ANALYZING AF RELAYING FOR MULTI-USER HSTRN IN THZ WIRELESS SYSTEM

A thesis submitted in partial fulfilment of the requirements for

The award of the degree of

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in

Communication Systems

By

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BONAFIDE CERTIFICATE

This is to certify that the project titled **ANALYZING AF RELAYING FOR MULTI-USER HSTRN IN THZ WIRELESS SYSTEM** is a bonafide record of the work done by

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In partial fulfilment of the requirements for the award of the degree of **Master of Technology in Communication Systems** of the **NATIONAL INSTITUTE OF TECHNOLOGY, TIRUCHIRAPPALLI,** during the year 2023-2024.

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ABSTRACT

We delve into analyzing the coverage probability within a multiuser hybrid satellite-terrestrial relay network (HSTRN) employing opportunistic scheduling. The HSTRN architecture is dedicated to aggregating top-tier services for terrestrial users, including applications within the realm of the Internet of Things (IoT). Within this network, the signal broadcasted from the satellite undergoes amplification by a relay and is subsequently directed to the terrestrial user exhibiting the highest instantaneous signal-to-noise ratio (SNR) in their respective channel.

To comprehend the analytical coverage probability, we derive approximations specifically tailored for the amplify-and-forward (AF) relaying technique. Our study delves into analyzing the multiuser relay network, factoring in Rician shadowed fading from the source to the relay and accounts for the Terahertz (THz) link between the relay and the destination. To validate our investigation and assess the performance variance among AF relaying methodologies, we conduct both simulation-based evaluations and analytical verifications.

Keywords: HSTRN, Amplify and forward, opportunistic scheduling, coverage probability, variable gain relaying, THZ Relay fading, Rician fading.

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LIST OF ABBREVIATIONS

Abbreviations	**Description**
HSTRN	Hybrid Satellite Terrestrial Relay Network
AF	Amplify and Forward
DF	Decode and Forward
SNR	Signal to Noise Ratio
CCI	Co-Channel Interference
CSI	Channel Straight Information
BER	Bit Error Rate
LOS	Line of Sight
ASEP	Average Symbol-Error Probability
FHP	Frequent Heavy Shadowing
ASER	Average Symbol Error Rate

CHAPTER 1
INTRODUCTION

1.1 Satellite Communication Overview:

Satellite communication is a wireless technology that utilizes man-made satellites orbiting Earth to send and receive various types of data, like voice, video, and other forms of communication, across long distances. It's a crucial part of global telecommunications, serving many industries and applications. This technology relies on networks of either geostationary satellites, which stay fixed over one spot on Earth, or low Earth orbit (LEO) satellites that move quickly and require constellations for continuous coverage.

This system involves sending signals between ground stations, called Earth stations or ground terminals, and satellites in space. These signals can carry voice, data, internet traffic, TV broadcasts, and more. It allows for two-way communication: users send signals from their ground terminals to satellites, which then relay them to the intended destination, be it another ground station or a different satellite. One major benefit of satellite communication is its ability to reach remote or underserved areas, like rural or maritime regions, where traditional infrastructure isn't feasible or accessible.

Satellite communication serves various purposes, facilitating long-distance telephone and internet services, including global internet connectivity and international calls. Providers of satellite TV utilize geostationary satellites to broadcast television channels worldwide. Navigation systems such as Global Navigation Satellite Systems (GNSS), including GPS, rely on satellite communication to furnish precise positioning and timing information. Additionally, satellites play a pivotal role in gathering weather data and relaying it to Earth for meteorological applications. Earth-observing satellites capture imagery and data essential for environmental monitoring, disaster management, and agricultural purposes.

Despite its advantages, satellite communication encounters challenges associated with signal latency stemming from the considerable distance between Earth and satellites, signal interference, spectrum allocation, and the expenses related to satellite deployment and upkeep.

The domain of satellite communication undergoes continuous evolution, driven by technological advancements. These advancements include the deployment of low Earth orbit (LEO) and medium Earth orbit (MEO) constellations, which promise reduced latency and heightened capacity, contributing to the ongoing transformation in satellite technology.

Satellite communication is a vital technology that connects the world, providing essential services for communication, navigation, broadcasting, and data collection across vast distances and in areas where traditional terrestrial infrastructure is limited.

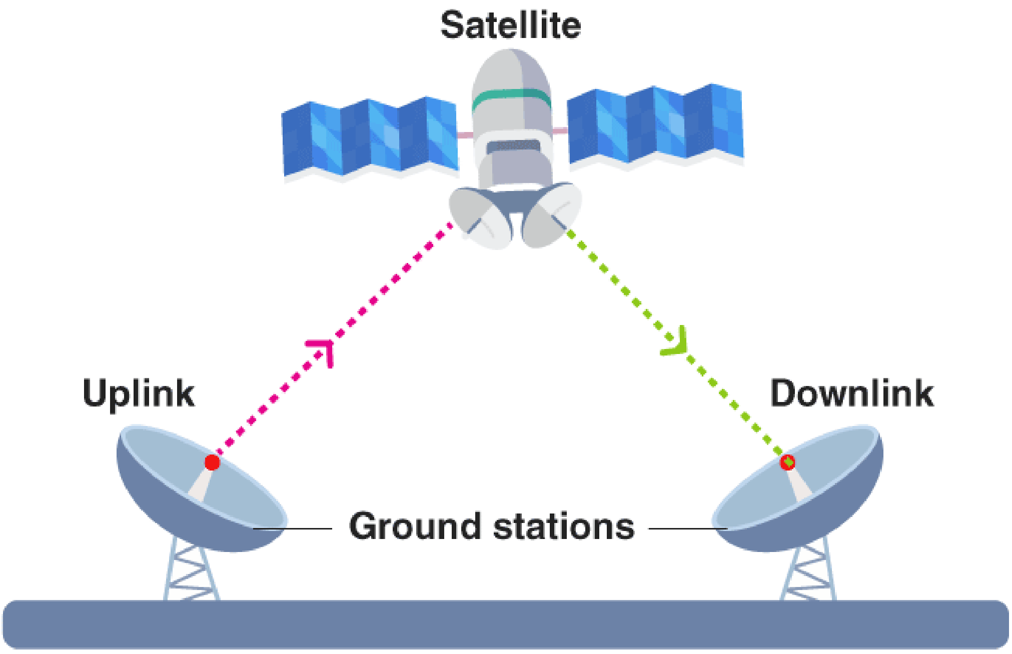

Figure 1.1: Satellite Communication

1.2 Hybrid Satellite Terrestrial Relay Networks (HSTRN) Overview:

A hybrid satellite-terrestrial relay network, or HSTRN, is a type of communication infrastructure that combines terrestrial and satellite relay technologies to offer connection to a range of locations, including underserved and distant areas. In order to provide a more reliable and adaptable communication solution, this hybrid method seeks to capitalize on the advantages of both satellite and terrestrial networks.

The network typically includes a satellite uplink, which is responsible for transmitting data from a ground station to a satellite in orbit. This satellite can be in geostationary orbit (GEO) or part of a low Earth orbit (LEO) constellation, depending on the specific network design. Users located in areas with limited terrestrial infrastructure receive signals from the satellite. They use satellite dishes or other receiving equipment to access the network.

In addition to satellite connectivity, HSTRNs incorporate terrestrial relay nodes or base stations that are strategically positioned across the service area. These relay nodes can be part of existing cellular networks, Wi-Fi networks, or dedicated relay stations. Users within the coverage area of these terrestrial relay nodes can connect to the network using standard wireless devices such as smartphones, tablets, or laptops. HSTRNs are designed to facilitate seamless handover between satellite and terrestrial modes as users move within the network's coverage area. This ensures uninterrupted connectivity, even as users transition between satellite and terrestrial coverage zones.

Rural Connectivity: HSTRNs are particularly valuable for extending connectivity to rural and remote areas where building extensive terrestrial infrastructure is challenging or cost prohibitive. They help bridge the digital divide by offering internet access, voice services, and other telecommunications capabilities to underserved communities. In emergency situations and disaster recovery efforts, HSTRNs can play a critical role in maintaining communication when traditional networks may be disrupted or overloaded. HSTRNs are used to provide connectivity in maritime environments, on airplanes, and in other transportation sectors where reliable communication is essential.

Because of the signal's orbital trip to and from the satellite, satellite communication adds extra latency. Real-time applications such as video conferencing and online gaming may be impacted by this. Even if developments in satellite technology, such LEO constellations, are meant to cut costs, deploying and maintaining satellite infrastructure can be costly. There may be bandwidth limitations during periods of high demand on satellite systems due to their limited capacity that is shared by numerous users.

HSTRNs can be made more flexible and efficient by integrating cutting-edge technologies like Network Function Virtualization (NFV) and Software-Defined Networking (SDN). In order to provide a dependable method of communication and internet access to places that might otherwise remain underserved or disconnected, HSTRNs are a flexible solution that addresses connection difficulties in a variety of contexts. The quality of life, employment prospects, and emergency response capacities in rural and isolated areas can all be greatly enhanced by their implementation.

1.3 Relay Network:

In addition to the significant propagation delay, complex link conditions can cause problems for satellite links. Since satellites travel through orbit at hundreds to thousands of kilometers per hour, the satellite communication link needs to pass through the atmosphere to get to the ground. Thus, meteorological conditions such as rain, clouds, fog, and water vapor can have an impact on satellite communication systems. For a band over 10 GHz, rain attenuation is the most significant component. In contrast to terrestrial systems, bad weather can cause extreme channel fading on satellite communications, which might cause a communication failure. Compared to terrestrial networks, it is more difficult to get timely and accurate channel state information due to the significant propagation delay of satellite communications. MEO/LEO satellite motion is fast compared to Earth's surface. As a result, the satellite-e-ground links experience faster time variations, larger phase shifts, and greater Doppler shifts. Without any decoding, a HSTRN signal. A DF relay has a far higher complexity than an AF relay because of its complete processing capability.

The DF protocol demands a sophisticated media access control layer, an element absent in the AF protocol. In essence, a DF relay approaches the complexity level of a base station. The pivotal question arises: does the performance gain achieved by the DF relay outweigh its intricate nature? Addressing this query partly involves quantifying the performance enhancement. However, consensus in the literature regarding the superior relaying protocol—AF or DF—remains elusive. While some studies favor the DF protocol, others advocate the opposite stance. Notably, numerical simulations have revealed that, in the context of uncoded BPSK modulation, AF multi-hop relaying outperforms DF concerning outage probability and bit error rate (BER). This discrepancy was attributed to the error propagation effect in DF relaying surpassing the noise amplification seen in AF relaying. Additionally, an analysis of maximum likelihood demodulation in coherent cooperative diversity for uncoded BPSK systems demonstrates that DF relaying, when employing more than one relay, sacrifices roughly half of the diversity offered by AF relaying.

In networks constrained by power limits, the Amplify-and-Forward (AF) cooperative strategy presents a direct solution. It involves relays amplifying the analog domain signal without requiring supplementary signal processing. Conversely, in settings without such limitations, the decode-and-forward (DF) technique emerges as a sophisticated cooperative strategy. Here, the received signal undergoes initial decoding, followed by additional signal processing at the relays to amplify the signal.

1.4 Motivation:

Using Terahertz (THz) channels between a relay and a multi-user destination in wireless communication systems presents several interesting applications and motivations. THz frequencies, which range from approximately 0.1 terahertz (THz) to 10 THz, offer unique advantages and capabilities that can be harnessed for specific use cases. THz channels can provide extremely high data rates due to their large available bandwidth. This makes them suitable for applications where massive data transfer is required, such as THz channels can support the streaming of ultra-high-definition and 3D video content with minimal latency, enhancing the quality of multimedia experiences. Virtual Reality (VR) and Augmented Reality (AR) applications demand high data rates for immersive experiences. THz channels can enable seamless, high-fidelity interactions in virtual worlds. In scenarios like cloud data centers or remote scientific research, THz links can facilitate rapid data transfers, improving efficiency. THz channels can serve multiple users simultaneously, making them valuable in situations where several users need high-speed communication.

In smart city environments, THz communication can support numerous devices and sensors, enabling efficient data collection, monitoring, and management. THz links can offer high-speed internet access to passengers on trains, buses, and airplanes, ensuring connectivity during travel. At large gatherings, concerts, or sports events, THz channels can handle the connectivity needs of a densely packed audience. Motivations. THz frequencies occupy a relatively uncongested portion of the electromagnetic spectrum. As lower-frequency bands become crowded, THz bands become more attractive for high-capacity wireless communication. THz signals have inherently short propagation ranges due to high atmospheric absorption. This short-range characteristic is advantageous for localized communication, reducing interference from neighboring networks. For real-time applications like gaming, industrial automation, and remote surgery, THz communication provides reduced latency, which is essential. THz signals are less likely to be intercepted because they are susceptible to interference from the surroundings. Wireless communications may become more private and secure as a result. The feasibility of THz communication for real-world applications has increased due to developments in THz transceiver technology, such as the creation of small and energy-efficient components. THz communication is being investigated as a basic technology to enable ultra-high-speed networks and the Internet of Things (IoT) as we move toward future generations of wireless networks (e.g., 6G and beyond).

1.5 Objective

the multiuser hybrid satellite terrestrial relay network's (HSTRN) coverage probability under opportunistic scheduling should be studied. High-quality services like the internet of things are accumulated via HSTRN-based networks for users on land. The relay amplifies the signal that is simulcast from the satellite and sends it to the terrestrial user with the highest instantaneous signal-to-noise ratio (SNR) on their specific channel. When analyzing Rician shadowing fading from source to relay, Multiuser Relay Network takes into account the THz link from relay to destination.

1.6 Applications

[1] Telecommunications: Enhancing wireless communication capabilities for remote and underserved areas where traditional infrastructure is limited or absent. Providing high-speed internet, voice services, and connectivity to rural regions.

[2] Emergency and Disaster Response: Facilitating reliable communication during emergencies or natural disasters when traditional networks might be disrupted. Quick deployment of communication networks for rescue operations.

[3] Transportation Sector: Offering robust communication for planes, ships, and other transportation modes, ensuring continuous connectivity even in remote areas or during transit.

[5] Healthcare and Telemedicine: Enabling high-bandwidth communication for telemedicine applications, facilitating remote diagnostics and consultations in underserved regions.
[6] Agriculture and Rural Development: Supporting smart agriculture by providing real-time data transfer for monitoring crops, weather conditions, and improving agricultural practices in remote areas.
[7] Research and Exploration: Supporting scientific research and space exploration by enabling high-speed communication between spacecraft, space stations, and ground control etc.

1.7 Thesis Organization

The document is presented in five chapters.

- Chapter 1: Introduction and overview of Satellite Communication. It includes theProblem Statement, objective of the thesis.
- Chapter 2: Explains the Fundamental concepts, Basic Principles of HSTRN.
- Chapter 3: Discuses the System model, Related Work, Outage probability andCoverage probability calculations for variable gain relaying in HSTRN.
- Chapter 4: Discuses the simulated results.
- Chapter 5: Concludes the thesis with a summary of the research done andrecommendation for future work, references.

CHAPTER 2
LITERATURE REVIEW

2.1 Literature Review

Research in THz communication has explored the potential of Fixed Gain AF relaying due to the unique characteristics of THz frequencies, such as a wide available bandwidth and relatively short propagation range. The literature discusses the design and optimization of Multi-User HSTRNs that leverage THz frequencies. These networks aim to combine the benefits of satellite and terrestrial relaying to serve multiple users efficiently. Studies highlight that Fixed Gain AF relaying in HSTRNs can enhance coverage and data rates in THz wireless systems, especially in areas with challenging line-of-sight conditions or obstacles. Efficient spectrum management and allocation strategies are crucial in THz wireless systems. Researchers are exploring techniques to allocate the THz spectrum dynamically based on user demand and channel conditions. To improve system capacity and reliability, researchers have investigated multi-user diversity techniques in THz HSTRNs. These techniques exploit the spatial and temporal diversity among users to enhance overall network performance. Accurate channel modeling and characterization for THz frequencies are essential for designing reliable HSTRNs. Researchers have developed channel models that consider atmospheric absorption and scattering effects.

In order to reduce signal attenuation, THz communication mostly relies on beamforming and precoding techniques. Advanced beamforming techniques are discussed in studies to improve signal delivery in multi-user environments. Research is concentrated on security and privacy issues since THz transmissions are sensitive to atmospheric conditions. We investigate secure transmission techniques in multi-user HSTRNs. Scholars recognize that THz communication poses regulatory problems related to spectrum allocation and licensing. For THz HSTRNs to be deployed in a practical manner, it is imperative that these issues be recognized and resolved. Certain research works investigate useful applications of Fixed Gain AF relaying in THz HSTRNs, such as the creation of THz transceiver hardware and real-world testbeds. Future research topics are frequently highlighted in the literature in this field at the end, including creating ways for adaptive relaying, enhancing energy efficiency, and incorporating THz communication into new technologies like 6G networks.

2.2 Outage Probability and Coverage Probability

Investigating outage probability is a critical aspect of wireless network research, entwined with factors like interference and transmission capacity. It's deeply tied to channel characteristics such as scheduling and power usage. Understanding outage probability and its limits helps establish the best contention density among channel-seeking nodes, following a predefined outage probability constraint. This then defines TC, representing area spectral efficiency from this optimized density.

This definition, stemming from outage probability analysis, holds immense value for understanding wireless ad hoc networks. Interference typically hampers performance in wireless networks. Outage and success probability, along with Signal-to-Interference-plus-Noise Ratio (SINR), are closely linked to interference. Hence, characterizing outage probability requires grasping interference intricacies. Analyzing interference involves studying network geometry (transmitting nodes' spatial distribution) and the path loss law governing signal attenuation over distance.

Interference is essentially the sum of identically and independently distributed random variables. Some distributions and attenuation laws offer closed-form expressions for interference and Signal-to-Interference Ratio (SIR), guiding network performance (Weber, S., 2005). In vast wireless networks, segregating concurrent transmissions in frequency isn't entirely feasible due to limited spectrum. Hence, some transmissions unavoidably overlap in time and frequency bands, though they're spatially separated. This results in undesired transmitter signals adding to desired ones at a receiver.

Outage probability (OP) and transmission capacity (TC) results highlight scenarios where interference pushes the Signal-to-Interference Ratio (SIR) below a threshold. While obtaining exact outage probability formulas via interference distribution isn't universally possible, bounding the Cumulative Distribution Function (CDF) of interference helps establish outage probability limits. Using Laplace transforms enables precise closed-form outage probability calculations for specific distributions, including Rayleigh fading in certain exponential distributions.

Poisson networks garner significant attention due to their analytical tractability, aided by Slyvniak's theorem, probability-generating function, and Laplace transform understanding. Our study employs an unconventional approach—multiplying path loss by a fading coefficient—contrary to most wireless network studies using path loss coefficients. This approach allows us to compute the Laplace transform of SIR and establish upper outage probability bounds. This section introduces new closed-form expressions for precise OPs amidst transceiver impairment.

$$P_{out}(x)=\Pr\{\gamma \leq x\}$$

$$P_c(x) = 1- P_{out}(x)$$

This is where γ represents the effective Signal-to-Noise and Distortion Ratio (SNDR) across the entire system.

CHAPTER 3
PROPOSED WORK

3.1 Basics Of HSTRN

The increasing demand for faster communication and higher data rates emphasizes the critical role of satellite communication capacity in upcoming communication systems. In indoor environments, weak mobile network signals often plague terrestrial users due to low satellite elevation, obstructed line of sight, or adverse environmental conditions. This not only impacts mobile network performance but also prompts exploration into various relaying techniques to bolster coverage and reliability.

A promising solution to this challenge lies in the hybrid satellite-terrestrial relay network (HSTRN), a practical system architecture significantly reducing signal interference. These hybrid networks efficiently deliver multimedia services while upholding quality-of-service standards for mobile users. The HSTRN architecture seamlessly integrates cooperative relaying methods with mobile satellite communication systems. Previous studies extensively examine HSTRN performance using Amplify and Forward and Decode and Forward relaying in single-user scenarios.

Amplify-and-forward (AF) relaying, among these methods, operates without the need to decode the source's message. It employs a bi-phase cooperation protocol where the source transmits the signal initially. Subsequently, the AF relay amplifies the received noisy and faded signal, selecting the high Signal-to-Noise Ratio (SNR) signal and transmitting it to the destination.

The evolution of HSTRN now extends to multi-user scenarios due to the growing demand for high throughput services for numerous terrestrial users. Multiuser HSTRN studies use opportunistic user scheduling to leverage multiuser diversity and mitigate fading through diversity schemes. Space diversity techniques like Fixed gain and Variable gain counteract fading and shadowing effects. Variable gain adjusts signal strengths from the satellite to achieve uniform gains, while fixed gain maintains a constant value for degraded signals from the satellite to the user.

Integrating the HSTRN model with terrestrial relays enhances efficient mobile communication alongside satellites. It facilitates broadcast/multicast services with extensive coverage, even in shadowed areas like shopping malls or tunnels, without disrupting portable terrestrial users.

This research investigates and analyzes the outage and coverage probability of a multi-user HSTRN employing amplified and forward-based methods. Specifically, the network includes one satellite, K dedicated relays, a direct-link user connected to the satellite, and a relay-aided user seeking assistance from K dedicated relays or the direct-link user to access satellite signals. Previous studies often overlook coverage probability analysis for this scenario, neglecting the focus on determining the system's coverage probability. This work addresses this gap by deriving an analytical formula for coverage probability using the Hypergeometric function.

3.2 System model:

The system setup involves a satellite (S), a dedicated relay (R), and multiple users (D). Within this multi-user relay network, the relay acts as an intermediary between the source and numerous receivers. We analyze the Rician shadowed fading between the source and the relay (SR) and the Terahertz (THz) link connecting the relay to the destination (RD). Our primary focus is on the amplify-and-forward (AF) relay approach, where the relay amplifies the signal received from the source and transmits it to the destination with the highest Signal-to-Noise Ratio (SNR). Specifically, a fixed-gain AF relay assists in establishing communication between the source and the destination.

The system's design ensures wide-ranging radio access from the source to the relay via radio frequency (RF) and establishes a fronthaul link from the relay to the destination using THz technology. To enable this, the relay integrates a frequency up-converter to generate THz signals from low-frequency RF. Notably, there's no direct connection between the source and destination because the THz and RF transmissions operate on distinct carrier frequencies.

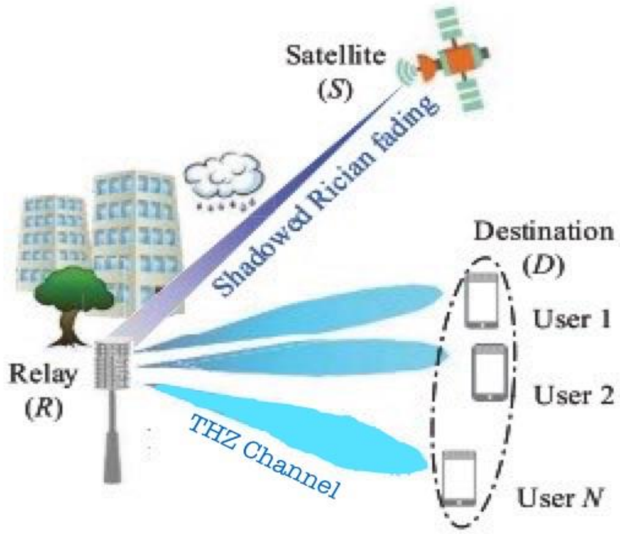

Figure 3.2: System model

Given the timestamp, in each time slot, we aim to attain the maximum user data rate while minimizing noise. Consequently, the reception at the Kth user is expressed as follows.

$$Y_{D,k}(t) = G\sqrt{P_S}\, h_{RD,k} Y_R(t) + n_{RD,k}(t)$$

Where,

P_S represents the relay's transmit power,

$h_{RD,k}$ is the channel coefficient of the terrestrial link connecting the relay to the Kth user,

$n_{RD,k}(t)$ is the RD variance σ^2_{RD} and zero mean AWGN noise.

for the relay with variable gain, the end-to-end SNR at K_{th} user γ_D is given by

$$\gamma_D = \frac{\gamma_{SR}\gamma_{RD}}{\gamma_{SR}+\gamma_{RD}}$$

Here we are using Amplify and forward – THz Technique with Variable gain – Single destination and Satellite – Relay is Rician shadowed fading, Relay-Destination is Rayleight+THz fading.

Given the assumption that the Shadow-Rician (SR) fading is followed by the S-R link, the probability density function (PDF) γ_{SR} of is provided as

$$f_{\gamma_{SR}}(x) = \frac{m^m}{c_r(k+m)_r^m \bar{\gamma}_r} exp\left(-\frac{1}{c}\left(\frac{x}{\bar{\gamma}_r}\right)\right) F_1\left(m, 1; \frac{k}{c(k+m)}\left(\frac{x}{\bar{\gamma}_r}\right)\right)$$

$$f_{\gamma_{SR}}(x) = \frac{m^m}{c_r(k+m)_r^m \bar{\gamma}_r} exp\left(-\frac{1}{c}\left(\frac{x}{\bar{\gamma}_r}\right)\right) \sum_{l=0}^{\infty} \frac{\Gamma(a+l)\Gamma(b) z^l}{\Gamma(a)\Gamma(b+l)\, l!}$$

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$$f_{\gamma_{SR}}(x) = \sum_{l=0}^{\infty} \frac{w_{SR,l}\ exp\left(-c_{SR}x\right) x^l\, c_{SR}^{l+1}}{l!}$$

$$c_{SR} = \frac{1+k_{SR}}{\bar{\gamma}_{SR}}, \quad w_{SR,l} = \frac{\Gamma\left(m_{SR}+l\right)\ k_{SR}^L\, m_{SR}^{\ m_{SR}}}{\left(k_{SR}+m_{SR}\right)^{l+m_{SR}} \Gamma\left(m_{SR}\right)\ l!}, \quad \bar{\gamma}_{SR} = \frac{\rho_s}{\sigma_R^2}$$

Where,

- $\{K_r, m_r\}$ the parameters for fading,
- ${}_1F_1$ is the hypergeometric function that confluences.

The Cumulative Distribution function(CDF) of the S-R link is defined as,

$$F_{\Upsilon_{SR}}(x)=\frac{m_{SR}^{m_{SR}}\left(1+K_{SR}\right)}{\left(K_{SR}+m_{SR}\right)^{m_{SR}}}\left(\frac{x}{\overline{\Upsilon_{SR}}}\right)\Phi_2\left(1-m_{SR},m_{SR},2,-\frac{\left(1+K_{SR}\right)x}{\overline{\Upsilon_{SR}}},-\frac{\left(1+K_{SR}\right)m_{SR}x}{\overline{\Upsilon_{SR}}\left(K_{SR}+m_{SR}\right)}\right)$$

Expanding Φ_2,

$$F_{\Upsilon_{SR}}(x)=\frac{m_{SR}^{m_{SR}}\left(1+K_{SR}\right)}{\left(K_{SR}+m_{SR}\right)^{m_{SR}}\overline{\Upsilon_{SR}}}\sum_{p,q}^{\infty}\frac{(1-m)_p\,(m)_q}{(2)_{p+q}}\left(-\frac{1+K}{\overline{\Upsilon_{SR}}}\right)^{p+q}\frac{\left(\frac{m}{K+m}\right)^q}{p!q!}x^{p+q+1}$$

The Probability Density Function (PDF) γ_{RD} is provided as follows, assuming that the R-D link experiences Rayleigh plus THZ fading.

$$f_{\Upsilon_{RD}}(x)=x^{-1+\frac{\Upsilon_D^2}{2}}\Gamma\left(1-\frac{\Upsilon_D^2}{2},\frac{x\lambda_D\sigma_D^2}{A_{0D}^2P_R}\right)$$

3.3 Coverage probability for variable gain relaying

Now that we've derived the closed-form formula for the coverage probability within the HSTRN model employing variable gain, we can determine the coverage probability for a relay operating with variable gain.

The probability of the Signal-to-Noise Ratio (SNR) falling below a specific threshold is termed as the coverage probability. In the context of variable gain, the outage probability is expressed as,

$$P\left(\frac{\Upsilon_{SR}\Upsilon_{RD}}{\Upsilon_{SR}+\Upsilon_{RD}}\leq T\right)=P\left(\Upsilon_{SR}\leq\frac{\Upsilon_{RD}T}{\Upsilon_{RD}-T}\right)$$

$$P\left(\Upsilon_{SR}\leq\frac{\Upsilon_{RD}T}{\Upsilon_{RD}-T}\right)=\int_T^{\infty}F_{\Upsilon_{SR}}\left(\frac{Tx}{x-T}\right)f_{\Upsilon_{RD}}(x)\,dx$$

So Variable gain, coverage probability is,

i.e.

$$Pc = 1 - P\left(\gamma_D \le T\right)$$

$$Pc = 1 - P\left(\frac{\gamma_{SR}\gamma_{RD}}{\gamma_{SR} + \gamma_{RD}} \le T\right)$$

$$Pc = 1 - P\left(\gamma_{SR} \le \frac{T\gamma_{RD}}{\gamma_{RD} - T}\right)$$

$$Pc = 1 - \int_T^{\infty} F_{\gamma_{SR}}\left[\frac{Tx}{x - T}\right] f_{\gamma_{RD}}(x)\, dx$$

Substituting value of fγRD (x) and FγSR(x) we get,

This integration process will result in the equation for the coverage probability associated with variable gain. In this context, the integration is performed concerning x, representing γRD.

$$Pc = 1 - \int_T^{\infty} \frac{m_{SR}^{m_{SR}}\left(1 + K_{SR}\right)}{\left(K_{SR} + m_{SR}\right)^{m_{SR}}\overline{\Upsilon}_{SR}} \sum_{p,q}^{\infty} \frac{(1-m)_p (m)_q}{(2)_{p+q}} \left(-\frac{1+K}{\overline{\Upsilon}_{SR}}\right)^{p+q} \frac{\left(\frac{m}{K+m}\right)^q}{p!q!} x^{p+q+1} \left[\frac{Tx}{x-T}\right] x^{-1+\frac{\Upsilon_D^2}{2}} \Gamma\left(1 - \frac{\Upsilon_D^2}{2}, \frac{x\lambda_D \sigma_D^2}{A_{0D}^2 P_R}\right) dx$$

This concludes the proof.

CHAPTER 4

SIMULATION RESULTS

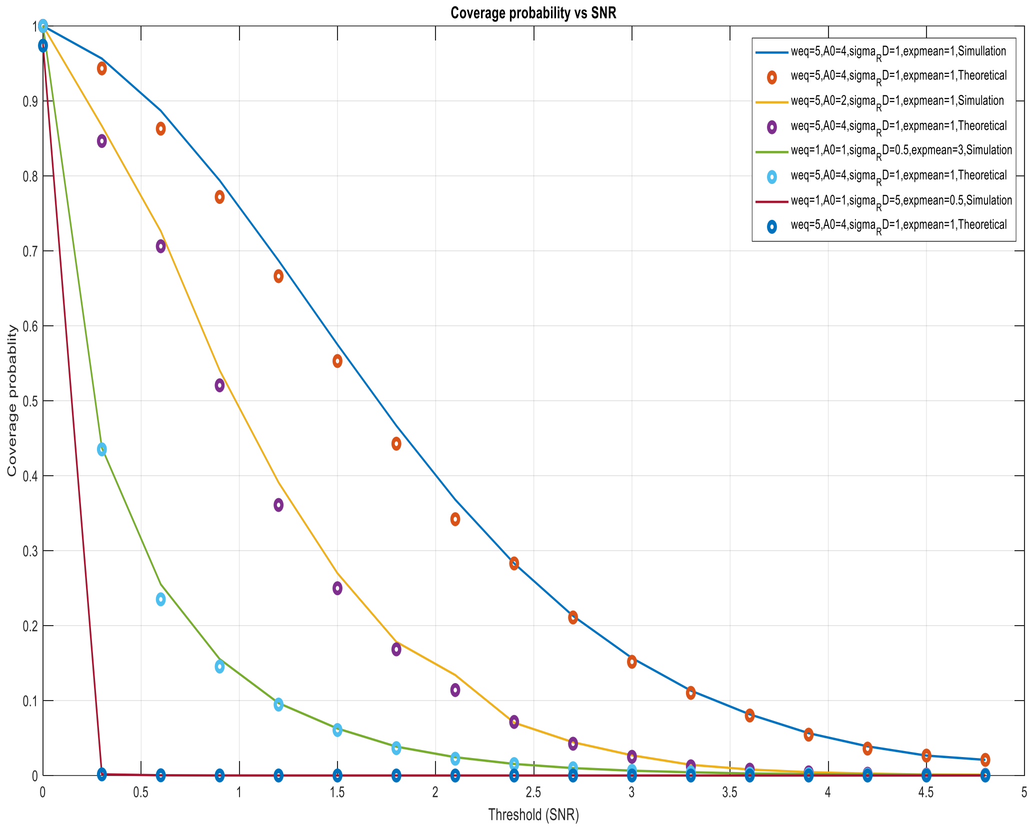

Figure 3.3a: Comparing the coverage probability when the Rayleigh THZ parameters Weq and A0 are changed.

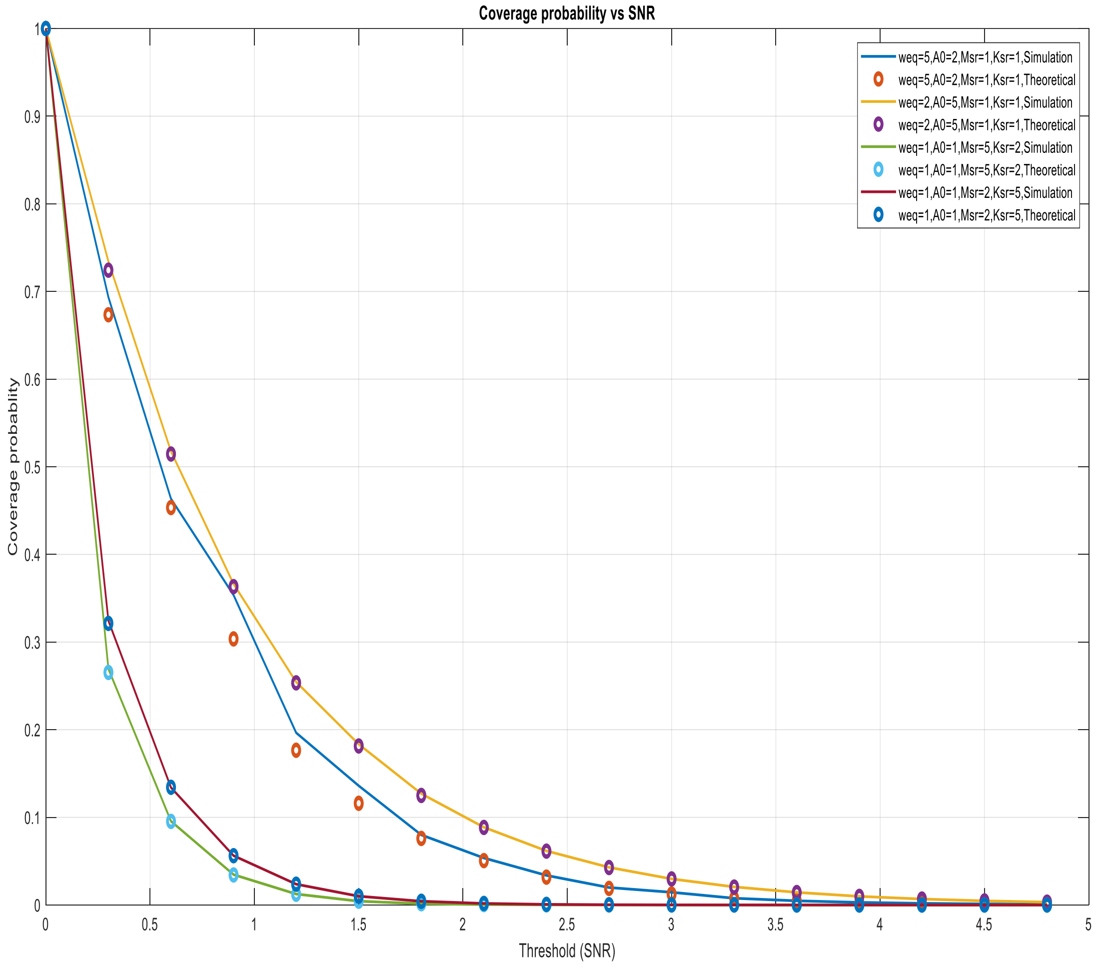

Figure 3.3b: Comparing Coverage Probability as the fading parameters, Msr and Ksr, are changed.

CHAPTER 5
CONCLUSION

5.1 Conclusion

The HSTRN model THZ wireless system coverage probability will be investigated for a range of SNR values in this study. Our consideration of T (SNR Threshold) pertains to variable gain, which ranges from 0 to 5. By adjusting the instantaneous SNR (γD), we will be able to see how shadowing and Rician fading affect the THZ channel or THZ link. The coverage probability plot is explained for different SNR values in Figures 1 and 2. The results of the simulation and the analysis are roughly in agreement. We can infer from the graphic that the variable gain has a higher likelihood of matching the threshold values in terms of coverage. The coverage probability for changing fading parameters (Msr, Ksr, Weq, and A0) is also plotted in this figure. Because of the shadowing effect, there will be a lower chance of system coverage.

In this Chapter, we conclude the work done. We discussed following things,

- We investigated the performance of HSTRN, a promising communication architecture that has the potential to increase service coverage and significantly lessen the effects of shadow fading in future wireless communications.
- We also studied analytical expressions Coverage probabilityto evaluate the behavior of the HSTRN.
- Studied about how relay network works in Hybrid satellite terrestrial network (HSTRN) and how Amplify and Forward (AF) and relaying network works.
- Simulation results have been plotted between SNR and Coverage probability and this gives insight about how outage and coverage probabilities will change with SNR.

5.2 FUTURE SCOPE:

Continued advancement in Terahertz wireless systems, improving data rates, reliability, and minimizing interference to make it more viable for practical applications. Integration of artificial intelligence algorithms to optimize resource allocation, relay node placement, and adaptive networking strategies for improved network performance. Focus on developing robust security protocols for Terahertz wireless systems to safeguard data transmission and ensure user privacy. Integration with the Internet of Things (IoT) for diverse applications like smart cities, environmental monitoring, and industrial automation, leveraging the high bandwidth and connectivity offered by Terahertz systems. Synergies with 5G networks and future-generation communication technologies to create hybrid networks that provide seamless connectivity across different frequency bands.

Developing industry standards and commercializing technology for widespread adoption in various sectors, contributing to economic development and global connectivity. Continued research and development in this area holds immense potential for transforming communication networks, improving connectivity in remote areas, advancing technological capabilities, and addressing various societal challenges across the globe.

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