

A Novel Multiple Relay Selection Technique for RF Energy Harvested Relay Networks

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CERTIFICATE

This is to certify that the dissertation entitled "A Novel Multiple Relay Selection Technique for RF Energy Harvested Relay Networks" submitted by MADHUSHREE SAHA (Examination Roll No: M4ETC23013; University Registration No: 160202 of 2021-2022) of Jadavpur University, Kolkata, is a record of bonafide research work under my supervision and be accepted in partial fulfilment of the requirement for the degree of **MASTER OF ELECTRONICS AND TELE COMMUNICATION ENGINEERING** of the institute. The research results represented in this thesis are not included in any other paper submitted for the award of any degree to any other university or institute.

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**DECLARATION OF ORIGINALITY AND COMPLIANCE OF
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I hereby declare that this thesis titled "A Novel Multiple Relay Selection Technique for RF Energy Harvested Relay Networks" is an original research work done by me under the guidance of my supervisor. This work has not been submitted previously to any other institute.

All the information has been obtained and presented in accordance with Academic rules and Ethical Code of Conduct of the institute.

I also declare that, as required by the rules and conduct, I have cited and referenced the materials that are not original to this work.

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CERTIFICATE OF APPROVAL*

The foregoing thesis is hereby approved as a creditable study of an engineering subject and presented in a manner satisfactory to warrant acceptance as prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not necessarily endorse or approve any statement made, opinion or conclusion drawn there in but approve the thesis only for which it is submitted.

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ABSTRACT

The utilization of Radio Frequency (RF) for Energy Harvesting (EH) in wireless communication networks has become popular in recent time. RF can be used for powering the network nodes which has limited energy, as well as to perform data transmission. Signal transmission is very much affected by the channel fading. Cooperative communication could be used to reduce the effects of channel fading. In cooperative communication, relaying technique is used to transmit the data from source to destination in smaller hops. This improves the transmission reliability and the radio coverage of the wireless network. The performance of a relay-assisted cooperative network greatly depends on the selection strategies of a set of best performing relays or a best relay, whichever applicable, from a given set of relays. However, only one selected relay based on optimized performance may not provide the best performance constantly in the network. Keeping this point in mind, a dual-hop relay-assisted network with energy harvesting capability is taken into consideration in this thesis. The best relays are chosen to serve the high-quality communication in a set transmission block time. In order to address afore mentioned problem, a new relay selection algorithm to select best four relays, has been discussed in this thesis work. The proposed model has been simulated using MATLAB R2015a platform. The throughput performances of this new algorithm have been analyzed. A comparative study of the proposed algorithm and the existing algorithms has also been presented.

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

In this chapter an introduction to the thesis work has been provided. At first, the background of this work has been presented briefly. After that, based on this background, motivation of work is set. Then, the objectives of this thesis work have been defined. The methodology has been mentioned next. Following this methodology, the contributions of this thesis have been listed in this chapter. Finally, for better understanding the outline of the thesis has been sum up.

1.2 BACKGROUND

The new generation of wireless network demands high-speed connections as well as good Quality of Service (QoS). An important factor to design such wireless communication systems is energy efficiency. In addition to empower energy-efficient data transmission, Radio Frequency (RF) energy transfer and afterwards harvesting techniques can be used to give power to the networks with energy constrained resources like Wireless Sensor Networks (WSN), Body Area Networks (BANs) as well as Internet of Things (IoT). Conventional energy harvesting schemes such as solar, wind, etc. are always not so dependable due to random behavior of nature. So sometimes they may be less efficient than RF energy harvesting scheme when sustainability and QoS requirements of a wireless system are considered. Moreover, RF waves are sometimes harmful for the biosphere. So, if it is possible to produce energy from RF wave, it adds an extra dimension to the other energy harvesting schemes. Furthermore, the infrastructure required to capture solar, wind, and tidal is somewhat costly. RF energy can be a practical source of sustainable energy as it is considerably used both in indoors (such as Wi-Fi signals from wireless routers) as well as outside (DTV signal, cellular communication signals etc). RF-EH is also a more economical option for boosting up networks that are situated in dangerous, unreachable regions.

Other than wireless energy harvesting, two other wireless energy transfer methods are inductive coupling and magnetic resonance coupling. But the strategies use near-field transmission methods, which makes them less useful. RF-EH networks provide both energy as well as information in a safe and systematic way through Simultaneous Wireless Information and Power Transfer (SWIPT) technique. SWIPT is a modest method

to preserve the performance of wireless networks without modifying the transmitter hardware. Cooperative communication is a brand-new model for communication systems. Relays are used here in between source and destination, to transmit the signal from source to destination. This reduces the connection failure due to propagation error. Transmit diversity can be achieved by cooperative communication and hence it performs better in wireless communication system. During transmission, by using diversity technology the efficiency of wireless communications improves due to the signals with a separate fading path, across the various dimensions like time, space, frequency etc. The relay selection techniques can further enhance the efficiency of a cooperative relaying system. Selection of relay and maximum RF energy transfer are two different issues in a relay-assisted RFEH network. However, with the development of technologies, the optimal trade-off between them is improving day by day so that the receiver performance can improve.

1.3 MOTIVATION

The output performance of relay-aided RFEH is difficult to assess since the data delivered from the relay to the destination may not always be correctly communicated. Additionally, the system throughput under “K-relay cooperative system” that utilizes all “K” relays to forward signal, suffers as “K” increases. This is due to the allocation of time slot under Time Division Multiple Access (TDMA) per relay.

The simplest and most practical of all of these methods is relay selection. Numerous relay selection strategies have already been presented in CHAPTER 2. Even while all of these models are sound in theory, they might not stand up in practical situations where the best channels for service quality improvement are relaying links that are experiencing severe fades. Relay selection techniques are designed based on SNR performances, throughput performances etc. In many previous works, only one best relay has been chosen. But this selection process is not always fruitful in real case scenarios. It may happen that, the chosen best relay somehow becomes faulty or loses its performance during a communication process as communication environment is random. This served as an inspiration to design a new relay selection algorithm to select best four relays from a given set of relays to offer better throughput performance of the system.

1.4 OBJECTIVE

The main objective of this thesis work has been to design a new relay selection strategy to select a set of best four relays from a given set of relays, based on their throughput performance. To meet this requirement, the new model has to be proposed, analysed mathematically and also through simulation. Finally, the

effectiveness of the proposed work needs to be established by comparing the performance of this new work with the relevant existing works.

1.5 METHODOLOGY

The proposed model portrayed as a wireless network system consisting of a single source and destination node with single antenna, where in between source and destination node, several RF energy-harvesting capable relay nodes are present. Firstly, throughput of all the relays has been calculated. After that, an algorithm has been established to select best four relays based on their throughput. Then, from these best four relay set, another selection has been made, and finally one relay has been selected which has the highest throughput. Again, using this highest throughput relay, the throughput performance of the proposed algorithm has been compared with the existing relay selection algorithms. The proposed model has been simulated by using MATLAB R2915a software with the help of Monte Carlo simulation.

1.6 CONTRIBUTIONS

The major contributions to this work are as follows:

- A relay selection strategy has been devised to select the best four relays for the proposed system model. The strategy selects the relay with highest throughput performance for the communication thorough a two round relay selection. The four relays which are selected in the first round are only applicable for further selection.
- The proposed system model has been simulated considering the TSR and PSR protocol to study the throughput performances.
- Performance of the proposed relay selection algorithm has been compared with the existing relay selection algorithms.

1.7 OUTLINE

This thesis is structured as follows:

- Chapter 2 presents the comprehensive literature review of related research in wireless energy harvesting networks with cooperative relays. The numerous relay selection strategies employed in the past has been also discussed.
- Chapter 3 presents a brief theoretical background needed for the understanding of the proposed system model. It explains the concept of RF energy harvesting

technique and its basic operation. This chapter also discusses two type of relay scheme and relaying protocols.

- Chapter 4 discusses the proposed system model of relay-aided RF energy harvesting network. This chapter also discusses the best four relay selection strategies.
- Chapter 5 presents the simulations of the proposed work that have been completed and based on the presented results, a comparative analysis among proposed relay selection strategy and two existing strategies has been done.
- Finally, Chapter 6 brings the thesis to a close. Also taken into consideration are some of the potential future linked works.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

A review of literature on relay-aided RF Energy Harvesting Network has been presented in this chapter. An overview of the prevalent work on cooperative relay schemes and relaying protocols used in RF EHN has been studied. Various relay selection strategies have been discussed. Outcome of the literature review has been analyzed here.

2.2 REVIEW OF THE RELATED WORK

The process and algorithm have been described in [1]-[4] how a sensor network can increase its lifetime by using surrounding environmental energy. The process is known as energy harvesting. The architecture, energy source and storage techniques of a sensor network has been investigated deeply. Functions of different nodes of an Environmental Energy Harvesting Framework (EEHF) are explained which has enough knowledge about environmental energy. This knowledge will help to increase the life time of sensor networks. The process of data communication has not been mentioned in these works.

The above drawback has been addressed in [5]. A wireless battery-less mouse model with RF transmitter and microcontroller has been considered for short range data communication. It has verified in the paper that the RF transmitter is capable to communicate data in the range of 1meter at 2.17mW power. Very low power wireless interface SoC for data communication in a shorter range has been explained and targeted low power consumption has been achieved. Relaying schemes and protocols for data transmission have not included in this paper.

Two types of Relaying schemes AF and DF in [6] and Relaying protocols – TSR and PSR are investigated in [7] with the help of a system model, comprising a source, relay and destination node. The network outage probability has been analysed and its closed-form expression has established. Optimal throughputs are calculated for different

transmission rate and noise parameters. These analyses are done for a single relay antenna, not for multiple antennas.

To omit the above drawback, it has suggested in [8] that, multiple antennas placed in same area increases the energy harvesting power per area ratio. A four-antenna board and a double antenna board layout has been proposed and discussed in details to establish the concept of locating multiple antennas in one place, which increase the energy of an energy harvesting device. The procedure to select the best relaying antenna has not incorporated here.

Previous limitation has been encountered in [9]-[10]. A system model comprising a single source, destination and multiple antenna relay nodes has been described here. Achievable throughput for different relaying antennas against different values of transmitted power and different distance from source to destination has been plotted to select the best relaying antenna. Best relay selection process and advantages of it have not been clearly discussed in this paper.

Above shortage of information has been given clearly in [11]. An Amplify-and-Forward (AF) cooperative diversity system with a source, destination and multiple relay nodes has been investigated here where the source node has direct and indirect (via relays) links with destination. To avoid large number of channels due to multiple relays, a best relay has been selected here, so that only two channels has needed. The best relay has been selected here best on the highest SNR achieved by the relay at destination node. The closed form expressions of symbol error probability, outage probability and moment generating function (MGF) have been derived for total SNR at the destination. The average values of the symbol error probability, and SNR has been calculated. Moreover, from the value of MGF, the amount of outage probability, fading, and SNR moments have been calculated. Furthermore, the asymptotic behavior of the symbol error probability has been also derived here. Only AF relays has been considered here. Study of DF relays has not been included in this paper.

The study of DF relays has been considered in [12]. A relay selection scheme based on the threshold value of SNR has been proposed here. A system model has been investigated comprising a source, multiple relays and a destination node. In this proposed scheme efficient relays have been selected by comparing the SNR value of SNR from source to relay to a predefined threshold, and the best relay has been chosen by the destination node based on the SNR value of relay to destination path. A simple threshold function has been proposed here. It is seen that under this proposed threshold, this network achieves full diversity order $(N+1)$ when N number of relays are

chosen in the network. Here only one source node has been considered in the system model. Arrangement of multiple source node was beyond the scope of this paper.

Above mentioned limitation has been overcome in [13]. A sort-based relay selection algorithm has been provided here for DF relay scheme. Here the system model has been consisted of multiple source node and multiple relays. The necessary as well as sufficient conditions have been derived here for a relay to be attainable to a source. It is seen that the relay selection strategy could reduce the computational complexity as well as system overhead considerably. In have been reduced by this proposed algorithm. It has been shown here, by passing the source signal via feasible relay, to the destination, channel capacity has been improved compared to the direct source to destination link. The proposed algorithm allows each relay to make individual decision on its feasibility though the final decision on source and relay pairing has been made centrally. In this paper it has been demonstrated that, using this proposed algorithm the system performance has improved over the existing ones. Relay selection strategy for half duplex dual-hop communication has not been incorporated in this study.

The missing information of the previous work has been included in [14]-[15]. A sub-optimal relay selection strategy has been discussed here. A Decode-and-Forward (DF) cooperative diversity system has been considered here comprising a source, multiple relays and a destination node. Half duplex dual-hop communication system has been investigated here. A relay has been selected here which is capable to maintain the link quality constantly beyond a predefined threshold. At the destination node, SNR value is calculated from the received output. The end-to-end system performance has been derived in terms of outage probability. It is shown that, by using moderate threshold, the proposed scheme offers much lesser complexity than an optimal relay selection scheme. Single destination node has been considered here.

Solution for multiple destination node is given in [16]-[17]. Microwave-enabled Wireless Energy Transfer (WET) as well as signal processing techniques have described with by a transceiver structure consisting of relay with multiple antennas and multiple receiver nodes. Two design paradigms: simultaneous wireless information and power transfer (SWIPT) and wireless power communication networks (WPCN) are studied to indicate the performance gain when energy and information transfer are considered jointly. Relay selection technique for WPCN has not been included in this work.

Above missing information has been incorporated in [18]. A WPCN has been investigated which contains a source-destination pair and multiple Decode and Forward (DF) relays. A threshold of energy has been developed for the relay selection. The derivation of the

approximate analytical expression for the minimized outage probability is provided. In this paper nothing has been mentioned about bandwidth efficiency of the network.

To combat the above drawback, a new relay selection technique known as Maximum Link Source-Relay-Destination (MLSRD) is designed [19] to improve the spectral efficiency in a Cooperative Communication System (CSS). It has been shown that the bandwidth efficiency of the proposed scheme with MLSRD outperforms the CSS without MLSRD. Modulation scheme has not been included here.

Above missing information has been incorporated in [20]. Here, ASK modulation is included in the modelling of SWIPT system. Simulation is carried out using LabVIEW platform. The system model has two paths. One is RFEH and another is Information Decoding (ID). ID path contains ASK demodulator which uses RF envelope detector. Here, ASK modulated RF signal has been considered at 900 MHz. In this paper only ASK modulation based SWIPT system has been shown. Other modulation techniques like PSK, QAM etc. has not been included.

Improvisation of the previous paper has been done in [21]-[22]. PSK and QAM based modelling of SWIPT system have been discussed here. The system model consists of PSK and QAM generator circuits, VST and LabVIEW has been used for simulation. It has been proved here that modulation scheme has high impact on data transmission quality. Also, a comparative analysis between PSK and QAM based SWIPT system has been shown. The performance of AF or DF relay based SWIPT system has not been included in this work.

Above drawbacks has been sentenced in [23]. Here the performance of an AF relay based SWIPT system has been analyzed. In the system model, single source and destination node as well as in between M numbers of relay nodes are present. A direct path is also present between source and destination. Among the M relays best relay has been chosen based on highest amount of harvested energy. Information is forwarded to destination through that relay. The maximal ratio combiner (MRC) combines the two signals at the destination. The expression of the system outage probability has been established. It has been shown that the proposed system model outperforms the conventional non-direct links systems. DF relay based SWIPT has not been included here.

A DF relay based SWIPT system has been examined in [24]. Here also a direct link is present in between source and destination. At the destination selection combination (SC) scheme has been used for combine the signals. The derivation of the closed loop expression of outage probability is provided. The integral form of the ergodic process

has also been derived. Finally, it has been proved that this DF model is better than the conventional model. This work has not included information about half duplex or full duplex communication.

Above drawbacks have been sentenced in [25]-[26]. Outage probability analysis for SWIPT has been discussed for a point-to-point communication model using AF half duplex relay node with single antenna. Throughput and outage probability has been plotted for different values of transmit power, SNR, critical temperature, and relay distance from the source node. Relay control for SWIPT in full duplex relay network has been examined in [27]-[28] in case of a TSR based two-way relay network and in a nonorthogonal multiple access system and average throughput has been calculated. Here only AF relay has been considered.

In [29], maximum transmission rate has been studied for a system comprising a two-hop DF relay and source & destination node. A comparative study between AF & DF relay's sum rate has been included. The algorithm aiming at resource optimization for a multicarrier relay with SWIPT has been provided. Here, non-ideal form of energy consumption is used by involving non-ideal power amplifier. This paper does not provide any information about the minimization of relay transmission power.

Above missing information has been included in [30]. This paper attempts to propose an algorithm to choose the best relay based on minimum relay transmission power, where interference temperature constraints and the secondary user SINR requirements have been satisfied. In this algorithm l_0 norm is approximated as l_1 norm. A minimum relay transmission power constraint problem has been constructed to choose the proper relays. However, independent transmission of information has not been considered.

In [31] a SWIPT system has been proposed with independent information & transmission channel. System model with separate power transmission and information transmission path has been described in detail. This model solves the problem of dependency of the information transmission on power transfer. Here no information has provided about the technique of throughput control.

In [32] an adaptive relay selection scheme and data transmission method have been designed for cooperative communication. A characteristic of Reed-Solomon (RS) codes has been used by this algorithm, due to this the proposed relay selection algorithm does not need a priori information at the source node. By using this RS code, the optimal relay has been selected by the source node for cooperative communication. Furthermore, the maximum throughput according to the result of optimal relay selection can be changed

by this proposed transmission scheme. Author has not focused on imperfections of the hardware in this process.

The above limitation has been overcome in [33]. Here the imperfections of the hardware of a PS-SWIPT system have been examined. These imperfections are IQ imbalance, amplifiers' nonlinearity and phase noise. Bad effects of these imperfections are determined with a system model consisting of two continuous power source and a relay with energy harvesting capability. The expression of the received signal at the destination node has been derived considering the hardware imperfection and distortion. Non-linear energy harvesting in SWIPT has not been examined here.

The above-mentioned drawback has been sentenced in [34]. Non-linear energy harvesting in case of PS and TS EH protocol-based relay with SWIPT technology has been investigated. A system model with battery assisted relay and direct linked source and destination node has been considered. At the destination node signals are combined by optimal combining. It has been shown that direct linked technique increases the throughput of the system and decreases energy consumption of the relay. Throughput expression of the practical nonlinear model has been established. Two-way transmission of Relay has not been incorporated in this paper.

Above missing information has been incorporated in [35]-[36]. Two-way transmission relay based SWIPT system for PS receiver has been described. Two strategies of transmission have been proposed, which are Delay-Limited-Relay (PS-LDR) and Delay-Tolerated-Relay. A two-way half duplex relay communication system has been considered to explain the above strategies. Also, a comparative study between these two strategies has been shown in terms of SNR value. Study of network service time has not been mentioned in this paper.

Limitations of the above has been overcome in [37]. To increase the service time, a SWIPT network with cache memory equipped relay has been proposed. The system model consists of a source node, a destination node and multiple DF relay nodes with cache memory, which has energy harvesting capacity and follows TSR protocol. Best relay has been selected based on maximum relay destination throughput and the energy stored in the relay. Maximum throughput and maximum energy stored in the relay verses source power has been plotted. In this paper hybrid model of relay with both TS and PS protocol in SWIPT has not been inserted.

Disadvantages of the previous work has been overcome in [38]-[39]. Joint power allocation and power splitting control in a SWIPT system has been investigated with the

system model which has a source, relay and multiple users and one base station (BS). Trade-off between transmission rate and harvested energy have been studied. Hybrid TS and PS is applied at relay for energy harvesting. Transmission rate verses number of users and total transmit power has plotted. Device to device network with SWIPT technology is beyond the scope of this paper.

Above restrictions have prevailed over in [40]-[43]. In a disaster situation to ensure self-sustained communication, a device to device (D2D) network with SWIPT technology has been proposed and discussed in details with the system model consists of a Base station, a single cell which covers CUEs (character terminal users) and D2D users. It assures connectivity with devices having drained back-up. Time switching technique is used for energy harvesting and information decoding simultaneously. SWIPT technique allows limited battery capacity mobile devices aiming for harvesting energy from ambient RF sources, which improves the energy efficiency in D2D networks. However, in a disaster situation, energy deficiency of the source node has not been combated in this paper.

Above inefficiency has been overcome in [44]. In this paper a model has been studied comprising a source, multiple relays and one base station. Here, source node selects the best relay to transmit signal to the base station. An algorithm has been established to calculate the highest throughput of the best relay. Throughputs have been plotted against different distances between source and the selected relay node. Also, throughput has been plotted against time switching factor using TSR protocol. In this paper only one best relay has been selected from a pool of relays and multiple relay selection technique has not been included.

In [45] multiple relay selection technique has been studied. The capacity maximizing relay selection strategy has been introduced in this paper. A full duplex energy harvesting relay system has been considered here. In this proposed relay selection scheme multiple relays have been chosen simultaneously to improve the system performance. It has been studied here that, at low SNRs, the strategy of selecting only one best relay, not always gives the optimal relay. Moreover, in this paper a greedy relay selection strategy with quadratic complexity for full duplex energy harvesting relay networks has been displayed. However, the selection of multi-relay on the basis of SNR threshold has not been considered here.

Above issue has been addressed in [46]. Here a system model including a source node, multiple relay nodes and a destination node has been considered. Necessary mathematical expressions and algorithm has been described to select the best four relays from a set of five relays and seven relays. Best four relays have been selected here on the basis of SNR values. Comparison between relay-pool with five relays and seven relays has been plotted here considering the SNR.

2.3 OUTCOME OF THE REVIEW

A survey of the literature on relay-aided RF energy harvesting networks has been presented in this chapter. A general overview of cooperative relaying in RF energy harvesting networks along with a detailed discussion of two important relaying protocols - Amplify-and-Forward (AF) and Decode-and-Forward (DF) have been discussed. One of the major problems with relay-aided RF energy harvesting communication network architecture is the power-energy trade-off. One remedy for the aforementioned problem is choosing the appropriate relay. The detailed review presented in this chapter reveals the fact that selection of the proper relay can be made singly or as a set of relays. Many research works have already been carried out in this direction. However, the research advancement in the direction of relay selection strategies reveals that few research works have been carried out in line with the multi-relay selection. So, there is an immense scope to continue research in this direction. Following this direction, a novel relay selection strategy has been proposed in this thesis to select the best four relays from a given set of relays, based on their throughput performances.

CHAPTER 3

THEORETICAL BACKGROUND

3.1 OVERVIEW

This chapter gives an overview of the theoretical background of the proposed work. A brief discussion of the relaying schemes has been included here. The types of relaying protocols of RF energy harvesters have been overviewed in this chapter. Some relay selection strategies have also been explained here.

3.2 RF ENERGY HARVESTING RELAYING NETWORK

A simple RF energy harvester relaying network has three nodes, these are Source, relay and destination. Source transmits RF signals to relay. Here the relay is capable of RF energy harvesting. Relay node does not have any battery or external power system, it has only RF energy harvester. This relay node absorbs RF signal from ambience and harvests energy from this RF signal. Now, using this harvesting energy, relay receives the signal from source and retransmits it to the destination node. A simple relaying network has been shown in Fig. 3.1.

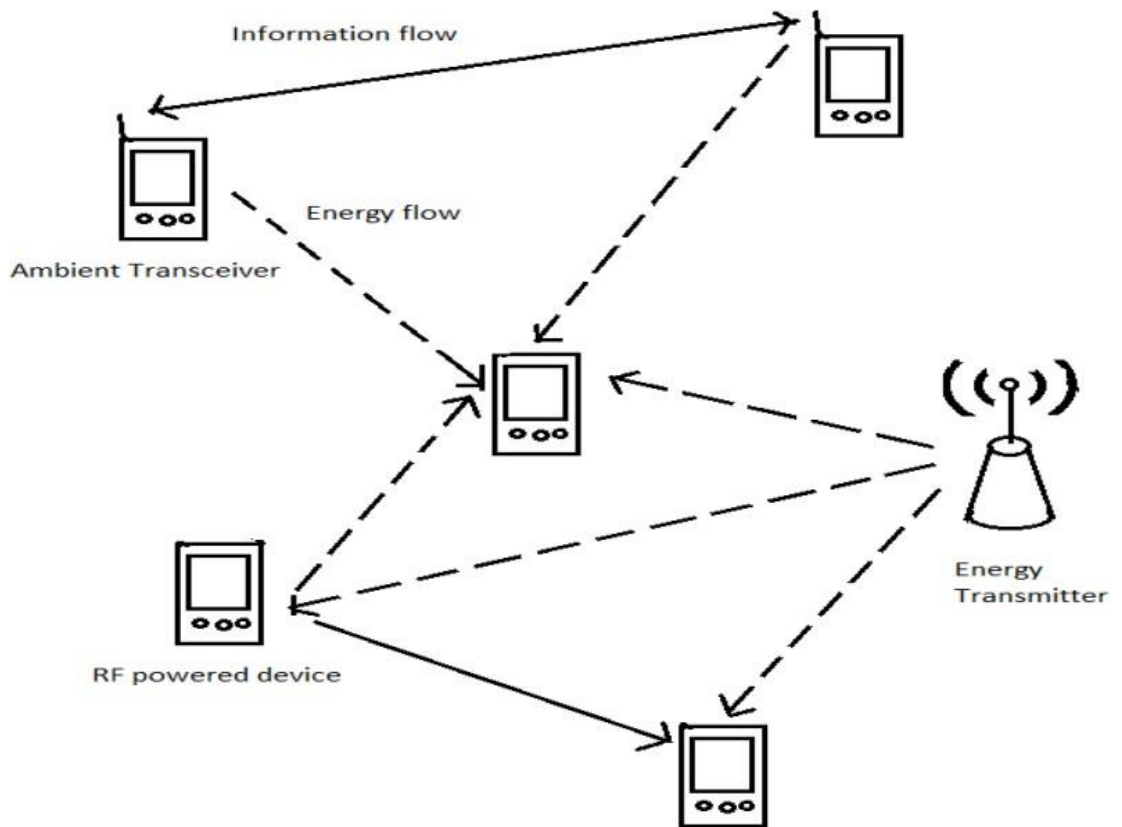


Fig 3.1. An infrastructure-less architecture of RF- EHN[46]

3.3 RELAYING SCHEMES

There are two types of relaying schemes are present. They are- Amplify and Forward (AF) and Decode and Forward (DF).

Amplify and Forward (AF): By Laneman et al. [46], a straightforward cooperative signaling technique was presented and assessed. The signal from the source is amplified at the relay in this relaying technique before being transferred to the target. This strategy's primary drawback is that the relay amplifies both the signal and the noise. As a result, this protocol is only employed when the relay should have a minimal time delay in decoding and encoding the message or when the relay has limited computational capabilities. The block-wise amplification of the received signal y_R in the AF protocol can be described as a signal multiplied by an amplification factor (β), which normalizes the received strength.

The received power at the relay is given by

$E[|y^2_R|] = E[|h_{S,R}|^2]E[|x_S|^2] + E[|z_{S,R}|^2] = |h_{S,R}|^2\xi + 2\sigma^2_{S,R}$ [46] and the amplification factor “ β ” can be calculated by $\beta = \sqrt{\frac{\xi}{|h_{S,R}|^2\xi + 2\sigma_{S,R}^2}}$ [46], based on the assumption that the relay can estimate the channel characteristics completely [46].

Decode and Forward (DF): This strategy was used in the research by Sendris et al. [47]. By employing this method, the relay station decodes the signal it has just received from the source node before relaying it to the destination station. The relay uses the checksum method and error-correcting codes to identify and fix any mistakes in the signal it receives. Since there is no amplified noise in the sent signal, which was a problem with AF protocol, it is widely utilized as a data processing tool at the relay. The relay, however, needs both processing power and bandwidth in order to correctly complete the decoding task. In order to avoid the delay caused by the first method, there is another method that processes the signal by decoding and re-encoding it symbol by symbol.

3.4 RELAYING PROTOCOLS

Relays in communication networks can help with spatial variety and help prevent fading. Source nodes can transfer data to their intended destinations using the network's shorter hops thanks to cooperative relaying. The effectiveness of the network is boosted by this. However, the relays' performance may be limited if they lack a reliable power source. Because of this, the relays perform RF energy harvesting, which not only provides energy but also enables data transmission over the relay utilizing the harvested power. Depending on the receiver design, two techniques are frequently employed for RF energy harvesting in cooperative relay networks: Both the Time Switching Relaying (TSR) protocol and the Power Splitting Relaying (PSR) protocol are based on the Time-switching-receiver architecture.

Time switching relaying (TSR) protocol: Fig. 3.2 [48] depicts the transmission frame construction used at the relay node to harvest energy and analyses data. In this case, the relay first uses a portion of the entire time slot (T) to capture RF energy before beginning source-relay communication with the remaining half of T. The final time-slot is used for communication between the relay and the destination using the harvested power.

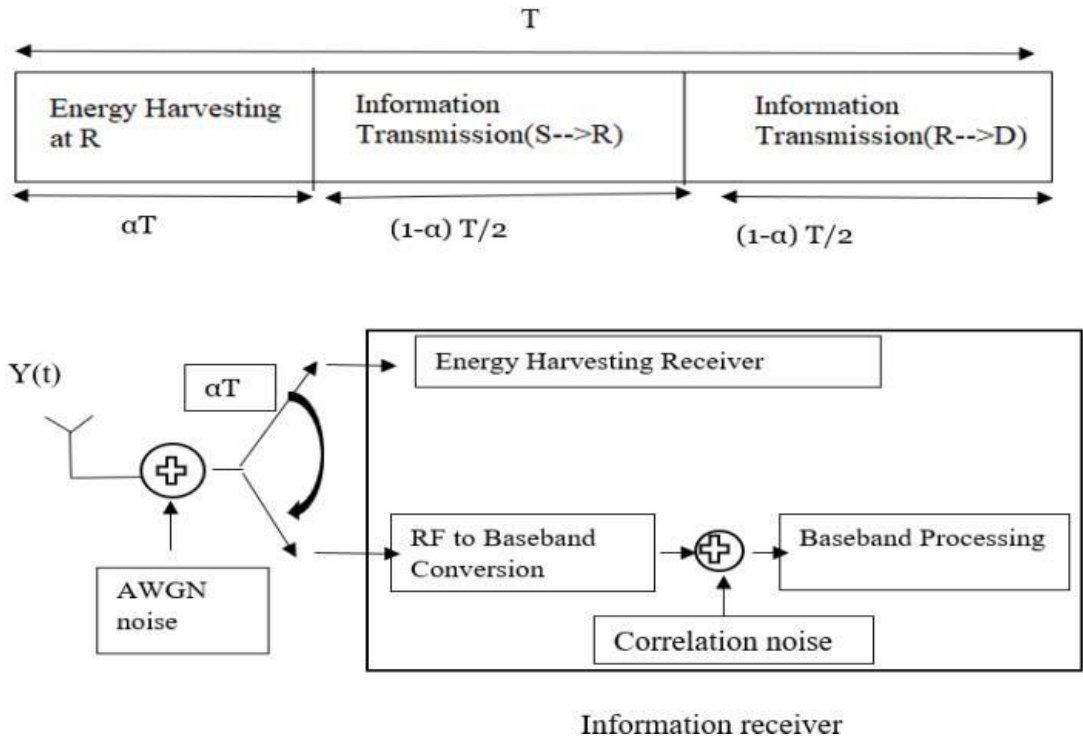


Fig3.2. A relay receiver using TSR protocol [48]

Power Splitting Relaying (PSR) protocol: The PS receiver is used at the relay as depicted in Fig 3.3[48]. in this protocol, the receiver splits its power (P) based on the power splitting ratio (ρ), where some of the source power ρP is used for RF energy harvesting and the remaining power, $[(1-\rho)P]$ is utilized to decode the received data.

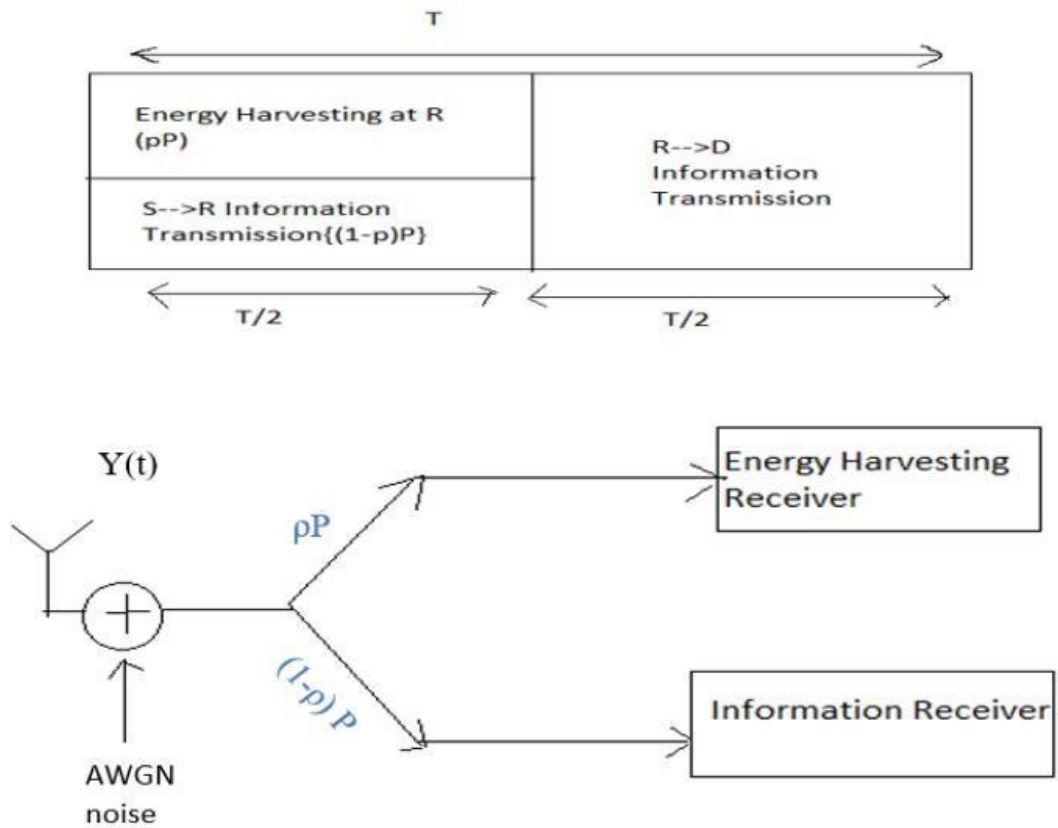


Fig 3.3. A relay receiver using PSR protocol [49]

3.5 DISCUSSION

A brief discussion on the theoretical background of this thesis work has been provided in this chapter. The various cooperative relaying protocols such as, TSR and PSR that can be applied in an RF Energy Harvesting network have been described, along with the accompanying mathematical equations. Moreover, different relaying schemes such as AF and DF have also been included here. A thorough explanation of the proposed work is provided in the following chapter.

CHAPTER 4

PROPOSED WORK

4.1 OVERVIEW

Relay selection is essential for attaining diversity benefit and ensuring Quality of Service (QoS) in cooperative networks. In a relay network that uses energy harvesting technique, the best relay can be selected from a set of relays based on its throughput performance, SNR, stored energy and many other qualities of that relay.

In this proposed relay selection method best four relays have been selected from some finite set of relays, based on their throughput performances. The proposed algorithm has been described in this chapter to choose the best four relays. The proposed system model has been described with necessary assumptions and mathematical expressions.

4.2 PROPOSED SYSTEMMODEL

A single source (S) to destination (D) communication is carried out with the help of relay (R) in an energy harvesting network where the source signal is transmitted to destination via the best relay ($S - D - R$) link.

4.2.1 ASSUMPTIONS

The following are some of the assumptions to be Considered.

- In this architecture source and destination has single antenna. It is a half-duplex system.
- Rayleigh fading channel is considered from source to relay, then from relay to destination.
- All relays are Amplify and Forward (AF) type of relays.
- All relays are energy harvesting capable.
- Initially source has zero energy to transmit information to relay, so it collects energy wirelessly from the relays.
- All the relays supply energy to the source at the same time.

4.2.2 BASIC SYSTEM DIAGRAM

The basic system diagram has been shown in Fig. 4.1, where 'n' number of relay nodes (R1, R2,...,Rn) are considered. These relays with energy harvesting capability, wirelessly deliver the energy to the source node. Source then selects best four relays among 'n' number of relays. These four relays have the highest throughput in the pool. Next, among these best four relays, source sends information to the relay with highest throughput performance. By any chance, if this best relay-throughput goes below threshold, then second best relay transmits the information from source to destination node. In the event of a failure, the third or fourth best relay sequentially transfers the information to the destination.

All the relay nodes are present at different distances from the source node. Let, $d_1, d_2, d_3, d_4, \dots, d_n$ are the distances from source to relay node R1, R2, R3, R4, ..., Rn. Between source and relay there is a channel gain of h_{rn} and between relay and the destination there is a channel gain of h_{bs} .

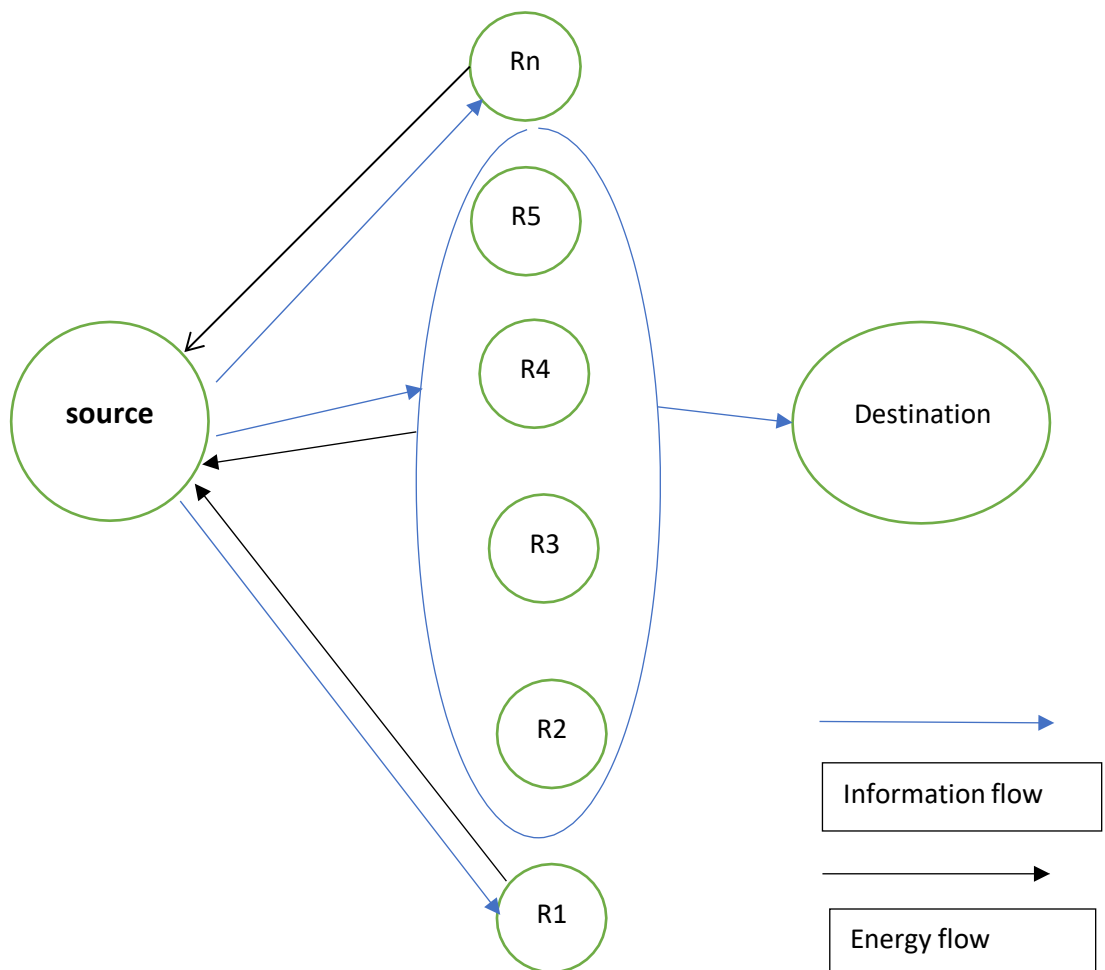


Fig. 4.1: The basic system model

4.2.3 TIME FRAME STRUCTURE

Here, source gets the energy from the relays. Let total communication time be T from source to destination and αT time be the time slot required for energy harvesting. That means in αT time, relays send energy to the source node and source gets charged, where $0 < \alpha < 1$. This αT time is known as energy harvesting time. Information flow takes place over the remaining period $(1-\alpha)T$. Again, information flow time is divided into two parts, $(1-\alpha)\beta T$ and $(1-\alpha)(1-\beta)T$, where $0 < \beta < 1$. In time $(1-\alpha)\beta T$, information flows from source to selected relay; whereas, during the time $(1-\alpha)(1-\beta)T$, information flows from relay to the destination node. The corresponding timing diagram has shown in Figure 4.2.

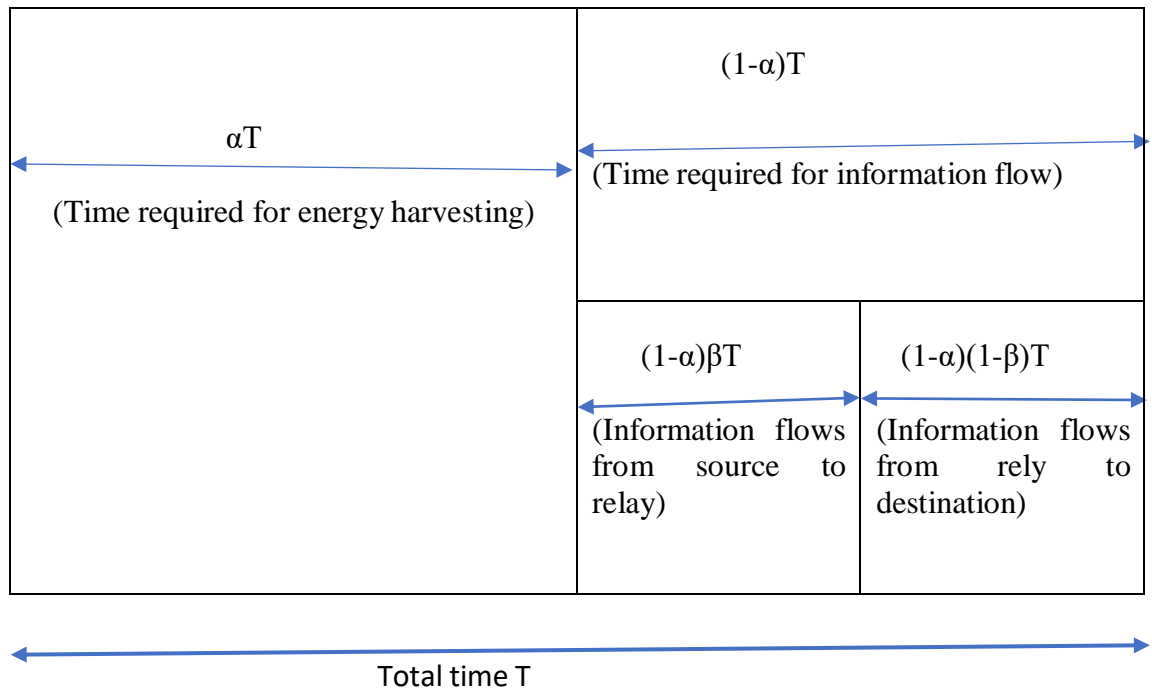


Fig. 4.2: Timing diagram

4.3 PROPOSED ALGORITHM

An algorithm has been proposed in Fig. 4.3 to select the best four relays from a large set of relays.

```

Begin
Input number of relays N;
        d1,d2,d3....dn;
        dbs,
        P;
        energy harvesting efficiency  $\delta$ ;
        path loss constant K;
        path loss index a;
        variance  $\sigma^2$ 
Set n=1
While n<=N
  
```

Do

$$\Upsilon_1 = P * h_{d_{bs}} / \sigma^2;$$

$$\Upsilon_2 = h_{u_{rn}} * \delta * P * \sum_{n=1}^N h_{u_{rn}};$$

$$\beta_1 = \ln(1 + \Upsilon_1) / ((W(\Upsilon_2 - 1)/e) + 1 + \ln(1 + \Upsilon_1))$$

$$\beta_2 = \log_2(1 + \Upsilon_1) / (\log_2(1 + \Upsilon_1) + (W(\Upsilon_2 - 1)/e) + 1) * \log_2 e$$

$$\alpha_1 = \left[e^{w^{[(\frac{\Upsilon_2}{\beta} - 1)/e] + 1}} - 1 \right] / \left[e^{w^{[(\frac{\Upsilon_2}{\beta} - 1)/e] + 1}} - 1 \right] + \Upsilon_2 / \beta$$

$$\alpha_2 = [(1 + \Upsilon_1)^{(1-\beta)/\beta} - 1] / [(1 + \Upsilon_1)^{(1-\beta)/\beta} - 1 + \Upsilon_2 / \beta]$$

if $\alpha_1 \leq \alpha_2$

$$\alpha = \alpha_1$$

$$\beta = \beta_2$$

else

$$\alpha = \alpha_2$$

$$\beta = \beta_1$$

End if

$$\text{Throughput } R = (1 - \alpha) * \beta * \log_2(1 + ((\alpha * \Upsilon_2) / ((1 - \alpha) * \beta)))$$

Update $n = n + 1$

End while

$$\text{Array} = [R_1 \ R_2 \ R_3 \ R_4 \ \dots \ R_n]$$

Sort the Array

Set data rate $r = 1$;

$$\text{Threshold} = 2^{2 * r} - 1;$$

If $\text{Array}[] > \text{Threshold}$

$$\text{Selected array } [R_1 \ R_2 \ R_3 \ R_4] = \text{Array} []$$

End If

If $R_1 \geq \text{Threshold}$

$$\text{Throughput} = R_1$$

Else If $R_1 < \text{Threshold}$

$$\text{Throughput} = R_2$$

Else If $R_2 < \text{Threshold}$

$$\text{Throughput} = R_3$$

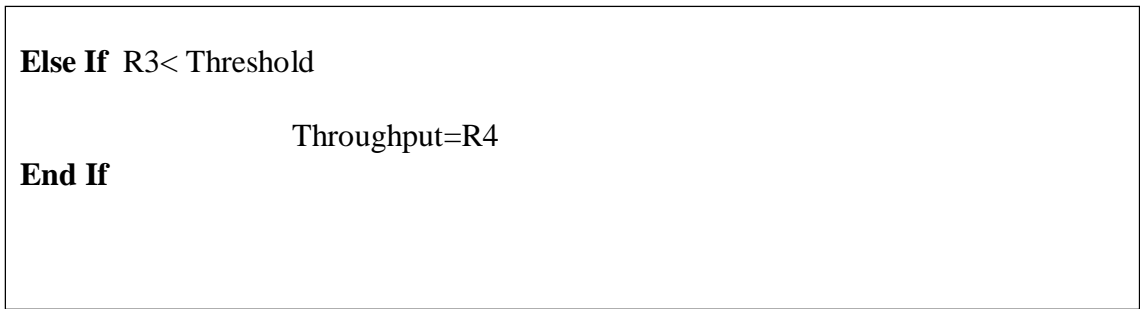
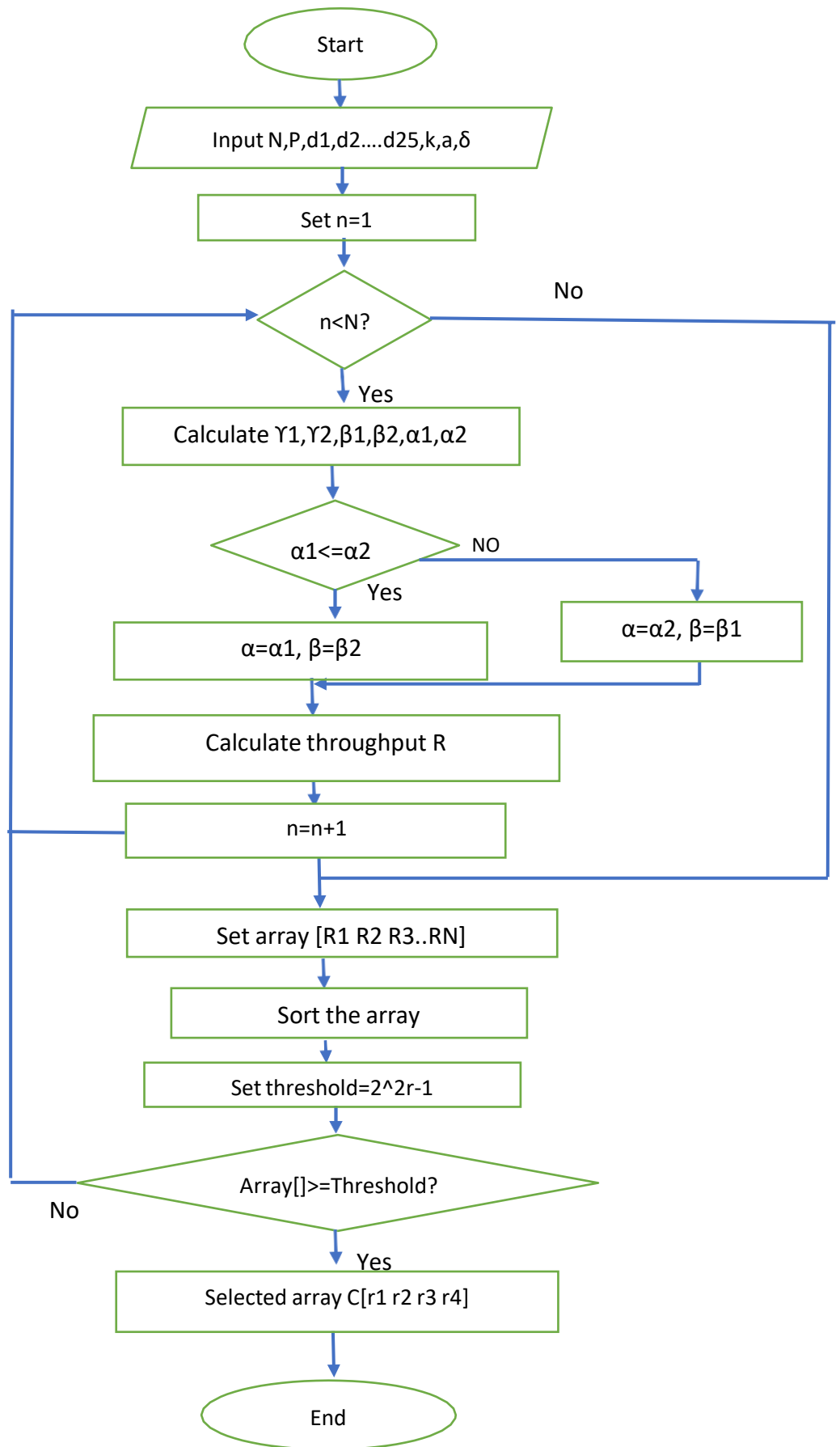


Fig.4.3 Algorithm for best four relay selection

4.4 FLOWCHART OF THE PROPOSED ALGORITHM

Above algorithm has been presented below in the form of flow chart for better understanding.



4.5 DISCUSSION

The proposed multiple relay selection strategy for RF energy harvested relay networks has been presented in this chapter. The description of the proposed model has been provided here with necessary diagrams and mathematical expressions. All the required assumptions for the simulation purpose have been listed. A detailed description of the proposed algorithm has been given. The flowchart of the proposed algorithm has also been included in this chapter for better understanding.

CHAPTER 5

RESULTS AND ANALYSIS

5.1 OVERVIEW

The simulation results of the proposed work have been presented in this chapter. A new relay selection strategy has been proposed where best four relays have been selected, based on their throughput performances, from a given finite set of relays. Their throughput performances have been simulated and compared with the existing works [15] and [44]. Different number of relay-sets has been considered here and throughput performances has been analyzed over different distances. Also, throughput performances of TSR and PSR protocols have been presented here. The proposed model has been simulated using MATLAB R2015a. The results are obtained using Monte-Carlo simulation. The specification of the computer used for simulation purpose are-Windows 10, 64-bit OS, 4 GB RAM, Intel Core i5-3317U CPU, processor running at 1.70 GHz. The detailed analysis and comparison of the proposed algorithm has been presented in the subsequent sections.

5.2 PARAMETER SETTING

Table 5.1 includes a list of the input settings of simulation.

Table 5.1. Setting of parameters used in the simulation [44]

Number of relays (N)	10,15,20,25
The distance between source and relay, d (m)	5,7,9,11,13,15,17,19,21,23,25,27,29,31,33,35,37,39,41,43,45,47,49,51,53
The transmit power of the relay, p (w)	0.8
The noise power, σ^2 (dBm)	-114
Path loss constant, k	0.0001
Path loss component, a	3.5
Energy harvesting efficiency, δ	0.5
Data rate threshold (bps/Hz)	3

5.3 SELECTION OF BEST RELAY SET FROM VARIOUS RELAY SET SIZE

The best four relays have been selected from a given set of relays. The best relay has been chosen from the small subset of best four relays to transmit the signal to target node. Moreover, this selection has been extended for relay sets of variable size, such as, 10,15,20 and 25. A comparison of the relay selection based on throughput values for various relay set size has been shown below.

Table 5.2. Comparison of relay selection based on throughput values

No. of relays	Throughput of the selected relays (bps/Hz)				α and β values of the best relay	
	R1	R2	R3	R4	A	B
10	4.6664	4.0466	3.6456	3.2659	0.3126	0.7276
15	4.3636	3.8011	3.3340	3.1940	0.3234	0.7485
20	4.0614	3.4380	3.4306	3.2190	0.7285	0.8984
25	3.5726	3.5681	3.5352	3.3370	0.7369	0.9064

From the above Table, it has been observed that, with the increasing size of the relay set, the achievable throughput has decreased. Because, when the number of relays increase in a set, distance from source to relay also increases. Throughput decreases for larger distance. Also, it has been noticed that, α and β values get enhanced with the increased size of the relay set or lowered value of throughput. Here α represents the energy harvesting time ratio and β represents the data transfer time ratio of the remaining time, in the given time block. With the increasing distance, α goes high and remaining time for relay selection and data transfer becomes low. Then from the remaining time, β has to take a larger time ratio to transfer the data to larger distance. Ultimately, the throughput decreases.

5.4 THROUGHPUT VERSUS DISTANCE ANALYSIS FOR BOTH TSR AND PSR PROTOCOLS FOR A PARTICULAR RELAY SET SIZE

The throughput performance of the proposed relay selection algorithm for different distances between source and selected relay has been shown in Fig 5.1. and

Fig 5.2. Here both TSR and PSR protocol has been considered. The effectiveness of the proposed algorithm has also been contrasted with earlier efforts [15] and [44].

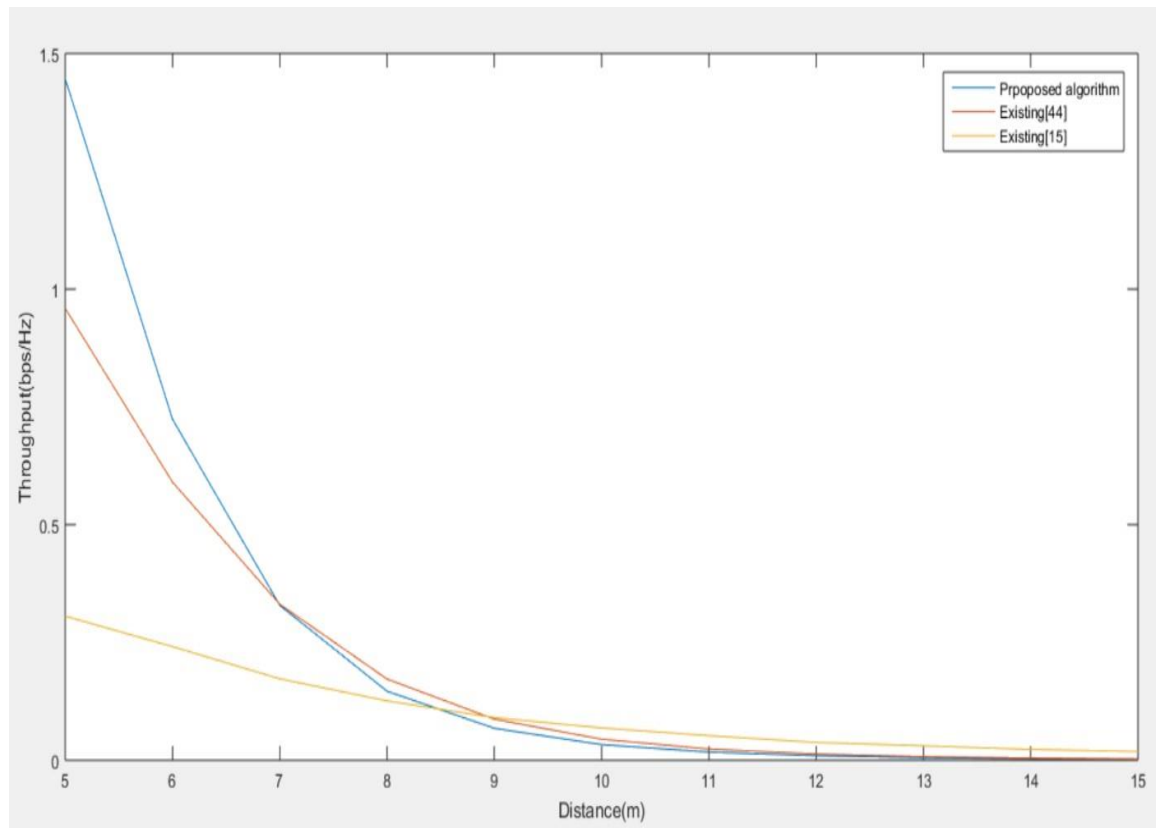


Fig 5.1. Variation of throughput values with distance for TSR protocol

It has been clearly observed that, initially the throughput of the proposed algorithm is much higher than the existing algorithms [15] and [44]. For example, at a 5m of distance from source to relay, throughput of the proposed algorithm is 1.45 bps/Hz, whereas, the throughputs of existing algorithms [44] and [15] are 0.90 and 0.30 bps/Hz, respectively. Over a range of distance of 5m to 7m, the proposed algorithm outperforms the existing two algorithms. Moreover, over the range of distance of 7m to 8.5m, the throughput of the proposed algorithm is slightly inferior to the existing algorithm [44] but it performs better than the existing algorithm [15]. Over a distance of 9m, the throughput of the proposed algorithm is slightly lower than the existing algorithms [44] and [15].

It has been clearly observed that the throughput has been decreased with the increasing value of distance from source to selected relay. But the rate of decrease is not same for all. Also, the rate of decrease is different for different interval of distance. Initially all relays have achieved high throughput but, as the distance increases from source to relay, throughput decreases rapidly. In case of the proposed algorithm and Existing[44], at a certain value of distance, throughputs fall sharply. After that certain point throughput decreases very slowly. For Existing[15] throughput is very low compared to the others. Here throughput does not fall very sharply. For more clear understanding throughput values has been shown in Table 5.3.

Table 5.3. Comparison of Throughput values of proposed algorithm for TSR protocol

Distance(m)	Algorithm	Throughput (bps/Hz)
5	Proposed algorithm	1.45
	Existing[44]	0.90
	Existing[15]	0.30
8	Proposed algorithm	0.20
	Existing[44]	0.18
	Existing[15]	0.15
11	Proposed algorithm	0.05
	Existing[44]	0.05
	Existing[15]	0.10

From Table 5.3, it has been calculated that, when the distance is 5m, throughput of the proposed algorithm is 37.93% and 79.31% greater than Existing[44] and Existing[15], respectively.

In Fig 5.2 PSR protocol has been considered to plot the throughput against distance. It has been clearly observed that, initially the throughput of the proposed algorithm is much higher than the existing algorithms [15] and [44]. For example, at a 5m of distance from source to relay, throughput of the proposed algorithm is 1.18 bps/Hz, whereas, the throughputs of existing algorithms [44] and [15] are 0.74 and 0.05 bps/Hz, respectively. Over a range of distance of 5m to 8.5m, the proposed algorithm outperforms the existing two algorithms. Over a range of distance of 9 to 11m, the throughput of the proposed algorithm is almost same as the existing algorithm [44] but better than the existing algorithm [15]. The Throughput is insignificant over a distance of 11m.

Considering Fig 5.1 and 5.2 it is evident that in case of both TSR and PSR protocols, the proposed algorithm provides the highest throughput, comparing to the other two existing algorithms [15] and [44]. This is because of the fact that in the proposed algorithm two step relay selection strategy has been followed. At first, the best four relays have been selected. Then from these selected relay set, the highest throughput achiever relay has been chosen to forward the signal from source node to the destination.

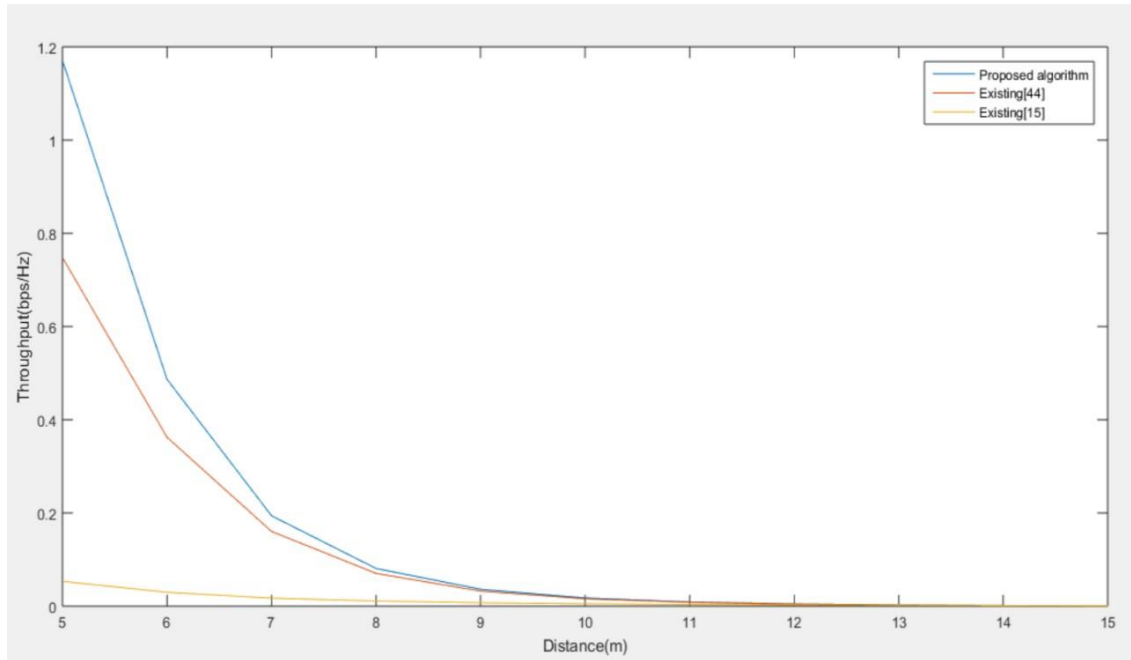


Fig 5.2. Variation of throughput values with distance for PSR protocol

The detailed analysis of the Fig 5.2 has been shown with the help of Table 5.4.

Table 5.4 Comparison of Throughput values of proposed algorithm for PSR protocol

Distance(m)	Algorithm	Throughput(bps/Hz)
5	Proposed algorithm	1.18
	Existing[44]	0.74
	Existing[15]	0.05
8	Proposed algorithm	0.1
	Existing[44]	0.09
	Existing[15]	0.01
11	Proposed algorithm	0.01
	Existing[44]	0.01
	Existing[15]	0

When the distance between the source and relay is 5m, throughput of the proposed algorithm is 37.2% greater than the existing algorithm [44] and 95.76% greater than existing algorithm[15]. When this distance is changed to 8m, the proposed algorithm throughput is 10% and 90% more than existing algorithms [44] and [15] respectively. So,

it has been shown that, with the increasing distance, differences of the throughputs decrease for both TSR and PSR protocol.

5.5 COMPARISON OF THROUGHPUT PERFORMANCE BETWEEN TSR AND PSR PROTOCOLS

Here, using the proposed algorithm four relays have been selected from the sets of ten and fifteen relays. Their throughput performances have been compared for both TSR and PSR protocol. In Fig 5.3 the comparison has been shown by MATLAB simulation.

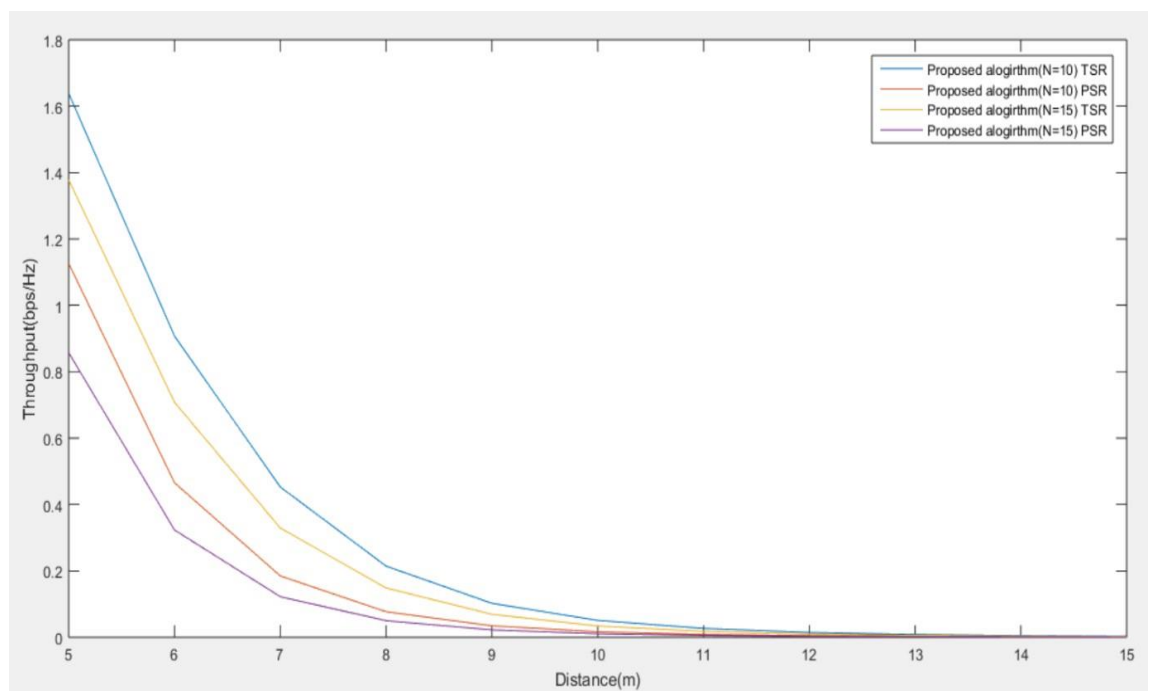


Fig 5.3. Performance comparison of TSR and PSR protocol for proposed algorithm

It can be observed that throughputs decrease with the distance. The throughput of the proposed algorithm for TSR protocol with ten relays in a relay set, has much higher throughput than the others. The rate of decreasing of throughput is different for different interval of distance.

Here it has been shown that the TSR protocol has higher throughput than the PSR protocol in both cases when number of relays in the set is ten and fifteen. Because in case of PSR, power splitting antenna faces some problems like, power loss, signal distortion more than time switching antennas [50]. Another observation is that the throughput value is lesser in case of relay-set with fifteen relays than the relay-set with ten relays. This thing has been discussed in section 5.5 With more details.

For better understanding of the comparison of TSR and PSR protocol performance, Table 5.5 has been shown.

Table 5.5 Comparison of TSR and PSR protocol for proposed algorithm

Distance(m)	No. of relays(N)	Protocol	Throughput (bps/Hz)
5	10	TSR	1.62
		PSR	1.38
	15	TSR	1.12
		PSR	0.85
8	10	TSR	0.20
		PSR	0.18
	15	TSR	0.10
		PSR	0.08
11	10	TSR	0.01
		PSR	0.01
	15	TSR	0.01
		PSR	0.01

For 5m distance from source to selected relay, throughput for TSR protocol is 14.8 % more than PSR in case of 10 relays and TSR throughput is 24.1% more than PSR throughput, in case of 15 relays.

5.6 THROUGHPUT COMPARISON OF THE PROPOSED ALGORITHM FOR VARIOUS RELAY SET SIZE

The throughput or achievable data rate performance of proposed algorithm has been analyzed and compared for N=10, 15,20 and 25 number of relays. Best four relays have been selected from these sets of relays. Fig 5.4 describes the performance of achievable data rate of the above sets of relays.

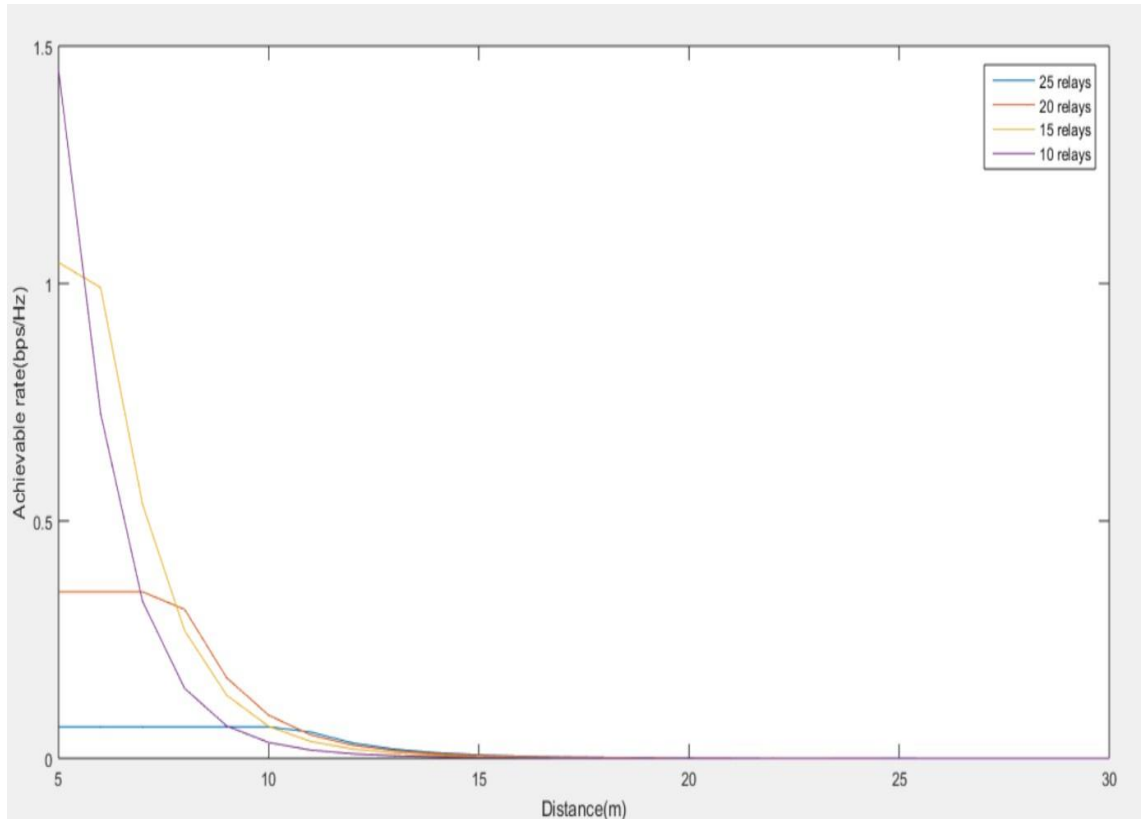


Fig 5.4. Comparison of achievable data rate of the proposed algorithm

From the Fig 5.4, it has been seen that throughputs decreases with distance. Decreasing rate is different for all throughputs. For the relay set with twenty relays, the throughput is initially constant for the interval 5 to 7m, then it has started to decrease. For the relay set with twenty-five relays, the throughput is initially constant for the interval 5 to 11m, then it has started to decrease. After 15m, the change in throughput is insignificant.

It has been seen that relay set having ten relays, has the highest achievable rate when the distance is 5m, and relay set having twenty-five relays has lowest performance. At 5m of distance, relay set having fifteen relays has lower performance than relay set having ten relays, and higher than relay set having twenty relays. So, it has been observed that, with the increasing number of relays in a set, achievable rate decreases at smaller distance. The reason of this is, with the increasing number of relays in a set, the distance also increases from source to the selected relay. Since, all the relays are not present in the same distance from source. With the increasing distance, channel fading also increases. Due to this the achievable rate decreases. So, to get the higher throughput, it is necessary to utilize a relay set with small number of relays. This scenario has been clearly shown in Table 5.6.

Table 5.6 Comparison of achievable rate of N=10,15,20,25 relay sets

Distance(m)	No. of relays (N)	Achievable rate (bps/Hz)
5	10	1.48
	15	1.05
	20	0.35
	25	0.05
10	10	0.05
	15	0.07
	20	0.1
	25	0.07
15	10	0
	15	0
	20	0
	25	0

For 5m distance from source to relay, relay set having ten relays has the highest achievable rate which is 29.05% more than the relay set having fifteen relays, 76.35% more than the relay set having ten relays and 96.62% more than the relay set having ten relays.

5.7 DISCUSSION

In this chapter, the proposed algorithm has been simulated using MATLAB R2015a and the throughput performance has been examined and compared with the one best relay selection strategies. It has been observed that when the number of relays is less in the set, throughput is higher. The relay set having ten relays (N=10) has the highest throughput among N=15,20 and 25 relay sets. The proposed algorithm has higher throughput for both TSR and PSR protocol than the existing optimized relay selection algorithms. The achievable rate decreases of the proposed algorithm as the distance increases from source to the selected relay.

CHAPTER 6

CONCLUSION

6.1 CONCLUDING REMARKS

A new relay selection algorithm has been proposed in this thesis. Here, a model has been considered with a source, destination and multiple relay nodes. Four best relays have been selected from a set of relays. Different set size of relay such as, 10, 15, 20 and 25 has been considered here based on their throughput performances. Two relaying protocols, TSR and PSR have been considered to calculate the throughput of the relay. In the proposed model, relays are present at different distances from the source node. Initially, source node has insufficient energy to transmit the signal. Then the source node gets charged by all the relay nodes, which are energy harvesting capable. The throughput performance of this algorithm has been analyzed and compared with the existing two algorithms [15] and [44]. Throughput based on different distances has been plotted here for TSR and PSR protocols.

Our findings from the MATLAB simulation results are as follows:

- The throughput is higher for the relay sets comprising lesser number of relays compared to the relay sets with large number of relays, for both TSR and PSR protocols.
- For smaller distance of source to relay node, proposed algorithm gives the highest throughput. As the distance increases, value of throughput decreases sharply and at a certain distance the throughput becomes almost zero.
- Throughput decreases with distance at a higher rate for the proposed algorithm which gives the highest throughput initially. For the existing algorithms [15] and [44], the rate of fall in throughput with distance is lower than that of the proposed work.
- The throughput performance of the proposed algorithm has also been compared with the existing algorithms [15] and [44] for a relay set size of 10. It is found that the proposed work shows much better performance than the existing ones up to a certain distance between the source and the relay, after which, the throughput performance of the proposed work fails to outperform the other existing works.

6.2 FUTURE SCOPE

The algorithm that has been studied in this work is just one of many procedures that are used for relay selection purpose. It can be extended and

modified further in order to improve the network performance. This algorithm can incorporate the two attributes of relay selection strategy, best SNR and best throughput, both in together. This algorithm can also be modified for DF relay scheme and a comparative study of AF and DF relay can be possible. Furthermore, the proposed model can be modified by incorporating multisource node for better performance. This proposed model can be simulated using a network simulating platform, such as NetSim. SWIPT technology can be introduced in this model. This proposed work can also be improved by using MIMO technology.

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