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An Empirical Study of Multi-instance RPL Protocol

دراسة تجريبيه لبروتكول RPL متعدد التوجيه

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Authorization

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Zainab Al _Assedi

The Researcher

Dedication

Praise is to God, May He is glorified and exalted, praiseworthy of the majesty of His face and the greatness of His authority, and to Him is all praise, and to Him is the grace, and blessings and peace be upon the Prophet Muhammad and his good and pure family.

After God Almighty succeeded me in completing this work, I can only prostrate to God Almighty in recognition of his grace to me, praising him for his blessings on me, hoping for pardon, forgiveness, guidance and success.

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Zainab. Al-Assedi

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Abbreviations	Meanings
LOWPAN	Low Power Area Network
RFID	Radio Frequency Identification Group
MRHOF	Minimum Rank Objective Function with Hysteresis
MRHOF0	Minimum Rank Objective Function Zero with Hysteresis
OCP	Objective Code Point
C-RPL	Cooperative between Instances Of RPL
DODAGs	Destination Oriented Directed Acyclic Graphs
DAG	Directed Acyclic Graph
DODAG	Destination Oriented Directed Acyclic Graph
DIS	DODAG Information Solicitation
DIO	DODAG Information Object
DAO	Destination Advertisement Object
RPL	Routing Protocol for LLN
OF	Objective Function
IoT	Internet Of Things
LLN	Low Power and Loss Network
QOS	Quality Of Service
WSN	Wireless Sensor Network
PDR	Packet Delivery Ratio
OF0	Objective Function Zero
EXT	Expected Transmission Count
PDR	Packet Delivery Ratio
RPL	Routing Protocol for Low Power and Loss Network

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Abstract

Wireless Sensor Network (WSN) technology is used to support service delivery in various real-life application such as the medical section. The routing protocol for Low Power and Loss Network (RPL) is outlined to serve a suitable routing protocol for packets in WSN. There are many important issues in the RPL protocol like packet loss within the WSN and sensor power consumption. Various Objective Functions (OF) in RPL aimed to find the routes from source nodes to a destination node. In this thesis, we will provide an evaluation to find which OF is more logical for a WSN in the medical section where the Packet Delivery Ratio (PDR) of WSN and the sensors' power consumption are important concerns. Expected transmission Count (ETX) and Objective Function Zero (OF0) of RPL were experienced in multiple network densities and network topologies such as the grid and random topology to determine the most effective objective function of WSN design in the medical section.

The experiments were design to compare single instance RPL and multi-instance RPL to specify the most effective in WSN in terms of power consumption and the rate of packet delivery and an average of latency time. The experiments were conducted in the Cooja simulator, where the WSN network consists of a group of twenty-five nodes. The nodes are distributed in the network forming two topologies; random and grid. The simulation results showed that the OF0 is more efficient regarding the PDR and power consumption compared to the ETX in random topology. In additions, the PDR value is better in OF0 function and power consumption, the average of latency time has a large difference between single and multi-instance RPL protocol as well as the effect by the network density and RX values.

Keywords: RPL, WSN, Multi-instance, ETX, OF0.

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المُلخص

تُستخدم تقنية شبكة الاستشعار اللاسلكية (WSN) لدعم عملية تقديم الخدمات في العديد من التطبيقات منها الحقل الطبي. وقد تم طرح العديد من البروتوكولات لتلائم العمل في مثل هذه الشبكات، ومن أهمها كان بروتوكول RPL. هذا البروتوكول يعاني من العديد من نقاط الضعف والتي فقدانن الحزم في الشبكة واستنزاف طاقة المستشعرات. تهدف وظائف الهدف المختلفة في بروتوكول (RPL) إلى إيجاد المسارات من المصدر إلى الهدف. سنقدم في هذه الأطروحة تقييماً حول معرفة أكثر وظائف الهدف بالنسبة لشبكة الاستشعار في القسم الطبي، حيث تكون نسبة توصيل الحزم (PDR) واستهلاك طاقة أجهزة الاستشعار لشبكة الاستشعار من أهم المشاكل التي يجب الانتبهاه لها عند تصميم الشبكات في الحلق الطبي. تم تجربة وظائف الهدف منها احتساب الوقت المتوق لارسال الحزم (ETX) والوظيفة الغرضية الصفرية (OF0) في الشبكات متباينة الكثافة وطوبولوجيا الشبكة الثابتة والطوبولوجيا العشوائية، لتحديد وظيفة الهدف الأكثر فعالية الخاصة بتصميم شبكة (WSN) في التطبيقات الطبية.

في هذا الرساله قمنا بالعديد من التجارب لمقارنة بروتوكول (RPL) احادي ومتعدد التوجية من أجل تحديد ايها الأكثر فعالية في شبكة (WSN) من ناحية استهلاك الطاقة، ومعدل تسليم الحزم، بالإضافة إلى متوسط وقت الاستجابة. تم إجراء التجارب باستخدام Coooja، حيث تتكون شبكة (WSN) من خمسة وعشرين عقدة تتوزع في الشبكة على شكل طوبولوجيا عشوائية وطوبولوجيا ثابتة. اظهرت نتائج التجارب أن الوظيفة الغرضية الصفرية (OF0) أكثر كفاءة فيما يتعلق ببروتوكول (RPL) واستهلاك الطاقة مقارنة بعدد الإرسال المتوقع (ETX) في الطوبولوجيا العشوائية. بالإضافة إلى أن نسبة توزيع الحزم (PDR) أفضل في الوظيفة الغرضية الصفرية واستهلاك الطاقة. حيث يتميز متوسط وقت الاستجابة بالاختلاف بين بروتوكول (RPL) الفردي ومتعدد التوجيه بالإضافة إلى تأثير كثافة الشبكة.

الكلمات المفتاحية: متعدد التوجيه، بروتوكول RPL.

Chapter One

Introduction

1.1 Introduction

Recently, the Internet of things (IoT) has a potential future and a wide range of applications; such as smart transportations, such as smart grids and smart cities etc. (Sebastian and Sivagurunathan, 2018). The definition of the Internet of things has been proposed by several different groups; such as the Cluster of European Research Projects and Radio Frequency Identification Group RFID (Bélissent, 2010). Thus, the Internet of Things was defined as a group of connected tools by the Internet for the purpose of data exchange and interaction.

While the internet of things is defined in the smart environment as follows: "The interconnection of sensing and actuating devices for providing the ability to share the information across platforms through a unified framework, and developing a common operating design for enabling innovative applications, all this is achieved by seamless large-scale sensing, data analytics and information representation using cutting edge ubiquitous sensing and cloud computing.

There are many challenges facing wireless sensor networks WSN, the network is not lost and saving power to the nodes in the event that nodes are spread in sparse places. Therefore, developing routing protocols for network low power and lossy network LLN is one of the main aspects that must be focused on (Q. Le and Ngo-quynh, 2014).

To overcome these challenges, many studies were conducted by researchers, the most important of which is the RPL Protocol, deducing that the Internet of Things communication depends mainly on the RPL protocol. "IPv6 Routing Protocol for Low Power and Loss Network" (Clausen, Herberg and Philipp, 2011). The RPL routing protocol is used in over low power area network 6LoWPAN, and 6LoWPAN is considered one of the applications of wireless sensor networks. WSN which uses the internet protocol IPv6 to sensor addressing (Pradeska, Najib and Kusumawardani, 2016).

In previous studies, the use of single instance RPL protocol was proved to be ineffective in terms of high latency and low packet delivery ratio PDR. Therefore, in this work, multiple instances of the RPL protocol, which is one of the routing protocols used in IOT networks and based on IEEE 802.15, will be used. The objective functions in the RPL protocol, which are defined as the mechanism by which path is chosen when across networks, are formed are developed by two types. This research will focus on comparing and evaluating performance between two objective functions of the RPL protocol, namely objective function zero OF0 and expected transmission count ETX.

1.2 Problem Statement

The previous studies have described the use of a single instance of the RPL protocol, and the performance of the protocol was characterized by high latency, and low packet delivery ratio (PDR). The reason for this is the use of one instance of the RPL protocol will not be realistic to represent all nodes that produce different data operations, because all nodes will be treated as if they have the same goals and the same characteristics to be achieved. To solve these obstacles, the multiple instances of the RPL protocol will be done of use.

The ipv6 routing protocol for low power and loss network RPL is one of the routing protocols that are used to route packets in wireless sensor networks, and it is a critical factor affecting information exchange and communication between different wireless sensors. The overall performance of a low-power network and LLN network loss is on choosing the appropriate routing protocol and the quality of its implementation.

The development of the wireless network is a result of people's requirements to connect and benefit from technologies. Wireless sensor networks are considered an example of these networks where a great number of small devices connecting with their environment might be inter-networked together and accessible via the Internet. While these devices might be distributed in a random way, a routing protocol is required protocol is the typical protocol for IPv6-based multi-hop WSN. IP address is utilized to determine the routing IP packets to another network. It is included in the packet header to specify the source and the target of each packet. It is worth mentioning that IPv6 address is used to indicate and detect a network node cooperating in an computer network utilizing IPv6 or a network interface of a computer.

Thus, controlling some factors plays an important role in the performance of routing protocols; such as controlling the packet delivery ratio, convergence time, power consumption and control traffic overhead. Therefore, the performance comparison between OF0 and ETX function will be evaluated for the purpose of proving its effectiveness in terms of packet delivery ratio, latency time, power consumption and control traffic overhead. In order to achieve this purpose, Cooja simulator is used, which means the comparison is based on a number of stated goals and to indicate which of these functions is the best for improving network reliability.

1.3 Research Questions

1. What is the impact of using multi-instance and single-instance RPL protocol on the requirements and conditions of wireless sensor networks, in terms of packet delivery ratio, latency time, and power consumption.

2. How the two objective functions OF0 and ETX affected by multi-instance RPL protocol.

3. How could the packet delivery ratio, latency time and power consumption be effected by multi-instance RPL protocol.

1.4 Goal and Objectives

The aim of this study is:

1- Demonstrate the efficiency of the multi-instance RPL protocol, by using the OF0 and ETX functions for the purpose of clarifying the difference between them.

2- Determine which objective function is better regarding packet delivery ratio, latency time, power consumption and packet delivery ratio.

1.5 Motivation

In order to choose the best protocol for RPL, a broad and accurate comparison of all elements and functions within the WSN will be made. After that, the best design suits the network can be chosen. In this research, a comprehensive study of this topic will be conducted, and a comparison will be made between OF0 and ETX functions; in terms of packet delivery ratio, latency time, power consumption. Thus, the best function that improves network reliability can be determined.

1.6 Contribution and Significance of Research

A comparison between the different functions related to the RPL protocol in terms of the single and multi-instance RPL protocol will be made, which includes the OF0 and ETX. Consequently, after conducting the experiments in terms of the percentage of package delivery and latency time, power consumption, determining which is better between the OF0 and the ETX. The functions will be checked by making sure that they are working properly, therefore improving the network reliability of the multi-instance.

The RPL protocol will be relied on to design the multi-instance network and prove its effectiveness.

1.7 Thesis Outline

Chapter 1 provided a general introduction to Multi-instance RPL protocol. The research problem, objectives, and scope are also discussed. The rest of this thesis is organized as follows:

Chapter 2 introduces a background Multi-instance RPL protocol. Also, it presents comprehensive details on the fundamentals of simulation. Numerous studies and recent related works are discussed thoroughly.

Chapter 3 discusses the proposed methodology and illustrates the proposed architecture.

Chapter4 details a complete discussion of the simulation scenarios and the results of the proposed algorithms.

Chapter5 concludes the thesis by summarizing the findings and how they relate to the research problem and objectives. It also outlines the possible directions that could expand this research work in the future.

Chapter Two

Literature Review and the Related Research Works

2.1 Overview

Chapter two provides a brief background of RPL protocol, and it re-views the recent works studied RPL protocol but focusing on the multi-instance RPL has utilized in medical applications. Section 2.2 discusses the WSN. Section 2.3 presents a routing protocol overview .and section 2.4 RPL objective functions. And Section 2.5 reviews the recent research works applied.

2.2 Introduction

Wireless Sensor Network(WSN) can also be defined as a set of sensors that are used to transmit or follow a specific physical phenomenon; such as temperature, humidity, or length ...etc. (Ullo, Liberata, and Sinha,2020). And then, transfer the information about the phenomenon wirelessly to the data processing center to take advantage of this data without the need for the human being within the place of the physical phenomenon. Sensors send data through wireless sensor networks; such as networks sensor.

These networks are used for military surveillance, traffic monitoring, control, maritime transport, and military affairs. Notwithstanding the development of this technology, there are still many problems that face the wireless sensor networks; such as the lack of reliability of wireless communication systems, limited power, and contract failure. The sensor network consists of three elements; the sensors, the user, and the sensing bodies. Usually, WSN network can be defined as a network of nodes that work cooperatively to sense the surrounding environment around them and control them. As these nodes are not linked via wired media, they use wireless communication to communicate with the network and other nodes in IOT network (Mustafa Kocakulak and Ismail Butun, 2017).

There are several protocols operating within the wire sensor network; such as the RPL with several protocols, such as IPv4 and OSI. RPL is a routing protocol for WSN with low power consumption and generally susceptible to packet loss. It is not only a proactive protocol based on distance vectors and, optimized for multi-hop and many-to-one communication, but also supports one-to-one messages.

RPL is, also, the de facto WSN routing protocol for communications where it operates by discovering routes as soon as it becomes operational. (David Airehrour and Jairo Gutierrez, 2018). Moreover, the WSN effectively and easily enables humans to control things from close and distance, consequently communicate with physical objects; such as a car, a computer, and many different programs. And this is called the primitive form of the WSN.

2.3 WSN Topology Overview

The network topology is defined as the way in which the nodes and links within the network are arranged to correspond with each other (Groth, David,and Skandier ,2005). The network topology is a mediator for the transmission of physical signals. And, it is the way in which data travels across the network between devices regardless of the physical connection of the devices. And since there are many examples of physical networks topology; such as star, tree, ring, circular and point to point networks, and each of them consisting of different of nodes and links. There are different network topologies for network, but the main three topologies are described below:

1-Star Network: Star work is considered a local area network (LAN) where all the nodes are straightly connected to a common central computer. And via the central computer, every workstation is incidentally connected to each other, these connections are revealed as a straight line and might be wired or wireless links. It is worth mentioning that the star network topology operates well when workstations are at separated points. Hence, it is simple to add or remove workstation(Zhang, Zheng, and Hu,2008).

2-Tree Network : This tree topology provides a specific type of formation where the elements linked are arranged like the branches of a tree. It is used to arrange the computers in a corporate network or the information in a database. In this topology, there is a central root node the top-level of the hierarchy which is connected to one or more other nodes that are one level lower in the hierarchy the second-level and with a point-to-point link between each of the second-level nodes and the top-level central root node, also each of the second-level nodes will have one or more other nodes that are one level lower in the hierarchy the third-level connected to it. (Sosinsky, and Barrie,2009).

3-Mesh Network: In this local network topology, the fundament nodes connect straightly, effectively and non-hierarchically to as many nodes as possible and work with one another to accurately route data from/ to client. The mesh networks effectively self-organize and self-configure, so they are able to reduce installation overhead. Some of the nodes of the network are connected with a point-to-point link to more than one other node in the network, which makes it possible to take advantage of some of the redundancy that is provided by a wholly physical connected mesh topology, without the expense and complexity required for a connection between every nodes in the network. (Zhang, 2014).

2.4 Routing Protocol Overview

There are many protocols that work on the Internet of Things applications, the most important of which are routing protocols where WSN have low power consumption and are generally prone to packet loss. Moreover, as it is a proactive protocol based on distance vectors and addition, it works as an optimized for multi-hop, and many-to-one communication, and also supports individual messaging, RPL can support a variety of link layers, including those with limitations with potential losses or used in devices with limited resources, therefore this protocol can quickly create network paths and share routing.

RPL is considered a variable quantity and source routing protocol which follows the Destination oriented Directed Acyclic graph (DODAG). This protocol creates more than one RPL instances in a network and every instance includes more than one DODAG. It has two types of nodes. Storing and non-storing node, the storing node can gather and send the data to another node. As for the non-storing node, it sends the data directly to another node. RPL can assist an extensive variety of link layers together with those with limitations, with possible losses or that are used in devices with limited resources. This protocol can rapidly generate network routes, share routing knowledge and accommodate the topology in an systematic way. (Sankar, and Srinivasan,2018).

There is also a set of rules that control how to communicate with network equipment; such as routers or nodes with each other, and how to distribute information related to network topology (Le,Q& Magdanz,2014). As a result, you can choose the best path to be able to obtain information from the used and represented topology in many represented procedures in creating an RPL structure which is similar to a tree-like graph. It is called a Directed Acyclic Graph DAG or vector graph, which has the technique where all edges are oriented in such a way in which there are no turns, which means the orientation of all edges, is included in paths directed to one or more root nodes and ending at the node(Górska , and Donado ,2014).

As a result, each node within the network has what is called a rank, therefore the rank increases as it moves away from the root node Destination Oriented DAG DODAG, and then, the nodes re-send the packets using Track selection apps or messages, where the messages are controlled, in order to be classified to three messages: DIA (Dodag Information Object), DAO (Destination Advertisement Object) and DIS (Dodag Information Solicitation), therefore DISDODAG is used to request information from the nearby DODAG. Thus, the device requests a directive to discover the current networks. The second step is from DIO, as it is a message sharing information from the DAG (Sebastian A. and Sivagurunathan, 2018).

Consequently, it is sent in response to DIS messages in order to be used periodically to update the nodes information that is located in the network structure. And the last step is the DAO, which is the goal of updating to the destination. Thus, messages are sent in the direction of DODAG, which updates all contract information.

2.4.1 Single Instance RPL protocol

RPL is a routing protocol for low power WSN with low power consumption and generally susceptible to packet loss. Also, it is a protocol for distributing commands over the grid; which means RPL assures Quality of Service QoS at the network layer in wireless sensor networks through the logical subdivision of the network in multiple instances, each one relies on a specific Objective Function. (Oana Iova, Gian Picco and others, 2016).

RPL creates a topology similar to a tree called DAG, where each node within the network has an assigned rank, which increases as the teams move away from the root node DODAG. Whereas the nodes send back the packets using the lowest standard, the route is chosen through DIO DAG and DIS, where a message is sent in the direction of

DODAG; which is the message that is sent to update all information because the RPL protocol depends on two algorithms to create and depended on the routing to send messages.

In RPL, a set of nodes which are having a common objective are joined to provide what so-called: an instance. An instance can be used to represent the nodes which are generating a specific type of data traffic. Multiple RPL instances are used for supporting the performance of real-life systems. The performance is assessed using Cooja simulator in term of two key routing performance metrics: average Packet Delivery Ratio (PDR) and average latency. RPL node may belong to multiple RPL instances, It may operate as router in some and as a leaf in others. (Nassar,Gouvy, and Mitton, 2017).

The instance is a set of one or more Destination Oriented Directed Acyclic Graphs DODAGs that share one RPL Instance, which means; each RPL instance operates independently of other RPL instances and implements a different Objective Functions. Therefore, in a single instance, all information from the root to all nodes is taken into an account. A network may simultaneously run multiple instances of RPL when routing requirements differ within the same Low power and Loss Network LLN. A node can be part of only a single DODAG per RPL Instance (Sebastian A& Sivagurunathan, 2018).

2.4.2 Multi-Instance RPL Protocol

Also, in RPL, multi-overlapping DODAGs over the entire network can be used to provide different levels of QoS in the network layer. (Sidnei Junior, André Riker and others, 2020) As shown in figure 2.1, the difference between single instance and multi-instance is that each level of a DODAG is called an instance, which is a group of multiple DODAGs. The network contains more than one RPL instance; therefore the RPL node can share multi-instance RPL. Each RPL instance works independently from the other

RPL instances where the instance consists of one or more DODAG. Also, it can participate in multiple situations to transfer different types of traffic at the same time.

Therefore, DODAG RPL identifies two types of paths depending on the trees in which the data in DODAG moves up and down, where the upward direction provides a path towards the roots of the DODAG of the nodes, and when the traffic is down to the roots as shown in figure 2.1.

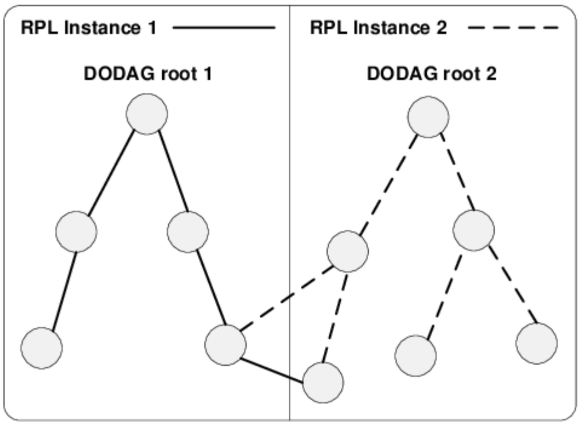

Figure 2.1 DODAG in Tow Instance.

2.4.3 Dynamic Multi-instance RPL Protocol

As it is a process that takes place through the router, it is based on redirecting the data through different paths or a specific destination based on the current conditions of the communication circuits within the system, and it can also direct the network about the damages; such as loss of nodes or communication between nodes. These damages can be skipped if there are other available nodes. Therefore, dynamic routing allows as many paths as possible to remain valid in response to any change. If there is information sent through a DIS DAG, it works with all nodes and uses fixed routing. And in the case of a loss of communication between the nodes, it takes different paths to vanish the failure between the nodes.

2.5 Objective Functions of RPL

The Objective Function OF is used by RPL to specify how the routing metric and constraints should be used to reach specific objectives. For example, the OF may specify that the objective is to find the constrained shortest path where the constraint is related to the node power mode (T. Winter, Thubert, 2012). Whereas there are several target functions; such as EXT, OF0 Objective Function Zero, OF Objective Function, MRHOF Minimum Rank Objective Function with Hysteresis, MRHOF0 and Minimum Rank Objective Function Zero with Hysteresis. Therefore, OF0 and EXT will be used in this thesis.

2.5.1 Objective Function Zero

OF0 is designed as a default OF that will allow interoperation between implementations in a wide spectrum of use cases. The OF0 does not specify how the link properties are transformed into a rank increase, and leaves that responsibility to the implementation rather, OF0 enforces normalized values for the rank increase of a normal link and its acceptable range, as opposed to formulating the details of its computation (P. Thubert, 2012). The Objective Function OF determines how RPL protocol contract will be selected and optimized Paths inside instance of RPL protocol. The OF is determined by the Objective Code Point OCP. OF defines how nodes translate one or more measures and constraints, and also define themselves into a value called Rank, which approaches the node distance into the root of the DODAG (T. Winter, 2012).

2.5.2 Expected Transmission Count

The ETX is defined as the expected number of transmissions required to transmit and acknowledge a packet on the link successfully (Zhang, Zheng, and Hu,2008). By which RPL allows the use of the objective functions to construct routes that optimize or constrain a routing metric on the paths. Since this specification describes ETXOF; which is an objective function that minimizes of ETX. The RPL protocol path computation uses ETXOF results in minimum-ETX paths from the nodes to the DAG roots, for instance, paths that reduce the amount of 15 packet transmissions for packet delivery from nodes in the WSN to the DAG root (O. Gnawali,, 2010). And ETX can be considered as a link metric that predicts the number of retransmissions needed for a packet to be successfully received, in order to find the best path and predicting the number of retransmissions needed to receive the packet.

2.6 Related Work

We review what the researchers previously presented in this section, and also an examination of the performance of objective RPL-based on functions and recommended metrics, which are specified for Low Power and Loss Networks.

A study by (Sidnei Junior, André Riker and others, 2020) noticed that each node has a rank based on hop-distance from the root in a DODAG, which increases by going down the tree to the root. In general, this reveals the node's individual position comparing to other nodes that taking the root as reference. The exact calculation of the rank is specified by an objective function, which can consider other aspects, such as delay, energy consumption, or path loss, RPL is designed to allow the system to create and run more than one RPL instance. Multiple instances of RPL can coexist in the network and multiple DODAGs can be constructed in each instance. The idea of multiple RPL instances comes in need of optimizing the network paths for different objective functions. The same network nodes can also run two or more instances RPL to serve a performance criterion given by an objective function. For instance, one RPL instance seeks to reduce the latency, while another instance aims to decreased energy consumption.

A multiple RPL instances for enhancing the performance of IoT-based on systems, the nature and the diversity for the types of data traffic in IoT-based on systems are the main motivations for thinking about employing multiple RPL instances in such systems, in which an instance can be used to represent the nodes which are generating a specific type of data traffic (Al-Abdi and Mohammed, 2019). The results show it that the using of multiple RPL instances improves the performance of the IoT-based systems in term of PDR and average of latency time , As well as, this thesis aims to demonstrate the efficiency of a multi-instance RPL protocol, using the Objective functions OFO and ETX for the purpose of clarifying the difference among them.

Another study by (Banh, Mai, dan .alfred, 2018) evaluated the performance of RPL by using two objective functions and two RPL instances in network layer. Where the comparison was made between single and multi-instance in term of three performance matrices: routing tree convergence, latency, and the PDR value. And the simulations were made by using the Cooja simulator with two types of data; regular data and critical data. The authors set the value of successful Reception Ratio to three values: 70%, 85%, and 100%. the routing tree convergence metric; in one hand, the results show it that using multiple instance increase the routing tree convergence time in a comparison with a single instance and multi-instance, this because every node has to join the both DAGs . Thus, the convergence time needs more time to complete the two DAGs construction. On the other hands, by using multiple instances, the performance in term of latency and PDR value is also better , and created multiple RPL instances with a cooperative between instances called (C-RPL) which organize multi-instance RPL protocol to create energy-efficient coalitions taking in account both the OF for each instance and other network characteristics. The main stone in C-RPL is what the authors called “collation”, which consists of multiple instances with a collaborative relationship between the nodes to improve their efficiencies. The authors presented a fairness analysis for networks with multiple instances to manage the tradeoff between performance and power consumption. To evaluate C-RPL, the authors made a comparison between C-RPL and RPL with different traffic using Matlab. The comparison was made between four RPL versions: RPL, (RPL II) RPL version two, C- RPL and C-RPL No Cooperation Game (C-RPL NCG). The results show that C-RPL creates instances efficiently according to the objective functions and other network conditions. In term of power consumption, CRPL always trends to consume less power by adapting the number of created instances regarding network densities. And it provides a more balanced energy consumptions and performance.

And another study by (Monowar& Basheri,2020), In healthcare system organizations such as hospitals, it is important to have an efficient healthcare monitoring system in which the patients' vital signs are collected from multiple sensors and transformed in order to the decisions makers, to be analyzed and take the appropriate actions. The IPv6 Routing Protocol for Low-Power and Loss Networks (RPL) was developed to act as an appropriate routing protocol .In the RPL, a set of nodes, which are connected and have a common objective are grouped to represent an instance, whereas advanced networks were used of the connection to decrease packet loss and decrease energy consumption. Many of nodes in the traditional network with different densities used in the study, where a comparison will be made between the two targets functions OF0 and ETX with 100 dispensers in different ways within the places allocated to them. We will be able by reducing the packet loss and power consumption after making the comparison to specific which function is better.

The developments of the standard MAC level QoS techniques are revealed with the focus on network layer QoS mechanism (Rajalingham,G., Gao,Y., Ho,QD.,and Le-Ngoc ,H.) . Clearly, the effectiveness of multiple instances of the RPL network graph, rely on distinctive objective functions, for QoS distinctiveness is investigated. According to that effect, three modifications of RPL, standard RPL, multi-instance RPL (RPL-M) and multi-instance RPL with prioritized channel backoffs (RPL-M+) Long with two distinct traffic classes have been examined as data traffic rate and composition was varied. As for the results, RPL alone cannot support the QoS requirements essential for SG AMI traffic. A single instance of the RPL graph cannot represent the statistics of multiple traffic classes, as their relative composition is varied. The RPL-M outperformed RPL-M+ with meeting all traffic class requirements.

Another study by (Sankar, and Srinivasan,2018) provided an approach to accelerate the network lifetime by reducing the node energy consumption. The aim is to provide a combination of ETX, Load and battery depletion index(BDI)based composite metric in RPL. This composite metric follows the reducible property. DODAG sends DIO control messages to all participant nodes. The participant node selects the best parent from DODAG rank. The rank calculatd from minimum value of the composite metric in the DODAG. Finally, sender or participant node sends the data to DODAG root towards the best parent in the DODAG. Thus, it improves the packet delivery ratio, reduces the traffic load and improves network lifetime. The simulation results reveal that the EL-RPL improves the network lifetime by 8-12% and packet delivery ratio 2-4%, and provides the best performance in terms of network lifetime, packet delivery ratio and end-to-end delay compared to RERBDI RPL and OF-FL RPL.

A study provided a OFQS an RPL-compliant objective function, with a multi-objective metric mOFQS that considers by design the delay and the last energy in the battery nodes alongside with the quality of the links in order to be used with the standard protocol RPL in a SG environment by (Nassar, Gouvy,and Mitton2017) . The aim is the adaption to the number of instances (traffic classes) providing a QoS differentiation based on the different Smart Grid applications requirements. Simulation results shows that OFQS achieves significant improvement in terms of End-to-End delay, network lifetime and PDR while ensuring a load balancing among the nodes, compared to MRHOF with ETX and OF0 with HC, in a multiple instances environment. It provides a low packet delivery latency and a higher packet delivery ratio while extending the lifetime of the network compared to literature solutions.

A study by **(Al-Shargabi,and Aleswid ,2020)** provided an investigational assessment of ETX and OF0 objective function of RPL to evaluate their effectiveness regarding power consumption and PDR in a healthcare scenario under different topologies. Without the engagement of human, WSN can be defined as a set of sensors that are applied in the sense of monitor specific or biochemical aspects. The recent benefits of IOT technology can be used to support service delivery in several real-life application such as the healthcare systems. The study provides an assessment to discover which OF is more efficient for a WSN in a healthcare scenario where the Packet Delivery Ratio (PDR) of WSN and the sensors' power consumption are prominent concerns. Expected transmission Count (ETX) and Objective Function Zero (OF0) of RPL were examined in various network densities and network topologies such as the grid and random topology. The simulation outcomes revealed that the OF0 is more efficient regarding the PDR and power consumption compared to the ETX in random topology. The results of experiments revealed that the OF0 is more efficient regarding the PDR with the comparable rate on power consumption as compared to ETX. Therefore, the design of a WSN in healthcare especially in ICU based on the application of the RPL protocol would be implemented based on OF0 rather than ETX where the PDR rate must be high because if it was low, patients in ICU might face a high risk or death. Moreover, in this paper, the implementation was based on one instance of RPL, as future work, we intend to investigate the use of multi-instance RPL.

Another study by (**Junior,et al. ,2020)** provided a solution called DYNAmic multiple RPL instances for multiple ioT applications (DYNASTI), which provides more dynamism and flexibility by managing multiple instances of RPL. Routing Protocol for LLNs (RPL) appeared as a routing protocol to be used in IoT scenarios where the devices have restricted resources. DYNASTI is a solution of multiple instances towards multiple applications, which aims to give a more flexible and dynamic management of multiple instances, enables the suitability of normal applications while critical applications have priorities in traffic, and coexistence between regular and sporadic applications. The results acquired by DYNASTI revealed a general efficiency enhancement for the network, since there was an enhanced optimization of resources, mostly in the contraction of the control messages and energy consumption. DYNASTI results in fewer lost applications' messages and shortest delay for critical applications compared to the state-of-the-art approach in which there is no interruption of control and application messages and scheduling of instances.

2.7 Summary

To summarize the related work in comparison with the work conducted in this thesis presented in Table 2.1.

Table 2.1 Summary of related works.

ID	Title	Year	Previous Studies	In this thesis
1	Using multiple RPL instances for enhancing the performance of IoT-based systems.	2019	This study operates to get the benefits of multiple RPL instance supporting in order to use them for optimizing Real-life systems performance where it will be evaluated using the Cooja simulator X as main steering performance.	Demonstrating the efficiency of RPL, using OFO and ETX functions to clarify the difference among them.
2	DYNASTI—Dynamic Multiple RPL Instances for Multiple IoT Applications in Smart City	2020	This paper addresses multi-instance problems; such as a lack of flexibility and dynamism in managing multiple instances and service differentiation for applications. the goal of this work is to develop a solution called Dynamic Multiple Instances RPL protocol for multiple IoT applications, which provides more dynamism and flexibility through managing multiple instances of RPL. As a result, traffic performance for multiple applications is improved through routing.	In addition to demonstrating the efficiency of RPL, and the multi-instance RPL work on enhancement for IoT network the two functions used are OF0 and ETX.
3	Towards Multi-instance QoS Efficient RPL for Smart Grid	2017	This study improves RPL smart grids since its main objective function does not allow characterization of QoS. To overcome this, we suggest OFQS as an objective function with a multi-target meter that takes into account the delay and residual energy of the battery nodes along with the quality of the links. the function automatically adapts to the number of cases (traffic categories) providing differentiation in QoS based on the requirements of different smart grid applications.	Demonstrating multi-instance RPL protocol efficiency, using OFO and ETX functions for the purpose of clarifying the difference between them, and identifying the best among OFO and ETX in terms of packet delivery ratio with multi-instance RPL. Besides, convergence time, power consumption and traffic control.

ID	Title	Year	Previous Studies	In this thesis
4	On Providing Differentiated Service and Exploiting Multi-Instance RPL for Industrial Networks that have Power Loss and Low-Power	2019	The researchers propose RPL, a multi-instance RPL solution for lost and low power and loss network LLNs. MI-RPL identifies four cases into four distinct traffic classes for industrial monitoring applications in terms of delay and reliability. MI-RPL also introduces compound steering metrics and proposes an objective function to calculate the most appropriate path for each condition.	This thesis works to show the advantages and the efficiency of the multi-instance RPL protocol, as well as the functions, are used with it. Thus, clarifying the difference between the multi-instance RPL protocol and the single instance RPL.
5	Dynamic RPL for multi-hop routing in IoT applications	2017	This paper works on the use of RPL protocol in dynamic networks and introduces improved RPL protocol for different applications with dynamic mobility and varied network requirements. The implementation of RPL is designed with a new dynamic target function to improve PDR, end-to-end delay, and power consumption while maintaining low packet load and loop avoidance.	The multi-instance RPL protocol was used with two functions OF0 and ETX as well as with dynamic technology to improve packet delivery ratio, power consumption, and average of latency time
6	Multi DODAG in RPL for Reliable Smart City IoT	2018	Researchers propose RPL is designed to meet the needs of a constrained IoT environment where RPL protocol uses Objective Functions ETX and Hop Count to improve parent selection as track selection. Researchers propose newer target functionality for IoT applications for network management and security. Therefore, they suggest the use of Multi DODAG in RPL to improve performance and smart city applications	Here, the functions OF0, EXT are used, for the purpose where the network used for reliability and PDR, power consumption and latency time using the multi-instance RPL protocol

ID	Title	Year	Previous Studies	In this thesis
7	Quality of Service Differentiation for Smart Grid Neighbor Area Networks through Multiple RPL Instances		In this study, the developments of the standard MAC level QoS techniques are revealed with the focus on network layer QoS mechanism.	In results, RPL alone cannot support the QoS requirements essential for SG AMI traffic.
8	Energy and Load Aware Routing Protocol for Internet of Things		The provided goal of this study is to accelerate the network lifetime by reducing the node energy consumption.	The simulation results reveal that the EL-RPL improves the network lifetime by 8-12% and packet delivery ratio 2-4%, and provides the best performance in terms of network lifetime, packet delivery ratio and end-to-end delay compared to RERBDI RPL and OF-FL RPL.
9	Towards Multi-instances QoS Efficient RPL for Smart		This study provides OFQS an RPL-compliant objective function, with a multi-objective metric mOFQS that considers by design the delay and the last energy in the battery nodes alongside with the quality of the links in order to be used with the standard protocol RPL in a SG environment.	Simulation results shows that OFQS achieves significant improvement in terms of End-to-End delay, network lifetime and PDR while insuring a load balancing among the nodes, compared to MRHOF with ETX and OF0 with HC, in a multiple instances environment. It provides a low packet delivery latency and a higher packet delivery ratio while extending the lifetime of the network compared to literature solutions.
10	Performance of RPL in Healthcare Wireless Sensor Network		This study performs an investigational assessment of ETX and OF0 objective function of RPL to evaluate their effectiveness regarding power consumption and PDR in a healthcare scenario under different topologies.	The results of experiments revealed that the OF0 is more efficient regarding the PDR with the comparable rate on power consumption as compared to ETX. Therefore, the design of a WSN in healthcare especially in ICU based on the application of the RPL protocol would be implemented based on OF0 rather

ID	Title	Year	Previous Studies	In this thesis
				than ETX where the PDR rate must be high because if it was low, patients in ICU might face a high risk or death. Moreover, in this paper, the implementation was based on one instance of RPL, as future work, we intend to investigate the use of multi-instance RPL.
11	DYNASTI—Dynamic Multiple RPL Instances for Multiple IoT Applications in Smart City		This study aims to provide a solution called DYNAmic multiple RPL instances for multiple ioT applications (DYNASTI), which provides more dynamism and flexibility by managing multiple instances of RPL.	The results acquired by DYNASTI revealed a general efficiency enhancement for the network, since there was an enhanced optimization of resources, mostly in the contraction of the control messages and energy consumption. DYNASTI results in fewer lost applications' messages and shortest delay for critical applications compared to the state-of-the-art approach in which there is no interruption of control and application messages and scheduling of instances.

Chapter Three

Methodology and the Proposed Work

3.1 Overview

The proposed methodology is presented in this chapter organized as the following: Section 3.2; discusses the importance of RPL protocol performance metrics of WSN-based healthcare system monitoring systems in multi instance RPL. Section 3.3; presents and analyzes the comparative study of RPL protocol methodology and its implementation steps. Finally, Section 3.5; where a summary is given of this chapter.

3.2 Introduction

The details of the steps that will be implemented to achieve this research will be provided with this chapter, and also giving answer to the main research questions which are:" What is the impact of using single and multi-instance RPL protocol on the requirements of WSN, in terms of packet delivery ratio, latency time, power consumption and control traffic overhead? And, how are the two objectives functions OFO and ETX will be affected by multi-instance RPL”. Also, how the WSN is designed in the field of health care system. Thus, an WSN scenario will be designed in a healthcare scenario. Where WSN contains devices sensors distributed in various departments; such as the intensive Care Unit, the Intermediate Care Department, the Emergency section and the Operating Room. The WSN and implementation of multi-instance RPL will be simulated using Cooja simulator for showing the extent of effectiveness and studying power consumption, packet delivery ratio and control traffic overhead. Two models of the network topologies will be built where a random topology and a grid topology will be designed. Therefore, OF0 and EXT can be measured in the Cooja simulator.

3.3 Research Methodology

The methodology used in this thesis, as illustrated in figure 3.1, consists of the following steps:

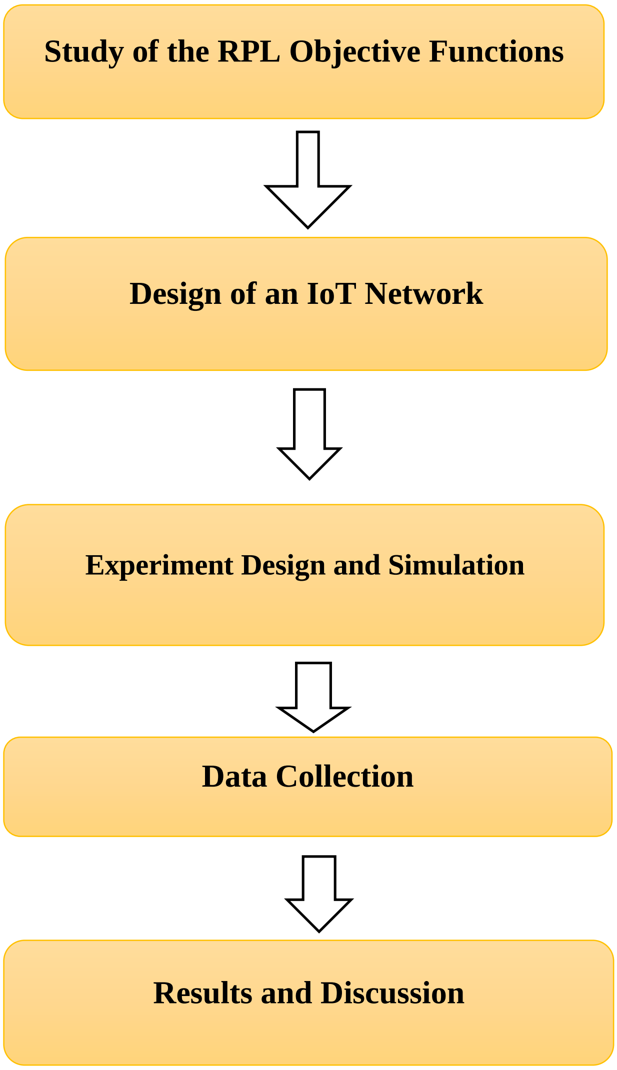

Figure 3.1 Research Methodology.

3.3.1 Study of the RPL Objective Functions

RPL is a routing protocol for a WSN, where we have two functions for this thesis, OF0 and EXT, designed to work between nodes depending on single-instance RPL protocol and multi-instance RPL protocol. These two functions in single and multi-instance RPL protocol will be applied within the Cooja simulator based on a pre-set scenario to obtain information to evaluate the power consumption, PDR, convergence time, and average latency. Accordingly, the EXT function is used to evaluate the best path between nodes, whereas the OF0 function is used to find the number of hops. Therefore, in this thesis, the two objective functions EXT and OF0 will be used to explain the difference, in order to demonstrate the efficiency of the multi-instance RPL protocol and determine which of them is better in the rate of packet delivery, where they will be subjected to experiments in different network densities, also with different numbers of nodes.

3.3.2 Design of WSN

The WSN has implemented in a Cooja simulator in the medical departments where it was used to represent the WSN, and the reason for choosing the medical departments that we mentioned because they are the most important sections of the hospital. This WSN will be implemented on two floors from where there are various departments, such as emergency department and the intensive care unit (ICU) and the critical care unit (ICC) and the operating room. Based on what a scenario was designed before, where the intensive care department contains 5 beds, critical care contains 5 beds, emergency contains 10 beds, and the operation room contains 5 beds. Because there is a need in the wards of the above-mentioned and departments that contain a group of sensors related to healthcare or patient status, each patient must be monitored and his vital signs are taken periodically , as shown in figure 3.2, to be able to record vital sings such as temperature, pressure.

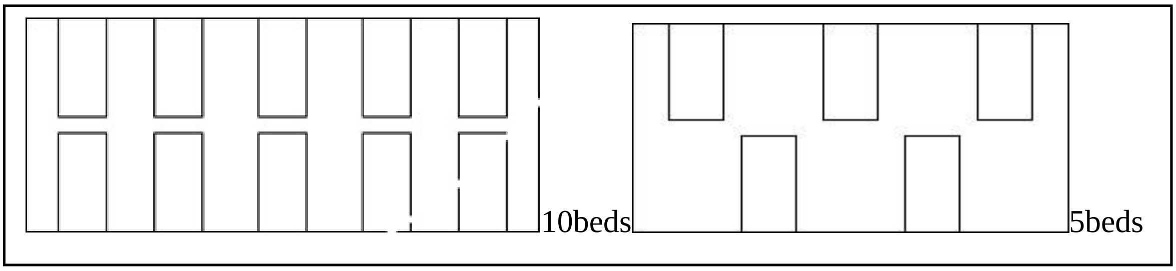

Figure 3.2 First Floor Internal Departments of the Hospital.

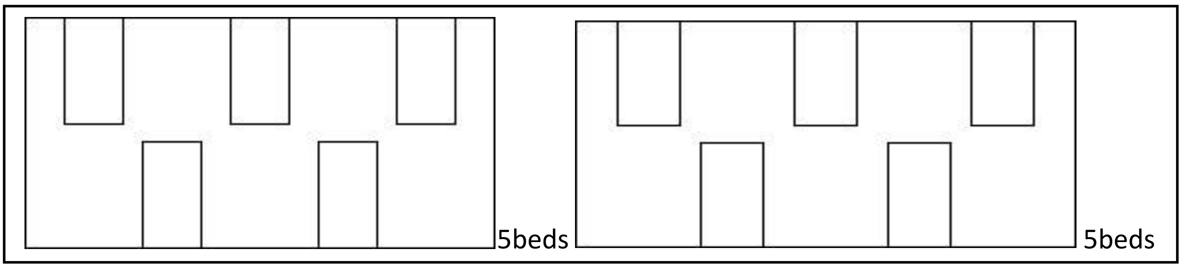

Figure 3.3 Second Floor Internal Departments of the Hospital.

Cases of patients will be divided according to the following classifications:

-Ordinary patients

- medium cases

- severe cases

The given vital signs; such as pressure and temperature, show that this floor has close care, focused care, and inpatients, where vital signs continuously and periodically must be communicated within 1 minute for ordianary patients, 30 seconds for medium cases, and 20 seconds for severe cases. The table below 3.1 shows 3 periods of transmission and the size of the sent packets. Furthermore, the following Table 3.1 indicates the periods of transmission and the size of the sent packets.

Table 3.1 The Proposed values for Data Traffic Sending Interval and Packet Size.

Data Traffic Type	Sending Interval	Packet Size
Severe cases	Average of 20 seconds	16bytes
Medium cases	Average of 30 seconds	48bytes
Ordinary patients	Every 1 minute	48bytes

3.3.3 Experiment Design and Simulation

The topology of the network depends on the distribution of the section, as shown in the figure in the previous section. This section provides more details about the construction of the topology for these sections and how different types of traffic can be expressed in practicing using the Cooja simulator. The process of dividing groups of nodes will be adopted to form the network topology. It is assumed that each patient is evaluated a random and grid topology for each health section that has a different topology in one bed, and is connected to two health medical devices to collect two types of vital signs in relation to the number of sensors nodes responsible to collect the vital signs. It is assumed that 25 sensors distributed in the medical wards in each department will be equated, where ETX will be used as a critical data traffic function and the objective function OF0 for traffic. Thus, we can conduct this experiment in designing the WSN healthcare network using multi-instance RPL protocol, and with Cooja simulation.

Based on the parameter, as shown in the following table 3.2, Simulation Value parameter or OF0 outside Mote semi-transmission type: 100% 100 m, Transmission range: 80%, the ratio of simulation time: 900 seconds, Squared area: 1000 square meters, the topology: Random and Grid topology. After which, we design a WSN network and response, as there is a need in the wards of the above-mentioned departments that contain a group of sensors where the state of health for each patient must be monitored, as shown in the following form table 3.2

Table 3.2 Simulation Parameters and their values.

Parameter	Value
Objective functions	OF0, ETX
Mote type	Sky mote
Transmission Ratio	100%
Transmission Range	100 M
RX Ratio	100% 80%
Simulation time	900 Second
Squared area	1000 Meters
Topology	Random, Grid

3.3.3.1 Random & Grid topology

As illustrated in figure 3.4 and figure 3.6, two types of different topologies will be used, such as random topology and grid topology, where the nodes will be distributed twice in two different types of networks topologies within different densities that were previously determined so that 25 nodes will be distributed in each case until the total number of nodes reaches 100 nodes in all types of topology. Also, as illustrated in the figure the Cooja simulator through which the work environment was created, where the figure contains the first group of a node created in the random topology, of which there are 25 colored nodes with a green balloon representing the first of the mentioned health departments, which is the operating room.

The numbers that are represented by the proportions in black are RX value. Besides, the area, which is covered by TX-Rang and the circle in grey, is its extent in which the whole contract will be created.

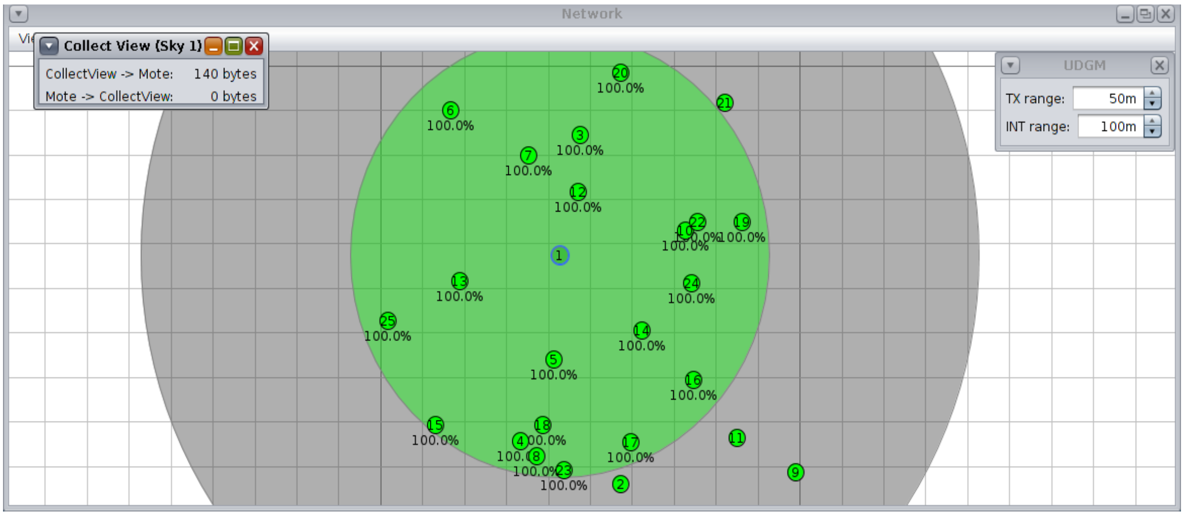

Figure 3.4 First Group Nodes of Random Topology.

As illustrated in figure 3.5, it shows the second group established in the random topology, which represents the next section of the health departments, which is the emergency department that is colored in pink, as well as the energy consumption figures for the TX Rang.

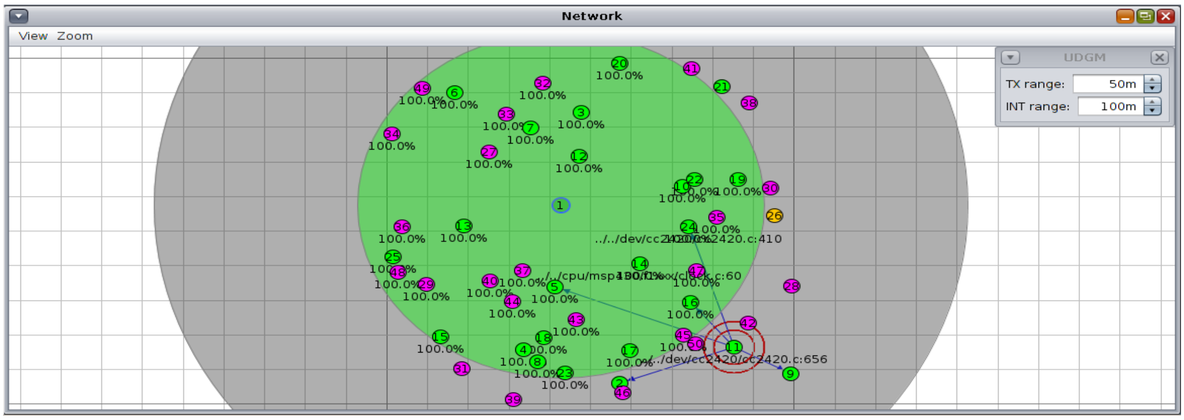

Figure 3.5 Second Group Nodes of Random Topology.

As illustrated in the figure 3.6, it shows a grid topology, where 100 group nodes were created sequentially according to the health sections; where the blue-colored part represents the emergency department, the orange-colored part represents the intensive care department, the yellow-colored part represents intensive care department, and the white part represents the operating room.

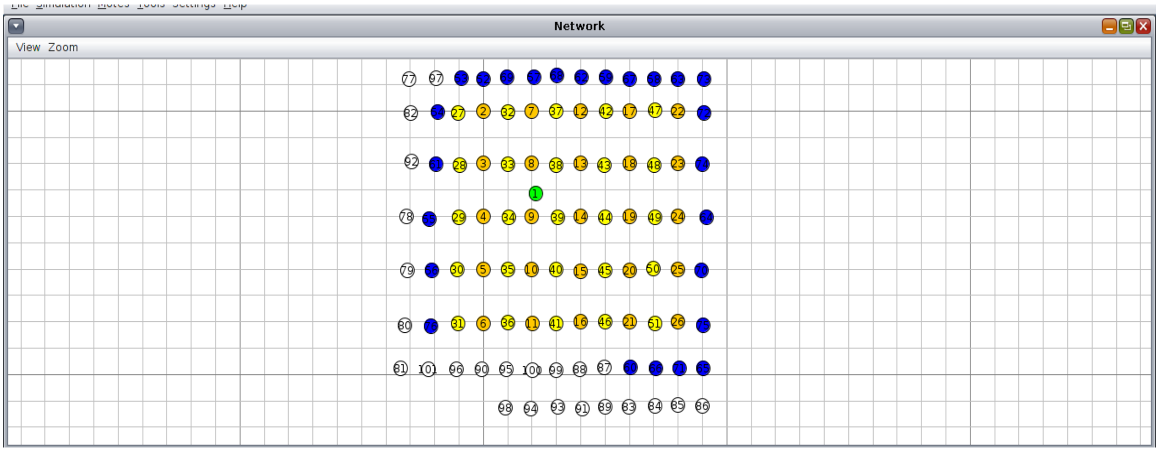

Figure 3.6 Nodes of Grid Topology.

3.3.4 Data collection

In this stage, parameters are entered in the Cooja simulator in order to implement, and then collecting data through random topology and grid topology; We can deduce that the grid distribution minimizes the number of parent changes due to the nodes position. In grid topology, nodes have the same rank from the sink node while in random topology they are distributed randomly(Lamaazi,and Benamar,2018). This design is executed by relies on OF0 and another relies on ETX in random topology and grid topology, which represents 100 nodes in random topology with RX100% and RX80% and another 100 nodes in grid topology with RX100% and RX80,Then a comparison is being made single instance and multi-instance RPL protocol to evaluate the results. And the information that leads to choosing the best between the two objective functions of the multi-instance RPL protocol OF0 and ETX will be collected through this comparison. Thus the best results in terms of power consumption, packet delivery ratio and latency time in single and multi-instance RPL protocol will be taken, then performance comparison between them.

Based on information and data extracted through the Cooja simulator inside WSN, a comparison will be made between single instance RPL protocol and multi-instance RPL protocol and the information extracted in order to choose the best among them in terms of low power consumption, the rate of delivery of packages and the average of latency time within the different topologies that we use; the random topology and the grid topology.

Chapter Four

Experimental Results and Evaluation

4.1 Overview

The implementation and results of the previously proposed methodology of multi-instance RPL protocol will be presented in this chapter which is organized as the following: Section 4.2; an introduction to the implementation and evaluation of results will be presented, section 4.3; the implementation of the experiment will be presented, section4.4; the parameter setting for the proposed approaches and comparisons between objective functions will be shown, section 4.5; the results of implementations and shows the PDR values, power consumption will be revealed, section 4.6; the average of latency time and comparisons between single and multi-instance RPL will be displayed , and section 4.7; a summary for this chapter will be presented.

4.2 Introduction

The experimental evaluation study of multi-instance RPL protocol by collecting data from Cooja simulator will be presented in this section. The purpose of the experiments is to evaluate the two objective functions; OF0 and EXT, in terms of packet delivery ratio and power consumption using the multi-instance RPL protocol. Where experiments are performed with different numbers of nodes and different topologies; such as the random topology and the grid topology and applied to a specific scenario in order to verify the effect of these parameters on multi-instance RPL protocol performance. These parameters will be analyzed in detail basing on the experimental results obtained from the Cooja simulation. Therefore, new results were noted in order to provide a comparison OF0 and ETX and evaluate the performance through the results obtained in this chapter.

The COOJA interfaces are the main and preferred way to analyses and interact with simulated nodes and flexible Java-based simulator designed for simulating networks of sensors running the Contiki operating system. COOJA simulates networks of sensor nodes where each node can be of a different type; differing not only in on-board software, but also in the simulated hardware. COOJA is flexible in that many parts of the simulator can be easily replaced or extended with additional functionality. Example parts that can be extended include the simulated radio medium, simulated node hardware, and plug-ins for simulated input/output. A simulated node in COOJA has three basic properties its data memory, the node type, and its hardware peripherals. The node type may be shared between several nodes and determines properties common to all these nodes. (Dunkels, Gron, vall, and Voigt,2004).

4.3 Performance of single instance and multi-instance RPL protocol implementation rely on OF0

The experiments have been placed under different network topologies, where 100 nodes will be distributed according to the interval time; therefore, every 25 nodes will be distributed at different times. By using random topology and grid topology, we will observe the performance of OF0 for different values of RX. We will change the RX values 80% and 100% and evaluate the performance of the single-instance and multi-instance RPL protocol in terms of delivery ratio and power consumption. The result of this simulation is obtained from the pinned nodes OF0. The medium is extracted so that we can notice the differences after making a comparison, as the illustrated following figure 4-1 and the figure 4-2. Run results in COOJA simulator to the scenario, to obtain accurate results each scenario multiple runs

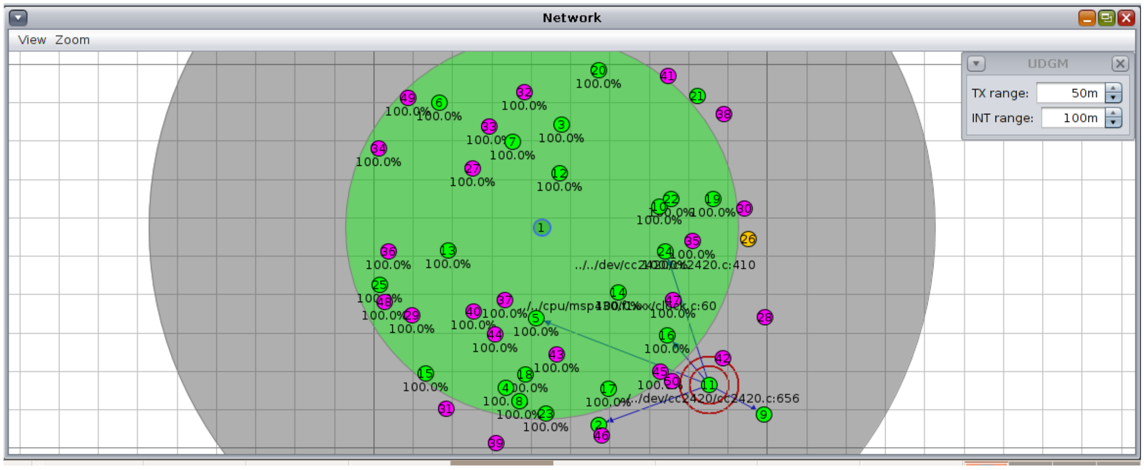

Figure 4.1, The Total groups of Nodes are created in Random Topology.

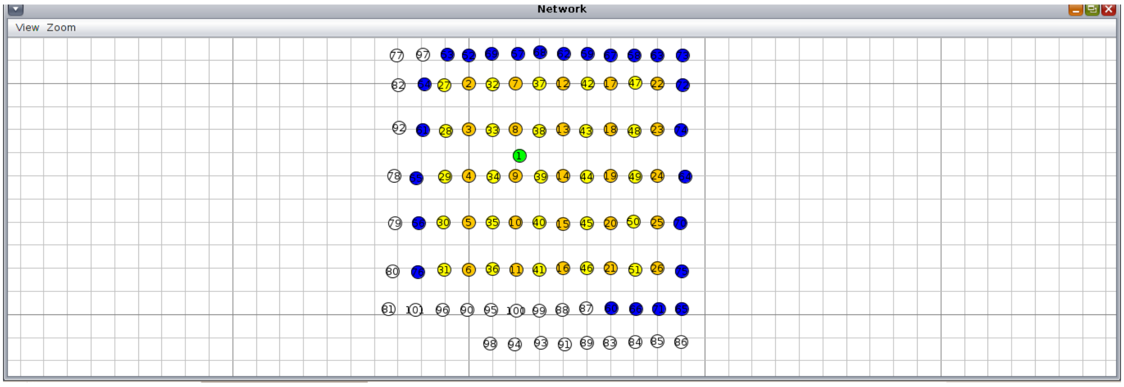

Figure 4.2 The Total Groups of Nodes are created in a Grid Topology.

4.3.1 Packet Delivery Ratio in Random Topology

The PDR behavior is presented based on the changes in RX which are first implemented in a random topology, were compared when using RX 100 and 80% whereas receipt values fixed at 100% and as illustrated in the figure 4.3. The emerged results in single instance and multi-instance RPL, the percentage of PDR when RX100% was 92.9% for single instance RPL and 94.6% for multi-instance RPL. It can be concluded that the PDR percentage increased with the increasing value of RX. PDR behavior is presented based on the change in RX value and different topologies, the percentage of PDR when RX80% in single instance RPL around 91.7% and 91.5% in multi-instance

RPL, so the delivery rates are good when using RX 100%, as it is sufficient to sending messages.

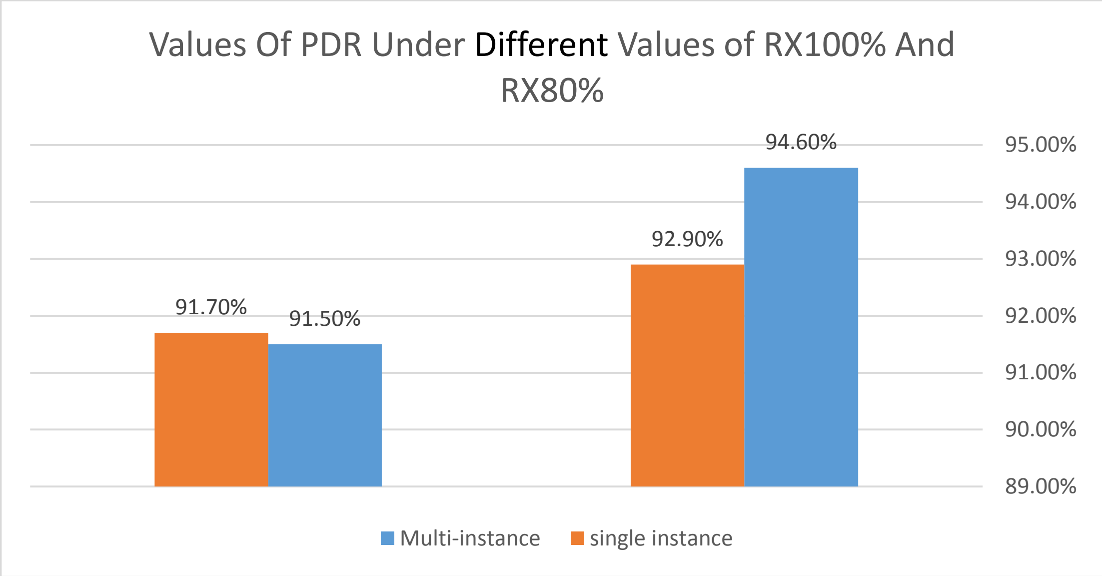

Figure 4.3, PDR when RX ratio 100%and RX 80%.

4.3.2 Packet Delivery Ratio in Grid Topology

PDR behavior when applied to different network topologies is directly affected by the network density, the percentage of PDR value when RX100% is 89% in single instance RPL and 92.5% in multi-instance RPL when the percentage of PDR value when RX80% in single instance RPL was 84% and 87.2% in multi-instance RPL also, results from a good delivery ratio depends on the network topology. In the following figure 4.4, we notice that the value of PDR decreases by a slight difference when RX 80%.

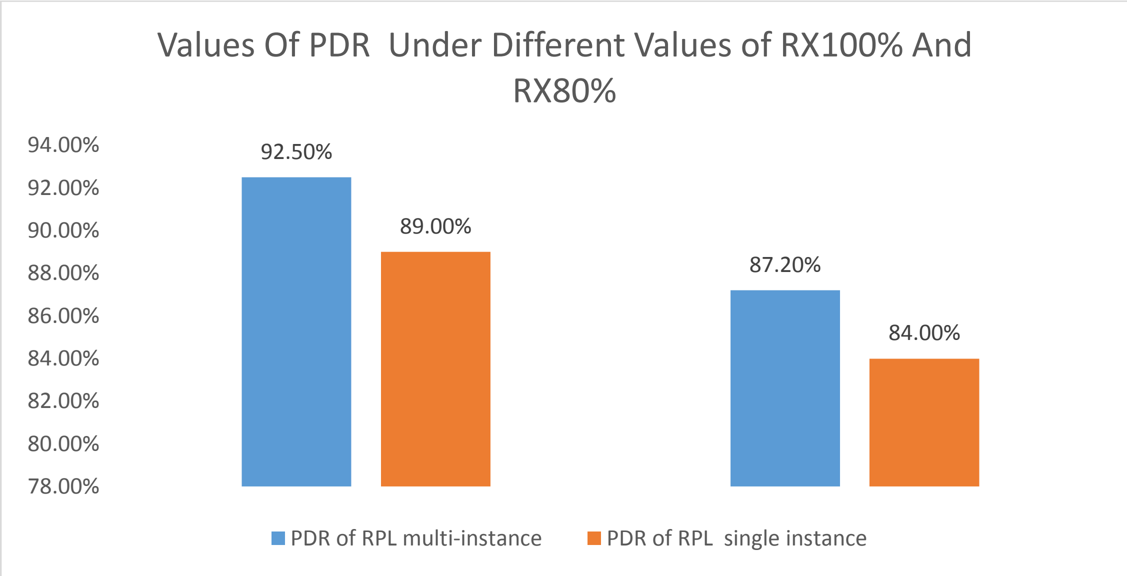

Figure 4-4 Results for PDR when RX 100% and RX 80%.

Total results in table 4-1 shows that the OFO gives a different result for the packet delivery ratio when it is implemented using different network topology.

Table 4.1 Results for PDR when RX 100% and RX80% in single instance and multi-instance RPL

RX	**Topology**	**PDR of single instance RPL**	**PDR of multi-instance RPL**
100%	random	92.9%	94.6%
80%	random	91.7%	91.5%
100%	grid	89%	92.5%
80%	grid	84%	87.2%

4.3.3 Power Consumption in Random Topology of RX100% for Single Instance RPL

The power consumption behavior based on the levels of reception that appeared in the random topology using single instance RPL, where the lower power consumption value was observed as illustrated in figure 4.5, when RX 100% the value is 1.7%.

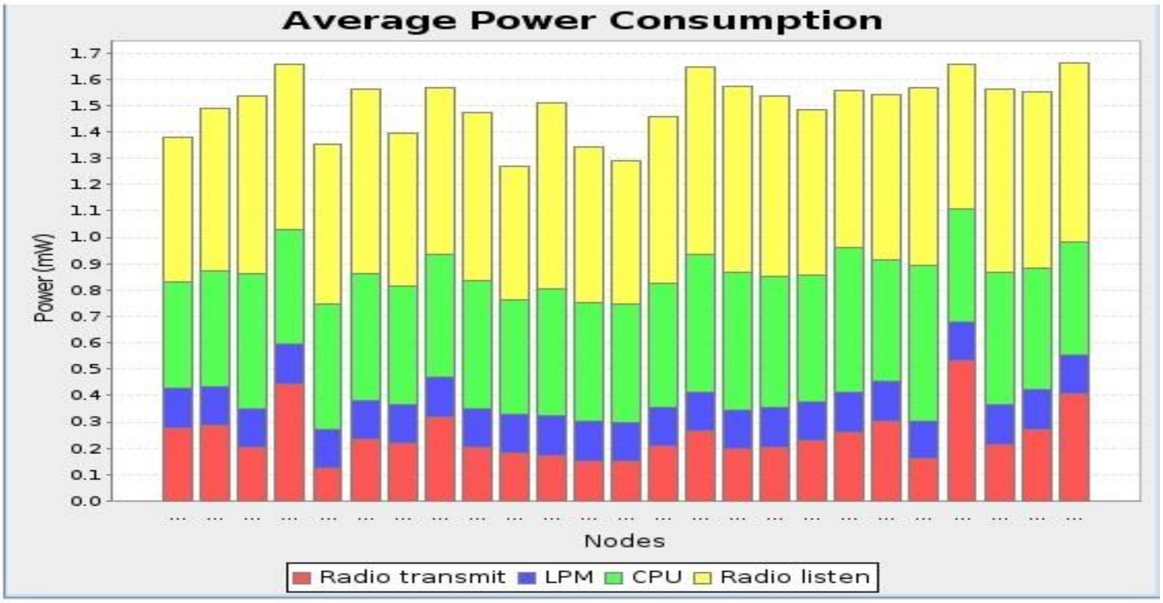

Figure 4.5 Power Consumption when RX 100% in Single Instance RPL.

4.3.4 Power Consumption in Random Topology of RX 80% for Single Instance RPL

The power consumption behavior based on the levels of reception that appeared in the random topology using single instance RPL, where the lower power consumption value was observed as illustrated in the figure 4.6, when RX 80% we have the value 1.4%.

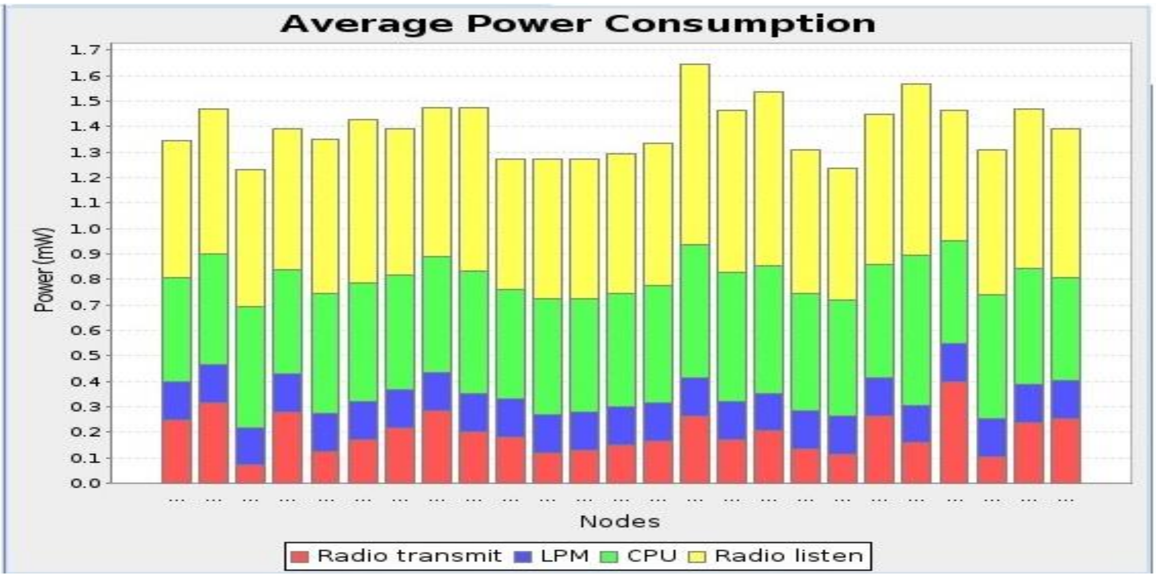

Figure 4.6 Power consumption when RX 100% in Single Instance RPL.

4.3.5 Power Consumption in Random Topology of RX 100% for Multi-Instance RPL

As illustrated in figure 4.7, the power consumption behavior based on the levels of reception that shows in the random topology, we observe the increased value of power consumption in multi-instance RPL, when RX 100% we have a result of 3.3%.

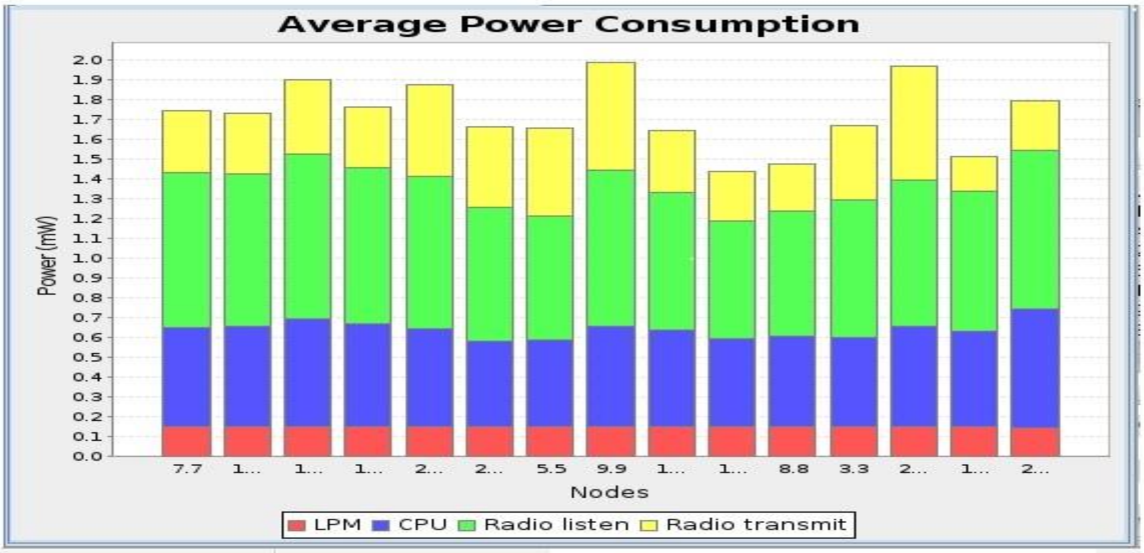

Figure 4.7 Power consumption when RX 100% in Multi-Instance RPL.

4.3.6 Power Consumption in Random Topology of RX 80% for Multi-Instance RPL

As illustrated in the figure 4.8, the value of power consumption, in multi-instance RPL for the random topology, is about 3.7% when RX 80%. This value is enough to keep energy without loss and consumption.

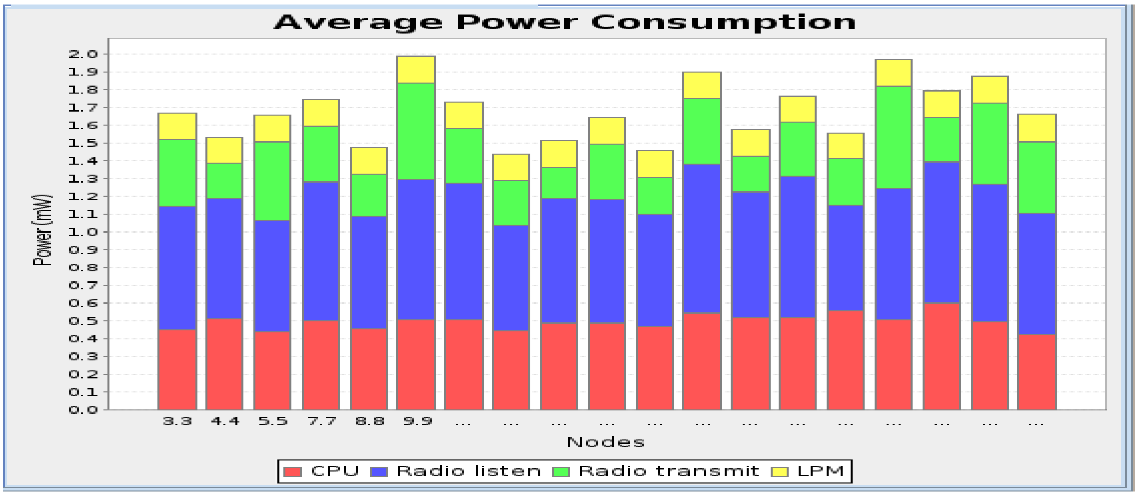

Figure 4.8 Power consumption when RX 80% in Multi-Instance RPL

4.4 Performance of Single Instance and Multi-Instance RPL Implementation Rely on EXT

We set the experiments under different network densities to 25 nodes using a the random topology and the grid topology to monitor EXT performance for different values of RX100% and RX 80% values are changed, and a comparison of the single and multi-instance RPL protocol behavior will be made in terms of packet delivery ratio and power consumption.

4.4.1 Packet Delivery ratio in Random Topology

In the figure 4.9 illustrated the behavior of PDR based on ETX in the random topology, we observe that the PDR values are different by various network topology, the percentage of PDR when RX100% is 86.7% in single instance RPL and 87.4% in multi-instance RPL .the percentage of PDR when RX80% is 88% in single instance RPL and 90% in multi-instance RPL. The behavior of PDR in figure 4.9 is illustrated when performing a PDR simulation, the value reached 100% when the RX value is greater than or equal to 80% and this means that can use the RX value of 100% instead of 80%.

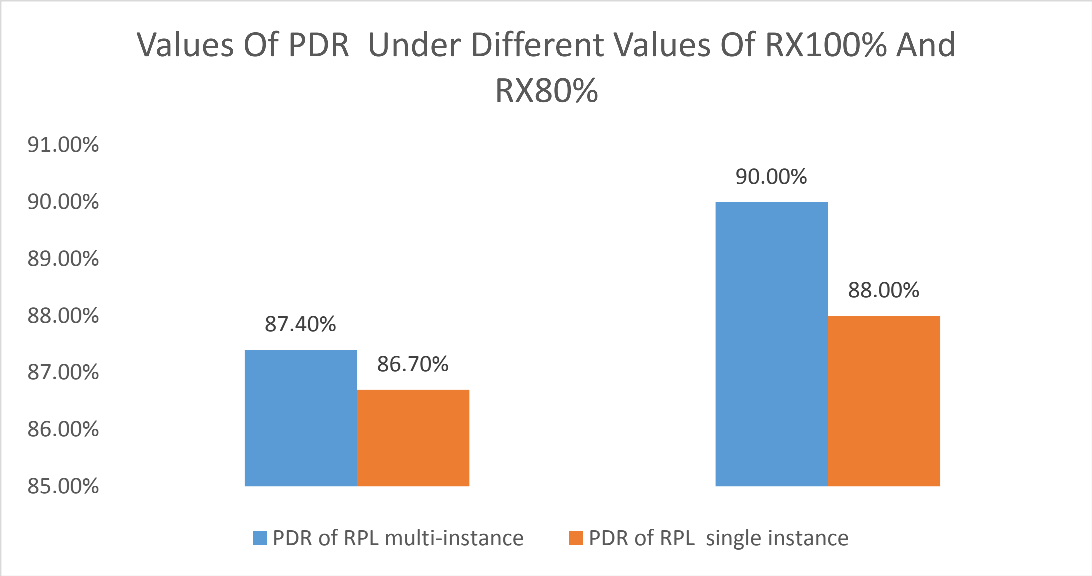

Figure 4.9 Results for PDR when RX 100% and RX 80%.

4.4.2 Packet Delivery Ratio in Grid Topology

As shown in the values of PDR in Figure 4.10 when implemented to the grid topology, the PDR value is directly changed by changing the network density so that it changes between the random topology and the grid topology, the percentage of PDR when RX100% is 86% in single instance RPL and 93% in multi-instance RPL and when RX80% is 80% in single instance RPL and 91.3% in multi-instance RPL, resulting in a good delivery ratio based on the grid topology. After observing the results in grid topology, it observed is that the PDR provides a good delivery rate when RX100%.

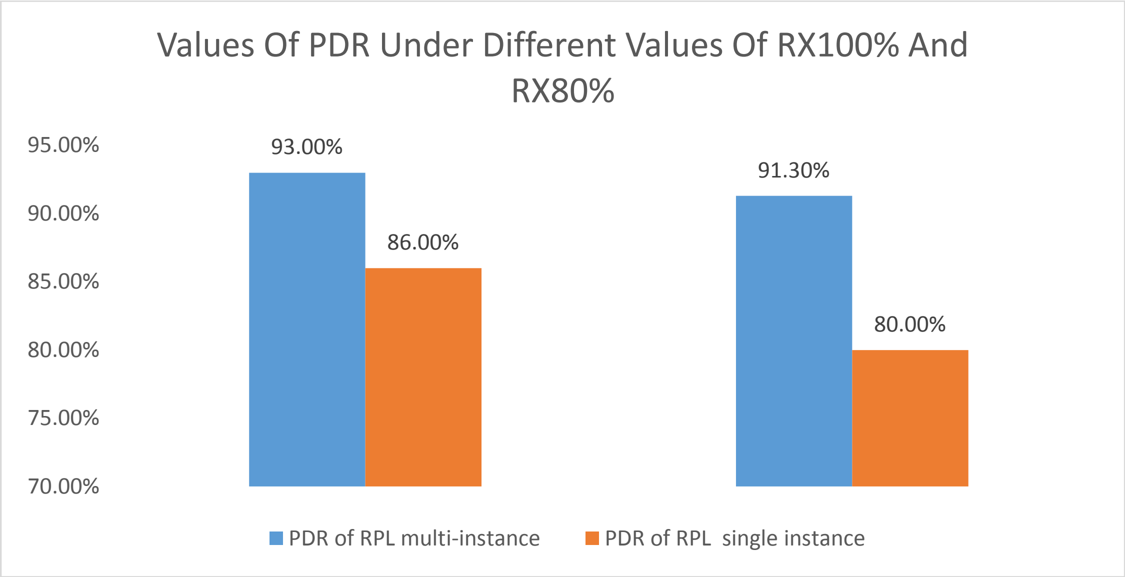

Figure 4.10 Results for PDR when RX 100% and RX 80%.

Total results in table 4-2 shows that the ETX gives a better result for the packet delivery ratio when implemented using different network topology.

Table 4.2 Results for PDR when RX 100% RX80% in single instance and multi-instance RPL.

RX	Topology	PDR of single instance RPL	PDR of multi-instance RPL
100%	random	86.7%	87.4%
80%	random	88%	90%
100%	grid	86%	93%
80%	grid	80%	91.3%

4.4.3 Power Consumption in Random Topology of RX 100% for Single instance RPL

As illustrated in figure 4.10, it shows the power consumption behavior based on the reception levels in the random topology, we note that the power consumption values decreased by decreased RX value, and when RX100% we have 1.8%.

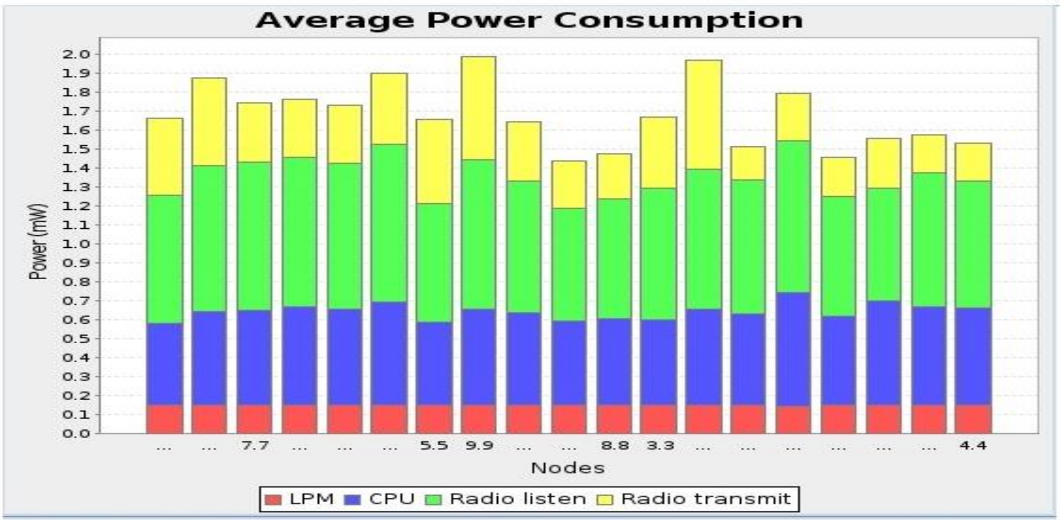

Figure 4.11 Power Consumption when RX100 in Single instance RPL

4.4.3 Power Consumption in Random Topology of RX 80% for Single instance RPL

As illustrated in figure 4-11, it shows the behavior of power consumption based on RX levels in random topology when RPL single instance, it has been observed that the values of power consumption have decreased, and the RX values have been decreased as the average power consumption is less, and when the RX80% we get the value1.65%.

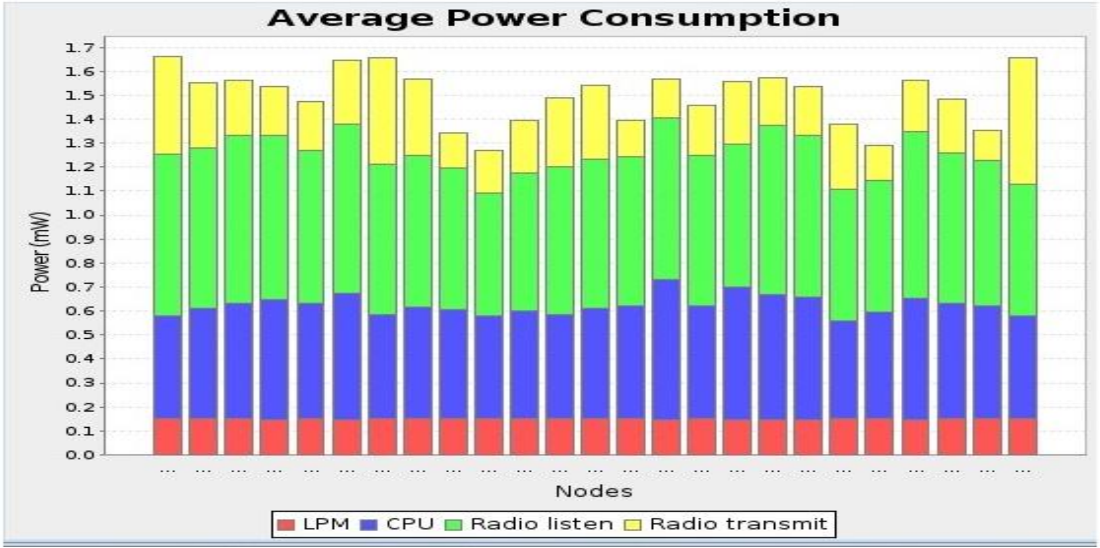

Figure 4.12 Power consumption when RX 80% in single instance RPL

4.4.4 Power Consumption in Random Topology of RX 100% for multi-instance RPL

As illustrated in figure 4.12, it shows the behavior of power consumption based on RX value in random topology, and the RX values have been increased as the average power consumption is good, and when the RX100% we have the result 2.9%.

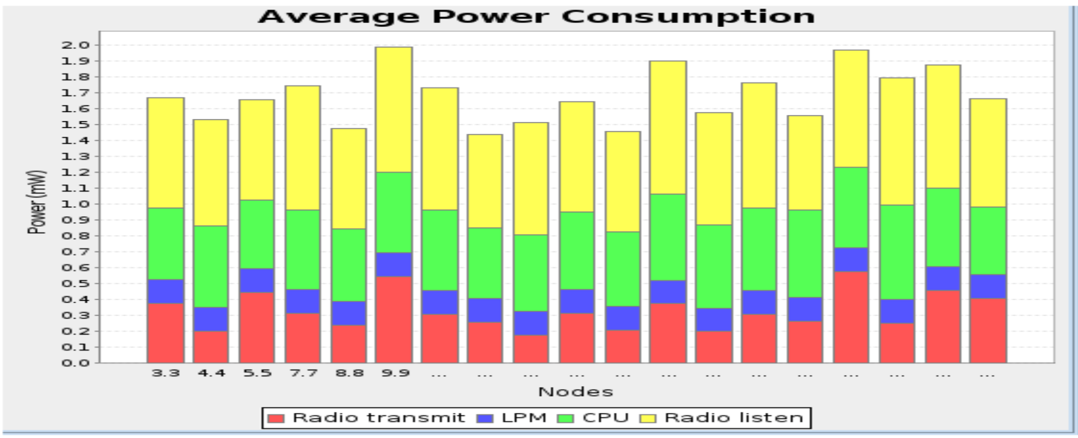

Figure 4.13 Power consumption when RX 100% in Multi-Instance RPL.

4.4.5 Power Consumption in Random Topology of RX 80% for multi-instance RPL

As illustrated in figure 4.13 it shows the behavior of power consumption based on the reception levels in the random topology, where we notice decreasing in the values of power consumption, the values of RX increased as the average power consumption is good, and when RX100% we have the result 2.676%.

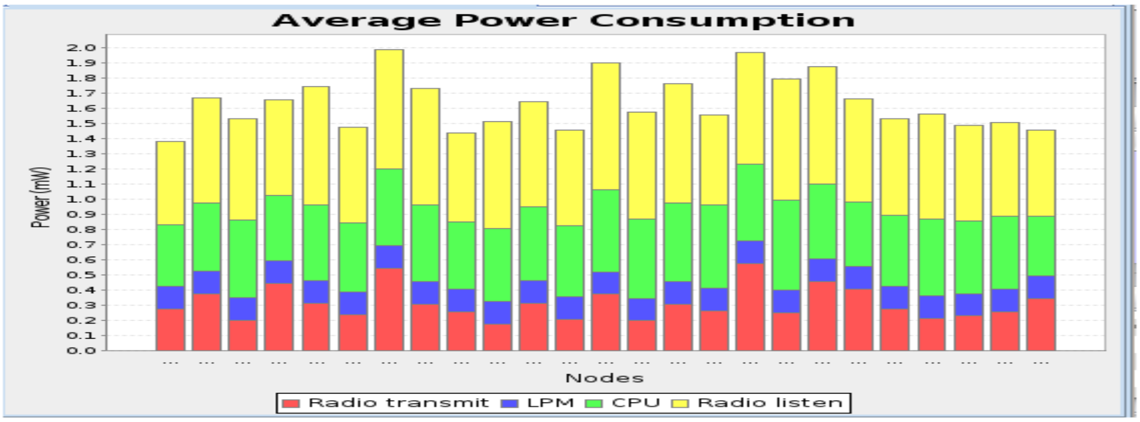

Figure 4.14 Power consumption when RX 100% in Multi-Instance RPL.

4.5 Single instance and Multi-instance RPL Protocol performance reliance on OF0 and EXT.

By keeping the node packet reception ratio constant, a good result of the simulation of nodes that installed OF0 or EXT is done by setting a fixed number of nodes, and also the different topologies which give us the opportunity to monitor OFs under different network densities can be obtained. Therefore, we accurately compared the main effects of using OF0 and EXT to evaluate the behavior of the RPL protocol the PDR as well as the power consumption of each of the used topologies.

4.5.1 Packet Delivery Ratio

The result in the random topology was used, and it is found that the average packet delivery for OF0 when single instance RPL is, the highest value, approximately 92.9%, in multi-instance RPL 94.6%, the average packet delivery ratio for EXT when single instance RPL is, the highest value 88%, and in multi-instance RPL approximately is 90%, and when using the grid topology to represent the average packet delivery percentage, the results show different values for PDR behavior. the average packet delivery rate for OF0 when single instance RPL is the highest value, around 89%, and in multi-instance RPL the highest value 92.5%, and the average packet delivery rate for EXT when single instance RPL is, the highest value, around 86%, and in multi-instance RPL, the highest value 91.3%. It was observed that the PDR set of simulation results in OF0 and EXT gave good PDR as OF0 outperformed ETX. This is because of a slight difference in topologies that were used. As illustrated in table 4.3, we observed in the network of 25 nodes that the average PDR is good when the network density of RX 100% using a random topology or grid topology.

Table 4.3 Shows values of PDR when Single instance and Multi-instance RPL.

RX	Topology	PDR when RPL Single instance	PDR when RPL Multi-instance
100%	random	92.9%	94.6%
80%	random	91.7%	91.5%
100%	grid	89%	92.5%
80%	grid	84%	87.2%
100%	random	86.7%	87.4%
80%	random	88%	90%
100%	grid	86%	93%
80%	grid	80%	91.3%

4.5.2 Power Consumption

The results were used in the random topology for values of power consumption because it has the best values of power consumption, and it was found that the average power consumption for OF0 when RX 100% approximately 1.7% in single instance RPL and 3.7% when RX80% in RPL multi-instance as the highest values, when the average power consumption for ETX is when RX100% approximately 1.8% in single instance RPL and when RX 80% is around 2.676% in multi-instance RPL as the highest values. Therefore it is observed that the values of power consumption set of simulation results OF0 and EXT gave a good value of power consumption, and the good values founded when RX 80% in multi-instance RPL.

4.6 Latency Time for Single Instance and Multi-instance RPL

It is the network setup time when the last node in the network joins to DAG and gets its IP address. The latency time represents the time at which the DAG is completely constructed and all nodes in the network have joined to DAG, for three types of data traffic which is the severe cases and the medium cases and the ordinary patients, we observe slight difference in latency time between RX100% and RX80%, as shown in Figure 4.14 in single instance RPL and in Figure 4.15 multi-instance RPL. The results show the average of latency time when RX 100% around 19sec in single instance RPL and in multi-instance RPL approximately 0.0767sec, the average latency time when RX 80% is around 25sec in single instance RPL and in multi-instance RPL approximately is 0.0567sec.

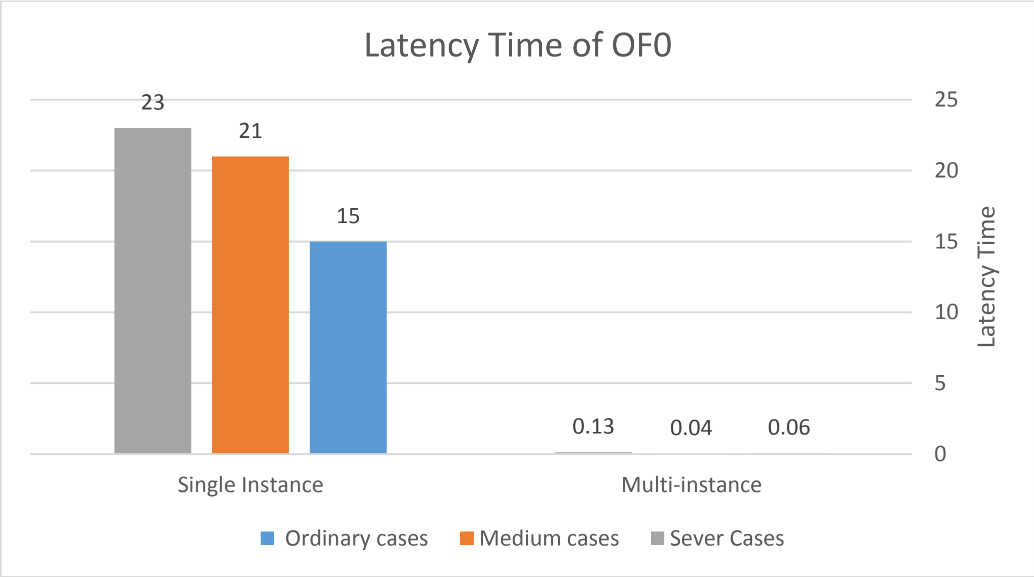

Figure 4.15 Latency Time of OF0.

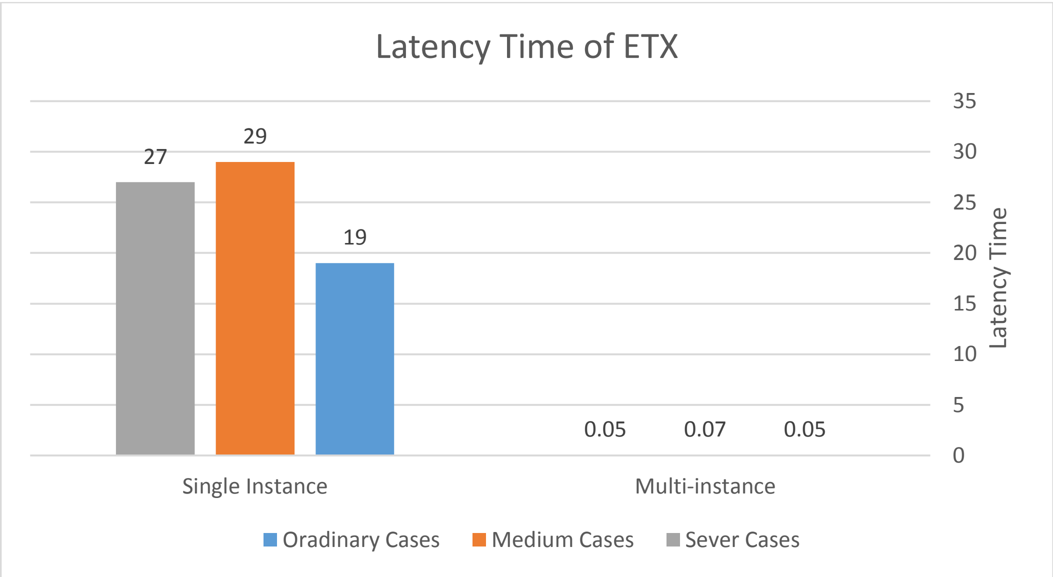

Figure 4.16 Latency Time of ETX.

The results shows in figure 4. 17 The average of latency time by the equation

Average Latency = Total Latency / Total Packets Received when RX100% around 19sec in single instance RPL and in multi-instance RPL approximately 0.0767sec, the average latency time when RX80% is around 25sec in single instance RPL and in multi-instance RPL approximately 0.0567sec.

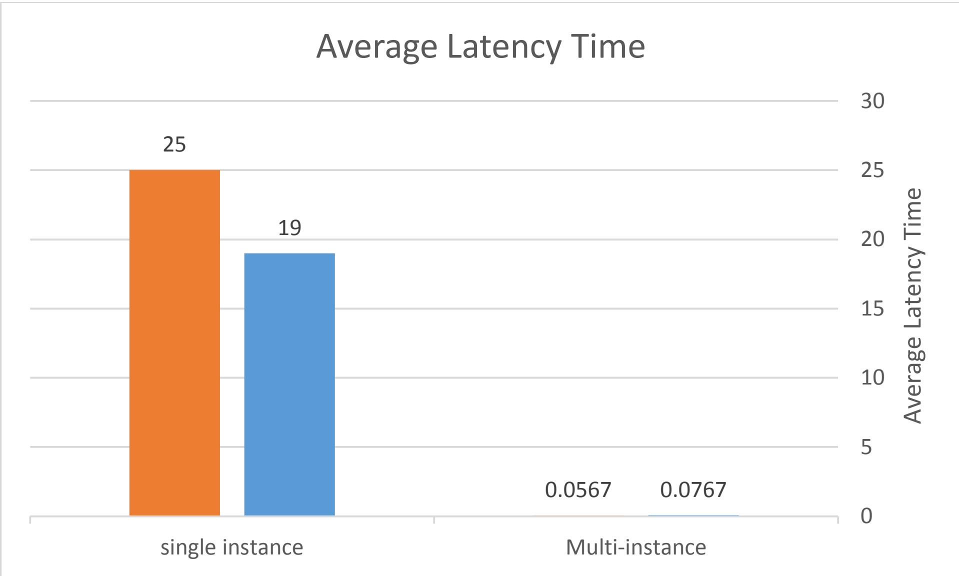

Figure 4.17 Average Latency Time.

4.7 Summary

The implementation of the methodology that was previously put up before being presented in this chapter, where it was implemented in a specific scenario in the medical department in order to make a comparison among the objective functions of RPL protocol in order to prove effectiveness OF0 and ETX in single instance and multi-instance by using different topologies networks: the random topology and the grid topology, where this comparison was implemented in the Cooja simulator under different RX values: RX100% and RX80%. The results showed that OF0 is better in comparison with EXT, in conserving power consumption and maintaining a rate package delivery when applying it with random topology and grid topology. And the results showed average latency time when is better value in multi-instance RPL more than single instance RPL under different values of RX: RX100% and RX80%.

Chapter Five

Conclusions And Future Work

5.1 Conclusion

In this thesis, a comparison between the single and multi-instance RPL functions was presented in order to specify the best function in terms of delivery rate and the power consumption and latency time based on a specific scenario that we used in the health care system. So that, a comparison between objective functions OF0 and ETX twice was made; once in single instance RPL , and another in multi-instance RPL using different topologies networks ,with random topology and with grid topology by using different RX values: RX100% and RX80%. The results were taken and developed by using the random topology and the grid topology, where these experiments were conducted through a certain number of nodes with different topologies density.

Regarding the question, what is the impact of using multi-instance and single-instance RPL protocol on the requirements and conditions of wireless sensor networks, in terms of packet delivery ratio, latency time, and power consumption. We concluded from the results effect of using single and multi-instance RPL protocol on the rate of PDR value where approximately82% in single instance RPL while the value different in multi-instance RPL is approximately 90%.As for the latency time we note different values of average latency time between single and multi-instance RPL by using RX100% and RX80% while the value is approximately 22sec in single instance RPL and around 0.0667 sec in multi-instance RPL. And rate of power consumption different between single and multi-instance approximately is 1.63% in single instance RPL and around 3.14% in multi-instance RPL.

Regarding the question, how the tow objective functions OF0 and ETX effected by multi-instance RPL protocol... The results show that the objective functions OF0 and ETX affected by using multi-instance RPL protocol, we note performance varies of OF0 and ETX, while OF0 is better more than ETX in the rate of PDR and it reduces rate of power consumption more than ETX.

Regarding the question, How could the packet delivery ratio, latency time, and power consumption be affected by the multi-instance RPL protocol? We concluded from the results that the values of PDR, power consumption and latency time are effected by using multi-instance RPL, so that it is a good delivery ratio and the lowest consumption rates also good average latency time.

The results showed that the function OF0 is the best when delivering packages in terms of the highest values of package delivery rates, and the average of power consumption as well as the highest in multi-instance RPL protocol and the average of latency time is better in multi-instance RPL protocol more than single instance RPL protocol, which helps us in developing the healthcare system to get vital signs periodically, and do not put the patient's life at risk ,as the PDR has low value in one of the important sections healthcare that will put the patient at risk or death, therefore WSN network will be designed in one of the most important healthcare sections, and the results will be configured in order to use the OF0 function in a sensitive section as well as other sections where ETX will be used as it has a low value of delivery rate.

5.2 Future Work

As a future work, we intend to continue studying the use of multi-instance RPL along with other various QoS. Beside using dynamic specification of RPL in different networks and topologies related to specific application such as smart cities and smart grid.

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