Performance of Efficient Multi Cell Massive MIMO System

Abhishek Thakur

Supervisor
Dr. Ramesh Ch. Mishra

Department of Electronics & Communication Engineering
Indian Institute of Information Technology Senapati, Manipur

EC400 Project II
April 2019

Outline

Introduction

Massive MIMO (multiple input, multiple output) is a key technology for 5th generation wireless communication to provide:

- Higher spectral efficiency (SE).
- Data throughput in the fifth-generation (5G) wireless technology
- In this technology, multiple antennas are used at both the source (transmitter) and the destination (receiver).
- Main Benefits: Huge spectral efficiency, high reliability and high energy efficiency.

Massive MIMO System

- A generic Massive MIMO system is shown, Where a BS equipped with M antennas serving K user terminal.
- It is assumed that $M >> K$.
- One coherent time interval T is divided into two phases: duration τT is divided for Training phase and rest for the information and power transmission.

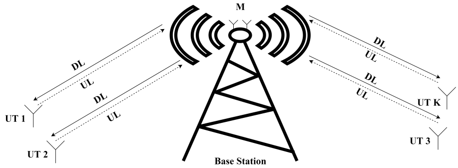


Figure: A generic Massive MIMO system having M antenna at BS and K UT.

Literature Survey

- Massive MIMO for the next generation wireless system.[1]
- Downlink achievable rate of massive MIMO enabled swipt systems over Rician channel.[2]
- The downlink transmission is estimated by the uplink data transmission. Channel reciprocity is discussed here.[3]

[1] larsson2014massive E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, "Massive mimo for next generation wireless systems," *IEEE communications magazine*, vol. 52, no. 2, pp. 186–195, 2014.

[2] dong2018downlink G. Dong, H. Zhang, and D. Yuan, "Downlink achievable rate of massive MIMO enabled swipt systems over Rician channels," *IEEE Communications Letters*, vol. 22, no. 3, pp. 578–581, 2018.

[3] raeesi2018performance O. Raeesi, A. Gokceoglu, Y. Zou, E. Björnson, and M. Valkama, "Performance analysis of multi-user massive MIMO downlink under channel non-reciprocity and imperfect CSI," *IEEE Transactions on Communications*, 2018.

Literature Survey

- Wireless system with unlimited number of antenna.[4]
- There is some limit which is decided by energy efficiency of the system.[5]
- Throughput optimization for Massive MIMO syatem.[6]

---

[4]marzetta2010noncooperative T. L. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," *IEEE Transactions on Wireless Communications*, vol. 9, no. 11, pp. 3590–3600, 2010.

[5]khan2017energy T. A. Khan, A. Yazdan, Y. Maguire, and R. W. Heath, "Energy efficiency of wireless information and power transfer with massive MIMO," *85th Vehicular Technology Conference (VTC Spring), IEEE*, pp. 1–5, 2017.

[6]yang2015throughput G. Yang, C. K. Ho, R. Zhang, and Y. L. Guan, "Throughput optimization for massive MIMO systems powered by wireless energy transfer," *IEEE Journal on Selected Areas in Communications*, vol. 33, no. 8, pp. 1640–1650, 2015.

Literature Survey

- Various Linear precoding technique for Massive MIMO is discussed here.[7]
- Frequency reuse factor or sub bands to reduce the pilot contamination.[8]

[7] beulah2015performance V. A. Beulah and S. Markkandan, "Performance analysis of precoding techniques for massive MU-MIMO systems," *IEEE International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS)*, pp. 1–5, 2015.

[8] chataut2018optimal R. Chataut and R. Akl, "Optimal pilot reuse factor based on user environments in 5G massive mimo,"*IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC)*, pp. 845–851, 2018.

Problem Formulation

- Most of the research in this field evaluated performance under the assumption that the channel is reciprocal. Not much work is done to understand the impact of channel reciprocity errors on the system performance. So, there was a need of investigation on massive MIMO performance under reciprocity error.
- Also, As the global demand for wireless data traffic is increasing also new technology like IOTs are evolving and around 23 billion device will be internetworked by 2020 also wireless traffic is doubled every two year. So there is a improvement needed in area and data throughput.

Problem Formulation

After going through the above literature survey, we came across the following problem which includes:

- The simultaneous wireless information and power transfer performances like harvested energy, achievable rate of massive MIMO in channel reciprocity and channel reciprocity errorr.
- Optimization of area or data throughput by increasing the spectral efficiency of massive MIMO without increasing the bandwidth and cell density.
- Performance of massive MIMO system is analyzed in various linear precoding scheme like ZF and MR.
- We have also tried to quantify the meaning of massive by deriving the energy efficient regime of massive MIMO.
- BER performance of Massive MIMO.

Channel Matrix

- Rician channel is used as the transmission range is quite short in massive MIMO system, there is dominant line of sight propagation present.

The pdf of rician fading can be expressed as:

$$F_R(r) = \begin{cases} \frac{r}{\sigma^2} e^{-(\frac{r^2+A^2}{2\sigma^2})} I_o(\frac{Ar}{\sigma^2}) & 0 \leq r < \infty, A \geq 0 \\ 0 & otherwise \end{cases} \tag{1}$$

The rician distribution can also be described in terms of parameter 'K' which is called as rician factor which is the ratio of deterministic signal power and variance of the multipath envelope.

$$K_{dB} = 10 log(\frac{A^2}{2\sigma^2}) \tag{2}$$

Channel Matrix

- The channel vector between BS and k-th user is given as:

$$\vec{h}_k = \sqrt{\frac{\beta K}{K+1}}\vec{A} + \sqrt{\frac{\beta}{K+1}}\vec{Z} \tag{3}$$

Here, $\beta = Cd^{-\alpha}$ is the large scale fading depend on the distance d between BS and user. $\vec{A}$ denotes the deterministic signal component, $\vec{Z} \sim \mathcal{N}(0_M, I_M)$ denotes the random component of the k-th user.

Channel Reciprocity Error Modelling

- The reciprocity error matrix is given as:

$$\vec{E}_r = \vec{H}_t \vec{H}_r^{-1} = diag(\frac{h_{t,1}}{h_{r,1}} \dots \frac{h_{t,m}}{h_{r,m}} \dots \frac{h_{t,M}}{h_{r,M}}) \quad (4)$$

- The channel matrix after considering the reciprocity error i.e, effective channel response is given as:

$$\vec{H}_{ij} = [diag(\vec{h}_k)]\vec{E}_r = [\vec{H}_k]\vec{E}_r \quad (5)$$

- When, $\vec{E}_r = 1$ i.e, $(\vec{H}_{it} = \vec{H}_{ir})$ then the channel is completely reciprocal i.e, downlink is estimated via uplink transmission.

Downlink Transmission

- In downlink transmission, information signal and power is transmitted to the user k. The information signal transmitted to k_{th} user is denoted as x_k. The signal $\vec{y}_k$ received at k_{th} user is denoted as:

$$\vec{y}_k = \underbrace{\sqrt{p_k}\vec{h}_k^H \vec{w}_{lk} x_k}_{\text{desired signal}} + \underbrace{\sum_{j \neq k}^{K} \sqrt{p_j}\vec{h}_k^H \vec{w}_{lk} x_j}_{\text{interference signal}} + \underbrace{\vec{n}_k}_{\text{noise signal}} \tag{6}$$

where p_k represent the transmitted power and $\vec{w}_{lk}$represents the linear precoding vector of the k_{th} user.

Linear Precoding Vector

- Precoding vector for ZF is given as:

$$\vec{w}_{lkZF} = \frac{\hat{\vec{H}}^{\dagger}}{\sqrt{\vec{E} \| \ \vec{H}^{\dagger} \ \|^2}} \tag{7}$$

- Precoding vector for MR is given as:

$$\vec{w}_{lkMR} = \frac{\hat{h}_k}{\sqrt{\vec{E} \| \ \hat{h}_k \ \|^2}} \tag{8}$$

Harvested energy

- The energy harvested by the k_{th} user is given as:

$$E_k = \eta_k \vec{E}[| \, h_k^H \sum_{t=1}^{K} p_t w_{lk} \, |^2] \tag{9}$$

Here, η_k is the conversion efficiency at the UT.

- ρ_k fraction of received power is used for the decoding information.
- while as remaining fraction $(1 - \rho_k)$ is used for harvesting energy.

Simulated Result

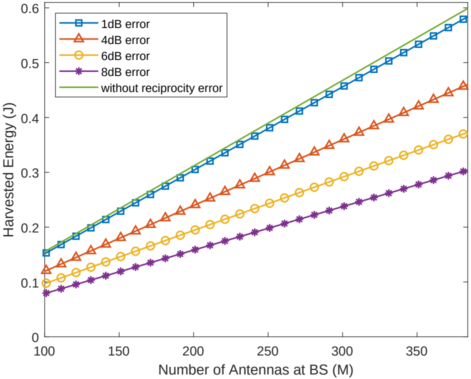


Figure: Average harvested energy versus number of antennas at BS for different values of reciprocity error amplitude.

Spectral Efficiency

- Spectrum efficiency is the efficient use of bandwidth so that the maximum amount of data can be transmitted with minimized errors.
- Spectral efficiency which is measured in bits/s/Hz per unit area or bits/s/Hz/cell is upper bounded by the shanon capacity or achievable rate i.e, $(1-\tau) \times log_2(1+SINR)$.
  The Achievable Rate (bits/s/Hz) of the k_{th} user is given as:

$$R = (1-\tau) log_2 \left(1 + \frac{\rho_k p_k \vec{E}(\mid \vec{h}_k^H \vec{w}_{lk} x_k \mid^2)}{\vec{E} \mid \sum_{j \neq k}^{K} \sqrt{p_j} \vec{h}_k^H \vec{w}_{lk} x_j) \mid^2 + \sigma_n^2} \right) \tag{10}$$

Simulated Result

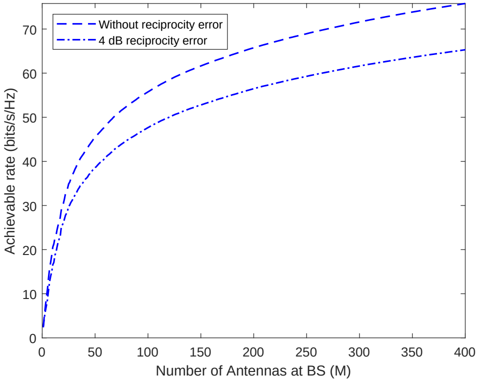


Figure: Average achievable rate versus number of antennas at BS.

Area Throughput

- To keep up with the rapid increasing traffic growth, a key goal of the 5G technologies is to improve the area throughput by orders of magnitude hundred times, higher throughput are regularly mentioned as 5G design goals.

$$Throughput = BW * CD * SE \tag{11}$$

Here, bandwidth (Hz) is denoted as BW and cell density (cells/km^2) is denoted as CD and spectral efficiency (bits/sec/Hz per unit area) or (bits/sec/Hz per cell) is denoted as SE.

Simulated Result in MR precoding

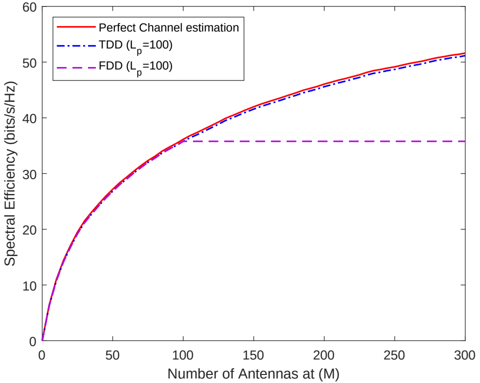


Figure: Average downlink spectral efficiency versus number of BS antennas is plotted with maximum ratio precoding ($L_p = 100$).

Simulated Result in ZF precoding

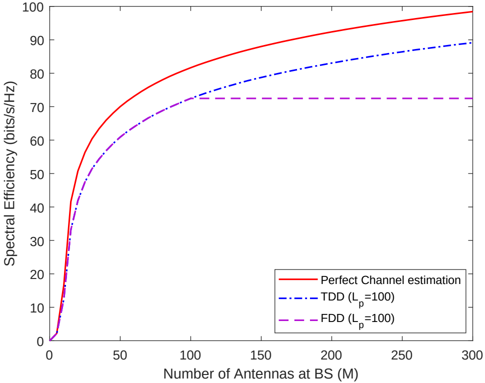


Figure: Average downlink spectral efficiency versus number of BS antennas is plotted with zero forcing precoding ($L_p = 100$).

TDD or FDD

- FDD: In frequency division duplex (FDD) mode the bandwidth is split into two separate parts: one for the uplink and one for the downlink.
- TDD: In time-division duplex (TDD) mode where the whole bandwidth is used for both downlink and uplink transmission. Hence, TDD is the preferable mode since it not only requires shorter pilots than FDD, but is also highly scalable since the pilot length is independent of the number of BS antennas.

Energy Efficiency

- Energy efficiency is simply achievable rate per unit power consumption at the base station. Its unit is bits/sec/joule.
- The power consumed is in the form of circuitry power consumption and transmitted power.
  The circuit power consumption includes:
- The computational power, $P_c = \frac{2MK^2B}{S\eta_{BS}}$. η_{BS} is the computational efficiency, it is measured is flops/watt and $\frac{B}{S}$ is coherence block per second.
- KRP_d is the power consumed in decoding the received data, R is an user average achievable rate and P_d is the power consumption by the decoder.

Energy Efficiency

- P_l is the power consumed in the linear precoding process at BS for ZF processing power consumed is $\left(\frac{B(\frac{K^3}{3}+3MK^2+MK)}{S\eta_{BS}}\right)$.

Energy efficiency is given as:

$$EE = \frac{(1-\tau)log_2\left(1+\frac{\rho_k p_k \vec{E}(|\vec{h}_k^H \vec{w}_{lk} x_k|^2)}{\vec{E}|\sum_{j\neq k}^{K}\sqrt{p}_j \vec{h}_k^H \vec{w}_{lk} x_j)|^2+\sigma_n^2}\right)}{KRP_d + \frac{2MK^2B}{S\eta_{BS}} + \left(\frac{B(\frac{K^3}{3}+3MK^2+MK)}{S\eta_{BS}}\right) + P_f} \tag{12}$$

Here, P_f is the fixed power consumption in deploying antenna at BS.

Simulated Result

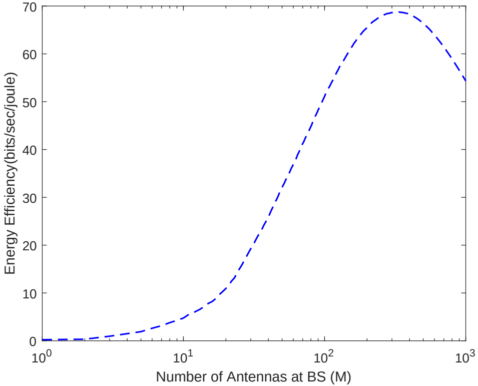


Figure: Energy efficiency curve.

Frequency Reuse Factor

- Each cell has been allocated a frequency band. Each channel is equidistant from its co-channel and hence the co-channel interference is optimally distributed. F is called as the frequency reuse factor or pilot reuse factor that is given as:

$$F = i^2 + ij + j^2 \tag{13}$$

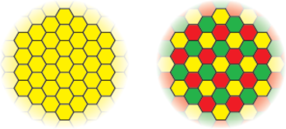
Here, i is the number of cells in horizontal direction and j is the number of cells i.e, 60° to the horizontal direction. For the value of i=(0,1,2...) and j= (0,1,2...), F can take the value (1,3,4,7...).

Frequency Reuse Factor

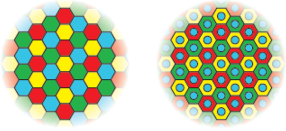
- We note that with a pilot reuse factor of $f = 7$, one can divide the cells into seven different disjoint group of different frequency range.
- As Interference is more likely to occur at the boundary of the cell than the center of the cell. So, we can divide each cell into twosubcells: cell edge and cell center. The latter is known as fractional pilot reuse.
- Pilot reuse factor is increased to minimize the pilot contamination or co-channel interference, but it divides the available resource bandwidth.

Frequency Reuse Factors

- Only the cells with the same color use the same pilot sequences, and thereby cause pilot contaminated interference. In the lower right case, each cell is divided into two sub-cells with different sets of pilots.
- There is no contamination between cells with different colors.



$f = 1$ $f = 3$



$f = 4$ $f = 4$

Simulated Result in MR Precoding

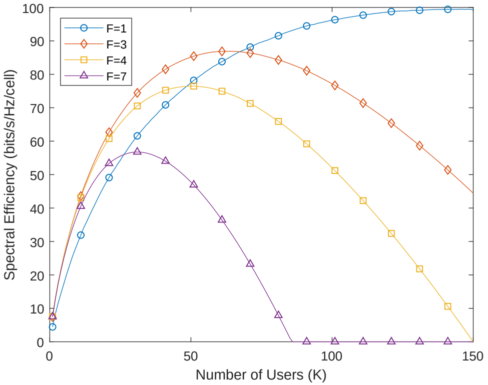


Figure: Average spectral efficiency versus the number of users, with maximum ratio precoding and different pilot reuse factors at SNR=10dB.

Simulated Result in ZF Precoding

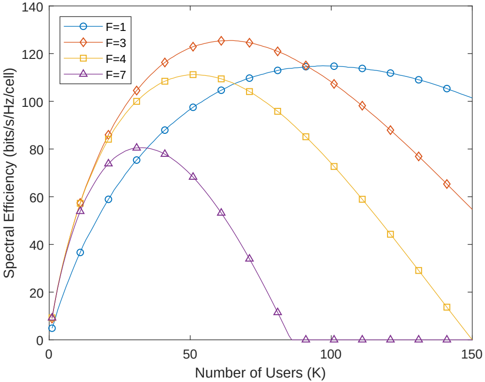


Figure: Average spectral efficiency versus the number of users, with zero forcing processing and different pilot reuse factors at SNR=10dB.

Spectral Efficiency Maximization

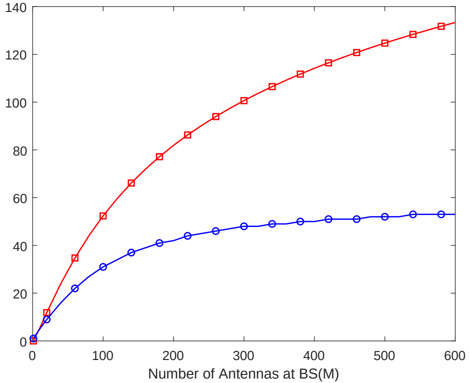


Figure: Average spectral efficiency versus the number of BS antennas, with ZF processing at pilot reuse factor f = 3, and an SNR of 10 dB, and the corresponding number of users to achieve the highest spectral efficiency.

Spectral Efficiency Maximization

- In 4G network communication system, spectral efficiency is in the range of 2-4 bit/s/Hz/cell.
- The Massive MIMO network as considered in simulated result achieves 53 bit/s/Hz/cell using M=100 antennas, which is a 20 times improvement over 4G network
- With M=400 antennas the Massive MIMO system achieves around 112 bit/s/Hz/cell, which is an incredible 40 times improvement over previous generation network.
- Thus, spectral efficiency and number of user is maximized in 5G communication.

Bit Error Rate

- Massive MIMO is the asymptotically noise and interference free communication.
- BER is almost negligible as the number of antenna is too large at the base station and the mobile station. The BER in multi antenna system is given as:

$$BER \approx \binom{2M-1}{M} \left(\frac{1}{SNR}\right)^{M} \tag{14}$$

For low SNR, BER is almost negligible. Thus, massive MIMO is a errorless and noise free communication system.

Simulated Result

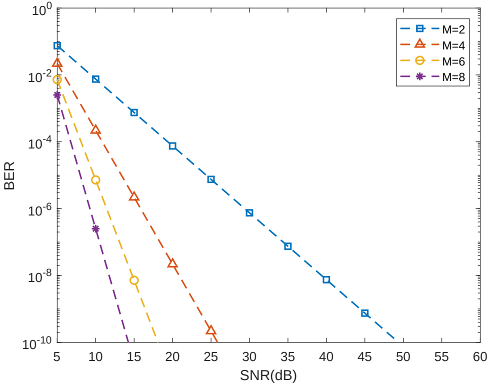


Figure: BER versus SNR(dB) for different smaller values of BS antenna M.

Simulated Result

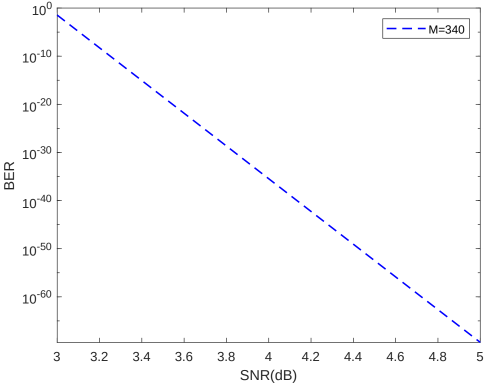


Figure: BER versus SNR(dB) at M=340.

Observation Table

M(No. of antenna)	SNR(dB)	BER(approx.)
2	49	10^{-10}
4	26	10^{-10}
6	18	10^{-10}
8	14	10^{-10}
340	5	10^{-70}

Table: SNR and BER for different value of M.

Conclusion

- We have evaluated the performance of massive MIMO in this paper, we have analyzed the average harvested energy and achievable rate of massive MIMO under rician fading channel.
- Also, due to channel reciprocity error performance has decreased.
- We have quantified the term massive through energy efficiency curve.
- We used various linear precoding scheme to estimate the channel state information and maximize the spectral efficiency.
- We have used the technique of frequency reuse to minimize pilot contamination.

Conclusion

- Frequency reuse factor is increased when user density is less and vice versa for user's resource optimization.
- Also, we have seen that massive MIMO gives around 50 times more spectral efficiency than the previous 4G network technology.
- Simulated result shows that massive MIMO is also a error and interference free communication system, for small value of SNR, bit error rate is negligible.
- Hence, we have analyzed the performance of energy efficient multi cell massive MIMO system.

References I

- E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, "Massive MIMO for next generation wireless systems," *IEEE communications magazine*, vol. 52, no. 2, pp. 186–195, 2014.
- G. Dong, H. Zhang, and D. Yuan, "Downlink achievable rate of massive MIMO enabled swipt systems over Rician channels," *IEEE Communications Letters*, vol. 22, no. 3, pp. 578–581, 2018.
- O. Raeesi, A. Gokceoglu, Y. Zou, E. Björnson, and M. Valkama, "Performance analysis of multi-user massive MIMO downlink under channel non-reciprocity and imperfect CSI," *IEEE Transactions on Communications*, 2018.
- D. Mi, M. Dianati, L. Zhang, S. Muhaidat, and R. Tafazolli, "Massive MIMO performance with imperfect channel reciprocity and channel estimation error," *IEEE Transactions on Communications*, vol. 65, no. 9, pp. 3734–3749, 2017.
- T. L. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," *IEEE Transactions on Wireless Communications*, vol. 9, no. 11, pp. 3590–3600, 2010.

References II

- T. A. Khan, A. Yazdan, Y. Maguire, and R. W. Heath, “Energy efficiency of wireless information and power transfer with massive MIMO,” *85th Vehicular Technology Conference (VTC Spring), IEEE*, pp. 1–5, 2017.
- G. Yang, C. K. Ho, R. Zhang, and Y. L. Guan, “Throughput optimization for massive MIMO systems powered by wireless energy transfer,” *IEEE Journal on Selected Areas in Communications*, vol. 33, no. 8, pp. 1640–1650, 2015.
- T. M. Nguyen and L. B. Le, “Joint pilot assignment and resource allocation in multicell massive MIMO network: Throughput and energy efficiency maximization,” pp. 393–398, 2015.
- V. A. Beulah and S. Markkandan, “Performance analysis of precoding techniques for massive MU-MIMO systems,” *IEEE International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS)*, pp. 1–5, 2015.
- R. Chataut and R. Akl, “Optimal pilot reuse factor based on user environments in 5G massive mimo,”*IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC)*, pp. 845–851, 2018.

References III

A. Ruperee and S. Nema, “Fractional frequency reuse to enhance down link performance in mu massive mimo,” *International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET)*, pp. 1804–1809, 2016.

THANK YOU