A CURTAIN RAISER TO MULTI-ANTENNA RECEIVERSAND MIMO SYSTEMS

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Abstract: It is considered that multiple-input multiple-output (MIMO) systems are known for condensed complexity and thus cost. Either one, or both, link ends choose the best L out of N available antennas. This implies that only L in lieu of N transceiver chains have to be built and also the signal processing can be simplified. We show that in ideal channels, full multiplicity order can be achieved, and also the number of independent data streams for spatial multiplexing can be maintained if certain conditions on L are fulfilled. We then discuss the impact of system non-idealities such as boisterous channel assessment, correlations of the received signals, etc.What new technology does is create new opportunities to do a job that customers want done!

Introduction: Multiple-Input and Multiple-Output (MIMO) is a radio communications technology or RF technology that is being mentioned and used in many new technologies these days.Multiple-Input and Multiple-output (MIMO) systems are a natural addition of developments in antenna array communication. Consequent upon which, MIMO systems provide a number of advantages over single-antenna-to-single-antenna communication. Sensitivity to fading is reduced by the spatial diversity provided by multiple spatial paths. Under certain environmental conditions, the power requirements associated with high spectral-efficiency communication can be significantly reduced by avoiding the compressive region of the information-theoretic capacity bound. Here, spectral efficiency is defined as the total number of information bits per second per Hertz transmitted from one array to the other.In wireless mobile radio communication, there is an endless quest for increased capacity and improved quality. Within this area, we have during the last years studied ways to utilize antennas with multiple elements in an intelligent way.

Wi-Fi, LTE(Long Term Evolution), and many other radio, wireless and RF technologies are using the new MIMO wireless technology to provide increased link capacity and spectral efficiency united with improved link reliability using what were earlier seen as interference paths. Even todaythere are many MIMO wireless routers on the market, and as this RF technology is becoming more extensive, more MIMO routers and other things of wireless MIMO equipment will be seen. As the technology is intricate many engineers are asking what is MIMO and how does it work.

Multiple Input Multiple Output (MIMO) Systems for Wireless Communications: In communication theory, MIMO refers to radio links with multiple antennas at the transmitter and the receiver side. Given multiple antennas, the spatial dimension can be exploited to develop the performance of the wireless link. The performance is usually measured as the average bit rate (bit/s) the wireless link can provide or as the average bit error rate (BER) and the one which has most importance usually depends on the application.For a MIMO channel, duplex method and a transmission bandwidth, the system can be classified as**:**

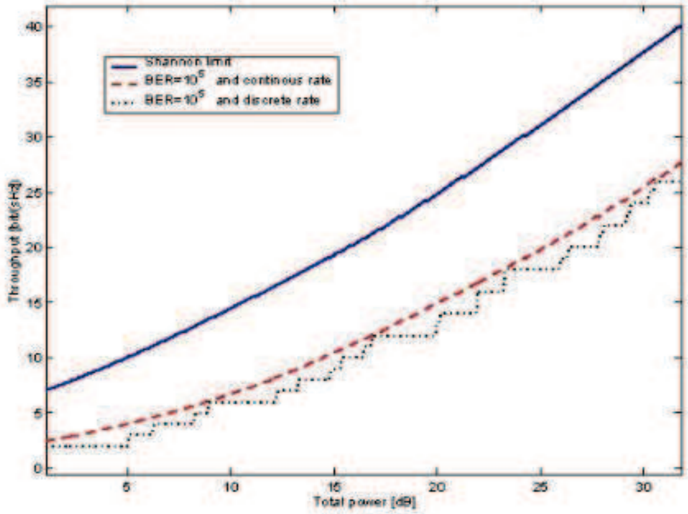
- Flat or frequency selective fading
- With full, limited or without transmitter channel state information (CSI) where full CSI means the knowledge of the total MIMO channel transfer function.

In a TDD system with a duplex time less than the coherence time of the channel, full CSI is accessible at the transmitter, as such, the channel is reciprocal. In FDD systems, a feedback channel from the receiver to the transmitter that provides the transmitter with some partial CSI exists generally. This is the information of which subgroup of antennas to be used or which eigenmode of the channel that is strongest. It is also probable to get a highly vigorous wireless link without any CSI at the transmitter, by means of transmit diversity. Diversity can be accomplished through space-time codes, like the Alamouti code for two transmit antennas and high bit rates is achieved by spatial multiplexing systems, such as the pioneer system from Bell Labs abbreviated as BLAST.

If a broadband wireless connection is preferred, the symbol rate must be increased further which at a point leads to a frequency selective channel. Then, there are two ways to go, either totake up pre- or post-equalization of the channel or to divide the channel into many narrowband flat fading sub-channels, a technique utilized by OFDM, and transmits our data on these sub streams, without the need for channel equalization. Hence, it is always likely to convert a frequency selective channel to many flat fading channels using OFDM and apply the developed flat fading MIMO signaling techniques to each of these sub-channels.

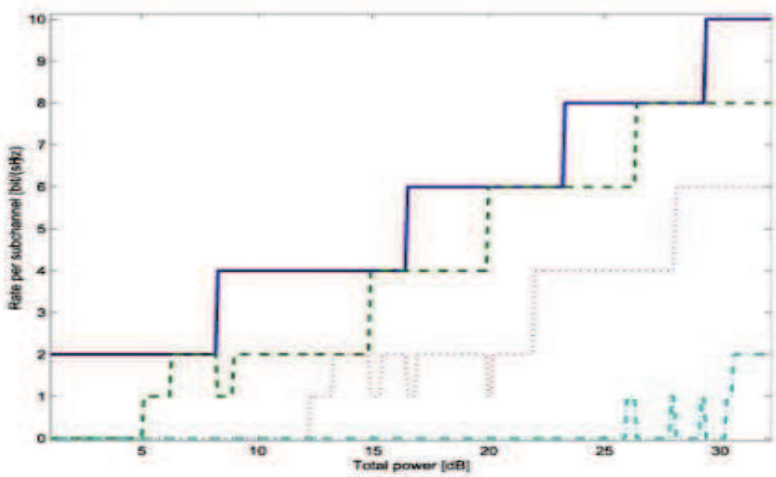
The research on MIMO systems has so far considered flat fading MIMO channels, with or without CSI at the transmitter. Some results of the recent research is shown below.

MIMO with Full CSI at the Transmitter: When full CSI is available at the transmitter, it is feasible to transmit data on the MIMO channel eigenmodes. A MIMO system with N transmit antennas and M receive antennas has min (N,M) eigenmodes. The gain of these eigenmodes is proportional to the singular values of the MIMO channel, so they have different power. It issuggested to use adaptive modulation techniques to transmit over these eigenmodes, to maximize the bit rate or minimize the BER of the transmission.

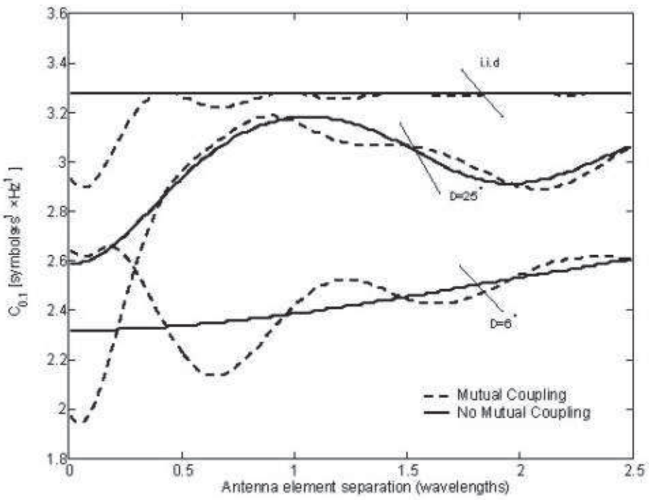


The figure above shows the data throughput (bit/(sHz)) as a function of total transmits power for a 4 times 4 MIMO system in a Rayleigh fading channel. The blue curve is the Shannon limit and the dashed curve the throughput of the BER is fixed at the target 10^{-5}. In practice, the data rates chosen for the sub-channels cannot be arbitrarily chosen, they must belong to the discrete set of modulation types (BPSK, QPSK, 16QAM…) so the dotted curve depicts the throughput when adopting the discrete rates.

The figure below shows the rate per sub channel corresponding to the figure above. We see that the sub channel with the lowest gain is only used when the total power (SNR) is larger than 26 dB



MIMO Performance in Correlated Channels with No CSI At The Transmitter: When CSI is not accessible at the transmitter, transmit diversity at a low implementation complexity can be attained with orthogonal space-time block codes (STBC). Multiple antennas at a portable device imply that the antenna spacing has to be small. This implies that the signals that enter the different antennas will be correlated and the performance will degrade. An important constraint in the model for the scattering channel is the angle spread D of the received signals. With small antenna element spacing, the mutual coupling isimportant, and in our model the electromagnetic coupling has been considered.

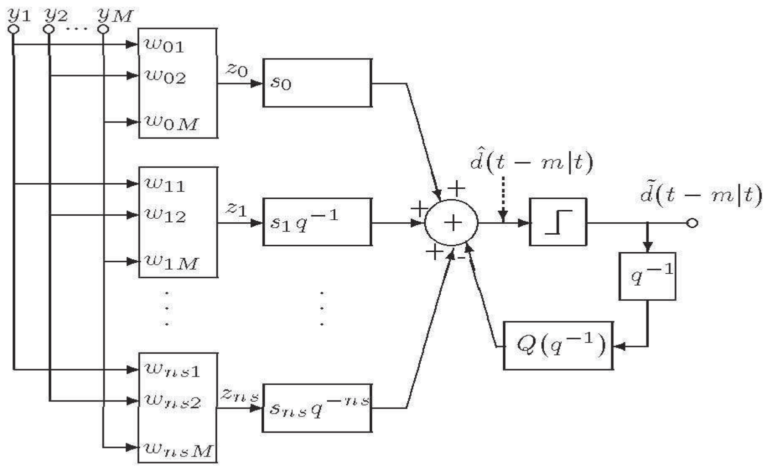


The figure offered above shows the outage capacity at 10% probability, which is the bit rate per Hz time when varying the antenna element separation (assuming dipoles). The i.i.d. Rayleigh of bandwidth that can be transmitted over the 2 times 2 MIMO Rayleigh fading channel 90% of the fading channel is also shown as a reference, and it is clearly seen how the correlation (introduced by the angle spread D) reduce the capacity of the channel. When mutual coupling is taken into consideration, the curves oscillate, due to the oscillating behaviour of the mutual impedance between two adjacent dipoles. It is fascinating to note that when the signals are highly correlated (D=6 degrees), the mutual coupling actually improves the outage capacity for small antenna element spacing, by de-correlation of the signals.

Algorithms for Combined Spatial and Temporal Equalization in TDMA: The received baseband signal in a TDMA Cellular System is corrupted by noise, by inter-symbol interference due to multipath propagation and by co-channel interference from other users.If only one antenna element is accessible at the receiver one can use filtering of the received time series in order to estimate the transmitted sequence, i.e. temporal equalization. If several antenna elements are available, it becomes possible to perform spatial filtering by forming beams in the direction of a desired signal. Noise and interference and also delayed signals which would lead to a consequence in inter-symbol interference, can then be suppressed if they arrive from other directions.

The 'beam forming' concept can be pooled with temporal equalization, resulting in *spatio-temporal equalization*. It then becomes feasible to make effective use of the energy in delayed signals arriving from several directions, while suppressing the signals from co-channel interferers.Spatio-temporal equalization can be performed by simplifying the single-input-single-output (SISO) DFE to a multiple-input-single-output (MISO) DFE. One can also use a MLSE Viterbi detector.A MISO DFE will, by necessity, contain a larger number of adjustable parameters than a SISO DFE. This leads to two potential problems.The adjustment of many filter constraints, based on short training sequences, is sensitive to noise. Maladjustment may lead to poor performance.The computational complexity of the algorithm will increase.

These two key issues have been investigated, for different filter structures and different adjustment schemes. The structure of one promising algorithm, the Multiple Independent Beam Decision Feedback Equalizer (MIB-DFE), is demonstrated below.

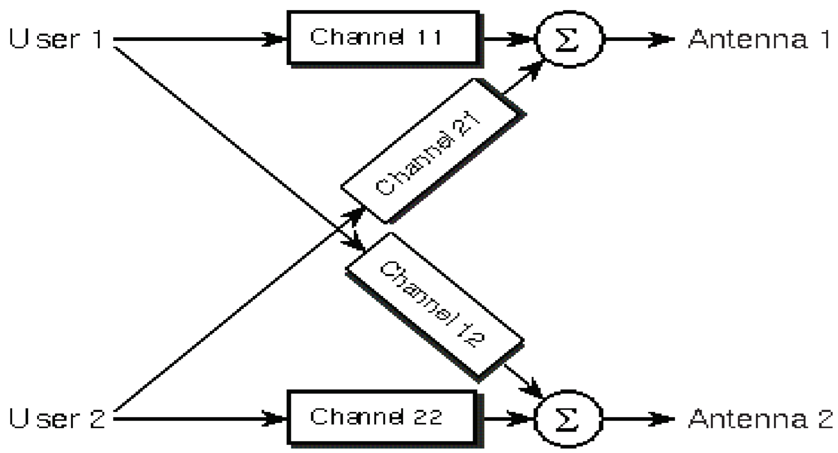


When multiple antenna elements are present, we may investigate the still harder task of detecting several users simultaneously, on the same frequency band. The research in this direction on multiuser detection is known in the field.The use of arrays of antenna elements is practical at the base station, but much less practical at the mobile. The investigated techniques are therefore primarily applicable in the transmission from the mobiles to the base stations.

Channel Reuse within Cell: In a TDMA system, the combination of a certain time slot and a certain frequency is called a *channel*. In a cellular system, each channel is used by multiple base stations. However, due to interference from one base station to another, not all channels are used in all cells. Instead, channels are reused at anexact interval. The interval with which the channels are reused is called the *reuse distance*. In a GSM system, the reuse distance is between 9 and 30.

In future, the spatial dimension must be exploited more scrupulously. The first step is certainly to decrease the reuse distance. This is the primary objective. If each channel could be used in each cell, the system capacity would rise by a factor equal to the reuse distance in the current system. But if an even larger increase in capacity is wanted, we have to lower the reuse distance*below* one or, in other words, perform *channel reuse within cell*.

This could actually be used as tools for such a scheme. For such an application, one of the users in the cell is considered as "desired", whereas the remaining users are considered as "interference". The signals from the other users will be considered as coloured noise, which can be significantly suppressed by using combined temporal and spatial equalization. Another option would be to consider the signals as signals rather than as colored noise. We could in this case use the property that all signals are digital, i.e., they can only assume a finite number of values. The model would in this case be a multiple input-multiple output (MIMO) channel model. As input we would use the transmitted symbols from all users, and as output the sampled output from the antenna. The situation is depicted to the right for a case with two users and two antennas.

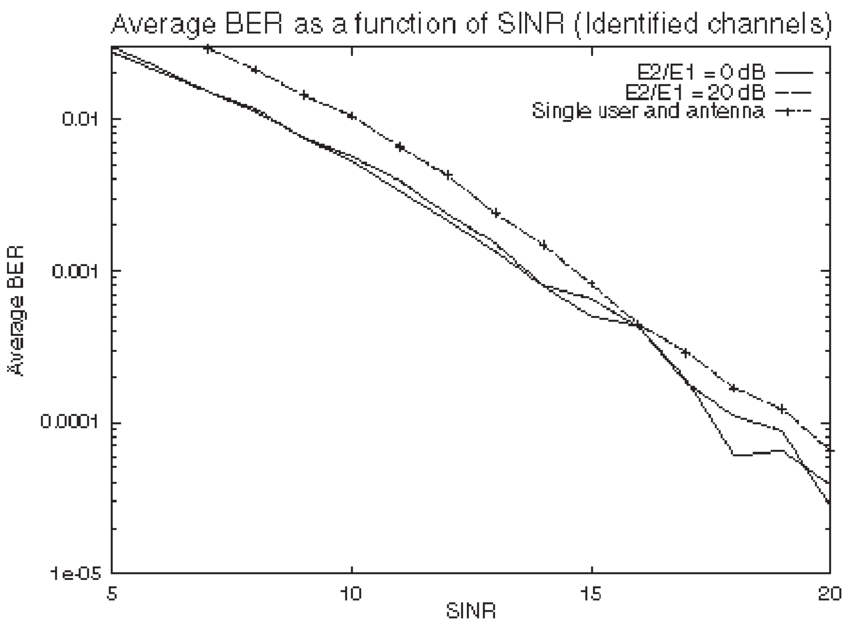


The problem of *interference suppression* has then become a problem of *multiuser detection*.A multiuser detector to detect both signals simultaneously can be used. The problem is very similar to the multiuser detection problem encountered in a DS-CDMA system.

To solve this multiuser detection problem, it is possible to use generalizations of any equalizer used to alleviate inter-symbol interference, i.e. a linear equalizer, a decision feedback equalizer or the Viterbi algorithm. The generalization is relatively straightforward. The derivation is based on a multivariable channel model of the form

$$\bar{y}(t) = \mathbf{B}_0\bar{d}(t) + \mathbf{B}_1\bar{d}(t-1) + \cdots + \mathbf{B}_n\bar{d}(t-n) + v(t)$$

Here, d is a vector of input symbol and y is a vector of channel outputs. The matrix coefficients **B** constitute the channel and are the basis for the equalizer design. A multivariable DFE to solve the multiuser detection problem has been derived.This multivariable DFE is described in greater detail in the sectionResearch on multiuser detectors for CDMA based cellular systems. To address the performance of this multiuser detector, simulations in a scenario which resembles a GSM system with two users and two antennas in each cell have been performed. As were the case for the CDMA system, it is of interest to investigate the performance when the received powers of the users are very different. In this case, the transmit powers of the users are either equal or differ by 20 dB.



The structure of the transmission is similar to the structure in GSM: the data is transmitted in bursts of length 148 with a training sequence of length 26 in the middle. Parameter estimation was performed using ordinary LS. The system is stimulated for signal to noise ratios between 5 and 20 dB. The performance is compared to the performance of a corresponding system where one user and one antenna were removed.

The system performs better with two users and two antennas than with one antenna and one user. This algorithm will also be applied to measurements from an antenna array. These measurements are supplied by Ericsson.

This paper has tried to raise the curtain for an overview of MIMO systems with antenna selection. The transmitter, the receiver, or both use only the signals from a subset of the available antennas. This allows considerable reductions in the hardware expense. The most significant conclusions one can arrive after going through a reading of this paper include:

- Antenna selection retains the diversity degree (compared to the full-complexity system), for both linear diversity systems with entire channel knowledge, and space-time coded systems. However, there is a penalty in terms of the average SNR.
- For spatial multiplexing systems (BLAST), antenna selection at the receiver only gives a capacity comparable to the full-complexity system as long as $Lr \geq Nt$ (and similarly for the selection at the transmitter).
- Optimum selection algorithms have a complexity (N/L). However, fast selection algorithms exist that has much lower (polynomial with N) complexity, and perform on a par with full-complexity systems.
- For low SNR, spatial multiplexing does not necessarily maximize capacity when antenna selection is present. The same is true for strong interference.
- For low-rank channels, transmit antenna selection can increase the capacity compared to a full-complexity system (without channel knowledge at the TX).
- Channel estimation errors do not decrease the capacity significantly if the SNR of the pilot tones is comparable to, or larger than, the SNR during the actual data transmission.
- Frequency selectivity reduces the effectiveness of antenna selection.
- Switches with low attenuation are required both for transmitter and receiver.
- Antenna selection is an extremely attractive scheme for reducing the hardware complexity in MIMO systems

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