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BER PERFORMANCE AND ANTENNA SELECTION FOR BEST TRANSMISSION IN SPATIAL MODULATION

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Abstract—The selection of the best transmits structure using transmission optimized spatial modulation (SM), a unique single-stream multiple-input multiple-output (MIMO) transmission technique. SM enables a trade-off between the size of the spatial constellation diagram and the size of the signal constellation diagram. Based on this fact, the novel method, named transmission optimized spatial modulation (TOSM) minimizes the average bit error probability (ABEP).The traditional antenna selection methods, the proposed method relies on statistical channel state information (CSI) instead of instant CSI, and feedback is only needed for the optimal number of transmit antennas. In addition, TOSM has low computational complexity as the optimization problem is solved through a simple closed-form objective function with a single variable. Simulation results show that TOSM significantly improves the performance of SM at various channel correlations.

I. INTRODUCTION

The need to curtail the carbon footprint and the operation cost of wireless networks requires an overall energy reduction of base stations (BSs) in the region of two to three orders of magnitude. At the same time, a significant increase in spectrum efficiency from currently about 1.5 bit/s/Hz to at least 10 bit/s/Hz is required to cope with the exponentially increasing traffic loads. These challenges the design of multiple-input multiple-output (MIMO) systems associated with the BS. A typical long-term evolution (LTE) BS consists of radio-frequency (RF) chains, baseband interfaces, direct current to direct current (DC-DC) converters, cooling fans, etc. Each RF chain contains a power amplifier (PA), and Pas contribute around 65% of the entire energy consumption. The efficiency of state-of-the-art (SOTA) PAs is about 30% only, i.e. more than two thirds of the energy is consumed in quiescent power. This drives research on minimizing the overall BS energy consumption instead of the energy required for the RF output stage only. As a result, power optimization of PAs has been studied. In, cell discontinuous transmission (DTX) was proposed to enable the BSs to fall into a sleep mode when there is no data to convey, so that the overall energy consumption can be reduced. Based on that concept, another optimization method using on/off PAs was reported in [8], and a similar work was conducted for MIMO orthogonal frequency division multiple access (OFDMA) systems. However, those studies have the following limitations: i) they focus on the operation of RF chains, while modulation schemes are not considered; ii) the optimization is implemented within each individual RF chain; and iii) the benefit is inversely proportional to the traffic load. When the BS has to be operated in the active mode continuously, the above methods would fail to achieve any energy-saving gain. Therefore it is necessary to study energy reduction on a more comprehensive level, including not only hardware operations, but also modulation schemes.

While multi-stream MIMO schemes, such as vertical Bell Labs layered space-time (V-BLAST) and space-time block coding (STBC), offer high spectrum efficiency, unfortunately, they need multiple RF chains that heavily compromise theenergy efficiency. Meanwhile, spatial modulation (SM) is a unique single-stream MIMO technique, where the bit stream is divided into blocks and each block is split into two parts: i) the first part activates one antenna from the antenna array while the remaining antennas do not emit a signal; ii) the bits in the second part are modulated by a signal constellation diagram, and sent out through the activated antenna. The use of a single active antenna makes SM a truly energy-efficient MIMO transmission technique, because only one RF chain is required, regardless of the number of transmit antennas used. At the same time, SM ensures spatial multiplexing gains as information is encoded in the antenna index. However, like all other MIMO schemes, SM suffers performance degradation caused by channel correlations. Trying to improve the performance of SM against channel variations, an adaptive method was proposed in, where one

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candidate is selected from several optional SM structures. Although the performance of SM can be improved to some extent, this method has the following weaknesses: i) it requires instant channel stateinformation (CSI), and therefore it is not suitable for fast fading channels; ii) the relation between the adaptive selection and the channel correlation has not been exploited; and iii) despite using a simplified modulation order selection criterion, it still requires significant processing power.

A novel adaptive antenna selection method for optimum transmission in SM. As a three dimensional modulation scheme, SM enables a trade-off between the size of the spatial constellation diagram and the size of the signal constellation diagram, while achieving the same spectrum efficiency. Based on this unique characteristic, transmission optimized spatial modulation (TOSM) aims to select the best combination of these two constellation sizes, which minimizes the average bit error probability (ABEP). To avoid the prohibitive complexity caused by exhaustive search, a two-stage optimization strategy is proposed. The first step is to determine the optimal number of transmit antennas, and this is performed at the receiver. In the second step, the required number of antennas is selected at the transmitter.

1.1 GENERALISED SPATIAL MODULATION

Author: A. Younis, N. Serafimovski, R. Mesleh, and H. Haas

The generalized spatial modulation (GSM) is a relatively new modulation scheme for multi-antenna wireless communications. It is quite attractive because of its ability to work with less number of transmit RF chains compared to traditional spatial multiplexing (V-BLAST system). By using an optimum combination of number of transmit antennas (N_t) and number of transmit RF chains (N_{rf}), GSM can achieve better throughput and/or bit error rate (BER) than spatial multiplexing. First, quantify the percentage savings in the number of transmit RF chains as well as the percentage increase in the rate achieved in GSM compared to spatial multiplexing; 18.75% savings in number of RF chains and 9.375% increase in rate are possible with 16 transmit antennas and 4- QAM modulation. A bottleneck, however, is the complexity of maximum-likelihood (ML) detection of GSM signals, particularly in large MIMO systems where the number of antennas is large. Specifically, propose a Gibbs sampling based algorithm suited to detect GSM signals. The algorithm yields impressive BER performance and complexity results. For the same spectral efficiency and number of transmit RF chains, GSM with the proposed detection algorithm achieves better performance than spatial multiplexing with ML detection.

1.2 SPACE-TIME BLOCK CODES FROM ORTHOGONAL DESIGNS

Author: V. Tarokh, H. Jafarkhani, and A. Calderbank

It introduce space–time block coding, a new paradigm for communication over Rayleigh fading channels using multiple transmit antennas. Data is encoded using a space–time block code and the encoded data is split into n streams which are simultaneously transmitted using n transmit antennas. The received signal at each receive antenna is a linear superposition of the n transmitted signals perturbed by noise. Maximum likelihood decoding is achieved in a simple way through decoupling of the signals transmitted from different antennas rather than joint detection. This uses the orthogonal structure of the space–time block code and gives a maximum-likelihood decoding algorithm which is based only on linear processing at the receiver. Space–time block codes are designed to achieve the maximum diversity order for a given number of transmit and receive antennas subject to the constraint of having a simple decoding algorithm.

The classical mathematical framework of orthogonal designs is applied to construct space–time block codes. It is shown that space-time block codes constructed in this way only exist for few sporadic values of n. Subsequently, a generalization of orthogonal designs is shown to provide space-time block codes for both real and complex constellations for any number of transmit antennas. These codes achieve the maximum possible transmission rate for any number of transmit antennas using any arbitrary real constellation such as PAM. For an arbitrary complex constellation such as PSK and QAM, space–time block codes are designed that achieve 1=2 of the maximum possible transmission rate for any number of transmit antennas. For the specific cases of two, three, and four transmit antennas, space–time block codes are designed that achieve, respectively, all, 3=4, and 3=4 of maximum possible transmission rate using arbitrary complex constellations. The best trade off between the decoding delay and the number of transmit antennas is also computed and it is shown that many of the codes presented here are optimal in this sense as well.

1.3 FRACTIONAL BIT ENCODED (FBE) SPATIAL MODULATION

Author: N. Serafimovski, M. Di Renzo, S. Sinanovic, R. Y. Mesleh, and H. Haas

A method for overcoming the limitation on the number of transmit antennas in SM and allow the transmitter to be equipped with an arbitrary number of antennas. SM is a novel approach to multiple-input-multiple-output (MIMO) systems which entirely avoids inter-channel interference (ICI) and requires no synchronisation between the transmit antennas, while achieving a spatial multiplexing gain. This is performed by mapping a block of information bits into a constellation point in the signal and spatial domains. In SM, the number k of information bits that are encoded in the spatial domain is directly related to the number M of transmit antennas, in particular $M = 2k$. This means that the number of transmit antennas must be a power of two. A solution to this limitation in SM which increases the granularity of the data encoding process in the spatial domain by using fractional bit encoding; the novel method is called FBE-SM.

1.4 BEP OF SPACE MODULATION OVER NAKAGAMI-M FADING

Author: M. Di Renzo and H. Haas

It introduces SPACE modulation is a digital modulation concept for Multiple-Input Multiple-Output (MIMO) wireless systems. Recent results have shown that it can outperform many state-of-the-art transmission technologies. The fundamental innovation is the introduction of the so called spatial constellation diagram, which is used for data modulation. More specifically, improved performance is not achieved through the simultaneous transmission of multiple data streams, but by encoding the information bits onto the spatial positions of the antennas at the transmitter.

Two basic space modulation concepts exist in the literature. 1) Space Shift Keying (SSK) modulation, where the incoming bit stream is used to identify a single antenna of the antenna-array that is switched on for transmission. The information bits are mapped onto the channel impulse responses of the end-to-end wireless links. The main benefit of SSK modulation is a low implementation complexity. 2) Spatial Modulation (SM), which is a hybrid modulation scheme combining Phase Shift Keying (PSK) or Quadrature Amplitude Modulation (QAM) with SSK modulation. In SM, each block of information bits is transmitted through two information–carrying units: some bits are modulated using either PSK or QAM, while the others using SSK modulation.

1.5 SPATIAL MODULATION FOR MULTIPLE-ANTENNA WIRELESS SYSTEMS

Author: M. Di Renzo, H. Haas, and P. M. Grant

A multiple-antenna techniques constitute a key technology for modern wireless communications, which trade-off superior error performance and higher data rates for increased system complexity and cost. Among the many transmission principles that exploit multiple-antenna at the transmitter, the receiver, or both, Spatial Modulation (SM) is a novel and recently proposed multiple-antenna transmission technique which can offer, with a very low system complexity, improved data rates compared to Single-Input-Single-Output (SISO) systems, and robust error performance even in correlated channel environments. SM is an entirely new modulation concept that exploits the uniqueness and randomness properties of the wireless channel for communication. This is achieved by adopting a simple but effective coding mechanism that establishes a one-to-one mapping between blocks of information bits to be transmitted and the spatial positions of the transmit antenna in the antenna-array.

1) **Just one transmit–**antenna is activated for data transmission at any signaling time instance. This allows SM to entirely avoid the ICI, to require no synchronization among the transmit–antenna, and to need only one RF chain for data transmission. This is in net contrast with respect to conventional MIMO schemes where the multiple–antenna are used to simultaneously transmit multiple data streams. SM to exploit a low–complexity single–stream receiver design for optimal Maximum–Likelihood (ML) decoding.

2) **The spatial position of each transmit–**antenna in the antenna–array is used as a source of information. This is obtained by establishing a one–to–one mapping between each antenna index and a block of information bits to be transmitted, which results in a coding mechanism that can be called transmit–antenna index coded modulation. This allows SM to achieve a spatial multiplexing gain with respect to conventional single–antenna systems since part of the information is implicitly conveyed by the position of the transmit–antenna. Accordingly, even though just one antenna is active, SM can also achieve high data throughput.

1.6 CHANNEL CAPACITY OF MIMO ARCHITECTURE

Author: S. Loyka

MIMO communication architecture has recently emerged as a new paradigm for wireless communications in rich multipath environment. Using multi-element antenna arrays at both transmitter and receiver, which effectively exploits the third spatial dimension in addition to time and frequency dimensions, this architecture achieves channel capacity far beyond that of traditional techniques. In independent Rayleigh channels the MIMO capacity scales linearly as the number of antennas under some conditions. However, some impairments of the radio propagation channel may lead to a substantial degradation in MIMO performance. Some limitations on the MIMO capacity are imposed by the number of multipath components or scatterers. Another limitation on the MIMO channel capacity, which is somewhat analogous to the multiple path limitation, is due to the correlation between individual sub-channels of the matrix channel. Increase in the correlation coefficient results in capacity decrease and, finally, when the correlation coefficient equals to unity, no advantage is provided by the MIMO architecture. The effect of fading correlation on the MIMO channel capacity has been investigated in details in using an abstract one-ring scattering model. However, this approach does not allow studying the effect of correlation in an explicit way.

Channel capacity of the two-antenna MIMO architecture has been investigated as an explicit function of the correlation coefficient. The general case of -antenna architecture has been considered in using the uniform correlation matrix model, i.e. when all the correlation coefficients are equal. This model may be used for the worst-case analysis or for some rough estimation using the average value of the correlation coefficient. However, the uniform model is somewhat artificial-one expects that the correlation of neighboring sub channels is higher than that of distant sub channels. In this way, arrive to the exponential correlation model, which has been successfully used for many communication problems. The MIMO channel capacity using the exponential correlation matrix model by analytical techniques and derive a simple formula for the channel capacity indicating its validity range. The model, increase in correlation is equivalent to decrease in the signal-to-noise ratio under some realistic conditions. For example, γ=0.7 is equivalent to the 3 dB decrease in SNR as compared to the case of γ=0. Finally compare this model with the uniform model and show that the exponential model predicts better MIMO performance.

1.7 BIT ERROR PROBABILITY OF SM-MIMO OVER GENERALIZED FADING CHANNELS

Author: M. Di Renzo and H. Haas s

The performance of spatial modulation multiple-input-multiple-output wireless systems over generic fading channels. More precisely, a comprehensive analytical framework to compute the ABEP is introduced, which can be used for any MIMO setup, for arbitrary correlated fading channels, and for generic modulation schemes. It is shown that, when compared with state-of-the-art literature, our framework 1) has more general applicability over generalized fading channels, 2) is, in general, more accurate as it exploits an improved union-bound method, and, 3) more importantly, clearly highlights interesting fundamental trends about the performance of SM, which are difficult to capture with available frameworks.

1.8 APPROACHES TO ENERGY EFFICIENT WIRELESS ACCESS NETWORKS

Author: Oliver Blume, Dietrich Zeller, Ulrich Barth

Due to increasing data traffic rates and rollout of advanced radio transmission technologies wireless networks consume increasing amount of energy and contribute a growing fraction to the CO_2 emissions of ICT industry. Thus, climate and cost issues now shift the research focus of wireless communications to energy consumption and energy efficiency. Two approaches can be followed: Incremental improvements of existing systems or a clean slate re-design with a fundamental change of paradigms. The EC FP7 project EARTH is a 30 month project aiming for a reduction of the overall energy consumption of 4G mobile broadband networks by 50%, regarding network aspects and individual radio components from a holistic point of view. The Green Touch Initiative is a privately financed consortium addressing fundamental research that will pave the way to much higher reductions for future systems in the order of several magnitudes.

II. PROPOSED SYSTEM

2.1 SYSTEM MODEL

2.1.1 SM transmitter

The Fig 2.1 shows a $N_t \times N_r$SM-MIMO system transmitter, where N_t and $N_r$are the number of transmit antennas and the number of receive antennas, respectively. Unlike the original SM, only a subset of the transmit antennas is used. The size of the spatial constellation diagram, i.e. the number of utilized transmit antennas, is denoted by N, while the size of the signal constellation diagram is denoted by M. The bit stream is divided into blocks with the length of η_s bits, where $\eta_s = log_2(N) + log_2(M)$ is the number of bits per symbol. Each block is then split into two units of $log_2(N)$ and $log_2(M)$ bits. The first part activates a single transmit antenna from the spatial constellation diagram, and the currently active antenna is denoted by x_{tact}. The second part chooses the corresponding symbol $X_l (1 \leq l \leq M)$ from a specific signal constellation diagram, such as phase shift keying (PSK) or quadrature amplitude modulation (QAM), and sends it out through the activated antenna. The transmitted signal of SM is represented by a vector x = [0, . . . , x_{tact}, . . . , 0] T of N elements, where the tact-th element is $X_l$and all other elements are zero.

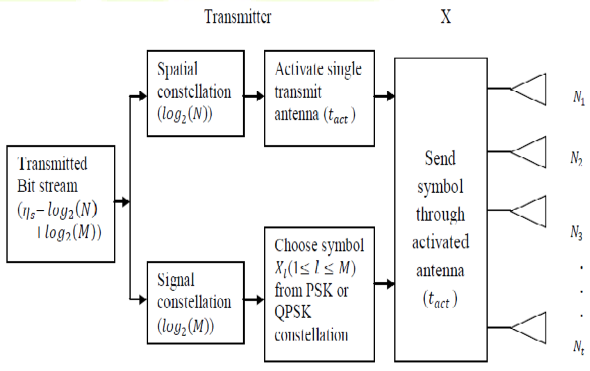

Fig 2.1 Block diagram of SM transmitter

2.1.2 SM wireless channel:

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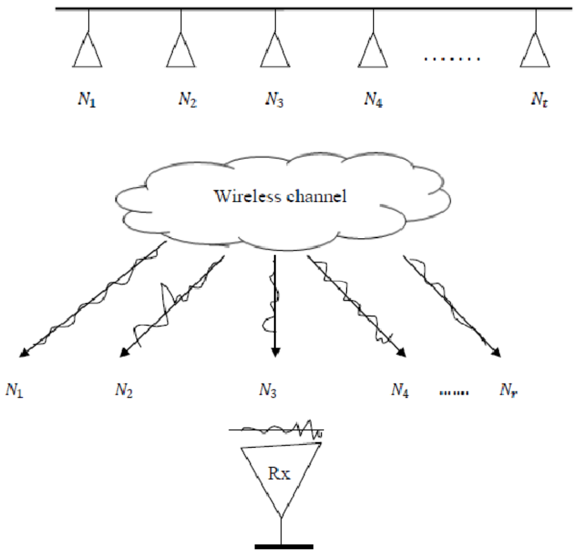

Fig 2.2 SM wireless channel

The fading coefficient of the link from the t-th transmit antenna to the r-th receive antenna is denoted by $h_{t,r}$=$\beta_{t,r}$ exp (jϕ_t,r), where $\beta_{t,r}$ and $\phi_{t,r}$ are the amplitude and the phase, respectively. The channel fading distribution as well as the CSI is assumed to be known at the receiver. Nakagami-m fading is considered in this paper, i.e. $\beta_{t,r}$ ~ Nakagami ($m_{t,r}$, $\Omega_{t,r}$), where $m_{t,r}$is the shape parameter (when $m_{t,r}$= 1, the channel is Rayleigh fading) and $\Omega_{t,r}$ is the spread controlling parameter. The phase ϕ_t,r is uniformly distributed between (−π, π].

On selecting the transmit antennas, the receive antennas are assumed to be independent without loss of the generality. The correlation coefficient between the amplitudes of the two propagation paths from the transmit antennas $t_i$and t_j to the r-th receive antenna is denoted by $p_{t_{j,t_{i},r}}$. The exponential correlation matrix is based on the fact that the channel correlation decreases with increasing the distance between antennas. The absolute distance between $t_i$and t_j is denoted by d_{t_i,t_j}, and the correlation between those two antennas is given by

$$p_{av}=\frac{1}{N_r}\left(\frac{1}{N_t(N_t-1)}\sum_{t_i=1}^{N_t}\sum_{t_j\neq t_i=1}^{N_t}p_{t_{j,t_i,r}}\right)$$

The average degree of the channel correlations, denoted by ρ_{av}, is calculated by:

$$p_{t_{j,t_{i},r}} = p_{s(r)}^{d_{t_i,t_j}} ,0 \leq p_{s(r)} \leq 1$$

2.1.3. SM receiver

Fig 2.3 shows the received signal is y = HX + w, where H stands for the channel matrix, the vector w = [w_1, . . . , w_{Nr}]T and w_r, the noise at the r-th receive antenna, is a sample of complex additive white Gaussian noise with distribution CN(0,N_0). Across receive antennas; the noise components are statistically independent. The signal-to-noise ratio (SNR) is defined as γ = E_mL/N_0, where E_m is the average energy per symbol transmission and Ldenotes the path loss without shadowing. In addition, the required RF output energy per bit is denoted by E_b= E_m/η_s. The transmitted information bits are decoded by the joint maximum likelihood (ML) detection.

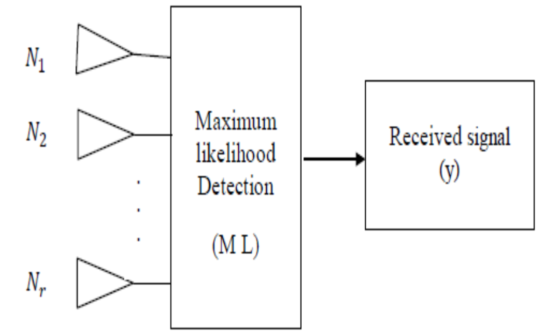

Fig 2.3 SM receiver

2.2 ABEP FOR TOSM

For correlated and identically distributed (c.i.d.) Rayleigh fading channels, have m_r= 1 and $\Omega_{t,r}$ = Ω for all t and r. The ABEP is given by,

$$\text{AEBP} = \frac{B(M)^{2Nr}+C(2^{\eta_s}\eta_s-Mlog_2(M))}{\eta_s\gamma^{Nr}}$$

where ,

$$\text{B}=(\frac{2}{\Omega})^{\text{Nr}}\frac{1}{\pi^{2Nr+1}}\int_0^{\pi}(sin\theta)^{2Nr}\ d\theta$$

and

$$\text{C} = \frac{4^{Nr-1}\Gamma(N_r+0.5)}{\Omega^{Nr}\sqrt{\pi}\Gamma(N_r+1)}\left(\sum_{k=0}^{-\infty}\frac{\Gamma(2k+1)\rho_{av}^k}{4^k(k!)\Gamma(k+1)}\right)$$

2.3 BASE STATION ENERGY CONSUMPTION BASED ON TSOM

The required $E_m$using TOSM is computed by,

$$E_m = \frac{N_0}{L}\left(\frac{F(M_{opt})}{\eta_s R_b}\right)^{\frac{1}{Nr}}$$

where F(M) = B(M) ^{2nr}+ C(22$^{\eta_s}\eta_s$− M $log_2(M)$) and R_b denotes the value of the target BER.

The required RF output power is obtained by,

$$P_m = \frac{R_b N_0}{\eta_s L}\left(\frac{F(M_{opt})}{\eta_s R_b}\right)^{\frac{1}{Nr}}$$

2.3.1 Continuous Mode

In the continuous mode, the RF chains are always delivering output power of the same level. The energy consumption per bit of a BS based on TOSM is obtained by with Nact = 1

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$$E_{BS} = \frac{P_0}{R_b} + \frac{\varsigma N_0}{\eta_s L}\left(\frac{F(M_{opt})}{\eta_s R_b}\right)^{\frac{1}{Nr}}$$

Where, ςstands for the slope that quantifies the load dependence N_{act} activated antennas.

2.3.2 DTX Mode

The DTX mode conveys data with full load, and the instantaneous
data rate. Compute E_{BS} in the DTX mode as follows,

$$E_{BS} = \frac{P_0}{R_b} + \frac{N_0}{\eta_s L}\left(\varsigma + \frac{P_0 - P_s}{P_{max}}\right)\left(\frac{F(M_{opt})}{\eta_s R_b}\right)^{\frac{1}{Nr}}$$

2.4 DIRECT ANTENNA SELECTION

Select a subarray of N_{opt} antennas from the size-N_t antenna array. The chosen subset should achieve the minimum ABEP of all subarrays with the same size. Since B_N is irrelevant to the channel correlations, the problem is equivalent to finding the subarray with a minimum c_N. Like the traditional transmit antenna selection (TAS) methods, this issue can be solved by an exhaustive search. However, this results in an unaffordable complexity for a large ηs. Taking ηs = 6 and N_{opt} = 16 as an example, the full search space is about 5 × 1014, which is prohibitive for practical implementations. Here, propose a novel TAS method based on circle packing, which can directly determine the selection. As the correlation coefficient $p_{ti,tj}$is inversely proportional to the distance $d_{ti,tj}$, a rational solution is to maximize the minimum geometric distance between any pair of the chosen antennas. This is equivalent to the circle packing problem in mathematics.

Fig 2.4 shows the circle packing solutions for various numbers of antennas, where the antennas are located at the circle centers. In the original problem, each circle must fit inside the square boundary. The problem at hand is slightly different where the circle centers are restricted to be inside the boundary, and in Fig.2.4 this is shown by dashed lines. It is worth noting that this solution requires fully flexible positions. Thus, we refer to it as ideal circle packing (ICP). However, the antenna positions are fixed in practice, and the subarray cannot be perfectly allocated by ICP. Instead, a realistic circle packing (RCP) is developed by selecting those antennas closest to the ideal positions. In Fig 3.5, an RCP solution is demonstrated for the case of Nt = 32 and N = 8. As can be observed, the selection presents a similarity to the solution for N = 8 in Fig 3.4. With an increase of Nt, the RCP solution becomes closer to ICP as the antenna array supplies a larger flexibility in positions.

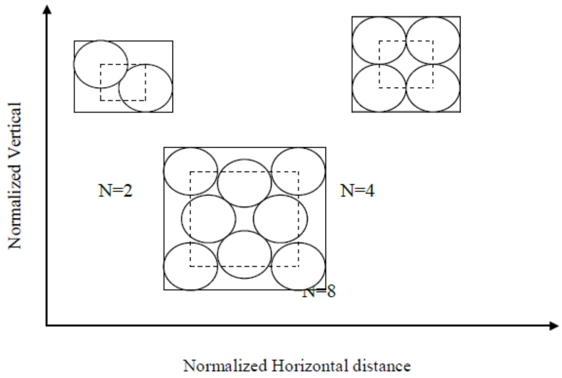


Fig 2.4 Examples of circle packing problems

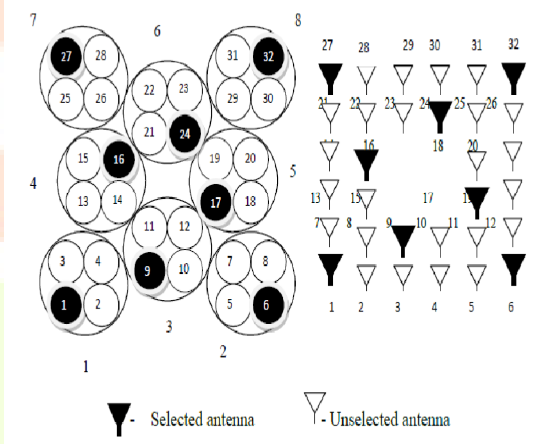
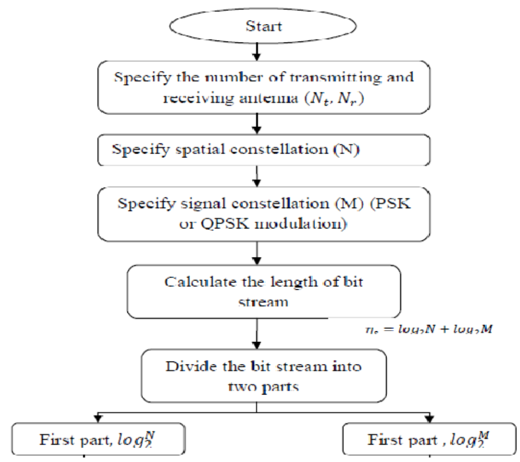


Fig 2.5 RCP for selecting 8 out of 32 antennas

2.5 FLOW CONTROL



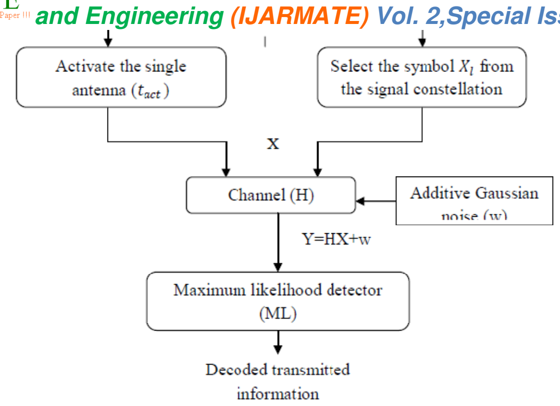


Fig 2.6 Flow diagram

III. RESULTS AND DISCUSSION

3.1 BER PERFORMANCE OF DIRECT ANTENNA SELECTION

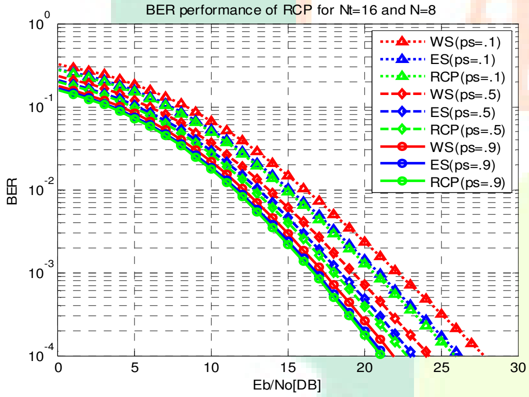


Fig 3.1 BER performance of RCP Nt=16 and N=8

The BER performance of the proposed RCP approach is evaluated against two baseline schemes: i) the exhaustive search (ES); and ii) the worst case where the neighbouring antennas are selected. We refer to this scheme as worst selection (WS) in the sequel. Fig 3.1 and Fig 3.2 present the BER performance of RCP for ηs = 4 and 5, respectively. Due to the intractable complexity of ES, the results when ηs> 5 are not presented. In addition, the antenna area is assumed to be the same to ensure a fair comparison for different ηs. Therefore, ρs is used instead of ρ_{av}. As shown, the RCP scheme achieves almost the same performance as ES with a gap of less than 0.3 dB. Furthermore, the negligible difference between RCP and ES is barely affected by the channel correlations, whereas the performance of WS becomes much worse as the correlation increases. To achieve the same BER value of 1 × 10-4 in the case of selecting 8 out of 32 antennas, in comparison with WS, RCP obtains an energy saving of 1.1 dB and 2.0 dB at ρs= 0.1 and 0.9, respectively.

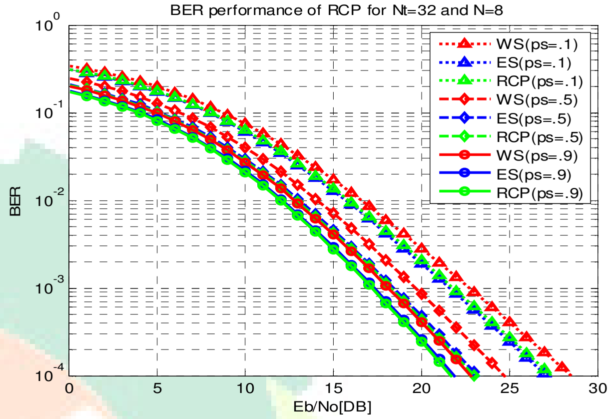


Fig 3.2 BER performance of RCP Nt=32 and N=8

3.2 BER PERFORMANCE OF TOSM

The complexity of the MIMO system depends on the number of RF chains rather than the total number of transmit antennas. Despite the requirement of large antennas at the transmitter, TOSM needs only one RF chain. For this reason, it is reasonable to compare our approach to fixed-SM schemes with the same ηs. Based on the obtained optimal N, we evaluate the BER performance of TOSM. Assuming Nr = 2 and Eb/N0 = 25 dB, Figs 3.3-3.5 show the BER results against the channel correlation for ηs = 4, 5 and 6, respectively. The case of N = 1 is referred to as single-input multiple-output (SIMO).

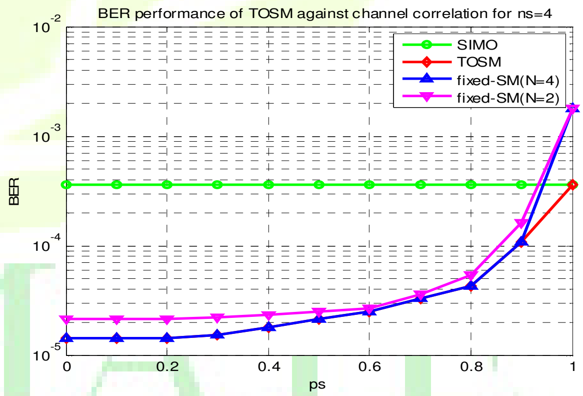


Fig. 3.3 BER performance of TOSM against channel correlation for ηs = 4.

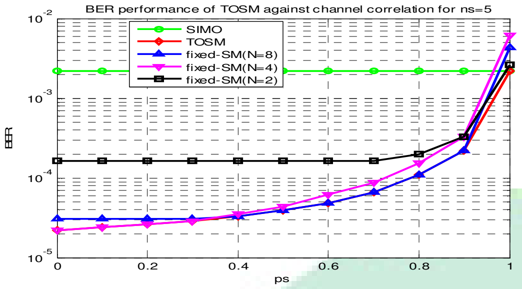


Fig. 3.4 BER performance of TOSM against channel correlation for ηs = 5.

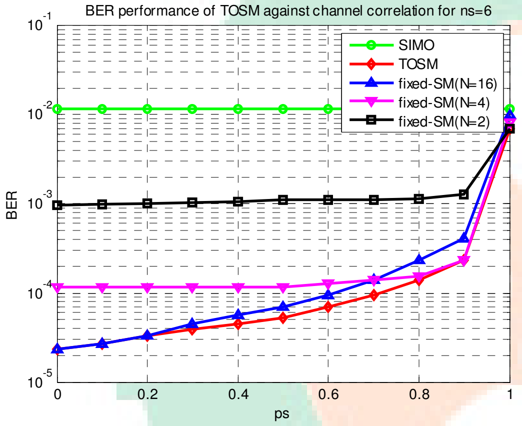


Fig. 3.5 BER performance of TOSM against channel correlation for ηs = 6.

The following trends are observed: i) fixed-SM with more antennas is not always better than those using fewer antennas. This signifies that the benefit does not simply come from employing more transmit antennas; ii) TOSM always performs better than or equal to fixed-SM schemes, which validates the optimization results; and iii) when ηs increases, TOSM employs more transmit antennas and performs much better than the fixed-SM with a small N. Specifically, TOSM slightly outperforms fixed-SM with N = 2 at both low and high correlations for ηs = 4. However, for ηs = 5and 6, TOSM can always achieve a significant gain except when the channel correlation is extremely high. Similar, but less pronounced trends are noticed at lower SNRs

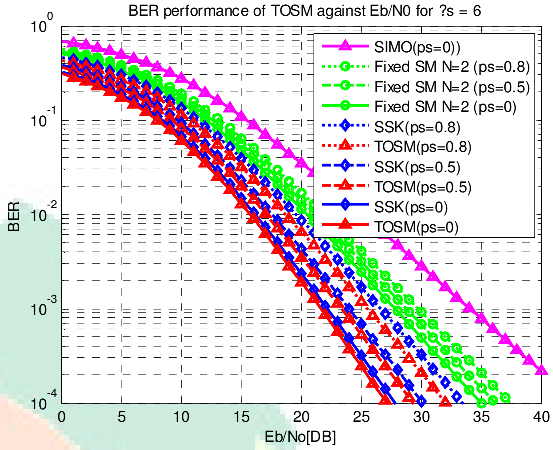


Fig 3.6 BER performance of TOSM against Eb/N0 for ηs = 6

In Fig 3.6, the BER performance of TOSM is shown as a function of Eb/N0 for ηs = 6. As can be seen, TOSM significantly outperforms the other schemes for all presented SNRs and various channel correlation degrees. When the channels are independent, i.e. ρs = 0, TOSM saves energy in the regions of 0.8 dB, 8.7 dB, and 15.1 dB relative to SSK, fixed-SM with N = 2, and SIMO, respectively. As ρs increases, TOSM outperforms SSK more significantly. Conversely, fixed- SM with N = 2 is only slightly affected by the channel correlation, and the advantage of TOSM is diminishing with an increase of ρs. However, the gain of TOSM over fixed-SM with N = 2 still exceeds 4 dB at ρs = 0.8.

IV. CONCLUSION

An optimum transmit structure for SM, which balances the size of the spatial constellation diagram and the size of the signal constellation diagram. Instead of using exhaustive search, a novel two-stage TAS method has been proposed for reducing the computational complexity, where the optimal number of transmits antennas and the specific antenna positions are determined separately. The first step is to obtain the optimal number of transmit antennas by minimizing a simplified ABEP bound for SM. In the second step, a direct antenna selection method, named RCP, was developed to select the required number of transmit antennas from an antenna array. Results show that TOSM improves the BER performance of the original SM significantly.

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