

# HIGH PERFORMANCE ORDERING SCHEME FOR MIMO TRANSMISSION

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## ABSTRACT

*The QR-OSIC receiver design for the transmitter-side power allocated MIMO system. Based on the properties of the function and ordering results, we develop the efficient ordering algorithms in combination with the PA scheme. From the convexity of the  $\lambda$ -function, we derive the ordering strategy that makes the channel gains converge to their geometric mean. Based on this approach, the fixed ordering algorithm is first designed, for which the geometric mean is used for a constant threshold. To further improve the performance, the modified scheme employing adaptive thresholds is developed using the correlation among ordering results. Theoretical analysis and simulation results show that proposed ordering schemes using QR-decomposition not only require a reduced computational complexity compared to the conventional scheme, but result in improved error performance.*

**Keywords**— Detection ordering, MIMO, OSIC, power allocation, QR-decomposition.

## I. INTRODUCTION

The utilization of multiple-input multiple-output (MIMO) systems has been an active area of research as well as practical transceiver implementations for their great potential of enhancing the system's performance. The V-BLAST architecture proposed in also referred to as the BLAST-ordered successive interference cancellation (B-OSIC) detector, is regarded as an attractive solution that exploits this potential. In a B-OSIC receiver, the data stream with the strongest signal-to-interference-noise ratio SINR is selected first and subtracted from the received signal, and the procedure is successively performed for the remaining multiple data streams. For equal power allocation (PA) across the transmit antenna array, it is optimal in terms of bit error rate (BER) or equivalently minimum-mean-square error (MMSE) the knowledge of the channel is available at the transmitter, a further performance improvement can be achieved using appropriate PA schemes. Based on the notion that the data stream with the smallest SINR degrades the overall error performance, PA schemes for the B-OSIC have been suggested in which reduces the computational complexity and the feedback overhead by adopting a diagonal precoding matrix for the PA. Most of the PA schemes for the closed-loop systems mainly focus on the transmitter-side processing strategies, while attempts for the joint optimization for the PA at the transmitter and the detection ordering scheme at the receiver have not been fully investigated.

In this project, it is to derive new detection ordering strategy and schemes from joint transceiver design, which is distinct from previous studies. To obtain a closed-form solution, a QR-factorization based approach will be employed. First the BER is provided, minimization condition, derived from the convexity of the  $\lambda$ -function in the PA scheme. It is demonstrated that the ordering strategy, which makes the channel gains converge to their geometric average, achieves the improved error performance. Based on this observation, we develop the two ordering algorithms, which are identical except for the threshold adaptation. The basic algorithm determines the detection-order using the geometric mean as a constant threshold, whereas the modified ordering scheme for robust convergence adaptively updates the threshold by taking into account the previous ordering results. The comparison of the cumulative distribution is conducted to confirm the superiority of the adaptive design. It is also shown that proposed ordering schemes using QR-decomposition obtain not only lower implementation complexity but also better BER performance compared to the conventional B-OSIC algorithm.

## II. SYSTEM MODEL

Let us consider a MIMO system with transmit antennas and receive antennas. The flat-fading MIMO channel is expressed by the matrix with the element representing the channel gain from  $t$ th transmit antenna to  $r$ th receive antenna. The received signal vector is written as

$$\mathbf{y} = \sqrt{\frac{E_s}{N_t}} \mathbf{H} \mathbf{P} \mathbf{x} + \mathbf{n} \quad \dots\dots\dots(1)$$

where  $\mathbf{x} = [x_1, \dots, x_{N_t}]^T$  denotes the  $N_t \times 1$  transmitted signal vector, and  $\mathbf{n} = [n_1, \dots, n_{N_r}]^T$  is the  $N_r$  dimensional noise vector with elements following complex zero mean Gaussian distribution with variance of  $\sigma_n^2$ .  $E_s$  is the total transmitted signal energy on  $N_t$  transmit antennas and  $\mathbf{P} = \sqrt{N_t} \cdot \text{diag}(P_1, P_2, \dots, P_{N_t})$  denotes the diagonal PA precoding matrix.

To express the signal model for the MMSE-QR detector, an  $(N_r+N_t) \times N_t$  augmented channel matrix  $\tilde{\mathbf{H}}$ , an  $(N_r+N_t) \times 1$  extended receive vector  $\tilde{\mathbf{y}}$  and an  $N_t \times 1$  zero matrix  $\mathbf{0}_{N_t,1}$  can be written as [8]–[10]

$$\tilde{\mathbf{H}} = \begin{bmatrix} \mathbf{H} \\ \sigma_n \mathbf{I}_{N_t} \end{bmatrix} \xrightarrow{\text{ordering}} \tilde{\mathbf{Q}} \tilde{\mathbf{R}} \quad \text{and} \quad \tilde{\mathbf{y}} = \begin{bmatrix} \mathbf{y} \\ \mathbf{0}_{N_t,1} \end{bmatrix} \quad \dots\dots\dots(2)$$

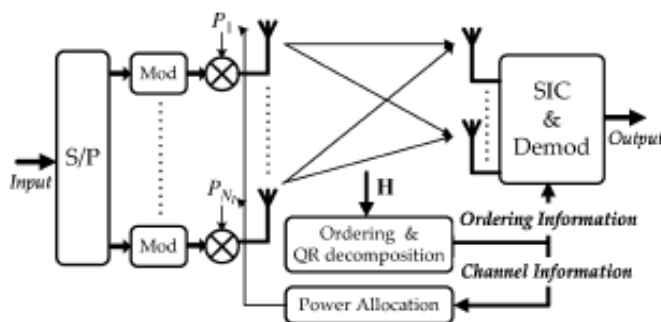


Fig. 1: MIMO transmission model with QR-OSIC detector.

The upper triangular matrix  $\tilde{\mathbf{R}}$ , which is differently defined by the detection-order, determines the SINR [9], and the postdetection SINR  $\rho_k$  of the  $k^{\text{th}}$  data stream is given as [2]

$$\rho_k = \frac{E_s}{\sigma_n^2} P_k^2 \tilde{R}_{k,k}^2 - 1, \quad k = 1, \dots, N_t. \quad \dots\dots\dots(3)$$

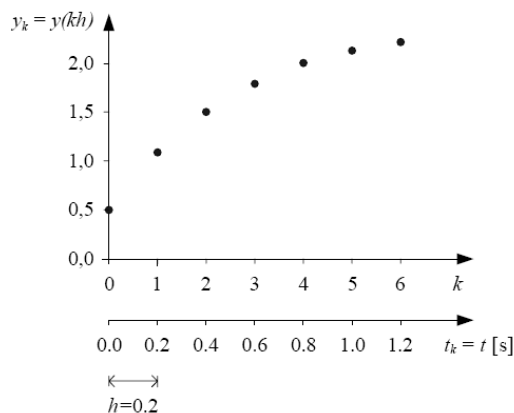
The QR-decomposition based OSIC detection for BER-minimized PA transmission can be performed using the architecture shown in Fig. 1. Based on the feedback information of the diagonal elements  $\tilde{R}_{k,k}$ , transmission power  $P_k$  is assigned to each data stream. The independently encoded symbols are processed through a diagonal PA matrix and then transmitted from  $N_t$  data streams. The QR-OSIC receiver detects the transmit symbols sequentially in accordance with the designated detection-order.

## III. PROPOSED DETECTION ORDERING ALGORITHMS

### 3.1 BASICS OF SIGNALS AND SYSTEMS:

#### 3.1.1 Discrete Time Signals:

A discrete-time signal is a sequence or a series of signal values defined in discrete points of time. These discrete points of time can be noted  $t_k$  where  $k$  is an integer time index. The distance in time between each point of time is the time-step, which can be denoted  $h$ . Thus,



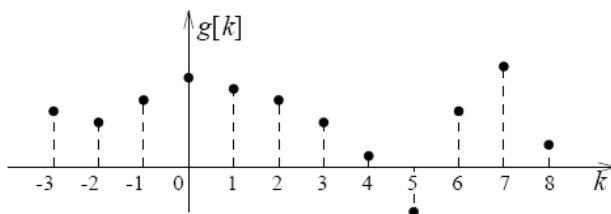
$$h = t_k - t_{k-1} \dots \dots \dots (1)$$

The time series can be written in various ways:

$$\{x(t_k)\} = \{x(kh)\} = \{x(k)\} = x(0), x(1), x(2), \dots \dots (2)$$

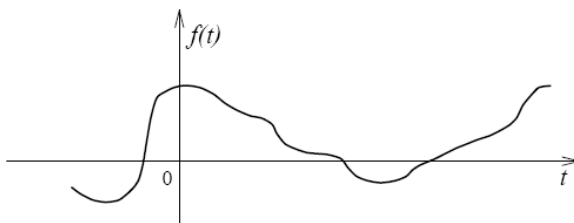
To make the notation simple, we can write the signal as  $x(t_k)$  or  $x(k)$ . Examples of discrete-time signals are logged measurements, the input signal to and the output signal from a signal filter, the control signal to a physical process controlled by a computer, and the simulated response for a dynamic system.

A **discrete signal** is a uniquely defined mathematical function (single-valued function) of an independent variable  $k$  which is a set of integers. Such a signal is represented in Figure. In order to clearly distinguish between continuous and discrete signals, we will use in this book parentheses for arguments of continuous signals and square brackets for arguments of discrete signals, as demonstrated in Figures. If  $k$  represents discrete time (counted in the number of seconds, minutes, hours, days ...) then  $g[k]$  defines a discrete-time signal.



### 3.1.2 Continuous Time Signals :

A *continuous signal* is a mathematical function of an independent variable, where represents a set of real numbers. It is required that signals are *uniquely* defined in except for a finite number of points. For example, the function  $f(t)=\sqrt{t}$  does not qualify for a signal even for  $t>0$  since the



Square root  $t$  of has two values for any non negative  $t$ . A continuous signal is represented in Figure. Very often, especially in the study of dynamic systems, the independent variable  $t$  represents time. In such cases  $f(t)$  is a time function.

### 3.1.3 Description of the BER Performance :

As in the derivation of the post-detection SINR, the error rate is also affected by the channel gains and the transmission power. A PA scheme for the average BER minimization under the assumption of the QR-decomposition of the channel matrix and no error propagation in successive cancellation of the data streams has been proposed. The PA scheme for BPSK modulation can be expressed as the average BER of the PA can be approximated with a constellation-specific constant the average BER as well as the post-detection SINR is determined by the allocated power and the channel gain. Because of the convexity property of the  $Q$  function, the resulting BER is minimized by the detection ordering of the QR-OSIC receiver such that all diagonal elements of the matrix are equal to their geometrical average, and alternatively the PA scheme at the transmitter which makes the product of two variables and identical for all data streams. As the real MIMO channel is characterized by several spatial-temporal properties, the condition

(i) is not practical in spite of its optimality.

(ii), different detection-order leads to different transmission power and hence power gain should be also differently assigned. This indicates that an appropriate detection ordering strategy incorporates with the PA scheme can achieve the improved BER performance.

A PA scheme for the average BER minimization under the assumption of the QR-decomposition of the channel matrix and no error propagation in successive cancellation of the data streams has been proposed in The PA scheme for BPSK modulation can be expressed as

$$\begin{aligned} \text{minimize} \quad & \frac{1}{N_t} \sum_{k=1}^{N_t} Q(\sqrt{2}\gamma_s P_k \bar{R}_{k,k}) \approx \frac{1}{N_t} \sum_{k=1}^{N_t} Q(\sqrt{2\rho_k}) \\ \text{s.t.} \quad & \sum_{k=1}^{N_t} P_k^2 = 1, \quad 0 < \forall P_k < 1, \\ & \bar{R}_{k,k} \geq 0, \quad k \in \{1, \dots, N_t\} \end{aligned} \quad (4)$$

where  $Q(x) = \sqrt{1/2\pi} \int_x^\infty e^{-(t^2/2)} dt$  and  $\gamma_s = \sqrt{E_s/\sigma_n^2}$ . We assume  $\bar{R}_{k,k} \geq 0$  because it is defined as the norm of the  $k$ th column of the augmented channel matrix [8]. For general constellations, the average BER of the PA can be approximated with a constellation-specific constant [7], [11].

As can be observed in (4), the average BER as well as the post-detection SINR is determined by the allocated power and the channel gain. Because of the convexity property of the  $Q$ -function, the resulting BER is minimized by (i) the detection ordering of the QR-OSIC receiver such that all diagonal elements of the matrix are equal to their geometrical average, and alternatively (ii) the PA scheme at the transmitter which makes the product of two variables and identical for all data streams. As the real MIMO channel is characterized by several spatio-temporal properties, the condition (i) is not practical in spite of its optimality. On the other hand, in (ii), different detection-order leads to different, and hence should be also differently assigned. This indicates that an appropriate detection ordering strategy incorporates with the PA scheme can achieve the improved BER performance.

#### Definition of bit error rate:

As the name implies, a bit error rate is defined as the rate at which errors occur in a transmission system. This can be directly translated into the number of errors that occur in a string of a stated number of bits. The definition of bit error rate can be translated into a simple formula:

$$\text{BER} = \text{number of errors} / \text{total number of bits sent}$$

#### Explanation of bit error rate:

The medium between the transmitter and receiver is good and the signal to noise ratio is high, then the bit error rate will be very small - possibly insignificant and having no noticeable effect on the overall

system. However if noise can be detected, then there is chance that the bit error rate will need to be considered.

The main reasons for the degradation of a data channel and the corresponding bit error rate, BER is noise and changes to the propagation path (where radio signal paths are used). Both effects have a random element to them, the noise following a Gaussian probability function while the propagation model follows a Rayleigh model. This means that analysis of the channel characteristics are normally undertaken using statistical analysis techniques.

For fibre optic systems, bit errors mainly result from imperfections in the components used to make the link. These include the optical driver, receiver, connectors and the fibre itself. Bit errors may also be introduced as a result of optical dispersion and attenuation that may be present. Also noise may be introduced in the optical receiver itself. Typically these may be photodiodes and amplifiers which need to respond to very small changes and as a result there may be high noise levels present. Another contributory factor for bit errors is any phase jitter that may be present in the system as this can alter the sampling of the data.

### **BER and $E_b / N_0$ :**

Signal to noise ratios and  $E_b/N_0$  figures are parameters that are more associated with radio links and radio communications systems. In terms of this, the bit error rate, BER, can also be defined in terms of the probability of error or POE. To determine this, three other variables are used. They are the error function, erf, the energy in one bit,  $E_b$ , and the noise power spectral density (which is the noise power in a 1 Hz bandwidth),  $N_0$ .

It should be noted that each different type of modulation has its own value for the error function. This is because each type of modulation performs differently in the presence of noise. In particular, higher order modulation schemes (e.g. 64QAM, etc) that are able to carry higher data rates are not as robust in the presence of noise. Lower order modulation formats (e.g. BPSK, QPSK, etc.) offer lower data rates but are more robust.

The energy per bit,  $E_b$ , can be determined by dividing the carrier power by the bit rate and is a measure of energy with the dimensions of Joules.  $N_0$  is a power per Hertz and therefore this has the dimensions of power (joules per second) divided by seconds. Looking at the dimensions of the ratio  $E_b/N_0$  all the dimensions cancel out to give a dimensionless ratio. It is important to note that POE is proportional to  $E_b/N_0$  and is a form of signal to noise ratio.

### **Factors affecting bit error rate, BER:**

It can be seen from using  $E_b/N_0$ , that the bit error rate, BER can be affected by a number of factors. By manipulating the variables that can be controlled it is possible to optimize a system to provide the performance levels that are required. This is normally undertaken in the design stages of a data transmission system so that the performance parameters can be adjusted at the initial design concept stages.

The interference levels present in a system are generally set by external factors and cannot be changed by the system design. However it is possible to set the bandwidth of the system. By reducing the bandwidth the level of interference can be reduced. However reducing the bandwidth limits the data throughput that can be achieved.

It is also possible to increase the power level of the system so that the power per bit is increased. This has to be balanced against factors including the interference levels to other users and the impact of increasing the power output on the size of the power amplifier and overall power consumption and battery life, etc.

Lower order modulation schemes can be used, but this is at the expense of data throughput.

It is necessary to balance all the available factors to achieve a satisfactory bit error rate. Normally it is not possible to achieve all the requirements and some trade-offs are required. However, even with a bit error rate below what is ideally required, further trade-offs can be made in terms of the levels of error correction that are introduced into the data being transmitted. Although more redundant data has to be sent with higher levels of error correction, this can help mask the effects of any bit errors that occur, thereby improving the overall bit error rate.

## Proposed Ordering Strategy and Algorithms

Since the  $\phi$ -function has convex and decreasing properties, the average BER minimization problem (4) can be simplified to maximize the product of two variables  $P_k$  and  $\bar{R}_{k,k}$

$$\begin{aligned} & \text{maximize } P_1 \bar{R}_{1,1} \\ & s.t \quad P_1 \bar{R}_{1,1} = P_2 \bar{R}_{2,2} = \dots = P_{N_t} \bar{R}_{N_t, N_t} \\ & \quad \sum_{k=1}^{N_t} P_k^2 = 1, \quad 0 < \forall P_k < 1. \end{aligned}$$

Using the following Properties of

$$P_1 \bar{R}_{1,1} = P_2 \bar{R}_{2,2} = \sqrt{1 - P_1^2} (\det(\bar{\mathbf{R}}) / \bar{R}_{1,1}), \quad P_1^2 = (\det^2(\bar{\mathbf{R}}) / (\bar{R}_{1,1}^4 + \det^2(\bar{\mathbf{R}})))$$

$P_1 \bar{R}_{1,1} = \max P_1^2 \bar{R}_{1,1}^2$  the problem of two transmitting antennas can be written as

$$\begin{aligned} & \text{maximize } \frac{\bar{R}_{1,1}^2 \cdot \det^2(\bar{\mathbf{R}})}{\bar{R}_{1,1}^4 + \det^2(\bar{\mathbf{R}})} = \phi(\bar{R}_{1,1}) \\ & s.t \quad P_1 \bar{R}_{1,1} = P_2 \bar{R}_{2,2}, \quad P_1^2 + P_2^2 = 1. \\ & s.t \quad P_1 \bar{R}_{1,1} = P_2 \bar{R}_{2,2}, \quad P_1^2 + P_2^2 = 1. \end{aligned}$$

Note that  $\phi$ , and therefore the above considerations imply that  $\phi$  is gradually increasing as  $\bar{R}_{1,1}$  approaches to  $\infty$ . In other words, the ordering strategy that makes  $\phi$  converge to  $\infty$  achieves higher post-detection SINR, which also further improves the overall BER performance. From (4), it can be extended to the system with transmit antennas. To satisfy the derived strategy, we establish the fixed ordering algorithm, the architecture of which arranges the channel gains to minimize for all where the list of elements are rearranged with the parenthesized subscript implying the reverse order in which the elements are to be detected and the ordered set is a permuted sequence of them. Using the correlation among ordering results, the modified ordering algorithm employing adaptive criteria can be developed for robust convergence. For instance, in system, selecting an element 1 as will, in general, result in a different than if element 2 or 3 was selected. It also affects the remaining sets which decide  $\phi$ . Moreover, channel gains are constrained via  $\phi$ . Motivated by the above properties, we propose the adaptive ordering design which continually renews the thresholds by controlling the weights with reference to previously determined channel gains. Substituting the variable thresholds into the fixed method, we get where  $\phi$  denotes the threshold for  $\phi$ . The adaptive ordering algorithm can be considered as the reduced-sized fixed ordering process extracting the already decided gains thus it plays a large part in balancing among ordering results. If the sign of  $\phi$  is distributed to one side serially, the adaptive ordering algorithm enables the following channel gain to be on the opposite side by adjusting  $\phi$ . This allows more channel gains to converge to  $\phi$ . To identify it, the cumulative distributions of  $\phi$  with four transmit/receive antennas are drawn in Fig. 3. The small gap between two similar schemes is noticeable because the adaptive algorithm is equivalent to the fixed one for slight differences in  $\phi$ . The process of the proposed detection ordering algorithms are summarized in Table I, with indicating the  $i$ th column of matrix  $\mathbf{R}$ , indicating the  $i$ th row and  $j$ th column's element of matrix and vector denoting the permutation of the columns of  $\mathbf{R}$ .

## PROPOSED DETECTION ORDERING ALGORITHMS

Step	Operation(s) per each step
1.	$\mathbf{R} \equiv \mathbf{0}_{N_t}, \mathbf{Q} \equiv \mathbf{H}, \mathbf{k} \equiv \{1, \dots, N_t\}, \mu_1 = \mu$
2.	<i>for</i> $i = 1, \dots, N_t$
3.	$\tau_i = \ \bar{\mathbf{Q}}_{(:, i)}\ ^2$
4.	<i>end</i>
5.	<i>for</i> $l = 1, \dots, N_t$
6.	$k_l = \arg \min_w  \sqrt{\tau_w} - \mu_l $
7.	Fixed : $\mu_{l+1} = \mu_l$ , Adaptive : $\mu_{l+1} = \frac{N_t - l + 1}{N_t - l} \sqrt{\mu_l / \bar{R}_{l,l}^{N_t - l + 1}}$
8.	$\bar{\mathbf{R}}_{(:, l)} \rightleftharpoons \bar{\mathbf{R}}_{(:, k_l)}, \tau_l \rightleftharpoons \tau_{k_l}$
9.	$\mathbf{k}(l) \rightleftharpoons \mathbf{k}(k_l), \mathbf{Q}_{(1:N_t-l-1, l)} \rightleftharpoons \bar{\mathbf{Q}}_{(1:N_t-l-1, k_l)}$
10.	$\bar{\mathbf{R}}_{(l,l)} = \sqrt{\tau_l}$ $\bar{\mathbf{Q}}_{(:, l)} = \mathbf{Q}_{(:, l)} / \bar{\mathbf{R}}_{(l,l)}$
11.	<i>for</i> $m = l + 1, \dots, N_t$
12.	$\bar{\mathbf{R}}_{(l,m)} = \bar{\mathbf{Q}}_{(:, l)}^H \cdot \bar{\mathbf{Q}}_{(:, m)}$
13.	$\bar{\mathbf{Q}}_{(:, m)} = \mathbf{Q}_{(:, m)} - \bar{\mathbf{R}}_{(l,m)} \cdot \bar{\mathbf{Q}}_{(:, l)}$
14.	$\tau_m = \tau_m - \bar{\mathbf{R}}_{(l,m)}^2$
15.	<i>end</i>
16.	<i>end</i>

The complexity comparison between the B-OSIC and the QR-OSIC receiver is not discussed in this paper. Fortunately, the efficiency of the QR-OSIC receiver which reduces the computational complexity by an order of magnitude is proven.

In a B-OSIC detector with , the total numbers of multiplications and additions are and , respectively. On the other hand, the OSIC receiver using QR-factorization requires multiplications and additions. Because of the multiple calculations of pseudo-inverse for nulling and ordering, the B-OSIC requires higher computational cost. When, the numbers of multiplications and additions are given with the complex floating point operations (flops)

## IV. SIMULATION RESULTS

We consider an uncoded MIMO system with 3\*3, 4\*4 transmit/receive antenna configurations and BPSK modulation. The effects of error propagation are not ignored, and simulations are used to obtain the actual performance. For each of the MIMO systems and for a specific value of SNR, a quasi-static channel is assumed for the performance evaluation, for which the channel gain is constant over a frame and changed independently from frame to frame. To concentrate our point on comparing ordering algorithms, we postulate the perfect channel estimation at the receiver and error-free PA information at the transmitter. Fig. 4 shows the average BER performance comparison for MIMO systems with three transmit/receive antennas and the simulation results of four transmit/receive antennas are depicted in Fig. 5. Here, the dashed line indicates a system with the BER-minimized PA scheme, whereas the solid line represents a system without the PA. The QR receiver with the PA but no ordering, denoted as QR-SIC w/ PA, has similar performance to the open-loop OSIC systems without the PA. This demonstrates the importance of the detection-order for successive detection. As expected, without the PA, the B-OSIC outperforms the QR-OSIC receiver. Despite the reduced complexity, however, power controlled MIMO systems employing the proposed ordering strategy achieve the improved error performance compared to those with the B-OSIC algorithm. It is sufficient to confirm the superiority of the proposed design because the ordering algorithms of previous studies comply with the strategy of the B-OSIC [5]–[8]. A further performance improvement in the high SNR region can be explained in terms of the error propagation, since the PA scheme as well as the proposed QR-OSIC receiver is designed under the assumption of the error-free decision in previous detection stages.

## Definition of MIMO:

MIMO (multiple input, multiple output) is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver). The antennas at each end of the communications circuit are combined to minimize errors and optimize data speed. MIMO is one of several forms of smart antenna technology, the others being MISO (multiple input, single output) and SIMO (single input, multiple output).



### Explanation of MIMO transmission:

Consider a wireless communication system with  $N_t$  transmit (TX) and  $N_r$  receive (RX) antennas. The idea is to transmit different streams of data on the different transmit antennas, but at the same carrier frequency. The stream on the  $p$ -th transmit antenna, as function of the time  $t$ , will be denoted by  $s_p(t)$ . When a transmission occurs, the transmitted signal from the  $p$ -th TX antenna might find different paths to arrive at the  $q$ -th RX antenna, namely, a direct path and indirect paths through a number of reflections. This principle is called multipath. Suppose that the bandwidth  $B$  of the system is chosen such that the time delay between the first and last arriving path at the receiver is considerably smaller than  $1/B$ , then the system is called a narrowband system. For such a system, all the multipath components between the  $p$ -th TX and  $q$ -th RX antenna can be summed up to one term, say  $h_{qp}(t)$ . Since the signals from all transmit antennas are sent at the same frequency, the  $q$ -th receive antenna will not only receive signals from the  $p$ -th, but from all  $N_t$  transmitters. This can be denoted by the following equation (the additive noise at the receiver is omitted for clarity)

$$x_q(t) = \sum_{p=1}^{N_t} h_{qp}(t) s_p(t),$$

To capture all  $N_r$  received signals into one equation, the matrix notation can be used:

$$\mathbf{x}(t) = \mathbf{H}(t) \mathbf{s}(t),$$

where  $\mathbf{s}(t)$  is an  $N_t$ -dimensional column vector with  $s_p(t)$  being its  $p$ -th element,  $\mathbf{x}(t)$  is  $N_r$ -dimensional with  $x_q(t)$  on its  $q$ -th position and the matrix  $\mathbf{H}(t)$  is  $N_r \times N_t$  with  $h_{qp}(t)$  as its  $(q,p)$ -th element, with  $p = 1, \dots, N_t$  and  $q = 1, \dots, N_r$ . A schematic representation of a MIMO communication scheme can be found.

Mathematically, a MIMO transmission can be seen as a set of equations (the recordings on each RX antenna) with a number of unknowns (the transmitted signals). If every equation represents a unique combination of the unknown variables and the number of equations is equal to the number of unknowns, then there exists a unique solution to the problem.

### Graphical output:

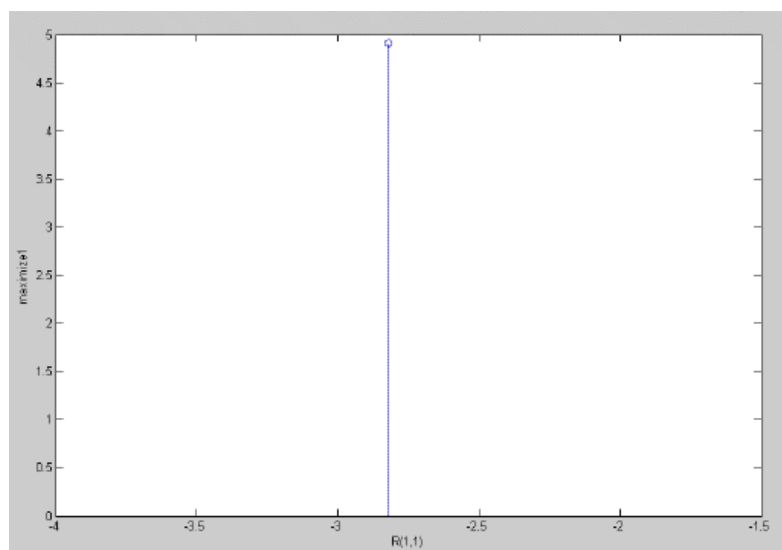
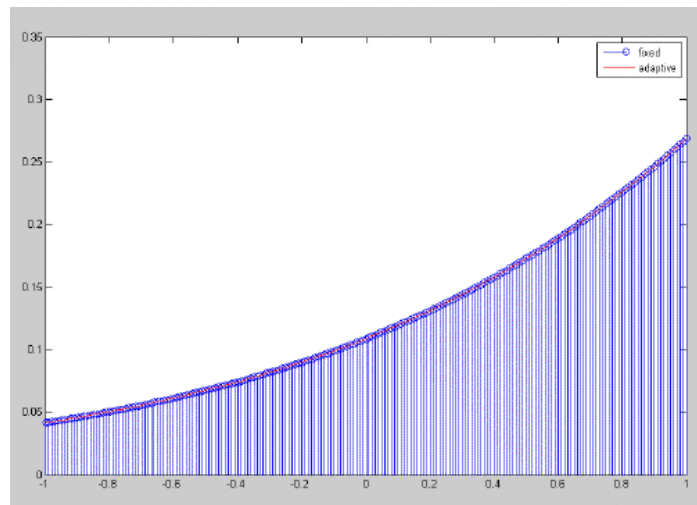


Fig 4.1: Graph of  $R(1,1)$



Fig 4.2: Comparison of cumulative distribution of  $\hat{R}_{k,k} - \mu$ 

To find the direction of increasing, a plot of the objective function  $\emptyset(\hat{R}_{1,1})$  versus  $\hat{R}_{1,1}$  is given in Fig. 4.2. It is observed that  $\emptyset(\hat{R}_{1,1})$  increases as  $\hat{R}_{1,1}$  tends to  $\mu$ . When differential calculus is applied to  $\emptyset(\hat{R}_{1,1})$  we also obtain

$$2\bar{R}_{1,1} (\bar{R}_{1,1}^4 - \det^2(\bar{\mathbf{R}})) = 0$$

$$\bar{R}_{1,1} = \sqrt{\det(\bar{\mathbf{R}})} = \mu.$$

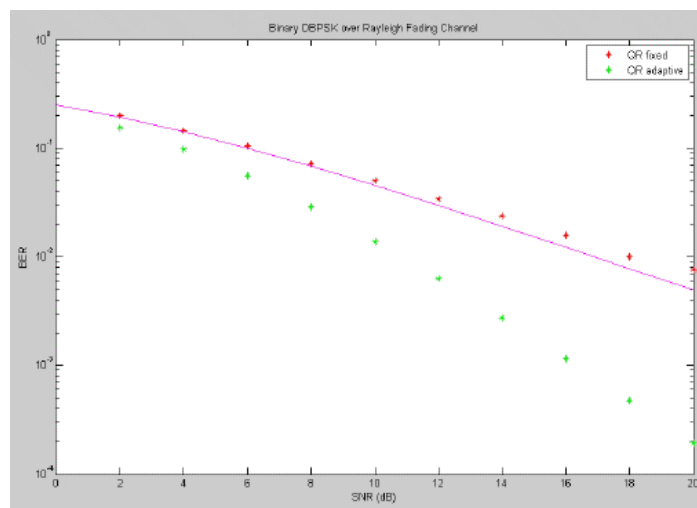


Fig 4.3: Average BER performance of MIMO systems with four transmit/receive antennas.

Fig. 4.3 shows the average BER performance comparison for MIMO systems with three transmit/receive antennas and the simulation results of four transmit/receive antennas are depicted. Here, the dashed line indicates a system with the BER-minimized PA scheme, whereas the solid line represents a system without the PA. The QR receiver with the PA but no ordering, denoted as QR-SIC w/ PA, has similar performance to the open-loop OSIC systems without the PA. This demonstrates the importance of the detection-order for successive detection. As expected, without the PA, the B-OSIC outperforms the QR-OSIC receiver. Despite the reduced complexity, however, power controlled MIMO systems employing the proposed ordering strategy achieve the improved error performance compared to those with the B-OSIC algorithm. It is sufficient to confirm the superiority of the proposed design because the ordering algorithms of previous studies comply with the strategy of the B-OSIC. A further performance improvement in the high SNR region can be explained in terms of the error propagation, since the PA scheme as well as the proposed QR-OSIC receiver is designed under the assumption of the error-free decision in previous detection stages.

## V. CONCLUSION AND FUTURE ENHANCEMENT

### CONCLUSION:

In this study, we investigate the QR-OSIC receiver design for the transmitter-side power allocated MIMO system. Based on the properties of the  $\lambda$ -function and ordering results, we develop the efficient ordering algorithms in combination with the PA scheme. In spite of less computational effort, the proposed ordering schemes decrease the overall BER in comparison with the previously derived B-OSIC scheme. Because of the post-detection SINR increment, the coded systems with the derived approach can also be expected to achieve the performance improvement.

### FUTURE ENHANCEMENT:

Because of the post-detection SINR increment, the coded systems with the derived approach can also be expected to achieve the performance improvement.

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