# Investigation of Energy Harvesting in Cognitive Internet of Things (CIOT) Network

By

Mohammad Sultan Shafayat Nayeem

12121007

Md.Tahmid Imtiaj

12221064

Nazifa Rahman Chowdhury

14321053

A thesis report submitted to the Electrical and Electronics Engineering in partial fulfillment of

The requirements for the degree of

B.Sc. in (EEE)

Electrical and Electronics Engineering

BRAC UNIVERSITY

April 2019

## Declaration

It is hereby declared that

1. The thesis report submitted is our own original work while completing degree at BRAC University.

2. The thesis report does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.

3. The report does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.

4. We have acknowledged all main sources of help.

**Student's Full Name & Signature:**

**Mohammad Sultan Shafayat Nayeem**
**12121007**

**Md. Tahmid Imtiaj**
**12221064**

**Nazifa Rahman Chowdhury**
**14321053**

## Approval

The thesis titled "Investigation of Energy Harvesting in Cognitive Internet Things (CIOT)" is submitted by
Mohammad Sultan Shafayat Nayeem (12121007)
Md.Tahmid Imtiaj (12221064)
Nazifa Rahman Chowdhury (14321053)

Of Spring, 2019 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of B.Sc. in Electrical & Electronics Engineering on 25-04-2019.

**Examining Committee:**

| | |
|---|---|
| Supervisor:<br>(Member) | Dr. Saifur Rahman Sabuj<br>Assistant Professor, EEE<br>BRAC UNIVERSITY |
| Program Coordinator:<br>(Member) | Dr. Saifur Rahman Sabuj<br>Assistant Professor, EEE<br>BRAC UNIVERSITY |
| Departmental Head:<br>(Chair) | Dr. Shahidul Islam Khan<br>Professor, EEE<br>BRAC UNIVERSITY |

## Acknowledgement:

First of all, I would like to thank Almighty Allah for his mercy and charity. This thesis is the most significant accomplishment in my life and would have been impossible without the will and wish of the almighty and I am grateful to him.

Most of all, We would like to express our deepest gratitude and respect to our supervisor and mentor as well Dr. Saifur Rahman Sabuj, Assistant Professor, BRAC University for introducing me in the arena of Cognitive Internet of Things and for his continuous inspiration, guidance and invaluable support during this research work. Next, I would like to thank all the teachers and staffs of the EEE department for their cordial help and assistance during my study period.

Finally, I would like to thank my parents for their continuous support, encouragement and sacrifice throughout the years and I will be obliged to them forever for all they have done.

## Abstract

The internet of things (IOT) speaks to a shining prospect that an assortment of common apparatuses can interface to one another, as well as with the rest of the internet, to endlessly make strides our lives. For the purpose of life improvement, variety of common appliance can connect to one another which represent a bright prospect by the IOT (Internet of things). Many challenges have been brought out by limited features of IOT devices which are unique communication and security challenges. In this paper, cognitive IOT (CIOT) where an IOT arrange works as the auxiliary framework utilizing the relay secure schemes which are used where the spectrum shortage problem occurs. It is occurred when a large number IOT devices are being used in a network. On the other hand, IOT based devices generally transfer data from sharing spectrum scarcity. A wireless energy harvesting (EH) node is used as a relay to improve the battery lifetime of an IOT devices. In this paper, we review a mathematical model of cognitive IOT. Secondly, we have also reviewed the mathematical expression of signal to noise ratio (SNR) for instantaneous power splitting (INT-PS), pre-coded power splitting (PRE-PS), instantaneous time splitting (INT-TS), pre-coded time splitting (PRE-TS). In addition to, we also considered the security issue with an un-trusted relay for maintaining the performance for CIOTs. The secure performances of the proposed schemes are evaluated through capacity and SNR. Finally, the influences of the power splitting and the time splitting ratios are also discussed through simulations.

# Table of Contents

**List of Tables**

**List of Figures**

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction to Internet of Things

The term Internet of things (IOT) has discovered by Kevin Aston in 1990 as the title of the presentation which was a technical revolution that introduced us with the modern global connectivity, enumerating and communication era.

In $20^{th}$ century IOT has become the most burning topic around the world because the networking system of IOT has the ability to provide global information, exchange spanning home, vehicular, healthcare monitoring system and industrial environment within a device. Now-a-days IOT is successful to create attraction human being along with the researcher because of its technology which promises to serve a smart human being life. Internet of things provide flexibility to communicate with lots of sensor based devices using a number of energy though internet. Today the whole world is dependable on internet. People are from anywhere, anyone using internet for controlling and monitoring parameters which makes internet of things the next big revolution on digitalization of commercializing products. IOT is a worldwide network of interconnected objects which is uniquely addressable, maintaining protocols, allows people and thing to be connected by anything, anyone, anyplace at any time. IOT has different technologies such as cloud service, data modeling, storing, reasoning, processing and communication technologies where Cognitive IOT is a network where things or objects are interconnected in different unused spectrum.

The main visionaries of IOT are communicating, collecting, monitoring data, gathering information from the sensors based devices through internet, cognitive IOT technologies will make it possible for general people what is happening more deeply after removing complexity of gathering information or data from the devices where IOT works as a secondary system through spectrum sharing. IOT based devices generally transfer data through sharing spectrum, when lots of IOT devices are connected a serious complexity occurred which may cause spectrum scarcity. Making information and data in physical term (CIOT) works as solution to solve this scarcity which will make people more understandable. Considering the spectrum scarcity issues and the security system an under relay spectrum sharing is used through (CIOT). A data or information can be used or transferred through the relay without any blockade of energy. To exaggerate the security system of the CIOT network the destination sends the jamming signals to jam the untrusted relay.

Communication security is a critical issue to maintain IOT networks due to massive application in governmental, industrial, commercial and military applications. A lightweight protocol with high efficiency which is capable to give solutions for the security issues in the IOT. That is what we focused on the physical layer security (PLS) system because of its built in security which is theoretically unbreakable. The main reason of using PLS capitalizing the wireless channels and the interference environments to keep the information confidential from eavesdropping. To Amplify-and-forward relaying protocol is used and destination-aided-jamming strategy has taken to protect the information from being intercepted by the untrusted relay. An intelligent secure scheme and a preceded secure are proposed for the CIOT networks based on Time splitting (TS) and Power splitting (PS) policies. To evaluate secrecy performance we followed the probability of successfully secure transmission ($P_{SST}$) which is ensure satisfaction the interference threshold constraint that indicates the secrecy rate of the transmission is positive [1].

## 1.2 Review of Previous Works and Observation

According to the latest surveys by 2020, 500 billion devices will be connected to the internet which create interest people to study on IOT. We have discussed some contribution of different authors related to CIOT, energy harvesting and energy consumption and its suppression in this section.

H. Hu [1] ***et al***. proposed PLS security system which is secured for communication security because of its built in security which theoretically unbreakable. Their paper is to be considered as the first paper which has considered the security issue in an under relay CRn with an untrusted relay from the PLS perspective maintaining secrecy performance for CIOT network.in their paper a wireless energy harvesting (EH) node is used as a relay to improve the coverage's of an IOT device. Basically their paper considered secure data transmission problem between the objects and the destination via the Wireless EH untrusted relay.

R. Han [2] ***et al***. considered in their paper to allocate spectrum scarcity cognitive radio based IOT devices. They concentrate on the optimal spectrum allocation strategy when transmit data through cognitive IOT based network between many links. When all the links transmit data flow they also share a new spectrum channel so that the search space spectrum allocation problem gets a solution as an exponential growth depend on the network condition. To avoid multi-objective spectrum allocation problem, they apply Non-Dominated Sorting Genetic Algorithm-NSGA2- which has the ability to manifest high performance in many objective optimizations.

K. Zaheer [3] ***et al***. proposed a huge study on Cognitive radio based IOT system along with the huge survey about different architecture and every layer of framework which functionally works in CIOT system. That also includes IOT strategic research and innovation that includes IOT related future technologies, network and communication, processes, data management, security and privacies, device level energy issues and IOT protocol convergence for future development. They also explained VO and CVO creation without providing details about objects further use in framework. They have highlighted decision theoretic schemes for CIOT, overview of game theoretic solution for cognitive decision making in IOT, propose the solution for intelligent decision making in IOT devices for many multiple making task.

C. Majumder [4] ***et al.*** proposed a strategy which minimizes the overall energy consumption of cognitive nodes when they involve in transmitting data and therefore the transmitting power of cognitive sensor node needed not more than 20 dBm. A few number of study exist on low complexity robust algorithm to determine the OPS. They formulated a joint optimization problem which is further simplified to determine the OPS. To estimate the OPS they organized two algorithm based on Exhaustive Search (ES) and low complexity Karush-Kuhn-Tucker (KKT). To evaluate the performance, they proposed an algorithm with its cognitive features which is incorporated into a distributed time-slotted channel access scheme.

Wu [5] ***et al.*** presented a comprehensive definition for CIOT which is inspired by the effectiveness of human cognition. They argued that only connection is not enough, they believe general objects should have the ability to learn, think, understands both physical and social worlds by themselves. Basically their purpose was to create bridging between the physical world (with objects, resources, etc.) and the social world (with human demand, social behavior, etc), to form an intelligent physical-cyber-social (iPCS) system and also enabling network operation and intelligent service provisioning.

Moon [6] ***et al.*** proposed dynamic spectrum access strategy for IOT applications for the cellular network and cognitive radio-enabled low power wide area networks (CR-LPWANs) operating in both licensed and unlicensed bands. Using CR-LPWANs, each IOT device can sense the unused spectrum in both licensed and unlicensed spectrum bands. His aim is to maximize the spectrum capacity for unlicensed cognitive radio-enabled IOT networks and also ensure that it never interfaces with the licensed networks.

Otermat [7] ***et al.*** presented in their paper that FM radio range is underutilized that have gigantic populace and these areas have empty FM radio range of no less than 13 MHz with adequate range dividing between neighboring FM radio channels. The range dispersing gives the expected transfer speed to information transmission and gives enough data transfer capacity to limit obstruction presented by neighboring anticipated and unpredicted FM radio stations also, other low-control short-go IOT gadgets. To guarantee that low-control short-run IOT gadgets keep up dependable interchanges empty radio range, for example, the FM radio range in these zones, should be utilized through psychological radio. The fast development of the IOT has introduced another class of low control short-go remote gadgets that require radio range for the trading of data. The quick development of IOT is putting an extraordinary interest on the radio range. To conquer this interest, low-control short-go IOT gadgets need to grasp new also, creative advancements for the trading of data. Intellectual Radio (CR) a gadget to change its transmission parameters, for example, recurrence and transmit control, to gain by the states of the empty radio range. IOT gadgets that utilize CR innovations, CIOT gadgets, would accept the job of an optional client concerning the essential permit holder of the empty range. Optional use, or auxiliary permitting, of empty range should be conducted in a way that limits obstruction to the essential client. The information are broke down to figure out which areas give unallocated FM radio range than can be utilized for the optional permitting of low-control short-go CIOT gadgets.

## 1.3 Motivation

IOT network has been proposed for many years but due to the spectrum scarcity problem when performing the many devices then Cognitive IOT has been advocated. It is a complex process when four IOT component-person, intelligent objects, technological ecosystem and process performs for making it happens in physical terms and all these process occurs within a security system. Now energy harvesting is now a fascinating area of research which is not only useful for sensors, used in IOT based devices but also a challenge when the whole world is looking for the green energy as an alternative source. In our paper we propose Radio Frequency for converting it into energy which is not an old process but the easiest way to produce energy. The idea of using RF energy technologies will help to improve the white merchandise and mechanical scene kindness of their keen usefulness, green maintainability and generally higher effectiveness .We actually analyses a system model of Cognitive IOT where energy is harvesting from RF in a relay node data is securely transfer from source to destination along with the harvested energy. There are lots of techniques to use in the relay but we use Time Splitting (TS) and Power Splitting (PS) policy for transferring data and energy. Generally TS and PS policy is a receiver based architecture which is used in the relay node and we investigate the performance on how it processes the data and energy harvesting for destination source.

## 1.4 Objective of Thesis

The goal of this research is to investigate the performance of energy harvesting and information processing in cognitive IOT network model through a node. To meet the goal, the following objectives have been identified.

1. To review a network model of CIOT.
2. To analyze process of harvesting energy from the RF.
3. To analyze the PS and TS receiver based architecture in relay node.
4. To derive mathematical expressions of Instantaneous power splitting (INT-PS), Pre-coded power splitting (PRE-PS), Instantaneous time splitting (INT-TS) and Pre-coded time splitting (PRE-TS). For identifying their performance we analyses SNR value and Capacity Value against Ps [dBm], $\eta$, $\rho$ and $\tau$.

## 1.5 Organization of Thesis

Chapter-1 contains principle characteristics of IOT and CIOT and their powerful influence on human activities. This chapter also discussed about the previous contribution of different authors related to CIOT, energy harvesting and energy consumption.

Chapter-2 contains the energy efficient techniques which we can relate into green communication. The execution of any remote correspondence frameworks is exceedingly subject to the spread channel thus a point by point information of radio engendering is essential for improvement of remote interchanges. Secondly, the basic concepts of two way reliable communication has been illustrated with mathematical model based on QOS requirements for selecting IOT devices. Thirdly, we list the operation modes of RF energy scavenging. In addition to, we have also listed the homogeneous and heterogeneous RF sources. At last, this chapter covers the millimeter waves, small cell network, massive mimo, femtocell, beamforming and full-duplex methods to achieve 5G network.

In chapter-3, we derived the energy harvesting and information processing equation of Intuitive secure scheme based on Power Splitting (INT-PS), Pre-coded secure scheme based on Power Splitting (PRE-PS), Intuitive secure scheme based on Time Splitting (INT-TS) and Pre-coded Secure scheme Based on Time Splitting (PRE-TS) .

In chapter-4, we simulated the equations in Mat lab to get SNR value and Capacity value against different variable such as power Ps [dBm], energy transform efficiency $\eta$, power splitting factor $\rho$ and time splitting factor $\tau$ at different points. Finally, we analyzed the data to find out which one has high performance and which one has low performance based on their SNR value.

Chapter-5 presents the concluding remarks of all the chapters and highlights some possible tasks for further development.

## Chapter 2

# ENERGY HARVESTING, EFFICIENCY AND GREEN COMMUNICATION

## 2.1 Introduction

We have never try to make ourselves understand that everything we are using for our day to day life is because of the groundbreaking advancements in wireless sensor networks (WSNs). We do not need to know about themselves but we definitely need to be conscious of internet of things (IOTs). It has become one of the most conceivable technologies for different kind of services and many more applications. An IOT network can be defined as a network of physical objects, devices ,vehicles and other items that are interconnected with different kinds of micro-controllers, equipped with transceivers and embedded with protocols for the dissemination of their sensing and control information. In addition to, there are some important issues that are interconnected with energy harvesting and efficiency such as huge data rate, increased price of energy and ecological impact of carbon. Therefore, energy harvesting and efficiency are leading us to a new era of communication which is called Green communication. In this paper, we are going to survey various techniques of power optimization. Thus, our primary focus is on the use of relays and simultaneous wireless information and power transfer (SWIPT) to improve the energy efficiency of the network. Some energy efficiency techniques which we are going to use in our paper:

- Simultaneous Wireless Information and Power Transfer
- Millimeter waves
- Small Cells

- Massive MIMO
- Relays

## 2.2 Simultaneous Wireless Information and Power Transfer (SWIPT)

Wireless Power Transfer (WPT) introduced people not only communicate in a short distance but also initially they represented long distance transmission. After a time being, it became necessary to experiment with other alternative wireless information and power transfer techniques. On the other hand, radio frequency energy harvesting (RF-EH) allows wireless nodes to recharge their batteries from receiving radio frequency signals [9]. Instead of using fixed power grids or any other power transfer sources radio frequency (RF) harvest energy from ambient electromagnetic sources which represents simultaneous process of information and power transfer [11]. Therefore, with this communication system we are emerging our life style into fifth generation (5G) system .Moreover, conventional forms of renewable energy can also be applicable for green energy transfer.

- Time Splitting
- Power Splitting
- Antenna Switching
- Partial Switching

## 2.3 Relays

Relays in a system network are one of the most important agent if the system depends on the system capacity and the coverage area between Base Station (BS) as well as Relay Node (RN) [10]. Line of sight communication can easily reduce the problem between longer and shorter path thus it can reduce the power required for transmission [9]. Foremost in order, one way based relay schemes were used between a certain time periods therefore, it has become more significant to survey on different Relaying mechanisms [9].

- One Way Relaying (OWR)
- Two Way Relaying (TWR)

### 2.3.1 Two Way Relaying

For enabling additional energy efficiency and to forward more data to the destinations, two way relaying scheme is more coherent due to its potentiality. Everyone has tried to convoy on how to effectuate higher throughput with a lower power consumption [9]. As a result, two way relaying scheme is more efficient to gain more throughput.  In addition to, researchers prefer two way relaying scheme than one way. Two way relaying scheme recommended only two phases for communicating between two terminals whereas one way relaying process needs four phases to communicate with two terminals. In two way relaying process, sources of the network system try to transmit their signals to relays [9]. Subsequent to, one of the relaying strategies either amplify and forward (AF) or decode and forward (DF) are used to broadcast the signals to the destination terminal [13]. With the exception of, compress and forward (CF) is another relaying strategy which follow the quantization process [13].

### 2.3.1.1 Decode and Forward

In this protocol, the Decode and Forward relay takes energy from the source signal [13]. Multiple source-destination pairs are added via one DF Relay node which is wireless powered by multiple source-destination nodes [13]. Outage performance is analyzed under various transmission power allocation strategies for forwarding information from the relay node to destination node. In the first step, the relay decodes the source message in one block and thus, it sends the re-encoded message in the next step. DF is more complex on the other hand, it simplifies the relay selection and rate control [13]. In the end, DF protocol is a protocol that is not capable of providing more transmission and hence Energy consumption is decreasing.

### 2.3.1.2 Amplify and Forward

The Amplify and Forward relay protocol is a protocol which defines wireless cooperative communications. Cooperative communication improves the overall system network remains in the Relay [13]. As discussed in [2.3.1.1], AF is much simpler to implement than DF. In this scheme, the relay at first receives a signal which it amplifies in the last time slot. Thus, the relay sends an amplified version of receives signals. However, it is more challenging to design relay selection and rate control algorithms for AF techniques [13].

### 2.3.1.3 Compress and Forward

Within the quantization process, Compress and forward relaying at first receive a signal which further encoded [13]. Therefore, new encoded version of quantized received signal has been promoted which definitely needs more delay.AF desire much less power consumption than DF and CF [13]. On the other hand, AF did not require any quantization process nor decoding process.

## 2.4 Mathematical Model of Transmitting Signals from Relays

Let us consider, a mathematical model consisting of a half-duplex relay with AWGN and let denote the first time slot. At first, we need to consider a source signal which can be a base station or a mobile node. We are considering a source signal $x_s$ [a], received signals at the relay $[a]$, therefore a destination signal $y_d$ [a].

$$y_r[a] = \sqrt{P}_s g_{s,r} x_s[a] + z_r[a] \tag{2.1}$$

We are going to take two time slots. In the above equation [2.1], we will observe the signals related with source and receive signal.

$$y_d[a] = \sqrt{P}_s g_{s,d} x_s[a] + z_d[a] \tag{2.2}$$

After that, in the second time slot [a+1], source keeps silent and therefore, Relay will be working as a transmitter. The transmitted signals from the relay again retransmit and then for DF relay the retransmitted signals will be working such as the following equation [2.3],

$$[a + 1] = \hat{x}\,[a] \tag{2.3}$$

For AF relay the transmitted signal is represented as equation [2.4],

$$[a + 1] = \beta\,[a] \tag{2.4}$$

$$\beta = \frac{\sqrt{P_r}}{\sqrt{P_s|g_{s,r}|^2 + N_0}} \tag{2.5}$$

After calculating the signal gain, signal to noise ratios need to be calculated as well, Therefore,

$$SNR_{s,d} = \frac{\sqrt{P_s}|gs,r|^2}{N_0} \tag{2.6}$$

$$SNR_{s,d} = \frac{\sqrt{P_s}|gs,r|^2}{N_0} \tag{2.7}$$

$$SNR_{r,d} = \frac{P_r|gr,d|^2}{N_0} \tag{2.8}$$

From the receiving to the destinations, each of the signals from different relays are expressed. From the Destination signal we can find the followings,

$$Y_{r,d} = \frac{\sqrt{P_r}}{\sqrt{P_s|G_{s,r}|^2+N_0}} Y_{r+} Z_{r,d} \quad (2.9)$$

$$y_{r,d} = \frac{\sqrt{P_r}}{\sqrt{P_s|G_{s,r}|^2+N_0}} \sqrt{P}_s G_{r,d} G_{s,r} X_s + Z_{r,d} \quad (2.10)$$

$$N_0^1 = \left(1 + \frac{P_r|G_{r,d}|^2}{P_s|G_{s,r}|^2+N_0}\right) N_0 \quad (2.11)$$

AWGN (Additive White Gaussians Noise) with variance $N_o^1$ given by equation (2.11).

At the destination, there are two signals, one from receiving source and another is from the relay.

The final signal is gained from using Maximal Ratio Combiner and given as follow,

$$y = h_1 y_{s,} + h_2 y_{r,} \quad (2.12)$$

We need to calculate the two of h values.

$$h_1 = \frac{\sqrt{P}_s G_{s.d}^*}{N_0} \quad (2.13)$$

From (2.13) equation, there has been used the conjugate value.

We are going to take the $h_1$ value and put the value into the equation (2.12)

$$h_2 = \frac{\frac{\sqrt{P_r}}{\sqrt{P_s|G_{s,r}|^2+N_0}} \sqrt{P}_s G_{s,r}^* G_{r,d}^*}{\left(1+\frac{P_r|G_{r,d}|^2}{P_s|G_{s,r}|^2+N_2}\right) N_0} \quad (2.14)$$

After observation of the two h values, instantaneous signal to noise ratio from source S to relay selected for reception $R_i$ for in-band and out-band relaying are represented by follows,

$$\sigma SR_i = \frac{G_{SRiP_S}}{G_{Rj\ R_j}+N_0} \geq \sigma_0 \quad (2.15)$$

$$\sigma SR_i = \frac{G_{SRi} P_S}{N_0} \geq \sigma_0 \quad (2.16)$$

$$\sigma R_i D = \frac{G_{Rj} D P_{R_j}}{N_0} \geq \sigma_0 \quad (2.17)$$

$$P_{R_j} = \frac{\sigma_0 N_0}{G_{R_j D}} \quad (2.18)$$

$P_R$ is the power of the relay,

$$P_S = \frac{\sigma_0 (G_{R_j} R_j + N_0)}{G_{SRi}} \quad (2.19)$$

$P_S$ is the power of the source.

For Full duplex transmission, single best relay selection based upon the conjugate value is given by,

$$R = argmin\left(P_S^* + P_{R_j}^*\right) \quad (2.20)$$

Without interference at the relay, the power from source and ma-link relay selection is given by,

$$P_S = \frac{\sigma_0 N_0}{G_{SRj}} \quad (2.21)$$

$$R = argminmin\left\{P_S^*,\ P_{R_j}^*\right\} \quad (2.22)$$

From determining the argument value, it will be helping us to find the best possible way to equipped relay for minimum power usage.

## 2.5 Reliable Communication through relays

The reliability is defined as the probability of transmitting power of each IOT devices over a given channel. For reliable communication, resource allocation is one of the first and foremost scheme to achieve more services to provide. The maximum number of IOT devices present in a network, depend upon an allocation scheme which provides QOS (Quality of Services) to the devices. On the other hand, there must be a link between the IOT devices and IOT-GW (Gateway). Therefore the reliability of the path between IOT devices and IOTGW to be optimized. For improving the performance of a system network, Device-to-device communication (D2D) has become a revolutionary technology. The only communication that provides Connectivity between IOT devices and the associated IOT-GW.D2D communication is the only way to provide not only connectivity but also the reliability between the links. The network performance of a system depends upon the increasing access rate, Sum throughput and average link reliability of IOT devices.

## 2.6 Energy Scavenging of IOT Device

Energy Scavenging is the process of grasping the power from various aspects of external sources, apprehend and accumulate the power. External sources can be defined as an ambient energy such as solar energy, Kinetic energy, Thermal energy, salinity gradients and the large amount of Electromagnetic energy exists in the environment. The Energy that has been stored is used for Wireless Sensor Networks (WSNs), wearable electronics devices, small autonomous devices as well.

As a consequence, we are trying to focus on the ambient energy in this paper which is being used in every aspects of telecommunication sectors at this present era. According to all communication aspects, WSNs do not have a direct means to receive power for operation. Researchers have been investigating various energy harvesting methods pivot on the nature of ambient radio-frequency sources. An IOT device with a fixed antenna can harvest energy only from a single band. Therefore, it is being appreciated if we think about a viable solution. A cognitive radio (CR) technology, has already been using throughout the world. This is an independent technology which fulfills the desired Quality of Services (QOS) of IOTs. On the other hand, it has one of the most remarkable features. It can easily exploit both the licensed and unlicensed spectrums. There are basically two classifications of ambient RF sources which will also be described in our paper.

### 2.6.1 Homogenous RF Sources

In homogeneous RF process, all the sources of the specified network will be working or transmitting on the same frequency band [16]. Therefore, energy harvesting can easily be optimized if RF harvester tune themselves whatever the frequency band desires.

### 2.6.2 Heterogeneous RF Sources

On the other hand, Operating on different spectrum bands with same or different power levels is one of the most important feature of RF sources [16]. For optimizing maximum energy harvesting an association mechanism needs to be operated [16]. As a result, harvesting sources are needed and they also need to tune themselves with the associated antennas.

### 2.6.3 Energy Scavenging Model

In heterogeneous RF process, RF sources are available to IOT devices for energy harvesting. RF sources can easily operate on different spectrum bands with same or with different power levels [15]. Primary as well as the secondary sources for harvesting energy needs to be considered. An IOT device tune its antenna to the frequency band of the primary sources and therefore stars energy harvesting [15]. As a result, all the other sources available in the network will be transmitting data as secondary RF sources.

Let, we need to consider a sensor node denoted by I from primary sources and from the secondary sources, we can consider another source k, Comparing to the secondary radio-frequency sources, primary radio-frequency sources use higher transmission power. In addition to, they can be available most of the times.

$$E_{i,k}^{th} = \eta P_k \frac{G_k G_i \lambda^2}{\left(4\pi d_{i,k}\right)^{\propto}} \times xt^h \tag{2.23}$$

$$E_i^h = \sum_{z_{1=1,t=1}}^{\bar{p}} E_{i,z1}^{th} + \sum_{z_2=1,t=0}^{\bar{s}} E_{i,z_2}^{th} \quad (2.24)$$

From the second equation, the t differentiate between the primary RF sources if t= 1 and the secondary sources if t = 2. Finally, the overall harvesting energy can be found as follows:

## 2.7 Operation Modes for RF Energy Scavenging

In view of the attributes of reaping reception apparatus of IOT gadgets, Antenna works either in a fixed or psychological and the idea of encompassing (RF) radio recurrence sources [16]. For augmenting vitality collecting, an IOT gadget must be outfitted with intellectual receiving wire [15]. The IOT gadget with intellectual radio wire will work in various groups. Notwithstanding, they are equipped for tuning themselves into the ideal frequencies. Then again, we can without much of a stretch go to an exchange that, gadget outfitted with fixed radio wires will work just in the single band [15]. In this article, we will watch a task methods of Radio Frequency (RF) sources which drives us to find out about the idea of reception apparatuses in the IOT gadgets. In the accompanying table, in view of the multifaceted nature and the necessities, four operational methods of Radio Frequency vitality gathering have been characterized [15].

From the following table, it has been observed that, we have considered both the homogeneous and heterogeneous radio frequency sources. However, IOT device with cognitive antennas will harvest more energy depending on the operational modes.

| Modes | IOTS | RF Sources | Complexity | Requirements |
|---|---|---|---|---|
| **1.** | Fixed Antenna | Homogeneous | Very Low | Switch On |
| **2.** | Fixed Antenna | Heterogeneous | Very Low | Switch On |
| **3.** | Cognitive Antenna | Homogeneous | Low | Tuning |
| **4.** | Cognitive Antenna | Heterogeneous | Medium | Tuning And Clustering |

**Table 2.1: Operational Modes for RF Energy Scavenging [15]**

## 2.8 Green Communication

Telecom vendors as well as operators are moving towards green telecommunication networks [19]. Therefore, it has become a vital part for today to inquire the aspects of green communication. In addition to, network of green communication requires renewable energy sources which we can relate with Wind energy as well as solar energy. As per as the topology of a green network, the agile basis bases and FEMTO cells have been used [22]. There are some number of sites and these sites are working all day long continuously. Thus, it is being required to save energy. For evolving Green communication, a standard wireless sensor network is required. It can help to make sure all sensors and controls are interchangeable and therefore, it will help to increase efficiency of energy use. Every new generation of wireless networks delivers faster speeds and more functionality to our smart phones. For instance, 1G brought us the very fast cell phones to us [20]. Secondly, 2G helped us to text from one corner to another. In addition that, 3G brought us to make ourselves easy by introducing online communication and 4G delivered the speeds that we are enjoying today. Owing to the fact that, more users come online 4G networks have just about reached the limit of what they are capable of at a time when users want even more data for their smart phones and devices. As a consequences, we are heading our lives towards 5G network which is considered as the next generation wireless of communication. One of the most important features of 5G network is, it will be very helpful as it is being able to handle a thousand times more traffic than today's network. Therefore, it will be ten times faster than 4G LTE. For instance, downloading an HD movie under a second.5G network will be the foundation of virtual reality autonomous driving the internet of things. At present, there are 5 brand new technologies emerging as a foundation of 5G which leading our lives towards Green communication [19].

### 2.8.1 Millimeter Waves

On the presumption that, on the off chance that we consider the advanced mobile phones or some other electronic gadgets in our home, we can without much of a stretch discover that, quite certain frequencies on the radio recurrence range commonly those under 6 Giga-hertz however these frequencies are beginning to become increasingly busy, Carriers can just crush to numerous bits of information on a similar measure of radio recurrence range as more gadgets come online we are going to begin to see slower administration and more dropped associations. The arrangement is to open up some new land so analysts are exploring different avenues regarding broadcasting on shorter millimeter waves those that fall between 30 to 300 Giga-hertz [26]. This segment of range has never been utilized in any sorts of electronic gadgets. Then again, there is a confinement that millimeter waves cannot go through structures or different deterrents and they will in general be seen by plants and downpour. To get around from this specific issue, specialists are attempting to utilize little cell arrange innovation [26].

### 2.8.2 Small Cell Network

Today's wireless networks rely on large high powered cell towers to broadcast their signals over long distances. Higher frequency millimeter waves have a harder time travelling through obstacles which means moving here and there, it will lose its signals. Small cell networks would solve this problem using thousands of low power mini base stations [19]. Therefore, these base stations will be much closer together than traditional towers forming a sort of relay team to transmit signals around obstacles. When a user move behind an obstacle, his smart phone will automatically switch to a new base station in better range of his device allowing him to keep his connections.

### 2.8.3 Massive MIMO

MIMO stands for Multiple-Input Multiple-Output. 4G base stations have about a dozen ports for antennas that handle all cellular traffic. On the other hand, massive MIMO base stations can support about a hundred ports. As a result, it could increase by the capacity of today's network. Massive MIMO comes with its own complications [26]. At present, cellular antennas broadcast information in every direction at once. The surroundings crossing signals would cause serious Interface.

### 2.8.4 Beamforming

Beamforming resembles a traffic flagging frameworks for cell motions as opposed to broadcasting toward each path, it would enable a base station to send a center stream of information to a particular client [23]. Subsequently, this accuracy avoids impedance and it is far more effective than some other procedures. For this situation, progressively proficient methods the stations could deal with all the more approaching and active information streams without a moment's delay. For example, a client is remaining in a bunch of structures and he is attempting to make a telephone call. After here and there, it is being seen that the flag is ricocheting off of encompassing structures and jumbling with different signs from clients in that particular territory. A Massive MIMO based station gets these signs and keeps track of the planning and the heading of their landing [26]. In this manner, it utilizes flag preparing calculations to triangulate precisely where every flag is coming from and plots the best transmission course back through the air to each telephone. At times, it will even bob singular parcels of information in various ways off of structures or different articles to shield signals from meddling with one another. Therefore, a sound information stream sent just to the client who was attempting to make a telephone call which will tend us to the new innovation which is Full-Duplex.

### 2.8.5 Full-Duplex

At once being, when individuals were utilized tocarrywalky-talkative, they needed to alternate talking and tuning in so as to convey [19]. The present cell base stations have a similar hold up. A fundamental receiving wire can just complete one occupation at once either transmit or get [22]. This sort of strategies called correspondence which is the inclination for radio waves to travel both forward and in reverse along a similar recurrence. For example, in the event that we think about a wave like train stacked up with information, the recurrence it is going on resembles the train track and if there is a second train attempting to go on the other way on a similar track then we will watch an obstruction. Thus, on the off chance that we need to make an answer of this issue, we have to put every one of the trains on various tracks or frequencies. What's more that, we can make that progressively proficient by working around correspondence? Researchers, have recommended silicon transistors to make fast switches that stop the retrogressive job of these waves.

Analysts are as yet working out a large number of the crimps with millimeter waves, Small cell systems, Massive MIMO, Beam framing and Full-Duplex [26]. Truth be told, all of 5G is as yet a work in advancement. It will probably incorporate other new advances as well. Making these frameworks cooperate will be an entire other test yet in the event that specialists can make sense of that ultra-quick 5G administration could land in the following five years.

# Chapter 3

# PERFORMANCE ANALYSIS OF ENERGY HARVESTING IN COGNITIVE IOT

## 3.1 Introduction

A (CIOT) network has been proposed where the (IOT) device acts as a secondary user. Cooperative jamming which is used by authors to achieve secure transmission. The sensor node acts as the secondary user. The secondary system transmitted information to a full duplex wireless energy harvesting (EH) node. Energy harvesting (EH) secure schemes are based on the assumption that the nodes are trusted. For numerous PLS schemes authors adopted a successive amplify and forward relaying scheme. The inter-relay interference was used to jam the untrusted nodes. A multi-hop line network was considered where each node received signals transmitted by its neighbors.

Kalamkar investigated the problem of secure co-operative communication with the help of a wireless energy harvesting (EH) untrusted node. For this destination, aided co-operative jamming was used.

## 3.2 System Model

The viewed CIOT network is proven in Figure 3.1, where an IOT network works as the secondary network, and the main community has an essential receiver P. The main transmitter is positioned a ways away from the IOT community as in [1]. Therefore, there is no interference from the fundamental transmitter to the IOT network. In the secondary IOT network, an IOT machine S which we denoted as source and that will try to transmit to the Destination, D through an EH untrusted relay node R.

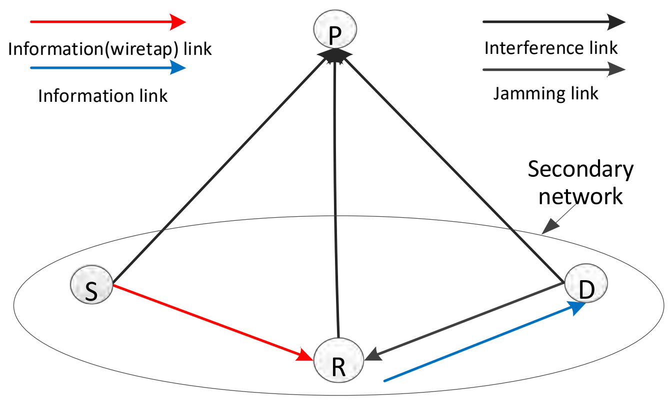


**Figure: 3.1 a brief system model of CIOT network [1]**

Each node of the energy harvester is geared up with a single antenna and works in half-duplex mode. Figure 3.1 is a brief system model of CIOT network where S is denoted as source, R is denoted as relay and D is denoted as destination point. Channel reciprocity is assumed as in [1]. For secondary transmissions, the interference with the important receiver P is required to be beneath the interference threshold T. Power splitting (PS) and Time splitting (TS) primarily based receiver-architecture are used at R. Figure 3.2 With power splitting P the statistics receiver and the energy receiver are each in on mode for a period of T. The relay splits the received power into two purposes. One of them are, energy harvesting at the relay node and another will be working as the information processing and transmission.

## 3.3 Secure Schemes based on PS Policy

The primary advantage of this policy is the ability to save conductor material via a single-ended single phase system which only requires a single phase supply in the distribution transformer [18].

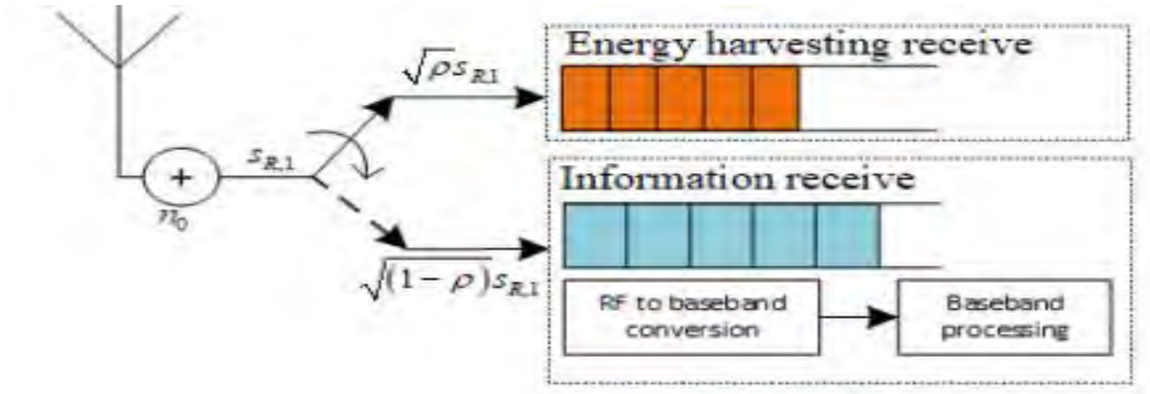


**Fig 3.2: Power Splitter [1]**

In the figure of PS policy, a transmission period of T. T is divided into two phases with equal durations. Here S and D transmit simultaneously to R with power $P_s$ and $P_d$ respectively. D is used an energy source to R. In fig. 3.1, the RF signals that are received for information decoder and RF energy harvester are divided into two streams and have different power levels. The amount of RF signal in the energy harvester is denoted by ρ and information receiver is denoted by 1 – ρ. In this thesis downlink SWIPT is considered from the base station or the access point from the RF powered device. The device is capable of performing energy harvesting and information decoding at the same time because of the power splitting architecture.

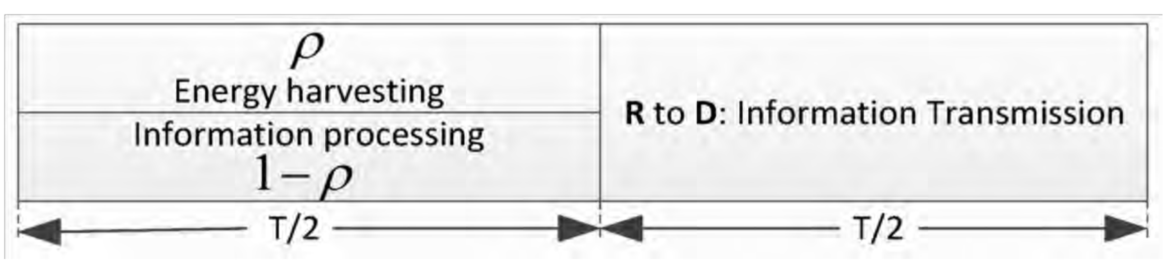


**Fig 3.3: The PS Policy [29]**

In the PS policy Figure (3.2), let T be the transmission period which is divided into two equal phase. Here S and D can be seen to transmit simultaneously to R with power $P_s$ and $P_d$ respectively. D is used as an energy source to R.

### 3.3.1 Energy Harvesting and Information Processing of Int-PS

At first, the energy harvester node will be working in the relay node.

Therefore,

$$E_H{}^{INT-PS} = \boldsymbol{\eta}\, \rho(P_s|h_{SR}|^2 + P_D|h_{DR}|^2)\frac{T}{2} \tag{3.1}$$

Where,

Now, the harvested energy can be expressed as

$||h_c||^2$ is the channel power gain

$g_c$ is the exponential distribution

$f_{|hc|}2\ (x)$ is the probability density function

Now the transmit power,

$$P_H{}^{INT-PS} = \frac{E_H{}^{INT-PS}}{T/_2} = \frac{\boldsymbol{\eta}\, \rho(P_s|h_{SR}|^2 + P_D|h_{DR}|^2)\frac{T}{2}}{T/_2}$$

$$= \boldsymbol{\eta}\ (P_s|h_{SR}|^2 + P_D|h_{DR}|^2) \tag{3.2}$$

Where,

$x_s$ is the information signal of unit power

$x_D$ is the jamming signal with unit power transmitted from D

$n_r$ is the additive white Gaussian noise (AWGN) at R

So, the received signal is written by,

$$y_r = \sqrt{(1-\rho)}P_S h_{SR} x_S + \sqrt{(1-\rho)}P_D h_{DR} x_D + n_r \tag{3.3}$$

The signal to interference plus noise ratio (SINR) at R

$$\gamma_R{}^{INT-PS} = \frac{(1-\rho)P_s|h_{SR}|^2}{(1-\rho)P_D|h_{DR}|^2+\sigma_R^2} \quad (3.4)$$

The received signal $y_{p1}$ at the primary user P is written as

$$y_{p1} = \sqrt{P_S}h_{SP}x_S + \sqrt{P_D}h_{DP}x_D + n_{p1} \quad (3.5)$$

The received power of interference plus AWGN at P is written as

$$P_{I1}{}^{INT-PS} = P_s|h_{SP}|^2 + P_D|h_{DP}|^2 + \sigma_{P1}^2 \quad (3.6)$$

Here In the second phase-transmitted power for relay is written as

$$x_r = \beta y_r \quad (3.7)$$

Where,

$$\beta = \sqrt{\frac{P_H}{(1-\rho)(P_s|h_{SR}|^2 + P_D|h_{DR}|^2 + \sigma_D^2}}$$

The received signal at D is written as,

$$y_D = hRDxR + nD$$

$$= h_{RD}\, \beta\sqrt{(1-\rho)}(\sqrt{P_S}h_{SR}x_S + \sqrt{P_D}h_{DR}x_D) + h_{RD}\,\beta n_r + n_D \quad (3.8)$$

Remaining signal can be written as

$$Y'_D = \beta\sqrt{(1-\rho)}P_s h_{SR}h_{DR}x_S + \beta h_{DR}n_r + n_D \quad (3.9)$$

The signal to noise ratio (SNR) at D is written as,

$$\gamma_D{}^{INT-PS} = \frac{\boldsymbol{\eta}\,\rho(1-\rho)P_s|h_{SR}|^2|h_{DR}|^2}{\beta^2|h_{DR}|^2\sigma_R{}^2 + \sigma_D^2}$$

$$= \frac{\boldsymbol{\eta}\,\rho(1-\rho)P_s|h_{SR}|^2|h_{DR}|^2}{\boldsymbol{\eta}\,\rho|h_{DR}|^2\sigma_R{}^2+(1-\rho)\sigma_D^2+\frac{\sigma_R{}^2D^2}{P_s|h_{SR}|^2+P_D|h_{DR}|^2}} \quad (3.10)$$

The instantaneous power interference to P in the second phase can be represented as

$$P_{I2}{}^{INT-PS} = \boldsymbol{\eta}\, \rho(P_s|h_{SR}|^2 + P_D|h_{DR}|^2)\, |h_{RD}|^2 + \sigma_{P2}^2 \quad (3.11)$$

### 3.3.2 Energy Harvesting and Information Processing at Pre-PS

Here, the transmit signals from S and D,

$$x'_S = h_{SR}^{-1} x_s \quad (3.12)$$

$$x'_D = h^{-1}{}_{DR} \quad x_D \quad (3.13)$$

The transmit R becomes,

$$P_H PRE{-}PS = \eta(PS + PD) \quad (3.14)$$

(1-$\rho$) at the received signal in the first phase is used for information processing at R,

$$y_{p1} = \sqrt{P_S}\frac{h_{SP}}{h_{SR}}x_S + \sqrt{P_D}\frac{h_{DP}}{h_{DR}}x_D + n_{p1} \quad (3.15)$$

The SINR at R is written as

$$\gamma_R{}^{PRE-PS} = \frac{(1-\rho)P_s}{(1-\rho)P_{D+\sigma_R^2}} \quad (3.16)$$

The received signal P is written as

$$y_{p1} = \sqrt{P_S}\frac{h_{SP}}{h_{SR}}x_S + \sqrt{P_D}\frac{h_{DP}}{h_{DR}}x_D + n_{p1} \quad (3.17)$$

The instantaneous interference at p,

$$P_{I1}{}^{PRE-PS} = P_S\frac{|h_{SP}|^2}{|h_{SR}|^2} + P_D\frac{|h_{DP}|^2}{|h_{DR}|^2} + \sigma_{P1}^2 \quad (3.18)$$

In the second phase,

$$x_R = \beta y_r \quad (3.19)$$

$$\beta = \sqrt{\frac{P_H{}^{PRE-PS}}{(1-\rho)(P_s + P_D) + \sigma_R^2}} \quad (3.20)$$

The received signal $y_D$ is written as

$$y_D = \beta\sqrt{(1-\rho)}P_S h_{RD} x_S\ \beta h_{DR} n_R + n_D \qquad (3.21)$$

The signal SNR at D is written as

$$\gamma_D{}^{PRE-PS} = \frac{\eta\ \rho(1-\rho)P_s|h_{DR}|^2}{\eta\ \rho|h_{DR}|^2\sigma_R{}^2 + (1-\rho)\sigma_D^2 + \frac{\sigma_R^2\sigma_D^2}{P_s+P_D}} \qquad (3.22)$$

So, the received power at interference plus noise and P can be defined as,

$$P_{I2}{}^{PRE-PS} = \eta\ \rho(P_s + P_D)\ |h_{RP}|^2 + \sigma_P{}^2 \qquad (3.23)$$

## 3.4 TS Policy for Secure Scheme

In the Fig. 3.3 the time-switching figure is operated on a manner that is time slot based. This means, at any given time, the information receiver or the RF energy harvester is connected to the antenna. To be specific, the architecture first harvests energy by using τ amount of time and then decodes information in the remaining 1- τ amount of time using reserved energy from the capacitor.

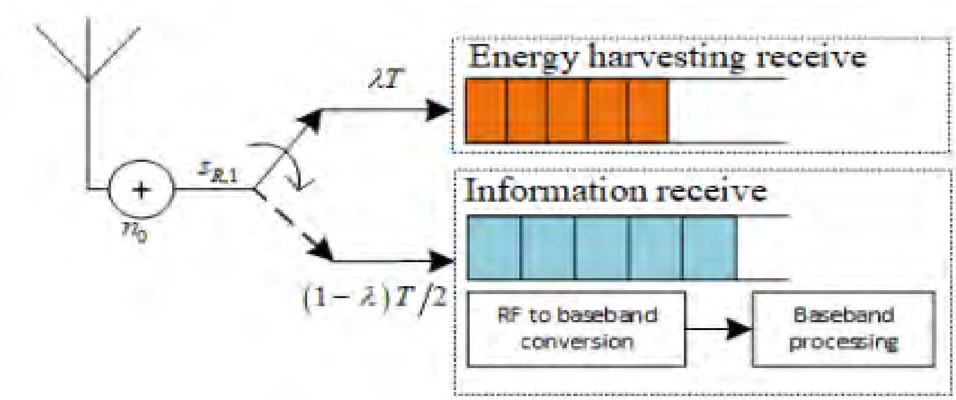


**Fig 3.4: Time Splitting [29]**

For the time-switching architecture, the device alternately performs energy harvesting and information decoding.

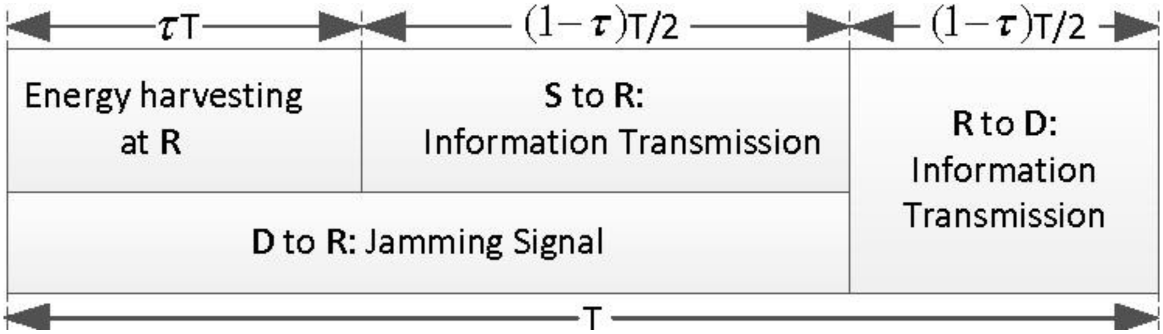


**Figure 3.5: The TS Policy [1]**

Here,

From figure 3.4, τ is the time splitting ratio, S transmit the information, D denotes a jamming signal, R amplifies and forward the received signal to D

## 3.4.1. Energy Harvesting and Information Processing of INT-TS

The harvested energy can be expressed as,

$$E^{\mathrm{HINT-TS}} = \boldsymbol{\eta}\tau\mathrm{T}P_D|h_{DR}|2 \quad (3.24)$$

The transmit power,

$$P_H{}^{INT-TS} = \frac{E_H{}^{INT-PS}}{(1-\tau)\mathrm{T}/_2}$$

$$= \frac{\boldsymbol{\eta}\tau\mathrm{T}P_D|h_{DR}|^2}{(1-\tau)\mathrm{T}/_2}$$

$$= \frac{2\boldsymbol{\eta}\tau\mathrm{T}P_D|h_{DR}|^2}{(1-\tau)} \quad (3.25)$$

Received by R is written as

$$y_R = \sqrt{P_S} h_{SR} x_S + \sqrt{P_D} h_{DR} x_D + n_R \tag{3.26}$$

The received SINR at R is written as

$$\gamma_R{}^{INT-TS} = \frac{P_s |h_{SR}|^2}{P_D |h_{DR}|^2 + \sigma_R^2} \tag{3.27}$$

Received signal at $y_{P1}$ can be expressed as

$$y_{P1} = \sqrt{P_S} h_{SP} x_S + \sqrt{P_D} h_{DP} x_D + n_{P1} \tag{3.28}$$

The instantaneous interference power is written as

$$P^{\mathrm{I1INT-TS}} = PS\ |hSP|2 + PD\ |hDP|2 + \sigma P21 \tag{3.29}$$

Now,

$$x_R = \beta y_R\ ;$$

$$\beta = \sqrt{\frac{P_H{}^{INT-TS}}{P_S\ |h_{SR}|^2 +\ P_D\ |h_{DR}|^2 + \sigma_R^2}} \tag{3.30}$$

At D,

$$y_D = \beta \sqrt{P_S} h_{DR} h_{SR} x_S +\ \beta h_{DR} n_R + n_D \tag{3.31}$$

SNR at D,

$$\gamma_D{}^{INT-TS} = \frac{P_s |h_{DR}|^2 |h_{SR}|^2}{|h_{DR}|^2 \sigma_R^2 + \frac{(1-\tau)\,(P_S\,|h_{SR}|^2 + P_D |h_{DR}|^2 + \sigma_D^2)\sigma_D^2}{2\eta\tau \mathrm{T} P_D |h_{DR}|^2}} \tag{3.32}$$

In the second sublet can be represented as

$$P_{I2}{}^{INT-TS} = \frac{2\eta\tau\mathrm{T} P_D |h_{DR}|^2}{(1-\tau)} |h_{RP}|^2 + \sigma_{P2}^2 \tag{3.33}$$

## 3.4.2. Energy Harvesting and Information Processing of Pre-TS

The transmit power at R,

$$P_H{}^{PRE-TS} = 2\,\frac{\eta\tau P_D}{1-\tau} \tag{3.31}$$

The received signal,

$$y_R = \sqrt{P_S}x_S + \sqrt{P_D}x_D + n_R \tag{3.32}$$

The SNR at R,

$$\gamma_R^{PRE-TS} = \frac{P_S}{P_D + \sigma_R^2} \tag{3.33}$$

After denoting the received signal,

$$y_{P1} = \frac{\sqrt{P_S}h_{SP}}{h_{SR}}x_S + \frac{\sqrt{P_D}h_{DP}}{h_{DR}}x_D + n_{P1} \tag{3.34}$$

Now here at P,

$$P_{I1}^{PRE-TS} = \frac{P_S|h_{SP}|^2}{|h_{SR}|^2} + \frac{P_D|h_{DP}|^2}{|h_{DR}|^2} + \sigma_{P1}^2 \tag{3.35}$$

Where,

$$x_R = \beta y_R\ ;$$

$$\beta = \sqrt{\frac{P_H{}^{PRE-TS}}{P_S\ +\ P_D\ + \sigma_R^2}} \tag{3.36}$$

The received signal at D,

$$y_D = \beta\sqrt{P_S}h_{DR}x_S + \beta h_{DR}n_R + n_D \tag{3.37}$$

The SNR at D,

$$\gamma_D^{PRE-TS} = \frac{P_S|h_{DR}|^2}{|h_{DR}|^2\sigma_R^2 + \frac{(1-\tau)(P_S+P_D+\sigma_R^2)\sigma_D^2}{2\eta\tau P_D}} \tag{3.38}$$

In the second sub slot can be expressed as

$$P_{I2}^{PRE-TS} = \frac{2\eta\tau P_D}{1-\tau}|h_{RP}|^2 + \sigma_{P2}^2 \tag{3.39}$$

# CHAPTER 4

## Result and Discussion

We have reviewed four equations, which are INT-PS, PRE-PS, INT-TS and PRE-TS (i.e. 3.11, 3.21, 3.30, 3.39). We put them on mat lab to generate graph for identifying their performance analysing SNR and Capacity against $P_s$ [dBm], η, ρ and τ.

Performance of higher SNR is good and for lower SNR value the performance will be low. Below we will analyze four graphs and identify which equation among INT-PS, PRE-PS, INT-TS and PRE-TS are performing better by seeing their SNR value.

### 4.1 SNR vs. $P_s$

In the figure 4.1 we can see that there are four variables which are INT-PS, PRE-PS, INT-TS, and PRE-TS. To simulate the Matlab program we have considered n = 0.5; p = 0.5; t = 0.5; T = 1.

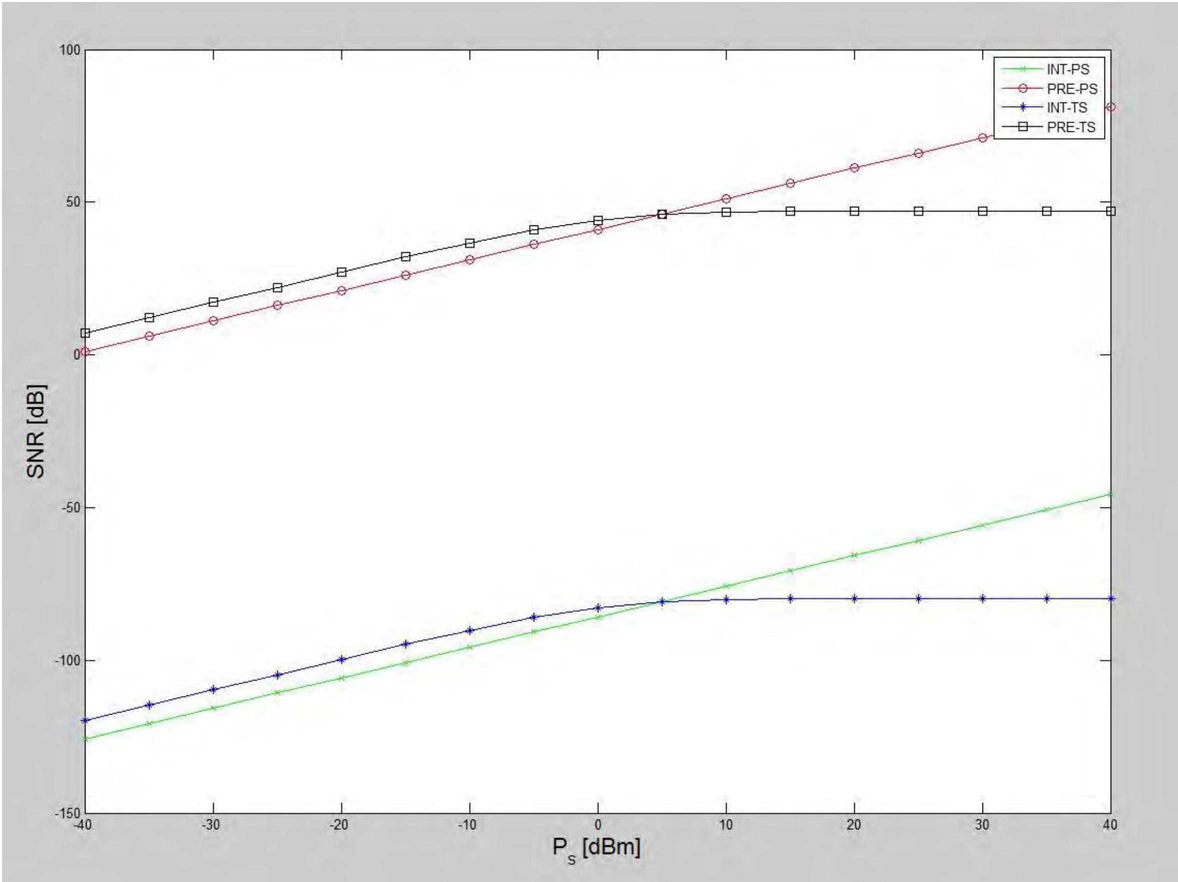


**Fig 4.1: SNR value under various $P_s$**

If we start from the below we can see that,

INT-PS started from approximately SNR = -125 dB and increased linearly to almost SNR= -53 dB.

On the other hand, INT-TS started from SNR= -120 dB. Firstly, it increased linearly up to SNR = -115 dB then it went straight intersecting INT-PS at approximately SNR = -120 dB and $P_s =$ 5 dBm.

In the above portion of the graph, we can see similar activities. PRE-PS in a linear line starting from SNR = 0 dB and ended at SNR = 75 dB. INT-TS went linearly starting from SNR = 5 dB up to SNR = 45 dB. Then it intersected PRE-PS at SNR = 40 dB and $P_s = 5$ dBm, then it went as a straight line.

In addition to, we know performance of lower SNR value is less than higher SNR value. So here, performance of INT-TS will be least and performance of PRE-PS will be highest.

## 4.2 SNR vs. η

In the above figure 4.2 we can see that there are four variables which are INT-PS, PRE-PS, INT-TS, and PRE-TS. To simulate this Matlab program we have considered n = 0:0.1:1; p = 0.5; t = 0.5; T = 1.

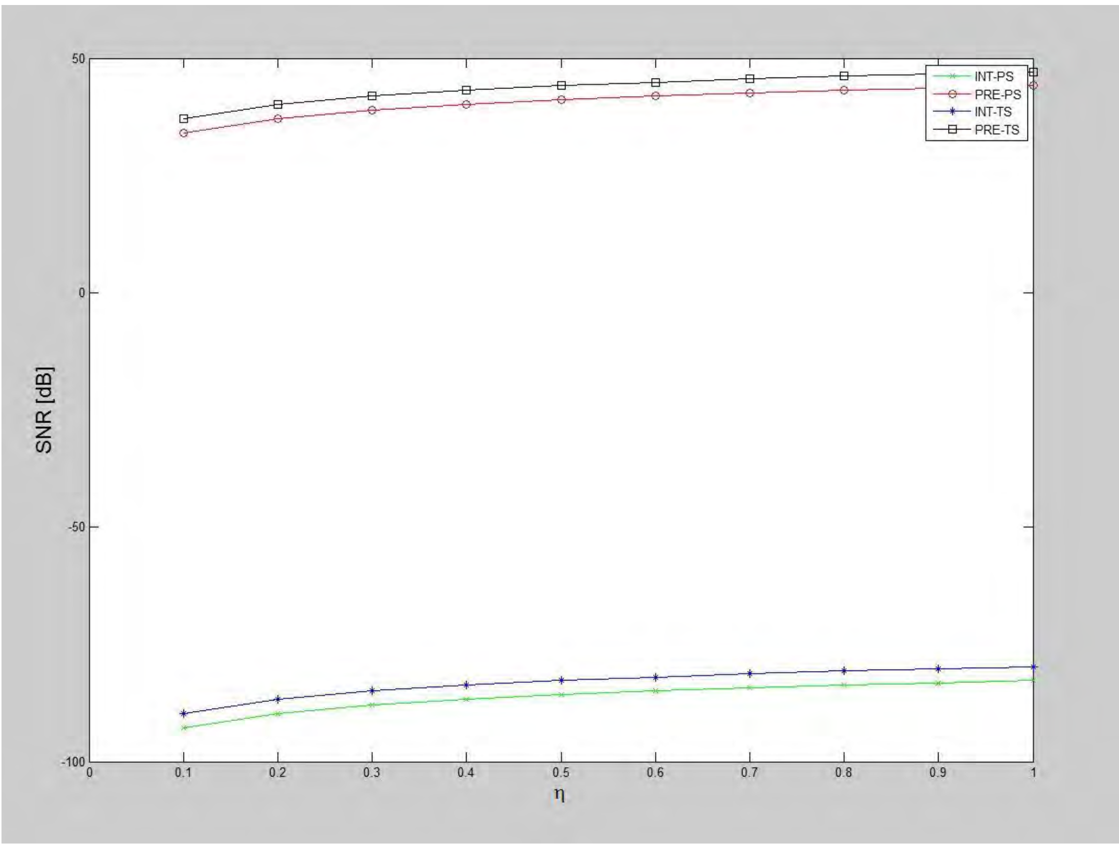


**Fig 4.2: SNR value under various η**

If we start from the below we can see that-

INT-PS started from approximately SNR= -110 dB and slowly increased to almost SNR= -120 dB.

INT-TS started from approximately SNR= -115 dB and slowly increased to almost SNR= -125 dB.

PRE-PS started from approximately SNR = 35 dB and slowly increased to almost SNR = 45 dB.

INT-TS started from approximately SNR = 40 dB and slowly increased to almost SNR = 49 dB.

No intersection can be seen in this graph.

We know performance of lower SNR value is less than higher SNR value. So here, performance of INT-PS will be least and performance of PRE-TS will be highest.

### 4.3 SNR vs. ρ

In the above figure 4.3 we can see only two variables INT-PS and PRE-PS. To simulate the Matlab program we have considered n = 0.5; p = 0:0.1:1; t = 0.5;T = 1.

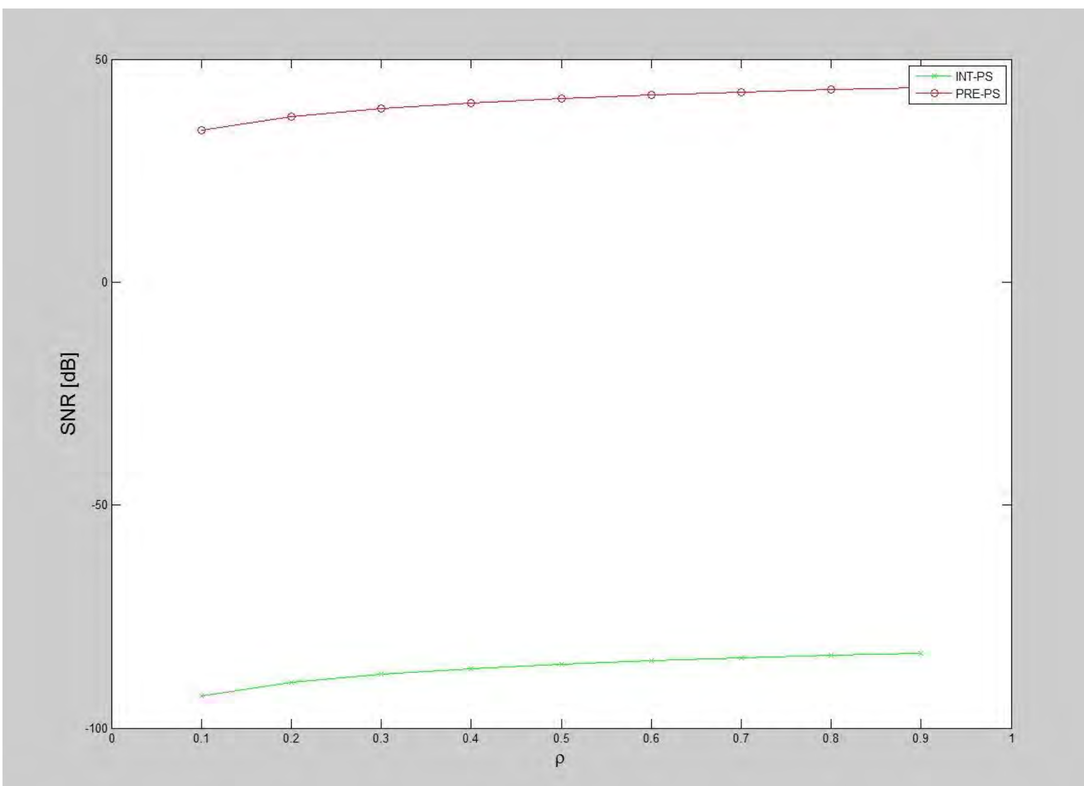


**Fig 4.3: SNR value under various ρ**

Analysing the graph we found that-

In the bottom section, INT-PS started from SNR = -90 dB at $\rho = 0.1$. It slowly increased and ended at $\rho = 0.9$ with a value of SNR = - 80 dB

In the upper section, PRE-PS started from SNR = 35 dB at point $\rho = 0.1$ and ended at point $\rho = 0.9$ with a value of SNR = 45 dB.

No intersection can be seen here.

We know performance of lower SNR value is less than higher SNR value. So here, performance of INT-PS will be least and performance of PRE-PS will be highest.

## 4.4 SNR vs. τ

In above figure 4.4 we can see only two variables INT-TS and PRE-TS. To simulate this Matlab program we have considered n = 0.5; p = 0.5; t = 0:0.1:1; T = 1;

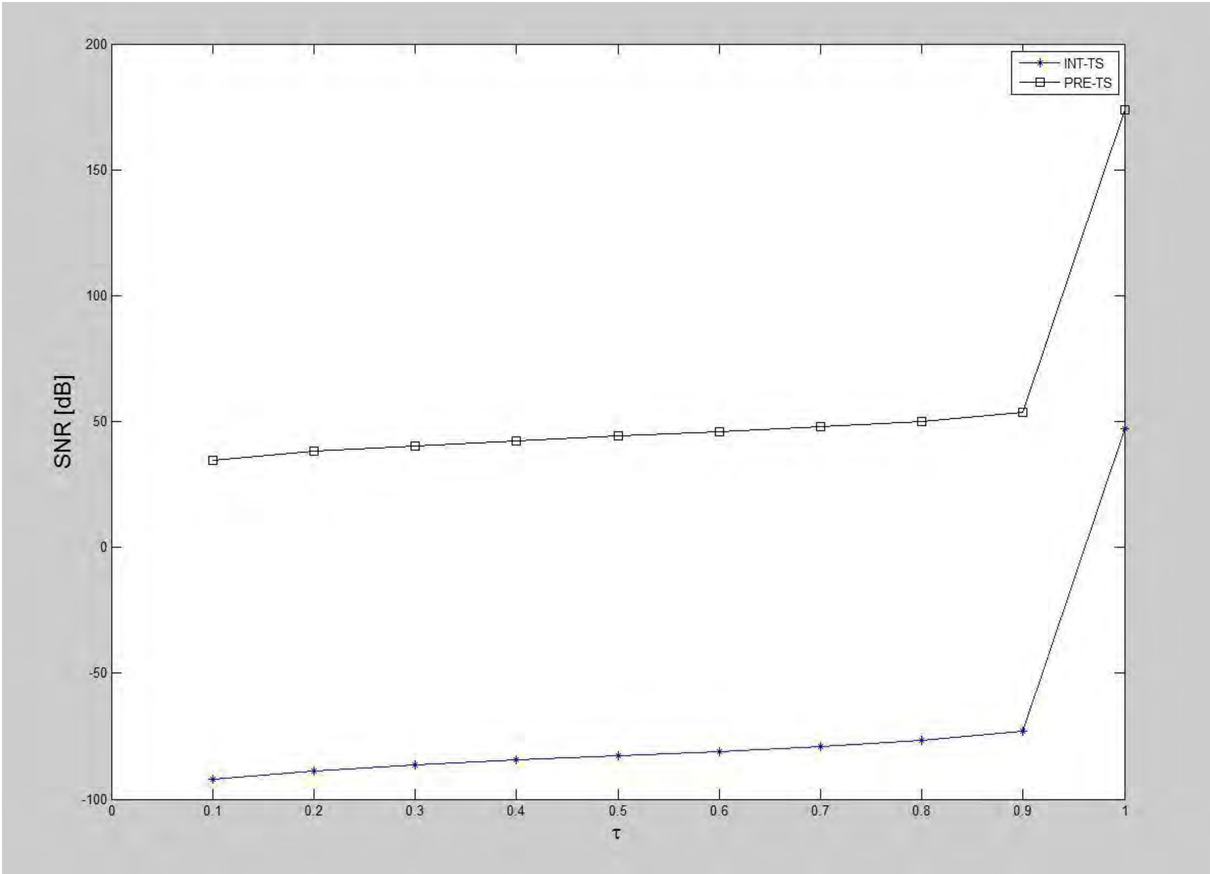


**Fig 4.4: SNR value under various τ**

Analysing the graph, we found that,

In the bottom section, INT-TS started from SNR = -90 dB at τ = 0.1. It slowly increased up to τ = 0.9 with a value of SNR = -80 dB and then suddenly a linearly increase in SNR can be seen.

In the upper section we can see similar activities. PRE-TS started from SNR = 35 dB at τ = 0.1. It slowly increased up to τ = 0.9 with a value of -80 dB and then suddenly a linearly increase in SNR can be seen.

No intersection can be seen here.

We know performance of lower SNR value is less than higher SNR value. So here, performance of INT-TS will be least and performance of PRE-TS will be highest.

## 4.5 Capacity vs. $P_s$

In the above figure 4.5 we can see that there are four variables which are INT-PS, PRE-PS, INT-TS, PRE-TS. To simulate this Matlab program we have considered n = 0.5; p = 0.5; t = 0.5; T = 1.

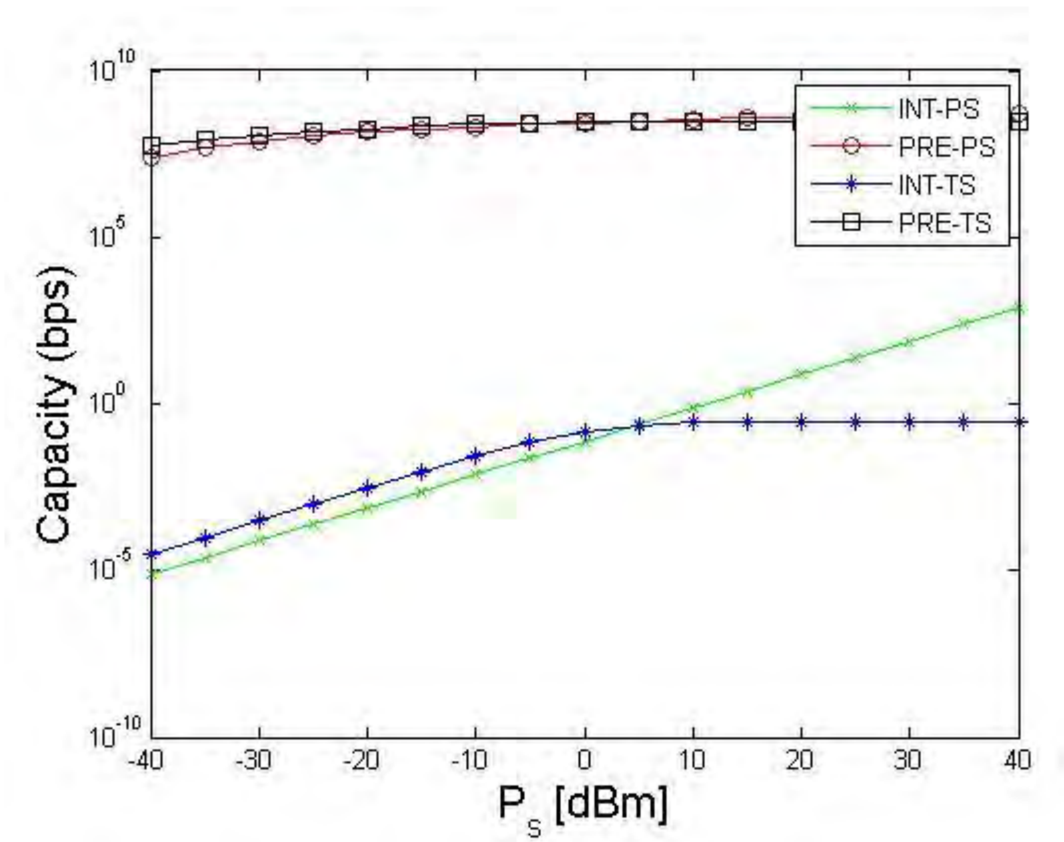


**Fig 4.5: Capacity (bps) value under various $P_s$ [dBm]**

If we start from the below we can see that,

INT-PS started with capacity $= 10^{-5}$ bps approximately and linearly increased to almost capacity $10^{3}$ bps.

INT-TS started with capacity = $10^{-5}$ bps approximately and slowly increased to almost capacity $10^{-1}$ bps and then went as a straight line intersecting INT-PS at $P_s = 5\ dBm$.

PRE-PS and PRE-TS both started with capacity = $10^3$ bps approximately and slowly increased to capacity = $10^2$ bps and went as a straight line.

## 4.6 Capacity vs. η

In the above figure 4.6 we can see that there are four variables which are INT-PS, PRE-PS, INT-TS, and PRE-TS. To simulate this Matlab program we have considered n = 0:0.1:1; p = 0.5; t = 0.5; T = 1.

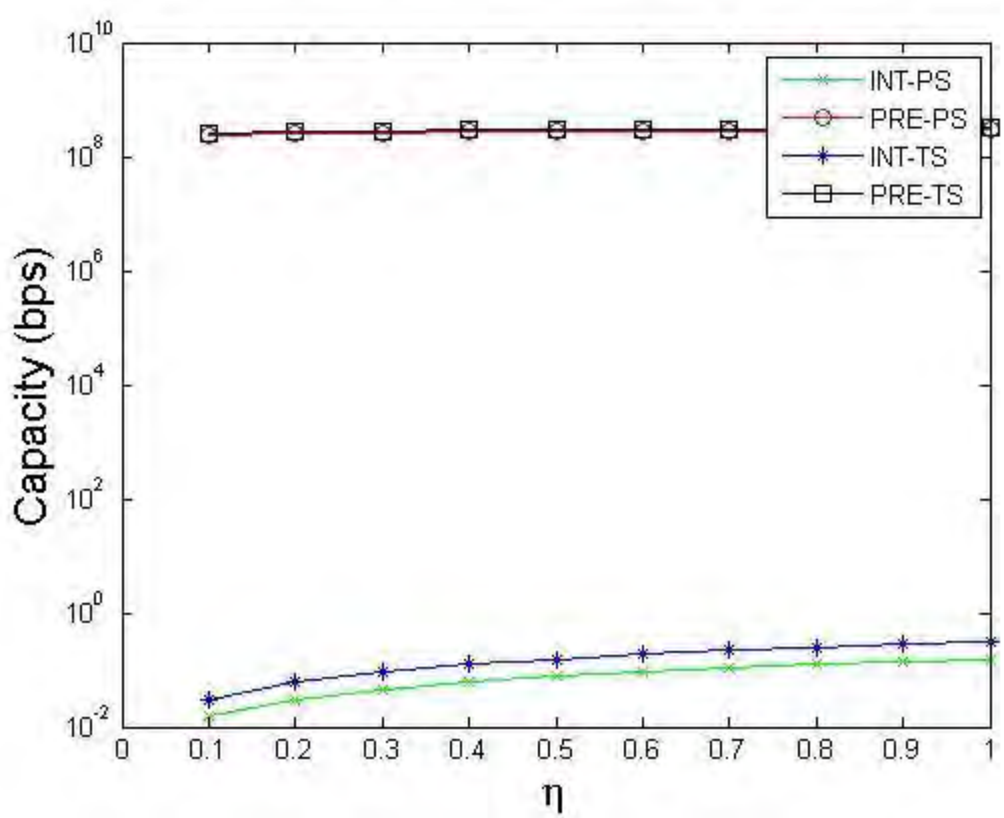


**Fig 4.6: Capacity (bps) value under various η**

If we start from the below we can see that-

INT-PS started with capacity $10^{-2}$ bps approximately at η = 0.1 and linearly increased to almost capacity $10^{-1}$ bps.

INT-TS started with capacity $10^{-2}$ bps approximately at η = 0.1 and linearly increased to almost capacity $10^{-1}$ bps.

PRE-PS and PRE-TS both started with capacity $10^{8}$ bps approximately at η = 0.1 and went as a straight line.

## 4.7 Capacity vs. ρ

In the above figure 4.6 we can see that there are two variables which are INT-PS and PRE-PS. To simulate this Matlab we have considered n = 0.5; p = 0:0.1:1; t = 0.5;T = 1.

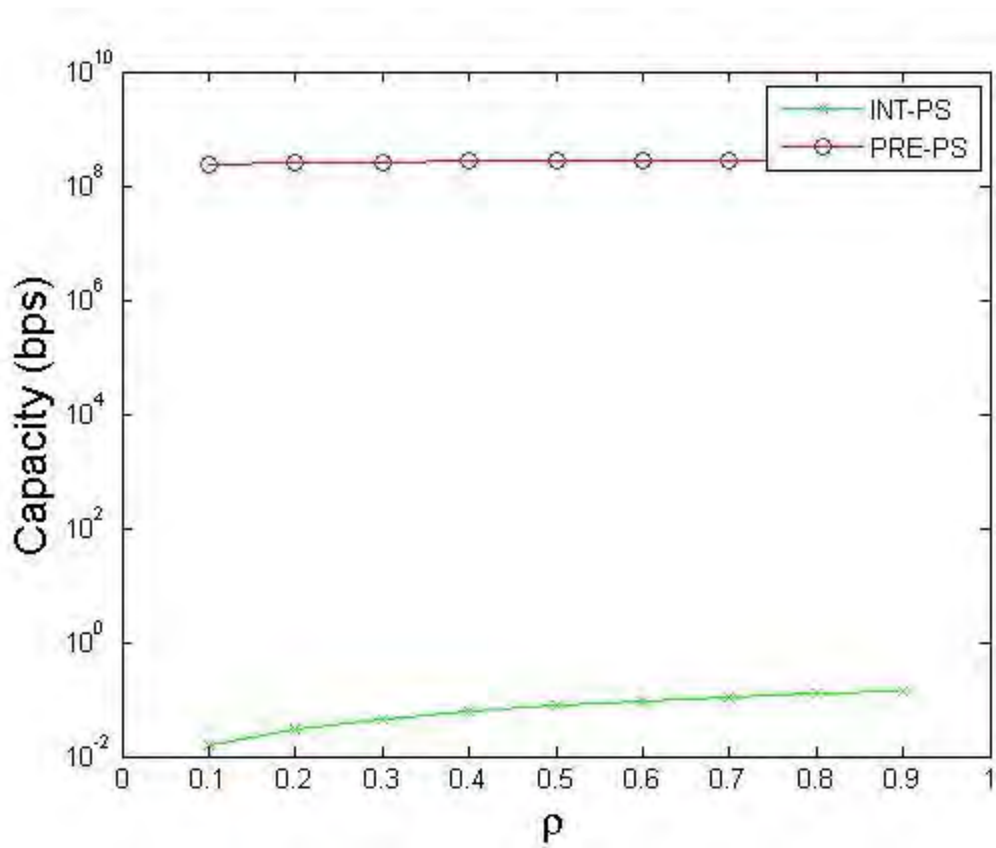


**Fig 4.7: Capacity (bps) value under various ρ**

If we start from the below we can see that-

INT-PS started with capacity $10^{-2}$ bps approximately at ρ= 0.1 and linearly increased up to almost capacity $10^{-1}$ bps at ρ= 0.9

PRE-PS started with capacity $10^{9}$ bps approximately at ρ= 0.1 and went as a straight line up to ρ= 0.9.

## 4.8 Capacity vs. τ

In the above figure 4.6 we can see that there are two variables which are INT-TS and PRE-TS. To simulate this Matlab we have considered n = 0.5; p = 0.5; t = 0:0.1:1; T = 1;

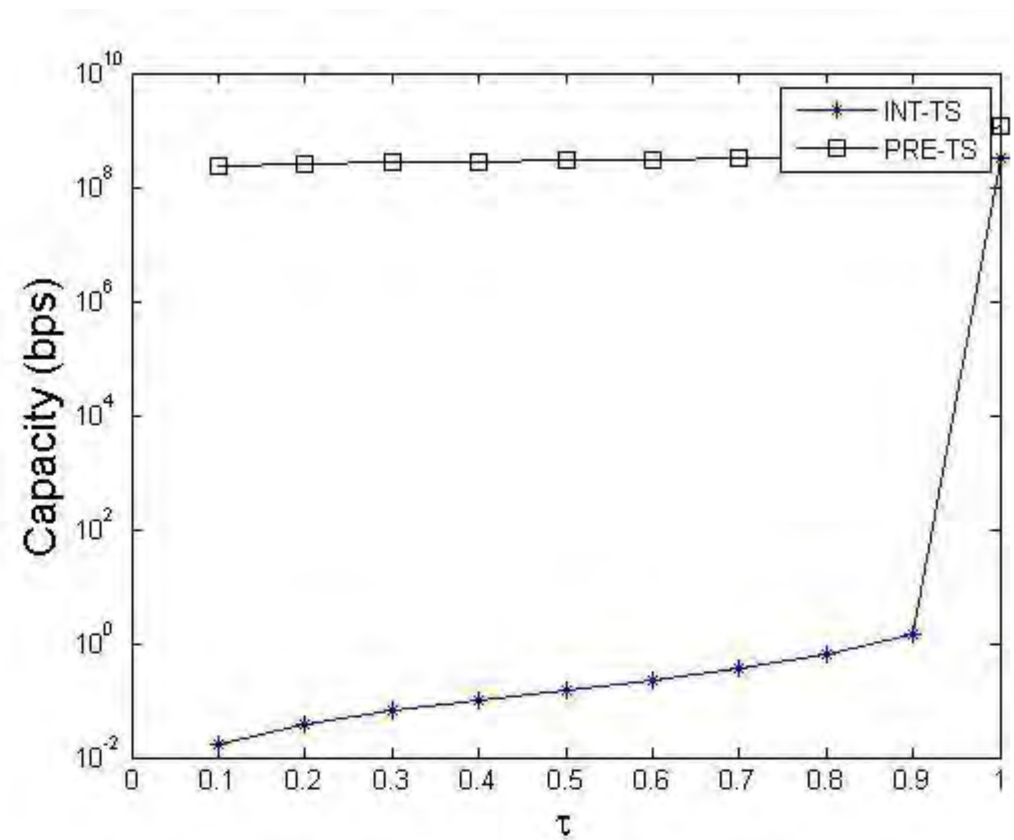


**Fig 4.8: Capacity (bps) value under various τ**

If we start from the below we can see that-

INT-TS started with capacity $10^{-2}$ bps approximately at τ = 0.1, slowly increased up to almost capacity $10^{0}$ bps at τ = 0.9 and then suddenly went to capacity $10^{0}$ bps linearly.

PRE-TS started with capacity $10^{8}$ bps approximately at τ = 0.1 and went as a straight line.

# CHAPTER 5

# CONCLUSION AND FUTURE WORK

## 5.1 Conclusion

We have investigated the performance of transferring data from source to destination using Time-Splitting and Power-Splitting policy along with energy harvesting through a relay. The salient features of our work are summarized below:

- In the case of secure transmitting data through lots of devices we consider a CIOT network model for evaluating SNR and capacity. For this we also need energy for our devices and we consider a relay which has the ability to transfer data securely and investigate the performance of providing harvested energy to the devices following the TS and PS policy.

- For transmitting power and data we have used PS policy in our relay where the RF signals are divided into two streams with different power levels for the information decoder and RF energy harvester and we also used TS architecture, where the device alternately performs energy harvesting and information decoding.

We have investigated four techniques, which are INT-PS, PRE-PS, INT-TS and PRE-TS. For identifying their performance we analyze SNR and Capacity with respect to Ps [dBm], $\eta$, $\rho$ and $\tau$. We know the performance is improvement for SNR value.

The performance result is analyzing below:

1. We get the better SNR value for PRE-PS and least SNR value for INT-TS under various Ps.

2. We get the better SNR value for PRE-TS and least SNR value for INT- PS under various $\eta$.

3. We get the better SNR value for PRE-PS and least SNR value for INT- PS under various $\rho$.

4. We get the better SNR value for PRE-PS and least SNR value for INT- PS under various $\tau$.

## 5.2 Future Works

Using RF frequency for harvesting energy is not new but the simplest process and the TS and PS policy for transferring data and energy through a relay is one of secured and cost effective process. There are still many issues for our CIOT system model that need to be investigated and some of them are discussed as below:

- Non Orthogonal Multiple Access (NOMA) with Time-switching-based-relaying (TSR) wireless sensor network (WSN)-NOMA and Power-switching-based-relaying (PSR) wireless sensor network (WSN)-NOMA can be considered for EH wireless sensor network [29] .

- Physical layer security (PLS) system can be used which is secured for communication security because of its built in security which theoretically unbreakable [1].
- The MIMO-OFDM system can be used which is a promising technique in high data rate wireless communication [30].

## References


[1] H. Hu et al., “Secure Communications in CIoT Networks with a Wireless Energy Harvesting Untrusted Relay” Sensors,2017.

[2] K. Zaheer et al., “A Survey of Decision-Theoretic Models for Cognitive Internet of Things (CIoT)”, IEEE journal on Digital Object Identifier,2018.

[3] C. Majumder et al., “Packet Size Optimization for Cognitive Radio Sensor Networks Aided Internet of Things”. IEEE journal on Digital Object Identifier,2016.

[4] Wu et al., “Cognitive Internet of Things: A New Paradigm Beyond Connection”, IEEE Internet Of things journal, vol. 1, no. 2,2014.

[5] Moon., “Dynamic Spectrum Access for Internet of Things Service in Cognitive Radio-Enabled LPANs”, Sensors,2017.

[6] D. T. Oternet et al., “Analysis of the FM Radio Spectrum for Secondary Licensing of Low-Power Short Range Cognitive Internet of Things Devices”, IEEE journal on Digital Object Identifier, 2016.

[7] R. Han et.al., “An Effective Multi-Objective Optimization Algorithm for Spectrum Allocations in the Cognitive-Radio-Based Internet of Things”, IEEE journal on Digital Object Identifier, 2016.

[8] Y. Zou; X . Wang,; W. Shen, “Optimal relay selection for physical-layer security in cooperative wireless networks” *IEEE J. Sel. Areas Commun.* 2013, *31*, 2099–2111.

[9] I. Krikidis; J. S. Thompson,; S . Mclaughlin, “Relay selection for secure cooperative networks with jamming”.*IEEE Trans. Wirel. Commun.* 2009, *8*, 5003–5011.

[10] P. N. Son.; D. Har; N. I. Cho ; H .Y. Kong, “Optimal power allocation of relay sensor node capable of energy harvesting in cooperative cognitive radio network”. *Sensors* 2017, *17*, doi: 10.3390/s17030648.

[11] W. Wang; K. C . Teh, ; K . H . Li, “Relay selection for secure successive AF relaying networks with untrusted nodes”. IEEE Trans. Inf. Forensics Secur. 2016, 11, 2466–2476.

[12] H. S. Nguyen; T. S. Nguyen; V. T. Vo; M. Voznak, “Hybrid full-duplex/half-duplex relay selection scheme with optimal power under individual power constraints and energy harvesting”. Comput. Commun. 2018, 124, 31–44.

[13] N. T. Do; V. N. Q. Bao; B. An, “Outage Performance Analysis of Relay Selection Schemes in Wireless Energy Harvesting Cooperative Networks over Non-Identical Rayleigh Fading Channels”. Sensors 2016, 16, 295.

[14] A. A. Nasir; X. Zhou; S. Durrani; R. A. Kennedy, “ Relaying protocols for wireless energy harvesting and information processing”. IEEE Trans. Wirel. Commun. 2013, 12, 3622–3636.

[15] S. S. Kalamkar ; A. Banerjee, “Secure communication via a wireless energy harvesting untrusted relay”. *IEEE Trans. Veh. Technol.* 2017, *66*, 2199–2213.

[16] A. Sun; T. Liang; B. Li Secrecy performance analysis of cognitive sensor radio networks with an EH-based eavesdropper. *Sensors* 2017, *17*, doi:10.3390/s17051026.

[17] Khan, A.A.; Rehmani, M.H.; Rachedi, “A Cognitive-Radio-Based Internet of Things: Applications, Architectures, Spectrum Related Functionalities, and Future Research Directions”. *IEEE Trans. Wirel. Commun.* 2017, *24*, 17–25.

[18] H. S . Nguyen; T. S. Nguyen; M. T. Nguyen; M. Voznak, “Optimal Time Switching-Based Policies for Efficient Transmit Power in Wireless Energy Harvesting Small Cell Cognitive Relaying Networks”. Wirel. Person. Commun. 2018, 99, 1605–1624.

[19] M. M. Mowla;I. Ahmad; D. Habibi; Q. V. Phuong, “A Green Communication Model for 5G Systems”.IEEE Trans. Green Commun. Network. 2017, 1, 264–280.

[20] M. Agiwal; A. Roy; N. Saxena, " Next Generation 5G Wireless Networks: A Comprehensive Survey".IEEE Commun. Surv. Tutor. 2016, 18, 1617–1655.

[21] Z. Ding; M. Peng; H. V. "Poor Cooperative non-orthogonal multiple access in 5G systems". IEEE Commun. Lett. 2015, 19, 1462–1465.

[22] N. Ye; H. Han; L. Zhao; A. "Wang Uplink Nonorthogonal Multiple Access Technologies Toward 5G:A Survey". Wirel. Commun. Mob. Comput. 2018, 2018, 6187580.

[23] L. Dai et al., "Non-orthogonal multiple access for 5G: Solutions, challenges, opportunities, and future research trends". IEEE Commun. Mag. 2015, 53, 74–81.

[24] Z. Ding; Z. Yang; P. Fan,; H. V. Poor, "On the performance of non-orthogonal multiple access in 5G systems with randomly deployed users". IEEE Signal Process. Lett. 2014, 21, 1501–1505.

[25] G. Wu, C. Yang, S. Li, and G. Y. Li, ''Recent advances in energy-efficient networks and their application in 5G systems,'' IEEE Wireless Commun., vol. 22, no. 2, pp. 145–151, Apr. 2015.

[26] Y. Niu, ''A survey of millimeter wave communications (mmWave) for 5G: Opportunities and challenges,'' Wireless Netw., vol. 21, no. 8, pp. 2657–2676, 2015.

[27] A. Orsino, I. Farris, L. Militano, G. Araniti, S. Andreev, I. Gudkova,Y. Koucheryavy,and A. lera, "Exploiting d2d communications at the network edge for mission-critical iot application, "in European Wireless 2017; 23th European Wireless Conference; Proceedings of. VDE, 2017, pp. 1-6.

[28] D. Feng, L. Lu, Y. Yuan-Wu, G. Li, S. Li, and G. Feng, "Device-to-device communication in cellular network, " IEEE Communications Magazine, vol. 52, no.4, pp.49-55, apr 2014 [online]. Available:https://doi.org/10.1109/mcom.2014.6807946.

[29] H. Nguyen et al. "Outage Performance Analysis and SWIPT Optimization in Energy-Harvesting Wireless Sensor Network Deploying NOMA", Sensors, 2018.

[30] A. Idris, K. Dimyati and S. K. S. Yusof, "Interference self-cancellation schemes for space time frequency block codes MIMO-OFDM system," International Journal of Computer Science and Network, vol. 8 no. 9, pp. 139-148, 2008.