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# Performance Evaluation for RIS-enabled THz Communications

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Capstone Project Final Report  
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**Abstract:**

The terahertz (THz) frequency band is attractive for the development of high data rate, large capacity, and low latency sixth generation (6G) wireless communications. A possible solution to the issues of excessive propagation losses in the THz band is the incorporation of reconfigurable intelligent surfaces (RISs), which are able to sensibly adjust the reflecting elements and improve the received power strength in the network. Moreover, different multiple access techniques can be considered to effectively allocate the power and spectrum resources among the users. Therefore, this work evaluates the performance of a RIS-aided Non Orthogonal Multiple Access (NOMA) THz system model with multiple users. The network resource allocation schemes are compared in terms of the Sum Rate maximization and different RIS deployment scenarios are discussed. The simulation results confirm the analytical derivations and present the RIS-THz link performance in various conditions.

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# Preface

I am sincerely grateful to my research supervisors Dr. Galymzhan Nauryzbayev and Dr. Mohd Hamza Naim Shaikh.

Nazarbayev University, April 26, 2024

# Chapter 1

## Introduction

The project is aimed to characterize a channel model to enable communication at the terahertz frequency band and evaluate the performance of such system. The analysis of the signals operating at high spectrum range requires to consider the amplitude fading, the factors of antenna gains, the transceiver hardware imperfections, issues of propagation losses, and the environmental conditions of the medium [1].

One of the technologies that can tackle the propagation loss issues is the reconfigurable intelligent surfaces (RISs) which are sensible and adjustable reflecting elements that can improve the transmission performance and energy efficiency [2]. A network with the RIS will be highly efficient in terms of performance – the attenuation issue is expected to be covered by estimating a virtual line-of-sight (LOS) path. As RIS-assisted networks are being studied, there is a demand for an accurate representation and analysis of the transmission systems.

Moreover, there are various strategies of providing user fairness in the network. Therefore, different multiple access techniques that can be applied for the project objectives have been studied. Resource allocation schemes are analyzed based on the principles of Orthogonal Multiple Access (OMA), NOMA and other RIS elements partitioning methods. Their effectiveness is compared in terms of the system sum rate, which is one of important performance metrics for user experience enhancement in future wireless networks.

One of the various fading channels being proposed to analyze the communication is an  $\alpha - \mu$  distributed fading. Using the  $\alpha - \mu$  fading model, we can accurately simulate the channel, capturing the multipath and shadowing effects. The review of recent findings in the area and software simulations are used in the project to investigate the topic and analyze the results.

## 1.1 Background and related works

The anticipated launch of the 6G wireless communication systems demands an advanced technology to support the new services. Future systems are expected to have features such as high data rate, robustness, scalability and low latency. The disruptive improvements of 6G will integrate the sensing, computing, control and communication in various spheres of human life. The technological advance will enable breakthroughs in the Internet of Things, artificial intelligence, cloud computing, big data and more [3]. In the research community, terahertz systems are called one of the most important enablers of 6G communication [4]. Utilizing the THz frequency band for cellular communications is to provide the required capacity and be the step to achieve transmission with great bandwidth.

The ultra-wide THz frequency band offers the required bandwidth resources, as well as enhanced capacity of the wireless systems. The symbol duration is expected to be at a picosecond-level, contiguous bandwidth at hundreds of gigahertz, and thousands of sub-millimeter-long antennas can be integrated to work, adjusted with the existing spectrum systems [5]. The analysis of the THz signals amplitude fading has to include the factors of antenna gains, the transceiver hardware imperfections, the transmission distance, operating frequency, and the environmental conditions including temperature, humidity, and pressure [6]. Another factor affecting the signal propagation is the molecular absorption loss, which however has a smaller impact on the system performance, compared to the propagation losses [7]. Different obstacles on the signal path have their effects on the signal intensity and propagation, and even the positioning of the same plane obstacle has various attenuation at the THz band [8]. Studying the THz propagation phenomena, authors in [9] describe the unique characteristics of the propagation models, free space path loss (FSPL), atmospheric absorption, and rain and snow attenuation as well.

To address the issues, a reconfigurable intelligent surface technology can be proposed. RIS is a composition of numerous reflective units, each of which is composed of electronic components that can passively reflect the incident waves. The reflection amplitude and phase are adjusted by a RIS control unit that manages the beam-forming. A network with a RIS will be highly efficient in terms of performance – the attenuation issue is expected to be covered by estimating the LoS path and using it for THz wireless communication [10]. The simulations suggest that the quality of the received signal and the channel capacity can be improved via RIS assistance in the target areas [3]. The communication systems will be able to adjust the propagation medium in real time, reflect the signal and lower the energy requirements. Such implementation of the RIS is a solution to many challenges of the wireless communications and sensing, once the optimization and analysis problems of the technology are realized [11].

In terms of deployment, RISs provide several attributes that make them a promising solution for THz communication systems. Firstly, they can operate across a broad spectrum of frequencies due to the reconfigurable nature [12]. This guarantees a comprehensive full-band response within THz networks. Secondly, the lightweight architecture allows a seamless hardware deployment both indoor and outdoor. Moreover, a reduction in thermal noise and energy consumption of the passive RISs makes them a compelling choice for efficient and adaptive THz communications.

As RIS-assisted systems are being studied, there is a demand for an accurate representation of the transmission. One of the various fading channels being proposed to analyze the communication is a stochastic approach [13], following which authors characterize the cascaded channel by  $\alpha - \mu$  fading and conclude that a cascaded link can outperform a direct THz channel by the outage probability (OP). The Gaussian, Rician, Nakagami-m, and fluctuating two-ray (FTR) distributions are discussed in [7], stating that the best fit among the chosen fadings is given by FTR, which allows for the reflective waves of a LoS propagation to fluctuate randomly. Therefore, investigations of the RIS-aided THz communications propose different channel models for the small-scale fading of the signal. Sets of experimental measurements results are fitted to multiple distributions to compare the small-signal fading, favoring the FTR distribution model [7]. However, the  $\alpha - \mu$  fading, that is not considered in that analysis, stands out to be well suitable as per other measurements and experimental results [14]. The method of moment generating function (MGF) is used in [10] to derive the closed-form expressions of distribution functions and study the combined effect of  $\alpha - \mu$  fading with pointing errors, while [15] also evaluates the effect of the hardware imperfections.

The current analysis of performance of the THz wireless transmissions attempts to find an approach to employ an exact characterization of multiple channel impairments in the link [16]. However, there are different approximations on the upper bound of the ergodic capacity, average signal-to-noise ratio (SNR) and average bit-error-rate (BER) performance with the impairments in the network [17], [18]. Another important consideration is the knowledge of channel phase shifts at the RIS. In current works, the random phase information is not always considered or correlated to the fading at the RIS elements [10]. The misalignment between the RIS and the destination at the THz link leads to random pointing errors that also need to be considered [19]. Authors in [20] provide an extensive literature review of the beam management technologies for RIS, highlighting the challenges of the THz systems. Other works with a focus on the accurate approximation of the channel distribution of cascaded RIS-aided networks show that the system models of cascaded RIS are sufficiently practical in dense urban areas, to bypass the obstacles [21].

Furthermore, the use of a cascaded distribution model is beneficial for the

opportunity to support a multiple access network. Namely, a direction of Non-orthogonal multiple access (NOMA) communications proposes a variety of techniques for such a system. Recent papers on the topic discuss the use of NOMA technology for RIS-assisted THz networks, stating that the performance enhancement is expected, but high processing complexity is one of the challenges connected to it [22]. The authors in [23] mention the tasks of bands allocation and user pairing in a THz-NOMA system and investigate the problem of sum rate maximization. On the top of this, the presense of phase shifts and beam misalignment should also be considered and adjusted to the particularity of the system. The performance analysis of THz-NOMA communication is currently under a research, and there are different transmission schemes that include the design of random errors, for example cognitive radio inspired NOMA in [24]. Additionally, the authors in [25] compared the OP and throughput of NOMA to that of the Rate-Splitting Multiple-Access (RSMA), concluding that RSMA can be better for some multi-user scenarios. Recent studies in [26] show the outage performance analysis comparing the indoor THz-based NOMA and OMA systems within different models. The authors in [27] illustrate that NOMA outperforms the conventional OMA approach in terms of user equipments' OPs. The full advantages of THz-NOMA can be realized only through optimizations and efficient signal processing implemented at both system and link levels.

The optimization problem of RIS deployment have been studied based on the knowledge of the user equipment locations in [28]. The authors in [29] consider a user priority-based resource assignment scheme and show that the performance of prioritized users improves significantly with an increase of allocated RIS elements. In [30], a cognitive radio-inspired NOMA is used to ensure cooperative use of the spectrum between the so-called primary and secondary users. In contrast, [31] proposes optimization algorithms with an initial approach of RIS serving a minimum Quality of Service (QoS) to all users, but without base station interference consideration. Low complexity resource allocation solutions are discussed in [32], highlighting that many current methods of RIS deployment involve high computational demands. Therefore, the authors provide comparison of latest algorithms in terms simulation time, however excluding the analysis of the increasing number of users in the system. Proper user clustering, coupled with power allocation, becomes a viable approach to uphold the user fairness and optimize resource utilization. For the Internet of Things (IoT) devices to be seamlessly interconnected in 6G networks, the spectrum allocation efficiency should be greatly improved. Multiple access schemes proposed can help to provide the required QoS, capacity maximization, and allocate resources in a way that minimizes the user interference [33].

The inherent combination of NOMA and RIS can unleash their full potential in the THz domain. As highlighted in [34], these technologies can complement

each other within wireless systems. While RIS enables control over the conditions necessary for NOMA realization, NOMA enhances the frequency efficiency and connectivity in RIS networks. Future 6G technology is also expected to support the autonomous vehicular RIS-assisted communications. In this application, it is crucial to consider the impact of the phase errors, as mentioned in [35], in the context of user mobility. Another important point to consider in the THz domain is the beam forming, which includes the beam blockage and squint effects. For example, the research in [36] highlights the lack of investigation into near- and far-field beam squint for large-scale antennas in RIS-aided THz networks in recent studies. The channel estimation problem in the presence of a near-field beam squint is approached using the machine learning techniques in [37].

The novelty of the analysis in this work is in the development of an efficient RIS elements allocation scheme that considers the propagation effects of the THz-NOMA channel and increases the achievable sum rate for multiuser uplink network. The channel model includes the effects of the molecular absorption losses, and an  $\alpha - \mu$  fading distribution. Future research includes an application of the machine learning techniques for THz applications, such as sensing mentioned in other works [38].

## 1.2 Motivation

Through the analysis of novel research and simulation of the fading channels, the accuracy of the THz channels representation is enhanced. Thus, the channel estimation can be improved, and better performance of communicating channel models for 6G technology can be found. Personal motivation is in the obtaining the professional skills in the field of communication that is important for my future career. The research of current works and inventions is an interesting part for my academic, professional and personal growth.

## 1.3 Beneficiaries

For the research area, this project presents efficient resource allocation schemes for further use in the RIS-enabled THz communications and their applications. The possible applications are not limited, and include the IoT applications, localization and sensing equipment, wireless 6G systems. The telecommunication sphere will benefit from advanced 6G and future technologies, from end-to-end users to the government applications and the surveillance companies. The enhanced capacity and bandwidth of the network are especially useful for the areas without internet coverage, or rural places. Thus, the project can also impact the national infrastructure.

## Chapter 2

# Methodology

### 2.1 Methods

The first research method is an analytical literature review that have helped to see the possible gaps and understand the area. To comprehensively assess the related works, the technical knowledge was gained through tutorial papers and latest journal articles and proceedings. A comparative analysis of the collected articles was done to observe the trends and possible inconsistencies. The insights gained from the literature review form the foundation for the following research and its methods. The novelty comparison of the literature on the topic of THz performance analysis is summarized in the Table 2.1.

The simulations were done using MATLAB and Wolfram Mathematica software. The programs were combined in use due to in-build possibilities differences between them. A list of required simulation parameters and variables was prepared from the literature review results, and the simulations have been updated throughout the research process.

Table 2.1: Novelty comparison of the THz literature

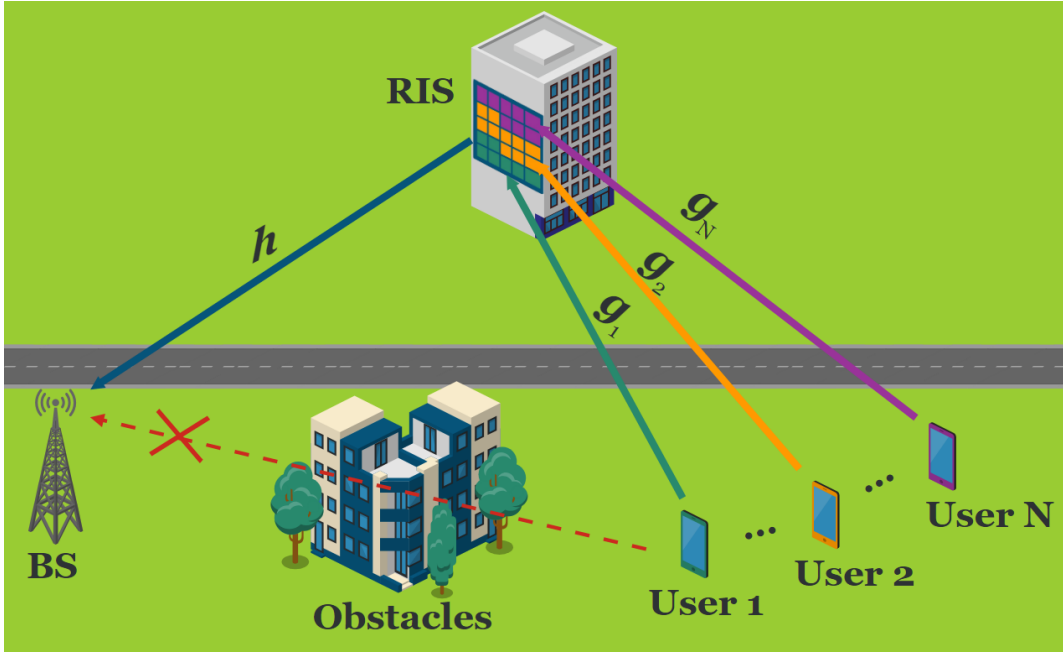
Paper	RIS	NOMA	Fading	Impairments	Performance metrics
[7]	✓	-	FTR	MA, PE, THI	OP, SNR, EC
[10]	✓	-	$\alpha$ - $\mu$	MA, PE, THI	OP, SNR, BER, EC
[13]	✓	-	$\alpha$ - $\mu$	MA, PS	OP, SNR
[15]	✓	-	$\alpha$ - $\mu$	MA, THI, PS	OP, SNR, EC, EE
[22]	✓	✓	Rician, Rayleigh	MA	OP, BER, Sum Rate
[25]	-	✓	-	MA	OP, SNR, Throughput
[26]	-	✓	-	MA	OP, SNR
[27]	✓	✓	Nakagami- $m$	MA, PE, PS	OP
[30]	-	✓	Rayleigh	PE	OP
[35]	✓	-	Generalized- $K$ , $\kappa$ - $\mu$ , dGG	PS, user mobility	OP, SNR, BER
[39]	✓	-	dGG	MA, PE, THI, PS, Turbulence	OP, SDNR
[40]	✓	-	dGG	MA, THI, Turbulence	OP, SDNR
[41]	✓	-	$\alpha$ - $\mu$	PS	SNR, Effective Rate
[42]	✓	-	$\alpha$ - $\mu$	MA, PE, PS	OP, EC
[43]	✓	-	$\alpha$ - $\mu$	MA, PE, PS	OP, SNR, BER
[44]	✓	-	Nakagami	PE, PS, Turbulence	SNR, EC
[45]	✓	-	$\kappa$ - $\mu$	MA, PE	OP, SNR, BER, EC
This project	✓	✓	$\alpha$ - $\mu$	MA	SINR, Sum Rate

In this table, dGG stands for double generalized Gamma distribution, FTR is fluctuating two-ray distribution, MA is molecular absorption, PE is pointing error, THI are transceiver hardware impairments, PS are phase shifts, OP is the outage probability, SDNR is signal-to-distortion-plus-noise ratio, SNR is signal-to-noise ratio, SINR is signal-to-interference-plus-noise ratio, BER is bit error rate, EC is ergodic capacity, EE is energy efficiency.

## 2.2 Theoretical Framework

Considered THz communication framework includes the path loss,  $\alpha - \mu$  fading and an uplink transmission from  $N$  multiple users to the base station (BS) through the RIS with  $M$  elements. As shown in Figure 2.1, a direct LoS THz signal will suffer from obstacles and propagation losses. Using the RIS, a new virtual LoS path is created, replacing the non-LoS transmission. The  $g_i$  and  $h$  are channel fading coefficients from  $i$ -th user to the RIS element and from RIS to the BS, respectively.

Multipath fading is modeled as an  $\alpha - \mu$  distribution, where random variables have a propagation medium non-linearity parameter  $\alpha$  and the multi-path components number parameter  $\mu$ . The parameter  $\mu > 0$  acquires values including non-integers, attributing to the correlation between the in-phase and quadrature of multi-path components in the signal [46].



**Figure 2.1:** System model for RIS-assisted THz communication network

The probability density function (PDF) of an  $\alpha - \mu$  random variable  $X$  is given as [16], [47]:

$$f_X(x) = \frac{\alpha \mu^\mu x^{\alpha\mu-1}}{r^{\alpha\mu} \Gamma(\mu)} \exp\left(-\mu \left(\frac{x}{r}\right)^\alpha\right), \quad (2.1)$$

where  $r = \sqrt[\alpha]{\mathbb{E}[R^\alpha]}$ ,  $\Gamma(z) = \int_0^\infty t^{z-1} \exp(-t) dt$  denotes the gamma function and  $\mathbb{E}[\cdot]$  is expectation operator.

The cumulative distribution function (CDF) of  $X$  given by [16], [47]:

$$F_X(x) = \frac{\gamma\left(\mu, \mu \left(\frac{x}{r}\right)^\alpha\right)}{\Gamma(\mu)}, \quad (2.2)$$

where  $\gamma(z, y) = \int_0^y t^{z-1} \exp(-t) dt$  is an incomplete gamma function.

The  $k$ -th moment of  $X$  is found by [47]:

$$E[X^k] = r^k \frac{\Gamma(\mu + k/\alpha)}{\mu^{k/\alpha} \Gamma(\mu)}, \quad (2.3)$$

It is assumed that all channels are quasi-static, flat fading and that a perfect channel state information is available at the transmitter. Let  $i = 1, 2, \dots, N$  denote the set of users. The users positions are modeled as uniformly distributed within a circular area of radius  $l$ , and the placements of RIS and BS are fixed. Hence,  $d_0$  represents the distance of RIS-to-BS, and  $d_i$  is the distance from  $i$ -th user to RIS.

The path gain coefficients are considered as [48], [49]:

$$\begin{aligned} H_0 &= \frac{c\sqrt{G_t G_r}}{4\pi f d_0} \exp(-0.5\rho d_0), \\ H_i &= \frac{c\sqrt{G_t G_r}}{4\pi f d_i} \exp(-0.5\rho d_i), \end{aligned} \quad (2.4)$$

where  $c$  is the speed of light,  $f$  is carrier frequency,  $G_t$  and  $G_r$  are antenna gains at Tx and Rx respectively, and  $\rho$  is a molecular absorption coefficient.

Thus, a total path gain for  $i$ -th link from user to the BS can be expressed as:

$$h_\ell^i = H_0 H_i, \quad (2.5)$$

The signal received from the THz links, taking into account the path loss, fading, and noise is expressed as:

$$y = \sum_{i=1}^N \left( h_\ell^i |h| |g_i| s_i \right) + n, \quad (2.6)$$

where  $s_i$  is the transmitted signal having a power of  $P$ , and  $n$  is the zero mean additive Gaussian noise with variance  $\sigma_n^2$ .

## 2.3 Performance Analysis

From Equation 2.3, the expectation of  $X$  can be found by setting  $k = 1$ . Using this value, the expectation for each links' parameters is known. Let  $\mathbb{E}[h]$  denote the expected fading gain of the channel  $h$ . Then, the total expected fading for  $i$ -th user-to-BS link is:

$$\mathcal{F}_i = \mathbb{E}[h]\mathbb{E}[g_i], \quad (2.7)$$

Introducing a parameter  $\gamma$  as an instantaneous SINR that can be calculated for each user's transmission:

$$\gamma_i = \frac{P_t}{P_n} h_\ell^i (\mathcal{F}_i M_i)^2, \quad (2.8)$$

where  $P_t$  is the transmit power of a signal,  $P_n$  is the power of noise, and  $M_i$  is the number of RIS elements assigned to this user (allocation schemes are discussed in the next section). The  $\gamma$  value incorporates the signal attenuation and number of RIS elements to accurately evaluate the SINR.

The received SINR at the destination is expressed as:

$$Y_i = \frac{\gamma_i}{\sum_{j=i+1}^N \gamma_j + 1}, \quad (2.9)$$

The Individual Rate for user  $N$  is defined as:

$$R_i = \log_2(1 + Y_i), \quad (2.10)$$

Then, the Sum Rate is:

$$R_{sum} = \sum_{i=1}^N R_i, \quad (2.11)$$

## 2.4 Elements Allocation Schemes

### 2.4.1 Equal element assignment scheme (EEAS)

The number of RIS elements can be evenly distributed among the users. The total number of RIS elements,  $M$ , is divided into the number of users in the system,  $N$ , to provide the amount of allocated elements to each user:

$$M_i = \frac{M}{N}, \quad (2.12)$$

This approach corresponds to the Jain's Fairness Index of 1 [50].

### 2.4.2 Distance-based element assignment scheme (DBEAS)

Alternatively, the number of RIS elements can be decided depending on the user-to-RIS distance.

- 1: **for**  $i = 1, 2, \dots, N$  **do**
- 2:     Calculate the user-to-RIS distance,  $d_i$
- 3:     Sort the distances  $d_i$  in ascending order
- 4:     Calculate the sum of all user-to-RIS distances:  $d_{sum} = \sum_{i=1}^N d_i$
- 5:     Allocate the number of RIS elements:  $M_i = \lceil \frac{d_i}{d_{sum}} \times M \rceil$
- 6: **end for**

This scheme allocates more elements to the users placed closest to the RIS, thus increasing the achievable capacity for those users.

### 2.4.3 OMA-based scheme (OMAS)

The OMA technique can be applied for elements assignment. The time division multiple access (TDMA) allocates all RIS elements to one user at a time period, providing  $M_i = M$ .

In case of the OMAS, the Equations 2.9 and 2.11 are evaluated differently. As every user transmits in a separate time slot and there is no interference,  $Y_i$  is directly equal to the value of  $\gamma_i$ , and the sum rate for the system is:

$$R_{sum} = \frac{\sum_{i=1}^N R_i}{N}, \quad (2.13)$$

### 2.4.4 Proposed element assignment scheme (PEAS)

In this scheme, the amount of allocated elements depends on the value of  $\gamma_{th}$ , which is set based on a value of a minimum rate threshold  $\gamma_{th} = 2^{R_{th}-1}$ . The relationship is expressed as follows:

$$M_i = \left\lceil \sqrt{\frac{\gamma_{th}^i (\gamma_{th}^i + 1)^{N-i}}{\frac{P_t}{P_n} h_\ell^i \mathcal{F}_i^2}} \right\rceil, \quad (2.14)$$

$$M_i = M - \sum_{\substack{j=1 \\ j \neq i}}^N M_j, \quad (2.15)$$

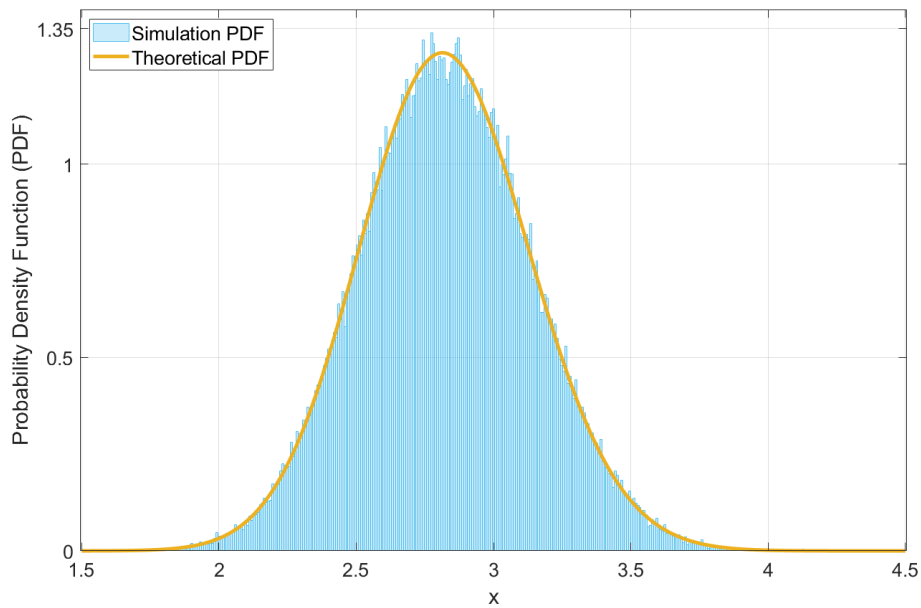
This approach provides each user with a minimum threshold SINR (QoS parameter), and considers the propagation parameters of each channel. This way, the users with the lowest expected fading and path loss acquire more elements and an achievable data rate of the system is increased. The PEAS is based on the NOMA technique, so all users share the same resources simultaneously.

## Chapter 3

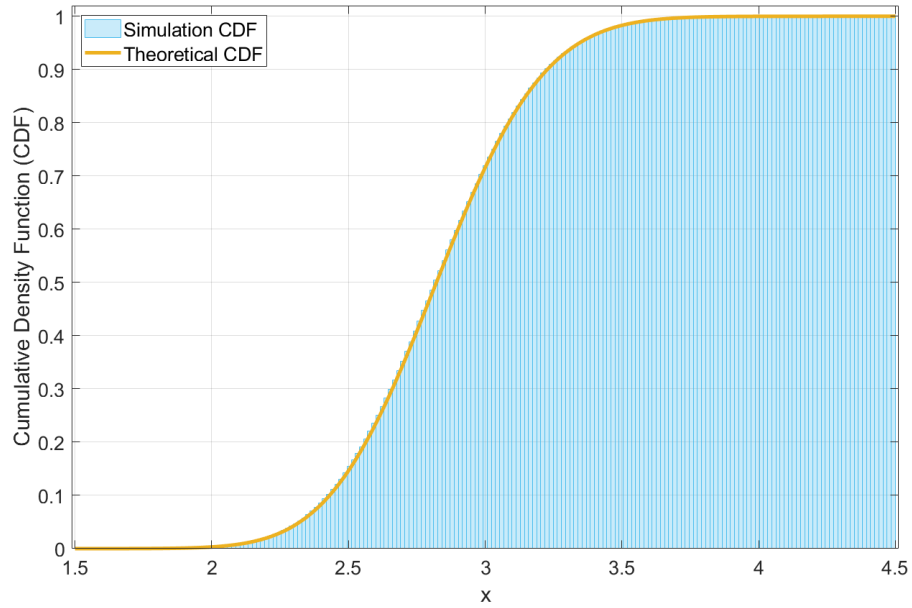
# Results and Discussion

### 3.1 Results

The plots for simulated and theoretical  $\alpha - \mu$  fading channels show the provided fit of this distribution to the obtained data. By comparing the simulated results with the theoretical predictions, the accuracy of the model for evaluating the performance and reliability of wireless communication systems operating in  $\alpha - \mu$  fading channels is shown.

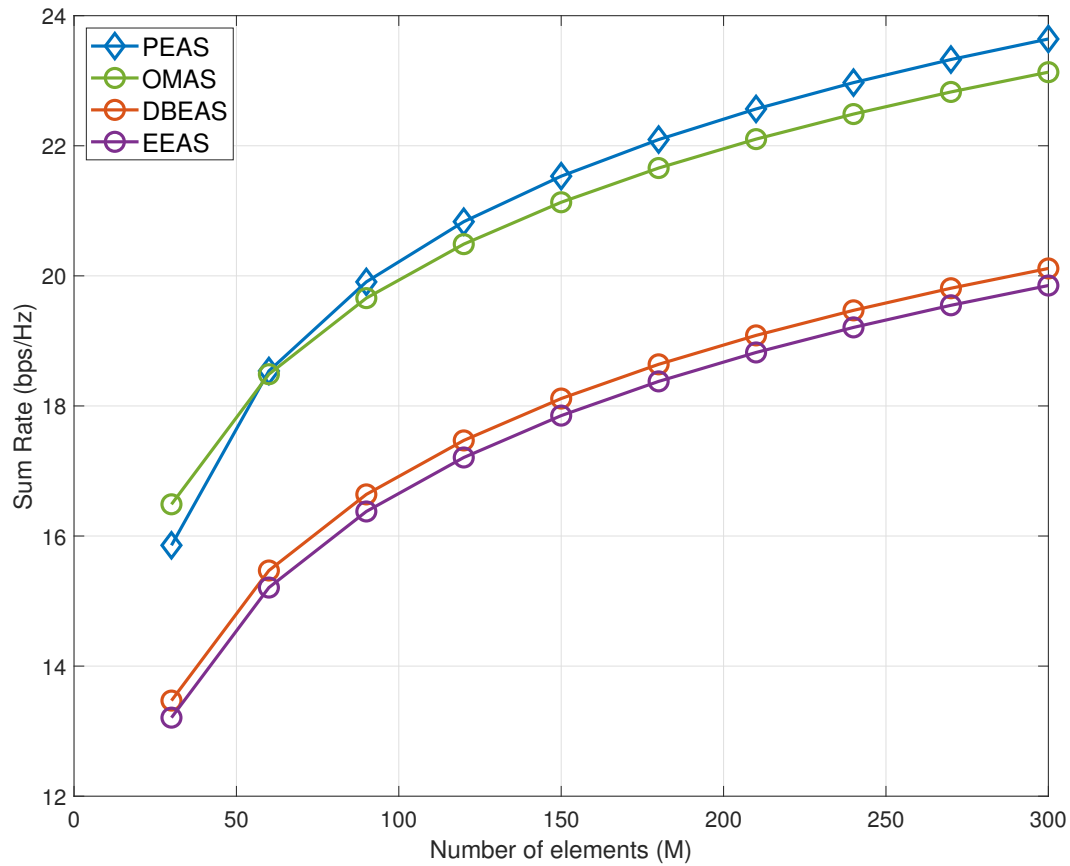


**Figure 3.1:** The PDF of  $\alpha - \mu$  fading channels for selected values of RIS elements.



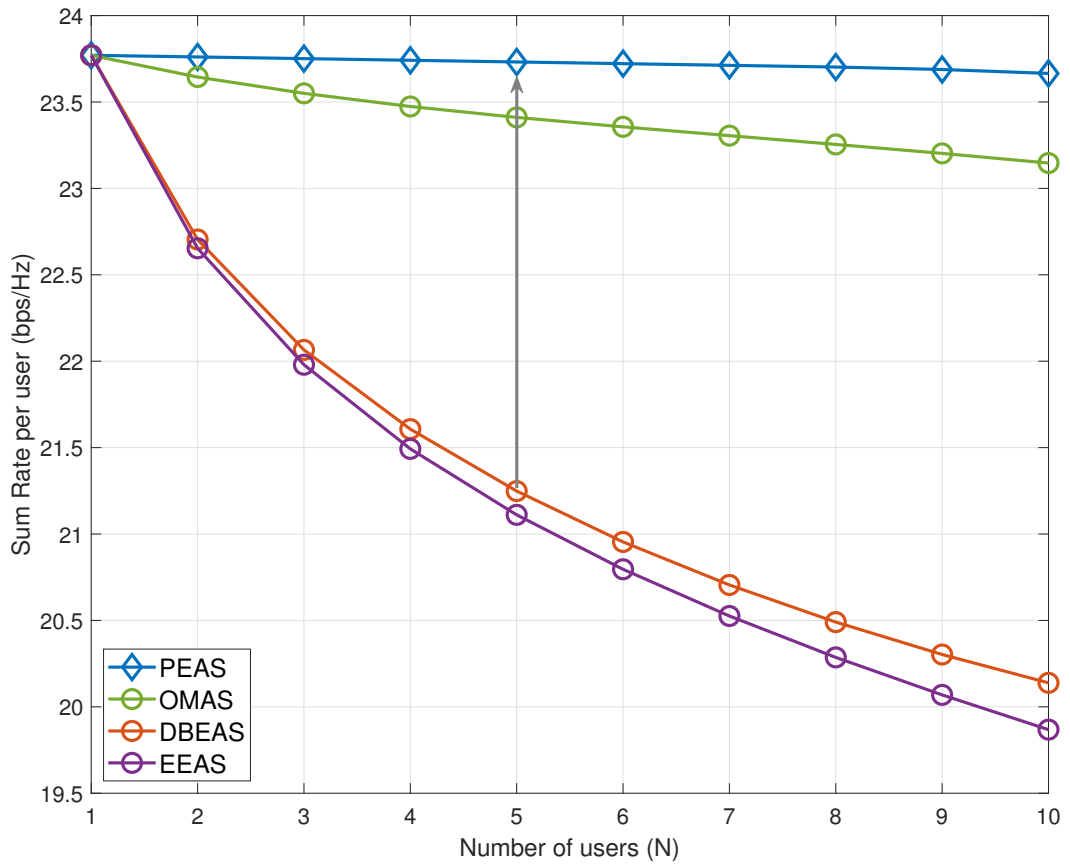
**Figure 3.2:** The CDF of  $\alpha - \mu$  fading channels for selected values of RIS elements.

Further, the results have been obtained through Monte Carlo simulations. For simulation purposes, the users are distributed within a circle with radius  $l = 30$  and the distance  $d_0$  is set to meters. All results are produced by averaging over 1000 iterations of randomly assigned user locations. It is assumed that the molecular absorption coefficient  $\rho = 3.18 \times 10^{-4}$  per meter,  $G_t$  and  $G_r$  are set to 20 dB, and carrier frequency  $f = 300$  GHz.  $P_t$  is set to 10 dBm in Fig. 3.3 and 3.4.



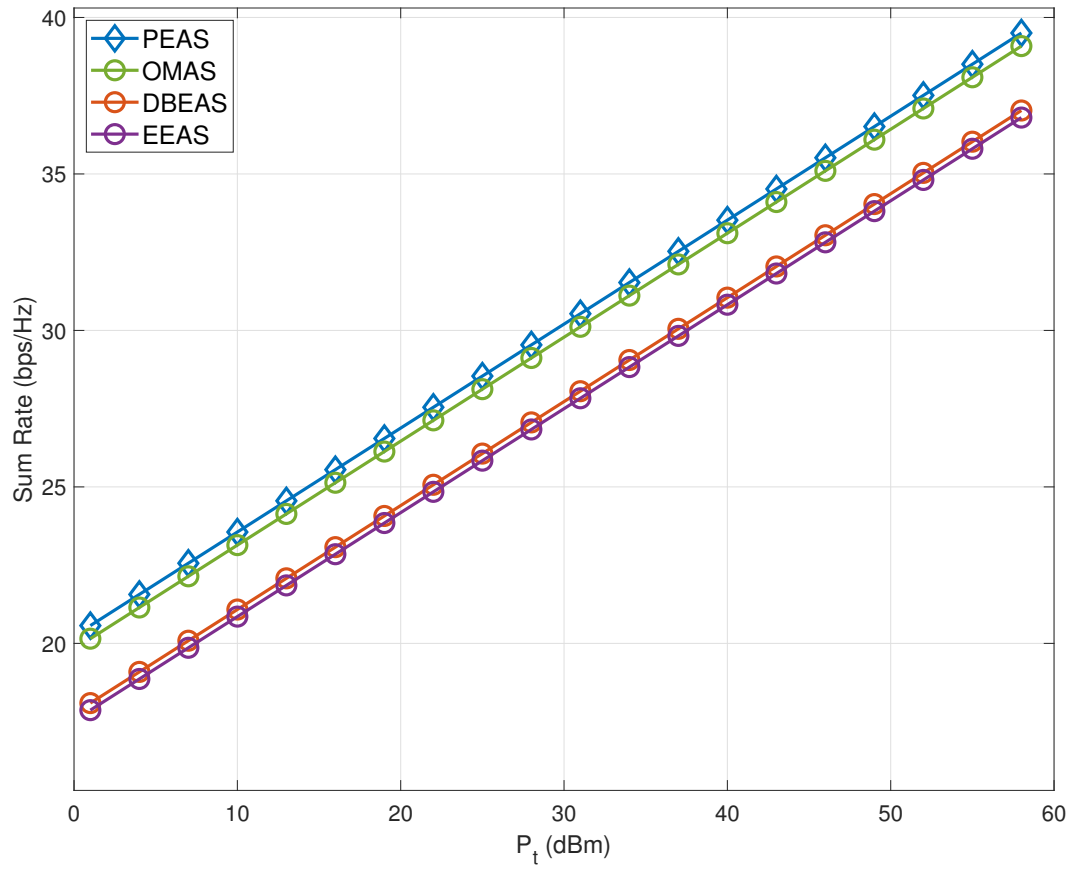
**Figure 3.3:** Sum Rate vs. the number of RIS elements for different schemes at  $N = 10$ .

From Fig. 3.3, it is seen how the sum rate increases with the number of RIS elements. Both the proposed scheme and OMAS perform better than the distance-based and equal element assignment schemes, as the achievable data rate is higher for these approaches. It is evident that the number of available RIS elements directly affects the performance of the RIS-THz network in all scenarios. This can be done using the effective resource allocation schemes, as well as physical use of larger RISs, or a system of cascaded RISs.



**Figure 3.4:** Sum Rate per user vs. the number of users for different schemes at  $M = 300$ .

Fig. 3.4 illustrates the Sum Rate per user with respect to the number of users and the values obtained using the proposed scheme outperform all other scenarios for multiple  $N$ . For a system with 5 users, the Sum Rate gain of the proposed scheme is 11.69% as compared to DBEAS, shown as a gray arrow in the figure. The OMAS-based scenario also provides a greater capacity compared to the DBEAS and EEAS, but the decrease persists as more users are introduced. There is a decrease in the case of a proposed scheme as well, but the number of RIS elements available to be assigned remains high even for larger systems.



**Figure 3.5:** Sum Rate vs. the transmit power for different schemes at  $N = 5$ .

Fig. 3.5 shows the results of the sum rate with respect to the transmit power in a system with 5 users. It can be observed that the proposed scheme and OMAS-based scenario provide the best rate and outperform rest of the schemes. The growth in all plots proceeds at a similar rate with the increase of  $P_t$  value. The number of users in the system does not significantly affect the pattern.

## 3.2 Discussion

This work investigated the Sum Rate of an uplink RIS-assisted THz multiuser network. The RIS element allocation scheme is proposed to enhance the transmission performance, and the simulation results were compared with other methods. Correspondingly, the SINR expressions were formulated considering the scheme accordingly. Numerical results illustrate the superiority of the proposed scheme in terms of data rate to introduce more users in the future networks. As it is seen, while OMA-based scheme provides a good result, the proposed scheme outperforms all other allocation schemes and presents an even better solution for networks of seamless connectivity.

For further investigation, systems of cascaded RISs configurations are considered. The results for PDF and CDF match the simulation outcomes, but the further step is to increase the number of RISs in the system and there is an opportunity to include more impairments in the channel model.

## Chapter 4

# Conclusion

In conclusion, embracing RIS-aided THz systems is essential for advancing the wireless communication technology. The tasks of system and its performance analysis have been completed. The theoretical analysis of the topic provided valuable outcomes on the RIS-aided THz-NOMA networks, guiding the required experiments. As mentioned, there are many paths for a further exploration within the topic, including the investigation of the deployment of resource allocation strategies, channel modeling for systems of cascaded RISs, and characterization of more of the possible channel impairments.

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