B. TECH PROJECT REPORT

On

THROUGHPUT ANALYSIS FOR UAV-ENABLED ENERGY HARVESTING RELAY SYSTEM

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DISCIPLINE OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, INDORE

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PROJECT REPORT

Submitted in partial fulfillment of the requirement for the award of the degrees

of

BACHELOR OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

Submitted by:

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Guided by:

Dr. Prabhat Kumar Upadhyay

INDIAN INSTITUTE OF TECHNOLOGY INDORE

December 2019

CANDIDATE'S DECLARATION

We hereby declare that the project entitled **"Throughput analysis for UAV-enabled energy harvesting relay system"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'Electrical Engineering' completed under the supervision of **Dr. Prabhat Kumar Upadhyay**, Associate Professor, Electrical Engineering, IIT Indore is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

Ravi Shankar C — K Sreejith

160002049 — 160002019

CERTIFICATE BY GUIDE

It is certified that the above statement made by the students is correct to the best of my knowledge.

Dr. Prabhat Kumar Upadhyay
Associate Professor
Discipline of Electrical Engineering
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CERTIFICATE

This report on **"Throughput analysis for UAV-enabled energy harvesting relay system"** is prepared under the guidance of Dr. Prabhat Kumar Upadhyay, Associate Professor, Discipline of Electrical Engineering, Indian Institute of Technology Indore.

Through this report, we firstly propose a detailed design of a UAV-enabled energy harvesting relay system model and explain the concepts to be utilized for the same. Secondly, we propose a new relaying technique for the UAV based on the above system model. We derive the throughput expression and do MATLAB simulations to prove better throughput performance of our proposed model. We present the results and highlight the insights gained in a well-defined manner to show that our design is technically sound and viable.

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ABSTRACT

In this project, a new relaying protocol has been proposed for a UAV-based relaying system. The UAV acts as a relay while moving in a circular path between two base stations having no Line-of-Sight. To tackle the energy scarcity problem in UAV, it harvests the energy from the signal transmitted by the source. Then, it transmits the message back in the latter half using the harvested energy to the destination. Energy harvesting and relaying strategies are implemented based on the integration of time switching relaying (TSR) and power splitting relaying (PSR). For the proposed model in the project, the end-to-end throughput equation has been derived and investigated to examine the performance of the model. Simulations and results show the effect of key parameters on the throughput performance of the model. Also, in comparison with the existing ferrying protocol proves that the proposed relaying protocol performs better due to decrease in pathloss in the transmission phase and due to effective spectral use of the channel.

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Chapter 1

1 Introduction

Enhancing the reliability of communication networks and especially maintaining communication links are critically essential in critical communication networks. In some situations, there is a possibility of losing Line-of-Sight (LoS) links. Then, it becomes necessary to use a relay for establishing a connection. But, relays have limited the energy and their frequent replenishment also increases operational cost. However, recent advancements in the energy harvesting technique help us to solve this problem. In the following sections, we will discuss the background and motivation for such a problem.

1.1 Background

In wireless communication systems, there are high chances for a communication link to get blocked, e.g., mountains or tall buildings block communication between cell phone towers. One of the most promising and reliable technique in such a scenario is relaying. In the relaying method, a relay is used to hop the information from the source to the destination. Relaying improves throughput, reliability, and range of communication. Though most of the previous work on relaying use stationary relays like radio towers, GEO satellites, etc., recent developments in UAV have propelled the use of UAV as a mobile relay.

Mobile relaying has many advantages when compared to stationary relaying, and it is apt to use UAV for the same. Due to the high mobility of UAV's they are keen to realize the challenges like finding suitable channel conditions [2] and acknowledge the benefits of mobile relay enabled communication when compared to that of traditional stationary relays. With the recent advantages in technology, UAVs make sure there is reliable wireless connectivity between two users without direct connectivity. Also, the deployment of UAV is less expensive when compared to building a cell tower or a base station. The present-day UAVs or drones can move with a speed of 163 mph, which makes them more suitable for situations like emergency response, military operation, etc., [1]. Though it is possible to design the trajectory of the UAV, our project considers UAV moving in a fixed trajectory for simplifying the problem.

1.2 Motivation

Despite having many advantages, UAV-assisted communication systems encounter many challenges. One such problem is that they run on batteries, which affects their performance and lifetime. Frequent replacing or recharging batteries can be inconvenient and costly. So, most of the present research has been focused on building energy harvesting methods and different ways to increase the energy efficiency of the UAV-assisted wireless communication systems [3], [4].

An emerging technique to prolong the lifespan of the energy-constrained relay nodes in communication networks is to explore and use radio-frequency (RF) signal by extracting the energy and processing the received signals simultaneously. Simultaneous wireless information and power transfer (SWIPT) has been a game-changer with its capability of completely utilizing the data as well as energy carried by the signal/EM wave. SWIPT has been the focus in most of the recent research work with emphasis on theoretical analysis [5], practical implementation [6] as well as applications in wireless communication systems. Based on SWIPT, authors in [7] propose TSR (Time Switching-based Relaying) and PSR (Power Splitting-based Relaying) protocol to ensure wireless energy harvesting and data processing at the energy-constrained relay/UAV. In our project, we use a UAV-based energy harvesting relay that receives the signal from the source. This signal is used for harvesting energy and storing data at the relay. Later this stored data is amplified and forwarded to the destination by using the harvested energy.

Though in [8], UAV based ferrying protocol has been proposed, there is a room for improving its performance in terms of throughput achieved. We then derive and analyze the throughput, which refers to the total no of bits that successfully reach the destination node and get decoded in a given time.

1.3 Concepts Employed

1.3.1 Energy Harvesting

Energy Harvesting in communication networks is a process by which nodes harvest the energy from sources like lasers, mechanical vibrations, and electromagnetic radiation. Our area of research focuses on obtaining energy from the ubiquitous electromagnetic radiations using the RF energy harvesting technique. Radio Frequency (RF) energy harvesting is a technique in which energy gets harvested from the received electromagnetic (EM) wave into DC (Direct Current) voltages. The fundamental block for implementing an RF energy harvester consists of

- Receiver antenna
- Impedance matching circuit
- Voltage doubler / Rectifier circuit

The DC energy received after the rectifier stage is either stored in a battery or a supercapacitor for latter use.

1.3.2 Relaying Protocol

SWIPT based relaying can be done in two ways

- Time Switching-based Relaying (TSR) protocol
- Power Splitting-based Relaying (PSR) protocol

In TSR protocol, the relay harvests the energy for some time and processes information for the remaining time. In PSR protocol, the relay harvests the energy from a portion of the signal and processes information out of the remaining portion.

1.4 Contribution

The main contributions of this project are summarized as follows:

- We apply energy harvesting techniques for a mobile UAV to improve its battery life.
- We propose the integration of TSR and PSR protocols for an AF(Amplify and Forward) based relaying network.
- We propose a new relaying protocol different from the existing ferrying protocol for a UAV-based relaying system to maximize throughput at the destination.
- For the proposed relaying protocol, we derive analytical closed-form expression for the achievable end-to-end throughput. The derived expressions provide insights into the effect of various relaying protocol parameters and system parameters on the system performance.
- We perform numerical simulations to find the optimal time switching ratios to maximize throughput.

The remainder of this project report is structured as follows. In Chapter 2, we brief the system model and the channel model of our project. Chapter 3 presents the proposed relaying scheme. In Chapter 4, we perform throughput analysis of the system. Chapter 5 presents simulations and results. Finally, in Chapter 6, the conclusions are drawn.

Chapter - 2

2 System Model and Channel Model

2.1 System Model

In our proposed scheme, we consider a scenario where there is no direct wireless link/Line-of-Sight between two base stations (BS1, BS2). To establish a communication link, we use a UAV (Unmanned Aerial Vehicle), which acts as a mobile relay between both the base stations. The UAV travels in a circular path parallel to the surface. The center of the circular path lies exactly above the center of the line connecting both BS1 and BS2 at a height (H_{uav}). The front view of the system model is shown in Fig. 1.

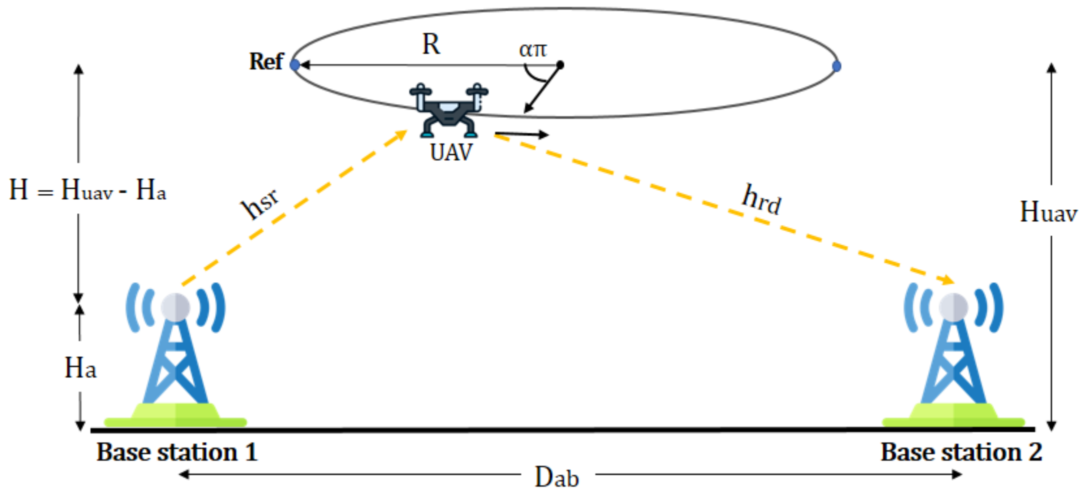

Figure 1: System model

UAV moves with a constant angular velocity $(\omega).BoththebasestationsandtheUAVareassumedtobe$
when it where θ is the angular displacement of UAV from the reference point. We split one complete revolution of UAV into two stages each of period T. In each stage, UAV covers an angular displacement of ϕ from the reference point. The top view of the system model for a single stage is given below.

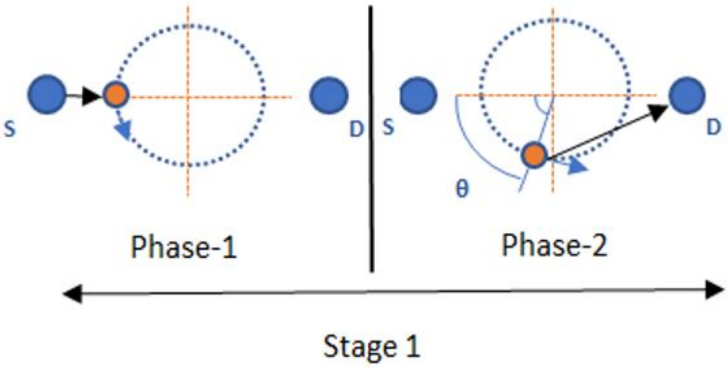

Figure 2: Top view of the system model

In the relaying protocol, the UAV sweeps an angular displacement of $\alpha\phi$ during Phase-1 and receives data from the source, which is used for harvesting energy and information processing simultaneously. Then from $\alpha\phi$ to ϕ, it begins to transmit the stored information to destination (D) in Phase-2. The same process repeats for the next half-cycle where Base station-2 acts as the source, and Base station-1 acts as the destination. We do analysis only for the first half-cycle as it applies the same for the next cycle too.

2.2 Channel Model

For Base station-1 (S), Base station-2 (D), and UAV (R) with a single transmit and receive antenna. It is assumed that channel from the source (S) to relay (R) i.e., $[h_{sr}]$ and signal from relay (R) to the destination (D) i.e., $[h_{rd}]$ follows the free-space path loss model as

$$h_{sr} = 10^{147.55-20*log(d_1)-20*log(f)}$$

$$d_1 = \sqrt{\left(\frac{(D_{ab})}{2} - R\cos\theta)^2 + (R\sin\theta)^2 + H^2\right)}$$

$$h_{rd} = 10^{147.55-20*log(d_2)-20*log(f)}$$

$$d_2 = \sqrt{\left(\frac{(D_{ab})}{2} + R\cos\theta)^2 + (R\sin\theta)^2 + H^2\right)}$$

where f is the transmission frequency, which is 700 MHz, and $d1$, $d2$ are the distances of R from S, D, respectively. Since the base stations are fixed and the UAV is moving with constant speed $V = 1m/s$, the maximum Doppler frequency is related to the velocity of UAV (V m/s) and the carrier frequency f as $f_d = (\frac{V}{c}) \times f$. Since $V << c$, we can ignore the Doppler shift.

We assume there are no additional nodes near the system to ensure that there is no interference from other sources, so that the information signal transmission is corrupted only by Gaussian noise. We also assume frequency division duplex mode with equal bandwidth (B) is given for both up-link and down-link. If there are any other nodes around the system, then we have also to consider the aspect of RF interference noise, which should be taken into account before passing through the decoder.

Chapter - 3

3 Proposed Relaying Protocol

We implement a SWIPT based relaying technique for our system model. Most of the previous works consider either the PSR or TSR based relaying protocol, but we incorporate both the protocols in a single block time to maximize the throughput from the source to destination by leveraging harvested energy from the received signal. And, this harvested energy is used for transmitting the processed signal at the relay (R) to destination (D).

Most of the previous works on UAVs have used conventional ferrying protocol for a full-duplex two way relaying to minimize the bit error rate (BER), but not much research has been directed for the throughput analysis by implementing energy harvesting. So we perform throughput analysis for both relaying protocols.

In our proposed protocol, we work on integrating TSR and PSR protocols for a UAV relay in our given system model. We split one complete revolution of the UAV into two stages further in each stage, and we split them into two phases.

- TSR-based Relaying Protocol
- PSR-based Relaying Protocol

Now, we will be discussing how the above protocols work and the way they have been implemented in our proposed scheme.

3.1 TSR-based Relaying Protocol

The proposed relaying protocol for energy harvesting, signal processing, and power-constrained transmission at UAV is shown in Fig.4. Here, in which we split each half of the revolution of the UAV is split into two stages each of period T

- Stage-1 => [BS1 (S) –> UAV (R) –> BS2 (D)]
- Stage-2 => [BS2 (S) –> UAV (R) –> BS1 (D)]

where BS1 and BS2 are Base station 1 and Base station 2 respectively.

The total time of one revolution will be 2T, where T is the time taken for each stage. In Stage-1, αT [Phase-1] time is used for transferring information from the source (S) to UAV (R) and the remaining (1-α)T [Phase-2] time is used for transferring the processed symbols from UAV (R) to destination (D), where α ($0 < \alpha < 1$) is time switching ratio. This is depicted in Fig. 2.

Here in Phase-1, we mainly emphasis on receiving the symbols from the source(s) and then send it to power splitter, which will be explained in the next section.

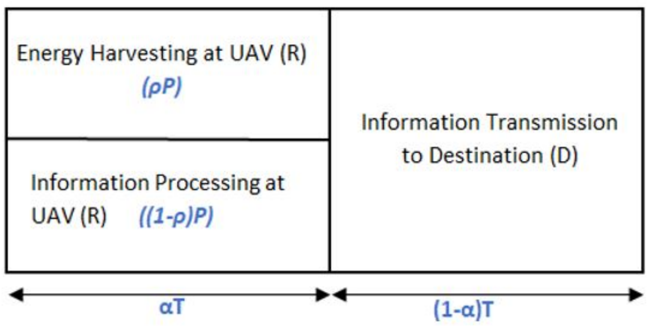

Figure 3: Relaying protocol

3.2 PSR-based Relaying Protocol

This protocol is only used in Phase-1. In this scheme, the received signal from the source (S) is passed through a power splitter, which splits the received power by a factor ρ ($0 < \rho < 1$) also known as Power splitting ratio. So ρ part of it is invested in the energy harvesting, and the left $(1 - \rho)$ is used for information processing. The PSR protocol with a power splitter achieves a better tradeoff between the amount of signal and energy received.

As we can see above that ρ doesn't obey the equality sign for values 0 and 1. For the first aspect when no energy has been harvested in that case our system model fails due to lack of power for transmission. And in the second aspect, when no symbols have been processed the entire energy has been used for harvesting the energy which is of no use.

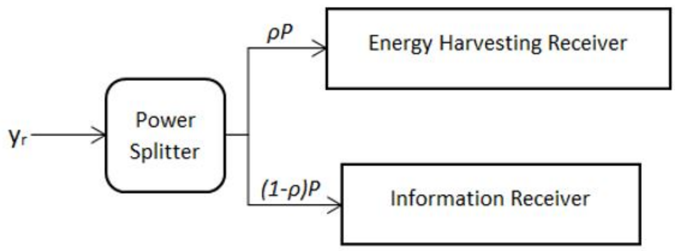

Figure 4: Power splitter

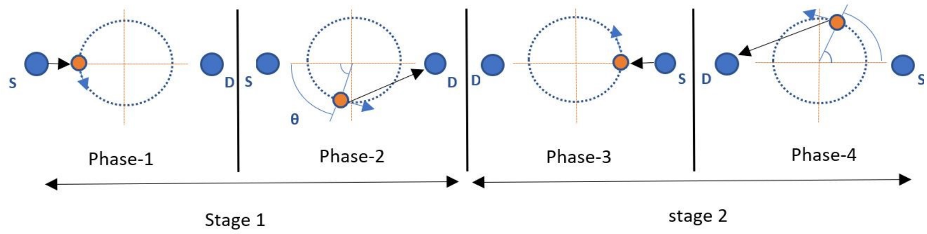

Figure 5: Top view

The above shown Fig.5, is the top view of the system model, which depicts the entire one complete revolution of UAV between the two base stations. As we can see, the center of the circle coincides with the center of the line segment joining the base stations. We assume this symmetry to decrease the complexity of solving the problem.

In our model, two stages are symmetric, and UAV takes equal time for completing both the stages. Each phase is split into two stages, depending upon the TSR protocol. In the Phase-1 of Stage-1, BS1 acts as the source (S) and BS2 as destination (D). UAV receives signal from the S and processes it for further transmission and also harvests the energy from them. In the Phase-2 of Stage-2, the processed signal is transmitted to the destination based on AF relaying. Our proposed protocol adopts the FIFO (First In First Out) scheme, which states that the information received first in Phase-1 is transmitted first in Phase-2.

Chapter - 4

4 Throughput Analysis

In our work, we mainly emphasize on how the throughput from the source (S) to destination (D) i.e., end-to-end throughput varies by implementing SWIPT based relaying technique with respect to factors like the source power (P_s), time switching ratio (α) and power splitting ratio (ρ).

As the proposed system model is symmetric and follows the free-space path loss model, Stage-1 and Stage-2 will exhibit the same performance. So we stick our analysis to Phase-1 since analysis of Phase-1 is similar to Phase-2.

In Phase-1, PSR protocol is used to establish an efficient communication link by implementing the energy harvesting and signal processing at the same time. In the Phase-2, the received symbols are amplified and forwarded (AF modulation) to D by using the power obtained from Phase-1. As mentioned in the previous chapter, our protocol follows the FIFO (First In First Out) scheme, i.e., .the symbol that has been received first by the relay (R) from the source (S) will be transmitted first in Phase-2.

So, the entire throughput analysis is divided into two parts as follows.

- Energy Harvesting
- Power Constrained UAV-assisted Transmission

4.1 Energy Harvesting

At first, the source (S) transmits symbols to the UAV as starting from the reference point. Let's assume that the source is transmitting the symbols at regular interval with a constant power P_s, and k denotes the symbol index. The received signal at UAV (R) can be given as

$$y_r[k] = \sqrt{P_s} h_{sr}[k] x[k] + z_r[k] \tag{1}$$

We assume $x[k]$ follows symmetric Gaussian distribution with zero mean and unit variance, i.e., $x[k] \sim N(0, 1)$. Also, $z_r[k]$ is the noise part that follows the Gaussian distribution with zero mean and variance ${\sigma_r}^2$, i.e., $z_r[k] \sim N(0, {\sigma_r}^2)$. As stated previously, there is no RF interference noise in our system. Hence, we can write ${\sigma_r}^2$ $= N_0$B. Therefore, the part of the signal that is received for energy harvesting is given by

$${y_r}^{EH}[k] = \sqrt{\rho}\ (\sqrt{P_s} h_{sr}[k] x[k] + z_r[k]) \tag{2}$$

Thus, the harvested energy (E_H) during Phase-1 of Stage-1 is given by integrating the instantaneous power obtained from each symbol over time αT which is given by

$$E_H = \frac{\rho P_s R}{V} \int_0^{\alpha\phi} h_{sr}[k]^2 \tag{3}$$

And the instantaneous throughput (bit rate) from S to R [Throughput1($\tau_1[k]$)] for each symbol received is expressed as

$$\tau_1[k] = Blog_2(1 + \gamma_s[k]) \tag{4}$$

Here, $\gamma_s[k]$ is the signal-to-noise ratio (SNR) of the received signal at the relay at each instant which is given by

$$\gamma_s[k] = \frac{(1-\rho)P_s h_{sr}[k]^2}{\sigma_r^2} \tag{5}$$

4.2 Power Constrained UAV-assisted Transmission

After passing through the power splitter, ρ part is sent for energy harvesting, and the remaining part (1-ρ) is transmitted to the signal processing unit, which stores the digital bits. The signal received at the signal processing unit is expressed as

$${y_r}^{IF}[k] = \sqrt{1-\rho}\;(\sqrt{P_s} h_{sr}[k]x[k]) + z_r[k] \tag{6}$$

In Phase-2, the stored symbols are AF amplified and forwarded to D by using the harvested energy. Hence, the final signal transmitted to the destination is given by

$$y_d[k] = \sqrt{P_{uav}}\, h_{rd}[k]\, \frac{{y_r}^{IF}[k]}{A} + z_d[k], \tag{7}$$

where P_{uav} and $z_d[k] \sim \zeta$N(0, ${\sigma_d}^2$) are transmission power at UAV ready to be used for transmission and Gaussian noise with mean zero and variance ${\sigma_d}^2$ at the destination node respectively.

Here, $A = (1-\rho)P_s {h_{sr}}^2 + {\sigma_r}^2$ is the total harvested energy from (6). We also assume ${\sigma_r}^2 = {\sigma_d}^2 = \sigma^2$ for the sake of simplicity.

We assume that the UAV gets the entire power used for transmission from the harvested energy, and there is no need for any extra energy from other battery sources. Thus, obtain the inequality constraint as follows

$$i.e.(1-\alpha)TP_{uav} \leq E_H$$

$$P_{uav} = \frac{E_H}{(1-\alpha)T} \tag{8}$$

After substituting (3) in (8), we get

$$P_{uav} = \frac{\rho P_s R}{V(1-\alpha)T} \int_0^{\alpha\phi} h_{sr}[k]^2 \tag{9}$$

To maximize end-to-end throughput, we consider that all the energy harvested is used for transmission. By substituting (6) in (7), the signal that is received at the destination (D) is expressed as

$$y_d[k] = \sqrt{\frac{(1-\rho)P_{uav}P_s}{A}}\, h_{sr}[k]\, h_{rd}[k]\, x[k] + \sqrt{\frac{(1-\rho)P_{uav}}{A}}\, h_{sr}[k]\, z_r[k] + z_d[k] \tag{10}$$

From the above equations, the instantaneous throughput from R to D [Throughput2 ($\tau_2[k]$)] can be given as

$$\tau_2[k] = Blog_2(1 + \gamma_d[k]) \tag{11}$$

where $\gamma_d[k]$ is the SNR of the transmitted signal at D at each instant and it is given by

$$\gamma_d[k] = \frac{\frac{(1-\rho)P_s P_u av h_{sr}[k]^2 h_{rd}[k]^2}{A}}{\frac{(1-\rho)P_s P_u av\sigma^2 h_{rd}[k]^2}{A} + \sigma^2} \tag{12}$$

After substituting (12) in (11) and simplifying, we get

$$\tau_2[k] = Blog_2\left[1 + \frac{P_s}{\sigma^2 \frac{1}{h_{sr}[k]^2} + \frac{(1-\rho)T(P_s h_{sr}[k]^2 + \sigma^2)}{E_H(\alpha,\rho) h_{sr}[k]^2 h_{rd}[k]^2}}\right] \tag{13}$$

4.3 End-to-end Throughput

The overall throughput (τ_1) from the source (S) to UAV (R) in Stage-1 can be given as

$$\tau_1 = \frac{\int_0^{\alpha T} \frac{(1-\rho)P_s h_{sr}[k]^2}{\sigma_r^2} dt}{\int_0^{\alpha T} dt} \tag{14}$$

and the overall throughput (τ_2) from UAV(R) to the destination(D) can be given by

$$\tau_2 = \frac{\int_{\alpha T}^{T} Blog_2\left[1 + \frac{P_s}{\sigma^2 \frac{1}{h_{sr}[k]^2} + \frac{(1-\rho)T(P_s h_{sr}[k]^2 + \sigma^2)}{E_H(\alpha,\rho) h_{sr}[k]^2 h_{rd}[k]^2}}\right] dt}{\int_{\alpha T}^{T} dt} \tag{15}$$

Thus, the end-to-end throughput from the source(S) to destination(D) in stage1 (τ) is given by

$$\text{End-to-end throughput}(\tau) = min(\tau_1, \tau_2)$$

In the next chapter, we do the simulations, based on the analytical expression obtained above. The simulation parameters [8] are given in Table-1 .

TABLE 1

SIMULATION PARAMETERS	
Parameter	Value
Source power(P_s)	60 dBm
Bandwidth(B)	20 MHz
Velocity(V)	1 m/sec
Radius(R)	5 m
Height(H)	10 m
Spectral density (N_0)	-147 dBm/Hz
D_{ab}	10 m

Chapter 5

5 Simulations and Results

In this section, we discuss the insights obtained from numerical simulations done in MATLAB based on the analytical expressions of throughput derived from the previous chapter. Here, we can investigate system performance by varying the system-parameters.

5.1 Throughput (τ) vs Time Switching Ratio (α)

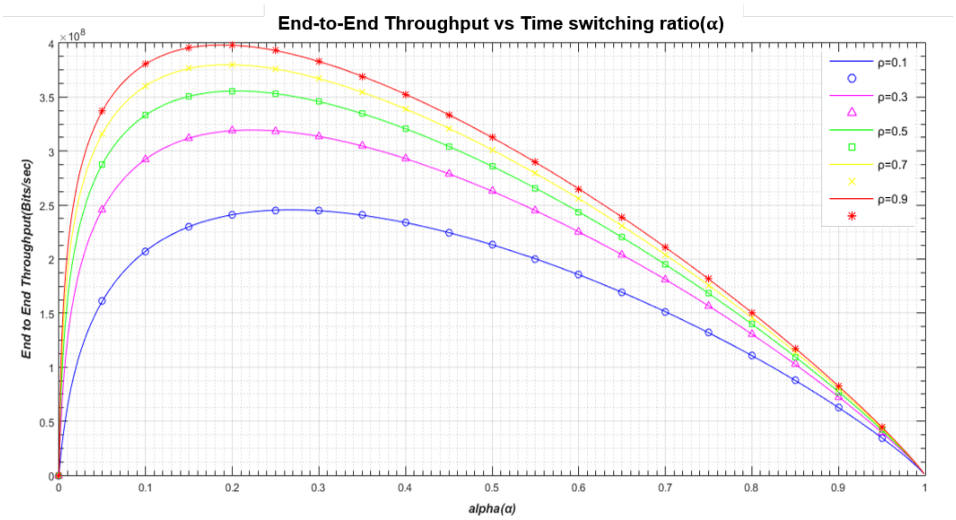

Figure 6: τ vs α

In Fig.5, the end-to-end throughput (τ) versus the time switching ratio (α) for different values of power splitting ratio [$\rho \in (0.1, 0.3, 0.5, 0.7, 0.9)$].

- We can see that the throughput attains maximum value for an optimal time switching ratio (α_{opt}).

- The simulation results of $\tau(\alpha)$ can be used to find the optimal value α_{opt}, which is the root of $\tau'(\alpha) = 0$, and can be obtained easily from the results from MATLAB by using find peak operator.

- As optimal time switching ratio α_{opt}, decreases the power splitting ratio (ρ) increases.

5.2 Throughput (τ) vs Power Splitting Ratio (ρ)

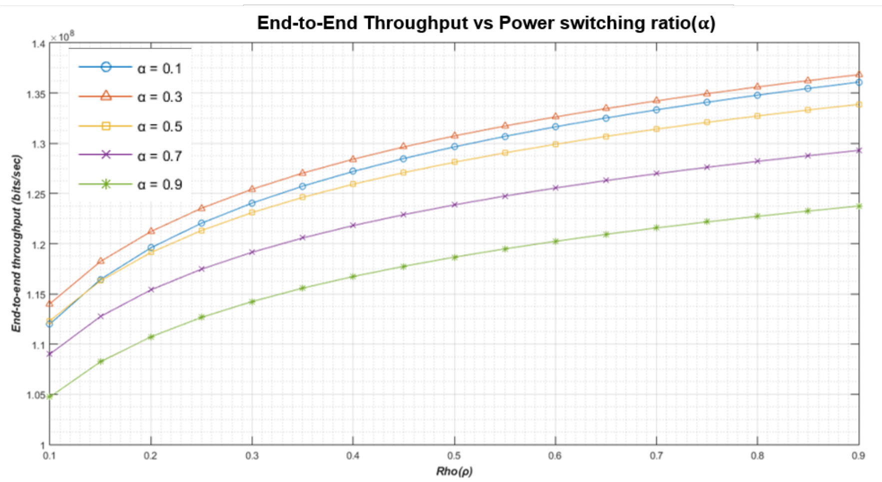

Figure 7: τ vs ρ

In Fig.6, the end-to-end throughput (τ) versus the power splitting ratio (ρ) has been plotted for different values of time switching ratio ($\alpha \in (0.1, 0.3, 0.5, 0.7, 0.9)$).

- We can observe that ρ does not affect the overall throughput from the source (S) to the destination (D) as it is monotonically increasing with ρ.

- As we increase time switching ratio, $\alpha = (0.1to0.3)$, we observe that throughput increases after when time swiching ratio,$\alpha = (0.5to0.9)$, increases throughput decreases clearly proving a α_{opt} value for which throughput maximizes.

5.3 Throughput (τ) vs Source Power (P_s)

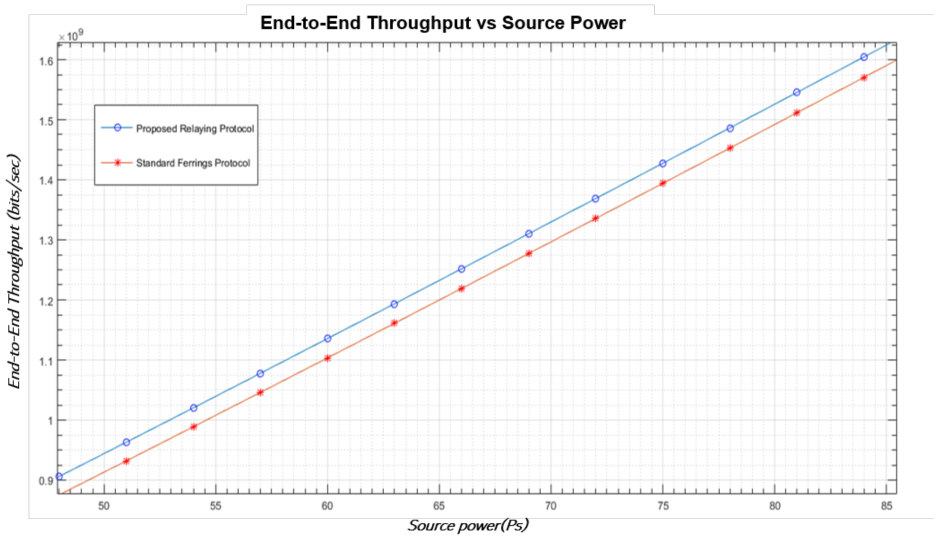

Figure 8: τ vs P_s

In Fig.7, the end-to-end throughput (τ) versus the power P_s has been plotted for our proposed relaying protocol and existing ferrying protocol keeping other system parameters constant. We can observe that our proposed relaying protocol achieves better throughput performance when compared to the existing ferrying protocol.

Next we plot the graphs of optimum-alpha and energy harvested with respect to system parameters.

5.4 Optimum-alpha (α_{opt}) vs Source Power (P_s)

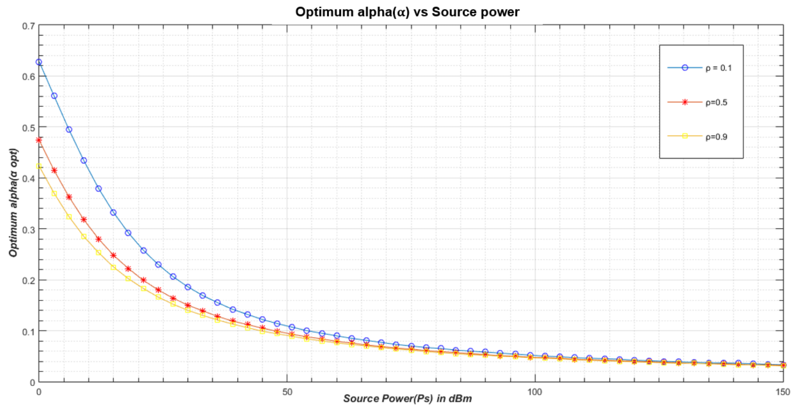

Figure 9: α_{opt} vs P_s

5.5 Optimum-alpha (α_{opt}) vs Height (H_{uav})

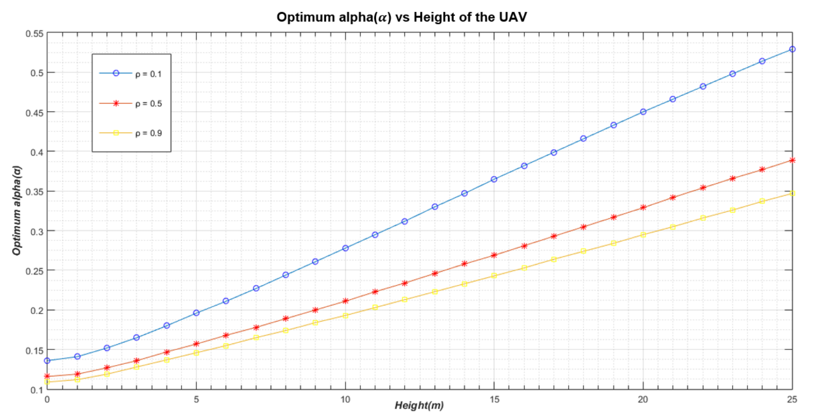

Figure 10: α_{opt} vs H_{uav}

5.6 Energy Harvested (E_H) vs Time Switching Ratio (α)

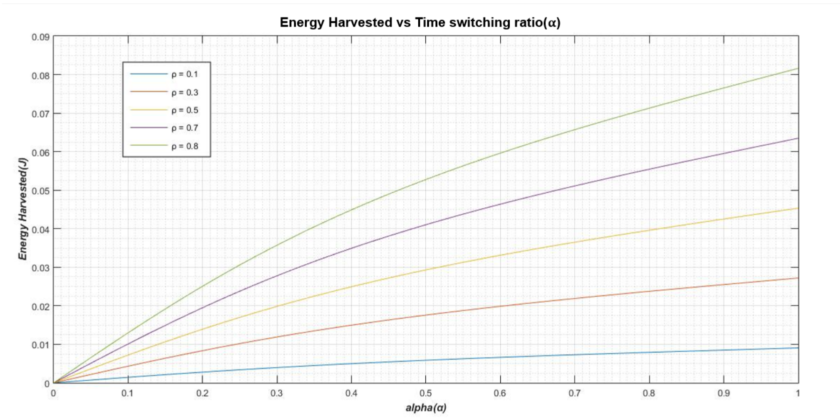

Figure 11: E_H vs α

5.7 Energy Harvested (E_H) vs Power Splitting Ratio (ρ)

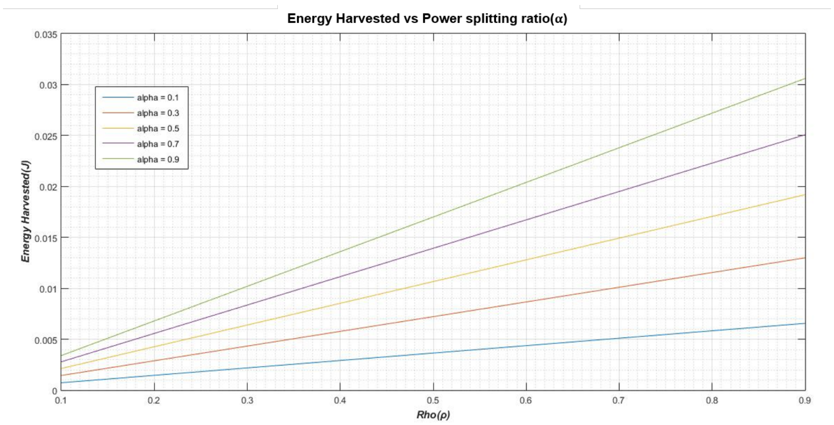

Figure 12: E_H vs ρ

The above graphs plotted are optimum-alpha and energy harvested with respect to system variables which is either monotonically increasing or decreasing. The above derived throughput equation decides the shape of the graph.

Chapter 6

6 Conclusions and Future Scope

In this report, we have considered a communication system having direct communication blockage and thereby deployment of a mobile UAV-relay. We have analyzed the possibility of applying energy harvesting for energy-constrained UAV-relay. Then we proposed a new relaying protocol by integrating TSR and PSR protocol. Our proposed protocol for UAVs is different from the existing ferrying protocol for relaying.

For the proposed model, we derived the closed-form expression of end-to-end throughput at the destination. Using the expressions, we conducted numerical simulations in MATLAB. We aimed to improve system performance by maximizing end-to-end throughput. The graphs obtained provide significant insights into the effect of system parameters on the performance. We optimized the time switching ratio (TSR), power splitting ratio (PSR) to maximize network rates. Then for the system parameters, we compared the performance of our relaying protocol with the existing ferrying protocol. Graphs showed better performance of our protocol than others.

While the future of UAVs in communication networks is promising, improving energy efficiency as well as spectral efficiency is vital to make it reliable and sustainable. Though we considered the UAV to be moving in a fixed path, it can be varied and optimized to improve the performance. Thus, trajectory optimization for increasing coverage and throughput in the case of multi-users is an open area for research.

References

[1] A. Merwaday and I. Guvenc. “UAV assisted heterogeneous networks for public safety communications”. *Wireless Communications and Networking Conference Workshops*, pages pp. 329–334, 2015.

[2] V. Sharma, K. Srinivasan, H.C. Chao, K.L. Hua, and W.H. Cheng. “Intelligent deployment of UAVs in 5g heterogeneous communication environment for improved coverage”. *Journal of Network and Computer Applications*, vol. 85:1–10, 2016.

[3] Y. Zeng and R. Zhang. “Energy-efficient uav communication with trajectory optimization”. *IEEE Transactions on Wireless Communications*, vol. 16, no.6:3747–3760, June 2017.

[4] J. Zhang, Y. Zeng, and R. Zhang. “Spectrum and energy efficiency maximization in uav-enabled mobile relaying”. *Proc. IEEE International Conference on Communications*, pages 1–6, May 2017.

[5] L.R. Varshney. “Transporting information and energy simulataneously”. *IEEE International Symposium on Information Theory*, pages 1612–1616, July 2008.

[6] 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 Transactions on Communications*, vol. 62, no. 5:1577–1587, May, 2014.

[7] A.A. Nasir, X. Zhou, and S. Durrani. “Relaying protocols for wireless energy harvesting and information processing”. *IEEE Transactions on Wireless Communications*, vol. 12, no. 7:3622–3636, 2013.

[8] F. Ono, H. Ochiai, K. Takizawa, M. Suzuki, and R. Miura. “Two-Way relay networks using Unmanned aircraft systems”. *IEEE 77th Vehicular Technology Conference*, DOI: 10.1109/WCSP.2017.8170970:1–10, 2013.