Good morning , my name is Xinyuan Xu.

This is the title of my final year project: Design and evaluation of beyond 5G wireless communication system.

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The backbone of this presentation would be my learnings about Rate Splitting, which is the actual topic of my FYP. I will first explain how my project title leads to Rate Splitting by sharing some very basic understandings. Then I will explain what has been learnt in this project, which could be split into 3 sections: AO, partial and feasibility.

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As we all know, the latest technology everyday consumer could enjoy falls under the name of 5G, the fifth generation of wireless communication technology. I personally use a 5G mobile phone. The gradual roll out of 5G network and service in UK has been going on for a while. Before the end of 2020, China aims at deploying hundreds of thousands new 5G base stations.

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Among 5G and of course 4G, one of the core technologies is our beloved  
MIMO, multiple input multiple output system. MIMO could offer a lot of  
technical benefits, like spatial multiplexing gain, diversity gain, just to name  
a few. These technical benefits brings many advantages which are more tangible to users, such as increased data rate, reduction in air-latency, improved energy efficiency and interference suppression etc.

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However, the benefits MIMO offer us have some cost. One of the most important one is around the quality of channel state knowledge at transmitter, whose abbreviation is CSIT. Maybe not that precise but easier to understand, the most obvious thing is that using multiple antenna at both sides of transmitter and receiver increases the number of channel gain estimation needed. No matter how you do the training, CSIT need to feedback to the transmitter to do the coordination, but feedback capacity is always limited. What’s more, any channel estimation inevitably has error and CSIT inaccuracy could leads to residual multi-user interference. This has become one of the major bottlenecks of system performance. In short, getting the benefit of MIMO has a high demand on accurate CSIT. So here comes the entry point of RS, instead of keeping the perfect CSIT assumption, RS addresses directly the problem of imperfect CSIT.

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Rate Splitting turns out not to be a brand-new idea, it could be dated back to analysis on two-user interference channel. But here we are applying it to a MU-MIMO system, on downlink, so broadcast channels. We have k users. First, the message of each user would be split into two parts, a part called common message, the other private message. The private message of each user would be coded individually. The common messages of all users could be combined, to get one final common message, which is w0 here, and it would be coded with a publicly available codebook. All the messages would be precoded by a linear beamformer before transmission. Then at each receiver, the common message would first be decoded. Successive Interference Cancellation would be applied before each user decode their private message. Piecing together the user private message and its share of common message we get the original message of each user.

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The beauty of RS, or how could RS be powerful, could be demonstrated by its difference with existing architectures. In non-orthogonal multiple access, superposition coding and SIC is used, and it aims at decoding the interference from other users completely. In Space Division Multiple Access, one jargon is multiple user linear precoding. After separating users in spatial domain, the interference left is treated as noise. Rate Splitting is able to adjust between the two schemes. If we go back to the previous diagram, by controlling the power, or rate or proportion of the common message, the amount of interference to decode is flexible. The paper written by Lina and Bruno has a very detailed explanation on this flexibility and other aspect, if you are interested to know more.

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For the rest of the presentation, I will talk about what I have done in this project. Of course, everything still moves around rates splitting. First, I was learning about an optimization algorithm called AO. The reference paper title is here. Naturally for any comm system, we would like to know its rate region or capacity etc. The problem of maximizing the WSR is not convex but using AO could make it block-wise convex. It has much lower complexity compared to DPC and achieves almost the same capacity region.

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The equation on the left is the problem formulation for WSR maximization. This also the MULP I would refer to later.

The steps on the right are the summary of AO algorithm. The longer name is WSRBF-WMMSE algorithm. In each iteration of optimization, new MMSE receive filter coefficients and weight matrix of user is calculated; the new version of the two is then used to update the precoder. This iterates until the WSR converges, and the convergence speed could be quite quick.

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The figure on the left shows one of the output of my MATLAB code, simulating the 2 user MULP rate region of using AO with perfect CSIT. In particular, the angle between user channels is pi divided by 3. Each line is the convex hull of 43 points and each point is generated using a different weight pair.

The original paper compares the rate region of AO against DPC rate region using only 1 random channel, whose result is a bit asymmetric and arbitrary. Personally, I favor the approach in the paper mentioned earlier, which compares the average rate region of MULP and DPC, of for example 100 random channels. This confirms that AO achieves most of the rate region of DPC.

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The second part of my project has been learning how RS handles partial CSIT. Since we don't have perfect knowledge at transmitter, we have error on channel estimation. One assumption or setting is that the power of the error would decrease when SNR increases. This is called quality scaling factor and determines the degree of freedom of RS. Also, because CSIT is imperfect, we only have a distribution describing the real channel and estimated channel. So the target to maximize has become (Ergodic )ESR.

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The two crucial techniques involved are SAA, and augmented WMSE method.

With SAA, the stochastic nature of the problem has been transformed into a deterministic one. For example, the real capacity is approximated by the average of 1000 random estimated channels, drawn i.i.d from the distribution. After SAA, a relationship between rate and WMMSE could be establish. With a transformation, the rate problem could be transformed into an equivalent problem on the right. By minimizing AWSMSE, the same set of precoders should be obtained.

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Then AO is applied again. The principle behind is the same as before. The process is divided into 3 parts and are all convex. The first two parts have closed form expressions, which greatly speeds up the algorithm. The last part has to be solved by CVX, which is slower, especially when high SNR is simulated.

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This slide shows the output of my simulation code, 2 user ER region, with defined error power. From the left one, it is clear that the rate region of RS is larger than that of MULP. The gap is more obvious at higher SNR. By comparing the two pictures, it can be seen that if the two user channels are less independent, the benefit of rate splitting scheme with only partial CSIT is even larger.

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The last part of my project is an experiment on the feasibility of algorithm used in the 2nd section but with a little variation. Not changing most parts of the code for rate splitting with partial CSIT, except that extra QoS constraints are added. The rate of both user needs to be larger than a threshold rate. As you can imaging, this would change the nature of the problem and it might be impossible to find a solution. For example, if SNR is only 10 dB but threshold rate has been set to 100 bits/s/Hz, instinctively this is not feasible. In the experiment, each data point is obtained by testing 100 random estimated channel, each with a maximum of 4 different precoder initialization methods and 2 decoding orders.

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The next slide shows how feasibility changes when threshold rate changes. When threshold is low, optimization is nearly always feasible. But when threshold is outside rate region, feasibility is zero. In between, the optimization could converge for part of the 100 test channels. By manually tracing the data using breakpoints and temporarily disable the new QoS constraint, I found one potential reason for this transit region. The first iteration of AO might not utilize enough transmit power that is available then with these precoders the threshold rate is not achieved.

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Previously, the variable in experiment has been SNR. On this slide, the variable is the relative weight between users and SNR has been fixed to 20dB. It has been found that at least with these 5 weight pairs, relative weight has no impact on feasibility.

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I would conclude my presentation on some personal reflection.

This my first time doing a research oriented project, rather than making something with specifications. It has been a novel experience and I certainly learnt a lot. One side benefit is that background reading and learning for this project in Autumn term has become a good preview for the Wireless Comm module in Spring term.

The backbone of this project has been optimization methods, from AO for MULP to AO for rates splitting with partial CSIT. They have been much more complicated than what is taught in Optimization lecture, but some key concepts are not hard to grasp. If the whole problem is non-convex, could it be broke up into convex subproblems. If one problem is hard to solve, could it be transformed into an equivalent problem that the output variable would be the same? And so on.

This project practiced again my skills in MATLAB. Also, the computation time needed for the feasibility experiments is too high. Thanks to my supervisor who gave me access to Imperial super computer and thanks to Lina who taught me how to use it and setting up batch processing, I have been able to run the simulation in time for the report. Although these are just tools, not really relevant to rate splitting, I still feel that it is important to share this valuable learning experience.

The last but not the least, this 2020 has been difficult. The pandemic has hit all of us and personally a lot of unfortunate things happened on me. I am glad that I can make it to today and hopefully conclude my 4 year university life.

Thank you for you listening. Do you have any question?