School of Engineering and Applied Science (SEAS), Ahmedabad University

B.Tech(ICT) Semester V: Wireless Communication (CSE 311)

- Group No : NOMA - S 16
- Name (Roll No) :
  Varshil Shah AU1841095
  Kahaan Patel AU1841110
  Hemil Shah AU1841135
  Vidit Vaywala AU1841128

- Base Article Title:

  1) B. Soni, D. K. Patel, Y. L. Guan, S. Sun, and Y. C. Chang, "Performance Analysis of NOMA aided Cooperative Relaying over $\alpha-\eta-\kappa-\mu$ Fading Channels ," Performance Analysis of NOMA aided Cooperative Relaying over $\alpha-\eta-\kappa-\mu$ Fading Channels - IEEE Conference Publication. [Online].

1 Introduction

This paper consists of the investigation of the outage analysis of Millimeter wave (mmWave) non-orthogonal multiple access (NOMA) based cooperative relaying system. We consider that the source communicates with user equipment with the aid of decode and forward relay using power domain downlink NOMA, and by sending messages in two time slots. Moreover, the $\alpha-\eta-\kappa-\mu$ fading channel is considered between source, relay and user equipment, which is recently proposed in literature as a good fit model for mmWave communication.

Assumptions

Note: For terminologies used in the assumptions, please refer to table 1.
The following are some of the assumptions that the article has taken.

- Downlink MMwave NOMA based Cooperative Relaying System consisting of a High-powered micro base station (S), user equipment (D) and a Relay (R) with decode forward protocol.
- Base Stattion Consists of a single large antenna which has narrow half-power beamwidth to overcome the pathloss in mmwave communication.
- SD (Source to Destination) link is weaker than SR (Source to Relay) Link.

- Relay mode has a constant source of Power Supply.
- All wireless links follow $\alpha - \eta - \kappa - \mu$ frequency flat fading distrbution.
- The parameters alpha, Eta, Kappa and Mu remain the same for SR, SD and RD links.
- D (Destination) and E (Envelope) operates in half duplex mode and are assumed to be equiped with single antenna.

Motivation behind considering NOMA and the $\alpha - \eta - \kappa - \mu$ model

NOMA has been studied over Rayleigh fading channels, studied the line of sight and non-line of sight links with different Nakagami-m fading parameters.

Cooperative relaying alongwith NOMA improves the throughput of fifth generation wireless networks. A new fading channel model has been proposed namely $\alpha - \eta - \kappa - \mu$ fading model which encompasses all the traditional and well established channel models. This proposed fading model has been verified experimentally in the scenarios like vehicle to vehicle communication, high frequency communications, mobile to mobile propagation, indoor to outdoor propagation in 5G, millimeter communications, etc.

Therefore the author has considered mmWave NOMA based cooperative relaying scheme over the $\alpha-\eta-\kappa-\mu$ fading channel model for a mobile user, which is a good fit for mmWave communication.

2 Performance Analysis of Our Base Article

- **System Model/Network Model** : The below image comprises the system model of this article. The explanation of the model is followed after the image.

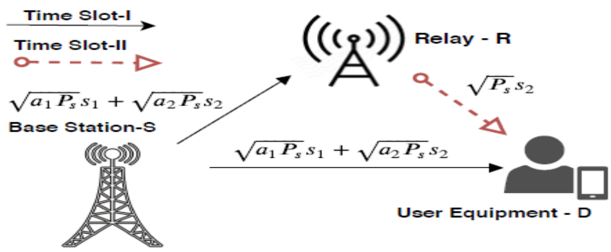

Fig. 1: System model

We have a **Base Station (S)**, a **Destination user (D)**, and a **Relay (R)**. We consider that the base station consists of a single large antenna which have narrow half-power beamwidth to overcome the pathloss in mmWave communication. D and E operate in half-duplex mode and are assumed to be equipped with single antenna.
We denote the channel fading coefficient between SD, SR, and RD as h_{SD}, h_{SR} and h_{RD} respectively.
We have to send two messages namely S1 and S2 from Source Base station (S) to Destination user (D) in two time slots as described below.

- **Time Slot 1:** Source (S) sends messages S1 and S2 to relay. Source also sends message S1 to Destination user.(D) in the same time slot

- **Time Slot 2:** The Relay (R) sends the decoded message S2 to Destination user. (D)

Note: The benefit of using NOMA over OMA here is that NOMA sends two messages in two time slots whereas OMA only sends 1 message in 2 time slots.

- **List of symbols and their description** (Please see the below table for your reference)

Symbol	**Description**
S	Base Station - Source
D	Destination User
R	Relay
α	Non-linearity parameter of the medium
η	Ratio of the total power of the in-phase and quadrature scattered waves of multipath clusters
κ	Ratio of total power of dominant components to the scattered total power
μ	Total number of scattered clusters
a_0	Antenna gain
τ	Path Loss Exponent
$d_{S_R}, d_{R_D}, d_{S_D}$	Distance between BS to relay, relay to user equipment and BS to user equipment respectively
γ	Instantaneous SINR
ρ	Transmission SNR
λ	$\|h^2\|$; h is the channel link

- **Detailed derivation of performance metric-I : outage probability of s1** The cumalative distribution function (CDF) of an envelope of an $\alpha-\eta-\kappa-\mu$ channel can be given as

$$F_E(x) = \frac{x^{\alpha\mu}e^{-\left(\frac{\alpha}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)}\sum_{k=0}^{\infty}\frac{k!m_k}{(\mu+1)_k}L_k^{\mu}\left(\frac{2(\mu+1)x^{\alpha}}{\mu}\right) \tag{1}$$

where E denotes envelope,where m_k is computed using parameters α,η,κ,μ, p, q and with the aid of recursive equation.

However we require CDF of channel gain $\lambda_b = |h_b|^2$, where b is [SR,SD,SE] respectively. Thus we can write cdf as

$$\begin{aligned} F_{\lambda b}(x) &= \int_0^{\sqrt{x}} f_{\lambda b}(\omega)d\omega \\ &= \frac{\sqrt{x}^{\alpha\mu}e^{-\left(\frac{\gamma^a}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)}\sum_{k=0}^{\infty}\frac{k!m_k}{(\mu+1)_k}L_k^{\mu}\left(\frac{2(\mu+1)\sqrt{x}^{\alpha}}{\mu}\right) \end{aligned} \tag{2}$$

Now the data rates odf Symbol s1 and s2 are given as R_1 and R_2 respectively.From this we can find the outage probability for message s1. The outage probability for message s1 can be defined as the event where either Relay R or User D fails to decode s1 successfully.

So outage probability for message s1 can be given as

$$\begin{aligned} PR(O_1) &= Pr(CS_1 < R) \\ &= 1 - Pr[min(\gamma_{SR}, \gamma_{SD}) > \phi_1] \\ &= 1 - Pr[\gamma_{SR} > \phi_1]Pr[\gamma_{SD} > d_1] \\ &= F_{\lambda_{SR}}(\phi_1) + F_{\lambda_{SD}}(\tilde{\phi_1}) - F_{\lambda_{SR}}(\phi_1)F_{\lambda_{SD}}(\tilde{\phi_1}) \end{aligned} \tag{3}$$

Now we have Instantaneous SINR at relay time slot-1 while decoding message s1 which can be given as

$$\gamma_{SR}^{s1} = \frac{a_1\rho\lambda_{SR}}{a_1\rho\lambda_{SR} + d_{SR}^{\tau}} \tag{4}$$

From here let assume that $\lambda_{SR} = \phi_1$, from equation above we get

$$\gamma_{SR}^{s1}a_1\rho\lambda_{SR} + \gamma_{SR}^{s1}d_{SR}^{\tau} = a_1\rho\lambda_{SR} \tag{5}$$

On arranging this terms we get

$$\begin{aligned} \phi_1 &= \frac{\gamma_{SR}d_{SR}^{\tau}}{a_1\rho - \gamma_{SR}a_2\rho} \\ &= \frac{\eta_1 d_{SR}^{\tau}}{\rho(a_1 - \eta_1 a_2)} \\ &= w \end{aligned} \tag{6}$$

Similarly let $\lambda_{SD} = \tilde{\phi_1}$ on solving we get

$$\begin{aligned}\tilde{\phi_1} &= \frac{\gamma_{SD} d_{SD}^{\tau}}{a_1\rho - \gamma_{SD} a_2 \rho} \\ &= \frac{\eta_1 d_{SD}^{\tau}}{\rho(a_1 - \eta_1 a_2)} \\ &= v\end{aligned} \tag{7}$$

Now as data rate for message s1 is given as R_1, we can say

$$\begin{aligned}\eta_1 &= 2^{2R_1} - 1 \\ \phi_1 &= \frac{\eta_1 d_{SR}^{\tau}}{\rho(a_1 - \eta_1 a_2)}\end{aligned} \tag{8}$$

From this , we substitute values of ϕ_1 and ϕ_2 in equation 3 and then substitute in CDF of channel i.e equation 2, we get

$$\begin{aligned}\Pr(O_1) = {} & \frac{w^{0.5\alpha\mu} e^{-\left(\frac{w^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_1=0}^{\infty} \frac{k_1! m_{k_1}}{(\mu+1)_{k_1}} L_{k_1}^{\mu}\left(\frac{2(\mu+1)w^{0.5\alpha}}{\mu}\right) + \frac{v^{0.5\alpha\mu} e^{-\left(\frac{v^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_2=0}^{\infty} \frac{k_2! m_{k_2}}{(\mu+1)_{k_2}} L_{k_2}^{\mu}\left(\frac{2(\mu+1)v^{0.5\alpha}}{\mu}\right) \\ & - \left[\frac{w^{0.5\alpha\mu} e^{-\left(\frac{w^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_1=0}^{\infty} \frac{k_1! m_{k_1}}{(\mu+1)_{k_1}} L_{k_1}^{\mu}\left(\frac{2(\mu+1)w^{0.5\alpha}}{\mu}\right) \times \frac{v^{0.5\alpha\mu} e^{-\left(\frac{v^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_2=0}^{\infty} \frac{k_2! m_{k_2}}{(\mu+1)_{k_2}} L_{k_2}^{\mu}\left(\frac{2(\mu+1)v^{0.5\alpha}}{\mu}\right)\right]\end{aligned} \tag{9}$$

- **Detailed derivation of performance metric-II : outage probability of s2**

  Given that data rate of symbol s2 is R_2 , we find outage probability of s2. Here therefore 3 possibilities of s2 getting outage .The outage depends on the three events as

$$O_2 = E_1 \cup E_2 \cup E_3$$

  where E1 indicates the event when the relay cannot successfully decoded s1, E2 is the event when relay successfully decodes s1, but fails to decode symbol s2 and E3 is the event when both s1 and s2 are successfully decoded at the relay, but the destination fails to decode symbol s2. Moreover, the events E_1, E_2 and E_3 are disjoint.

  So the outage probability can be given as ,

$$\Pr(O_2) = \begin{cases} \Pr(\lambda_{SR} < \phi_1) + \Pr(\lambda_{SR} \geq \phi_1, \lambda_{SR} < \phi_2) + \Pr\left(\lambda_{SR} > \phi_2, \lambda_{RD} < \frac{\eta_2}{\rho}\right); & \text{if } \phi_1 < \phi_2 \\ \Pr(\lambda_{SR} < \phi_1) + \Pr\left(\lambda_{SR} > \phi_1, \lambda_{RD} < \frac{\eta_2}{\rho}\right) & \text{Otherwise} \end{cases} \tag{10}$$

$$Pr(O_2) = F_{\lambda_{SR}}(\phi_{max}) + F_{\lambda_{RD}}(j) - F_{\lambda_{SR}}(\phi_{max}) F_{\lambda_{Rd}}(j) \tag{11}$$

Now as data rate for message s2 is given as R_2, we can say

$$\begin{aligned} \eta_2 &= 2^{2R_2} - 1 \\ \phi_2 &= \frac{\eta_2}{a_2\rho)} \\ \phi_{max} &= max\phi_1, \phi_2 \end{aligned} \tag{12}$$

From substituting this values in equation 12 and that value is substituted in equation 2 , we get

$$\begin{aligned} \Pr(O_2) = &\frac{\phi_{max}^{0.5\alpha\mu} e^{-\left(\frac{\phi_{max}^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_1=0}^{\infty} \frac{k_1! m_{k_1}}{(\mu+1)_{k_1}} L_{k_1}^{\mu} \left(\frac{2(\mu+1)\phi_{max}^{0.5\alpha}}{\mu}\right) + \frac{j^{0.5\alpha\mu} e^{-\left(\frac{j^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_2=0}^{\infty} \frac{k_2! m_{k_2}}{(\mu+1)_{k_2}} L_{k_2}^{\mu} \left(\frac{2(\mu+1)j^{0.5\alpha}}{\mu}\right) \\ &- \left[\frac{\phi_{max}^{0.5\alpha\mu} e^{-\left(\frac{\phi_{max}^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_1=0}^{\infty} \frac{k_1! m_{k_1}}{(\mu+1)_{k_1}} L_{k_1}^{\mu} \left(\frac{2(\mu+1)\phi_{max}^{0.5\alpha}}{\mu}\right) \times \frac{j^{0.5\alpha\mu} e^{-\left(\frac{j^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_2=0}^{\infty} \frac{k_2! m_{k_2}}{(\mu+1)_{k_2}} L_{k_2}^{\mu} \left(\frac{2(\mu+1)j^{0.5\alpha}}{\mu}\right) \right. \end{aligned} \tag{13}$$

- **Detailed derivation of performance metric-III : sum-rate analysis** The symbol s1 should be decoded at the relay for SIC and at the destination as well. The achievable rate for symbol s1 can be written as

$$\begin{aligned} C_{s1} &= 0.5min\{log_2(1+\gamma_{SD}), log_2(1+\gamma_{SR1})\} \\ &= 0.5log_2\left(1 + \frac{X\rho a_1}{X\rho a_2 + 1}\right) \\ &= 0.5log_2(1+X\rho) - 0.5log_2(1+X\rho a_2) \end{aligned} \tag{14}$$

Similarly, the achievable rate for symbol s2 can be given a

$$\begin{aligned} C_{s2} &= 0.5min\{log_2(1+\gamma_{SR}), log_2(1+\gamma_{RD})\} \\ &= 0.5log_2(1+min\{\lambda_{SR}\rho a_2, \lambda_{RD}\rho\}) \end{aligned} \tag{15}$$

Therefore, the average achievable rate for s1 can be written a

$$\bar{C}_{s_1} = \frac{0.5}{\ln(2)} \left[\underbrace{\int_0^{\infty} \ln(1+\rho x) f_X(x) dx}_{\bar{\omega_1}} - \underbrace{\int_0^{\infty} \ln(1+a_2\rho x) f_X(x) dx}_{\bar{\omega_2}} \right] \tag{16}$$

On utilizing the PDF, the expression for $\bar{\omega_1}$ can be simplified a

$$\begin{aligned} \bar{\omega}_1 = &\underbrace{\int_0^{\infty} \ln(1+\rho x) f_{\lambda_{SR}}(x) dx}_{I_1} - \underbrace{\int_0^{\infty} \ln(1+\rho x) f_{\lambda_{SR}}(x) F_{\lambda_{SD}}(x) dx}_{I_2} \\ &+ \underbrace{\int_0^{\infty} \ln(1+\rho x) f_{\lambda_{SD}}(x) dx}_{I_3} - \underbrace{\int_0^{\infty} \ln(1+\rho x) f_{\lambda_{SD}}(x) F_{\lambda_{SD}}(x) dx}_{I_4} \end{aligned} \tag{17}$$

On substituting the value of PDF of instantaneous SNR and on further simplification, I_1 can be expressed a

$$I_1 = \frac{\alpha}{2^{\mu}\rho^{\frac{\alpha\mu}{2}}} \sum_{k=0}^{\infty} \sum_{z=0}^{k} \frac{(-1)^z}{z!} \begin{pmatrix} k+\mu-1 \\ k-m \end{pmatrix} \frac{k! c_k}{\Gamma(\mu+k)\rho^{\frac{\alpha\mu}{2}}} \\ \times \int_0^{\infty} x^{\left(\frac{\alpha\mu+\alpha m}{2}\right)-1} \exp\left(\frac{-x^{\frac{\alpha}{2}}}{2\rho^{\frac{\alpha}{2}}}\right) \ln(1+\rho x) dx \tag{18}$$

On expressing the exponential and logarithmic functions in terms of Meijer's G-function gives

$$I_1 = \frac{\alpha}{2^{\mu}\rho^{\frac{\alpha\mu}{2}}} \sum_{k=0}^{\infty} \sum_{z=0}^{k} \frac{(-1)^z}{z!} \begin{pmatrix} k+\mu-1 \\ k-m \end{pmatrix} \frac{k! c_k}{\Gamma(\mu+k)\rho^{\frac{\alpha\mu}{2}}} \\ \times \int_0^{\infty} x^{\left(\frac{\alpha\mu+\alpha m}{2}\right)-1} \times G_{0,1}^{1,0}\left(\frac{-x^{\frac{\alpha}{2}}}{2\rho^{\frac{\alpha}{2}}}\bigg|_{0}^{-}\right) G_{2,2}^{1,2}\left(\rho x|_{1,0}^{1,1}\right) dx \tag{19}$$

This equation can be written as

$$I_1 = \frac{\alpha_{sr}}{2_{sr}^{\mu}\rho^{\frac{\alpha_{sr}\mu_{sr}}{2}}} \sum_{k=0}^{\infty} \sum_{z=0}^{k} \frac{(-1)^z}{z!} \binom{k+\mu-1}{k-m} \frac{k! c_k \rho^{\bar{\alpha}}}{\Gamma(\mu+k)\rho^{\frac{\alpha\mu}{2}}(2\pi)^{\alpha_{sr}-0.5}} \\ \times G_{2\alpha_{sr},2+2\alpha_{sr}}^{2+2\alpha_{sr},\alpha_{sr}}\left(\frac{0.5\rho^{-\alpha_{sr}}\cdot 2^{-2}}{\rho_{sr}^{\alpha}}\bigg|_{\Delta(2,0),\Delta(\alpha,1-\bar{\alpha}),\Delta(\alpha,1-\bar{\alpha})}^{\Delta(2,-\bar{\alpha}),\Delta(2,1-\bar{\alpha})}\right),$$

where $\bar{\alpha} = \left(\frac{\alpha_{sr}\mu_{sr}+\alpha_{sr}m}{2}\right)$ Similarly, on utilizing the definition of CDF and PDF, I_2 can be simplified as

$$I_2 = \sum_{k_1=0}^{\infty} \sum_{z_1=0}^{k_1} \frac{\alpha_{sr}}{2^{\mu_{sr}+\mu_{sd}+2}\Gamma(\mu_{sd}+1)\rho^{\frac{\alpha_{sr}\mu_{sr}}{2}}} \frac{(-1)^{z_1}}{z_1!} \binom{k_1+\mu-1}{k_1-z_1} \\ \times \frac{k_1! c_{k_1} 2^{z_1} \rho^{-\frac{\alpha_{sr}z_1}{2}}}{\Gamma(\mu_{sr}+k_1)} \sum_{k_2=0}^{\infty} \sum_{z_2=0}^{k_2} \frac{(-1)^{z_2}\cdot 2k_2!}{\mu_{sd} z_2! k_2} \binom{k_2+\mu}{k_2-z_2} m_{k_2}\rho^{-\frac{\alpha_{sd}}{2}} \\ \times \int_0^{\infty} x^{\beta-1} \exp\left(\frac{-x^{\frac{\alpha_{sr}}{2}}}{2\rho^{\frac{\alpha_{sr}}{2}}}\right) \exp\left(\frac{-x^{\frac{\alpha_{sd}}{2}}}{2\rho^{\frac{\alpha_{sd}}{2}}}\right) \ln(1+\rho x) dx,$$

where $\beta = \frac{\alpha_{sr}z_1+\alpha_{sr}\mu_{sr}+\alpha_{sd}\mu_{sd}+\alpha_{sd}}{2}$. On following similar steps as in previous expression, and on replacing with equivalent Meijer's G-function, we obtain:

$$
\begin{aligned}
I_2 = & \sum_{k_1=0}^{\infty}\sum_{z_1=0}^{k_1} \frac{\alpha_{sr}}{2^{\mu_{sr}+\mu_{sd}+2}\Gamma(\mu_{sd}+1)\rho^{\frac{\alpha_{sr}\mu_{sr}}{2}}} \frac{(-1)^{z_1}}{z_1!}\binom{k_1+\mu-1}{k_1-z_1} \\
& \times \frac{k_1! c_{k_1} 2^{z_1}\rho^{-\frac{\alpha_{sr}z_1}{2}}}{\Gamma(\mu_{sr}+k_1)} \sum_{k_2=0}^{\infty}\sum_{z_2=0}^{k_2}\frac{(-1)^{z_2}\cdot 2k_2!}{\mu_{sd}z_2!k_2}\binom{k_2+\mu}{k_2-z_2} m_{k_2}\rho^{-\frac{\alpha_{sd}}{2}} \\
& \times \int_0^{\infty} x^{\beta-1} G_{0,1}^{1,0}\left(\frac{-x^{\frac{\alpha_{sr}}{2}}}{2\rho^{\frac{\alpha_{sr}}{2}}}\Big|_{0}^{-}\right) G_{0,1}^{1,0}\left(\frac{-x^{\frac{\alpha_{sd}}{2}}}{2\rho^{\frac{\alpha_{sd}}{2}}}\Big|_{0}^{-}\right) G_{2,2}^{1,2}\left(\rho x\Big|_{1,0}^{1,1}\right) dx.
\end{aligned} \tag{20}
$$

Further, on expressing Meijer's G-function into its equivalent Fox H-function, the expression can be simplified as (21) as shown on top of the next page. In similar way, I3 can be derived as I1 and I4 can be derived as I2. Moreover, $\bar{\omega}_2$ will also consist of four terms, expressions of which can be obtained by replacing by a2 in I1 I4. Also, notice that the expression of $\bar{C}$ s2 is similar to $\bar{C}$ s1. Thus, on transforming the random variables and on solving in similar lines with I1 I4, the analytical expression can be derived.

$$
\begin{aligned}
I_2 = & \sum_{k_1=0}^{\infty}\sum_{z_1=0}^{k_1} \frac{\alpha_{sr}}{2^{\mu_{sr}+\mu_{sd}+2}\Gamma(\mu_{sd}+1)\rho^{\frac{\alpha_{sr}\mu_{sr}}{2}}} \frac{(-1)^{z_1}}{z_1!}\binom{k_1+\mu-1}{k_1-z_1} \times \frac{k_1! c_{k_1} 2^{z_1}\rho^{-\frac{\alpha_{sr}z_1}{2}}}{\Gamma(\mu_{sr}+k_1)} \sum_{k_2=0}^{\infty}\sum_{z_2=0}^{k_2}\frac{(-1)^{z_2}\cdot 2k_2!}{\mu_{sd}z_2!k_2}\binom{k_2+\mu}{k_2-z_2} m_{k_2}\rho^{-\frac{\alpha_{sd}}{2}} \\
& \times H_{1,0:0,1:2,2}^{0,1:1,0:1,2}\left[\left(1-\beta;\frac{\alpha_{sd}}{\alpha_{sr}},\frac{2}{\alpha_{sr}}\right)\Bigg| \begin{matrix} - \\ (0,1) \end{matrix} \Bigg| \begin{matrix} (1,1),(1,1) \\ (1,1),(0,1) \end{matrix} \Bigg| \left(\frac{-\rho^{\frac{\alpha_{sd}}{2}}}{2\rho^{\frac{\alpha_{sd}}{2}}}\right), \frac{-\rho^{\frac{\alpha_{sr}}{2}}}{2\rho^{\frac{\alpha_{sr}}{2}}}\right]
\end{aligned}
$$

3 Numerical Results

3.1 Simulation Framework

Here we have used the Cooperative relay system for sending messages from Base station to the User. The fading channel used here is $\alpha - \eta - \kappa - \mu$. So as we change the parameters the outage probability gets changed. The SNR taken into consideration here is from 1 to 25 dB. The value of the parameters are shown in the legends of the graphs respectively.

3.2 Reproduced Figures

- Reproduced Figure-1

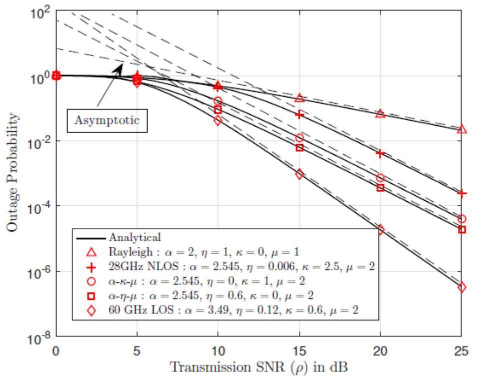

Figure 1: 1B

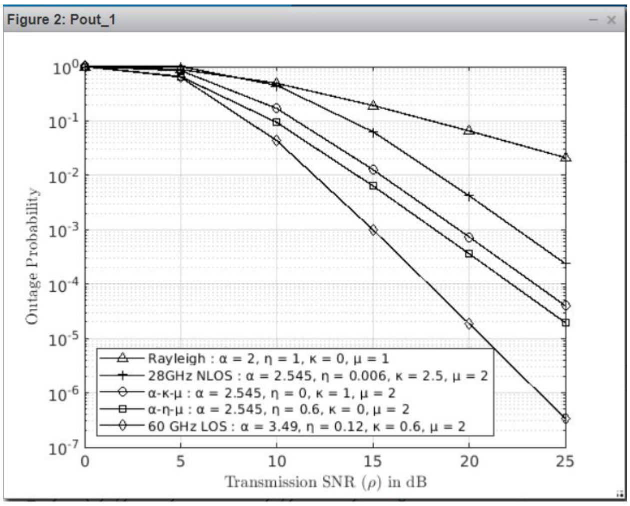

Figure 2: 1R

- Description: We are plotting the graph of Outage Probability versus transmission SNR for s1 message by changing the values of parameters $\alpha, \eta, \kappa, \mu$ for different channels.The equation used for plotting the graph is as follows:

$$\begin{aligned}\Pr(O_1) = {} & \frac{w^{0.5\alpha\mu}e^{-\left(\frac{w^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)}\sum_{k_1=0}^{\infty}\frac{k_1!m_{k_1}}{(\mu+1)_{k_1}}L_{k_1}^{\mu}\left(\frac{2(\mu+1)w^{0.5\alpha}}{\mu}\right)+\frac{v^{0.5\alpha\mu}e^{-\left(\frac{v^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)}\sum_{k_2=0}^{\infty}\frac{k_2!m_{k_2}}{(\mu+1)_{k_2}}L_{k_2}^{\mu}\left(\frac{2(\mu+1)v^{0.5\alpha}}{\mu}\right) \\ & -\left[\frac{w^{0.5\alpha\mu}e^{-\left(\frac{w^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)}\sum_{k_1=0}^{\infty}\frac{k_1!m_{k_1}}{(\mu+1)_{k_1}}L_{k_1}^{\mu}\left(\frac{2(\mu+1)w^{0.5\alpha}}{\mu}\right)\times\frac{v^{0.5\alpha\mu}e^{-\left(\frac{v^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)}\sum_{k_2=0}^{\infty}\frac{k_2!m_{k_2}}{(\mu+1)_{k_2}}L_{k_2}^{\mu}\left(\frac{2(\mu+1)v^{0.5\alpha}}{\mu}\right)\right]\end{aligned} \tag{20}$$

- Inferences : As seem from the graph, we can infer that the outage probability for the alpha-eta-kappa-mu channel model is significantly less than the Rayleigh channel model. Even when any one of the two parameters eta and kappa is 0, this model absolutely outweighs the performance of Rayleigh fading model and significantly decreases the chances of Outage. The lowest Outage probability is found in 60 GHZ LOS as can be seen in the graph above.

  Slope is highest for 60 GHz LOS link and least for the Rayleigh fading channel, and thus $\alpha - \eta - \kappa - \mu$ fading channel provides the maximum diversity gain.

- Reproduced Figure-2

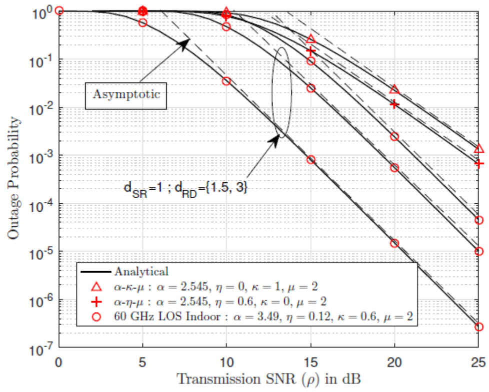

Figure 3: 2B

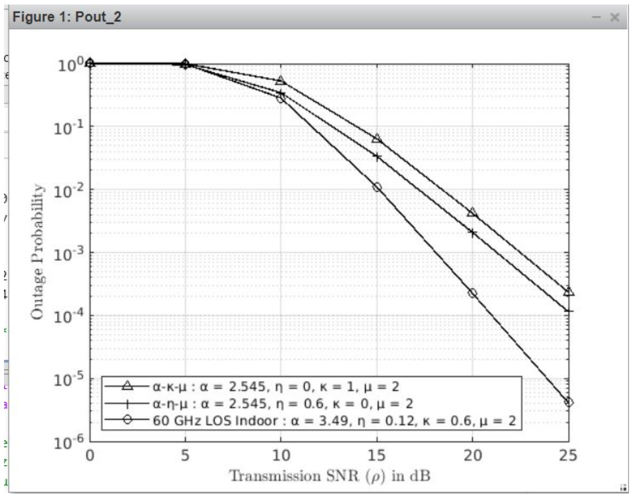

Figure 4: 2R

- Description: We are plotting the graph of Outage Probability versus transmission SNR for s2 message by changing the values of parameters $\alpha, \eta, \kappa, \mu$ for different channels.The equation used for plotting the graph is as follows:

$$\Pr(O_2) = \frac{\phi_{max}^{0.5\alpha\mu} e^{-\left(\frac{\phi_{max}^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_1=0}^{\infty} \frac{k_1! m_{k_1}}{(\mu+1)_{k_1}} L_{k_1}^{\mu}\left(\frac{2(\mu+1)\phi_{max}^{0.5\alpha}}{\mu}\right) + \frac{j^{0.5\alpha\mu} e^{-\left(\frac{j^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_2=0}^{\infty} \frac{k_2! m_{k_2}}{(\mu+1)_{k_2}} L_{k_2}^{\mu}\left(\frac{2(\mu+1) j^{0.5\alpha}}{\mu}\right)$$
$$- \left[\frac{\phi_{max}^{0.5\alpha\mu} e^{-\left(\frac{\phi_{max}^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_1=0}^{\infty} \frac{k_1! m_{k_1}}{(\mu+1)_{k_1}} L_{k_1}^{\mu}\left(\frac{2(\mu+1)\phi_{max}^{0.5\alpha}}{\mu}\right) \times \frac{j^{0.5\alpha\mu} e^{-\left(\frac{j^{0.5\alpha}}{2}\right)}}{2^{\mu+1}\Gamma(\mu+1)} \sum_{k_2=0}^{\infty} \frac{k_2! m_{k_2}}{(\mu+1)_{k_2}} L_{k_2}^{\mu}\left(\frac{2(\mu+1) j^{0.5\alpha}}{\mu}\right)\right. \tag{21}$$

- Inferences : The above graph shows the combined effect of fading parameters and varying distance for the considered system model on the outage probability of S2. We can see from the graph that the 60 GHZ LOS indoor link (marked with "circle" on the graph) provides maximum diversity gain and hence the least Outage probability. Moreover the slopes of the line with "triangle" and "plus" symbol are same , thus providing the same diversity gain.

- Reproduced Figure-3

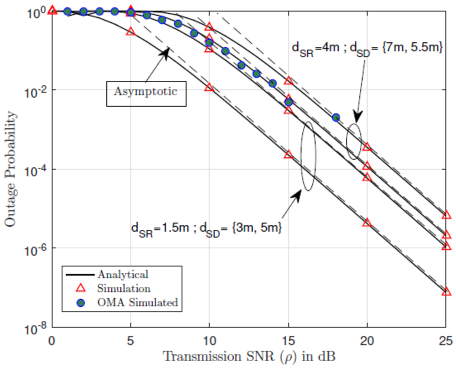

Figure 5: 3B

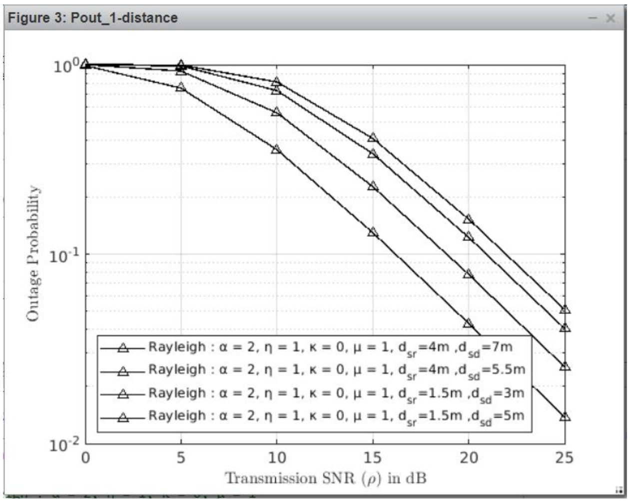

Figure 6: 3R

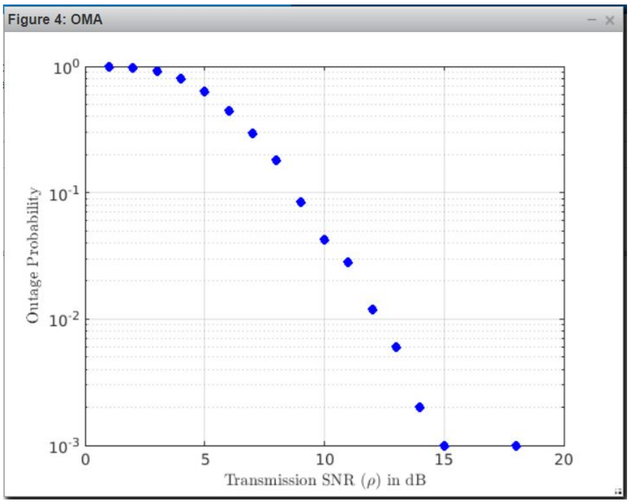

Figure 7: 3R

- Inferences : The above graph shows the effect of distance on the Outage Probability of S1. This result is plotted for 60 GHz LOS indoor communication link with parameters alpha = 2 , eta = 1 , kappa = 0, and mu = 1. We can notice that as the distance between cooperative users increases, outage increases. By knowing the bearable outage beforehand, this result can help us in the positioning the relay devices for mmWave based communications.

Note: On the right-hand side, the bottom figure consists of the Outage probability vs Transmission SNR of OMA channel model. We were not able to merge the two graphs and hence we plotted them seperately. The graphs are fit to scale and the output reflected is accurate.

• Reproduced Figure - 4

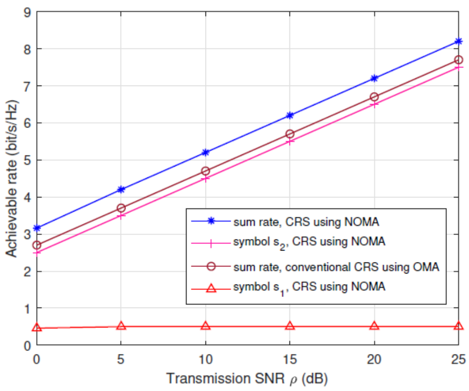

Figure 8: 4B

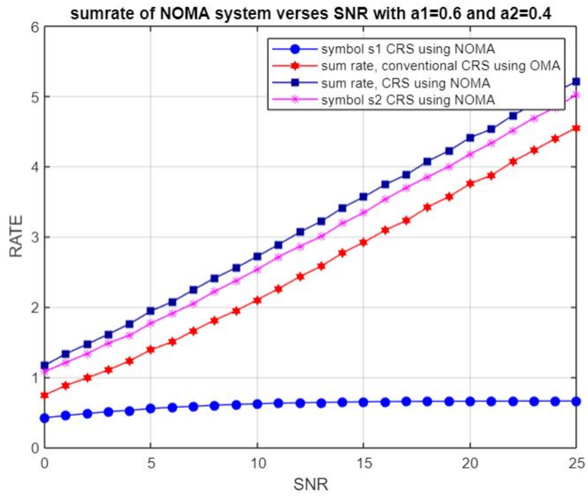

Figure 9: 4R

• Inferences : The graph above indicates the achievable sum rate comparison for NOMA and OMA aided cooperative relaying scheme for alpha = 2.545, eta = 0.0006, kappa = 2.5, mu = 2, dSR = dRD = 1m and dSD = 2m. We can observe from the plot that sum rate for the cooperative relaying scheme is better for NOMA as compared to OMA. This is expected due to the fact that in NOMA, two symbols are transmitted in two time slots as compared to OMA wherein only one symbol is transmitted in two time slots.

4 Contribution of team members

4.1 Technical contribution of all team members

Tasks	Varshil Shah	Vidit Vaywala	Kahaan Patel	Hemil Shah
Research and Documentation	✓	✓	✓	✓
Plotting figure 1	✓	✓		
Plotting figure 2			✓	✓
Plotting figure 3	✓		✓	
Plotting figure 4		✓		✓

4.2 Non-Technical contribution of all team members

Tasks	Varshil Shah	Vidit Vaywala	Kahaan Patel	Hemil Shah
Understanding the System Model	✓	✓	✓	✓
Report Writing Section 1				✓
Report Writing Section 2	✓	✓		
Report Writing Section 3		✓	✓	
Report Writing Section 4	✓			
Managing Team & Setting Deadlines			✓	✓