A Comparative Study of Intelligent Reflecting Surface and Relay in Satellite Communication

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Declaration

It is hereby declared that

1. The thesis submitted is our own original work while completing degree at BRAC University.
2. Parts of this thesis have been submitted to EAI Transactions on Scalable Information Systems with the title “A Comparative Study of Intelligent Reflecting Surface and Relay in Satellite Communication”. The thesis has been appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

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Abstract

One of the most significant technologies for worldwide telecommunication is satellite communication. The fundamental advantage of satellites is their extensive range. Low Earth Orbit (LEO) satellites have the least propagation delay and the best data rate when compared to other satellite types. Another recent technology being implemented in communication systems are Unmanned Aerial Vehicles (UAVs). UAVs provide a new dimension to the world of communication. The principal advantages of UAV are their high mobility and versatility. In this thesis, we build a communication system consisting of ground base stations, UAVs and LEO satellites. We then implement two communication schemes in our system and analyze their performance to find out the better performer. The two communication schemes that are employed are a Decode and Forward (DF) relay assisted scheme and an Intelligent Reflecting Surface (IRS) assisted scheme. In our results, we determined that when considering optimum power transmission and energy efficiency at the same achievable rate, the IRS scheme provided a much better performance than the DF relay scheme. The results of our thesis conclude that the IRS scheme is much more superior to the DF relay scheme.

Keywords: Energy efficiency, Intelligent Reflecting Surface, Relay, Satellite, Unmanned aerial vehicle.

Dedication

We dedicate our thesis to our loving parents who made us the people that we are today, who are always there for us whenever we need them, and who are always inspiring us with their love and goodness.

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Firstly, with all His mercy and affinity towards us, we would like to thank the Almighty. This thesis mirrors in our undergraduate program what we have studied and understood. We genuinely believe that we would not have been able to complete our undergraduate thesis work effectively without Almighty's kindness. In addition, we would like to mention that we would all be thankful and indebted to our supervisor, Dr. Saifur Rahman Sabuj, Assistant Professor, Department of Electrical and Electronic Engineering, BRAC University, for guiding us in the field of wireless communication and motivating us to be engaged in this sector. Throughout life, we will always recall his encouraging words and advice. We also want to show our appreciation to all the faculty and staff members of the Department of Electrical and Electronic Engineering, BRAC University, for their assistance and encouragement throughout both our academic life and thesis work. Lastly, we are grateful and thankful to our parents for all the hardship they have been to for us and their unconditional love and support throughout life.

Table of Contents

Chapter 3 System Model **24**

List of Figures

List of Tables

List of Acronyms

LEO	Low Earth Orbit
MEO	Medium Earth Orbit
GEO	Geostationary Earth Orbit
UAV	Unmanned Aerial Vehicle
DF	Decode and Forward
IRS	Intelligent Reflecting Surface
BS	Base Station
RTT	Round trip time
eNB	Evolved Node B
GW	Gateway
IoT	Internet of Things
NOMA	Non-orthogonal Multiple Access
SNR	Signal to Noise Ratio
MD	Mobile Device
AWGN	Additive White Gaussian Noise

List of Symbols

d_{eNB}	Distance between Evolved Node B
d_{GW}	Distance between gateway
$\theta_{\frac{RN}{UE}}$	eNB elevation angle
θ_{GW}	GW elevation angle
h_s	Height of s
c	Speed of light
R_E	Radius of Earth
B_r	Base station selected for receiving
B_t	Base station selected for transmitting
U_R	UAV selected for receiving
U_t	UAV selected for transmitting
x_d	Signal from source d
t	Time slot
y_e	Received signal at e
P_d	Transmit power of d
$c_{x,y}$	Channel coefficient between transmitter x and receiver y
n_e	Noise at receiver e

β	Signal gain
$n_{b,s}$	AWGN channel
N_0	Variance
$\gamma_{d,e}$	SNR from source d to destination e
$g_{x,y}$	Channel gain between x and y
R_{xyz}	Achievable rate of x-y-z link
σ^2	Variance of AWGN
Φ	Phase-shift
η	Amplitude reflection coefficient
θ_N	Phase shift variables
D_Q	Pitch angle fading
φ	Pitch angle
A_{eff}	Antenna aperture efficiency
μ	Rolloff factor
γ_0	SNR threshold
y_{abc}	Received signal from a to b to c
α	Attenuation through clouds and rain
d	Propagation distance between satellite or UAV and the mobile station

f_c	Carrier freaquency
G_a	Antenna gain of A
Λ	Gain of Rician small-scale fading
P_e	Dissipated power per element for each phase shifter

Chapter 1

Introduction

1.1 Introduction

The revolution in cellular communication has increased mobile data demand. Many technologies have been improved to reduce traffic overload such as 5G, IoT and Femtolets. The 5G portable communication framework gives a much higher level of execution than the past era of portable communication frameworks. 5G remote innovation is implied to provide higher multi-Gbps top information speeds, ultra-low latency, more reliability, gigantic organize capacity, expanded accessibility and a more uniform client encounter to more clients. Currently 5G technology has three major types of performance indicators which are enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC) and huge machine-type communications (mMTC). UAV assisted satellite communication are potential options for integrated 5G networks. It can illuminate the restrictions of the earthly framework counting the restricted secured ranges and expansive number of IoT gadgets per square kilometer.

The use of UAVs has opened up a new path for efficient wireless communication. UAV has the most advantage over any conventional base station for its mobility, working versatility and flexibility. UAVs such as drones are amazing for taking excellent quality airborne photos and videos, and collect an endless sum of imaging information. These high-resolution pictures can be utilized to form 3D maps and models. Since UAVs use GPS, they can be moved through precise locations. It can collect data in times of natural disasters to aid in security and recovery efforts. These are therefore also used in military purposes for emergencies.

UAV may act as mini base stations aiding in the exponentially growing mobile data demands of users. There are few challenges in UAV such as it constrains high energy and limited bandwidth. As it needs recharging, it has to be kept offline for bringing it back to ground. UAVs have much lesser power and bandwidth compared to other base stations. This results in inefficiency.

On the contrary, UAVs have huge space capacity. These can cover large areas even in populated urban and rural areas. Satellites are classified by their orbit type such as Geostationary Earth Orbit (GEO), Low Earth Orbit (LEO) and Medium Earth Orbit (MEO). From the performance comparison, it is observed that LEO satellites have the least propagation delay and the highest data rate while GEO has the opposite. The delay time of the satellite communication is affected by the number of satellites in the system and the number of ISLs per satellite. The average delay of a LEO satellite is a lot less than MEO satellite as LEO satellites are positioned a lot lower than MEO satellites. LEO satellites also operate in lower power than GEO and MEO satellites as it needs up-to two kilowatts per satellite for effectiveness. This is why LEO satellites are favorites for our proposed communication system as it has less delay and higher data rate.

On the other hand, LEO satellites require a huge number of satellites in a constellation for global coverage compared to GEO and MEO satellites. This is one of the major disadvantages of LEO satellites. These huge numbers of satellites require greater management cost. The performance of the LEO integrated networks is far better than the non-integrated networks as observed in a study. The second major disadvantage of LEO satellites is handover. Recent researches claim Doppler-based handover prioritization technique-based algorithms can fulfill Quality of Service limitations and make efficient use of satellite bandwidth.

A communication system is designed by considering some key factors such as energy efficiency, coverage and reasonable cost. It gets costly building a base station centric network because of long cables and tower constructions. UAVs can easily overcome these problems for its high mobility and it can be battery controlled. UAVs can easily boost the capacity and the coverage area of a wireless network. For this, it creates a link between widely separated areas. The combination of UAV and satellite can make a huge technological revolution in wireless communication.

1.2 Literature Review

Many researchers have been working on UAV and satellites for improving wireless communication so that many users can have better quality of service. In this section we have mentioned some significant research that has been done on UAV and satellites.

Li et al. (2020) has proposed a structure for satellite/ UAV which is operated by 5G non-orthogonal terrestrial network. The network is created and titled non-orthogonal multiple access (NOMA) to communicate with ground clients with the assistance of a decode-forward (DF) UAV relay by utilizing NOMA. The asymptotic behavior is communicated within the excessive signal to noise ratio to urge greatest execution. The recreation comes about being that there are a few mistake floors for the distant and the close clients due to the channel estimation mistake and the blackout execution and framework all through the execution by encouraging progress significantly by carefully selecting the area of UAV [1].

Guidotti et al.(2019) mentioned Satellite communication systems are changing our world to a modern world since it extends communication systems. The communication system is used for commercial and for connecting one device with another device far from each other. The earthbound network as of late created in unserved or under-served ranges and as of late 3GPP beginning a modern radio such as 5G non earthbound systems pointed at satellite framework. Ordinary satellite channel harms the path losses delays and Doppler shifts, posture separate challenges to our satellite-based NR systems. Based on architecture, 5G satellite systems are changing the network topology all over the world. The main theme of these challenges are the PHY/Mac procedures. Considering these problems different solutions are proposed here [2].

Zhao et al. (2018) suggested Unmanned airborne vehicles for satellite communication has come up for a sensational consideration for building the coordinated space-air-ground network and the consistent wide region scope. In this term paper, they proposed a blind beam tracking strategy where UAV is prepared with a crossover huge scale radio wire cluster. The impact of UAV route is mechanically alteration, which seems to point the beam towards the targeted satellite through beam stabilization and energetic segregation. Reenactment comes about are given to illustrate the prevalence of the proposed strategy over existing once [3].

Zaib et al. (2020) researched in this development era, unmanned aerial vehicles (UAV) are used for visual image or video from airborne vehicles or different military-based systems. The UAV vehicles are used for different areas for different purposes like in agricultural purposes, etc. The capabilities of drones are potentially stronger than other vehicles. In this research paper UAV’s channel modeling, interference mitigation and avoiding collision with one another is discussed here. The algorithm for security systems and energy harvesting techniques all are different. Various problems and research of this UAV is discussed from top to bottom of this research paper [4].

Ruan et al. (2020) gave the knowledge with diverse improvement of Internet-of-Things (IoT) gadgets and applications 5G internet makes quick information exchange and satellite airborne earthbound integrated network is for tall offices for this new era. The most challenges of the characteristics of cognitive SATINs and the necessities of IoT bring to asset administration. They analyze the potential of consolidating participation into cognitive SATINs for future intelligent IoT. They granted agreeable beamforming conspire to encourage secure and vitality productive IoT communication [5].

Huang et al. (2020) researched effective transmission for satellite airborne earthbound network which is known as multi antenna unmanned aerial vehicle which is utilized to help the satellite signal delivery. By considering the whole control imperative or per antenna control imperatives at the UAV they summarize an optimization issue to maximize the vitality productivity of the SATn which is based on the proportion of the ergodic capacity of the entire control utilization for communication at UAV. They connected Shadowed Rician fading whereas the UAV terminal interface is experienced connected Rician fading whereas the UAV terminal interface encounters connected Rician fading closed shape expression for the statics for the output signal to noise ratio. They simulated a result which is very effective of proposed BF schemes [6].

Marchese et al. (2019) said that the versatile communication will be progressing day by day developing higher capacity and upgraded rate, a lower latency and a more flexible and adaptable network of way better quality. The advancement of 5G versatile communication is characterized by a profound alter in our telecommunication division. The earthbound network like unmanned aerial vehicles can contribute to overcome the confinements of this network. The wide scope, higher strength and accessibility and moving forward user's quality of involvement will make a difference to create the 5G segment of communication improvement [7].

Joo et al. (2018) suggested a huge percentage of Internet users and long propagation delay of satellite communication make the terrestrial networks tough to function. This paper's research shows that a relay architecture with UAVs between satellites and the ground can enable low overhead satellite access. Satellite communication will cover the global area and robust services even worldwide. Future applications and communication will need the 5G satellite to make fastest data transfer. UAV devices will operate smooth and faster in 5G communication. The drawbacks and heterogeneous architecture has been proposed for ground aerial connection [8].

Kong et al. (2020) gave their insight on the satellite communication system, a crucial application for the provision of wireless telecommunication systems. The satellite sends a signal to an UAV via an FSO link subject to Gamma-Gamma distribution disturbance whilst the UAV forwards the decoded signal to several users through a RF link characterized by the correlated Rayleigh fading channel. Recently there has been a transmission called FSO/RF transmission which develops a sampling clock between the transmitter and receiver oscillators which is affecting transmission performance of frequency division multiplexing signal in visible light communication. The proposed scheme is developed through Gamma-Gamma fading channel and the UAV terrestrial network [9].

Qi et al. (2018) expects the mobile communication to become advanced day by day growing higher bandwidth and increased rate, a reduced latency, a more robust and scalable network of finer quality. A significant transition in today's telecommunication industry describes the evolution in 5G mobile communication. The terrestrial network like unmanned aerial vehicle can help resolve the shortcomings of this network. Broad coverage, greater resilience, accessibility and enhancing the quality of user interface will help to develop the 5G sector of communication development [10].

Tikhvinskiy et al. (2020) anticipates that for future generation 5G networks will develop a global communication network, which will help to connect one corner of the world to the other corner. The 5G network system will develop a fast communication mobile; computers can send data very fast. Three basic business models for 5G network are increasing Mobile Broadband Access (eMBB), Massive Internet of Things and Ultra-reliable low latency communication, which makes fast data transfer and massive data storage from satellite channel. Bent pipe principle and onboard processing network develops a frequency channelization of signals, which will be in 5G generation networks [11].

Sharma et al. (2020) propose a 3D mobile unmanned aerial vehicle that operates in a circular plane when an aerial eavesdropper is around a functioning UAV relay. Here, they propose a model, which is stochastics, a combined mobility paradigm for mobilisation of the UAV relays in a 3D cylindrical Cell with primary user tools. They consider sending an eavesdropper beneath the aces, first the eavesdropper is detected at a particular specific distance around an operating UAV relay and secondly the eavesdropper is found consistently arbitrary around the relay. For the nearest URS and uniform URS(UURS), they propose the precise PNZSC and SOP(UURS). Simulations are carried out to authentic research and hybrid satellite terrestrial network [12].

Liu et al. (2019) explores how long-distance drones will help enlarge UAV networks to precisely and successfully accomplish the range of missions . In UAV networks, relay technology can play an important role in assisting drones or devices to connect over long distance networks. The execution of self-organizing networks and various ground relay models optimization, relay selection in UAV communication networks introduces potential difficulties and issues. To make it more effective by providing heterogeneous dynamic, dense and restricted data characteristics quick data transfer and 5G communication will help a lot. The complex relay model helps to match games in UAV relay model discussion [13].

Hosseinali et al. (2019) investigates how unmanned aerial vehicles or unmanned aerial systems are important for 5G beyond communications. UAS to operate without a wiring system. The architecture of this wireless broadband device helps in airspace to communicate with other devices. Giving permission to fly airspace alongside commercial, freight and other remotely controlled aircraft is likely to require devoted and secure airspace at least near term whilst administering authorities adjust to using it.They make CNP links in this paper as they can be utilized for clarifying principles standards and difficulties in 5G satellite network . UAV-to-UAV communication and hardware such as UAV C2 and payload communication like millimeter wave is also mentioned [14].

Bithas et al. (2020) delves into how unmanned aerial vehicles (UAV) is developed with a 5G networking system in this modern digitalized era. 5G cellular networks make this vehicle faster and speed up data communication. The distance between ground to this vehicle is typically difficult. The electromagnetic radiation or acoustic wave is called Line-of-sight which will drive this vehicle. Small objects avoidance is easily completed by the algorithm but large object avoidance is quite hard. For this system a shadowed double scattering channel is developed with this Unmanned aerial vehicle. This whole UAV communication system will perform the signal capacity for this vehicle [15].

1.3 Motivation

UAVs are very likely acceptable to a large scale because of its vast range of application in various sectors. While integrated with wireless mobile networks, it can provide a broad variety of solutions to many communication challenges. It can unleash some innovative technologies for the modern world for its mobility and easy to operate. UAV based wireless communication can be the solution to the network congestion problem as it is reliable for its line-of sight communication link. But there are some challenges that might be a problem to all these innovative ideas. One of the challenges is energy efficiency management of the UAV. Our main goal in this thesis was to design two schemes for signal models and focus on the total power consumption and minimization of the both schemes.

1.4 Objective of the thesis

This study aims to build a communication model implementing mobile devices, base stations, UAVs and satellites having the lowest latency and maximum efficiency. To meet these requirements, we have identified the following objectives:

1. To investigate which type of satellite would be most suitable for our communication model.
2. Derive expressions for the uplink and downlink communications of the communication model by implementing two communication models: Decode and Forward (DF) relay assisted scheme and Intelligent Reflecting Surface (IRS) scheme.
3. Derive expressions for the channel model and power minimization to ensure minimum latency and high efficiency.
4. Form a clear comparison between the results of the two communication schemes to evaluate which communication scheme is the better performer.

1.5 Organization

Chapter 1

This is the introductory chapter. It provides a brief introduction to our topic along with writings that contained significant previous related works. This is followed by the motivation and our objective of the thesis.

Chapter 2

Chapter 2 contains the basics of LEO, MEO and GEO satellite channels, advantages and disadvantages and which is suitable for the specific operations for the modern world. It also contains background on UAVs and IRS.

Chapter 3

This chapter consists of 4 parts. First, we define the network paradigm of our communication model along with diagrams. Then we form the signal model for both DF relay assisted scheme and IRS scheme. Next, we develop the channel model taking various environmental factors into account. Finally, we focus on total power consumption and minimization of both the schemes.

Chapter 4

In chapter 4, we carried out simulations to compare and contrast between relay assisted schemes and IRS assistance schemes in both UAV and BS scenarios with varying N elements. We observe the effect of achievable rate on optimal transmission power, efficiency and effect of in number of elements in IRS on optimal transmission power and energy efficiency. Using the outcome of the carried-out simulations in this chapter we came to the conclusion to determine the superior scheme.

Chapter 5

In this chapter we present the concluding remarks of all the chapters and highlights some promising avenues of further development.

Chapter 2

2.1 Background of Satellite

2.1.1 Introduction

The next generation of wireless networking is envisioned to bring about a new era of extensive, high-bandwidth, low-latency methods of communications such as 5G. Nonetheless, 5G networking systems cannot be properly executable due to the financial cost of establishing terrestrial radio access networks (RANs) for a large portion of the population. Satellites are presumed to play a major role in overcoming this issue and providing high bandwidth networks for a large portion of the population. There are usually three main types of orbits such as LEO, MEO and GEO depending on the distances from the lowest to the highest from the earth.

2.1.2 GEO satellite

A geostationary satellite is a satellite which orbits the earth, it is placed at an altitude of roughly 35,800 kilometers precisely above the equator, it revolves within the same path of direction the world rotates (west to east). At this altitude, one single orbit takes 24 hours, an equivalent length of time the earth requires to rotate once on its axis. So, it seems nearly stationary in the sky compared to ground.

A single geostationary satellite has line of sight coverage with about 40 percent of the earth's surface. The lifetime of the satellites is very long. A geostationary satellite is often accessed by employing an antenna which involves pointing a small dish towards the locality within the sky where the satellite appears to drift.

GEO satellite has many advantages such as due to its greater height, it can cover a larger geographical area. About three satellites can cover our entire planet. Moreover, the satellites are visible for 24 hours incessantly from a fixed location on the earth. GEO satellites are perfect for applications regarding broadcasting and multi-point distribution. Due to its continuous visibility from earth all the time from a particular fixed location, no ground station tracking is required. Inter-satellite handoff is not needed in the GEO satellite system. Since fewer satellites are required to cover the whole earth, there is no doppler shift and therefore fewer complex receivers can be utilized for the purpose of satellite communication. The life-time of a GEO satellite is usually high, approximately around 15 years.

The drawbacks of the GEO satellites are the signal requires a substantial amount of time to travel from earth to satellite and vice versa. The signal travel delay is about 120ms in any particular direction. The distance of 35,800 km gives 120 ms latency with transmission speed of the signal of 3x108 m/sec. Therefore, it is unsuitable for point-to-point applications which call for time critical applications like real time video, voice, etc. High transmission power is required for GEO satellites. Due to placement of GEO orbit above the equator, it is strenuous to broadcast areas around the polar region. Because of long transmission distances, the return signal is extremely faint. This demands use of better LNA (Low Noise Amplifier) and advanced algorithms for signal processing within the satellite network. This raises the cost of the ground station equipment. This method provides poor coverage at higher latitude places which are typically greater than 77 degrees. Moreover, placing a satellite at a GEO stationary orbit can be very expensive.

2.1.3 MEO satellite

MEO satellites are regarded as a suitable medium between the LEO and the GEO sorts of satellite archetypal orbit during a circular pattern round the equator and usually twenty-four MEO satellites are needed to provide uninterrupted coverage. A medium earth orbit (MEO) satellite has an orbit ranging from a couple of hundred miles to a couple of thousand miles above the surface of the earth. This type of satellites has an orbit above low earth orbit (LEO) satellites however it is lower than geostationary (GEO) satellites.

The orbital periods of MEO satellites can vary from 2 to 12 hours. Some MEO satellites travel in orbits of almost perfect rings and therefore resulting in constant travel speed and altitude. Other MEO satellites travel in more broader orbits. The perigee is known as the lowest altitude of an elliptical orbit satellite and its apogee is the highest altitude above the surface. The orbital speeds are far greater near the perigee compared to lower in regions near apogee where orbital speeds are slower. A satellite travelling in an elongated orbit is observed to pass the sky in a few minutes when it is near perigee whereas it may take a few hours while it is travelling near apogee. Elliptical-orbit satellites are most feasible to access near apogee as the earth-based antenna orientation is not required to be redirected frequently and therefore the satellite remains above horizon for longer periods of time.

Multiple MEO satellites with appropriate harmonized orbits can accommodate wireless communication coverage globally. Due to the fact that MEO satellites are closer to the planet compared to geostationary satellites, earth-based transmitters with comparatively low power and average-size antennas can access the network. MEO satellites orbit at higher altitudes than LEO satellites, for this reason the coverage area on the earth’s surface is larger for every satellite.

Transmission delays are often defined because the time required for a symbol to travel to a satellite and backtrack to a receiver ground station. In this situation, there is short transmission delay as the travel distance for signals to and from the MEO satellite is short.

For application regarding real-time communications, the communication system will be smoother when the transmission delay is shorter. For instance, if a GEO satellite needs one-fourth of a second for one trip, then a MEO satellite will require only 0.1 seconds to finish the same trip. MEO operates in the frequency range from 2 GHz and above. For contrast, the quickest readily available commercial internet is typically around 100 MB/s which is less than tenth of the speed these MEO satellites will be capable of providing. MEO satellites are generally used for transmitting high-speed telephone signals. Ten or more MEO satellites are capable of covering the entire earth.

Further these satellites are sent into space and away from earth, more tools and measures are provided to guard the sensitive computer equipment that caused them to function. Heat pipes are used to conduct heat far away from the electronics to prevent overheating and redirect generated heat to other parts of the satellite in risk of freezing.

The advantages of MEO satellites are that MEO requires only a dozen satellites compared to LEO networks. It has a very straightforward design which requires a few reasonable numbers of handovers. MEO satellites travel at higher altitudes compared to LEO satellites. Therefore, fewer satellites are required to cover the entire surface of the earth. MEO satellites are deployed at lower altitudes in contrast to GEO satellites. For this reason, the time delay from earth to satellite and the other way around is a smaller amount, which is about 40 ms whereas compared to GEO satellites it is about 120 ms. However, MEO satellites consume marginally higher transmission power compared to LEO satellites. The system is cheaper compared to GEO.

One of the major drawbacks of MEO satellites is that the signal becomes faint by the time the signal arrives at earth station from MEO compared to LEO systems. This happens as higher altitude of MEO satellites increases the travel distance for signals. Therefore, more transmission power is required to compensate for pathloss and other attenuating factors. Moreover, observable duration from east is very short as it lasts for only 2 to 8 hours from a fixed location on earth this requires satellites to be tracked. Moreover, MEO systems are more expensive compared to LEO and several MEO satellites are required to provide steady coverage over a region.

Apart from defense applications, MEO satellites can be used for communication purposes. MEO systems are generally used in applications involving GPS tracking and mobile telephone communications. However, implementation of MEO is often considered as a viable solution for broadening requirements of asynchronous transfer mode (ATM) and other broadband communications networks.

2.1.4 LEO satellite

A low earth orbit (LEO) satellite orbits the earth at elevations which are lower in contrast to geosynchronous (GEO) satellites. LEO satellites travel in orbits ranging 2,000 and 200 kilometers above the earth. These are frequently utilized for applications regarding communications, military surveillance, spying and other imaging applications. Satellites made for communications appreciate the lower signal proliferation delay to LEO. This lower proliferation delay comes about in less inactivity. Being closer to the world features a clear advantage for a few sorts of earth observation satellites by settling smaller subjects with more noteworthy detail. LEO satellites are for the most part less costly to put as they require an amazing bargain less rocket to control to put. As compared to geosynchronous circling satellites at 36,000 km, LEO travels through a denser climate and in this way encounters much more streamlined drag. This implies they require more control to travel at higher speeds and make corrections to take care of their lower circles. Where geosynchronous satellite circles in time with earth revolution at almost 3.06 x 10^3 meters per second at LEO lackey might travel at 7.78 x 10^3 meters per second circling numerous times a day. The ISS circles at 400 km and makes a full revolution around the earth almost each 93 minutes. LEO satellites have a way less field of communication with earth than a satellite at more noteworthy elevation. They indeed have a quicker turn circular the earth. These variables require a group of stars of satellites to work together for some applications. A star grouping may be a gathering of satellites working together, dispersed so as to supply the desired coverage. The extent of LEO satellites closes where medium earth orbit (MEO) starts at 2,000 km. MEO expands to the reaches of geosynchronous orbit.

There are benefits of utilizing satellites in LEO orbits. The key for network administrator is to settle on the right satellite plan, innovation and circle for the machine and advertise they serve. There are 7 key components to see at:

Latency: Since the orbits in LEO satellites are lower and closer to Earth, they are able to provide very low latency for time-critical services. There is some debate that the latency factor is not very crucial and its importance depends heavily on the type of application it is being implemented in. The latency of GEO has minimal effect on user experience. Although latency is vital to areas such as electronic services trading, watching videos online and interactive applications such as games, with the emergence of 5G technology latency has become less of a priority.

Coverage: A large number of LEO satellites will be required to provide adequate coverage to a certain given area or location. On the other hand, the satellites will require much lesser power to provide this coverage since they are much closer to Earth. Hence there is a tradeoff to be decided in choosing a greater number of LEO satellites using lesser power or lesser number of GEO satellites using more power.

Effectiveness: As LEO satellites are continually moving relative to earth at a given minute, they have a propensity to spend tons of your time overseas and other uninhabited regions, making them less-efficient in that sense. Usually this happens to be the best choice when attempting to stow away a greater geographic zone as against GEO satellites. Keep in mind, GEOs remain in one area relative to a chosen spot relative to soil. This makes GEOs more proficient for littler and more particular locales.

Cost: In spite of the fact that littler LEO satellites are less exorbitant to make, more are ordinarily required at fair one event to have viable communication operations. GEO satellites on the other hand are bigger with more capacity but are required to work effectively in little sums. Within the future, it's anticipated that modern advancements in GEO innovation will offer assistance to altogether diminish their cost per unit. This not only applies to GEO today but the whole satellite industry. LEO satellites are exceptionally complex and costly when looking at the number of gateways required on the ground to function. This drives the whole cost of the in general framework up. In any case, large-scale generation of indistinguishable portals can offer assistance in decreasing these costs.

Complexity: Low earth circling satellites are more complex when it includes their costly ground receiving wires. The requirement for numerous ground satellites come from the numerous traveling LEOs in circle at one time. Modern staged cluster antennas can offer assistance to diminish complexity here but will have to be utilized in a more extensive assortment of heights which can be troublesome to install.

Frequency range: LEO satellites are always covering one another geologically. This makes overseeing their recurrence synchronization complex between frameworks since there are numerous different LEOs traveling all circular the world. Overseeing of these chaotic two-way frameworks in LEO circles can become greatly troublesome for engineers and administrators to allow all the LEO satellites to operate without activity deprivations. And that’s fair the begin as things get indeed more complex with LEOs once they must moreover arrange with the inverse GEO satellites at certain focuses along their orbital journey.

Time to plug and adaptivity: Since one GEO satellite can cover a chosen area, it's much less demanding to dynamically include modern satellites to the framework or supplant old ones. In any case, when it includes the different LEO satellites (a LEO constellation) in circle, an outsized parcel of the constellation will ought to be built before adding on to or supplanting the current constellation to supply benefit to an area. In some cases, the entire LEO constellation will ought to get supplanted by a replacement constellation when updating execution or executing alternative administrations. This includes time, costs and complexity.

The primary drawback of LEO satellite systems is that each satellite covers a smaller area as it is much closer to Earth. This results in the need for a greater number of satellites required for global coverage which is quite expensive. Additionally, a greater number of satellites also mean a greater number of handoffs. A complex ground station would be required to handle these handoffs with accuracy and efficiency. The effect of atmospheric factors is much more pronounced when using LEO satellites and this causes orbital disorientation. These effects can be minimized by proper maintenance and ensuring that the satellites stay on the intended target in the correct direction. LEO satellites are less efficient in densely populated areas. Leo satellites usually last for 5 to 8 years while GEO satellites tend to be functional for about 10 years. Hence the lifespan is another important factor to consider. From any one certain location, the satellite will be visible for a total of 15 to 20 minutes. This allows limited time for testing and troubleshooting.

2.2 Background of UAV

2.2.1 Introduction

UAVs are an emerging technology that have provided enormous benefits in communication technology. They have been implemented in various civil, public and military applications. The primary advantage of UAVs are their ability of dynamic deployment, low maintenance and high maneuverability. UAVs can be utilized as standalone airborne communication stages as flying base stations (BS). They can be utilized as portable transfers with onboard communication handsets to supply or upgrade communication administrations to ground clients amid excess activity requests and over-burden circumstances. These sorts of communications are commonly alluded to as UAV-assisted communications.

Along with relaying and base station operations UAVs, can be used for signaling purpose of navigation and surveillance applications. UAVs can be equipped with cameras and sensors that can provide valuable insights for search and rescue operations while simultaneously providing communication coverage in a disaster struck region.

UAVs can be used to provide URLLC type connections in remote or hard to reach places such as oceans, deserts etc. mmWave can be used for UAVs due to their large bandwidth, but it will be prone to high propagation loss and high probability of signal blockage.

In places such as cities, where population is dense, LoS links may not be available. In such places terrestrial segments can be utilized. Therefore, maximum coverage can be ensured by integration of satellite, UAV, and terrestrial components.

2.2.2 Benefits of UAV

In contrast with traditional terrestrial BS UAV`S have following advantages:

1. Line of Sight (LoS) connectivity: Compared to on ground BS, UAV`s have higher probability of connecting with users as fewer obstacles are faced.

2. Dynamic Deployment: Drones can be dynamically deployed according to needs of connectivity. If demand is low in a certain area fewer drones can be allocated there whereas additional drones can be routed to an area with a lot of traffic. They can also be deployed in places struck with disasters for emergency connectivity.

3. UAV-Based Swarm Networks: A cluster of UAVs can build multi-UAV networks to offer seamless connectivity to ground users and IoT connectivity due to high flexibility and rapid maneuverability.

4. Versatility of different types of UAVs: UAVs are characterized by their physical attributes: size, weight, and power (SWAP).

SWAP is directly proportional to UAV`s capabilities such as: operational altitude, coverage, computation and endurance. Different UAVs can be allocated task suited to their SWAP attributes.

5. Edge network capability: UAVs can provide its computing and storage resources for edge network controllers. This enables offloading computing tasks from IoT devices and store frequently demanded contents, thus reducing strain on backhaul channels.

2.3 Background of IRS

Intelligent Reflecting Surface (IRS) is an upcoming alternative for overcoming difficulties such as enhancing spectrum, energy efficiency and cost efficiency. Typically, an IRS consists of an IRS controller and a large number of passive components capable of reflecting incident waves with a flexible phase shift and amplitude. By combining those reflected signals systematically at a desired receiver, the received signal power can be improved as well as interference at a non-intended receiver can be avoided and privacy can be ensured. In addition, the IRS offers high resilience and functionality for practical application because of its light weight and conformal geometry. All those advantages make IRS compatible with existing technologies such as Amplify and Forward (AF), backscatter communication and Massive multi-input and multi-output (M-MIMO). In M-MIMO there are many active components and operating mechanism is transmission, whereas, IRS has passive components and operating mechanism is reflection. As the IRS only reflects RF signals as a passive array, there is less power consumption. On the contrary, AF relay actively produces new signals to assist in a source to destination transmission thus needs more power. Furthermore, in IRS assisted communication total received power is maximized since the same information is carried by both the reflect-path and direct-path signals, hence, there is no interference. But in backscatter communication an interference suppressor is needed at the receiver side since the backscatter receiver and the Radio Frequency (RF) source are located in the same device. All those merits make IRS attractive and researchers are trying to implement it in various communication networks like 6G wireless communication and Non-Orthogonal Multiple Access (NOMA).

Chapter 3

System Model

3.1 Introduction

This chapter consists of 4 parts. This chapter addresses the network paradigm of our system, the signal model, the channel model and the total power minimization.

3.2 Network Paradigm

We consider a wireless network with a single user mobile device (MD), single UAV, single base station (BS) and a single LEO satellite. The UAV and BS act as a relay or an IRS for communication between MD and satellite. The UAV and satellite are deployed at a height, h_u and h_s. We assume that each device is equipped with a single antenna. In uplink communication, signal transmission from MD to satellite is achieved with the help of BS and UAV as shown in Fig. 2.1. In the downlink communication, signal transmission starts from satellite to UAV or base station and finally to the destination user or mobile device.

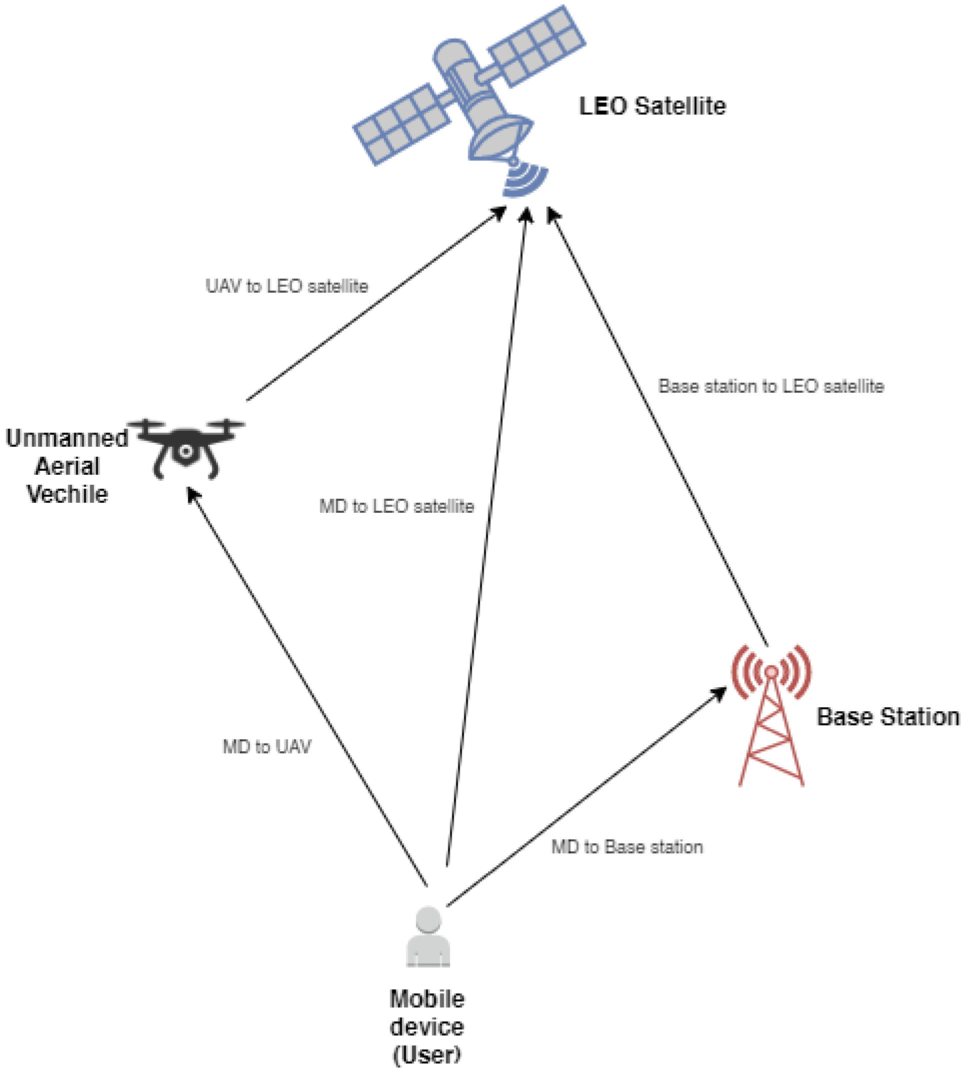

Figure 3.1.1 Uplink communication model.

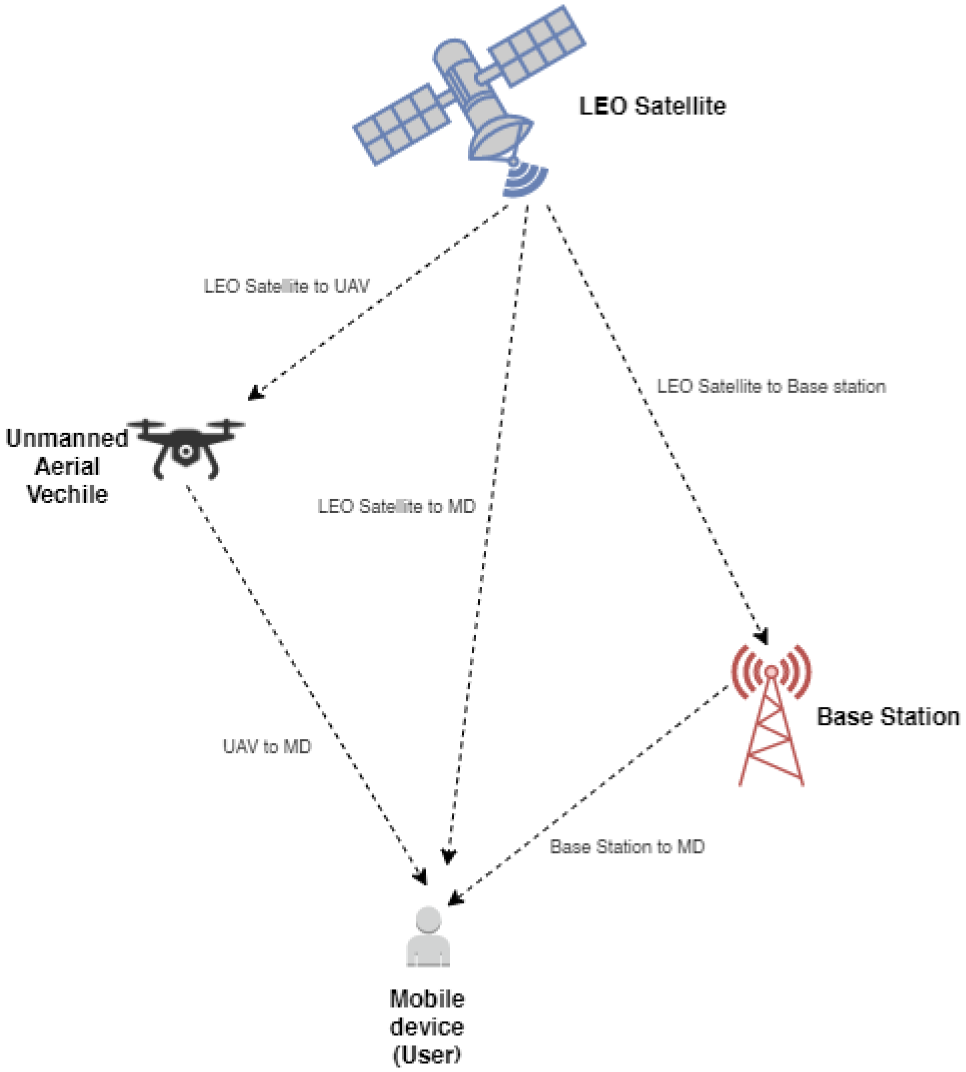

Figure 3.1.2 Downlink communication model.

3.3 Signal Model

In this section all the mathematical expressions are provided for the relay assisted scheme and the IRS-assisted scheme.

3.3.1 Uplink communications

During the uplink communication the signal can travel through 2 paths. The first path is from the user or mobile device (m) to the base station (b) and finally to the destination satellite (s). The second path is from the mobile device to the UAV to the satellite.

First time slot:

$$t \tag{1}$$

Source signal from mobile device in first time slot t:

$$x_m[t] \tag{2}$$

Received signal at base station in first time slot t:

$$y_b[t] = \sqrt{P_m} c_{m,b} x_m[t] + n_b[t] \tag{3}$$

Received signal at UAV in first time slot:

$$y_u[t] = \sqrt{P_m} c_{m,u} x_m[t] + n_u[t] \tag{4}$$

Received signal at satellite in first time slot t:

$$y_s[t] = \sqrt{P_m} c_{m,s} x_m[t] + n_s[t] \tag{5}$$

Here P_m and x_m represents the transmit power and information signal of MD. $c_{m,b}$ is the channel gain between MD and BS. $c_{m,u}$ is the channel gain between MD and UAV. $c_{m,s}$ is the channel gain between MD and satellite. n_b, n_u and n_s are the additive white Gaussian noise (AWGN) at BS, UAV and satellite.

Second time slot:

$$t+1 \tag{6}$$

Signal transmitted by base station in second time slot:

$$x_b[t+1] \tag{7}$$

For DF method, retransmitted signal from base station:

$$y_b[t+1] = \hat{x}_m[t] \tag{8}$$

For AF method, retransmitted signal from base station:

$$y_b[t+1] = \beta y_b[t] \tag{9}$$

Signal gain from base station:

$$\beta = \frac{\sqrt{P_b}}{\sqrt{P_m\left|c_{m,b}\right|^2 + N_0}} \tag{10}$$

SNR for mobile device to base station:

$$SNR_{m,b} = \frac{P_m\left|c_{m,b}\right|^2}{N_0} \tag{11}$$

SNR for base station to satellite:

$$SNR_{b,s} = \frac{P_b\left|c_{b,s}\right|^2}{N_0} \tag{12}$$

SNR for mobile device to satellite:

$$SNR_{m,s} = \frac{P_m\left|c_{m,s}\right|^2}{N_0} \tag{13}$$

Received signal at satellite from base station can be expressed as:

$$y_{b,s} = \frac{\sqrt{P_b}}{\sqrt{P_m\left|c_{m,b}\right|^2 + N_0}} c_{b,s} y_b + n_{b,s} \tag{14}$$

Substituting equation 3 in above equation:

$$y_{b,s} = \frac{\sqrt{P_b}}{\sqrt{P_m\left|c_{m,b}\right|^2 + N_0}} \sqrt{P_m} c_{b,s} c_{m,b} x_m + n'_{b,s} \tag{15}$$

Here $n_{b,s}$ is the AWGN channel with variance N_0 while $n'_{b,s}$ is the AWGN with variance N'_0 given by:

$$N'_0 = \left(1 + \frac{P_b\left|c_{b,s}\right|^2}{P_m\left|c_{m,b}\right|^2 + N_0}\right) N_0 \tag{16}$$

At the satellite, two signals are received. One signal is from the base station and another signal from the mobile device. We use Maximal Ratio Combiner:

$$y = h_1 y_{m,s} + h_2 y_{b,s} \tag{17}$$

Where,

$$h_1 = \frac{\sqrt{P_m} g^*{}_{m,s}}{N_0} \tag{18}$$

and,

$$h_2 = \frac{\frac{\sqrt{P_b}}{\sqrt{P_m\left|c_{m,b}\right|^2 + N_0}} \sqrt{P_m} c^*{}_{m,b} c^*{}_{b,s}}{\left(1 + \frac{P_b\left|c_{b,s}\right|^2}{P_m\left|c_{m,b}\right|^2 + N_0}\right) N_0} y_{b,s} \tag{19}$$

Signal received at satellite in the second time slot $(t + 1)$ from base station:

$$y_{s,b}[t + 1] = \sqrt{P_b} c_{b,s} \hat{x}_m[t + 1] + n_{s,b}[t + 1] \tag{20}$$

Signal received at satellite in the second time slot $(t + 1)$:

$$y_{s,u}[t + 1] = \sqrt{P_u} c_{u,s} \hat{x}_m[t + 1] + n_{s,u}[t + 1] \tag{21}$$

Here P_b and P_u represents the transmit power of BS and that of UAV. $\hat{x}_m$ is the decoded information signal of MD. $c_{b,s}$ is the channel gain between BS and satellite. $c_{u,s}$ is the channel gain between UAV and satellite. $n_{s,b}$ and $n_{s,u}$ are the AWGN at satellite.

Power levels:

$$P_B = \frac{\gamma_0 N_0}{c_{B,s}} \tag{22}$$

If reception with interference is considered at base station, source power is:

$$P_s = \frac{\gamma_0 (c_{m,B} P_m + N_0)}{c_{m,B}} \tag{23}$$

If no interference at base station, source power is:

$$P_s = \frac{\gamma_0 N_0}{c_{m,B}} \tag{24}$$

3.3.1.1 Decode and forward relay-assisted scheme

Applying repetition-coded DF from [29, 30], the achievable rate for MD-BS satellite link can be expressed as,

$$R_{mbs}{}^{DF} = \frac{1}{2} log_2(1 + \frac{2P_m g_{m,b} g_{b,s}}{(g_{m,b} + g_{b,s} - g_{m,s})\sigma^2}) \tag{25}$$

Where σ^2 is the variance of AWGN. P_m=P_b, $g_{m,b} = c^2{}_{m,b}$, $g_{b,s} = c^2{}_{b,s}$, $g_{m,s} = c^2{}_{m,s}$ and $\sigma^2 = \sigma^2{}_{b1} = \sigma^2{}_{sb} = \sigma^2{}_{s1}$.

Similarly, the achievable rate of MD-UAV-satellite link can be expressed as

$$R_{mus}{}^{DF} = \frac{1}{2} log_2\left(1 + \frac{2P_m g_{m,u} g_{u,s}}{(g_{m,u} + g_{u,s} - g_{m,s})\sigma^2}\right) \tag{26}$$

Where, P_m=P_u, $g_{m,u} = \sqrt{c_{m,u}}$, $g_{u,s} = \sqrt{c_{u,s}}$, $g_{m,s} = \sqrt{c_{m,s}}$ and $\sigma^2 = \sigma^2{}_{u1} = \sigma^2{}_{su} = \sigma^2{}_{s1}$.

3.3.1.2 IRS-assisted scheme

In this scheme, we assume that UAV and BS have integrated with N discrete IRS elements to assist communication between MD and satellite. In particular, the UAV-IRS and BS-IRS reflect the MD signal in the desired direction of the satellite with minimal power consumption. Hence, the phase-shift matrix of IRS is approximately calculated by a diagonal matrix as follows

$$\Phi = \eta \; diag(e^{j\theta_1}, e^{j\theta_2}, \dots \dots \dots, e^{j\theta_N}) \tag{27}$$

Where $\eta \in (0,1]$ represents the amplitude reflection coefficient and $\theta_1, \theta_2, \dots \dots \dots, \theta_N$ represents phase-shift variables.

The received signal from MD to satellite vis BS can be expressed as

$$y_{mbs}[t] = \sqrt{P_m}\left(c_{m,s} + c_{m,b}^T \Phi c_{b,s}\right) x_m[t] + n_{s2}[t] \tag{28}$$

Where n_{s2} is the AWGN at satellite.

Similarly, the received signal from MD to satellite via UAV can be expressed as

$$y_{mus}[t] = \sqrt{P_m}\left(c_{m,s} + c_{m,u}^T \Phi c_{u,s}\right) x_m[t] + n_{s3}[t] \tag{29}$$

Where n_{s3} is the AWGN at satellite.

From [29], the achievable rate from MD to satellite via BS and UAV can be expressed as

$$R_{mbs}^{IRS} = \left(1 + \frac{P_m\left(\sqrt{g_{m,s}} + N\eta\sqrt{g_{m,b} g_{b,s}}\right)^2}{\sigma^2}\right) \tag{30}$$

$$R_{mus}^{IRS} = \left(1 + \frac{P_m\left(\sqrt{g_{m,s}} + N\eta\sqrt{g_{m,u}g_{u,s}}\right)^2}{\sigma^2}\right) \tag{31}$$

Where $\sigma^2 = \sigma_{s2}^2 = \sigma_{s3}^2$.

3.3.2 Downlink communications

In the case of downlink, the signal travels through any one of the 2 available paths. The first path is from satellite to the base station to the mobile device. The second path is from the satellite to the UAV to the mobile device.

First time slot:

$$t \tag{32}$$

Source signal from satellite in first time slot t:

$$x_s[t] \tag{33}$$

Received signal at base station in first time slot t:

$$y_b[t] = \sqrt{P_s}c_{s,b}x_s[t] + n_b[t] \tag{34}$$

Received signal at UAV in first time slot t:

$$y_u[t] = \sqrt{P_s}c_{s,u}x_s[t] + n_u[t] \tag{35}$$

Received signal at mobile device in first time slot t:

$$y_m[t] = \sqrt{P_s} c_{s,m} x_s[t] + n_m[t] \tag{36}$$

Second time slot:

$$t + 1 \tag{37}$$

Signal transmitted by base station in second time slot:

$$x_b[t+1] \tag{38}$$

Signal transmitted by UAV in second time slot:

$$x_u[t+1] \tag{39}$$

For DF method, retransmitted signal from base station:

$$y_b[t+1] = \hat{x}_s[t] \tag{40}$$

For DF method, retransmitted signal from UAV:

$$y_u[t+1] = \hat{x}_s[t] \tag{41}$$

For AF method, retransmitted signal from base station:

$$y_b[t+1] = \beta y_b[t] \tag{42}$$

For AF method, retransmitted signal from UAV:

$$y_u[t+1] = \beta y_u[t] \tag{43}$$

Signal gain from base station:

$$\beta = \frac{\sqrt{P_b}}{\sqrt{P_s \left|c_{s,b}\right|^2 + N_0}} \tag{44}$$

Signal gain from UAV:

$$\beta = \frac{\sqrt{P_u}}{\sqrt{P_s \left|c_{s,u}\right|^2 + N_0}} \tag{45}$$

SNR for Satellite to Base Station:

$$SNR_{s,b} = \frac{P_s \left| c_{s,b} \right|^2}{N_0} \tag{46}$$

SNR for Base station to Mobile Device:

$$SNR_{b,m} = \frac{P_b \left| c_{b,m} \right|^2}{N_0} \tag{47}$$

SNR for Satellite to Mobile Device:

$$SNR_{s,m} = \frac{P_s \left| c_{s,m} \right|^2}{N_0} \tag{48}$$

SNR for Satellite to UAV:

$$SNR_{s,u} = \frac{P_s \left| c_{s,u} \right|^2}{N_0} \tag{49}$$

SNR for UAV to Mobile Device:

$$SNR_{u,m} = \frac{P_u \left| c_{u,m} \right|^2}{N_0} \tag{50}$$

SNR for Satellite to Mobile Device:

$$SNR_{s,m} = \frac{P_s \left| c_{s,m} \right|^2}{N_0} \tag{51}$$

Received signal at Mobile from base station can be expressed as:

$$y_{b,m} = \frac{\sqrt{P_b}}{\sqrt{P_s \left| c_{s,b} \right|^2 + N_0}} c_{b,m} y_b + n_{b,m} \tag{52}$$

Substituting equation 34 in above equation:

$$y_{b,m} = \frac{\sqrt{P_b}}{\sqrt{P_s \left| c_{s,b} \right|^2 + N_0}} \sqrt{P_s} c_{b,m} c_{s,b} x_s + n'_{b,m} \tag{53}$$

Here $n_{b,m}$ is the AWGN channel with variance N_0 while $n'_{b,m}$ is the AWGN with variance N'_0 given by:

$$N'_0 = \left(1 + \frac{P_b|c_{b,m}|^2}{P_s|c_{s,b}|^2 + N_0}\right) N_0 \tag{54}$$

Received signal at Mobile Device from UAV can be expressed as:

$$y_{u,m} = \frac{\sqrt{P_u}}{\sqrt{P_s|c_{s,u}|^2 + N_0}} c_{u,m} y_u + n_{u,m} \tag{55}$$

Substituting equation 35 in above equation:

$$y_{u,m} = \frac{\sqrt{P_u}}{\sqrt{P_s|c_{s,u}|^2 + N_0}} \sqrt{P_s} c_{u,m} c_{s,u} x_s + n'_{u,m} \tag{56}$$

Here $n_{u,m}$ is the AWGN channel with variance N_0 while $n'_{u,m}$ is the AWGN with variance N'_0 given by:

$$N'_0 = \left(1 + \frac{P_u|c_{u,m}|^2}{P_s|c_{s,u}|^2 + N_0}\right) N_0 \tag{57}$$

At Mobile Device, 2 signals are received. One from Base Station another from Satellite.

We use Maximal Ratio Combiner:

$$y = h_1 y_{s,m} + h_2 y_{b,m} \tag{58}$$

Where,

$$h_1 = \frac{\sqrt{P_s} g^*{}_{s,m}}{N_0} \tag{59}$$

At Mobile Device, 2 signals are received. One from UAV another from Satellite.

We use Maximal Ratio Combiner:

$$y = h_1 y_{s,m} + h_2 y_{u,m} \qquad 60$$

Where,

$$h_1 = \frac{\sqrt{P_s} g^*{}_{s,m}}{N_0} \qquad 61$$

Signal received at Mobile Device:

$$h_2 = \frac{\frac{\sqrt{P_b}}{\sqrt{P_s\left|c_{s,b}\right|^2 + N_0}}\sqrt{P_s}c^*{}_{s,b}c^*{}_{b,m}}{\left(1 + \frac{P_b\left|c_{b,m}\right|^2}{P_s\left|c_{s,b}\right|^2 + N_0}\right)N_0} y_{b,s} \tag{62}$$

Instantaneous signal to noise ratio from Satellite to Base Station selected for reception for in-band relaying:

$$\gamma_{s,B_r} = \frac{c_{s,B_r}P_s}{c_{B_t,B_r}P_{B_t} + N_0} \geq \gamma_0 \tag{63}$$

Instantaneous signal to noise ratio from mobile device to base station selected for reception for out-band relaying:

$$\gamma_{s,B_r} = \frac{c_{s,B_r}P_s}{N_0} \geq \gamma_0 \tag{64}$$

Instantaneous SNR from Base Station to Mobile Device considering no interference from source:

$$\gamma_{B_t,m} = \frac{c_{B_t,m}P_{B_t}}{N_0} \geq \gamma_0 \tag{65}$$

Instantaneous signal to noise ratio from Satellite to UAV selected for reception for in-band relaying:

$$\gamma_{s,U_r} = \frac{c_{s,U_r}P_s}{c_{U_t,U_r}P_{U_t} + N_0} \geq \gamma_0 \tag{66}$$

Instantaneous signal to noise ratio from Satellite to UAV selected for reception for out-band relaying:

$$\gamma_{s,U_r} = \frac{c_{s,U_r}P_s}{N_0} \geq \gamma_0 \tag{67}$$

Instantaneous SNR from UAV to Mobile Device considering no interference from source:

$$\gamma_{U_t,m} = \frac{c_{U_t,m} P_{B_t}}{N_0} \geq \gamma_0 \tag{68}$$

Power levels:

$$P_{B_t} = \frac{\gamma_0 N_0}{c_{B_t,m}} \tag{69}$$

$$P_{U_t} = \frac{\gamma_0 N_0}{c_{U_t,m}} \tag{70}$$

If reception with interference is considered at base station, source power is:

$$P_s = \frac{\gamma_0 (c_{B_t,B_r} P_{B_t} + N_0)}{c_{s,B_r}} \tag{71}$$

If reception with interference is considered at UAV, source power is:

$$P_s = \frac{\gamma_0 (c_{U_t,U_r} P_{U_t} + N_0)}{c_{s,U_r}} \tag{72}$$

If no interference at base station, source power is:

$$P_s = \frac{\gamma_0 N_0}{c_{s,B_r}} \tag{73}$$

If no interference at UAV, source power is:

$$P_s = \frac{\gamma_0 N_0}{c_{s,U_r}} \tag{74}$$

3.4 Channel Model

This channel model contains the pitch angle fading, path loss, Rician small-scale fading and atmospheric fading. The pitch angle fading is expressed as

$$D_Q(\varphi) = A_{eff}.cos\ cos\ (\varphi)^{\ \mu}\ \frac{32log2}{2\left(2arccos\left(\sqrt[\mu]{0.5}\right)\right)^2} \tag{75}$$

Here φ is the pitch angle. A_{eff} is the antenna aperture efficiency (considered unity), μ is the roll-off factor of the antenna.

For Mobile Station k positioned in (x_k, y_k) that is covered by beam l, the approximate pitch angle is

$$\varphi_{l,k} = 2acrtan\frac{\sqrt{(x_k - q_{l,1})^2 + (y_k - q_{l,1})^2}}{2h} \tag{76}$$

Here, altitude of Satellite or UAV is h, the center position covered by the beam l is $(q_{l,1}, q_{l,2})$.

The atmospheric fading is

$$U(d) = 10^{\left(\frac{3d\alpha}{10h}\right)} \tag{77}$$

Here, α represents the attenuation through the clouds and rain in dB/km. Ground Station (GS) to Satellite and UAV to satellite links can be affected by atmospheric parameters such as rain attenuation, cloud attenuation, oxygen attenuation, etc. Rain attenuation can cause severe degradation in communication links between satellites and UAV and BS. Attenuation power can vary according to volume, shape and quantity or intensity of rain droplets. In order to classify attenuation due to heavy rain circumstances, we have to take into account of rainy condition that occurs less than 1 percent of the time. During this time, heavy rainfall causes severe degradation in signal quality to the propagating signal. Water contents in clouds contribute to signal degradation by absorption and scattering of energy, particularly for frequencies greater than 10 GHz.

The propagation distance between Satellite or UAV and the Mobile Station d is approximately

$$d = \sqrt{h^2 + (x_k - q_{su,1})^2 + (y_k - q_{su,2})^2} \tag{78}$$

Here $(q_{su,1}, q_{su,2})$ indicates the position right below Satellite or UAV.

The precise expression of the channel model is

$$D = \left(\frac{c}{4\pi d f_c}\right)^2 . D_Q(\varphi). U(d). \gamma \tag{79}$$

Here γ is the Rician small-scale fading, f_c and c are the carrier frequency and the speed of light.

The expression of the channel gain for MD-satellite can be expressed as

$$c_{m,b} = \left(\frac{g}{4\pi d_{m,b} f_c}\right)^2 G_m G_b \varLambda \tag{80}$$

where G_m and G_b represent the antenna gain of MD and satellite. $\varLambda$ is the gain of Rician small-scale fading. f_c and c are the carrier frequency and the speed of light, respectively.

The expression of the channel gain for MD-BS can be expressed as

$$c_{m,b} = \left(\frac{c}{4\pi d_{m,b} f_c}\right)^2 G_m G_b \varLambda \tag{81}$$

where G_b represents the antenna gain of BS.

The expression of the channel gain for MD-UAV can be expressed as

$$c_{m,u} = \left(\frac{c}{4\pi d_{m,u} f_c}\right)^2 G_m D\left(\varphi_{m,u}\right) \varLambda \tag{82}$$

The expression of the channel gain for BS-satellite can be expressed as

$$c_{b,s} = \left(\frac{c}{4\pi d_{b,s} f_c}\right)^2 G_b G_s U\left(d_{b,s}\right) \varLambda \tag{83}$$

The expression of the channel gain for UAV-satellite can be expressed as

$$c_{u,s} = \left(\frac{c}{4\pi d_{u,s} f_c}\right)^2 G_s D\left(\varphi_{u,s}\right) U\left(d_{u,s}\right) \varLambda \tag{84}$$

3.5 Total Power Minimization

In this section, we find out the total power consumption for MD-BS-satellite and MD-UAV-satellite links. For the minimum power consumption, we assume that satellite requires a specific data rate $\underline{R}$.

3.5.1 Decode and Forward Relay-assisted scheme

In [29], total power consumption using DF relay for MD-BS-satellite and MD-UAV-satellite links can be expressed as

$$P_{T-mbs}^{DF} = \frac{P_{m-mbs}^{DF}}{\Omega} + \frac{1}{2}P_{mh} + P_{bh} + P_{sh} \tag{85}$$

$$P_{T-mus}^{DF} = \frac{P_{m-mus}^{DF}}{\Omega} + \frac{1}{2}P_{mh} + P_{uh} + P_{sh} \tag{86}$$

3.5.2 IRS-assisted scheme

After some manipulation in (30) and (31), optimal transmission power using IRS for MD-BS-satellite and MD-UAV-satellite links can be expressed as

$$P_{m-mbs}^{IRS} = \left(2^{\underline{R}} - 1\right)\frac{\sigma^2}{\left(\sqrt{g_{m,s}} + N\eta\sqrt{g_{m,b}g_{b,s}}\right)^2} \tag{87}$$

$$P_{m-mus}^{IRS} = \left(2^{\underline{R}} - 1\right)\frac{\sigma^2}{\left(\sqrt{g_{m,s}} + N\eta\sqrt{g_{m,u}g_{u,s}}\right)^2} \tag{88}$$

In [32], total power consumption using IRS for MD-BS-satellite and MD-UAV-satellite links can be expressed as

$$P_{T-mbs}^{IRS} = \frac{P_{m-mbs}^{IRS}}{\Omega} + P_{mh} + NP_e + P_{sh} \tag{89}$$

$$P_{T-mus}^{IRS} = \frac{P_{m-mus}^{IRS}}{\Omega} + P_{mh} + NP_e + P_{sh} \tag{90}$$

Where P_e represents the dissipated power per element for each phase shifter.

From [29], optimal number of IRS elements can be expressed as

$$N_{o-mbs} = \sqrt[3]{\frac{(2^{2\underline{R}} - 1)\sigma^2}{\eta^2 g_{m,b} g_{b,s} P_e}} - \frac{1}{\eta}\sqrt{\frac{g_{m,s}}{g_{m,b} g_{b,s}}} \tag{91}$$

$$N_{o-mus} = \sqrt[3]{\frac{(2^{2\underline{R}} - 1)\sigma^2}{\eta^2 g_{m,b} g_{b,s} P_e}} - \frac{1}{\eta}\sqrt{\frac{g_{m,s}}{g_{m,b} g_{b,s}}} \tag{92}$$

Chapter 4

Simulation Result and Discussion

4.1 Introduction

In order to evaluate differences between Relay-assisted schemes and IRS-assisted schemes, we must conduct and compare simulations of both schemes side by side with the same input parameters. In order to conduct simulation based on equations and relationships derived in Chapter 3, a MATLAB simulator was used which comprised a 3-Dimensional (3D) virtual environment of dimensions 100 x 150 x 1500000 m^3. In this virtual environment we consider a wireless network with a single user mobile device (MD), single UAV, single base station (BS) and single LEO satellite. The UAV and BS act as a relay or an IRS for communication between MD and satellite. Since many of the components in our simulation environment rely on stored and limited on board energy, lower consumption of power for a given achievable rate is appreciated.

The parameters of the simulations are as follows:

Parameter	**Value**	**Parameter**	**Value**
f_c	10 GHz	G_m	10
σ^2	2.3886×10^{-10}	G_b	100
η	1	G_s	1
μ	65	P_{mh}	100mW
ρ	1.45/1000	P_{bh}	100mW
Λ	0.1	P_{sh}	100mW
Ω	0.5	P_e	5mW

4.2 Effect of achievable rate on optimal transmission power

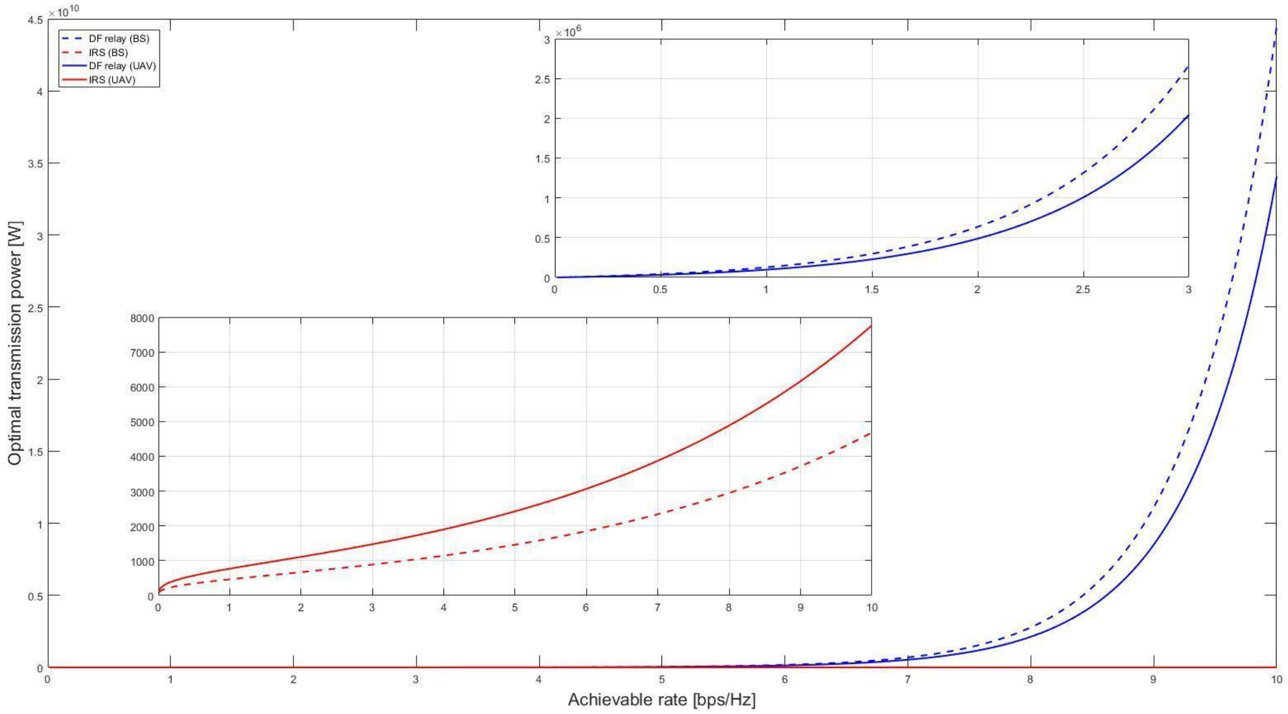

Figure 4.1 Optimal transmission power vs. achievable rate

Figure 4.1 shows comparison between BSs implemented with Relay assisted DF scheme and IRS scheme. In general, it can be stated that more optimal power is consumed for a higher sum achievable rate. To obtain a sub achievable rate of 8 bps/Hz, BS employing the DF relay scheme used optimal transmission power of 2.77 x 10^9 W whereas for IRS scheme implementation, the optimal transmission power was only 2947 W. This shows BS implementation of the IRS scheme is 99% more efficient in optimal power transmission, making it the better option in this case. To gain an achievable rate of 8 bps/Hz case of UAVs in both schemes, optimal transmission power for DF relay scheme was 2.129 x 10^9 W whereas optimal transmission power for IRS scheme was only 4886 W. UAV implementation of IRS scheme is 99% more efficient in optimal power transmission. Therefore, it is the ideal choice.

From this comparison it can be said that, BS implemented IRS scheme is the best method as it provides the same sub achievable rate for lowest power consumed.

	Sub achievable rate	Optimal transmission power for DF relay scheme for (W)	Optimal transmission power for IRS scheme (W)
BS	8 bps/Hz	2.77 x 10^9 W	2947
UAV	8 bps/Hz	2.129 x 10^9	4886

Table 4.1: Optimal transmission power for DF relay scheme and IRS relay scheme for BS and UAV

4.3 Effect of achievable rate on Efficiency

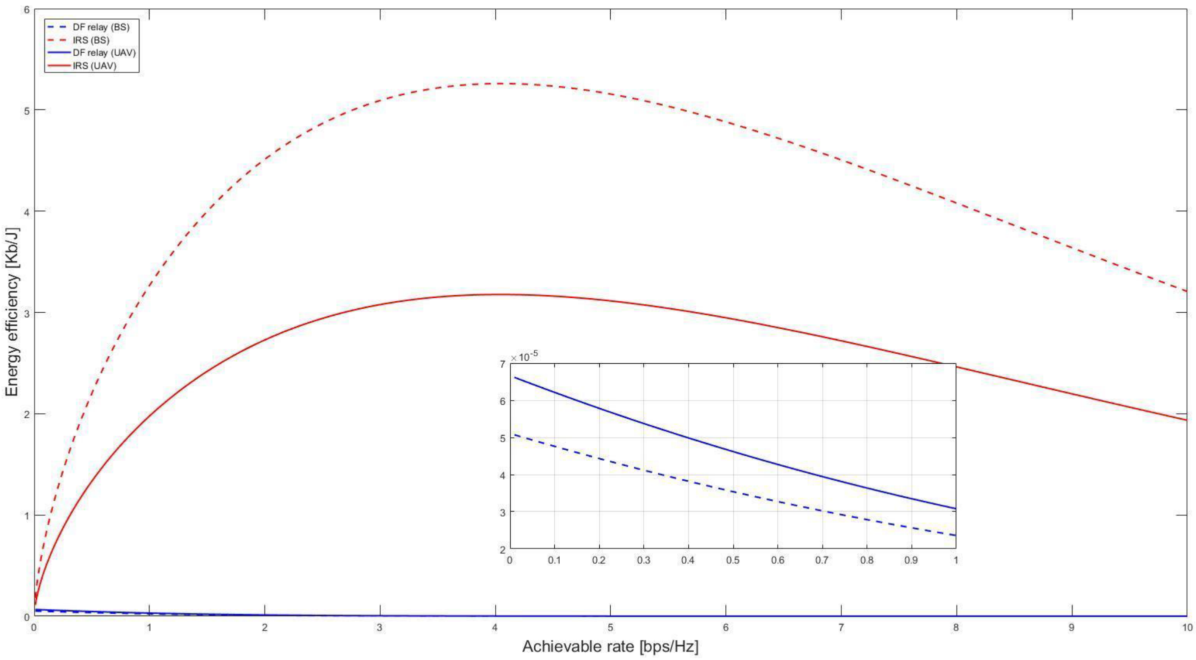

Figure 4.2 Energy efficiency vs. achievable rate

Energy efficiency is one of the key factors to be considered while implementing a communication scheme. Therefore, whichever scheme shows higher efficiency is considered as the better performer. Figure 4.2 shows the effect of achievable rate on efficiency for both

DF and IRS UAV and BS. In BS implementation of DF relay scheme, energy efficiency was 2.359×10^{-5} Kb/J for an achievable rate of 1 bps/Hz, while for IRS scheme it was 3.265 Kb/J for same achievable rate of 1 bps/Hz. The peak energy efficiency for the IRS BS occurs at an achievable rate of 4 bps/Hz with an energy efficiency of 5.259 Kb/J. Here IRS scheme is 99.99% more efficient compared to DF relay scheme, which makes it the superior method. In terms of UAV implementation, for an achievable rate of 1 bps/Hz, the energy efficiency for DF relay is 3.079×10^{-5} Kb/J whereas for IRS it is 1.976 Kb/J.

For the UAVs using IRS scheme maximum energy efficiency occurs at an achievable rate of 4.08 bps/Hz at an energy efficiency of 3.177 Kb/J. The IRS scheme is 99.99% more efficient compared to DF relay scheme for UAVs, which makes it the better performer. Among these four, BS implemented IRS scheme shows the highest efficiency.

Type	Achievable rate	Energy Efficiency DF relay scheme	Energy Efficiency for IRS scheme
BS	1 bps/Hz	2.359×10^{-5} Kb/J	3.265 Kb/J
UAV	1 bps/Hz	3.079×10^{-5} Kb/J	1.976 Kb/J

Table 4.2: Energy Efficiency for DF relay scheme and IRS relay scheme for BS and UAV

4.4 Effect of N number of elements in IRS on optimal transmission power

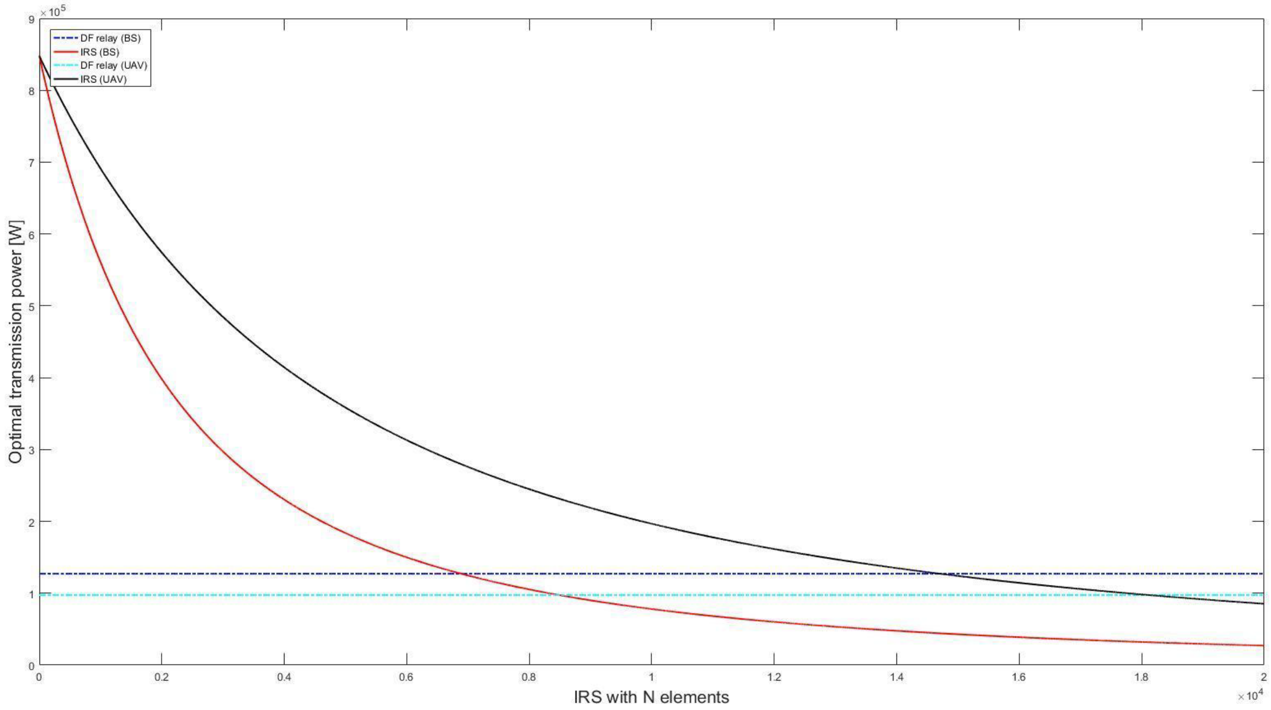

Figure 4.3 Optimal transmission power vs. IRS with N elements

It is imperative that the method in use utilizes the lowest amount of transmission power to ensure longer service time of network components. Figure 4.3 shows the effect of varying N number of elements in IRS on optimal transmission power. In terms of BS implementation, DF relay showed a constant optimal transmission power of 127.2 kW for all values of N whereas IRS showed a decreasing trend as N increased. For instance, at N = 4008, IRS scheme consumed an optimal transmission power of 229.8kW whereas DF relay utilized only 127.2kW. IRS scheme required nearly twice (44.65%) much power of the DF relay scheme. In this situation, DF relay proves to be better for BS implementation. When it comes to UAV, DF relay scheme consumed a constant optimal transmission power of 97.44 kW whereas for IRS scheme optimal transmission power reduced as the number of elements N increased. For instance, at N = 4014 IRS scheme consumed 413.5kW compared to DF relay`s 97.44 kW. This shows IRS schemes consume 76.44% more power compared to DF relay for lower values of N, making DF relay the better choice for UAV implementation.

At N = 6886, an optimum point can be observed where BSs consume an optimal transmission power of 127.2 kW for both DF relay and IRS schemes. For values of N above 6886, it can be observed that DF relay scheme consume more power. For instance, at N=9980, IRS BS consumed only 78.2kW which is 24.6% lower than DF Relay.

Similarly, in terms of UAV implementation, an optimum point occurs at an N value of 18120 for the IRS implemented UAV and the DF relay implemented UAV. At this point both the UAV has an optimal transmission power of 97.44 KW. However, similar to BS implementation, it can be observed that for values of N above 18120, DF relay schemes consume more power. For instance, at N=20000, IRS BS consumed only 85.31kW which is 14.25% less than the power utilized by DF Relay.

In summary, for values of N less than 6886 DF relay scheme is the better performer as it consumes less power whereas for instances where N is greater than 6886, IRS scheme is the better method. In terms of UAV implementation, IRS UAV consumes more power for values of N less than 18120, meanwhile for values of N greater than 18120, the DF relay UAV consumes more power which makes IRS scheme better. In both UAV and BS implementation, optimal transmission power reduces for IRS schemes when the number of elements increases.

Type	N	Energy efficiency for DF relay scheme	Energy efficiency for IRS scheme (W)	Type	N	Energy efficiency for DF relay scheme	Energy efficiency for IRS scheme (W)
BS	4008	127.2 kW	229.8kW	UAV	4014	97.44 kW	413.5kW
BS	6886	127.2 kW	127.2 kW	UAV	18120	97.44 kW	97.44 kW
BS	9980	127.2 kW	78.2kW	UAV	20000	97.44 kW	85.31kW

Table 4.3: IRS with N elements for DF relay scheme and IRS relay scheme for BS and UAV

4.5 Effect of N number of elements in IRS on energy efficiencies

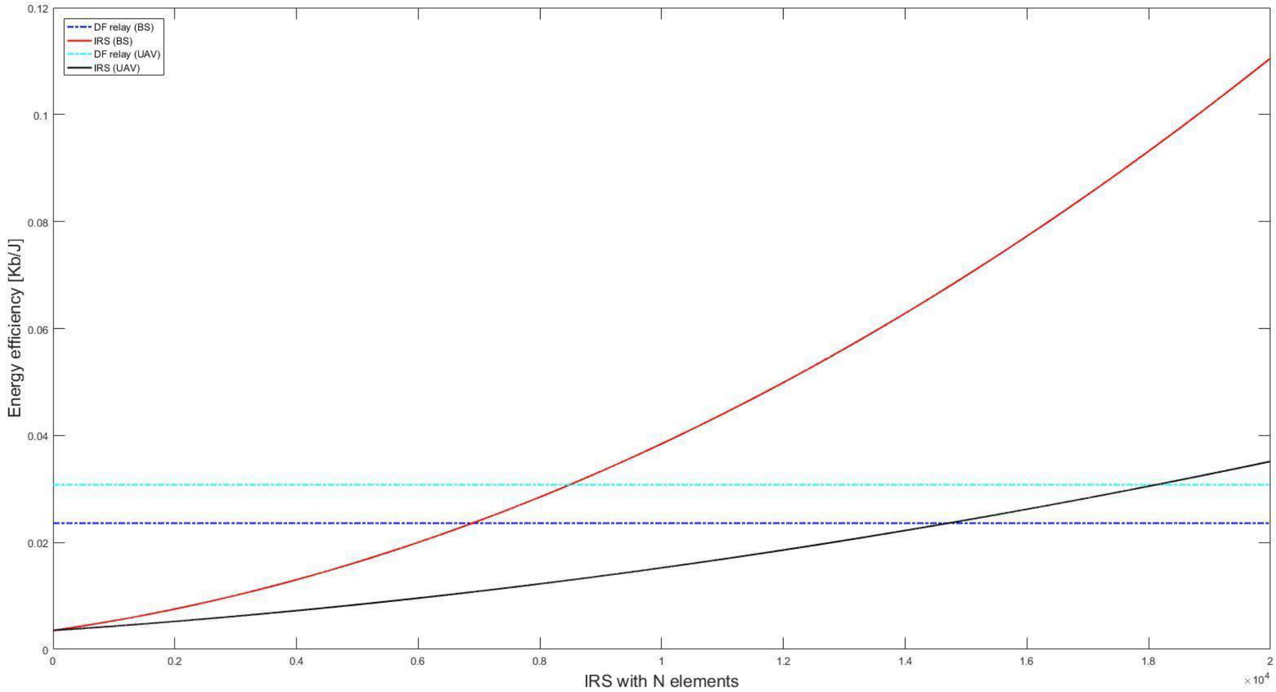

Figure 4.4 Energy efficiency vs. IRS with N elements

Power efficiency is undoubtedly one of the most concerning factors while considering a communication scheme. In this section, the effect of varying N elements in IRS on energy efficiencies has been studied. Figure 4.4 shows the effect of varying N number of elements in IRS on energy efficiencies. DF Scheme showed constant Energy efficiency for all values of

N. On the contrary, efficiency increases with the number of N for IRS schemes with an upward curve.

In case of BS implementation, DF relay scheme had a constant energy efficiency of 0.02359 Kb/J for all values of N. However, Energy efficiency for IRS increases as value of N increases. Considering N = 9809, BS with IRS implementation showed an energy efficiency of 0.03744 Kb/J . This shows an improvement of IRS scheme of 36.99% over DF relay scheme which indicates that IRS scheme is better for BS implementation at N=9809. An optimum point is reached between the IRS implemented BS and DF relay implemented BS at N = 6925. The energy efficiency for both cases is the same at this point and the value is 0.02359 Kb/J. However, at values of K lower than 6925, DF is more efficient. For example, at N= 4200, IRS BS`s efficiency is only 0.01366 kB/J which is 72.69% less efficient than DF scheme.

In comparison between DF relay and IRS over UAV implementation we can observe a similar pattern to BS implementation, energy efficiency remains constant for DF scheme even though N increases. DF relay scheme showed a constant energy efficiency of 0.03079Kb/J for all values of N. Meanwhile, energy efficiency for IRS UAVs increases with increasing values of N. At lower values of N, DF UAV is more efficient. For instance, at N = 4033, IRS UAV`s efficiency is only 0.007276 Kb/J which is 323% less efficient compared to DF relay. At N = 18110, energy efficiency reaches an optimum value of 0.03079 Kb/J for both DF relay and IRS scheme. However, when N increases beyond 18110, IRS UAVs provide better efficiency. For example, the IRS scheme exhibited 0.03333 Kb/J for N = 19230, which is a 7.62% increase in efficiency over DF relay scheme in UAV. This proves the IRS scheme is better for higher values of N.

To summarize, in case of BS implementation, DF relay BS has better efficiency when N is less than 6925, however IRS BS has the higher energy efficiency for values of N greater than 6925. Therefore, when N is less than 6925 DF is better and when N is greater than 6925 IRS is better, optimal efficiency is reached at N=6925. Similarly, for UAV implementation, at a value of N less than 18110, DF relay scheme is better and when N is greater than 18110, IRS scheme is better, optimal point is reached at N=18110.

Type	**N**	**Energy efficiency for DF relay scheme**	**Energy efficiency for IRS scheme (W)**	**Type**	**N**	**Energy efficiency for DF relay scheme**	**Energy efficiency for IRS scheme (W)**
BS	9809	0.02359 Kb/J	0.03744 Kb/J.	UAV	19230	0.03079Kb/J	0.03333 Kb/J.
BS	6925	0.02359 Kb/J	0.02359 Kb/J	UAV	18120	0.03079Kb/J	0.03079 Kb/J
BS	4200	0.02359 Kb/J	0.01366 kb/J	UAV	4033	0.03079Kb/J	0.007276 Kb/J

Table 4.4: Energy Efficiency for varying N of DF relay scheme and IRS relay scheme for BS and UAV

Chapter 5

Conclusion and Future Work

5.1 Conclusion

In our communication system, we implemented a detailed performance analysis of the relay scheme and the IRS scheme [22]. The results show that the power consumption of DF relay schemes was 99.99% higher than the IRS schemes considering the same achievable rate. However, the IRS scheme was clearly the better performer at comparing energy efficiencies at the same achievable rate. It was also visible that the IRS ground BS performed better than the IRS UAV. The IRS implemented was 99.99% more energy efficient and the IRS implemented BS was 99.99% more efficient. Finally, we can conclude that the IRS scheme provides a major performance upgrade over the DF relay scheme.

5.2 Future scope

Apart from the vast implementation of UAVs, there is a huge scope for the UAV related applications. Expanding the communication model over a large area would require UAVs operating together as a massive network. New technologies such as machine learning and stochastic geometry can be applied to form an efficient design. The possibility of an IRS acting as a shared resource for multiple UAVs can also be explored further. The data transmission rate and quality of service can be further enhanced by implementing a MIMO-OFDM system. Multiple Input Multiple Output (MIMO) helps in reducing the multipath fading and increasing the system capacity. Orthogonal frequency division multiplexing (OFDM) would help in eradicating orthogonality between sub carriers [16]. The power minimization of the system can be further by implementing a transmit antenna selection technique in a random Cognitive Radio

(CR) network. The results show that increasing threshold value and number of transmit antennas improved energy efficiency and gain [17]. Multiple relay cooperative communication is known for enhancing the performance of wireless networks. Orthogonal frequency division multiplexing (OFDM) transmission techniques with multiple output (MIMO) has promised significant improvements in reliability and throughput for wireless networks. MIMO-OFDM system under amplify and forward (AF) multiple relays might be developed to enhance system performance [18]. The Internet of things (IoT) is essential to send images and give feedback to monitor and classify plant diseases. IoT with environmental sensing and image processing devices may open a new era to monitor the health of plants [19]. Orthogonal frequency division multiplexing based cooperative communication can be implemented in UAVs for high data rate and enhanced capability as in [20]. The OFDM based decode and forward scheme has been explored over Nakagami fading channels. The DF scheme has shown promise in cooperative communication. Finally, non-orthogonal multiple access-based cognitive UAV-assisted ultra-reliable and low-latency communications (URRLCs) and massive machine type communication (mMTC) services can offer huge advantages in 5G communications and even more [21]. An mMTC service needs better energy efficiency and connection probability whereas a URLLC needs minimized latency.

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