Distributed MIMO

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***Abstract*—To evaluate the advantages of distributed base stations in multi-user multiple-input-multiple-output systems, we investigate the effects of different linear receivers (maximum ratio combining, zero forcing, and minimum mean squared error) and the distribution of antennas. Three key aspects have been analysed in this research: the system model for a single base station and multiple base stations, the affects on the performance from distributing the base stations and the performance of a massive distributed array of individual antennas. During this investigation, we will also discuss the effects of varying parameters and compare alternative models. From investigating and simulating we model the performance of different systems and can observe the advantages and disadvantages in comparison. The distribution of antennas in a circle around the center of a cell, at an optimal distance, improves the sum capacity of the system by approximately 5 bps/Hz. For massive antenna systems, the Signal-to-interference-plus-noise ratio is majorly increased by increasing the distribution of antennas.**

I. Introduction

5$^{\text{th}}$ Generation wireless systems have a growing interest in Massive Distributed MI-MO that is aimed to increase the data rates up to 5 Gbps, with a network latency under a millisecond and also increase the capacity and efficiency by a factor of 1000 [1]. This is very necessary with growing demands for higher data rates and user density increasing. The previous generation of wireless communication required high-powered cell towers to radiate signals over long distances, while 5G will be transmitted via large quantities of small cell stations located around dense areas, positioned on buildings and light poles. The problem with just increasing the number of MI-MO streams from a single base station is the channels become too correlated. By distributing the antennas and increasing the spatial separation, the performance improves. This uses an increased frequency like those used in broadband although the major trade-off is that it is more susceptible to wall loss. Multiple antennas are to communicate with one user at a time to assure connection and minimise fading.

The focus on this paper is to model and simulate the performance of a channel in a single cell, using up-link linear receiving and down-link linear precoding techniques and observe how the distribution of antennas affects the performance. The transmitting antennas are to be distributed geographically in circle array around the center of the cell, assuming they are connected via fiber optics with negligible delay and infinite bandwidth. The capacity of the systems is to be determined from the simulation by varying the signal-to-noise ratio, and comparing the different plots.

II. System Model

The model is to determine the maximum achievable rate for the channel, by observing the systems ergodic sum spectral efficiency, where the model is derived from prior research, for 4 users, K, in a cell. In this system the number of users, M, will be 6 which is the same as the model investigated [2][3]. This uses the equations II-.1 and II-.2 below where the SINR is the variable.

$$R_k = log(1 + SINR_{ul/dl,k}) \tag{II-.1}$$

$$E[R_{sum}] = E\Big[\sum_{k=1}^{K} R_k] \tag{II-.2}$$

The model for each SINR varies for each system, as each method utilises different techniques, for both up-link and down-link. The up-link Maximum ratio combining, MRC, maximises the SNR on each stream and ignores multi-user interference. The SINR for each k user is shown below in equation II-.3. The up-link Zero Forcing, ZF, method removes inter-user interference by diagonalizing the channel and ignores the effects of noise. The SINR for this model is shown below in in equation II-.4 The up-link Minimum Mean Squared Error, MMSE, which minimises the error signal received, the model for this is also shown below as equation II-.5.

$$SINR_{mrc,k} = \frac{p_{ul}\beta_k ||h_k||^4}{\sigma^2||h_k||^2 + p_{ul}\sum_{k'\neq k}^{K}\beta_{k'}|h_k^H h_{k'}|^2} \tag{II-.3}$$

$$SINR_{zf,k} = \frac{p_{ul}\beta_k}{\sigma^2[(H^H H)^{-1}]_{k,k}} \tag{II-.4}$$

$$SINR_{mmse,k} = p_{ul}\beta_k h_k^H \Big(p_{ul}\beta_k \sum_{k'\neq k}^{K} h_{k'}h_{k'}^H + I_M\Big)^{-1} h_k \tag{II-.5}$$

In this simulation we generate an MxK channel, H, which is a complex random variable with the distribution $H \sim CN(0, 1)$, this produces the variation in each simulation run hence why the expectation is taken. The dependent variable in the equations above is p_{ul}, which is determined as $\frac{\sigma^2}{SNR}$ where σ^2 is the noise power equal which is assumed to be 1 and SNR is the independent variable varying between -20 and 20 dB in the first simulation. The other unknown variable above is β_k, the received power, which is equal to 1 initially, replicating the known model. This produces the graph below in Figure 1, it can be seen that MRC reaches maximum capacity at 7bps/Hz where MMSE and ZF converge while continuing to increase.

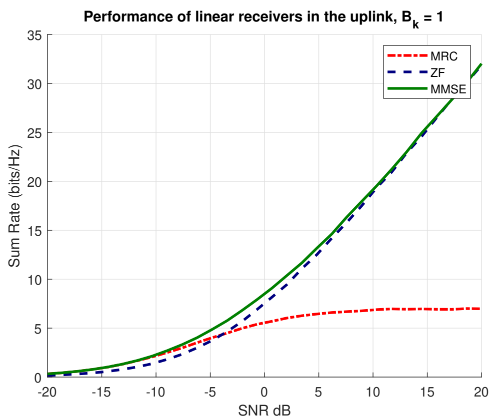

Figure 1: MU-MIMO Up-link Performance

The next part of this aspect is the down-link model, which uses a similar model, shown below in equation II-.6 and the equations in II-.7. Where W is determined from the precoder, also of size MxK. The performance of this model is shown in Figure 2, which has a decreased sum rate compared to Up-link for all precoders. It can be observed that the ZF is now significantly weaker than MMSE, as it does not converge, running nearly parallel on the graph in the higher SNR values. MMSE also being slightly better for the lower SNR value, and also it begins being equal to MRC then begins to diverge at -10dB

$$SINR_{dl,k} = \frac{p_{dl}\eta\beta_k|h_k^H w_k|^2}{\sigma^2||h_k||^2 + p_{dl}\sum_{k'\neq k}^{K}\eta\beta_{k'}|h_k^H w_{k'}|^2} \tag{II-.6}$$

$$W = \begin{cases} H & \text{MRC} \\ H(H^H H)^{-1} & \text{ZF} \\ H(H^H H + \frac{K}{SNR})^{-1} & \text{MMSE} \end{cases} \tag{II-.7}$$

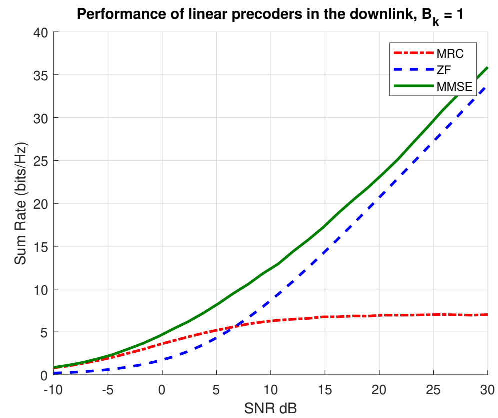

Figure 2: MU-MIMO Down-link Performance

The previous model produces a general performance of the systems although it lacks consideration of the size of the channel, the power used, and shadowing. This was ignored by setting $\beta_k = 1$, this value is the received power and is expressed as shown in equation II-.8 below. Where P_t is equal to SNR variable, L is log-normal shadowing with a variance of 8dB, d is the distance from a cell and γ is equal to 3 which is the constant path loss exponent [3].

$$\beta_k = P_t L d^{-\gamma} \tag{II-.8}$$

The variable of interest in this equation is the distance, which is to be determined using the following method. The model is desired to have 95% probability of having a received power greater than 0dB for a transmit power of 20dB. To determine this value, the CDF below was generated in Figure 3 which resulted in a distance of 1.68 units for Prob(β_k > 0dB) = 95%. This distance was determined by varying distance which shifted the CDF plot left or right by decreasing or increasing, respectively.

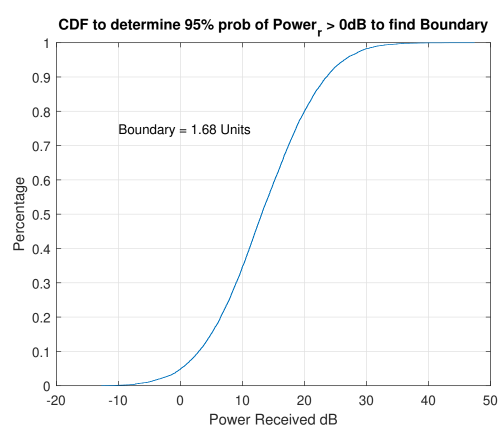

Figure 3: CDF to Determine Boundary Value

The distance value determined previously is to be used as the boundary for the cells in the future models to assure realistic performance. The users are to be dropped at random locations within this cell in groups of K users. This is shown below in Figure 4 where the base stations have been placed evenly around a circle with a radius equal to the boundary divided by the square root of two. The optimal distribution of cells is out of scope for this project, so it is simple to distribute them on a circular array. However, it was found that this was the optimal radius for the base station location when placed in a circle array for maximum performance.

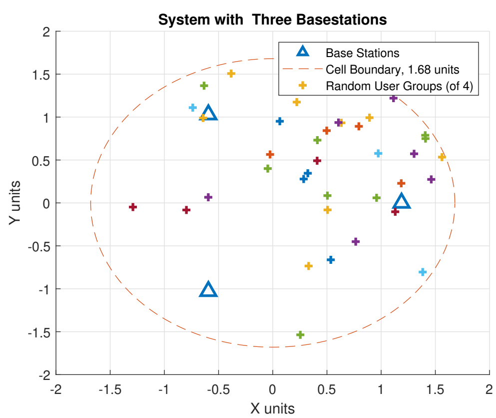

Figure 4: Geographical Distribution of 3 Base Stations

By implementing this model we can distribute multiple base stations to different locations, altering the SINR as the Power received is dependant on the distance from the power stations. By distributing the base station antennas into 3 separate base stations as shown in figure 4, the performance was expected to improve as the users become closer to antennas. This was implemented for the up-link which can be seen in Figure 5 below. The more right-hand side plots being the collocated case, and the other being the distributed case. An improvement can be noticed in each case, although it is more noticeable for MMSE and ZF. The sum capacity being increased by around 5 bps/Hz between 0db and 20db.

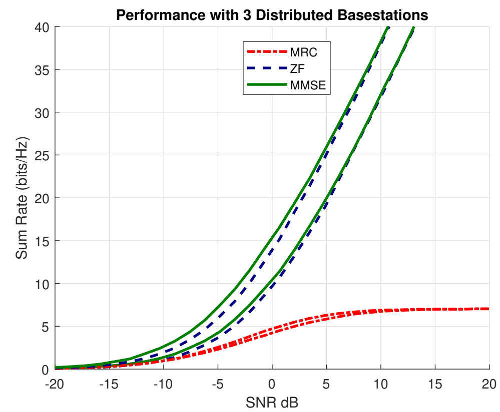

Figure 5: Sum Capacity for Collated and Distributed Base Stations

To get a different perspective on the performance of the systems, the CDFs were produced for the SINR of each channel at an SNR of 20dB. Figure 6 below shows the increase in performance for MMSE and ZF for the collocated case and the antennas being distributed between 2 and 3 base stations. The improvement can be observed as the amount of the base stations increase, MMSE probability of SINR being greater than 0dB going from 70% to 85% and the ZF increasing from 60% to 76%.

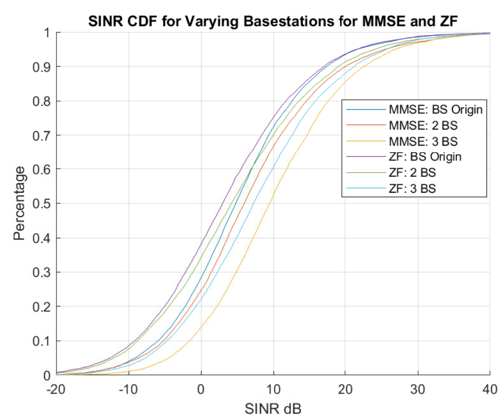

Figure 6: CDF for Varying Base Station Distributions

The final part of this investigation was to model the performance when distributing a massive array of antennas. Figure 7 below shows the increase of SINR by distributing 128 antennas around a circular array in a cell. This was repeated for ZF and MMSE and it can be observed that the linear receivers did not impact the performance as they have a very similar plot. It is unknown to us why this is the case, it expected that the system approaches a level of maximum saturation where the system can not get any better.

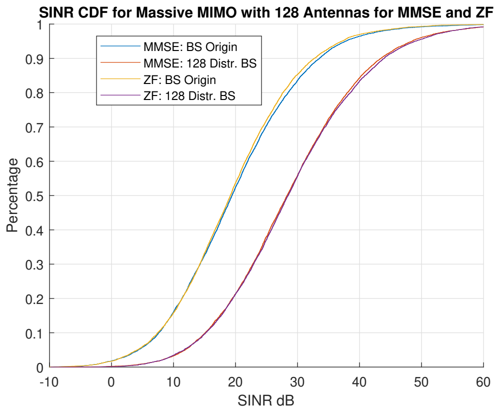

Figure 7: CDF for Massive MU-MIMO, Collated and Distributed

III. Conclusion

We have presented a study of the distributed antenna performance for different linear precoders. We have shown that the increase in the distribution of antennas increases the performance as the channels become less correlated and distance decrease. With analysis and simulation, we have shown how much the system is expected to improve using a known model. Furthermore, we have shown how the sum capacity of the system relates to the signal-to-noise ratio of the power transmitted.

References

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[2] Tataria, Harsh. (2017). Analysis of Multiuser Cellular Systems in Heterogeneous Channels

[3] Hien Quoc Ngo. (2015). Massive MIMO: Fundamentals and System Designs