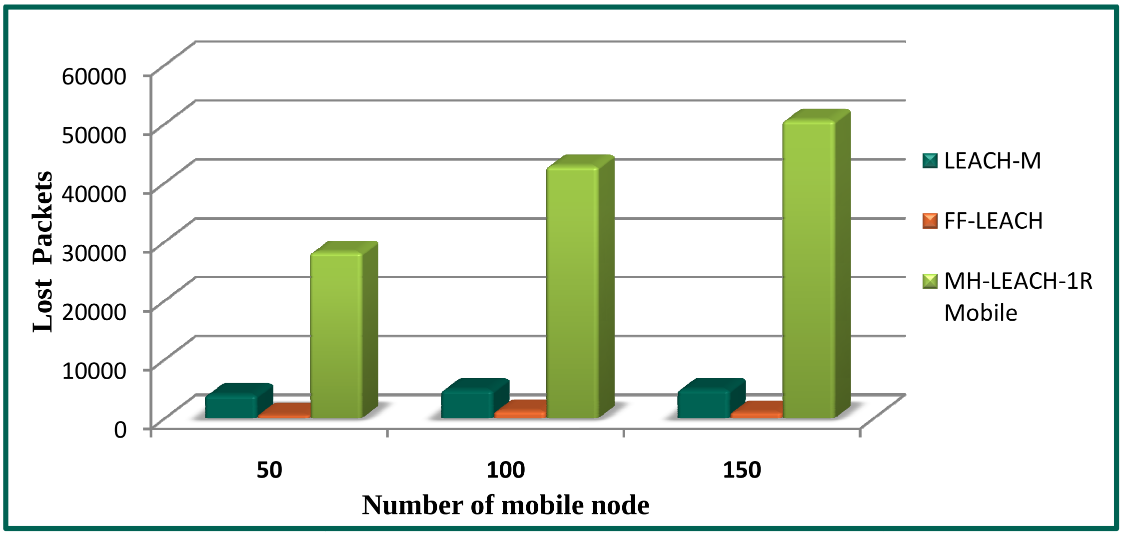

Figure 4.27: Comparison of No. of lost packets against Nb. of mobile nodes.

Figure 4.27 presents the amount of lost packets versus the increase the number of mobile nodes for the three protocols. The results show that FF-LEACH protocol has less lost packets than LEACH-M and MH-LEACH-1R Mobile protocols. This is due to the best clustering which maintains the same members and allows the isolated and moving sensors to join CHs just after one frame and the multi-hop which make in consideration the residual energy of CHs. It is clearly seen that MH-LEACH-1R Mobile has more lost packets because a large number of the members of cluster leave the cluster quickly and stay far from the CHs or the CH itself moved out the cluster and loses all of its members.

Conclusion of the 3rd scenario:

At the end of simulation, we conclude that:

- The velocity and the number of mobile nodes can improve the lifetime of the network; either if the sensors get closer to the CHs or CHs get closer to the BS which leads to less energy to transmit data.
- The increase of velocity and the number of mobile nodes increase the number of the lost packets due to the change of clusters.

4.7. Conclusion:

At the end of this chapter, and after the simulation of the three scenarios we conclude that mobility can improve the lifetime of the two protocols FF-LEACH and MH-LEACH-1R Mobile, but LEACH-M leads to more control packets especially after the increase of velocity or the number of mobile nodes, i.e., the nodes can get far from their CHs. Due to the single hop LEACH-M needed more energy to transmit data. We take the number of round in consideration if the application is not a real time. Otherwise, we take the number of rounds and number of lost packets in the same time.

FF-LEACH performed better than MH-LEACH-1R Mobile in term of lost packets due to the method of clustering which maintain the connectivity of the network and the multi-hop that takes in consideration the residual energy of CHs. In term of data delivery to CHs, FF-LEACH is better than the two other protocols because it maintains the same members especially if the velocity is low. However, in term of data delivery to BS, FF-LEACH protocol performed well because it has more data delivery to CHs and less to BS which means that it has the best clustering and data aggregation.

Currently, Mobile wireless sensor networks (MWSNs) are one of very important technology and are very dynamic research area where enhancements are constantly being sought, adding to their applications are very numerous and diverse, but the major problems in MWSNs are the conservation of the energy and the connectivity of the network.

In the first part of this these, different routing protocols have been evaluated (LEACH-M, FF-LEACH, and MH-LEACH-1R Mobile) in MWSN. These routing protocols are compared using MATLAB environment on Windows7. The comparison is based on the number of control packets, lost packets number of rounds, live nodes, data delivery to CHs, to the base station and the residual energy in each round. We conducted three different scenarios with different parameters.

Performance of each protocol has been analyzed and evaluated in each scenario. Our simulation results indicate that the mobility affects the performance of MH-LEACH-1R protocol in different terms. In the two other scenarios, FF-LEACH has the best performance in almost all metrics due to the best clustering and the efficient multi-hop properties inspired from the firefly algorithm which takes in consideration the residual energy. On the other hand, MH-LEACH-1R Mobile protocol does not support mobility and has more lost packets because of the large number of sensors which moved out of clusters especially if velocity or the number of mobile nodes is high.

As a future work, we may consider implementing other routing protocols in mobile wireless sensor networks and enhance them to produce more attractive and compelling protocols with both MWSNs and WSNs. This can be performed depending on the application requirements such as the mobile sink, both sensor nodes and sink are mobile, and multiple sinks etc. Thus more research work needs to be done in the future to find the respective application scenarios for our proposed protocol with all the related factors taken into consideration, as well as making a large study on the buffering of data when the sensors were isolated or moved.

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