Department of Electronics and Communications Engineering

Performance Analysis of Energy Harvesting Scheme using Dual-hop Wireless Link

This Thesis Paper has been submitted of the requirements for the degree of Bachelor of Science in Information and Communications Engineering.

Submitted By:

Suriya Yesmin (2018-2-50-010)

Sabera Mim (2019-1-50-002)

Md. Fahim Faisal (2019-1-50-006)

Supervised By:

Dr. Sarwar Jahan

Assistant Professor

Department of Electronics and Communications Engineering

September 28, 2022

Declaration

The Thesis entitled '**Performance Analysis of Energy Harvesting Scheme using Dual-hop Wireless Link**' is conducted under the guidance and supervision of Sarwar Jahan sir. This paper is the requirement for the successive completion of B.Sc. in Information and Communications Engineering under the Department of Electronics and Communications Engineering.

We hereby declare that this thesis represents our own work which has been done after registration for the degree of B.Sc. at East West University.

Students' Names and Signatures:

----------------------------------	----------------------------------	----------------------------------
Suriya Yesmin	Sabera Mim	Md. Fahim Faisal
ID: 2018-2-50-010	ID: 2019-1-50-002	ID: 2019-1-50-006

Approval

In partial compliance with the criteria, the thesis paper entitled 'Research on **Performance Analysis of Energy Harvesting Scheme using Dual-hop Wireless Link**' was submitted to the following respected members of the Board of Examiners of the Faculty of Science and Engineering.

For a Bachelor of Science degree in Information and Communications Engineering, the following students were accepted as satisfactory on September 28, 2022.

Name: Suriya Yesmin

ID: 2018-2-50-010

Name: Sabera Mim

ID: 2019-1-50-002

Name: Md. Fahim Faisal

ID: 2019-1-50-006

Supervisor

Dr. Sarwar Jahan

Assistant Professor

Department of Electronics and Communications Engineering

East West University, Bangladesh.

Dr. Mohammad Arifuzzaman

Associate Professor and Chairperson

Department of Electronics and Communications Engineering

East West University, Bangladesh.

Acknowledgement

We are really grateful because we managed to complete our thesis paper successfully by our supervisor. The completion of our thesis work brings with it a sense of satisfaction, but it is never complete without thanking everyone who made it possible.

Firstly, we would like to express our deep and sincere gratitude to our research supervisor Sarwar Jahan Sir, Assistant Professor, Dept. of Electronics and Communications Engineering, East West University, for giving us the opportunity to do research and providing invaluable guidance throughout this research. We thank our Supervisor Sarwar Jahan Sir for the guidance and encouragement in finishing this thesis and for teaching us.

Our deepest regards to Dr. Mohammad Arifuzzaman Sir, Associate Professor and Chairperson of Electronics and Communications Engineering Department, for encouraging and inspiring us to carry out the thesis work.

We would also thank to all the faculty members and staff of ECE Department for providing us with the required facilities and support towards the completion of the thesis.

We feel extremely grateful to our parents for their love, prayers, caring and sacrifices for educating and preparing us for future. Also, we would like to say thanks to friends and well-wishers for their help and cooperation during the thesis works.

Finally, our thanks go to all the people who have supported us to complete the research work directly or indirectly.

Contents

Abstract

In recent years, most researchers working in various fields of wireless communication have been conducting research to determine maximum channel capacity with the optimal solutions of signal energy at the receiving end of wireless communication system. The dual-hop energy harvesting (EH) connection presents several difficult issues, one of the most significant of which is optimizing the link parameters in order to obtain the highest possible signal-to-noise ratio (SNR) at the receiving end. In this thesis paper, the optimal condition of three parameters—"power supply at source terminal," "power splitting ratio," and "gain of relay"—is accomplished in three different methods. The above three parameters are optimized analytically from the profile of normalized channel capacity and bit error rate (BER) in both the first and second techniques. The corresponding graphs show maxima and minima at the same point, which indicates that this is the optimal point for the parameters. When we use the third method, we locate the point at which the gap between the 'normalized channel capacity' profiles of EH and non-EH is at its narrowest and most optimal.

1. Introduction

The expansion of wireless networks and the growing number of nodes that are equipped for wireless communication have made the impact on the power grid significantly worse by drawing more energy from the grid [1]. This expansion also indicates that more energy than ever before is transported via the air. According to the well-established first rule of thermodynamics, energy can neither be generated nor destroyed. It can only be transmitted between other forms. The energy harvesting sector is expanding quickly. Companies are investing in energy harvesting for a variety of reasons. Some are attempting to lower the cost of powering systems. Depending on how long the system will last, an initial investment in energy harvesting may pay off in the long run, even if it only produces a small amount of energy. Alternative energy sources are a method for extending the lifespan of industrial systems. Having a new sort of energy source enables the application to be installed in ordinarily inaccessible locations and to run for longer without requiring maintenance. Wireless sensors are one of the primary applications for energy harvesting [2]. These have already been installed in a great many locations, particularly for the purpose of smart meters. However, the uses are expanding as technology advances and new strategies for making use of electricity are developed.

Now, sensors stand alone in isolated or inaccessible regions to detect construction and bridge strains, air pollution, forest fires, imminent landslides, worn bearings, and wing vibration. Numerous industrial, medical, and commercial applications are dependent upon low-power wireless sensor networks. Off-grid and portable sensor nodes, however, rely on batteries for power and have the same issue as mobile phones. In these situations, it is best to get energy from the environment, which is often available in the form of light, heat, vibration, motion, or ambient RF, to make the battery last longer. If a device's energy demand is low enough and battery replacement would be difficult or costly, it may be feasible to forego the battery and rely only on ambient energy sources for power. When ultra-low-power MCUs are combined with energy harvesting, many applications that were not possible before are now possible [3].

The energy harvesting concept in wireless communication refers to the practice of gathering and storing RF energy from the environment to build self-sustaining nodes [4] that can function for extended lives without needing to be recharged in conventional methods [5]. Wireless energy harvesting (WEH) has emerged as one of the most promising solutions among various energy harvesting methods, such as vibration, light, and thermal energy extraction. This is due to the fact that WEH is one of the most promising solutions due to its simplicity, ease of implementation, and availability. Although there are several techniques for achieving energy efficiency, such as employing lightweight communication protocols [6] or adopting low-power radio transceivers [7], the emerging technological trend of energy harvesting offers a basic strategy for extending battery life. Thus, energy harvesting is a potential strategy for the growing Internet of Things [8]. In practice, energy may be gathered from environmental sources including thermal, solar, vibration, and radio-frequency (RF) energy sources [9]. Even though harvesting from the above environmental sources requires the presence of the corresponding energy source, RF energy harvesting has many advantages, such as being wireless, easily available in the form of transmitted energy (TV/radio broadcasters, mobile base stations, and hand-held radios), low cost, and small form factor implementation.

The area of energy harvesting has been the subject of a significant amount of study, which has led to the development of energy harvesting devices that are capable of extracting ambient energy from their surrounding environment. Wireless nodes that harvest their own energy are called energy harvesting nodes, and they have the ability to collect and store RF energy from their surroundings [10]. This RF energy might be ambient or interference; in other words, it could be a signal that was not intended for the harvesting node. Because of this, ambient RF energy can be classified as a kind of environmentally friendly communication [11], [12]. Because wireless media lose a lot of energy due to fading [13], a way of communicating that uses a dedicated transmitter to send energy to a harvesting node might be seen as more of a convenience than something that is good for the environment. IoT came into existence as a result of technological advancements in the wireless sector and in processing power [14]. In this context, IoT refers to the use of small wireless devices to collect data, such as sensor networks, or to automate commonplace objects like refrigerators. Nodes in wireless sensor networks (WSN) are expected to remain in a standby state for an extended period of time [15]. However, because of the constraints that currently exist in battery technology, it is difficult to develop a battery that can last for that long without negatively impacting the performance of the application that it is meant for [16].

Increased wireless sensor network (WSN) applications in modern wireless communication, ranging from environmental monitoring to human health control and security, exacerbate the difficulty of extending network lifetime. Energy harvesting (EH) has evolved as a valuable approach that can extend the battery life of wireless devices [17], [18] in response to the costly and difficult procedure of replacing or recharging batteries. Wireless energy harvesting (WEH) has garnered significant attention due to the controllability and predictability of the gathered energy as opposed to many conventional EH methods such as solar, thermoelectric effects, wind, vibration, etc. In WEH, the antennas of sensor nodes (SNs) pick up radio frequency radiation from the environment and use a suitable rectifier circuit to turn it into direct current (DC) voltage [19], [20]. In [21], discusses the fundamental ideas of EH sensor nodes and their applications. The gathered energy is stored in batteries for use during the transmission of data. This EH receiver architecture is often classified as a power-splitting (PS) or time-switching (TS) receiver. In a PS receiver, a portion of the received signal's power is utilized for energy harvesting while the remainder is used for information processing. In contrast, a TS EH receiver alternates between energy harvesting and information processing.

It is vital to provide the nodes that make up a sensor network with energy harvesting systems if they are to remain online for extended periods of time. Energy management is one of the most difficult issues that must be overcome when modeling and constructing an energy-harvesting communication system [22]. The availability of radio frequency (RF) ambient energy at any given point in time is unpredictable because of the random nature of ambient energy in general. As a result, it is required to develop optimum transmission strategies to represent the time-varying ambient energy in order for the system to properly harness the power that is entering. When employing a dedicated RF transmitter, on the other hand, the available energy density at the receiver input is very low due to substantial spreading loss. This is because the RF signal is spread out across a wider area. So, the RF energy harvesting (RF-EH) system needs to have power management algorithms that only certain people can use [23].

EH is commonly employed in cooperative relaying networks, in which a single or more intermediate nodes help to relay source-to-destination information in order to extend the range of wireless networks. Amplify-and-forward (AF) and decode-and-forward (DF) are two relaying techniques that are regularly employed [24]. In the AF protocol, the relay node amplifies the received signal before transmitting it to its destination. In contrast, in the DF protocol, the relay node decodes the received signal before sending the representation of the decoded signal to the destination. The relay nodes require their own power to transmit the source signal. So, the relay node won't be able to support the relay transmission if it runs out of energy. Traditional wireless systems just extract data from the signal received [25]. Information and energy are extracted from the incoming signal using a wireless energy harvester. In response, simultaneous wireless information and wireless transfer (SWIPT) [26] was developed, in which information and energy are concurrently retrieved from the received signal. SWIFT can be divided into two classes. The first category implies the same circuit may concurrently collect and extract information from the incoming signal [27]. However, the viability of this category is questionable, given there is no viable hardware implementation that can simultaneously extract information and energy [20]. In the second category, which is more useful, the receiver splits the received signal into separate energy and information circuits. This is called power splitting (PS). Cooperative communication is one implementation of EH networks that has recently evolved. These systems make use of the geographical distance between network nodes, using nodes close to the access station as relay gateways for faraway nodes. Thus, a unit of distance considerably reduces energy loss. Energy and information scheduling approaches in cooperative relay communications have been extensively investigated in order to achieve the optimal tradeoff between energy harvesting and spectrum efficiency [28].

The battery, which A. Volta invented in 1799, was the world's first viable source of electrical energy once he developed it. Batteries were able to get smaller as a result of the revolution in VLSI technology and other manufacturing methods, which enabled today's wireless, low-power electronics such as MEMS devices and the surge in mobile application development. Although inexpensive batteries are a primary agent driving this evolution, they also limit its ability to penetrate. The dream of ubiquitous computing, which is to have universal or broad wireless sensors everywhere, is accompanied by and overshadowed by the nightmare of battery replacement and disposal. Some applications of wireless sensor networks (WSN), embedded systems, and remote devices are deployed in such a complicated, obtuse, cryptic, onerous, and antagonistic environment that replacement and restoration of batteries are not realistic solutions for the long-term and evident usage of systems. As a result, the provision of the necessary electrical power for the functioning of such applications is a primary concern.

It is necessary to investigate potential alternatives to the use of traditional batteries as a source of energy. Utilizing the light, thermal, or mechanical energies that are present in the surrounding environment is one way to get the necessary quantity of electrical energy for these devices to function properly. This procedure aids in supplying endless energy so that the electronic item may be used for a longer period of time. Sunlight, temperature gradients, mechanical energy, and radio frequency energy are all examples of common types of ambient energy that may be converted into a source of electrical energy to power a variety of different devices. By utilizing these several energy-collecting sources, the lifespan and dependability will be boosted, and they will be able to be deployed in challenging environments where there is limited opportunity for human involvement [29], [30], [31]. As a result, the energy harvesting devices that were studied in this article do not require any kind of fuel, and as a result, they do not have a necessity that calls for their batteries to be replaced. The use of sensors or other devices that are powered by energy harvesters can offer crucial information on the operational, structural, and environmental circumstances in areas that are inaccessible [32], [33].

In fifth generation (5G) wireless systems, gigabit wireless access will become a reality thanks to a series of technological breakthroughs such as massive multiple-input and multiple-output (MIMO), fullduplex communication, and small cell architectures. This slew of new wireless services has fueled a slew of new wireless services, including mobile gaming, mobile TV, and mobile Internet. The limited operational lifetime of mobile devices owing to finite battery capacity is one of the most serious concerns that is negatively affecting the user experience as a direct result of the proliferation of mobile devices such as smartphones and tablets. Because of this, the radio-frequency (RF) energy harvesting approach has garnered a significant amount of study attention in recent years [34], [35]. When mobile devices are equipped with the capacity of RF energy harvesting, it is feasible to give a nearly endless supply of energy to those devices, thereby removing the need to connect those devices to the power grid in order to recharge their batteries. Simultaneous wireless information and power transfer (SWIPT) is a new topic that has emerged as a result of the combination of RF energy harvesting and the transmission of information. This topic has garnered a significant amount of attention from the academic community and, more recently, from the business world. To this point, different features of SWIPT systems have been examined. These include theoretical information limitations [26], [27], practical designs [36], [37], [20], the effect of incomplete channel state information [38], OFDM-based SWIPT systems [39], [40], and relay-assisted SWIPT systems [41] – [47]. It is important to point out that all of this earlier research uses the assumption that mobile devices get their power from the RF signals that are already present in their environments. However, despite the fact that this may be a workable solution for low-power devices such as sensors, it is generally not a practical option for powering bigger devices such as smartphones, tablets, and laptops [48]. As a solution to this significant limitation, the authors of [49] proposed a novel network architecture in which cellular base stations are covered by dedicated power beacons (PB), which can be used to supply energy to mobile devices by means of microwave power transfer. This new network architecture was presented as a response to the key limitation described above. Because the PBs do not require any backhaul links, the related costs of PB deployment are substantially cheaper. As a result, dense deployment of PBs to assure network coverage for a broad variety of mobile devices is achievable.

A practical solution, particularly for wireless sensor networks, is to extend the lifespan of wireless networks by utilizing energy harvesting (EH) techniques. Using EH, the power needed to run each wireless sensor node may be recharged from a wide variety of sources, including the sun, the wind, thermoelectric effects, and other physical phenomena. [50], [51]. Varshney has recently presented a novel and potentially fruitful approach in which the energy that is absorbed from radio frequency (RF) waves that are disseminated by nearby transmitters [26]. The fact that we can collect both information and energy at the same time is one of the many benefits that come with using this solution. This intriguing concept is amenable to application in the real world because of the existence of workable receiver designs, such as those seen in [52], [53], [36], [38], [54]. EH systems can primarily be divided into two types: (1) harvest-use (HU) systems, in which the harvested energy is used immediately and cannot be stored for later use; and (2) harvest-store-use (HSU) systems, in which the energy is first harvested, and then it can be stored for later use. Both of these types of systems have their advantages and disadvantages in [55], [8].

In recent years, there has been an uptick in the number of studies that concentrate on two-hop EH relay communication systems. Several EH relay systems, such as those found, for example, in [56]-[58], [34], [59] have been studied for use in single and multiple relay scenarios. In particular, Gunduz et al. proposed an optimal offline transmission scheme for both full-duplex and half-duplex transmission modes that maximizes the total amount of data that is transmitted to the destination within a constrained time deadline [56]. This particular scheme was developed for full-duplex and half-duplex transmission modes. The authors of [57] demonstrated that cooperative communication through the use of an energy buffer can give a larger maximum stable throughout compared to direct communication when the latter is constrained by low energy arrival rates. Luo et al. provided an optimum transmission strategy that confirmed the significance of adaptive power allocation in EH relay networks [58]. This policy was developed in consideration of two-hop relaying systems in which an EH source was assisted by a non-EH relay. This paper [34] has studied cooperative wireless networks with voluntary energy harvesting relays for cases where the signal-to-noise-ratio or the number of relays is large, showing that EH relays in cooperative communication can provide an effective solution for improving performance. The paper focuses on multiple EH cooperative amplify-and-forward (AF) relays. Very recently, Do et al. proposed a novel derivation approach to derive closed form approximations of system outage probability for EH-based dual-hop decode-and-forward (DF) relaying networks under partial relay selection and optimal relay selection [59]. This approach was developed to derive approximations of system outage probability. The time splitting ratio is the most important system parameter that plays a role in determining system performance in all EH-based wireless networks that use the time splitting approach. The authors have done their best research, and to the best of their knowledge, the optimal problem of time splitting ratio in the harvesting process has not been extensively examined, with the exception of the study [60]. An approximated value of the ideal time split that optimizes the instantaneous capacity in HU AF relaying networks was presented by Krikidis et al. in their paper [60]. On the other hand, the findings of this article are only applicable to a single relay.

The need for an adequate power supply for various electronic devices has increased significantly as a result of the proliferation of wearable electronic devices, the development of the Internet of Things (IoT), and the maturation of RF identification (RFID). An approach that is regarded to be both environmentally beneficial and self-sustainable is one that involves the collection of energy from the surrounding environment. Solar energy, thermal energy, piezoelectric energy, and radio frequency (RF) energy are only a few of the forms of power that have been put to use. Among these sources, the RF energy harvesting technique has recently received an increase in interest due to the abundant and unused ambient wireless signals in the environment [61]. These signals are produced by sources such as TV towers, cellular base stations, and wireless routers, amongst other things. The quantity of energy that is accessible for reception may be utilized to activate low-power electronic devices, which is especially convenient in situations when it is difficult or even hazardous to change the batteries in the device. The rectenna, which consists of an antenna and a rectifying circuit, is the most important part of the RF energy harvester. It is also the name of this component. A rectenna is an apparatus that can gather electromagnetic radiation and transform it into direct current (DC).

An antenna, a matching network, and a rectifier are the three primary components that make up a typical design for an RF energy harvesting network. This architecture is known as "typical architecture." The receiving antenna is able to capture RF energy from the surrounding environment, which may come from a variety of sources. Both the determinate Friis equation model and the probabilistic Rayleigh model are capable of providing an approximation of the radio frequency (RF) energy. According to them, [62] is the one that is more realistic and applicable in everyday life. A matching network is utilized so that the maximum amount of power is sent from the antenna to the rectifier section while simultaneously minimizing the amount of power that is reflected in [63]. The purpose of an RF-DC converter is to change the alternating current (AC) form of radio frequency (RF) energy that is received by an antenna into a direct current (DC) voltage that can either be used to directly supply electronic devices or be stored for later use.

In comparison to single-hop communication systems, dual-hop systems offer the benefit of increased coverage, throughput, and data rates. These advantages can be gained at the expense of single-hop systems. The signal travels from a source node to a destination node in a communication system using a dual-hop architecture by way of another node, which is referred to as the relay node. Regenerative and non-regenerative relay nodes are the two primary categories of relay nodes that are available. In non-regenerative relays, sometimes referred to as amplify and forward (AF) relays, the relay node receives a signal from the source node, amplifies this signal, and then sends it to the destination node. This process is known as the "amplify-and-forward" (AF) protocol. In regenerative relays, which are sometimes referred to as decode and forward (DF) relays, the relay receives a signal from the source node, decodes it, and then retransmits it to the destination node. This process is known as the "decode-and-forward" (DF) protocol [64]. One or more relays are used in the various wireless networks, such as wide area networks (WAN), metropolitan area networks (MAN), wireless local area networks (WLAN), wireless sensor networks (WSN), and Mobile Ad-hoc Networks (MANET), to improve end-to-end communication in terms of signal-to-noise ratio (SNR).In this section, we will talk about where the dual-hop wireless network is at right now. In [65], a large-scale fading model is utilized in dual-hop wireless connections to enhance Internet of Things applications (IoT). The authors compare the received signal strength in decibels (dB) and data rate in bits per second (bps) to the distance between the transmitter and receiver. In [66], the authors calculate the secrecy outage probability (SOP) of a decode-and-forward (DF)-

based dual-hop communication system with a source (S), relay (R), destination (D), and eavesdropper (E).

In the graph of SOP vs average SNR for varying link parameters, analytical results are compared to simulation results. Recent research has focused on the energy harvesting of wireless communications in an effort to preserve battery power. Energy Harvesting (EH) is employed in a dual-hop AF relaying network in [67] to observe the effect of the jamming signal on the performance of the secrecy. The authors present the relationship between SOP and the energy harvesting factor and transmit power. There is also a comparison between EH and non-EH schemes. Dual-hop multipoint-to-multipoint networks with a single relay are examined in [68], where the authors use power-splitting relaying protocol (PSR), optimum energy harvesting, and network distribution strategies for delay-tolerant and delay-intolerant scenarios. Under the energy harvesting technique, a nonlinear energy conversion model is applied to the relay. The difference between linear and non-linear energy harvesting is depicted by plotting the aggregate data rate versus transmitting power, the number of source nodes, and source-to-relay distance. An adaptive power splitting algorithm is used in the DF relaying connection in the paper [69], which considers both symmetric and asymmetric fading (Rayleigh and Rician fading) as possible channel models. Outage probability, effective transmission rate, and throughput are the three attributes that are utilized in the process of measuring the performance of the network. The relationship between the parameters is visually represented as follows: "total number of relay nodes," "the number of hops," "the throughput," and "transmission power of the source." One may find an analysis quite similar to this one in [70], which describes how the communication between the source and the destination is carried out with the assistance of a number of energy-harvesting cooperative nodes. The 'energy-exhausted probability' is used as a parameter in the measurement of the 'outage probability' relative to the signal-to-noise ratio (SNR) for energy-harvesting AF relay-aided systems. None of the aforementioned papers address the following two parameters: (a) the space diversity of wireless links; (b) the impact of the 'energy splitting ratio' of energy harvesting schemes. The works presented in the aforementioned publication make no reference to the optimization of a dual-hop EH network in any way. When a network is operating at its optimal condition in terms of the link parameters, the SNR at the destination is at its highest possible level, the BER is at its lowest possible level, the channel capacity or throughput is at its highest possible level, and the separation in channel capacity between EH and non-EH users is at its smallest possible level. This paper completes the job by taking into consideration the aforementioned four instances. The remainder of the thesis paper is structured as follows: Section 2 discusses some related works in the field of dual-hop EH that have been done; Section 3 delves into the fundamental theory of a dual-hop wireless link that operates on the concept of energy harvesting; Section 4 presents the findings that were derived from the examination of Section 3; and Section 5 develops a conclusion regarding the entire analysis.

2. Literature Review

In [71], the purpose of this study is to determine whether or not the addition of a third node, in the form of a wireless relay (R), located between the source node (S) and the destination node (D), can result in an increase in the system's overall energy efficiency. A comparison of the amount of energy used for each successful bit transmission in a collinear arrangement reveals that it is only possible to save energy when R is placed at a certain distance from S (or D), and that there exists an optimal location where energy saving is maximized. This is the case only when R is placed at the optimal distance. However, the amount of energy that may be saved when dealing with non-linear situations is dependent on the two-dimensional co-ordinates of R. In this case, they have found spots on the S–R–D plane that meet a minimum standard for saving energy. In [72], the study proposes a relay node iterative scheduling approach for dual-hop wireless networks that maximizes channel capacity. The suggested technique, which is based on the amplify-and-forward relay protocol, picks relay nodes iteratively according to the criterion that maximizes the instantaneous capacity when the destination node executes joint decoding. The selection procedure continues until the number of chosen relays equals the number of source transmitting antennas or until the channel's capacity no longer increases. The simulation results show that under different conditions, such as the total number of relay nodes, the number of source transmitting antennas, and the signal-to-noise ratios of the forward and backward channels, the algorithm can achieve greater capacity gains and multi-relay diversity gains than traditional algorithms and can get closer to the information-theoretic capacity upper bound.

In [73], the authors present a cooperative dual-hop decode-and-forward (DF) relaying communication paradigm based on an integrated information relay and wireless power supply aided by RF energy harvesting. In addition to facilitating communication between an energy-constrained source and a destination, the relay node also supplies power to them via the time-switching (TS) protocol. In addition, they introduced a relay selection protocol that allows the source to pick an appropriate relay connection based on the channel gain situation. The performance of the system in terms of outage probability and ergodic capacity across Rayleigh fading channels is evaluated in depth. Closed from an analytical equation, the Monte Carlo simulation result authenticates the outage probability of the examined system. The results demonstrate the effect of relay node count on outage probability and ergodic capacity. Using simulation results, the best time for a system to collect energy to get the most work done with the least chance of going down was also found. In [74], the authors provide an overview of the enabling technologies for efficient WEH, assess the lifetime of WEH-enabled IoT devices, and briefly examine the future trends in the design of efficient WEH systems and the associated research difficulties. The Internet of Things (IoT) is an emerging computer concept that outlines a network architecture in which ordinary physical things with unique IDs are automatically connected to the Internet. Such a sophisticated network requires energy-aware gadgets that are theoretically capable of gathering their essential energy from ambient sources for long-term and self-sustaining operation. Wireless energy harvesting (WEH) has been shown to be one of the most promising energy harvesting technologies, alongside vibration, light, and thermal energy extraction, due to its simplicity, ease of implementation, and availability.

Energy harvesting is the method by which ambient energy is absorbed and transformed into electricity for tiny autonomous devices, therefore making them self-sufficient; or the process by which energy is gathered from external sources, captured, and stored for use in electronic systems. Applications for energy harvesting are potentially widespread. Energy harvesting (or scavenging) is now used in building automation systems, remote monitoring and data collection devices, and wireless sensor networks [3]. Wireless Sensor Networks (also known as WSNs) are becoming more prevalent as a result of the growing demand for a variety of applications. Some examples of these applications include military surveillance, home automation, vehicle tracking, environmental monitoring, wildlife monitoring, health monitoring, and scientific exploration. In most cases, the battery capacity of sensor nodes is severely constrained. When designing long-lasting sensor networks with traditional batteries, it is not always possible to do so in an effective manner. In addition, it is quite difficult to replace the batteries in harsh climatic conditions, which makes it impossible to use the device. Therefore, one method for overcoming this challenge is to use an energy harvesting system to provide recharging capabilities for the batteries that power the sensor nodes. On the other hand, not all of the already-existing wireless sensor networks that harvest energy have developed an intelligent approach for making efficient use of both the energy management system and the harvesting system. The authors' review work is organized under the categories of energy management and approaches for collecting renewable energy in their presentation. The strategies of energy management include a discussion of the many different ways to reduce the amount of energy that is consumed by the energy-collecting sensor networks. In particular, they investigate protocol design tactics for conserving energy as well as key strategies such as prediction for increasing the amount of energy harvested from sensor nodes. They also provide an overview of their weaknesses as well as their capacity to work with the energy collecting system. They provide several different energy harvesting technologies, such as solar, wind, and others, in the context of plans for the collection of renewable energy. In addition to this, they explore the various energy harvesting methods, namely their protocol design methodologies for optimizing energy harvesting, and review the benefits and drawbacks of each of these mechanisms. This study also looks at a number of hard problems related to energy harvesting WSNs. It then looks at possible areas for future research and a few applications that have been made recently [75].

In [76], the research provided reviews for identifying potential sources of energy harvesting based on a variety of technical studies. The absence of adequate minuscule sources of electrical power has made it difficult to use downsized sensors, devices, and networks in practical settings, despite the fast breakthroughs that have been made in the design and production of these types of technologies. One of the most urgent and significant stimulating incitements for scientists and engineers to speed up their work today is the generation and storage of electrical energy for most mobile, WSN, embedded, and distant devices and systems. Energy harvesting, also known as energy scavenging, is the technique of obtaining energy from a user's surrounding environment in order to power a device. There are many different kinds of energy that can be saved, such as solar, thermal, mechanical, acoustic, wind, and wave energy, among many others. In [77], a dual-hop relayed wireless communication system is offered after merging the channel state information from both hops and the gain of the relay, which is referred to as a combined gain relay (CGR), is created as a result. This gain is dependent on the signal-to-noise ratio of the mean hop (SNR). Due to the long-term fading effects produced by the movement of the user within the area that is serviced by the wireless network, the proposed scheme can be efficiently applied in dual-hop transmissions with unbalanced mean SNRs. This is possible despite the fact that the mean SNRs are not balanced. Rayleigh fading channels are used for the purpose of analyzing the overall performance of the system. Important system performance indicators, including as the average end-to-end SNR, the average error probability, and the outage probability, are represented by closed-form formulas that are generated. An investigation is being conducted into the CGR's typical power usage, which, in certain instances, is lower when compared to the power consumption of existing relays. According to the numerical results and simulations, the system's overall performance has gotten better.

The authors of reference [78] discuss the design of a dual-hop visible light communication (VLC)/radio frequency (RF) communication system while taking electromagnetic compatibility into account. The article presents a series of curves that show the relationship between DC bias and information rate as the channel gain of the second link is varied. The requirement of optimization has been met, as shown by the graph, and it corresponds to the curves of channel capacity vs power splitting ratio presented in this work. There is also an example of optimization that can be found in [79], which shows how throughput may be maximized in a dual-hop EH connection by using a strategy called time splitting. There is some overlap between the image recovery methods used in this study and those used in [80], which examines picture recovery using the Alamouti scheme while using a single-hop wireless link. When it comes to pixel transmission, the authors make use of BPSK, QPSK, 8-PSK, and 16-QAM, while discrete wavelet transform (DWT) is utilized for image smoothing. The performance of the network is evaluated based on the bit error rate (BER) under different modulation schemes and with varied signal-to-noise ratios. Six different images were evaluated for the measurement of BER under 16-QAM, and the findings were determined to be closed. This was done so that the image dependency could be observed. In the last step, the RSA-encrypted picture is sent via the Alamouti model, where it is then retrieved with a high level of efficiency.

In [81], a dual-hop wireless full-duplex relay (FDR) network is presented. This network consists of two nodes and listening devices, each of which has a source relay and a destination relay. In wireless communication systems, the physical layer of security is frequently used to ensure the confidentiality of conversations that take place between a transmitter and a receiver across the channel that connects them. Energy harvesting is used to acquire electricity from the power beacon by both the relay and the source. In order to explore the amplify-forward (AF) and decode-forward (DF) secrecy capabilities in the energy harvesting power splitting system, two cooperative methodologies are applied. It has been demonstrated that the secrecy performance of an AF relay in the provided form is superior to the secrecy performance of a DF relay in the same situation. When there are 40 meters between the relay and the person listening in, an AF relay works better than a DF relay in an energy harvesting system. In [82], the authors proposed calculating the time splitting ratio that is best for wireless energy harvesting dual-hop relaying networks. With the help of the partial relay selection, the forward position for the second hop is given to the relay that has been deemed to be the most capable of gathering harvesting energy. In addition to this, they arrive at the closed form formula for the best temporal splitting ratio, which optimizes the system's instantaneous capacity. The system with the optimal time splitting ratio has been proven by numerical findings to be able to greatly boost instantaneous and ergodic system capacity at high signal-to-noise ratios for the same channel and system parameters. This can result in a large increase in system throughput.

In order to evaluate the efficiency of AF and DF-based EH relay networks, a number of studies have been conducted, each of which takes into account PS and TS-based protocols. Throughput and outage performances of TS, PS, and TS-PS protocols for a WEH in a DF relay network have been examined in [83, 84]. This research was conducted using a DF relay network. EH has been built by the authors of [85, 86] in order to investigate the outage performance of a multi-hop cognitive radio (CR) network, in which all of the secondary users harvest energy from dedicated power beacons (PB). The authors investigated a battery-assisted EH in two-hop AF relay networks and compared the performance of the TS and PS relay protocols in terms of throughput and degree of energy consumption [87]. In [88], an AF relaying EH network with a time-power-switching based protocol is also taken into consideration for the purpose of researching the outage probability and system throughput. The authors of [89] have constructed a DF relay-based WEH system model in order to conduct an analysis of the best system performance. This model was created by combining the WPCN and SWIPT network topologies. To convey the received signal, the authors of [90] suggested a relay selection process for a TS-based dual hop DF relay network. In this protocol, the best relay to send the signal was chosen based on how much energy was collected. In the study [91], the optimal relay was chosen based on having the best end-to-end signal-to-noise ratio (SNR) from the source to the destination in a non-identical Rayleigh fading channel. In [92], the source and the relays obtain their power from a multiantenna beacon that is operating in SWIPT mode. Both the AF and DF strategies of the relay selection protocol are utilized in the multi-hop situation, and the performance of a secondary network is assessed in [93]. Outage probability minimization is a challenge in EH-enabled DF relay-based CR networks, and the solution determines the harvesting time, source, and power of the relays [94].

To maximize the system throughput of a relay-based wireless EH network, the authors of document [95] presented a performance study of three power distribution methods, including the water-filling method, equal power distribution, and channel-gain-based power allocation strategies. In the paper referenced above [96], a joint optimization of time and power allocation is provided with the goal of increasing the average throughput of an EH-based relaying cooperative Internet of Things network. The concept of a relay node that only charges the Internet of Things nodes after harvesting electricity from a sustainable energy supply has been investigated. The probability analysis of outages, on the other hand, is outside the purview of these papers [95, 96]. In [97], the paper presents the outage performance of a SWIPT-based two-way DF relay network that uses the PS protocol. A PS ratio that is best for the transport of information and energy has been developed. Within the framework of underlay cognitive radio systems, the authors of [98] have developed a method to reduce the likelihood of an outage occurring in a bidirectional SWIPT-based DF relaying EH network. In [99], an examination of outage performance, average throughput, and optimal EH time was carried out using a TS-based full-duplex EH-enabled bidirectional DF relaying network. Since the researchers in [96–99] only took into account a single relay node in between the source and the destination, it was not necessary for them to construct a relay node selection strategy. In [100], the paper conducts a numerical investigation into the effects that the location of the relay node has on the amount of throughput that may be achieved and the likelihood of encountering an outage. A time that is best for the transfer of energy and the distribution of information is also calculated.

In [101], the authors analyze the energy efficiency in an energy harvesting incremental relay system while taking into account energy harvesting limits. Their analysis is based on the energy efficiency (EE) concept, which is derived from packet transmission. Their objective is to achieve the highest possible level of energy efficiency at the source node while simultaneously maximizing the use of the energy gathered by the relay. They begin by analyzing the energy efficiency of a point-to-point link using multilayer quadrature amplitude modulation (MQAM), and then they construct the notion of energy efficiency based on packet transmission. The challenge of optimizing energy efficiency in an incremental relay system is the next step, and it is articulated here. They explore two elements that impact energy efficiency in order to find a solution to the problem. These factors are transmission power and packet length. In addition to this, they provide an iterative approach for optimizing both the transmission power and the length of the packet, and they provide an intuitive explanation of the convergence. In conclusion, simulations have been done to show how useful the proposed method is. It can save a lot more energy than schemes that only try to maximize transmission power or optimize packet length. In this [102], study gives a state-of-the-art, succinct assessment of RF energy harvesting sources for low power applications. Additionally, it highlights outstanding research topics and future research objectives in ambient RF energy harvesting. Radio frequency (RF) energy harvesting is an emerging technology and study topic that promises to provide energy to run low-power wireless devices. This energy might be used to charge batteries or power other electronic devices. Recent developments in wireless communication systems and broadcasting technologies have made available a significant amount of freely propagating ambient RF energy, which has resulted in an increased level of interest in RF harvesting. This interest is primarily being driven by these recent developments. The main goal of an RF energy harvesting system is to turn the RF energy collected from the environment into DC power that can be used.

Radio frequency (RF) energy harvesting is a promising technique for energizing low-power electronic devices because of the sustainability it could offer as a result of the surge in ambient wireless signals it could utilize. This is due to the fact that radio frequency (RF) energy harvesting is able to collect electromagnetic radiation. A condensed literature review of this methodology is presented. In the first step of this process, a high-level overview of the structure of an RF energy harvesting network is presented. The second part gave some background information on the antenna and rectifier designs. At long last, a selection of cutting-edge architectural creations from the most recent decades is discussed in [103]. In [104], the authors optimize the relay power allocation ratio with the goal of increasing the transmission rates of simultaneous wireless information and power transfer (SWIPT) networks. When a single source connects with destination nodes using dedicated EH relays, the decode-and-forward (DF) relay technique is implemented for the first time. This takes place in the relay interference channels, also known as IFC. The original NP-hard problem is then converted into a concave optimization problem with the help of an algorithm known as successive convex approximation (SCA). This is done in order to ensure that all EH relays continue to function normally, maximize the amount of data that can be transmitted, and enhance the overall communication quality of the entire network. The Lagrangian multiplier approach, which is based on the Karush-Kuhn-Tucker (KKT) condition, is finally implemented in order to accomplish the goal of achieving the best power distribution for each relay. The numerical results show that the suggested method is accurate, quickly converges, and can increase transmission rates.

The experimental methods used to develop complete blocks of RF (radio frequency) energy harvesters for use in powering low-power devices are the focus of the study in [105], which describes such methods. Included in this are the tasks completed, the findings collected, the conclusions drawn, and any recommendations for additional enhancements. This configuration features a transducer, an energy conditioning unit, and an energy storage unit as its three primary components. The RF energy is transformed into an electrical form via the transducer, which can then be more easily conditioned and stored. There are three distinct types of antennas that are utilized as transducers. The conditioning subsystem will first rectify the voltage and then raise it until it reaches the necessary level before storing the energy. In practice, the amount of RF energy that is accessible varies throughout time. As far as harvesting goes, all that's left to do is store the energy in a storage unit, which in this case is a super capacitor. The most ideal gadgets to energize are ones such as wireless sensor nodes, calculators, remote controls, and phone chargers since they need a very negligible amount of power when in use. It is possible to power some low-power devices with radio frequency (RF) energy, if the technology used is good enough.

3. System Model

3.1 Dual-hop Wireless Link

To improve the quality of the signal that is received, a dual-hop wireless link is utilized. In this link, the signal that is being broadcast is first relayed by a suitable repeater that has some gain. Figure. 1 provides a visual representation of the dual-hop wireless link along with its link characteristics. The signal that was received at the relay may be represented as [106, 107]:

$$Y_R(t) = \sqrt{P_S}*h_{S\text{-}R}(t)*x(t) + n(t), \tag{1}$$

where P_S is the power that is transferred from the source, $h_{S\text{-}R}(t)$ represents the channel response from the source to the relay link, x(t) is the signal that is being transmitted and n(t) is the additive white Gaussian noise (AWGN) of the channel.

In the end, the signal that has been received will be,

$$Y_D(t) = G\sqrt{P_R}*h_{R\text{-}D}(t)*Y_R(t) + n(t), \tag{2}$$

where P_R is the power that is transferred by the relay, $h_{R\text{-}D}(t)$ is the channel response of relay to the destination link, *G* is the gain of the relay. Complexity is introduced into the analytical process by including time-sensitive channels. So, to keep the investigation as simple as possible, the independent variable time (t) will not be used.

If the SNR of the first-hop link is $\gamma_{S\text{-}R}$ and that of the second-hop link is $\gamma_{R\text{-}D}$ (found from Eqs. (1) and (2)) then equivalent SNR becomes [108,109]:

$$\gamma_{R\text{-}D} = (\gamma_{S\text{-}R}*\gamma_{R\text{-}D}) / ((\gamma_{S\text{-}R}+\gamma_{R\text{-}D})+c) \tag{3}$$

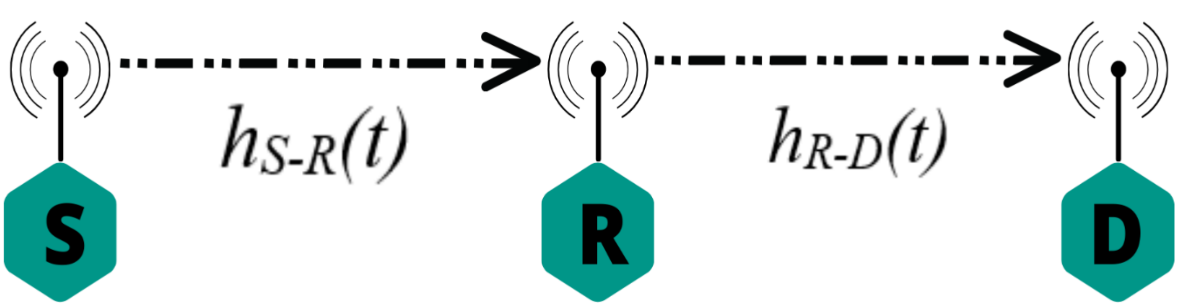


Figure. 1 Dual-hop wireless link

3.2 Energy Splitting at Relay Node

In the energy harvesting model of the dual-hop connection, the relay station gets power from the RF signal. The harvested energy is split as the ratio of ρ and (1- ρ), where portion ρ is used for transmitting the signal and that of (1- ρ) for signal processing like Figure. 2.

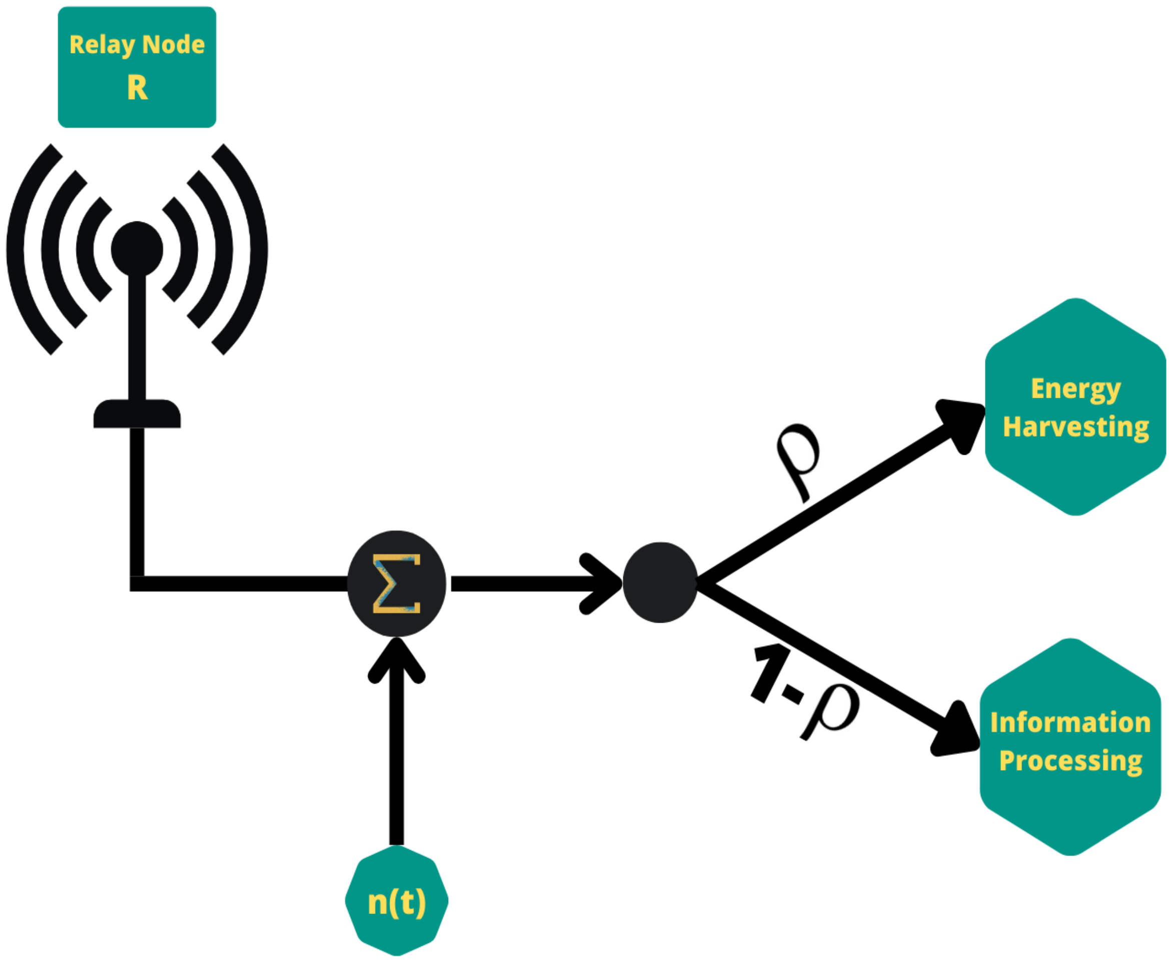


Figure. 2 Energy splitting at the relay

The signal that was received by the relay is,

$$Y_R = \sqrt{P}_S * h_{S\text{-}R} * x + n,$$

The fraction is utilized by the energy harvester, $\sqrt{\rho}Y_R$ for the purpose of sending the signal from the relay to its intended destination and the remaining amount $\sqrt{1-\rho}Y_R$ is applied to the signal processing that takes place at the relay R.

The solution [110,111] may be used to describe the signal that was received at R by the information processing unit:

$$Y_R^P = \sqrt{1-\rho}Y_R + n'$$
$$= \sqrt{1-\rho}\{\sqrt{P}_S * h_{S\text{-}R} * x + n\} + n' \quad (4)$$
$$= \sqrt{(1-\rho)}\sqrt{P}_S * h_{S\text{-}R} * x + (\sqrt{1-\rho})*n + n'$$

where n′ denotes the AWGN due to RF-to-baseband conversion.

The SNR from source to relay node is,

$$\gamma_{S\text{-}R} = ((1-\rho)*P_S*h^2_{S\text{-}R}) / ((1-\rho)*\sigma^2_n + \sigma^2_{n'}) \quad (5)$$

where σ^2_n and $\sigma^2_{n'}$ are the variance of n and n′ respectively. At the relay, the captured power denoted by $\eta\rho P_S$ is utilized to transmit the signal x to the destination; the efficiency with which energy is converted is denoted by η. If AF is present, the signal that is received at destination D will be [82], [112], [113],

$$Y_D = G\sqrt{\eta\rho P}_S\ h_{S\text{-}R}\ h_{R\text{-}D}\ x + n'', \quad (6)$$

where G is the amplification factor at the relay and n″ is the AWGN at the destination.

The SNR at the destination node can be written as,

$$\gamma_{R\text{-}D} = (\eta*G^2*h^2_{S\text{-}R}*h^2_{R\text{-}D}*\rho*P_S) / \sigma^2_D \quad (7)$$

where σ^2_D is the variance of n″.

In contrast to a normal dual-hop AF system, the energy harvesting technique has two separate SNRs that are denoted by the notations $\gamma_{S\text{-}R}$ and $\gamma_{R\text{-}D}$. The normalized channel capacity of the dual-hop relayed connection (where the unit for the capacity is bits/Hz) under energy harvesting is stated as:

$$C = \log_2\{1 + \min(\gamma_{S\text{-}R}, \gamma_{R\text{-}D})\} \quad (8)$$

Next this, we will show the findings that were derived from the numerical values of the link parameters in the following section.

4. Results

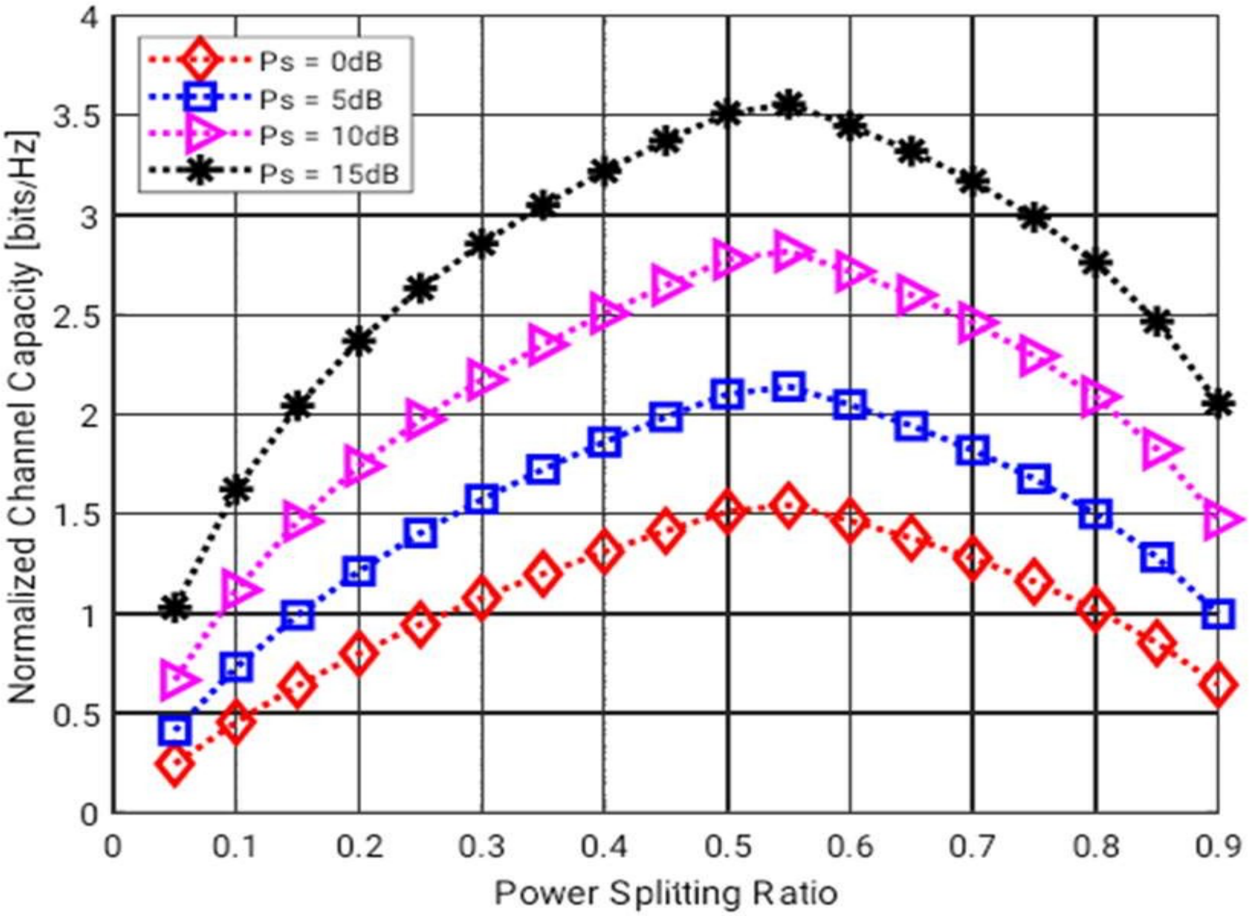
The following numerical values of link parameters are taken into consideration by us: $h_{S\text{-}R} = 0.351$, $h_{S\text{-}D} = 0.242$, $\eta = 0.5$, $\sigma^2_D = 0.05$, $\sigma^2_n = \sigma^2_{n'} = 0.02$, G = 8dB to calculate the normalized channel capacity while taking supply power, P_S = 0, 5, 10 and 15dB.

Table I

Parameters of 4 cases

P_S in dB	0	5	10	15
Gain of Relay (G)	6 dB	8 dB	10 dB	12 dB
Maximum SNR at receiving end in dB	1.8056	5.3143	8.6361	11.5423
Optimum ρ	0.66	0.55	0.4	0.3
BER QPSK	0.0838	0.0523	0.0153	9.331×10^{-04}
BER 16-QAM	0.1712	0.1356	0.0730	0.0119

4.1 Optimized Channel Capacity

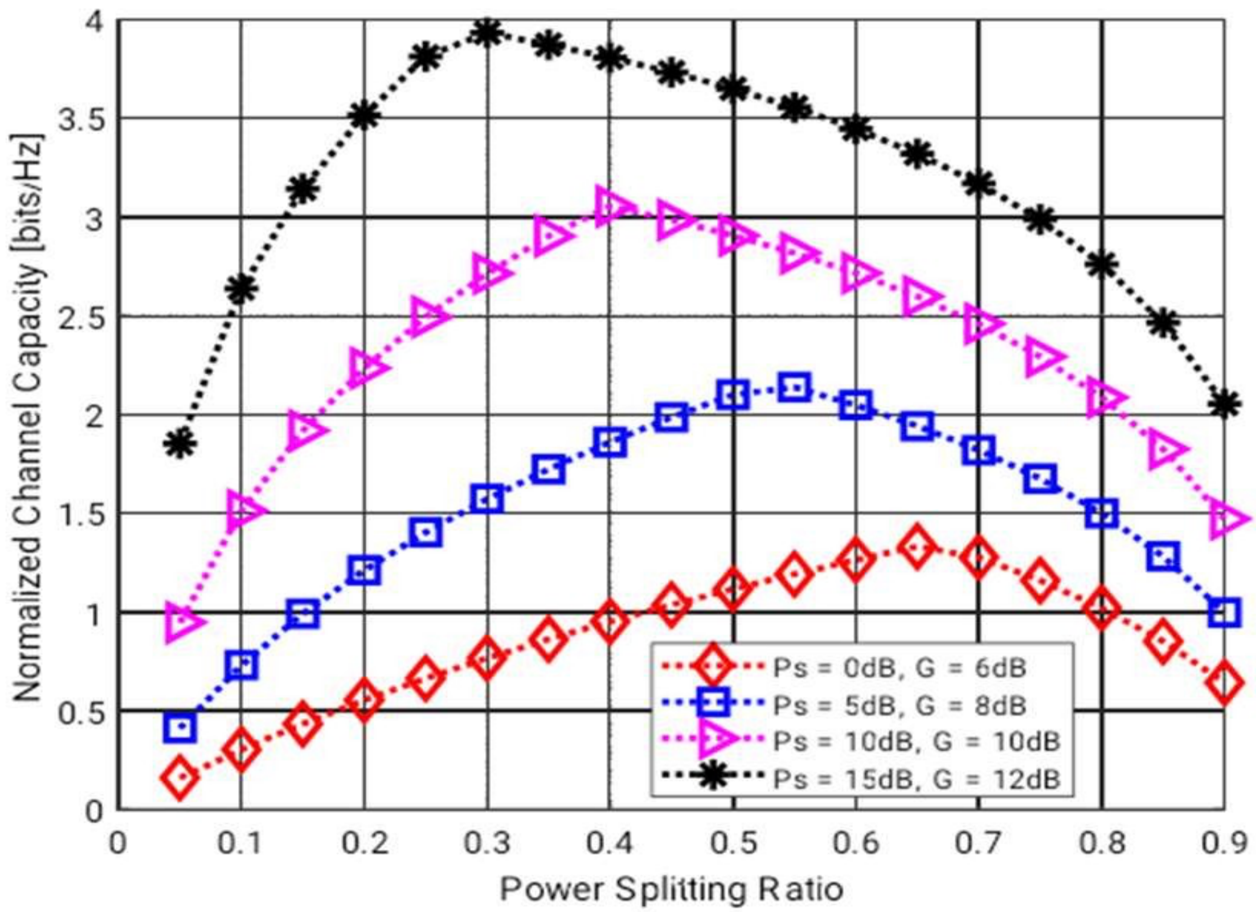


(a) Impact of P_S (G = 8dB)

Figure. 3 Variation of normalized channel capacity against power splitting ratio

Based on the data in Table I, we might conclude that, when P_S is assigned a higher value, the total SNR will likewise be found to be greater. According to what we saw in Figure. 3(a), the channel capacity is at its lowest point when P_S = 0dB throughout all four curves. When P_S = 5dB, the channel capacity is more than it was when the previous Ps value was in effect. When the P_S = 10dB, the channel capacity is once again increased compared to the previous P_S value. In conclusion, the point where P_S = 15dB is the point at which the channel capacity is the highest across all four curves. As a result, there is also an increase in the channel's capacity, when P_S is assigned a higher value, as illustrated in Figure. 3(a). In this scenario, the pick signal to noise ratio

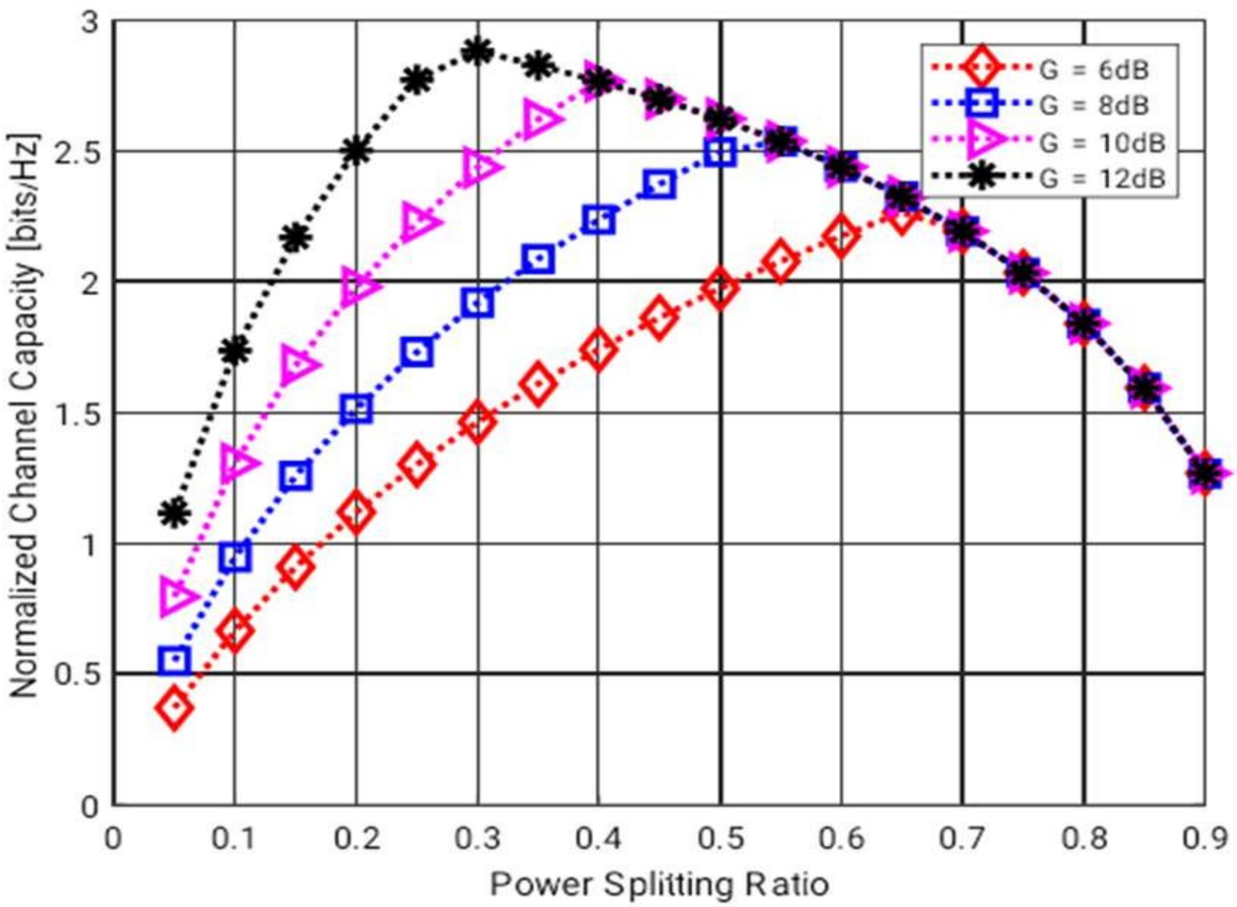
(PSNR) reaches an equilibrium point at a power splitting ratio of $\rho = 0.55$ across all four curves. The value of the power splitting ratio, denoted by the symbol ρ, is determined by the amount of energy that must be gathered to successfully transmit the signal from the relay to the destination, also known as the gain of the link R-D.



(b) Impact of both Ps and G

Figure. 3 Variation of normalized channel capacity against power splitting ratio

According to the findings of the energy model of the wireless sensor network (WSN), which is summed up in [114], the high gain relay is capable of transmitting information in a short amount of time, which results in the relay using a lower amount of energy. Therefore, the optimal power splitting ratio ρ_{opt} will be achieved at a lower value of ρ with an increment of relay gain G, as shown in Figure. 3(b) like [115]. From the graph in Figure. 3(b), the value of ρ is at its maximum when G = 6dB across all four curves (ρ = 0.66 at G = 6dB). When G is set to 8dB, the value of ρ is less than either the highest value or the value that came before it (ρ = 0.55 at G = 8dB). Once more, when G = 10dB, the value of ρ is less than the value it was before (ρ = 0.4 at G = 10dB). Lastly, the value of ρ is at its lowest point across all four curves when G = 12dB (ρ = 0.3 at G = 12dB). The effect of P_S and G working together on C is seen in Figure. 3(b).



(c) Impact of G (P_S = 8dB)

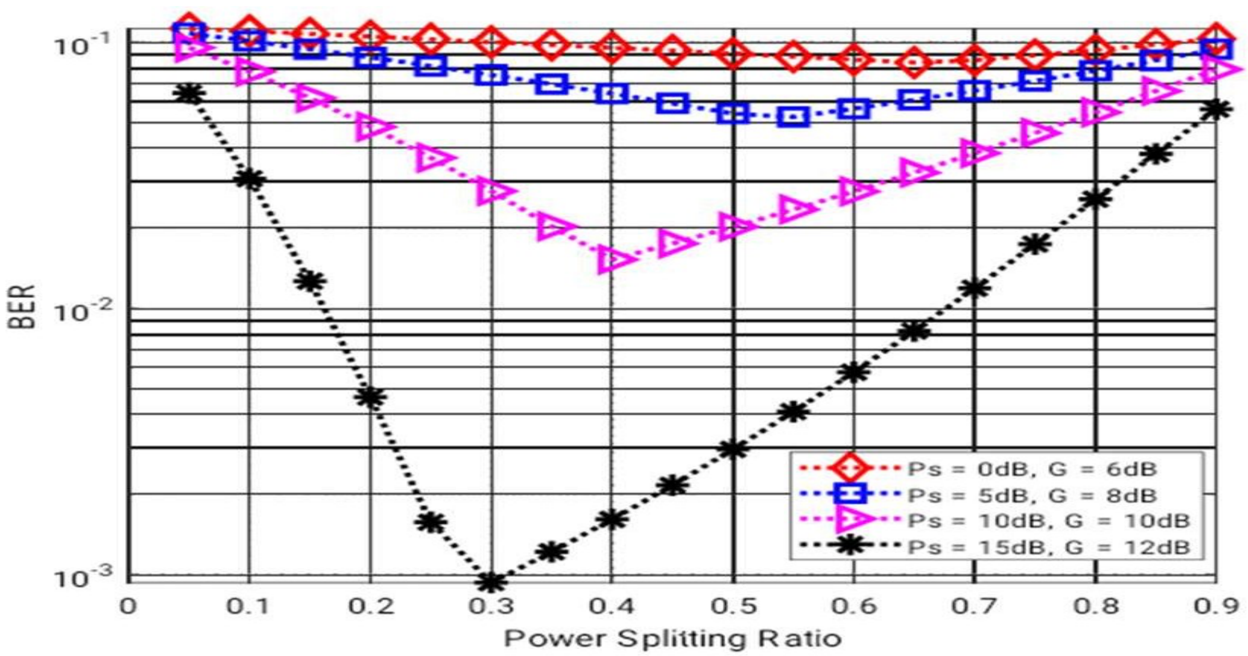
Figure. 3 Variation of normalized channel capacity against power splitting ratio

In Figure. 3(a), our goal was to demonstrate what would take place if we held G constant while increasing P_S by a certain amount. This finding demonstrated the impact of P_S when G was held constant. Following that, as shown in Figure. 3(b), we wanted to see what would happen if we simultaneously increased the P_S and the G. This finding demonstrated the impact that both P_S and

G had. Now, in Figure. 3(c), we try to figure out how the G changes in the outcome if we keep the P_S constant while increasing the G by a certain amount. As illustrated in the graph in Figure. 3(c), this graph demonstrates the impact of relay gain G only, while the PSNR or peak channel capacity, has a minimal effect compared to the combined effort of P_S and G of Figure. 3(b). On the other hand, the shifting of ρ does not change from what it was previously.

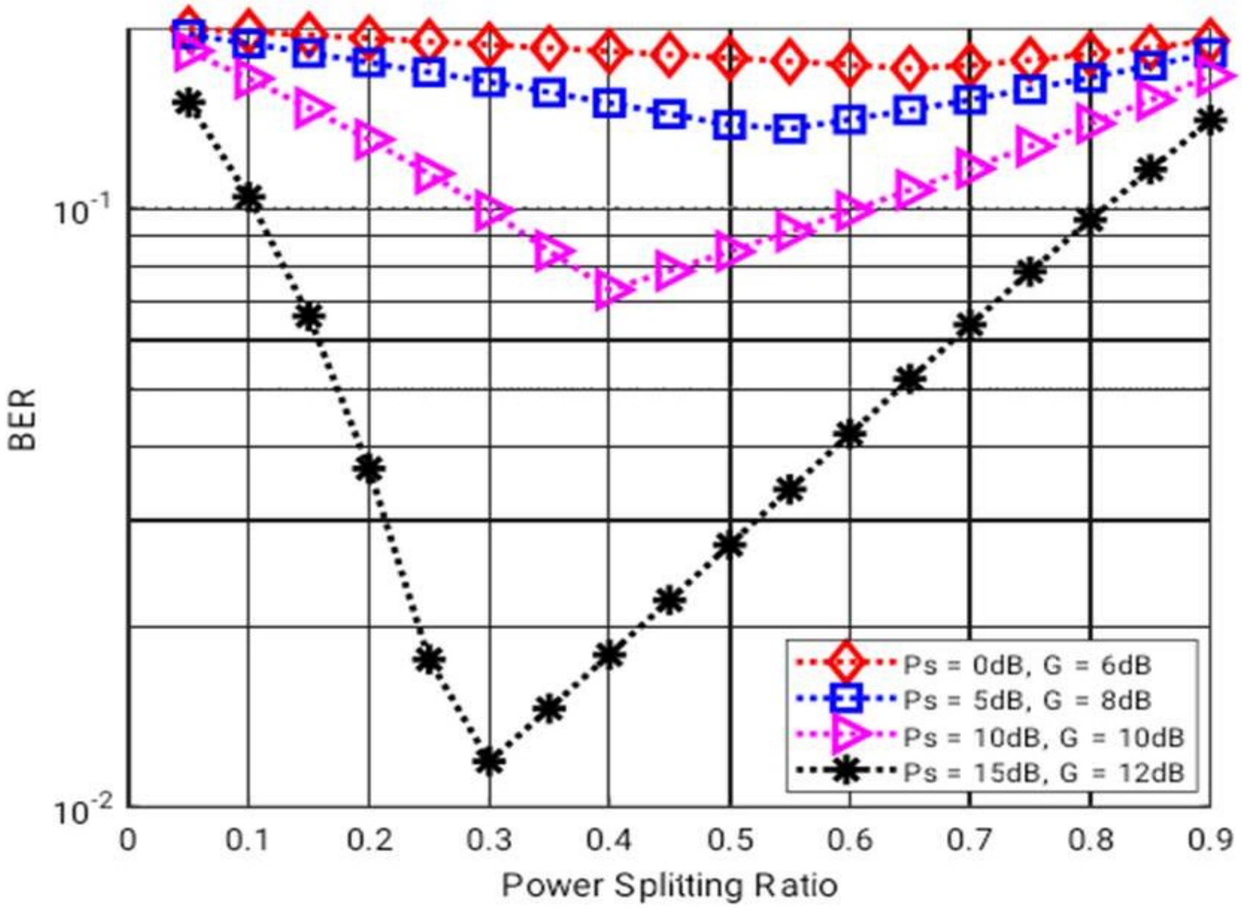
4.2 Optimized Bit Error Rate

The next thing that we do is make a graph of BER vs ρ using P_S and G as the parameters for both QPSK and 16-QAM. As can be shown in Figures. 4(a) and 4(b), the minimum value of BER can be seen to exist at the same optimal value of ρ. The link parameters and the results corresponding to Figures. 3 and 4 are shown in Table I. The optimal state of the EH link is achieved when the normalized channel capacity is at its highest and the bit error rate is at its lowest. But another thing to take note of in Figures. 4(a) and 4(b) is that, the bit error rate in QPSK is approximately less than 10^{-3}, whereas the bit error rate in 16-QAM is approximately close to 10^{-2}. Because of this, we can reach the conclusion that, the bit error rate in QPSK is lower than that in 16-QAM. The resulting figure is presented below for convenient inspection:



(a) QPSK

Figure. 4 Variation of BER against power splitting ratio

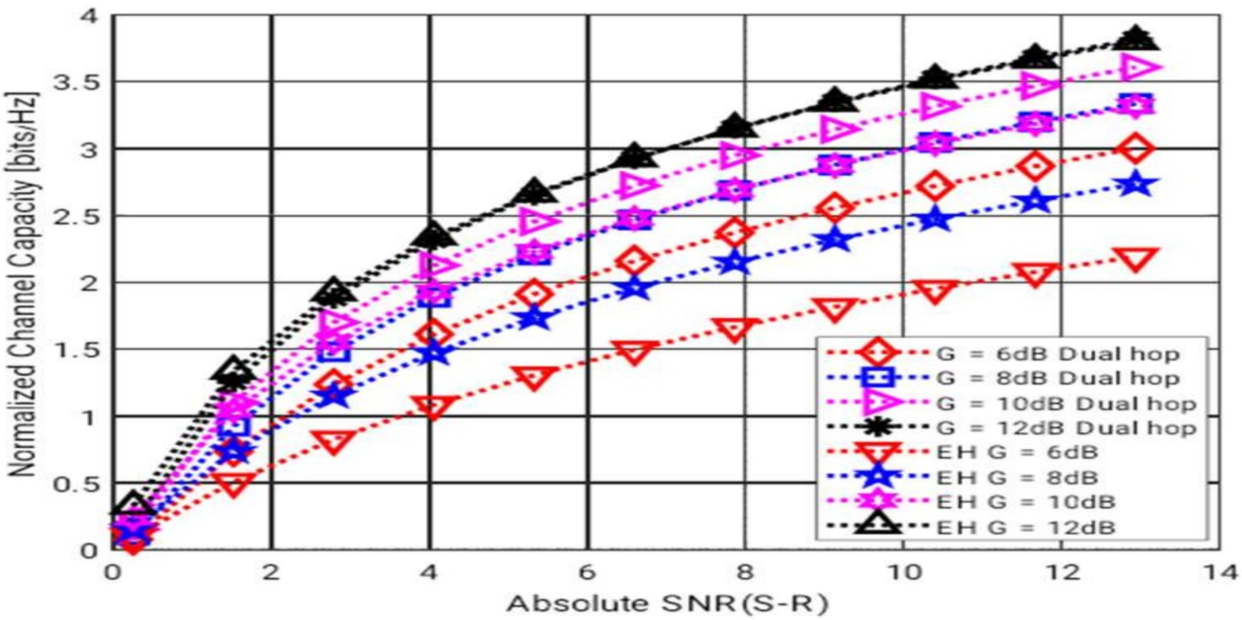


(b) 16-QAM

Figure. 4 Variation of BER against power splitting ratio

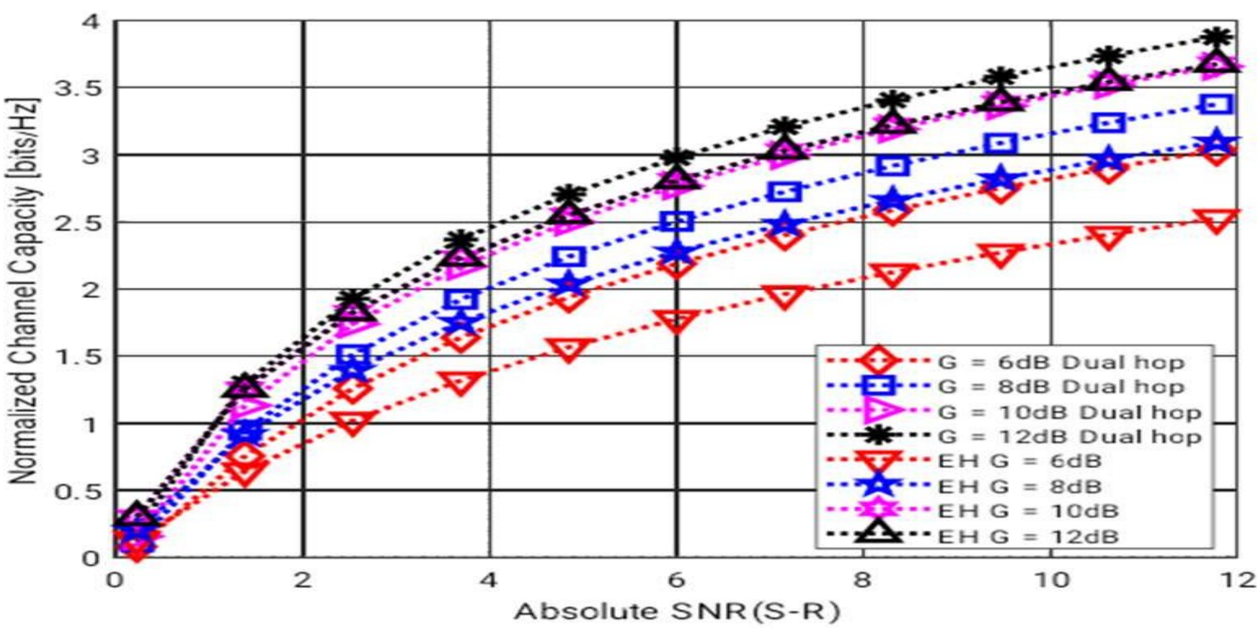
4.3 Optimized Gap Between the Channel Capacity of EH and Non-EH

In the non-EH model, the relay can use as much energy as is necessary to keep the desired SNR at the receiving end. However, in the EH model, the amount of energy that can be used is restricted; as a result, the desired SNR at the destination cannot always be guaranteed if the R-D link has a low gain. Therefore, the channel capacity of the non-EH model is greater than that of the EH model. Nevertheless, the gap between the two models is capable of being narrowed by selecting an appropriate value for ρ. Now, based on the difference in channel capacity between non-EH models and EH models, we will verify that the EH link has been optimized to its fullest capacity. If the relay has a low gain, the EH model is equivalent to the non-EH model when ρ is given a large value. However, if the gain of the relay is large, then two models will approach one another at a smaller value of the parameter ρ.



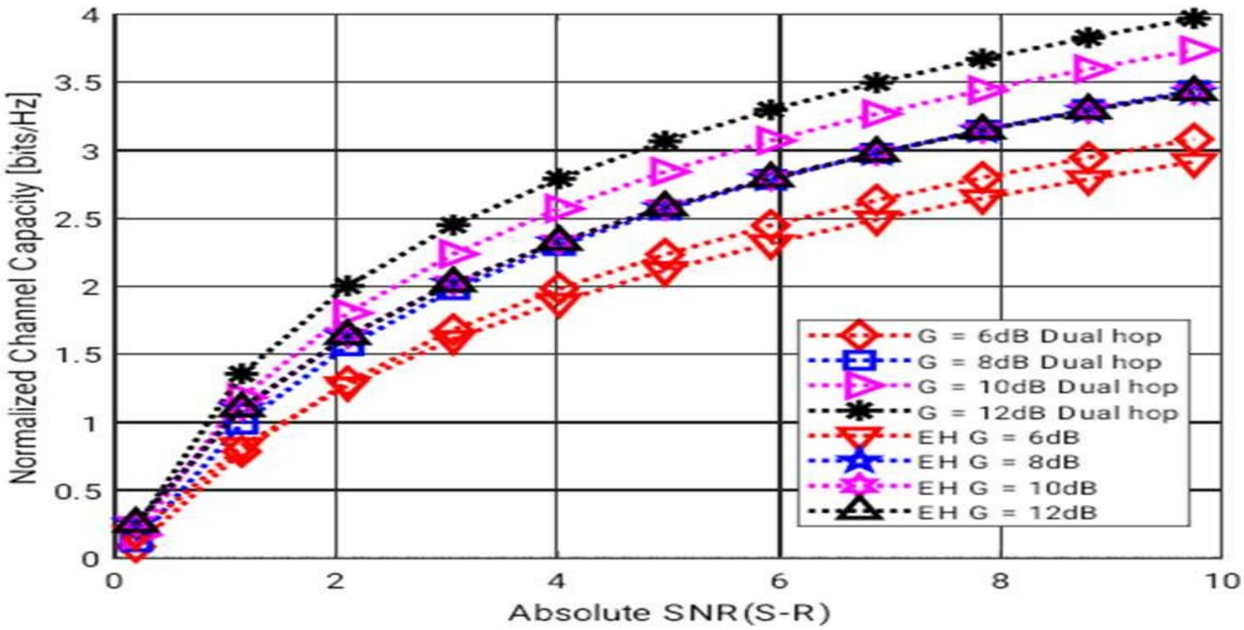
(a) $\rho = 0.3$

Figure. 5 Comparison of channel capacity of conventional dual-hop and EH scheme



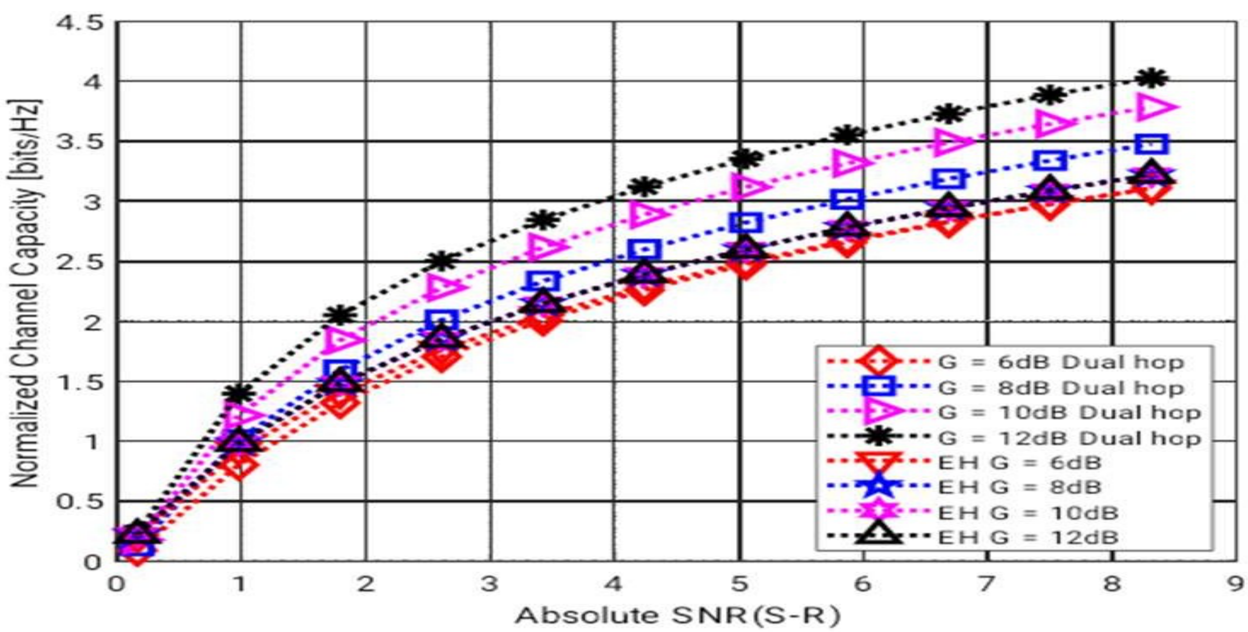
(b) $\rho = 0.4$

Figure. 5 Comparison of channel capacity of conventional dual-hop and EH scheme



(c) $\rho = 0.55$

Figure. 5 Comparison of channel capacity of conventional dual-hop and EH scheme



(d) $\rho = 0.66$

Figure. 5 Comparison of channel capacity of conventional dual-hop and EH scheme

To demonstrate what is descried in this section, the fact of the matter is that, the analytical channel gain of EH and non-EH is compared in Figures. 5(a)-(d). When compared to the other three pairs of curves, the parameters $\rho = 0.3$, $P_S = 15$ dB, and G = 12 dB are found to be near for one curve of EH and one curve from non-EH in Figure. 5(a). Again, this can be seen in Figure. 5(b), where the EH and non-EH curves merge together to form a closed shape when the following criteria are met: $\rho = 0.4$, $P_S = 10$dB, and G = 10dB. In a similar manner, we have discovered the near result for ideal parameters in Figures. 5 (c) and 5(d), which are respectively ($\rho = 0.55$, $P_S = 5$dB, G = 8dB) and ($\rho = 0.66$, $P_S = 0$dB, G = 6dB). In this case, we determined that there is an inversing relationship between the optimum value of ρ and relay gain G.

5. Conclusion

In our thesis work, we study the performance of the optimal condition for dual-hop wireless communication under EH in four distinct approaches. Additionally, we have identified the condition of maxima, minima, and peak SNR all at the same place. Under the same conditions, even the difference in distance between EH and non-EH individuals are shown to be minimal. Here, we only consider the wireless connection operating under the AWGN channel; nevertheless, in future we can work on small-scale fading channels, including space diversity on each link, to ensure that the optimal conditions are met for 5G wide area networks (WAN). We can apply the machine learning algorithm at each node to implement the optimal condition at the relay. In this algorithm, several link parameters of the S-R and R-D link can be used as the input variable for both training and test condition to provide the optimal value of output variables ρ, P_S, and G. These link parameters can be used to implement the optimal condition at the relay as well at the receiving end.

References

[1] A. Israr, Q. Yang, W. Li, and A. Y. Zomaya, "Renewable energy powered sustainable 5G network infrastructure: Opportunities, challenges and perspectives," J. Netw. Comput. Appl., vol. 175, p. 102910, 2021.

[2] Roundy, S., Wright, P. K., and Rabaey, “J. M. Energy Scavenging for Wireless Sensor Networks.”, Kluwer Academic Publishers: Norwell, 2004.

[3] Pop-Vădean, A., Pop, P.P., Barz, C. and Latinovic, T., "Research about harvesting energy devices and storage method," Carpathian Journal of Electrical Engineering, vol. 04, no. 2, pp. 102-120, 2015.

[4] S. Shen, Y. Zhang, C.-Y. Chiu, and R. Murch, "An Ambient RF Energy Harvesting System Where the Number of Antenna Ports is Dependent on Frequency," IEEE Trans. Microw. Theory Tech., vol. 67, no. 9, pp. 3821–3832, 2019.

[5] Q. Li, H. Liu, H. Ning, Y. Fu, S. Hu, and S. Yang, "Supply and Demand Oriented Energy Management in the Internet of Things," Adv. Internet Things, vol. 06, no. 01, pp. 1–17, 2016.

[6] Z. Sheng, C. Zhu, and V. C. M. Leung, “Surfing the internet-of-things: Lightweight access and control of wireless sensor networks using industrial low power protocols,” EAI Endorsed Trans. on Industrial Networks and Intelligent Systems, vol. 14, no. 1, 12 2014.

[7] V. Jelicic, M. Magno, D. Brunelli, V. Bilas, and L. Benini, “Analytic comparison of wake-up receivers for wsns and benefits over the wake-on radio scheme,” in Proc. of the 7th ACM Workshop on Performance Monitoring and Measurement of Heterogeneous Wireless and Wired Networks, ser. PM2HW2N ’12, 2012, pp. 99–106.

[8] S. Sudevalayam and P. Kulkarni, “Energy harvesting sensor nodes: Survey and implications,” IEEE Commun. Surveys Tuts., vol. 13, no. 3, pp. 443–461, Third 2011.

[9] G. Yang, C. K. Ho, and Y. L. Guan, “Dynamic resource allocation for multiple-antenna wireless power transfer,” IEEE Trans. Signal Processing, vol. 62, no. 14, pp. 3565–3577, July 2014.

[10] M. Cansiz, D. Altinel, and G. K. Kurt, "Efficiency in RF energy harvesting systems: A comprehensive review," Energy, vol. 174, pp. 292–309, 2019.

[11] H. S. Vu, N. Nguyen, N. Ha-Van, C. Seo, and M. Thuy Le, "Multiband Ambient RF Energy Harvesting for Autonomous IoT Devices," IEEE Microw. Wirel. Components Lett., vol. 30, no. 12, pp. 1189–1192, 2020.

[12] G. Yang, Q. Zhang, and Y. C. Liang, "Cooperative ambient backscatter communications for green internet-of-things," arXiv, vol. 5, no. 2, pp. 1116–1130, 2018.

[13] Y. Chen, Energy Harvesting Communications: Principles and Theories, 2019.

[14] A. Viswanathan, N. B. Sai Shibu, S. N. Rao, and M. V. Ramesh, "Security Challenges in the Integration of IoT with WSN for Smart Grid Applications," 2017 IEEE Int. Conf. Comput. Intell. Comput. Res. ICCIC 2017, pp. 0– 3, 2018.

[15] P. K. Sharma, Y. S. Jeong, and J. H. Park, "EH-HL: Effective communication model by integrated EH-WSN and hybrid LiFi/WiFi for IoT," IEEE Internet Things J., vol. 5, no. 3, pp. 1719–1726, 2018.

[16] C. M. Yu, M. Tala'T, C. H. Chiu, and C. Y. Huang, "Joint balanced routing and energy harvesting strategy for maximizing network lifetime in WSNs," Energies, vol. 12, no. 12, pp. 1–20, 2019.

[17] Chen, H., Zhai, C., Li, Y., & Vucetic, B. (2018). Cooperative strategies for wireless-powered communications: An overview. IEEE Wireless Communications, 25(4), 112–119.

[18] Lu, X., Wang, P., Niyato, D., Kim, D. I., & Han, Z. (2015). Wireless networks with rf energy harvesting: A contemporary survey. IEEE Communications Surveys Tutorials, 17(2), 757–789. (secondquarter).

[19] Piñuela, M., Mitcheson, P. D., & Lucyszyn, S. (2013). Ambient rf energy harvesting in urban and semiurban environments. IEEE Transactions on Microwave Theory and Techniques, 61(7), 2715–2726.

[20] Zhou, X., Zhang, R., & Ho, C. K. (2013). Wireless information and power transfer: Architecture design and rate-energy tradeof. IEEE Transactions on Communications, 61(11), 4754–4767.

[21] Sudevalayam, S., & Kulkarni, P. (2011). Energy harvesting sensor nodes: Survey and implications. IEEE Communications Surveys Tutorials, 13(3), 443–461. (third).

[22] G. Zhang, Y. Chen, Z. Shen, and L. Wang, "Distributed Energy Management for Multiuser Mobile-Edge Computing Systems with Energy Harvesting Devices and QoS Constraints," IEEE Internet Things J., vol. 6, no. 3, pp. 4035–4048, Jun. 2019.

[23] Y. Zhu, "Encoding Scheme to Reduce Energy Consumption of Delivering Data in Radio Frequency Powered Battery-Free Wireless Sensor Networks," vol. 67, no. 4, pp. 3085–3097, 2018.

[24] Do, T. N., & An, B. (2014). A Cooperative spectrum sensing schemes with the interference constraint in cognitive radio networks. Sensors, 14, 05.

[25] K. Tutuncuoglu and A. Yener, "Cooperative energy harvesting communications with relaying and energy sharing," 2013 IEEE Inf. Theory Work. ITW 2013, 2013.

[26] L. R. Varshney, "Transporting information and energy simultaneously," IEEE Int. Symp. Inf. Theory - Proc., pp. 1612–1616, 2008.

[27] P. Grover and A. Sahai, "Shannon meets Tesla: Wireless information and power transfer," pp. 2363–2367, 2010.

[28] K. Singh, A. Gupta, T. Ratnarajah, and M. L. Ku, "A General Approach Toward Green Resource Allocation in Relay-Assisted Multiuser Communication Networks," IEEE Trans. Wirel. Commun., vol. 17, no. 2, pp. 848–862, 2018.

[29] Onur, E.; Ersoy, C.; Delic, H.; Akarun, L., "Surveillance Wireless Sensor Networks: Deployment Quality Analysis," IEEE Network, vol.21, no.6, pp.48-53, November-December, 2007.

[30] Shi Lan, Miao Qilon, Jinglin Du, "Architecture of Wireless Sensor Networks for Environmental Monitoring," International Workshop on Education Technology and Training, 2008 and 2008 International Workshop on Geoscience and Remote Sensing. ETT and GRS 2008, vol.1, no., pp.579-582, 21-22 Dec. 2008.

[31] N. Akshay, M.P. Kumar, B. Harish; S. Dhanorkar, "An efficient approach for sensor deployments in wireless sensor network," International Conference on, Emerging Trends in Robotics and Communication Technologies (INTERACT), vol., no., pp.350- 355, 3-5 Dec. 2010.

[32] G Park, Farrar C R, Todd M D, Hodgkiss W and Rosing T, "Energy Harvesting for Structural Health Monitoring Sensor Networks," Technical Report, Los Alamos National Laboratories, LA, February 2007.

[33] Penglin Niu, Patrick Chapman, Raziel Riemer, Xudong Zhang, "Evaluation of Motions and Actuation Methods for Biomechanical Energy Harvesting", 35th Annul IEEE Power Electronics Specialists Conference Aachen, Germany, 2004.

[34] B. Medepally and N. B. Mehta, "Voluntary energy harvesting relays and selection in cooperative wireless networks," IEEE Trans. Wireless Commun., vol. 9, no. 11, pp. 3543–3553, Nov. 2010.

[35] W. Lumpkins, "Nikola Tesla's dream realized: Wireless power energy harvesting," IEEE Consumer Electronics Mag., vol. 3, no.1, pp. 39–42, Jan. 2014.

[36] R. Zhang and C. Ho, "MIMO broadcasting for simultaneous wireless information and power transfer," IEEE Trans. Wireless Commun., vol. 12, no. 5, pp. 1989–2001, May 2013.

[37] L. Liu, R. Zhang, and K. C. Chua, "Wireless information and power transfer: A dynamic power splitting approach," IEEE Trans. Commun., vol. 61, no. 9, pp. 3990–4001, Sep. 2013.

[38] Z. Xiang and M. Tao, "Robust beamforming for wireless information and power transmission," IEEE Wireless Commun. Letters, vol. 1, no. 4, pp. 372–375, 2012.

[39] D. W. K. Ng, E. S. Lo, and R. Schober, "Wireless information and power transfer: Energy efficiency optimization in OFDMA systems," IEEE Trans. Wireless Commun., vol. 12, no. 12, pp. 6352–6370, Dec. 2013.

[40] K. Huang and E. G. Larsson, "Simultaneous information and power transfer for broadband wireless systems," IEEE Trans. on Signal Processing, vol. 61, no. 23, pp. 5972–5986, 2013.

[41] A. A. Nasir, X. Zhou, S. Durrani, and R. A. Kennedy, "Relaying protocols for wireless energy harvesting and information processing," IEEE Trans. Wireless Commun., vol. 12, no. 7, pp. 3622–3636, Jul. 2013.

[42] Z. Ding, S. M. Perlaza, I. Esnaola, and H. V. Poor, "Power allocation strategies in energy harvesting wireless cooperative networks," IEEE Trans. Wireless Commun., vol. 13, no. 2, pp. 846–860, Feb. 2014.

[43] Z. Ding and H. V. Poor, "Cooperative energy harvesting networks with spatially random users," IEEE Signal Process. Lett., vol. 20, no. 12, pp. 1211-1214, Dec. 2013.

[44] Z. Ding, I.Krikidis, B. Sharif and H. V. Poor, "Wireless information and power transfer in cooperative networks with spatially random relays," IEEE Trans. Wireless Commun., vol. 13, no. 8, pp. 4440-4453, Aug. 2014.

[45] C. Zhong, H. Suraweera, G. Zheng, I. Krikidis, and Z. Zhang, "Wireless information and power transfer with full duplex relaying," IEEE Trans. Commun., vol. 62, no. 10, pp. 3447-3461, Oct. 2014.

[46] I. Krikidis, S. Sasaki, S. Timotheou, and Z. Ding, "A low complexity antenna switching for joint wireless information and energy transfer in MIMO relay channels," IEEE Trans. Commun., vol. 62, no. 5, pp. 1577–1587, May 2014.

[47] I. Krikidis, "Simultaneous information and energy transfer in large-scale networks with/without relaying," IEEE Trans. Commun., vol. 62, no. 3, pp. 900–912, Mar. 2014.

[48] K. Huang and X. Zhou, "Cutting last wires for mobile communication by microwave power transfer," submitted to IEEE Commun. Mag., 2014.

[49] K. Huang and V. K. N. Lau, "Enabling wireless power transfer in cellular networks: Architecture, modeling and deployment," IEEE Trans. Wireless Commun., vol. 13, no. 2, pp. 902–912, Feb. 2014.

[50] X. Jie and Z. Rui, "Throughput optimal policies for energy harvesting wireless transmitters with non-ideal circuit power," IEEE J. Sel. Areas Commun., vol. 32, no. 2, pp. 322– 332, 2014.

[51] H. Kaibin and V. K. N. Lau, "Enabling wireless power transfer in cellular networks: Architecture, modeling and deployment," IEEE Transactions on Wireless Communications, vol. 13, no. 2, pp. 902–912, 2014.

[52] X. Zhou, R. Zhang, and C. Ho, "Wireless information and power transfer: Architecture design and rate-energy tradeoff," IEEE Transactions on Communications, vol. 61, no. 11, pp. 4754 – 4767, 2013

[53] L. Liang, Z. Rui, and C. Kee-Chaing, "Wireless information transfer with opportunistic energy harvesting," in Proc. 2012 IEEE International Symposium on Information Theory Proceedings (ISIT), Conference Proceedings, pp. 950–954.

[54] S. Lee, K. Huang, and R. Zhang, "Cognitive energy harvesting and transmission from a network perspective," in Proc. 2012 IEEE International Conference on Communication Systems (ICCS), pp. 225–229.

[55] R. Rajesh, V. Sharma, and P. Viswanath, "Information capacity of energy harvesting sensor nodes," in Proc. 2011 IEEE International Symposium on Information Theory Proceedings (ISIT), Conference Proceedings, pp. 2363–2367.

[56] D. Gndz and B. Devillers, "Two-hop communication with energy harvesting," in Proc. 2011 4th IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), pp. 201–204.

[57] I. Krikidis, T. Charalambous, and J. S. Thompson, “Stability analysis and power optimization for energy harvesting cooperative networks,” IEEE Signal. Proc. Let., vol. 19, no. 1, pp. 20–23, 2012.

[58] Y. Luo, J. Zhang, and K. B. Letaief, “Throughput maximization for two-hop energy harvesting communication systems,” in 2013 IEEE International Conference on Communications (ICC), pp. 4180–4184.

[59] N. Do, V. Bao, and B. An, “Outage performance analysis of relay selection schemes in wireless energy harvesting cooperative networks over non-identical rayleigh fading channels,” Sensors, vol. 16, no. 3, p. 295, 2016. [Online]. Available: http://www.mdpi.com/1424-8220/16/3/295.

[60] I. Krikidis, Z. Gan, and B. Ottersten, “Harvest-use cooperative networks with half/full-duplex relaying,” in Proc. of the 2013 IEEE Wireless Communications and Networking Conference (WCNC), pp. 4256–4260.

[61] Kim, Sangkil, et al. "Ambient RF energy-harvesting technologies for self-sustainable standalone wireless sensor platforms." Proceedings of the IEEE 102.11 (2014): 1649-1666.

[62] T. K. Sarkar, J. Zhong, K. Kim, A. Medouri, M. Salazar-Palma, “A survey of various propagation models for mobile communication,” IEEE Antennas and Propagation Magazine, vol. 45, no. 3, pp. 51-82, June 2003

[63] J. Jose, S. George, L. Bosco, J. Bhandari, F. Fernandes, and A. Kotrashetti, “A review of RF energy harvesting systems in India,” 2015 Int. Conf. Technol. Sustain. Dev., pp. 1–4, 2015.

[64] Magableh, A.M., Aldalgamouni, T. and Jafreh, N.M.,"Performance of dual-hop wireless communication systems over the α–μ fading channels," International Journal of Electronics, vol. 101, no. 6, pp. 808–819, 2014.

[65] SooraNarasimhaRao, PabbaAkhil, VinothBabuKumaravelu and M. Arthi, ‘Dual – Hop Relaying for Quality of Service Improvement in IEEE 802.11ah–Downlink,’ International Conference on Communication and Signal Processing, pp.249-253, April 3-5, India 2018.

[66] Xiaojun Pan, Honglin Ran, Gaofeng Pan, YiyuanXie and Jiliang Zhang, ‘On Secrecy Analysis of DF Based Dual-hop Mixed RF-FSO Systems,’ IEEE Access, vol.7, pp. 66725-66730, May 2019.

[67] Nguyen Xuan Viet, Dao Thi Thu Thuy, Le Si Phu, Nguyen Hong Nhu, Ngo TienHoa, Dinh-Thuan Do, MiroslavVoznak, ‘Secure Performance Analysis of Adaptive Energy Harvesting Enabled Relaying Networks,’ Journal of Engineering Science and Technology, vol. 13, no. 12, pp. 4039- 4052, 2018.

[68] Syed Tariq Shah, Daniel B. daCosta, KaeWon Choi and Min Young Chung, ‘Dynamic Wireless Energy Harvesting and Optimal Distribution in Multipair DF Relay Network with Nonlinear Energy Conversion Model,’ Wireless Communications and Mobile Computing, pp.1-14, vol. 2018.

[69] Vikash Singh and Hideki Ochiai, ‘Performance analysis of the clustering-based multihop wireless energy harvesting sensor networks over symmetric and asymmetric fading channels,’ International Journal of Distributed Sensor Networks, vol. 13, no. 2, pp.1-12, 2017.

[70] ShaohongZhong, Huajun Huang and RenfaLi, ‘Performance analysis of energy-harvestingaware multi-relay networks in Nakagami-m fading,’ EURASIP Journal on Wireless Communications and Networking, pp.1-9, 2018.

[71] Chandra, A., Ghosh, B., Biswas, N., Brante, G. and Souza, R.D., "Energy efficient relay placement for dual hop wireless transmission," International Journal of Electronics Letters, 1(4), pp.198-209, 2013.

[72] Zhang-Yu, L.U.O. and Xiao-Lin, Z.H.O.U.,"A Relay Scheduling Algorithm in Dual-Hop Wireless Networks," Journal of Shanghai Jiaotong University, 45(03), pp.331, 2011.

[73] Biswas, S., Bepari, D. and Mondal, S., "Relay selection and performance analysis of wireless energy harvesting networks," Wireless Personal Communications, 114(4), pp.3157-3171, 2020.

[74] Kamalinejad, P., Mahapatra, C., Sheng, Z., Mirabbasi, S., Leung, V.C. and Guan, Y.L., "Wireless energy harvesting for the Internet of Things," IEEE Communications Magazine, 53(6), pp.102-108, 2015.

[75] Sah, D.K. and Amgoth, T., "Renewable energy harvesting schemes in wireless sensor networks: a survey," Information Fusion, 63, pp.223-247, 2020.

[76] Maurya S, Suman P, Radhakrishna M., "A Review of Energy Harvesting Techniques for WSN," Indian Institute of Information Technology-Allahabad, India. 2012.

[77] Tsiftsis, T.A., Karagiannidis, G.K. and Kotsopoulos, S.A., "Dual-hop wireless communications with combined gain relays," IEE Proceedings-Communications, 152(5), pp.528-532, 2005.

[78] Tamer Rakia, Hong-Chuan Yang, Fayez Gebali, and Mohamed-Slim Alouini, ‘Optimal Design of Dual-Hop VLC/RF Communication System with Energy Harvesting,’ IEEE Communications Letters, vol. 20, no. 10, pp. 1979 -1982, OCTOBER 2016.

[79] CaijunZhong, GanZheng, Zhaoyang Zhang, and George K. Karagiannidis, ‘Optimum Wirelessly Powered Relaying,’ Optimum Wirelessly Powered Relaying, IEEE Signal Processing Letters, vol. 22, no. 10, pp. 1728– 1732, October 2015.

[80] AnindaMajumder, Mohammad RaihanRuhin, TahsinaHashem, Md. Imdadul Islam, ‘Recovery of Image through Alamouti Channel with Incorporation of RSA Algorithm,’ Journal of Computer and Communications, vol. 4, pp. 1-10, February 2016.

[81] Sehito, N., Yang, S., Al Harbi, A.G., Abbasi, M.I., Khan, M.A., Khan, M.A. and Kamal, M.M., "Secrecy Performance by Power Splitting in Cooperative Dual-Hop Relay Wireless Energy Harvesting," Wireless Communications and Mobile Computing, 2022.

[82] Thanh, T.T. and Bao, V.N.Q., "Wirelessly energy harvesting DF dual-hop relaying networks: optimal time splitting ratio and performance analysis," Journal of Science and Technology: Issue on Information and Communications Technology, 3(2), pp.17-20, 2017.

[83] Elmorshedy, L., Leung, C., & Mousavifar, S. A. (2016). Rf energy harvesting in df relay networks in the presence of an interfering signal. In 2016 IEEE international conference on communications (ICC), pp. 1–6.

[84] Anh, V. N. Q. L. K. N., Bao, V. N. Q., & Le, K. N. (2018). Performance of tas/mrc wireless energy harvesting relaying networks over Rician fading channels. Wireless Personal Communications, 103, 1859–1870.

[85] Xu, C., Zheng, M., Liang, W., Yu, H., & Liang, Y.-C. (2016). Outage performance of underlay multi-hop cognitive relay networks with energy harvesting. IEEE Communications Letters, 20(6), 1148–1151.

[86] Zhang, J., Nguyen, N.-P., Zhang, J., Garcia-Palacios, E., & Le, N. P. (2016). Impact of primary networks on the performance of energy harvesting cognitive radio networks. IET Communications, 10(18), 2559–2566.

[87] Modem, S., & Prakriya, S. (2018). Performance of eh protocols in two-hop networks with a battery-assisted eh relay. IEEE Transactions on Vehicular Technology, 67(10), 10022–10026.

[88] Do, D.-T. (2016). Optimal throughput under time power switching based relaying protocol in energy harvesting cooperative networks. Wireless Personal Communications, 87, 3.

[89] Mishra, D., & De, S. (2017). i2 res: Integrated information relay and energy supply assisted rf harvesting communication. IEEE Transactions on Communications, 65(3), 1274–1288.

[90] Do, N. T. Bao, V. N. Q. & An, B. (2015). A relay selection protocol for wireless energy harvesting relay networks. In Advanced technologies for communications (ATC), 2015 international conference on (pp. 243–247) IEEE.

[91] Bao, V. N. Q., Duong, T. Q., da Costa, D. B., Alexandropoulos, G. C., & Nallanathan, A. (2013). Cognitive amplify-and-forward relaying with best relay selection in non-identical rayleigh fading. IEEE Communications Letters, 17(3), 475–478.

[92] Nguyen, N.-P., Duong, T. Q., Ngo, H. Q., Hadzi-Velkov, Z., & Shu, L. (2016). Secure 5g wireless communications: A joint relay selection and wireless power transfer approach. IEEE access, 4, 3349–3359.

[93] Mondal, S., Roy, S. D., & Kundu, S. (2018). Closed-form outage probability expressions for multi-hop cognitive radio network with best path selection schemes in rf energy harvesting environment. Wireless Personal Communications, 103, 2197–2212.

[94] Banerjee, A., & Maity, A. P. (2018). On outage minimization in relay assisted cognitive radio networks with energy harvesting. Ad Hoc Networks, 82, 46–55. https://doi.org/10.1016/j.adhoc .2018.07.012

[95] Nirati, M., Oruganti, A., & Bepari, D. (2019). Power allocation in wireless energy harvesting based relaying sensor networks. In 2019 4th international conference on recent trends on electronics, information, communication technology (RTEICT) (pp. 491–495).

[96] Chen, X., Liu, Y., Chen, Z., Cai, L. X., Cheng, Y., Zhang, D., & Hou, F. (2019). Resource allocation for sustainable wireless IoT networks with energy harvesting. In ICC 2019-2019 IEEE international conference on communications (ICC) (pp. 1–6).

[97] Ye, Y., Shi, L., Chu, X., Zhang, H., & Lu, G. (2019). On the outage performance of swiptbased three-step two-way df relay networks. IEEE Transactions on Vehicular Technology, 68(3), 3016–3021.

[98] Ghosh, T.M.S.P., & Acharya, T. (2019). On outage minimization in rf energy harvesting relay assisted bidirectional communication. Wireless Networks, 25, 3867–3881.

[99] Nguyen, X. X., & Do, D. T. (2017). Bidirectional communication in full duplex wireless-powered relaying networks: Time-switching protocol and performance analysis. Wireless Personal Communications, 98, 8.

[100] Mishra, D., & De, S. (2016). Optimal time allocation for rf-powered df relay-assisted cooperative communication. Electronics Letters, 52(14), 1274–1276.

[101] D. Liu, M. Zhao and W. Zhou, "Energy Efficiency Optimization in Energy Harvesting Incremental Relay System," 2018 10th International Conference on Wireless Communications and Signal Processing (WCSP), 2018, pp. 1-6, doi: 10.1109/WCSP.2018.8555571.

[102] Nechibvute, A., Chawanda, A., Taruvinga, N. and Luhanga, P., "Radio frequency energy harvesting sources," Acta Electrotechnica et Informatica, 17(4), pp.19-27, 2017.

[103] Wang, L., He, M., Wang, Z., Leach, M., Wang, J., Man, K. and Lim, E.G., 2016, October. Radio frequency energy harvesting technology. In 2016 International SoC Design Conferenc*e (ISOCC)* (pp. 219-220). IEEE.

[104] K. Ma, Z. Li, P. Liu, Z. Liu and J. Yang, "Optimization of Relaying Wireless Sensor Network with RF Energy Harvesting," 2019 3rd International Symposium on Autonomous Systems (ISAS), 2019, pp. 283-287, doi: 10.1109/ISASS.2019.8757734.

[105] Gunathilaka, W.M.D.R., Dinesh, H.G.C.P., Gunasekara, G.G.C.M., Narampanawe, K.M.M.W.N.B. and Wijayakulasooriya, J.V., 2012, August. Ambient radio frequency energy harvesting. In 2012 IEEE 7th International Conference on Industrial and Information Systems (ICIIS) (pp. 1-5). IEEE.

[106] BaofengJi, Bingbing Xing, Kang Song, ChunguoLi, HongWen,2 and LuxiYang, 'Performance Analysis of Multihop Relaying Caching for Internet of Things under Nakagami Channels,' Wireless Communications and Mobile Computing Volume 2018, Article ID 2437361, pp.1-9.

[107] Meihua Liu, Rui Jiang, and YouyunXu, 'DualHop Wireless Powered Communication Networks Assisted by Backscatter,' 2020 Workshop on Computing, Networking and Communications (CNC), pp.198-203, 17-20 Feb. 2020, Big Island, HI.

[108] Abu Sayed Md. MostafizurRahaman, Md. Imdadul Islam, and M.R. Amin, 'Selection of the Best Two-Hop AF Wireless Link under Multiple Antenna Schemes over a Fading Channel,' J Inf Process Syst, vol.11, no.1, pp.57~75, March 2015.

[109] Afsana Nadia Nova, A. R. Chowdhuray, Md. Imdadul Islam and M. Amin, 'Performance Evaluation of Two-Hop Wireless Link under Nakagami-m Fading,' International Journal of Advanced Computer Science and Applications (IJACSA), vol.4, no.7, pp.142-146, 2013.

[110] Yinghui Ye, Yongzhao Li, Fuhui Zhou, Naofal Al-Dhahir, and Hailin Zhang, 'Power Splitting-Based SWIPT With Dual-Hop DF Relaying in the Presence of a Direct Link,' IEEE Systems Journal, vol. 13, no. 2, pp. 1316 – 1319, June 2019.

[111] Ahmed A. Al-habob, Anas M. Salhab. Salam A. Zummo and Mohamed-Slim Alouini, 'Multi-Destination Cognitive Radio Relay Network with SWIPT and Multiple Primary Receivers,'2017 IEEE Wireless Communications and Networking Conference (WCNC), 19-22 March 2017, San Francisco, CA, USA.

[112] Aisha B. Rahman and Md. Fazlul Kader, 'Best Relay Transmission Aided Energy Harvesting in a Multi Relay Cooperative Network,' 2020 IEEE Region 10 Symposium (TENSYMP), 5-7 June 2020, Dhaka, Bangladesh.

[113] Hui Shi, YuemingCai, Dechuan Chen, Jianwei Hu, Weiwei Yang, and Wendong Yang, 'Physical Layer Security in an Untrusted Energy Harvesting Relay Network,' IEEE Access, vol. 7, pp. 24819–24828, February 2019.

[114] Nader F. Mir, 'Computer and Communication Network (2nd Edition),' 2015 Pearson Education, Inc.

[115] Nadhir Ben Halima and HatemBoujemaa, 'Cooperative communications with optimal harvesting duration for Nakagami fading channels,' Turkish Journal of Electrical Engineering & Computer Sciences, pp. 621 – 634, vol.28, no.2, 2020.