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

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

- Group No : NOMA S11
- Name (Roll No) :
  Umang Kamdar - AU1841069
  Jainesh Patel - AU1841101
  Vatsal Patel - AU1841103

- Base Article Title: Impact of Non-orthogonal Multiple Access on the Offloading of Mobile Edge Computing

  1) Base Article : Z. Ding, P. Fan and H. V. Poor, "Impact of Non-Orthogonal Multiple Access on the Offloading of Mobile Edge Computing," in IEEE Transactions on Communications, vol. 67, no. 1, pp. 375-390, Jan. 2019, doi: 10.1109/TCOMM.2018.2870894.

1 Performance Analysis of Base Article

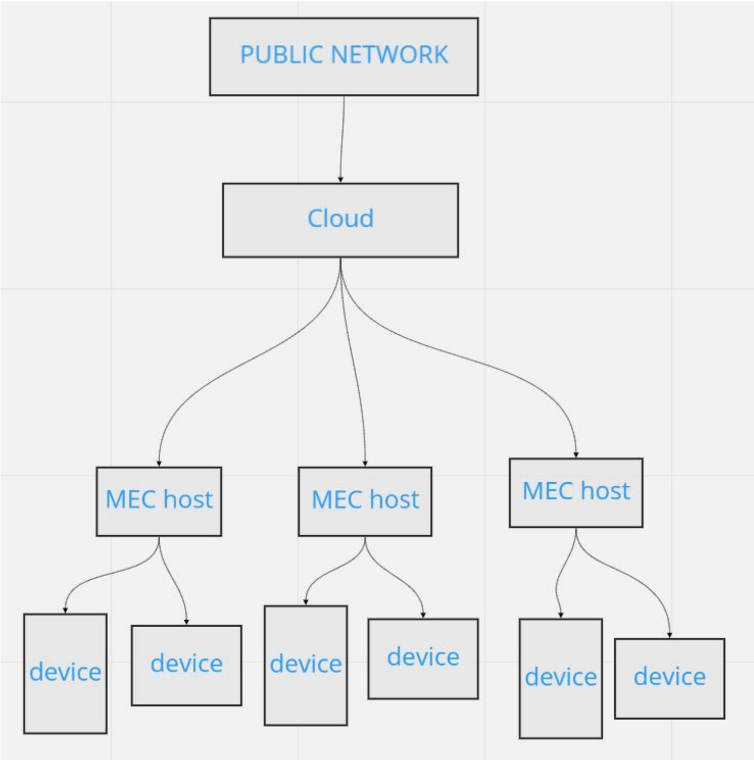
- List of symbols and their description

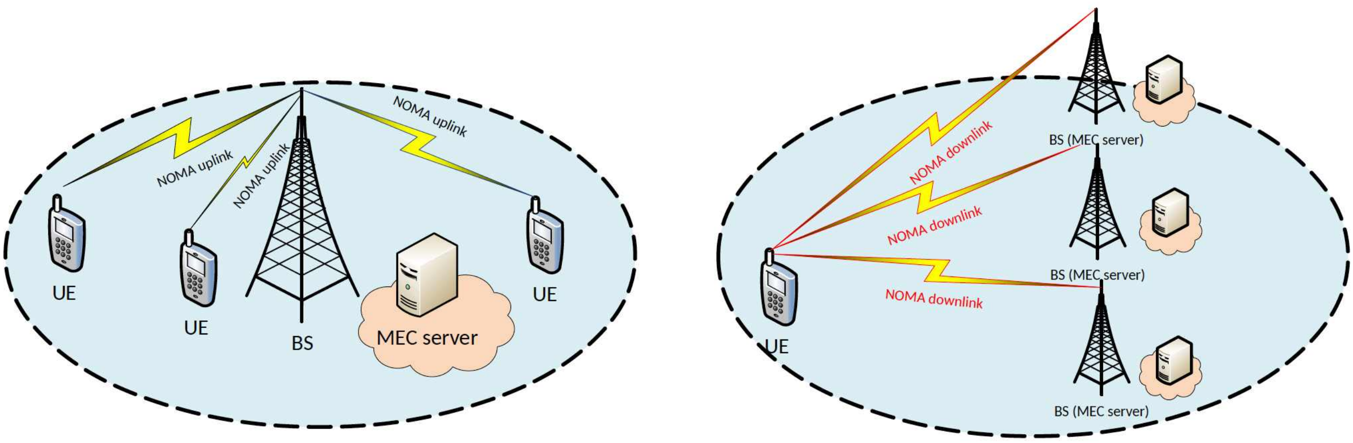
Symbol	**Description**
P_n	Offloading Probability
ρ_n	User n's transmit power in dB
ρ_m	User m's transmit power in dB
m, n, M	user1, user2, Total users
P_n^D	Probability for OMA-MEC to outperform NOMA-MEC
β	energy reduction parameter
η	$\frac{\rho_n}{\rho_m}$
h_m	Channel gain of user m
h_n	Channel gain of user n

System Model/Network Model :

⇒ In this article, the users' channels are assumed to be quasi-static Rayleigh fading.

⇒Also, here noise power is assumed to be normalized, which means that user n's transmit power is the same as ρ_n





NOMA uplink enabled MEC NOMA downlink enabled MEC

- Collecting and processing data closer to the customer reduces latency and brings real time performance to high bandwidth applications.
- Each user needs to complete computationally intensive tasks but limitation of computational capabil-

ities, user needs much time and energy to complete the task.

- To overcome the issue, MEC is key motivation.Figure illustrates the network of the system how user complete their task by offloading to MEC.
- To employ more resourceful computing facilities at the edge of mobile networks, such as access points and small-cell base station integrated with MEC servers.
- For this implementation, ask mobile users to offload their computationally intensive tasks to MEC servers.
- There are some assumptions to define the system.

  Assumption 1 : The user always prefer to offload their task to MEC servers. with this assumption, The cost of NOMA-MEC for offloading the task is compared with OMA-MEC.

- MEC consists of two phases.The first phase is Offloading that user transmit their tasks to MEC and the second phase is feedback phase. In this phase, MEC carry out the tasks and feed back to users.

  Assumption 2: The cost of the second phase of MEC are negligible for the purposes of our analysis.

  The energy required for a MEC server to compute the offloaded tasks as well as the transmission energy consumption during the second phase of MEC can also be omitted, since the MEC servers are not energy constrained.

- The performance of MEC is evaluated from latency and energy perspective.
- Latency of MEC:The time required for offloading task l of user i is given by

$$T_{(i,l)} = \frac{N_{(i,l)}}{R_{(i,l)}}$$

  Here $R_{(i,l)}$ means data rate for user i to offload task l and $N_{(i,l)}$ means data bits for user i for task

- Energy consumption of MEC: the total energy consumed by offloading all the L tasks of user i is given by

$$E_i = \sum_{l=1}^{L} P_{i,l}^{ow} \frac{N_{i,l}}{R_{i,l}}$$

  here the energy consumption during second phase of MEC is ommited.

- **Detailed derivation of performance metric-I**

We want to find the probability which measures the likelihood of the event that user n can complete its offloading within T_m, this can be written as:

$$P_n = P(R_n T_m \geq N)$$

It can be further expanded as follows:

$$= P\left(log\left(1 + \frac{\rho_n |h_n|^2}{\rho_m |h_m|^2 + 1}\right) \geq log\left(\rho_m |h_m|^2 + 1\right)\right)$$

By doing some manipulations, we can rewrite this as follows:

$$P_n = P\left(|h_n|^2 \geq \frac{\rho_m}{\rho_n}|h_m|^2 + \frac{\rho_m^2}{\rho_n}|h_m|^4\right)$$

Since we have know that $|h_1|^2 \leq |h_2|^2 \leq ... \leq |h_M|^2$, we can get $|h_n|^2 \geq |h_m|^2$ since $n > m$ here. With this we can divide the above probability in 2 events:

$$\left\{|h_n|^2 \geq \frac{\rho_m}{\rho_n}|h_m|^2 + \frac{\rho_m^2}{\rho_n}|h_m|^4\right\}$$

$$= \left\{|h_n|^2 \geq |h_m|^2, |h_m|^2 \geq \frac{\rho_m}{\rho_n}|h_m|^2 + \frac{\rho_m^2}{\rho_n}|h_m|^4\right\} + \left\{|h_n|^2 \geq \frac{\rho_m}{\rho_n}|h_m|^2 + \frac{\rho_m^2}{\rho_n}|h_m|^4, \frac{\rho_m}{\rho_n}|h_m|^2 + \frac{\rho_m^2}{\rho_n}|h_m|^4 \geq |h_m|^2\right\}$$

Considering the space limits, we have only focused on for the case of $\rho_n \geq \rho_m$ (we can also found the similar results for $\rho_n < \rho_m$)

$$\mathrm{P}_n = \underbrace{P\left(|h_n|^2 > \frac{\rho_m}{\rho_n}|h_m|^2 + \frac{\rho_m^2}{\rho_n}|h_m|^4, |h_m|^2 \geq \frac{\rho_n - \rho_m}{\rho_m^2}\right)}_{\mathrm{T}_1} + \underbrace{P\left(|h_n|^2 > |h_m|^2, |h_m|^2 \leq \frac{\rho_n - \rho_m}{\rho_m^2}\right)}_{T_2}$$

Now by using higher order statistics, we can find the joint pdf of $|h_n|^2$ & $|h_m|^2$ as follows:

$$f_{|h_m|^2,|h_n|^2}(x, y) = c_{mn} e^{-x} e^{-(M-n+1)y} (1 - e^{-x})^{m-1} \times (e^{-x} - e^{-y})^{n-1-m}$$

where, $c_{mn} = \frac{M!}{(m-1)!(n-1-m)!(M-n)!}$

T_1 can be written from the above mentioned equation as follows:

$$T_1 = c_{mn} \sum_{p=0}^{n-1-m} c_p \int_{\frac{\rho_n - \rho_m}{\rho_m^2}}^{\infty} e^{-(p+1)x} (1 - e^{-x})^{m-1} \times \frac{1}{M-m-p} e^{-(M-m-p)(\frac{\rho_m}{\rho_n}x + \frac{\rho_m^2}{\rho_n}x^2)} dx$$

where, $c_p = \begin{pmatrix} n-1-m \\ p \end{pmatrix} (-1)^{n-1-m-p}$

By doing some algebraic manipulations, we can write T_1 as follows:

$$T_1 = c_{mn} \sum_{p=0}^{n-1-m} \frac{c}{M-m-p} \sum_{l=0}^{m-1} \int_{\frac{\rho_n-\rho_m}{\rho_m^2}}^{\infty} c_l \times e^{\left(-(p+l+1+(M-m-p)\frac{\rho_m}{\rho_n})x-(M-m-p)\frac{\rho_m^2}{\rho_n}x^2\right)} dx$$

Further, it can be degraded as follows:

$$T_1 = c_{mn} \sum_{p=0}^{n-1-m} \frac{c}{M-m-p} \times \sum_{l=0}^{m-1} \int_{\frac{\rho_n-\rho_m}{\rho_m^2}}^{\infty} c_l e^{-a\left(x+\frac{b}{2a}\right)^2+\frac{b^2}{4a}} dx$$

Now, using some predefined formulas the above equation can be written as:

$$T_1 = c_{mn} \sum_{p=0}^{n-1-m} \frac{c_p}{M-m-p} \sum_{l=0}^{m-1} c_l e^{\frac{b^2}{4a}} \times \frac{\sqrt{\pi}}{2\sqrt{a}} \left(1 - \Phi\left(\frac{\max\{0,\rho_n-\rho_m\}}{\rho_m^2} + \frac{b\sqrt{a}}{2a}\right)\right)$$

Similarly, T_2 can be obtained as follows:

$$T_2 = 1 - \frac{M!}{(m-1)!(M-m)!} \sum_{l=0}^{m-1} c_l \frac{e^{-(M-m+l+1)\frac{\rho_n-\rho_m}{\rho_m^2}}}{M-m+l+1}$$

Finally, we can write the whole equation as:

$$\boxed{\begin{aligned} \mathrm{P}_n = & c_{mn} \sum_{p=0}^{n-1-m} \frac{c_p}{M-m-p} \sum_{l=0}^{m-1} c_l e^{\frac{b^2}{4a}} \times \frac{\sqrt{\pi}}{2\sqrt{a}} \left(1 - \Phi\left(\frac{\max\{0,\rho_n-\rho_m\}}{\rho_m^2} + \frac{b\sqrt{a}}{2a}\right)\right) + 1 \\ & - \frac{M!}{(m-1)!(M-m)!} \sum_{l=0}^{m-1} c_l \frac{e^{-(M-m+l+1)\frac{\max\{0,\rho_n-\rho_m\}}{\rho_m^2}}}{M-m+l+1} \end{aligned}}$$

where $\rho_i = \frac{P_i^{ow}}{P_{N0}}, i \in \{m,n\}, c_{mn} = \frac{M!}{(m-1)!(n-1-m)!(M-n)!} c_p = \begin{pmatrix} n-1-m \\ p \end{pmatrix} (-1)^{n-1-m-p}$,

$$c_l = \begin{pmatrix} m-1 \\ l \end{pmatrix} (-1)^l, \quad a = \frac{\rho_m^2}{\rho_n}(M-m-p), b = p+l+1+(M-m-p)\frac{\rho_m}{\rho_n},$$

and $\Phi(\cdot)$ denotes the probability integral.

- **Detailed derivation of performance metric-II**

We know that $P_n = T_1 + T_2$. In the following.

Since both ρ_m and ρ_n approach infinity and η is a constant, we can have the following approximation:

$$\frac{\max\{0, \rho_n - \rho_m\}}{\rho_m^2} + \frac{b\sqrt{a}}{2a} \approx \frac{b\sqrt{a}}{2a}$$

which implies that whether $\eta \geq 1$ or $\eta \leq 1$ has no impact on the high SNR approximation for T_1.

We know that $\Phi(x)$ has the following series representation:

$$\Phi(x) = \frac{2}{\sqrt{\pi}} e^{-x^2} \sum_{k=0}^{\infty} \frac{2^k x^{2k+1}}{(2k+1)!!}$$

By using the approximation first equation and the series representation in second equation, the first term of the probability P_n, T_1, can be rewritten as follows:

$$\begin{aligned} T_1 \approx c_{mn} & \sum_{p=0}^{n-1-m} \frac{c_p}{M-m-p} \sum_{l=0}^{m-1} c_l e^{\frac{b^2}{4a}} \frac{\sqrt{\pi}}{2\sqrt{a}} \\ & \times \left(1 - \frac{2}{\sqrt{\pi}} e^{-\left(\frac{b\sqrt{a}}{2a}\right)^2} \sum_{k=0}^{\infty} \frac{2^k \left(\frac{b\sqrt{a}}{2a}\right)^{2k+1}}{(2k+1)!!} \right) \end{aligned}$$

To facilitate the asymptotic studies, the series representation of the exponential functions, $e^{\frac{b^2}{4a}}$, is used and the probability T_1 can be expressed as follows:

$$\begin{aligned} T_1 = c_{mn} \textstyle\sum_{p=0}^{n-1-m} \frac{c_p}{M-m-p} & (\underbrace{\sum_{l=0}^{m-1} c_l \frac{\sqrt{\pi}}{2\sqrt{a}} \sum_{s=0}^{\infty} \frac{b^{2s}}{s!4^s a^s}}_{Q_1} \\ & - \underbrace{\sum_{l=0}^{m-1} c_l \frac{1}{\sqrt{a}} \sum_{k=0}^{\infty} \frac{2^k \left(\frac{b\sqrt{a}}{2a}\right)^{2k+1}}{(2k+1)!!}}_{Q_2}) \end{aligned}$$

where the two terms, Q_1 and Q_2, are evaluated separately in the following two subsections.

A. High SNR Approximation for Q_1

As, b = l + λ . To facilitate the high SNR approximation, the binomial expansion is applied to the term b^{2s} and we have the following expression:

$$\begin{aligned} Q_1 &= \sum_{s=0}^{\infty} \frac{\sqrt{\pi}}{s! 2^{2s+1} a^{s+\frac{1}{2}}} \sum_{l=0}^{m-1} c_l b^{2s} \\ &= \sum_{s=0}^{\infty} \frac{\sqrt{\pi}}{s! 2^{2s+1} a^{s+\frac{1}{2}}} \sum_{l=0}^{m-1} c_l \sum_{q=0}^{2s} \left(\begin{array}{c} 2s \\ q \end{array} \right) \lambda^{2s-q} l^q \end{aligned}$$

By exchanging the order of the sums, Q_1 can be rewritten as follows:

$$Q_1 = \sum_{s=0}^{\infty} \frac{\sqrt{\pi} \sum_{q=0}^{2s} \begin{pmatrix} 2s \\ q \end{pmatrix} \lambda^{2s-q}}{s! 2^{2s+1} a^{s+\frac{1}{2}}} \sum_{l=0}^{m-1} c_l l^q$$

1) If m is an odd number: The following properties of the binomial coefficients:

$$\sum_{l=0}^{m-1} c_l l^t = 0$$

for $0 \leq t \leq m2$, and

$$\sum_{l=0}^{m-1} c_l l^{m-1} = (-1)^{m-1}(m-1)!$$

Note that when m is an odd number, (m - 1) is an even number. In this case, Q_1 can be approximated at high SNR as follows:

$$Q_1 \approx \sum_{s=0}^{\frac{m-1}{2}} \frac{\sqrt{\pi}}{s! 2^{2s+1} a^{s+\frac{1}{2}}} \sum_{q=0}^{2s} \begin{pmatrix} 2s \\ q \end{pmatrix} \lambda^{2s-q} \sum_{l=0}^{m-1} c_l l^q$$

$$\approx \frac{\sqrt{\pi}}{(1)} \left(\frac{m-1}{2}\right)! 2^m a^{\frac{m}{2}} \sum_{q=0}^{m-1} \begin{pmatrix} m-1 \\ q \end{pmatrix} \lambda^{m-1-q} \sum_{l=0}^{m-1} c_l l^q$$

$$= \frac{\sqrt{\pi}(-1)^{m-1}(m-1)!}{\left(\frac{m-1}{2}\right)! 2^m a^{\frac{m}{2}}}$$

2) if m is an even number: In this case, $(m-1)$ becomes an odd number and $2 \left\lceil \frac{m-1}{2} \right\rceil =$ m, where $\lceil . \rceil$ denotes the ceiling function. Therefore, Q_1 can be approximated at high SNR as follows:

$$Q_1 \approx \sum_{s=0}^{\left\lceil \frac{m-1}{2} \right\rceil} \frac{\sqrt{\pi}}{s! 2^{2s+1} a^{s+\frac{1}{2}}} \sum_{q=0}^{2s} \begin{pmatrix} 2s \\ q \end{pmatrix} \lambda^{2s-q} \sum_{l=0}^{m-1} c_l l^q$$

$$\approx \frac{\sqrt{\pi}}{(3) \left\lceil \frac{m-1}{2} \right\rceil ! 2^{m+1} a^{\left\lceil \frac{m-1}{2} \right\rceil} + \frac{1}{2}} \sum_{q=0}^{m} \begin{pmatrix} m \\ q \end{pmatrix} \lambda^{m-q} \sum_{l=0}^{m-1} c_l l^q$$

$$= \frac{\sqrt{\pi}}{(4)} \frac{m-1}{\left\lceil \frac{m-1}{2} \right\rceil ! 2^{m+1} a^{\left\lceil \frac{m-1}{2} \right\rceil + \frac{1}{2}}} \left(m\lambda \sum_{l=0}^{m-1} c_l l^{m-1} + \sum_{l=0}^{m-1} c_l l^m \right)$$

Q_1 can be approximated as follows:

$$Q_1 \approx \frac{\sqrt{\pi}}{\left(\frac{m}{2}\right)! 2^{m+1} a^{\frac{m+1}{2}}} \left(m\lambda(-1)^{m-1}(m-1)! + \sum_{l=0}^{m-1} c_l l^m \right)$$

B. High SNR Approximation for $Q2$

On the other hand, after applying the binomial expansion to b^{2s}, Q_2 can be expressed as follows:

$$
\begin{aligned}
Q_2 &= \sum_{k=0}^{\infty} \frac{1}{(2k+1)!!2^{k+1}a^{k+1}} \sum_{l=0}^{m-1} c_l b^{2k+1} \\
&= \sum_{k=0}^{\infty} \frac{1}{(2k+1)!!2^{k+1}a^{k+1}} \sum_{p=0}^{2k+1} \begin{pmatrix} 2k+1 \\ p \end{pmatrix} \lambda^{2k+1-p} \sum_{l=0}^{m-1} c_l l^p
\end{aligned}
$$

Depending on the value of m, Q_2 can be evaluated differently in the following subsections.
1) if m is an odd number: In this case, $(m-2)$ becomes an odd number and 2 $\lceil \frac{m-1}{2} \rceil$ = m - 1, where $\lceil . \rceil$ denotes the ceiling function. Therefore,Q_2 can be approximated at high SNR as follows:

$$
\begin{aligned}
Q_2 &\approx \sum_{k=0}^{\lceil \frac{m-2}{2} \rceil} \frac{1}{(2k+1)!!2^{k+1}a^{k+1}} \sum_{p=0}^{2k+1} \begin{pmatrix} 2k+1 \\ p \end{pmatrix} \lambda^{2k+1-p} \sum_{l=0}^{m-1} c_l l^p \\
&\underset{(5)}{\approx} \frac{1}{m!!2^{\lceil \frac{m-2}{2} \rceil+1} a^{\lceil \frac{m-2}{2} \rceil+1}} \sum_{p=0}^{m} \begin{pmatrix} m \\ p \end{pmatrix} \lambda^{m-p} \sum_{l=0}^{m-1} c_l l^p \\
&\underset{(6)}{=} \frac{1}{m!!2^{\frac{m+1}{2}} a^{\frac{m+1}{2}}} \left(\sum_{l=0}^{m-1} c_l l^m + m\lambda(-1)^{m-1}(m-1)! \right)
\end{aligned}
$$

2) if m is an even number: In this case, $(m-2)$ is also an even number. Following steps similar to those in the previous subsections, Q_2 can be evaluated as follows:

$$
\begin{aligned}
Q_2 &\approx \sum_{k=0}^{\frac{m-2}{2}} \frac{1}{(2k+1)!!2^{k+1}a^{k+1}} \sum_{p=0}^{2k+1} \begin{pmatrix} 2k+1 \\ p \end{pmatrix} \lambda^{2k+1-p} \sum_{l=0}^{m-1} c_l l^p \\
&\approx \frac{1}{(m-1)!!2^{\frac{m-2}{2}+1} a^{\frac{m-2}{2}+1}} \sum_{p=0}^{m-1} \begin{pmatrix} m-1 \\ p \end{pmatrix} \lambda^{m-p} \sum_{l=0}^{m-1} c_l l^p \\
&= \frac{1}{(m-1)!!2^{\frac{m}{2}} a^{\frac{m}{2}}} (-1)^{m-1}(m-1)!
\end{aligned}
$$

On the other hand, the approximation for T_2 can be obtained by first rewriting T_2 as follows:

$$
\begin{aligned}
T_2 =& 1 - \frac{M!}{(m-1)!(M-m)!} \sum_{l=0}^{m-1} c_l \\
&\times \frac{\sum_{k=0}^{\infty} (-1)^k \frac{(M-m+l+1)^k \frac{(\eta-1)^k}{\rho_m^k}}{k!}}{M-m+l+1}
\end{aligned}
$$

$$= 1 - \frac{M!}{(m-1)!(M-m)!} \sum_{l=0}^{m-1} c_l (M-m+l+1)^{-1}$$
$$- \frac{M!}{(m-1)!(M-m)!} \sum_{l=0}^{m-1} c_l (-1)^k$$
$$\times \sum_{k=1}^{\infty} \frac{(M-m+l+1)^{k-1}(\eta-1)^k}{k!\rho_m^k}$$

By applying Proposition 1 and also using the fact that ρm approaches infinity, T_2 can be approximated as follows:

$$T_2 \approx - \frac{M!}{(m-1)!(M-m)!} \sum_{k=1}^{\infty} (-1)^k \frac{(\eta-1)^k}{k!\rho_m^k}$$
$$\times \sum_{q=0}^{k-1} \left(\begin{array}{c} k-1 \\ q \end{array} \right) (M-m+1)^{k-1-q} \sum_{l=0}^{m-1} c_l l^q$$

T_2 can be approximated as follows:

$$T_2 \approx \frac{M!}{(M-m)!} \frac{(\eta-1)^m}{m!\rho_m^m}$$

We can observe that the decay rate of T_1 is $\rho_m^{-\frac{m}{2}}$, but the decay rate of T_2 is ρ_m^{-m}. Therefore, at high SNR, T_1 is dominant and the proof for the lemma is complete.

$$\boxed{\mathrm{P}_n \approx \frac{1}{\rho_m^{\frac{m}{2}}} \sum_{p=0}^{n-1-m} \frac{\eta^{\frac{m}{2}} c_{mn} c_p}{(M-m-p)^{\frac{m}{2}+1}} \left(\tilde{Q}_1 - \tilde{Q}_2 \right)}$$

$$\tilde{Q}_1 \approx \begin{cases} \frac{\sqrt{\pi}(-1)^{m-1}(m-1)!}{\left(\frac{m-1}{2}\right)!2^m}, & \text{if } m \text{ is an odd number} \\ \frac{\sqrt{\pi}\mu_m}{\left(\frac{m}{2}\right)!2^{m+1}a^{\frac{1}{2}}}, & \text{if } m \text{ is an even number} \end{cases}$$

$$\tilde{Q}_2 \approx \begin{cases} \frac{\mu_m}{m!!2^{\frac{m+1}{2}}a^{\frac{1}{2}}}, & \text{if } m \text{ is an odd number} \\ \frac{(-1)^{m-1}(m-1)!}{(m-1)!!2^{\frac{m}{2}}}, & \text{if } m \text{ is an even number} \end{cases}$$

- **Detailed derivation of performance metric-III**

  Impact of NOMA on offloading energy consumption

  Here we compare OMA mode and NOMA mode that which is better energy efficient.

  Suppose user's transmit power in OMA mode is P_i which means that energy consumption for user i in OMA is TP_i and amount of data sent within time T is T $\log\left(1+\beta P_n^{ow}\left|h_n\right|^2\right)$

  In NOMA-MEC, Two users are transmiting using first time slot.User's pwer in NOMA is portion of that in OMA, so it is βP_n^{ow}.

  so, overall energy consumption for user in NOMA is 2TβP_n^{ow} and amount of data sent within 2T is

$$T\log\left(1+\frac{\beta P_n^{ow}\left|h_n\right|^2}{P_m^{ow}\left|h_m\right|^2+1}\right)+T\log\left(1+\beta P_n^{ow}\left|h_n\right|^2\right)$$

  β is an energy reduction parameter and needs to be smaller than $\frac{1}{2}$. To prove, NOMA-MEC is more energy efficient than OMA-MEC the following condition holds

$$2T\beta P_n^{ow}<TP_n^{ow}$$

  The probability for this event can be expressed as follows:

$$\begin{aligned}\tilde{\mathrm{P}}_n \triangleq & \mathrm{P}\left(T\log\left(1+\frac{\beta\rho_n\left|h_n\right|^2}{\rho_m\left|h_m\right|^2+1}\right)+T\log\left(1+\beta\rho_n\left|h_n\right|^2\right)\right.\\ & \left.\leq T\log\left(1+\rho_n\left|h_n\right|^2\right)\right)\end{aligned}$$

  The following equation provides the closed-form expression for $\tilde{\mathrm{P}}_n$.

  If $(1-\beta)\rho_m \geq \beta^2\rho_n$, the probability $\tilde{\mathrm{P}}_n$ can be expressed as follows:

$$\tilde{\mathrm{P}}_n=1-c_{mn}\sum_{p=0}^{n-1-m}c_p\sum_{l=0}^{m-1}c_l\frac{e^{-(M-m-p)\frac{1-2\beta}{\beta^2\rho_n}}}{(M-m-p)\tilde{a}}$$

  otherwise Proof. With some algebraic manipulations, $\tilde{\mathrm{P}}_n$ can be rewritten as follows:

$$\boxed{\tilde{\mathrm{P}}_n=\mathrm{P}\left(\left|h_n\right|^2\leq\frac{(1-\beta)\left(1+\rho_m\left|h_m\right|^2\right)-\beta}{\beta^2\rho_n}\right)}$$

  where $\kappa_1=\frac{1-2\beta}{\beta^2\rho_n-(1-\beta)\rho_m}$ and $\tilde{a}=\frac{\rho_m(1-\beta)(M-m-p)}{\beta^2\rho_n}+p+l+1$

2 Numerical Results

2.1 Simulation Framework

We want to find the P_n, i.e the Offloading Probability which measures the likelihood of the event that one user can complete its offloading within the other user's time. For this, we have considered total users to be M=5 and m,n are the two users who are offloading their tasks simultaneously. We have considered the User n's transmit power as ρ_n and User m's transmit power as ρ_m. We have assumed n^{th} user is strong user always since channel gain of n^{th} is higher than the m^{th} user in this aricle.

We have also considered the parameter η which is the ratio of ρ_n to ρ_m. We have a parameter named β which is energy reduction parameter. β needs to be smaller than $\frac{1}{2}$ since the constraint that NOMA-MEC is more energy efficient than OMA-MEC.

Now by using the parameters mentioned above, we can get the simulation graphs too.

2.2 Reproduced Figures

- Reproduced Figure-1

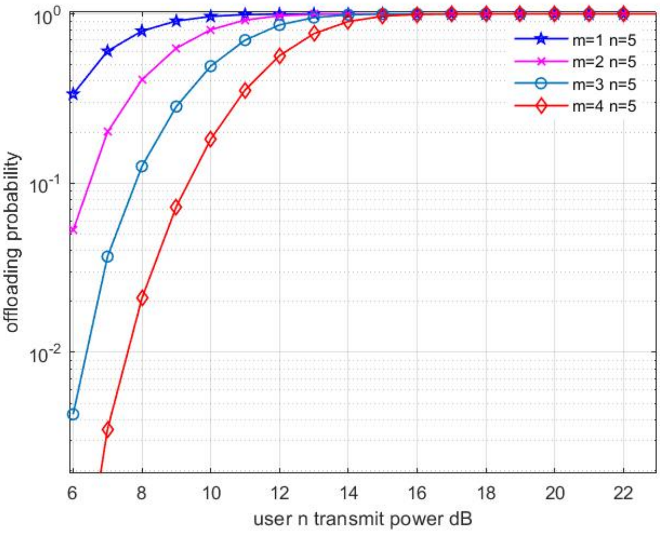
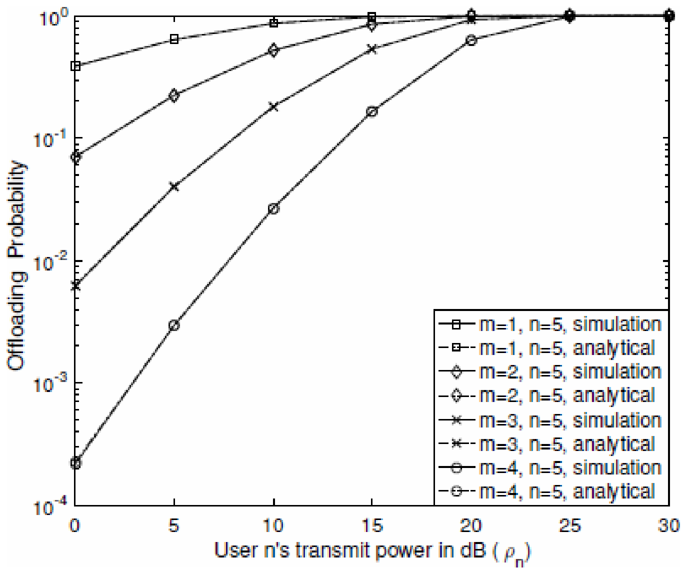


Figure 1: figure 1R



(a) $\rho_m = 10$ dB

Figure 2: figure 1B

- Here figure 1 represents offloading probability for uplink transmission. Offloading probability is shown with respect to user n's transmit power and assumed that user m has fixed power and there is not any performance degradation of user m's transmission.

- Our goal is that user m takes Tm time to complete the task, so user n has to complete the task within this time Tm only.

- Since user m's transmit power is fixed ,so time taken by user m to complete task which is Tm is also fixed. Now as we increase user n's transmit power, the data rate will also increase. So the probability that user n will complete the task within time Tm will also increase.
- So, here in figure 1 The offloading probability approaches to 1 when user n's transmit power is increasing.

- Reproduced Figure-2

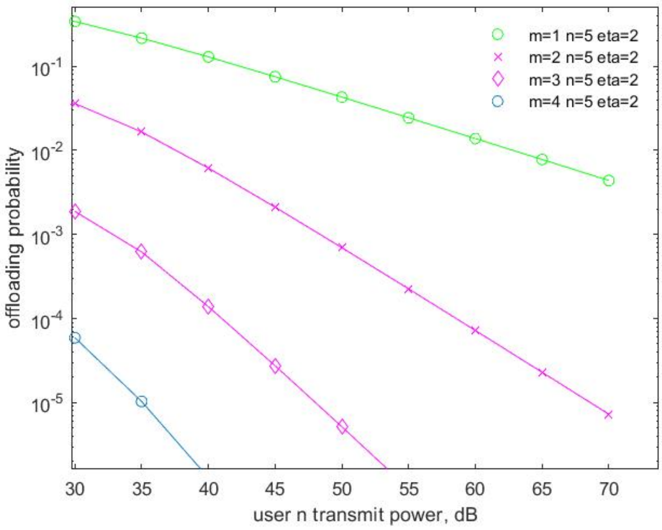
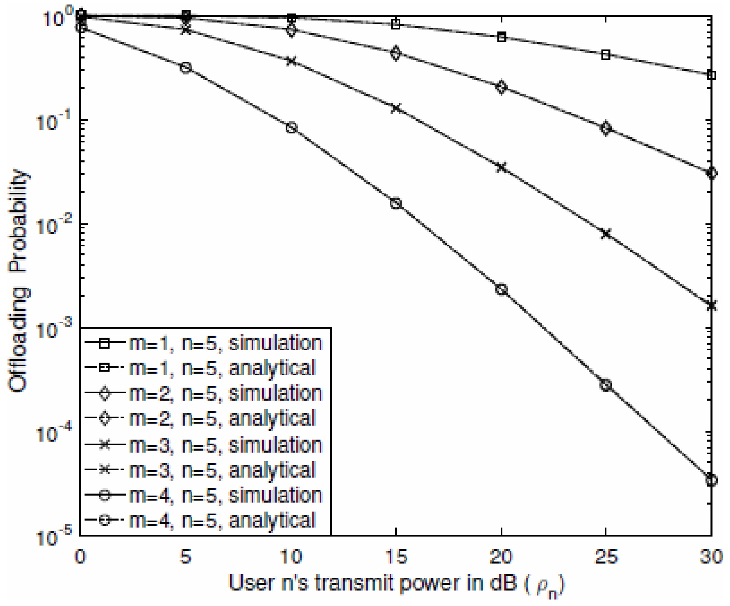


Figure 3: figure 2R



(b) $\eta = \frac{\rho_n}{\rho_m} = 2$

Figure 4: figure 2B

- Here figure 2 represents the offloading probability of user n with respect to user n's transmit power, but here the condition is that both user n's and m's transmit power approaches infinity but there ratio is constant.

- Here user m's transmit power is increasing so data rate will also increase, so time taken to complete the task Tm will decrease. So for user n , it is difficult to complete the task within time Tm, so offloading probability will decrease. It can be seen from graph clearly that probability decreases.

- Reproduced Figure-3

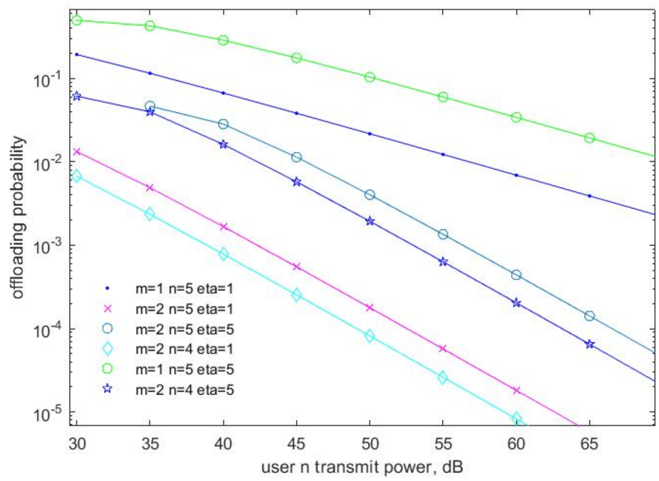


Figure 5: figure 3R

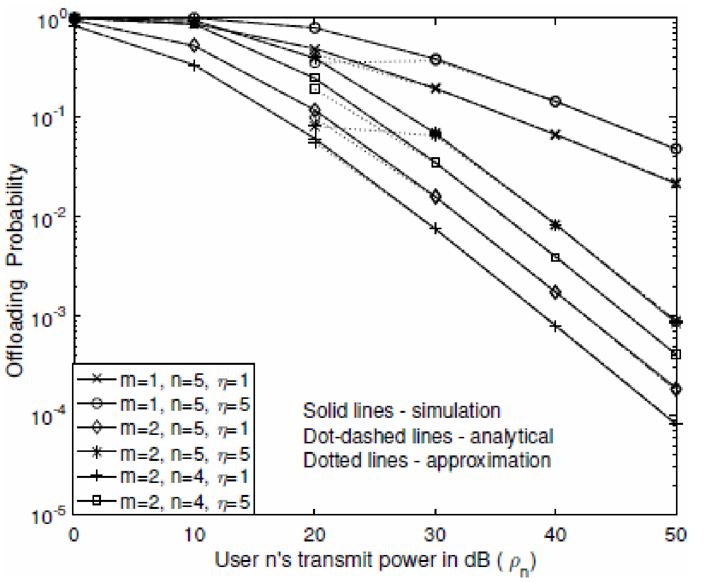


Fig. 2. The impact of the parameters, such as m, n, and η on the offloading probability, P_n. There are five users $M = 5$ and $\eta = \frac{\rho_n}{\rho_m}$.

Figure 6: figure 3B

- Here in figure 3 represents the impact of the different parameters like m,n and η on offloading probability.

- Users are ordered based on the channel condition and here index m and n represent how strong the channel of user m and user n is.η represents ratio of user n's transmit power and user m's transmit power.

- We can see that if m increase then offloading probability decreasing significantly and if n decrease then also same situation will happen.
- So from figure we can say that pairing of weak channel condition user and strong channel condition is best for the offloading probability.

- Reproduced Figure-4

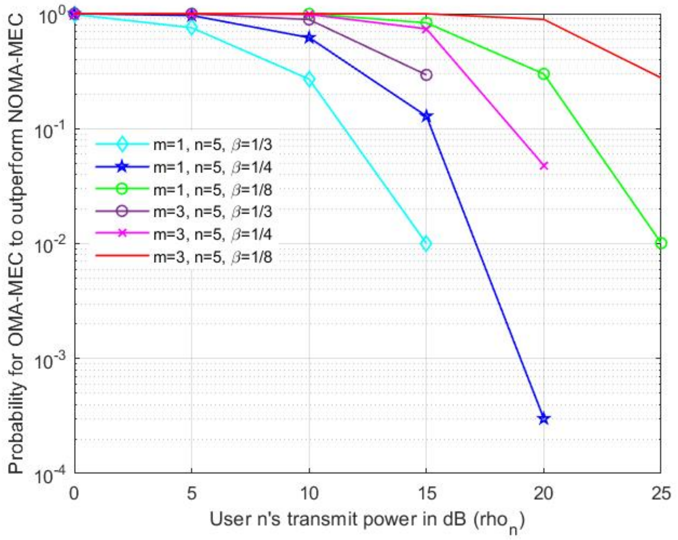
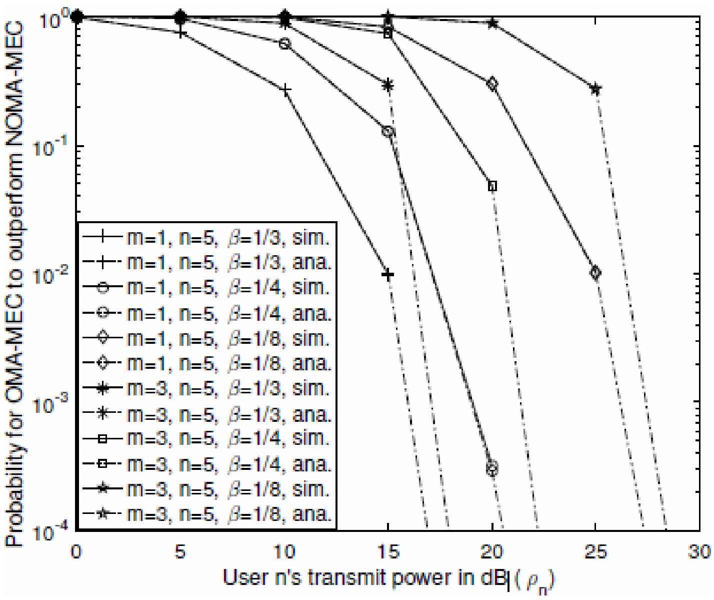


Figure 7: figure 4R



(a) $\rho_m = 10$ dB

Figure 8: figure 4B

- Here figure 4 represents the impact of NOMA-MEC on the energy consumption by plotting the probability for OMA-MEC to outperform NOMA-MEC.

- The ratio of the energy consumption of OMA mode and the energy consumption of NOMA mode is 2β, where β is an energy reduction parameter and needs to be smaller than $1/2$ so that NOMA can be better than OMA.

- If $\beta = 1/8$ means energy used by NOMA-MEC is quarter of the energy used by OMA-MEC. In this case, from figure we can see that the probability that OMA-MEC outperforms NOMA-MEC reduces to 10^{-2} for m=1. So , we can say that NOMA-MEC is better than OMA-MEC for the energy consumption.

- Reproduced Figure-5

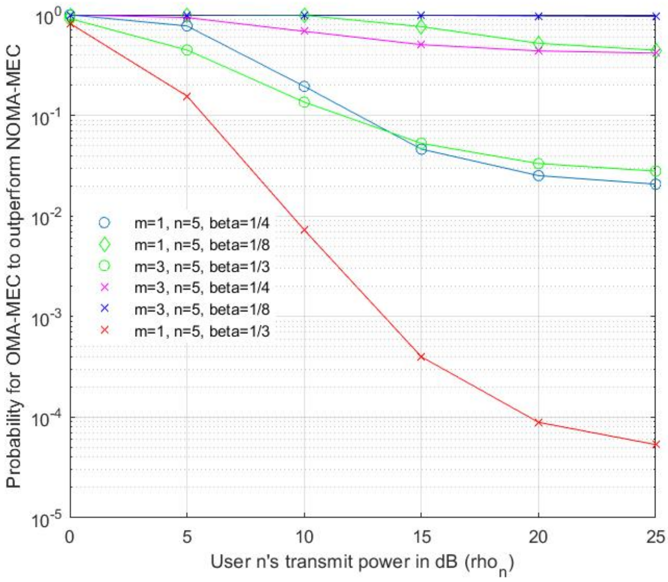
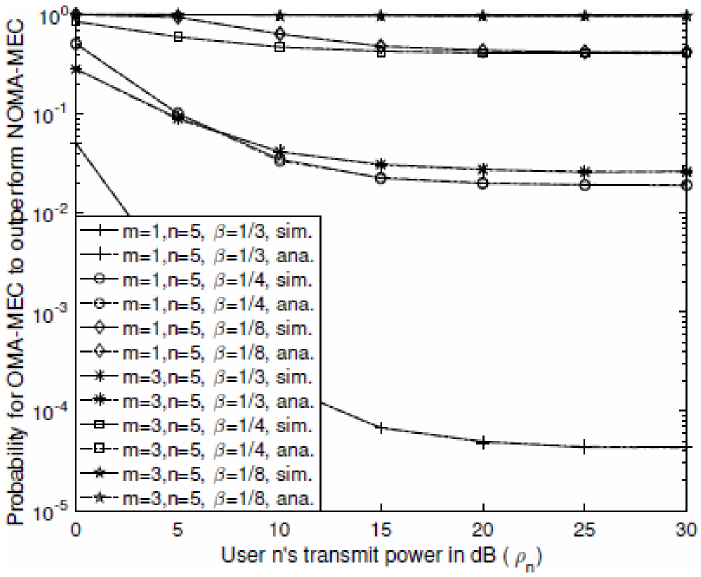


Figure 9: figure 5R



(b) $\eta = \frac{\rho_n}{\rho_m} = 5$

Figure 10: figure 5B

- Here figure 5 represents the impact of NOMA-MEC on the energy consumption by plotting the probability for OMA-MEC to outperform NOMA-MEC by taking different parameters and the condition that ρ_m and ρ_n approaches infinity such that their ratio remains constant.

- From figure, Here also Pairing of users plays major role for energy consumption.

- If m=1 and n=5 which is pairing of strong user and the weak user , the probability approaches to 10^{-4}. So , we can say that NOMA-MEC is better than OMA-MEC for the energy consumption.
- In figure, we can see that for m=1, the probability approaches to 10^{-4} while for m=3, the probability approaches to 10^{-2}; thus m=1 saves more energy than for m=3.

3 Contribution of team members

3.1 Technical contribution of all team members

Tasks	Umang Kamdar	Jainesh Patel	Vatsal Patel
Reproduction of Fig-1	✓	✓	✓
Reproduction of Fig-2	✓	✓	✓
Reproduction of Fig-3	✓	✓	✓
Reproduction of Fig-4	✓	✓	✓
Reproduction of Fig-5	✓	✓	✓

3.2 Non-Technical contribution of all team members

Enlist the non-technical contribution of members in the table. Redine the tasks (e.g Task-1 as report writing etc.)

Tasks	Umang Kamdar	Jainesh Patel	Vatsal Patel
Report writing	✓	✓	✓
Creation of MIRO frames	✓	✓	✓
Gathering of references	✓	✓	✓

4 References

[1] H. A. David and H. N. Nagaraja, Order Statistics. John Wiley, New York, 3rd ed., 2003.

[2] I. S. Gradshteyn and I. M. Ryzhik, Table of Integrals, Series and Products, 6th ed. New York: Academic Press, 2000.

[3] M. Vaezi, G. A. A. Baduge, Y. Liu, A. Arafa, F. Fang, and Z. Ding, "Interplay Between NOMA and Other Emerging Technologies: A Survey," IEEE Transactions on Cognitive Communications and Networking, vol. 5, no. 4, pp. 900–919, 2019.