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LOCATION BASED BEAMFORMING

When channel state information is available at the transmitter, it can be exploited to increase the throughput, or to enhance the performance of a multiple input multiple output (MIMO) system. Beamforming schemes, such as closed loop MIMO and transmit beamforming constitute efficient means to achieve the aforementioned objectives. A significant shortcoming of transmit beamforming schemes is the signaling overhead required to provide the transmitter with the downlink channel knowledge. Another drawback of transmit beamforming schemes is their sensitivity to channel state information accuracy. In this paper we suggest an alternative beamforming method that uses the receiver positioning data, for example GPS positioning data, to create the transmit beamforming vector. This approach is attractive as in many modern communications systems location based services provide the transmitter (for example a cellular base station) with continuous information respective to the physical position of the receiver (the celluar phone in this case). The location based beamforming method constructs preceding vectors that are optimized for line of sight scenarios. Our simulations show that line of sight precoders are superior to regular codebooks based precoders, such as the IEEE802.16e codebook, in line of sight scenarios. Surprisingly the proposed precoders exhibit acceptable (and even superior) performance in some non line of sight scenarios.

Transmit beamforming, Preceding codebook, line of sight.

Introduction

Transmit beamforming [8] plays an important role in modern multiple input multiple output (MIMO) communications systems. In transmit beamforming, the transmitter uses channel state information (CSI) to create directional (and other) transmission beams using multiple transmit antennas. The beams are usually constructed to maximize the quality of the communications link. In orthogonal frequency division multiplexing (OFDM) MIMO systems [7; 11], which turns the frequency selective channel into multiple flat fading channels, the beams are constructed using a precoding procedure [8]. By precoding we mean multiplying a data symbol (e.g., a complex valued scalar QAM symbol) with an $M\times 1$ vector, where $M > 1$ is the number of transmit antennas.

A key issue in transmit beamforming is the means to provide the transmitter with sufficiently accurate CSI. One solution is based on reciprocity [8] and is mostly applicable for time division duplex (TDD) systems. For example, in cellular networks where transmit beamforming is employed on the downlink (DL), the base station (BS) may estimate the downlink (DL) channel using signals transmitted by the mobile station (MS) on the uplink (UL). Such an approach is adopted in the TDD version of the IEEE802.16e (WiMAX) [3]. This standard includes a special *soundin*g signal transmitted by the MS to allow the BS to estimate the channel and facilitate the construction of precoding vectors.

In frequency division duplex (FDD), where reciprocity is compromised, the MS usually chooses the preferred precoding vector out of a predefined codebook, and feedbacks its index to the BS. For example, using a codebook of 64 possible vectors, the MS feedbacks 6 bits. This approach, which is known as closed loop (CL) MIMO is adopted by the LTE standard [9] which is FDD centric. Since the precoding vector is chosen by the MS based on the DL channel estimate, this approach eliminated the need for transmitter calibration, which is required in reciprocity based methods [9].

To set ideas straight we consider a MIMO system with *M* transmit antennas and a single receive antenna. The model for the received signal is

$$y = \boldsymbol{h}^* \boldsymbol{x} + \rho n, \tag{1}$$

where $(\bullet)^*$ denotes conjugate transposition, $\boldsymbol{h}^*$ is the $1 \times M$ channel vector, $\boldsymbol{x}$ is the $M \times 1$ transmitted vector and ρn is a complex normal noise with zero mean and variance equal to ρ^2. In transmit beamforming, the transmitted vector $\boldsymbol{x}$ is

$$\boldsymbol{x} = \boldsymbol{w} s, \tag{2}$$

where $(\bullet)^*$ s is a complex valued (scalar) QAM symbol and $\boldsymbol{w}$ is an $M \times 1$ channel precoding vector with $\|\boldsymbol{w}\|^2 = 1$ to ensure unity transmission power. Using (2), the received signal (1) is written as

$$y = \boldsymbol{h}^* \boldsymbol{w} s + \rho n, \tag{3}$$

which means that the instantaneous signal to noise (SNR) ratio at the receiver is

$$\text{SNR} = \frac{|\boldsymbol{h}^* \boldsymbol{w}|^2}{\rho^2}. \tag{4}$$

The optimal precoding vector (in the sense of maximal SNR and maximal capacity) is

$$\hat{\boldsymbol{w}} = \frac{\boldsymbol{h}}{\|\boldsymbol{h}\|}, \tag{5}$$

and the optimal SNR is $\|\boldsymbol{h}\|^2 / \rho^2$ (similarly to that in maximal ratio combining (MRC) in receive diversity). For example in uncorrelated Rayleigh channel, optimal transmit beamforming gives array gain (AG) of *M* and diversity order of *M* [8].

In case the precoding vector is chosen out of a predefined codebook, the maximal SNR solution is

$$\hat{\boldsymbol{w}}_c = \underset{\boldsymbol{w} \in \text{codebook}}{\text{argmax}} \; |\boldsymbol{h}^* \boldsymbol{w}|^2, \tag{6}$$

so it is obtained through correlating the channel with each of the vectors in the codebook. Codebooks are usually constructed following some optimality criterion which may depend of the characteristics of the channel [5].

LOS Specific Codebooks

Considering a linear array [6] with *M* transmission antennas, half wavelength spacing, and *K* paths with zero delay, the channel under the far field assumption is

$$\boldsymbol{h}^* = \sum_{k=1}^{K} a_k \left[e^{(-j\pi \cdot 0 \cdot \cos\theta_k)}, \ldots, e^{(-j\pi(M-1)\cos\theta_k)} \right], \tag{7}$$

where a_k is the complex valued coefficient of the *k*-th path and θ_k is the angle of the *k*-th path with respect to the array axis.

In line of sight (LOS), when the channel is composed of a single path (K= l), the channel takes the form

$$\boldsymbol{h}^* = a_1 \left[e^{(-j\pi \cdot 0 \cdot \cos\theta_1)}, \ldots, e^{(-j\pi(M-1)\cos\theta_1)} \right], \tag{8}$$

and all channel gains $|h_m| = |a_1|$ are equal. The channels h_m differ only in phase, depending on the θ_1. The LOS scenario is illustrated in Fig. 1. The situation is different in the case of non LOS (NLOS), where both channel gains $|h_m|$ and channels phases generally differ.

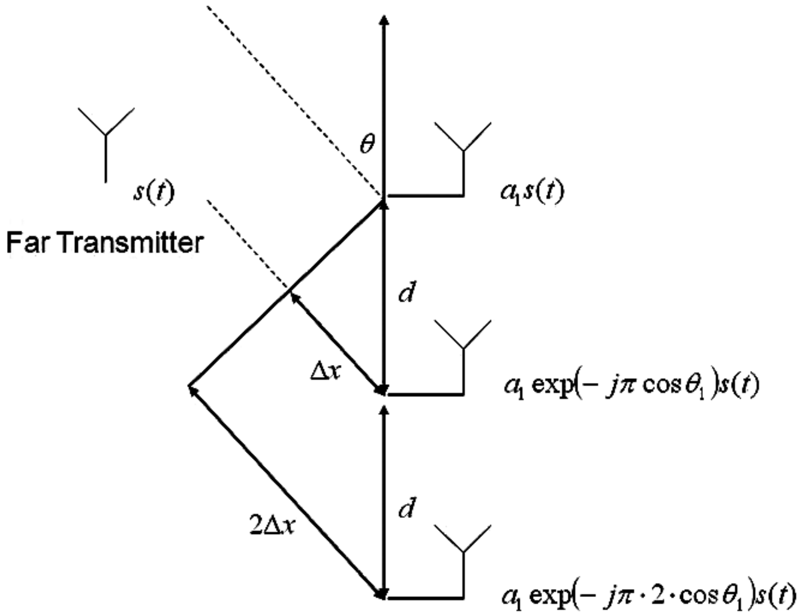

Fig. 1. An illustration of the LOS channel in the UL

This fundamental difference between LOS and NLOS leads to the understanding that in LOS we may employ a specific tailored codebook for LOS. All *N* vectors $\boldsymbol{v}_1, \ldots, \boldsymbol{v}_N$ in a LOS codebook

$$|\boldsymbol{v}_n(m)| = \frac{1}{\sqrt{M}} \quad \forall 1 \leq m \leq M, \tag{9}$$

and the elements differ only in phase. For example, a LOS codebook for a linear array will include vectors of the form

$$\boldsymbol{v}_n = \frac{1}{\sqrt{M}} \left[e^{(-j\pi \cdot 0 \cdot \cos\alpha_n)}, \ldots, e^{(-j\pi(M-1)\cos\alpha_n)} \right]^*, \qquad (10)$$

where α_n is parameter.

If follows that in LOS and near LOS, the LOS codebook may lead to superior performance compared to a general NLOS codebook with identical number of vectors, *N*. This is since the NLOS codebook should accommodate the channel gain variations and general phase variations characterizing the NLOS scenario, which lead to less «dense» sampling of the vector subspace.

Location Based Beamforming

Focusing on the specific structure of vectors in the LOS codebook for linear arrays (10), we understand that similarly to traditional phased array systems [2; 6], knowledge of the angle of arrival (AOA) respective to the UL of a certain MS may allow efficient estimation of the precoding vector required for DL transmission.

The UL AOA may be estimated using MUSIC like algorithms [10], which is based on spatial covariance estimation followed computation of the noise eigenvectors. In MUSIC the AOA is obtained by a search for the steering vector in the form of (10) with minimal projection on the noise eigenvectors.

Alternatively the AOA may be estimated using knowledge pertaining to the absolute physical location of the MS. Provided that the BS location is known, the MS absolute location is translated to the relative location w.r.t the BS. The absolute location is estimated via a triangularization procedure using ranging measurements at several BSs or via GPS readings.We note that location based beamforming requires additional calibration to account for the geometry of the array (e. g., in linear array the angle between the array axis and the magnetic north) instead of transmission-reception calibration required in reciprocity based and AOA estimation methods.

With the advent of location based services (LBS) [4], such as navigation application, location based advertisement and location enhanced web search, in many cases the BS is already equipped with the MS positioning. This positioning information may be used to construct the DL precoding vector without additional overhead (e.g., the sounding signal in reciprocity based methods and the codebook index in codebook based methods).

Focusing on GPS based positioning, and taking into account the limited GPS positioning accuracy (up to 20m in most cases) it is obvious that the beamforming (angular) precision is also limited. The beamforming angular accuracy grows with the separation between the BS and the MS as depicted in Fig. 2. The maximal angular error amax is

$$\alpha_{\max} = \arctan\left(\frac{20}{R}\right), \qquad (11)$$

where R is the separation between the BS and the MS, measured in meters. A natural approach to this problem would be to limit location based beamforming to cases where maximal angular error, α_{max} does not exceed a predefined threshold. Finally, location based beamforming may be employed when a near LOS scenario is detected and the MS is far enough from the BS. The exact threshold depends on GPS accuracy and BS beam width (which is also a function of the number of transmit antennas).

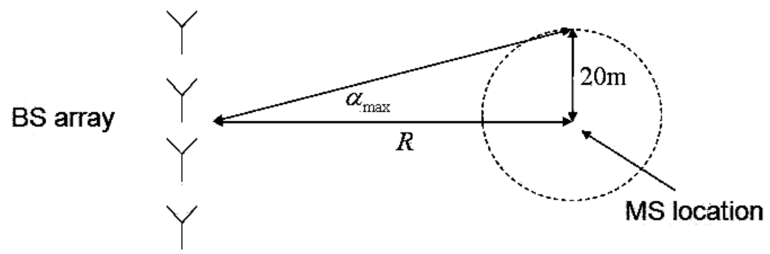

Fig. 2. The maximal angular inaccuracy of the gps positioning based beamformer.

Simulation Results

In order to evaluate the performance of the LOS codebook based beamforming method, we conducted a Monte Carlo simulation study. We adopted the Ped-B [1] model statistics (i.e., number of paths, paths' average power and paths' delay) and constructed the simplified geometric model (7), assuming the AOAs are uniformly distributed on $[0, \pi]$. We considered a MIMO scheme with 4 transmission antennas and a single reception antenna.

For the NLOS case we used the IEEE802.16e codebooks [3] with 8 and 64 vectors (corresponding to 3 and 6 feedback bits respectively). For the LOS case, we constructed simple codebooks with 8 and 64 vectors of the form (10) where α_n was chosen as

$$\alpha_n = \frac{\pi}{N}(n-1), \tag{12}$$

where N is the number of vectors in the codebook. We employed uncoded QPSK modulation and ran 1,000,000 channel realizations per SNR point.

We introduced a non zero Rician K factor (see [8], Page 79) to the first path to simulate the LOS component. The error curves for Rician factor K= lOdB which correspond to near LOS and 3 bit codebooks are given in Fig. 3. The LOS codebook outperforms the IEEE codebook by approx. 2dB at a target symbol error rate (SER) of 10^{-5}. The optimal precoder (5) is superior to both codebook based precoders as expected. The error curves for the case of K = lOdB and 6 bit codebooks are given in Fig. 4. Here the performance of the LOS codebook almost coincides with that of the optimal precoder. Both outperform the IEEE codebook by approx. 1.7dB.

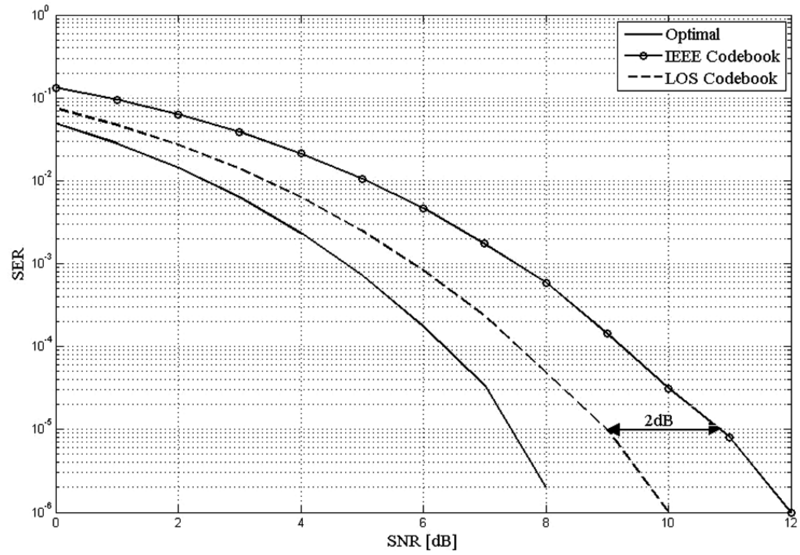

Fig. 3. Error curves corresponding to *K*= lOdB using 3 bit codebooks

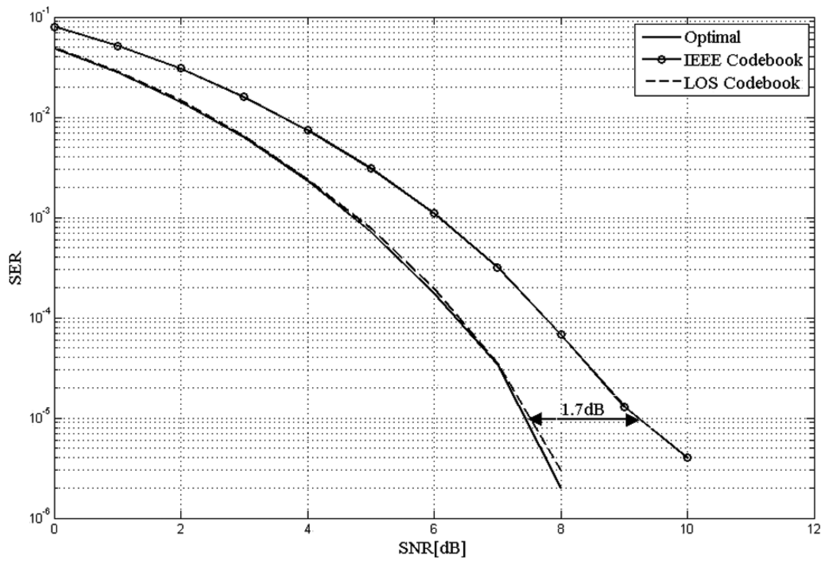

Fig. 4. Error curves corresponding to *K*= lOdB using 6 bit codebooks

Turning to the NLOS scenario captured by K = 0 (zero mean paths), the error curves for 3 bit codebooks are given in Fig. 5. Note that the LOS codebook slightly outperforms the IEEE codebook even though it is a NLOS scenario. The error curves for the case of K = 0 and 6 bit codebooks are given in Fig. 6. Here the IEEE codebook slightly outperforms the LOS codebook as expected.

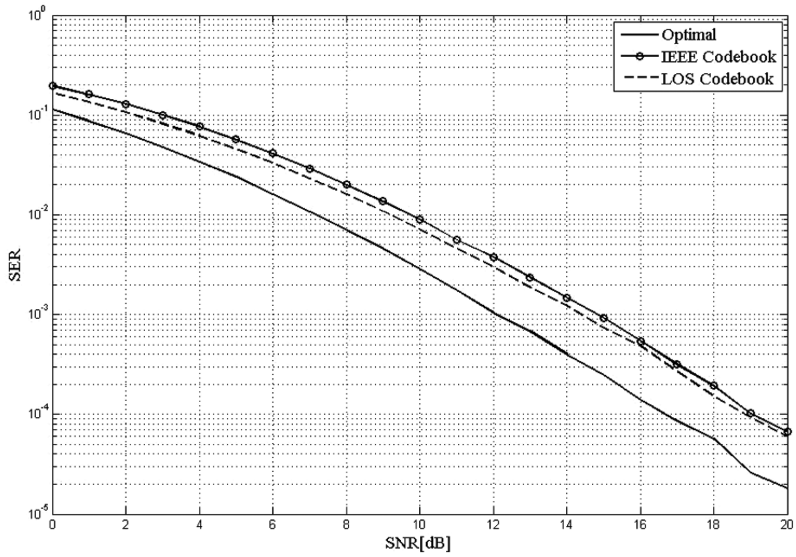

Fig. 5. Error curves corresponding to $K = 0$ using 3 bit codebooks

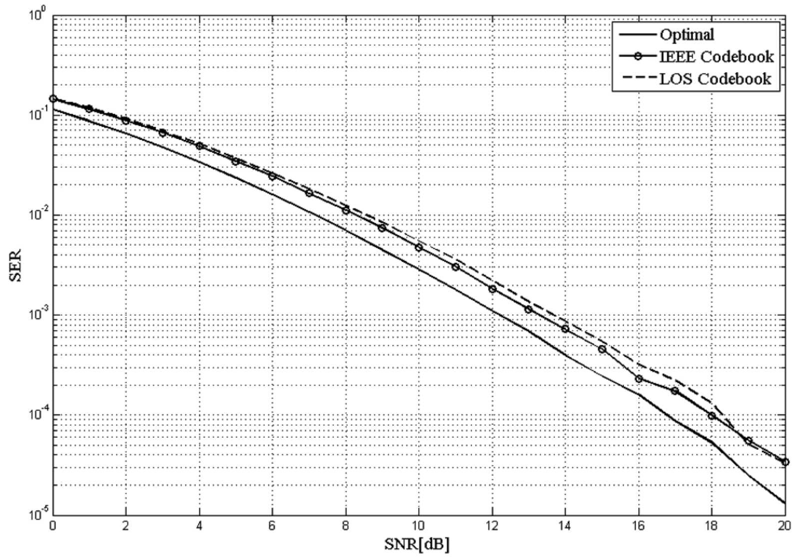

Fig. 6. Error curves corresponding to $K = 0$ using 6 bit codebooks

Discussion and Conclusions

In this paper we proposed precoding techniques which are tailored for the near LOS scenario. In near LOS the spatial channels experience similar gain and differ mainly by phase. We exploited this property to construct simple codebooks for this scenario. We further suggested precoding techniques based on the location of the receiver, for example using GPS positioning. We examined the performance of the proposed techniques using Monte Carlo simulation and compared them to those of the IEEE802.16e codebooks.

The simulation results show that as expected that LOS codebooks outperform the IEEE codebook in LOS and near LOS scenarios. A gap of approx. 2dB was observed. In NLOS scenarios the results are more interesting. In the 6 bit case the IEEE codebook outperforms LOS codebook. However, the gap is negligible. Perhaps the most surprising result is obtained in the 3 bit case where the LOS codebook outperforms the IEEE codebook.

A natural extension of the proposed LOS codebook approach is the inclusion of such codebooks in practical standards (such as LTE and WiMAX) to allow their application in near LOS scenarios. This will require a LOS detection mechanism and an additional single feedback bit to indicate the codebook chosen out of the possible two (regular, LOS). In some cases (e. g., in 3 bit codebooks) it may advisable to replace the current codebook with the proposed LOS codebook.

The fact that LOS based precoders exhibit superior performance in LOS and near LOS scenarios, and acceptable (and even superior) performance in some NLOS scenarios hints to an alternative approach to reciprocity and feedback methods. This approach is location based beamforming, in which pre-coding vectors are constructed based on MS positioning data. With the advent of LBS, location based beamforming may eliminate the need for precoding specific signaling or feedback in many practical scenarios.

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ПРОСТРАНСТВЕННО-ВРЕМЕННОЕ ФОРМИРОВАНИЕ ЛУЧА

Когда на антенную систему поступает информация о состоянии канала, ее можно использовать для увеличения пропускной способности или для повышения излучаемой мощности MIMO-системы. Использование антенных систем, таких как MIMO-системы замкнутого контура и направленные антенны, повышает эффективность достижения упомянутых выше задач. Значительным недостатком направленных антенн можно считать то, что для получения нисходящего сигнала, источник должен располагаться сверху. Еще одним недостатком можно считать чувствительность к изменениям состояния канала. Данная статья предлагает альтернативный способ формирования луча, использующий данные о местоположении принимающего устройства, например, GPS данные, для создания направляющего вектора. Привлекательность данного подхода объясняется тем, что во многих современных коммуникационных устройствах присутствует базовая станция сотовой связи, учитывающая местоположение принимающего устройства (в данном случае сотового телефона). Направленная антенна, использующая данные о местоположении принимающего устройства, выстраивает векторы, оптимизированные для тех случаев, когда принимающее устройство находится в зоне прямой видимости. Наши опыты показали, что в условиях прямой видимости предварительное кодирование с учетом зоны видимости дает лучшие результаты, чем при использовании матриц предварительного кодирования, таких как IEEE802.16e.

формирование луча, матрица предварительного кодирования, зона видимости.