Joint User and Receive Antenna Selection Algorithms for MU-MIMO Systems with Reduced Complexity

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Abstract

Short description of the project

This project investigates the user scheduling strategy of multi-user MIMO (MU-MIMO) systems using a transmit precoding scheme based on maximum signal to leakage and noise ratio (SLNR).

When users are equipped with multiple antennas, joint user and receive antenna selection may be performed and is shown to potentially provide superior performance to user selection schemes where users utilize all available antennas, especially at high SNR.

To overcome the impractical computational burden of exhaustive methods, two suboptimal algorithms are presented in this paper.
The simulation results show that the proposed suboptimal algorithms perform very close to the exhaustive joint user and antenna selection algorithm.

1 CHAPTER 1

Introduction

Wireless Communication History

MIMO is often traced back to 1970s research papers concerning multi-channel digital transmission systems and interference (crosstalk) between wire pairs in a cable bundle: AR Kaye and DA George (1970),Branderburg and Wyner (1974)and W. van Etten (1975, 1976).Although these are not examples of exploiting multipath propagation to send multiple information streams, some of the mathematical techniques for dealing with mutual interference proved useful to MIMO development. In the mid-1980s Jack Salz at Bell Laboratories took this research a step further, investigating multi-user systems operating over "mutually cross-coupled linear networks with additive noise sources" such as time-division multiplexing and dually-polarized radio systems.

Methods were developed to improve the performance of cellular radio networks and enable more aggressive frequency reuse in the early 1990s. Space-division multiple access (SDMA) uses directional or smart antennas to communicate on the same frequency with users in different locations within range of the same base station. An SDMA system was proposed by Richard Roy and Björn Ottersten, researchers at ArrayComm, in 1991. Their US patent (No. 5515378 issued in 1996[8]) describes a method for increasing capacity using "an array of receiving antennas at the base station" with a "plurality of remote users."

MIMO concept

MIMO technology has been standardized for wireless LANs, 3G mobile phone networks, and 4G mobile phone networks and is now in widespread commercial use. Greg Raleigh and V. K. Jones founded Airgo Networks in 2001 to develop MIMO-OFDM chipsets for wireless LANs. The Institute of Electrical and Electronics Engineers (IEEE) created a task group in late 2003 to develop a wireless LAN standard delivering at least 100 Mbit/s of user data throughput. There were two major competing proposals: TGn Sync was backed by companies including Intel and Philips, and WWiSE was supported by companies including Airgo Networks, Broadcom, and Texas Instruments. Both groups agreed that the 802.11n standard would be based on MIMO-OFDM with 20 MHz and 40 MHz channel options.TGn Sync, WWiSE, and a third proposal (MITMOT, backed by Motorola and Mitsubishi) were merged to create what was called the Joint Proposal.In 2004, Airgo became the first company to ship MIMO-OFDM products. Qualcomm acquired Airgo Networks in late 2006.The final 802.11n standard supported speeds up to 600 Mbit/s (using four simultaneous data streams) and was published in late 2009

In radio, multiple-input and multiple-output, or MIMO , is a method for multiplying the capacity of a radio link using multiple transmission and receiving antennas to exploit multipath propagation.MIMO has become an essential element of wireless communication standards including IEEE 802.11n (Wi-Fi), IEEE 802.11ac (Wi-Fi), HSPA+ (3G), WiMAX, and Long Term Evolution (4G LTE). More recently, MIMO has been applied to power-line communication for 3-wire installations as part of ITU G.hn standard and HomePlug AV2 specification.
At one time, in wireless the term "MIMO" referred to the use of multiple antennas at the transmitter and the receiver. In modern usage, "MIMO" specifically refers to a practical technique for sending and receiving more than one data signal simultaneously over the same radio channel by exploiting multipath propagation. MIMO is fundamentally different from smart antenna techniques developed to enhance the performance of a single data signal, such as beamforming and diversity. MIMO can be sub-divided into three main categories: precoding, spatial multiplexing (SM), and diversity coding.

Precoding is multi-stream beamforming, in the narrowest definition. In more general terms, it is considered to be all spatial processing that occurs at the transmitter. In (single-stream) beamforming, the same signal is emitted from each of the transmit antennas with appropriate phase and gain weighting such that the signal power is maximized at the receiver input. The benefits of beamforming are to increase the received signal gain – by making signals emitted from different antennas add up constructively – and to reduce the multipath fading effect. In line-of-sight propagation, beamforming results in a well-defined directional pattern. However, conventional beams are not a good analogy in cellular networks, which are mainly characterized by multipath propagation. When the receiver has multiple antennas, the transmit beamforming cannot simultaneously maximize the signal level at all of the receive antennas, and precoding with multiple streams is often beneficial. Note that precoding requires knowledge of channel state information (CSI) at the transmitter and the receiver.

Spatial multiplexing requires MIMO antenna configuration. In spatial multiplexing,[33] a high-rate signal is split into multiple lower-rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with sufficiently different spatial signatures and the receiver has accurate CSI, it can separate these streams into (almost) parallel channels. Spatial multiplexing is a very powerful technique for increasing channel capacity at higher signal-to-noise ratios (SNR). The maximum number of spatial streams is limited by the lesser of the number of antennas at the transmitter or receiver. Spatial multiplexing can be used without CSI at the transmitter, but can be combined with precoding if CSI is available. Spatial multiplexing can also be used for simultaneous transmission to multiple receivers, known as space-division multiple access or multi-user MIMO, in which case CSI is required at the transmitter.[34] The scheduling of receivers with different spatial signatures allows good separability.

Diversity coding techniques are used when there is no channel knowledge at the transmitter. In diversity methods, a single stream (unlike multiple streams in spatial multiplexing) is transmitted, but the signal is coded using techniques called space-time coding. The signal is emitted from each of the transmit antennas with full or near orthogonal coding. Diversity coding exploits the independent fading in the multiple antenna links to enhance signal diversity. Because there is no channel knowledge, there is no beamforming or array gain from diversity coding. Diversity coding can be combined with spatial multiplexing when some channel knowledge is available at the receiver.

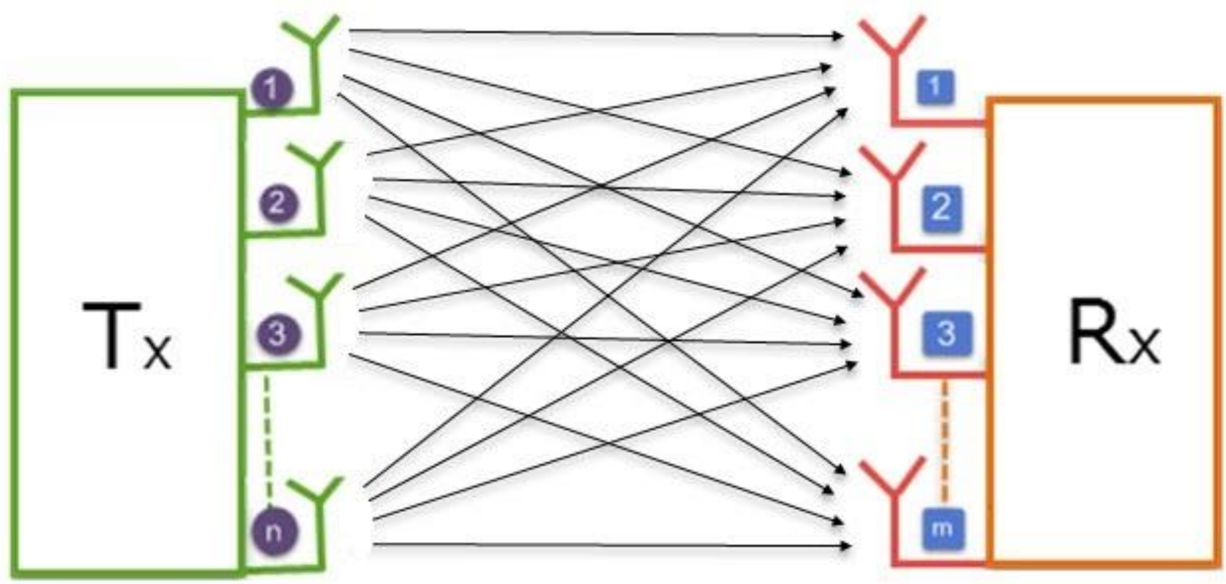

Figure a. 1: BASIC STRUCTURE OF MIMO

MIMO Formats - SISO, SIMO, MISO, MU-MIMO

There is a number of different MIMO configurations or formats that can be used. These are termed SISO, SIMO, MISO and MIMO. These different MIMO formats offer different advantages and disadvantages - these can be balanced to provide the optimum solution for any given application.
The different MIMO formats - SISO, SIMO, MISO and MIMO require different numbers of antennas as well as having different levels of complexity. Also dependent upon the format, processing may be needed at one end of the link or the other - this can have an impact on any decisions made.
SISO, SIMO, MISO, MIMO terminology

The different forms of antenna technology refer to single or multiple inputs and outputs. These are related to the radio link. In this way the input is the transmitter as it transmits into the link or signal path, and the output is the receiver. It is at the output of the wireless link therefore the different forms of single / multiple antenna links are defined as below:

- SISO - Single Input Single Output
- SIMO - Single Input Multiple output
- MISO - Multiple Input Single Output
- MIMO - Multiple Input multiple Output

The term MU-MIMO is also used for a multiple user version of MIMO as described below.

MIMO – SISO

The simplest form of radio link can be defined in MIMO terms as SISO - Single Input Single Output. This is effectively a standard radio channel - this transmitter operates with one antenna as does the receiver. There is no diversity and no additional processing required.

SISO - Single Input Single Output

The advantage of a SIS system is its simplicity. SISO requires no processing in terms of the various forms of diversity that may be used. However the SISO channel is limited in its performance. Interference and fading will impact the system more than a MIMO system using some form of diversity, and the channel bandwidth is limited by Shannon's law - the throughput being dependent upon the channel bandwidth and the signal to noise ratio.

MIMO – SIMO

The SIMO or Single Input Multiple Output version of MIMO occurs where the transmitter has a single antenna and the receiver has multiple antennas. This is also known as receive diversity. It is often used to enable a receiver system that receives signals from a number of independent sources to combat the effects of fading. It has been used for many years with short wave listening / receiving stations to combat the effects of ionospheric fading and interference.

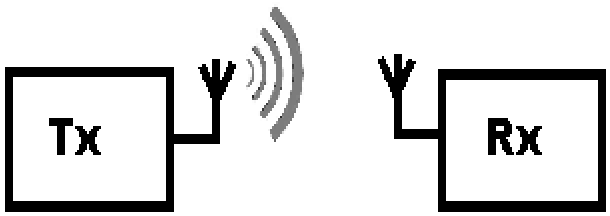

Figure a. 2 : SISO

SIMO - Single Input Multiple Output

SIMO has the advantage that it is relatively easy to implement although it does have some disadvantages in that the processing is required in the receiver. The use of SIMO may be quite acceptable in many applications, but where the receiver is located in a mobile device such as a cellphone handset, the levels of processing may be limited by size, cost and battery drain.

Figure a. 3 : SIMO

There are two forms of SIMO that can be used:

- Switched diversity SIMO: This form of SIMO looks for the strongest signal and switches to that antenna.

- Maximum ratio combining SIMO: This form of SIMO takes both signals and sums them to give the a combination. In this way, the signals from both antennas contribute to the overall signal.

MIMO – MISO

MISO is also termed transmit diversity. In this case, the same data is transmitted redundantly from the two transmitter antennas. The receiver is then able to receive the optimum signal which it can then use to receive extract the required data.

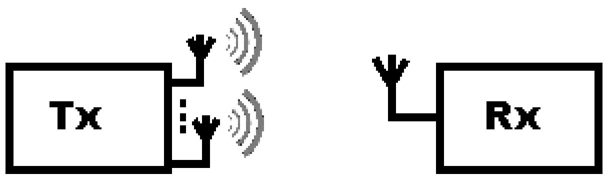

Figure a. 4 :MISO

MISO - Multiple Input Single Output

The advantage of using MISO is that the multiple antennas and the redundancy coding / processing is moved from the receiver to the transmitter. In instances such as cellphone UEs, this can be a significant advantage in terms of space for the antennas and reducing the level of processing required in the receiver for the redundancy coding. This has a positive impact on size, cost and battery life as the lower level of processing requires less battery consumption.
MIMO Where there are more than one antenna at either end of the radio link, this is termed MIMO - Multiple Input Multiple Output. MIMO can be used to provide improvements in both channel robustness as well as channel throughput.

MIMO - Multiple Input Multiple Output

In order to be able to benefit from MIMO fully it is necessary to be able to utilise coding on the channels to separate the data from the different paths. This requires processing, but provides additional channel robustness / data throughput capacity.

Figure a. 5 : MIMO

There are many formats of MIMO that can be used from SISO, through SIMO and MISO to the full MIMO systems. These are all able to provide significant improvements of performance, but generally at the cost of additional processing and the number of antennas used. Balances of performance against costs, size, processing available and the resulting battery life need to be made when choosing the correct option.

MIMO -Multiple Input Multiple Output basics

A channel may be affected by fading and this will impact the signal to noise ratio. In turn this will impact the error rate, assuming digital data is being transmitted. The principle of diversity is to provide the receiver with multiple versions of the same signal. If these can be made to be affected in different ways by the signal path, the probability that they will all be affected at the same time is considerably reduced. Accordingly, diversity helps to stabilise a link and improves performance, reducing error rate.

Several different diversity modes are available and provide a number of advantages:

- **Time diversity:** Using time diversity, a message may be transmitted at different times, e.g. using different timeslots and channel coding.
- **Frequency diversity:** This form of diversity uses different frequencies. It may be in the form of using different channels, or technologies such as spread spectrum / OFDM.
- **Space diversity :** Space diversity used in the broadest sense of the definition is used as the basis for MIMO. It uses antennas located in different positions to take advantage of the different radio paths that exist in a typical terrestrial environment.

MIMO is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used.

General Outline of MIMO system

One of the core ideas behind MIMO wireless systems space-time signal processing in which time (the natural dimension of digital communication data) is complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas, i.e. the use of multiple antennas located at different points. Accordingly MIMO wireless systems can be viewed as a logical extension to the smart antennas that have been used for many years to improve wireless.

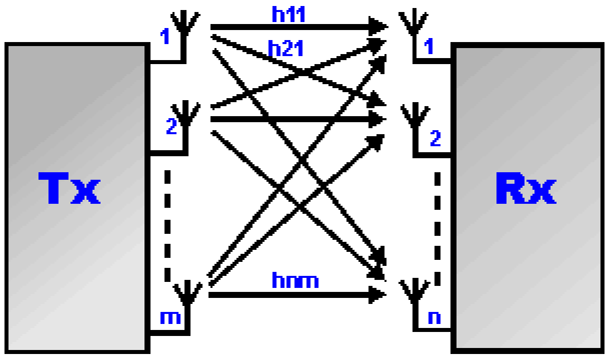

Figure a. 6 : General Outline Of MIMO System

It is found between a transmitter and a receiver, the signal can take many paths. Additionally by moving the antennas even a small distance the paths used will change. The variety of paths available occurs as a result of the number of objects that appear to the side or even in the direct path between the transmitter and receiver. Previously these multiple paths only served to introduce interference. By using MIMO, these additional paths can be used to advantage. They can be used to provide additional robustness to the radio link by improving the signal to noise ratio, or by increasing the link data capacity.

The two main formats for MIMO are given below:

- **Spatial diversity:** Spatial diversity used in this narrower sense often refers to transmit and receive diversity. These two methodologies are used to provide improvements in the signal to noise ratio and they are characterised by improving the reliability of the system with respect to the various forms of fading.

- **Spatial multiplexing :** This form of MIMO is used to provide additional data capacity by utilising the different paths to carry additional traffic, i.e. increasing the data throughput capability.

As a result of the use multiple antennas, MIMO wireless technology is able to considerably increase the capacity of a given channel while still obeying Shannon's law. By increasing the number of receive and transmit antennas it is possible to linearly increase the throughput of the channel with every pair of antennas added to the system. This makes MIMO wireless technology one of the most important wireless techniques to be employed in recent years. As spectral bandwidth is becoming an ever more valuable commodity for radio communications systems, techniques are needed to use the available bandwidth more effectively. MIMO wireless technology is one of these techniques.

MU-MIMO

Multi-user MIMO (MU-MIMO) is a set of multiple-input and multiple-output (MIMO) technologies for multipath wireless communication, in which multiple users or terminals, each radioing over one or more antennas, communicate with one another. In contrast, single-user MIMO (SU-MIMO) involves a single multi-antenna-equipped user or terminal communicating with precisely one other similarly equipped node. Analogous to how OFDMA adds multiple-access capability to OFDM in the cellular-communications realm, MU-MIMO adds multiple-user capability to MIMO in the wireless realm.

SDMA,[1][2][3] massive MIMO, coordinated multipoint (CoMP), and ad hoc MIMO are all related to MU-MIMO; each of those technologies often leverage spatial degrees of freedom to separate users.

MU-MIMO leverages multiple users as spatially distributed transmission resources, at the cost of somewhat more expensive signal processing. In comparison, conventional single-user MIMO (SU-MIMO) involves solely local-device multiple-antenna dimensions. MU-MIMO algorithms enhance MIMO systems where connections among users count greater than one. MU-MIMO may be generalized into two categories: MIMO broadcast channels (MIMO BC) and MIMO multiple-access channels (MIMO MAC) for downlink and uplink situations, respectively. Again in comparison, SU-MIMO may be represented as a point-to-point, pairwise MIMO.

To remove ambiguity of the words receiver and transmitter, we can adopt the terms access point (AP) or base station, and user. An AP is the transmitter and a user the receiver for downlink connections, and vice versa for uplink connections. Homogeneous networks are freed from this distinction since they tend to be bi-directional.

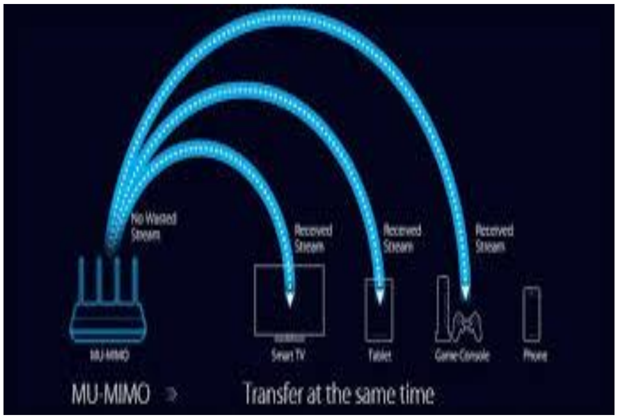

Figure d. 1 : MU MIMO

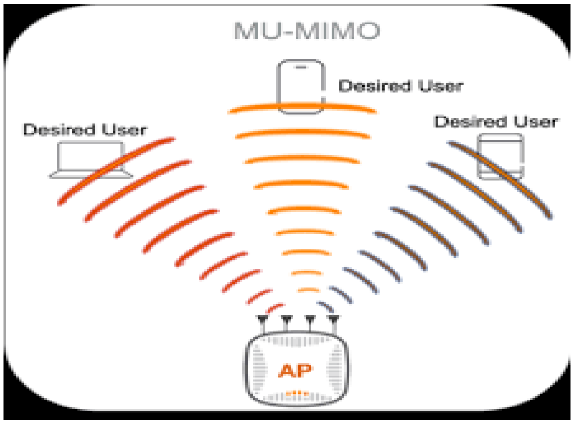

Figure d. 2 : MU MIMO

JURAS concept

This concept means joint user and receive antenna selection algorithm scheme.What it basically does is it selects first the receive antenna of a user with maximum capacity which means the receiver antenna which supports maximum data transfer facility at the given channel or bandwith and then it selects next receive antenna of a user where the sum capacity will be maximum which means the overall data transfer rate would be maximum at the given channel.

Hence here both user and its receiving antenna are simultaneously selected in order to increase the overall capacity which increases the data rate at the given channel or bandwidth.

Precoding

Precoding is a generalization of beamforming to support multi-stream (or multi-layer) transmission in multi-antenna wireless communications. In conventional single-stream beamforming, the same signal is emitted from each of the transmit antennas with appropriate weighting (phase and gain) such that the signal power is maximized at the receiver output. When the receiver has multiple antennas, single-stream beamforming cannot simultaneously maximize the signal level at all of the receive antennas.In order to maximize the throughput in multiple receive antenna systems, multi-stream transmission is generally required.

In point-to-point systems, precoding means that multiple data streams are emitted from the transmit antennas with independent and appropriate weightings such that the link throughput is maximized at the receiver output. In multi-user MIMO, the data streams are intended for different users (known as SDMA) and some measure of the total throughput (e.g., the sum performance or max-min fairness) is maximized. In point-to-point systems, some of the benefits of precoding can be realized without requiring channel state information at the transmitter, while such information is essential to handle the inter-user interference in multi-user systems.Precoding in the downlink of cellular networks, known as network MIMO or coordinated multipoint (CoMP), is a generalized form of multi-user MIMO that can be analyzed by the same mathematical techniques.

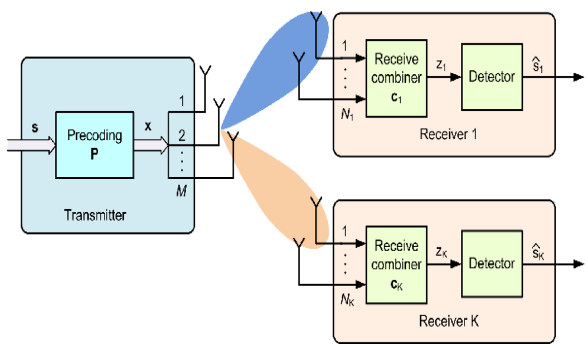

Figure f. 1 : precoding

Precoding in MU MIMO

In multi-user MIMO, a multi-antenna transmitter communicates simultaneously with multiple receivers (each having one or multiple antennas). This is known as space-division multiple access (SDMA). From an implementation perspective, precoding algorithms for SDMA systems can be sub-divided into linear and nonlinear precoding types. The capacity achieving algorithms are nonlinear,but linear precoding approaches usually achieve reasonable performance with much lower complexity. Linear precoding strategies include maximum ratio transmission (MRT),zero-forcing (ZF) precoding,and transmit Wiener precoding.There are also precoding strategies tailored for low-rate feedback of channel state information, for example random beamforming.Nonlinear precoding is designed based on the concept of dirty paper coding (DPC), which shows that any known interference at the transmitter can be subtracted without the penalty of radio resources if the optimal precoding scheme can be applied on the transmit signal.

While performance maximization has a clear interpretation in point-to-point MIMO, a multi-user system cannot simultaneously maximize the performance for all users. This can be viewed as a multi-objective optimization problem where each objective corresponds to maximization of the capacity of one of the users.The usual way to simplify this problem is to select a system utility function; for example, the weighted sum capacity where the weights correspond to the system's subjective user priorities. Furthermore, there might be more users than data streams, requiring a scheduling algorithm to decide which users to serve at a given time instant.

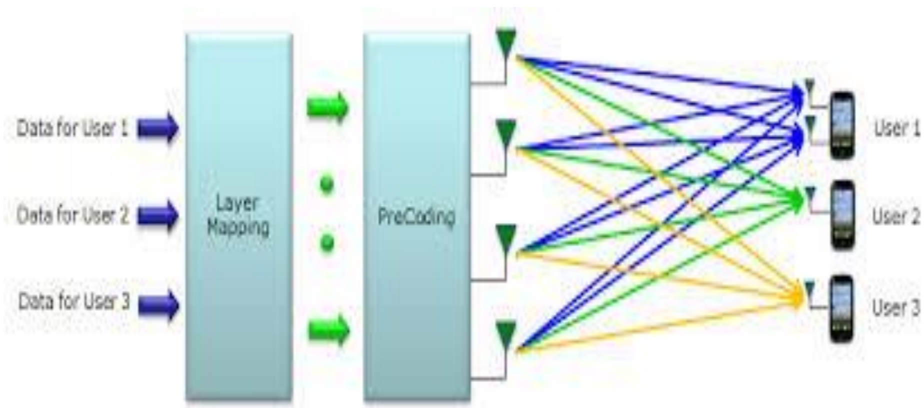

Figure g. 1 : precoding in MU MIMO

MU-MIMO and Sum Capacity

Multiuser multiple input multiple output (MU-MIMO) schemes have recently attracted research attention due to their capability of offering significant gain in system capacity by enabling simultaneous multiplexing of multiuser data streams into the same frequency and time resources. One of the major issues in MU-MIMO systems is how to design appropriate transmit precoding schemes to avoid co-channel interference (CCI) among the users.

Dirty Paper Coding (DPC) [1] is known to be an optimal scheme achieving the theoretical sum capacity [2]; however, it suffers from high complexity due to its non-linear processing.

Zero-Forcing (ZF) and Block Diagonalisation (BD) [3] are linear precoding techniques aiming to perfectly cancel CCI for each user. ZF and BD algorithms require sufficient degrees of freedom in the spatial domain in order to force the CCI to zero.

Generally, the number of transmit antennas is required be larger than the sum of receive antennas of all users; otherwise, time scheduling is necessary.

Another linear approach recently proposed in [4] is aimed to maximise a new performance criterion, referred to as the signal to leakage and noise ratio (SLNR). In contrast to interference which quantifies an amount of unwanted signal power from other users perceived at the desired user, leakage is a measure of how much signal power intended to a given user leaks into the others. Aiming to maximise SLNR instead of signal to interference and noise ratio (SINR) leads to suboptimal performance; however, it decouples the collective design criterion into individual user objectives and results in a closed-form solution for each user. In addition, it poses no restrictions on the number of antennas and offers superior performance in terms of bit error rate (BER) and outage probability compared to ZF solutions [4].

Although there is no limitation on the number of antennas and data streams in the SLNR-based solutions, [5] shows that increasing the number of receive antennas at a user can lead to additional signal leakage considered by other users, causing the degradation of their SLNR. As a result, the system may not benefit from simultaneously scheduling maximum data streams to all users, deploying all of their receive antennas. Therefore, user selection (possibly joint with receive antenna selection) remains necessary in MU-MIMO systems based on SLNR precoding design. Some user scheduling algorithms have been proposed in [7]-[9] for the SLNR-based precoding scheme with single-antenna receivers. The problem becomes more complicated when users are equipped with multiple antennas. In addition to choosing active users, it is possible to dynamically select the set of active receive antennas and allocate different numbers of data streams. In this project, it is shown that a joint user and receive antenna selection (URAS) scheme potentially provides significant gain over a user selection (US) scheme, where users utilizes all receive antennas when scheduled for data transmission, especially at high SNR. Note that the number of data streams may be chosen to be lower than the number of selected antennas in order to exploit receive beamforming. Two suboptimal joint user and antenna selection algorithms with dynamic data stream allocation are also proposed in this paper and are shown to achieve very similar performance compared to the exhaustive method.

2 Chapter 2

2.1 System model description

Let us consider a single cell single carrier downlink MU-MIMO system where the BASE STATION (BS) has N_t antennas and communicates with k users, each of which is equipped with multiple antennas as shown in figure 1.1. Let $N_{r,j}$ be the number of receive antennas of user j∈{1,2,… , K }. The full channel information between the BASE STATION (BS) and user j , denoted as $H_j^F \in \mathbb{C}^{N_{r,j} \times N_t}$, is assumed to be available at the BS. Each entry of H_j^F is assumed to be independent complex Gaussian variables with zero mean and unit variance. Based on available channel information from all users, the BS dynamically selects a subset of receive antennas and corresponding number of data streams, aiming to maximise an objective function, i.e. sum capacity (C_{sum}). A user who has at least one receive antenna selected can be scheduled for data transmission.

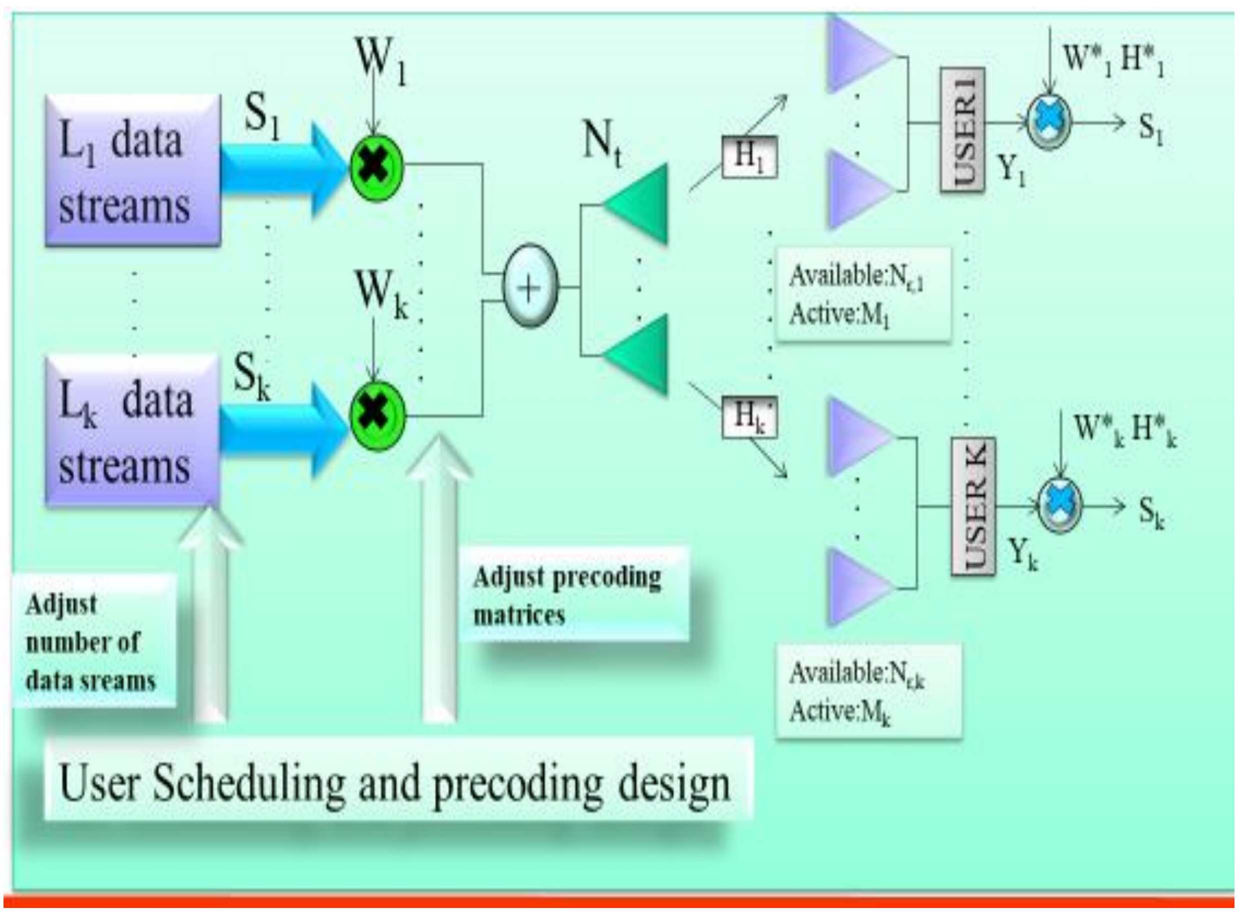

Figure 1. 1 : Block diagram of the downlink MU-MIMO system

Let M_j denote the number of receive antennas selected by the BASE STATION for the user j ,M_j<= $N_{r,j}$, and L_j denote the corresponding number of data streams,L_j<= min(N_t,M_j).

Thus, the set of scheduled users can be defined as U={j: j∈{1,2,… , K }}.The total number of data streams transmitted by the BS is given by $L= \Sigma_{j \in U} L_j$.
Data streams from each scheduled user j,$S_j \in C^{Lj \times 1}$, are pre-multiplied by a precoding matrix $W_j \in C^{Nt \times Lj}$. The BS indicates to each scheduled user the set of selected antennas so that only selected receive antennas can be involved in the decoding process. Let H_j be the channel matrix obtained by choosing the rows of H_j^F associated to the selected antennas for user j,$H_j \in C^{Mj \times Mt}$ .The received signal vector for each user j in the scheduled set can be given by-

$$\boldsymbol{y}_j = \boldsymbol{H}_j \boldsymbol{W}_j \boldsymbol{s}_j + \boldsymbol{H}_j \sum_{k \in U_i k \neq j} \boldsymbol{W}_k s_k + \boldsymbol{v}_j \qquad \text{-----------------} \ (1)$$

where

$$\text{Tr}\left(W_j^* W_j\right) = L_j, E\{s_j s_j^*\} = \left(E_j/L_j\right)\mathbf{I} \text{ and } \sum_{j \in U} E_j = E_{BS}$$

The first two conditions generalise the power constraints in [4] to limit the allocated power of user j to E_j. The third condition is added to ensure that the total transmitted power for all scheduled users does not exceed the maximum available power at the base station (E_{BS}). The additive noise vector, denoted as V_j , is assumed to have identical and independent complex Gaussian elements with variance σ^2 , i.e $E\{V_j V_j^*\} = \sigma^2_j I$. According to [4], the criterion of the SLNR precoding design is to obtain a precoding matrix which maximises the SLNR. This corresponds to the following optimisation problem.

$$W_j^o = \arg \max_{w_{j \in C}^{Nt \times L_j}} \frac{\text{Tr}\left(W_j^* H_j^* H_j W_j\right)}{\text{Tr}\left[W_j^* \left(\left(M_j \sigma_j^2 / E_j\right)\mathbf{I} + \widetilde{H}_j^* \widehat{H}_j\right) W_j\right]}$$

Subject to $\text{Tr}(W_j^* W_j)=L_j$ ------------- (2)

Where

$$\widetilde{H}_j = \text{vertcat}\,\{H_k : \forall k \in U \text{ and } k \neq j\}\left(\sum_{k+i} M_k \times N_t\right)$$

It is shown in [4] that the solution of (2) can be written as

$$\boldsymbol{W}_j^o = \rho \cdot \text{ eigvec }_{L_j}\{\boldsymbol{H}_j^* \boldsymbol{H}_j, \left(M_j \sigma_j^2 / E_j\right)\mathbf{I} + \widetilde{\boldsymbol{H}}_j^* \widetilde{\boldsymbol{H}}_j\}\left(N_\text{t} \times L_j\right) \qquad \text{------------} \ (3)$$

where the function eigvecL_j {A,B} returns a matrix containing L_j columns of eigenvectors (corresponding to the L_j largest eigenvalues), satisfying the generalised eigenvalue problem Ax = λBx. ρ is a normalisation factor so that Tr($W_j^* W_j$)=L_j.

For the decoding process, the matched filter $G_j = W_j^* H_j$, is applied as in [4]. The decoding vector can be given by

$$\hat{s}_j = G_j y_j = W_j^* H_j^* H_j W_j s_j + W_j^* H_j^* H_j \sum_{k \in U, k \neq j} W_k s_k + W_j^* H_j^* v_j$$

$$= D_j s_j + Q_j \sum_{k \in U k * j} W_k s_k + W_j H_j v_j$$

-------------- (4)

Where

$D_j = W_j^* H_j^* H_j W_j$ is a diagonal matrix and $Q_j = W_j^* H_j^* H_j$.

In this case, the signal to interference and noise ratio (SINR) for the data stream l of user j can be calculated as

$$\mathrm{SINR}_j^l = \frac{E\left[D_j s_j s_j^* D_j^*\right]_{ll}}{E\left[W_j^* H_j^* v_j v_j^* H_j W_j\right]_{ll} + E\left[\sum_{k \in U_k + j} Q_j W_k s_k s_k^* W_k^* Q_j^*\right]_{ll}}$$

$$= \frac{(E_j/L_j)\left[D_j D_j^*\right]_{ll}}{\sigma_j^2 \left[D_j\right]_{ll} + \left[Q_j\left(\sum_{k \in U, k \neq j} (E_k/L_k) W_k W_k^*\right) Q_j^*\right]_{ll}}$$

--------------------- (5)

Note that the SLNR precoding design in (2) also depends on the amount of power allocated to each user. Two simple power allocation schemes, namely Equal Power per User (EPU) and Equal Power per data Stream (EPS), are considered in this paper. The former assumes equal power allocation among all users, i.e.

$$E_j = \frac{E_{BS}}{|u|}, \forall j \in \mathcal{U}$$

while the latter allocates power to users relatively to the number of scheduled data streams, i.e.

$$E_j = \left(\frac{L_j^1}{L}\right) E_{BS}, \forall j \in \mathcal{U}$$

It will be shown in Section IV that EPS provides slightly higher sum capacity than EPU. Thus, EPS will be assumed for joint user and antenna selection schemes in Section III. In this case, SINR expression in (5) can be rewritten as

$$\mathrm{SINR}_j = \frac{(E_{BS}/L)\left[D_j D_j^*\right]_{ll}}{\sigma_j^2\left[D_j\right]_{ll} + (E_{BS}/L)\left[Q_j\left(\sum_{k\in U_k\neq j} W_k W_k^*\right)Q_j^*\right]_{ll}}$$
$$= \frac{\left[D_j D_j^*\right]_{ll}}{\left[\left(L\sigma_j^2/E_{BS}\right)D_j + Q_j\bar{W}_j\bar{W}_j^* Q_j^*\right]_{ll}}$$

-------------------------- (6)

Where $\bar{W}_j =$ horzcat $\{W_{k^*}\forall k \in u$ and $k \neq j\}\left(N_t \times \sum_{k\neq j} L_k\right)$.

Thus, the sum capacity can be calculated as

$$C_{\text{sum}} = \sum_{j\in U}\sum_{l=1}^{L_j} \log_2\left(1 + \frac{\left[\boldsymbol{D}_j \boldsymbol{D}_j^*\right]_{ll}}{\left[\left(L\sigma_j^2/E_{BS}\right)D_j + Q_j\widetilde{W}_j\widetilde{W}_j^* Q_j^*\right]_{ll}}\right)$$

---------------- (7)

3 Chapter 3

3.1 User selection vs joint user and receive antenna selection

This chapter examines the potential gain of URAS over US in terms of sum capacity. URAS yields significant gain compared to US, especially at high SNR. As the system is interference-limited at high SNR, allowing the system to disable low-benefit receive antennas at some users improves SLNR to the others, resulting in an improvement in system capacity. At low SNR, on the other hand, the system is noise-limited. Thus, it tends to exploit receive beamforming by allocating a single data stream with all available receive antennas to each scheduled user to obtain a maximal receive signal and thereby overcome noise .Moreover ,two power allocation schemes assumed in this paper contribute to very close performance. EPS results in slightly higher sum capacity compared to EPU, therefore, EPS is assumed for the remaining simulation results. Note that, although possible, multiplexing the maximum number of data streams to all users simultaneously (SLNR NS) does not provide an advantage in terms of sum capacity. The SLNR precoding design cannot find a solution to efficiently cancel inter-user interference leading to the saturation of capacity at high SNR, and no receive beamforming can be exploited causing low capacity at low SNR. With user and/or antenna selection, the system tries to allocate a reasonable number of data streams at every time instant. Fig. 3 shows the average achievable sum capacity as a function of the number of data streams multiplexed. At high SNR, achievable capacity seems to reduce when attempting to multiplex a number of data streams larger than the available spatial-domain degree of freedom, $min\left(N_t, \Sigma_j N_{r_t j}\right)$ (equal to 4 in this example). At low SNR, the peak capacity may be obtained with less data streams due to the exploitation of receive beamforming. It can be seen again that URAS is superior to US at high SNR, but similar performance at low SNR as previously discussed.

3.2 Suboptimal joint user and antenna selection algorithm

The comparison of sum capacity between the exhaustive search and the proposed suboptimal algorithms is given in Fig. 4. SA1 appears to have close performance to URAS EXH throughout the whole range of SNR, while SA2 fails to achieve similar capacity at high SNR due to the lack of precoding matrices update leading to degraded CCI cancellation capability at this range. Comparing to US EXH, the proposed algorithms offer very close performance at low SNR and outperform US EXH at high SNR although little gain is seen for SA2. This trend remains valid for different number of users as shown in Fig. 5. Note that the simulation results for the exhaustive schemes are provided up to 10 users due to the high complexity of the exhaustive algorithms.

4 Chapter 4

4.1 Joint user and antenna selection algorithms

Let $N_r = \sum_j N_{r,j}$ denote the total number of receive antennas and R={1,…N_r} denote the set of receive antenna indices of all users. The aim of the joint user and receive antenna selection algorithms is to find the subset of receive antennas S ⊆ R and the vector of corresponding number of scheduled data streams for all users, $\boldsymbol{l} = [L_1, \dots, L_K]^T$, which maximise the sum capacity in (7). The set of scheduled users is the derived by $u = \{j : j \in \{1, \dots, K\} \text{ and } L_j > 0\}$.

An exhaustive algorithm requires a search over $2^{N_r} - 1$ antenna combinations, each of which involves at least one possible data stream combination. for any significant number of receive antennas.This motivates the search for reduced-complexity suboptimal algorithms.

4.2 Suboptimal algorithm 1(SA-1)

This suboptimal algorithm can be divided into two phases.The first phase extends the ideas of the capacity-based iterative user selection algorithm as proposed in [9]. The algorithm first selects a receive antenna with the highest capacity. Then, from the remaining unselected antennas, it finds the next receive antenna providing the largest sum capacity. In this phase, the algorithm increases the number of data streams as it increases the number of antennas. This phase terminates when the sum capacity would reduce as a result of adding one more receive antenna (equivalent to one more data stream). It is clear, at the end of the first phase, that no further benefit can be obtained from multiplexing more data streams into the system. Nevertheless, the system may still achieve an extra gain from receive beamforming by adding more receive antennas to the selected users. Hence, in the second phase, the algorithm researches the remaining unselected antennas of the selected users without increasing the number of allocated data streams. The algorithm terminates when no extra sum capacity is achieved by the receive beamforming. The pseudo code of the algorithm can be summarised in Table I.

4.2.1 Algorithm (pseudo code)

1. **Initialization:**
2. UsrId = mapping between rx antenna id and user id
3. $\mathcal{R} = \{1, \dots, N_r\}, \delta = \emptyset, u = \emptyset, l = 0, \widetilde{H} = \emptyset$
4. $C_{\max} = 0$, flag $= 1$, phase $= 1$
5. **Do while flag = 1**
   - **a. for every $\boldsymbol{r} \in \boldsymbol{\mathcal{R}}$**
     - i. Let $\delta_{\text{tmp}} = \delta + \{r\}, W = \emptyset, H = \widetilde{H}, l_{\text{tmp}} = l$
     - **ii. Find the candidate user:**

       $$u = U\text{srId}(r), u_{\text{tmp}} = u \cup \{u\}, H_u = H[u\} = [H[u]; h_r]$$

     - **iii. If phase = 1**,

       $$l_{\text{tmp}}(u) += 1;$$

     - **iv. End**
     - v. $L_{\text{tmp}} = \text{sum}(l_{\text{tmp}})$
     - **vi. Find precoding $\boldsymbol{W_j}$ for every user $\boldsymbol{j} \in \boldsymbol{U_{\text{tmp}}}$**

       $$M_j = \text{size}(H_j, 1), E_j = L_j \cdot E_{BS}/L_{tmp}$$

       $$W_j \propto \text{eigvec}_{L_j}\left(H_j^* H_j, \left(\frac{M_j \sigma_j^2}{E_j}\right)\mathbf{I} + \tilde{H}_j^* \tilde{H}_j\right), \text{Tr}(W_j^* W_j) = L_j$$

       $$W\{j\} = W_j$$

     - **vii. Calculate sum capacity, denoted as $\boldsymbol{C_r}$**

       $$C_r = \sum_{j \in U_{\text{tmp}}} \sum_{i=1}^{M_j} \log_2\left(1 + \frac{\left[D_j D_j^*\right]_{ll}}{\left[\left(L_{tmp}\sigma_j^2/E_{BS}\right)D_j + Q_j \overline{W}_j \overline{W}_j^* Q_j^*\right]_{ll}}\right)$$

   - **b. End**
   - c. $\bar{r} = \text{argmax}_{r \in R} C_r$

d. **if $\boldsymbol{C}_{\vec{r}} > \boldsymbol{C}_{\mathbf{max}}$**

  i. **if phase $= \mathbf{1}$**

    $l(\overline{u}) += 1;$

  ii. **End**

e. **elseif phase $= \mathbf{1}$**

  i. $\mathcal{R} =$ remaining antennas of users in u,

  not been selected in δ phase $= 2$

f. **Else**

  i. flag $= 0$

g. **End**

6. **End**

Output: $\boldsymbol{\mathcal{S}}, \boldsymbol{\mathcal{U}}, \mathbf{l}$

TABLE 2. 1 : SA-1

4.3 Suboptimal algorithm 2(SA-2)

It is seen that the main computational burden of SA1 focuses on updating users' precoding matrices and evaluating the sum capacity [step (iv) and (v) in TABLE I, respectively]. The complexity can be further reduced by ignoring the effect of
power leakage from previously selected antennas to the candidate antenna. Thus, the algorithm is only required to compute the beamforming vector of the candidate antenna without updating the precoding matrices of the selected ones. Subsequent to this observation, it was found that treating each receive antenna as an individual user provides more robustness to the errors from outdated precoding matrices than considering multiple antennas at each user. In this case, the problem is transformed into a user selection problem with a single receive antenna per user. The solution of SLNR precoding design for a candidate antenna r in (3) is reduced to the maximum eigenvector, expressed as

$$\boldsymbol{w_r^o} = \boldsymbol{\rho} \cdot \ \textbf{max eigenvector} \left\{ \left(\left(\boldsymbol{L\sigma_{\bar{r}}^2 / E_{BS}} \right) \mathbf{I} + \boldsymbol{\widetilde{H}^* \widetilde{H}} \right)^{-1} \boldsymbol{h_r^* h_r} \right\} (\boldsymbol{N_t} \times \mathbf{1}) \text{ ---------- } (8)$$

where h_r and $\widetilde{H}$ contain the channel vector of the candidate antenna r and the previously selected antennas, respectively.
The sum capacity expression in (7) can also be rewritten as

$$\boldsymbol{C_r} = \sum_{i \in s_{tmp}} \mathbf{log_2} \left(\mathbf{1} + \frac{\left\| \boldsymbol{h_i W_{tmp}}(:,\boldsymbol{i}) \right\|^2}{\left(\frac{L_{tmp} \sigma_i^2}{E_{BS}} \right) + \sum_{i \in S_{lmp}, i * i} \left\| \boldsymbol{h_i W_{tmp}}(\boldsymbol{i},\boldsymbol{t}) \right\|^2} \right) \text{ ---------------------- } (9)$$

The details of SA2 are given in TABLE II. By treating each antenna as a separate user, no receive beamforming can be exploited. Thus, procedures in the second phase are excluded from SA2 and the number of data streams is always equal to the number of selected antennas. Remark that the resulting algorithm of SA2 becomes similar to the user selection algorithm proposed in [6], except that the sum power constraint
$\left(\sum_{j \in U} E_j = E_{BS} \right)$ is considered in the algorithm proposed here. It is also noted that once the selection process is done, the final precoding matrices used for data transmission are computed using (3) as in the conventional multi-antenna approach although it has been ignored during the selection process.

4.3.1 Algorithm (pseudo code)

1. **Initialization:**

   $\mathcal{R} = \{1, \ldots, N_r\}, \delta = \emptyset, L = 0, \mathbf{H} = \emptyset, \mathbf{W} = \emptyset$
   $C_{\max} = 0, \text{flag} = 1$

2. **Do while flag $= 1$**

   a. **for every $\boldsymbol{r} \in \boldsymbol{\mathcal{R}}$**

      i. Let $\delta_{\text{tmp}} = \delta + \{r\}$

      ii. $L_{tmp} = L + 1$

      iii. **Find precoding only for the candidate antenna**

      iv. $\mathbf{w}_r \propto$ max. eigenvector $\left(\left((L_{\text{tmp}}\sigma_r^2/E_{BS})\mathbf{I} + \widetilde{\mathbf{H}}^* \widetilde{\mathbf{H}}\right)^{-1} \mathbf{h}_r^* \mathbf{h}_r\right)$

      v. $\text{Tr}(w_r^* w_r) = 1$

      vi. $W_{\text{tmp}} = [W, w_r]$

      vii. **Calculate sum capacity, denoted as $\boldsymbol{C_r}$**

      $$C_r = \sum_{i \in \delta_{tmp}} \log_2\left(1 + \frac{\|\mathbf{h}_i \mathbf{W}_{\text{tmp}}(:, i)\|^2}{(L_{tmp}\sigma_i^2/E_{BS}) + \sum_{i \in \delta_{tmp}, i \pm i} \|h_i W_{tmp}(:, \tilde{\imath})\|^2}\right)$$

   b. **End**

   c. $\bar{r} = \text{argmax}_{r \in \mathcal{R}} C_r$

   d. **if $\boldsymbol{C_{\text{fr}}} > \boldsymbol{C_{\max}}$**

      $C_{\max} = C_{\bar{r}}, \delta = \delta + \{\bar{r}\}, \mathcal{R} = \mathcal{R} - \{\bar{r}\}$
      $L = L + 1$
      $W = [W, w_{\bar{r}}], \widetilde{H} = [\widetilde{H}\, ; h_{\bar{r}}]$

   e. **else**

i. flag $= 0$

f. End

3. End

Output: $\boldsymbol{\delta}(\boldsymbol{u}, \boldsymbol{l}$ **are derived from** $\boldsymbol{\delta})$

TABLE 2. 2 : SA-2

5 CHAPTER 5

5.1 Work done till now

Till now in this project,the basic understanding of MIMO and MU MIMO concepts is done and system model has been generated for applying the Joint user and receive antenna selection algorithm(JURAS) on MU MIMO system.The pseudocode for the JURAS algorithms has been designed and analyzed that is going to be written in MATLAB software for generating the simulation results for our project.
In this session we have designed the pseudocode for two suboptimal algorithms namely suboptimal algorithm 1 and suboptimal algorithm 2 that is going to be implemented in the MATLAB in the next session.

Till now in this session we have generalized the MU MIMO concept for implementing our JURAS algorithms and working of the model is understood.

In the next session we will implement these pseudocode in MATLAB and carry out our smimulation results on various aspects so as to analyze the JURAS scheme on every corner.

6 Conclusions

This project evaluated the potential gain of joint user and receive antenna selection over user selection in a MU-MIMO system using an SLNR-based precoding scheme with multiple antenna receivers. The performance gain is shown to be significant at high SNR.

Two suboptimal joint user and receive antenna selection algorithms were then proposed with dynamic data stream allocation. They are shown to perform very close to the exhaustive algorithm and even outperform the exhaustive user-only selection at high SNR, yet offer significantly lower complexity.

Although the proposed algorithms initially aim to maximise the sum capacity, they can be easily extended to incorporate fairness by modifying the objective function from the sum capacity to other weighted sum capacity criteria such as the rate proportional and max-min fairness.

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