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Source: Philips
Title: Performance of LTE DL MU-MIMO with dedicated pilots
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1. Introduction

One open issue in the design of MIMO schemes using precoding is how to communicate the precoding weights to the active terminals for correct detection of the signals at the receiving antennae. This can be done by using downlink control channel signalling or by employing precoded reference signals.

The quantity of interest for deriving the receive beamformer at the UE is given by the matrix product between the precoding matrix and the user's channel matrix. When using explicit signalling of the precoding weights, this quantity can be derived by estimating the channel matrix on the common pilots and multiplying the channel estimate by the known precoder. Conversely, if dedicated pilots are used the entries of the matrix product are estimated directly from these pilots. Hence, each dedicated pilot is precoded by one of the precoding vectors used for data and is transmitted from all transmit antennae, whereas common pilots are transmitted each from a single transmit antenna.

The use of precoded reference signals has the advantage of giving the Node B freedom of selecting the precoding weights without being constrained by a limited codebook size or set of possible precoders known to the terminals. For example, more sophisticated precoding techniques could be used based on information other than the basis vectors used for UE feedback. Moreover, the use of different codebooks or different codebook sizes by different UE's is facilitated by dedicated reference signals. In fact, with dedicated pilots, a UE need not know which codebooks the other active users have used for their feedback generation. Furthermore, dedicated reference signals enable open-loop beamforming techniques as described in [1].

In this paper we evaluate the impact of dedicated pilots on system throughput performance as compared to control channel signalling. We use a zero-forcing precoding technique as described in several previous contributions [2], [3], [4] and [5], [6]. The generation of the feedback from the terminals is based on channel vector quantisation and DFT codebook.

2. Implementation with dedicated pilot and common pilots

Let us denote with $\mathbf{H} = [\mathbf{h}_1, \dots, \mathbf{h}_M]$, an $N \times M$ sample channel matrix for a generic user and a generic OFDM subcarrier, with N being the number of receive antennae and M the number of transmit antennae. Let K be the number of independently encoded spatial layers being transmitted, forming the sample vector of symbols $\mathbf{x} = [x_1, x_2, \dots, x_K]^T$, and $\mathbf{G} = [\mathbf{g}_1, \dots, \mathbf{g}_K]$, the $M \times K$ beamforming matrix. We also denote the concatenation of the beamformer and the channel as $\bar{\mathbf{H}} = \mathbf{H}\mathbf{G} = [\bar{\mathbf{h}}_1, \bar{\mathbf{h}}_2, \dots, \bar{\mathbf{h}}_K]$, where $\bar{\mathbf{h}}_k$, $k = 1, \dots, K$ are the $N \times 1$ "equivalent" channels for each of the spatial streams, seen by the receiving antenna array.

If a pilot occupying subcarrier p is precoded by vector \mathbf{g}_k , then the estimate of the equivalent channel on the same subcarrier, $\hat{\mathbf{h}}_k^{(p)}$, is given by

$$\hat{\mathbf{h}}_k^{(p)} = \sqrt{P} \bar{\mathbf{h}}_k^{(p)} + \mathbf{n}^{(p)}, \quad (1)$$

where $\mathbf{n}^{(p)} \sim \mathcal{CN}(\mathbf{0}, \sigma_n^2 \mathbf{I})$ is an i.i.d. proper Gaussian noise vector and P is the transmit power budget.

Similarly, if a common pilot is in position q , the estimate of the channel vector from transmit antenna m to the receiving array, $\hat{\mathbf{h}}_m^{(q)}$, reads

$$\hat{\mathbf{h}}_m^{(q)} = \sqrt{P} \bar{\mathbf{h}}_m^{(q)} + \mathbf{n}^{(q)}. \quad (2)$$

These estimated values are then interpolated in frequency and time to yield the estimated matrix quantities, $\hat{\mathbf{H}}$ and $\hat{\mathbf{H}}$ in case of dedicated and common pilots, respectively, and for each frequency-time unit. When dedicated pilots are not available, the estimate of the equivalent channels is derived by multiplying $\hat{\mathbf{H}}\mathbf{G}$, where \mathbf{G} is known from signalling in the downlink control channel. In case of explicit signalling we assume that \mathbf{G} is known exactly, i.e. the control channel is error-free. We note that a non-negligible computational effort is required for these matrix multiplications.

Each active terminal can then compute, e.g. the MMSE receive beamformer for the spatial layer of interest. We remind that, according to the current working assumptions, in MU-MIMO mode only one layer/codeword is mapped to each user. Assuming that a UE wants to decode layer k , the $1 \times N$ MMSE spatial combiner, \mathbf{w}_k , is given by

$$\mathbf{w}_k = \hat{\mathbf{h}}_k^H \left(\hat{\mathbf{H}} \hat{\mathbf{H}}^H + \sigma_n^2 \mathbf{I}_N \right)^{-1}. \quad (3)$$

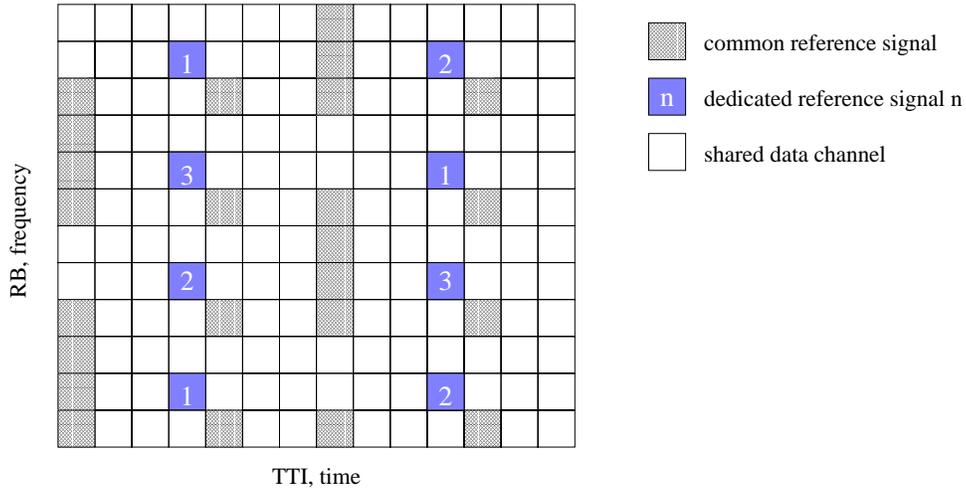


Fig. 1. Mapping of downlink dedicated reference signals: 4 precoded pilot symbols per time slot. Three precoded streams are considered in this example. The common reference signal pattern refers to the generic frame structure, normal cyclic prefix, as reported in [7]¹.

In Fig. 1 and 2 the two mappings of downlink dedicated reference signals considered in this paper are reported, corresponding to 4 and 8 precoded pilots per time slot, respectively. When a terminal is scheduled for transmission it can work out the position of its own pilot by sensing the strongest pilot signal, or, alternatively, the position information can be conveyed in the control channel. We assume that each scheduled user knows the number of MIMO layers being transmitted, such that the pilots can be assigned to the precoding vectors in a circular fashion as shown in Fig. 1 and 2. This information about the number of independently encoded layers is also required when explicit control signalling and common pilots are used. In fact, in this case a UE needs an explicit indication of the precoder in use, e.g. by a codebook index, hence it knows how many column vectors the precoding matrix has, i.e. the number of spatial layers being transmitted.

¹The common pilot positions has been slightly modified in [8] but the number of pilots per antenna port and time slot remains unchanged.

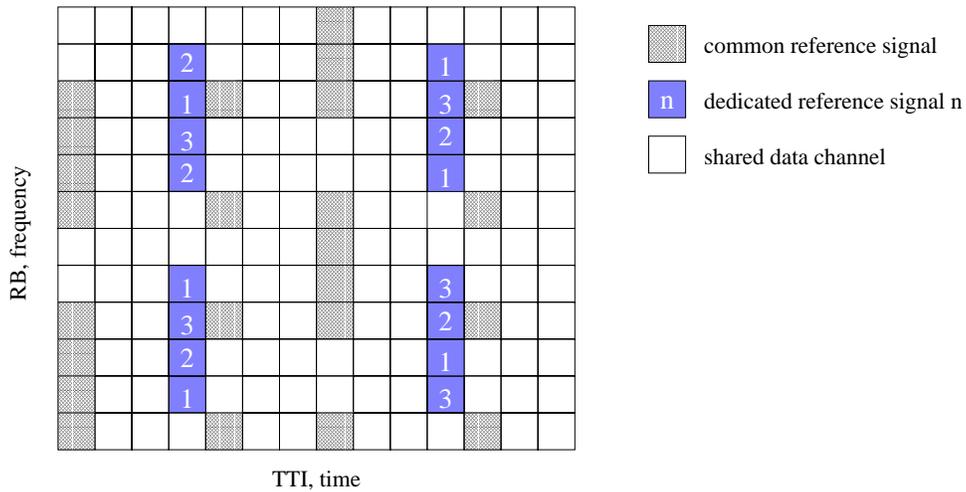


Fig. 2. Mapping of downlink dedicated reference signals: 8 precoded pilot symbols per time slot. Three precoded streams are considered in this example. The common reference signal pattern refers to the generic frame structure, normal cyclic prefix, as reported in [7]¹.

We note that the interpolation in frequency differs, in general, for precoded pilots and common pilots. In fact, for common pilots interpolation can be carried out over many resource blocks, or possibly over the entire bandwidth, which produces more accurate results. On the other hand, since adjacent resource blocks may use different precoding weights, we assume that interpolation of dedicated pilots is performed on a resource block basis.

3. System throughput results

We want to evaluate the impact on system throughput of pilot-assisted estimates of the equivalent channels at the UE's. In particular, we are interested in comparing the estimation method relying on precoded pilots versus the use of control signalling combined with common pilots. We consider two different frequency granularities of precoded pilots as depicted in Fig. 1 and 2.

The control channel is assumed to be error free and in case of precoded pilots, the scheduled UE's know the position of their own pilot exactly. In both cases, whether precoded pilots or control signalling is used, we assume that the active UE's know how many spatial layers/codewords have been transmitted.

Furthermore, we assume that the codebook-based feedback generation at the UE is done with full channel knowledge, i.e. any error in the channel estimate for feedback calculation is absorbed by the granularity of the codebooks in use. This is because in this contribution we do not consider the impact of errors in the channel estimate based on common pilots on the feedback generation. The codebooks used for UE feedback are DFT codebooks.

The throughput values in the simulations are corrected by the overhead due to precoded pilots or control signalling. For the calculation of the correction factor in the control signalling case, we assume that the spectral efficiency for transmission of the control information is 1 (e.g. QPSK modulation and rate 1/2 code).

The zero-forcing precoding technique (labelled here as CVQ-ZFEP for channel vector quantization-zero forcing with equal power distribution), user selection mechanism, feedback generation and MMSE receive beamforming calculation are described in detail in [2] and [4], while the main system simulation parameters used can be found in [3].

In Fig. 3 and 4 the average system throughput is reported for different DFT codebook sizes, for 1 and 2 receive antennae, respectively. The number of transmit antennae is 4 and the channel model is SCM, urban micro. We note that the impact of explicit signalling overhead on the throughput increases significantly with the feedback codebook size, such that a codebook size of 4 bits achieves best throughput performance with both 1 and 2 receive antennae.

Conversely, the overhead of precoded pilots is independent of the codebook size used for UE feedback. Furthermore, the precoded pilot pattern of Fig. 2 with 8 pilot symbols per time slot outperforms the 4-pilot pattern only for two receive antennae as the advantage of having a more accurate estimate of the equivalent channel outweighs the increased overhead. We also note that the gap in throughput performance between the ideal curve and the two estimation methods increases with the number of receive antennae because the size of the matrix that needs to be estimated increases and so does the impact of the estimation errors. We note, however, that the accuracy of the estimate of each single entry of the matrix $\hat{\mathbf{H}}$ or $\hat{\mathbf{H}}$ is unchanged, independently of the number of receive antennae.

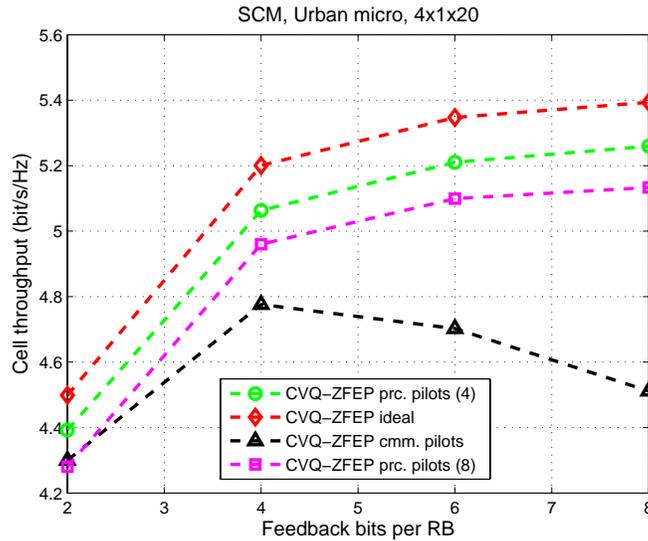


Fig. 3. Average system throughput corrected by signalling/pilot overhead versus codebook size used for UE feedback. 4 Tx antennae, 1 Rx antenna, 20 users per cell.

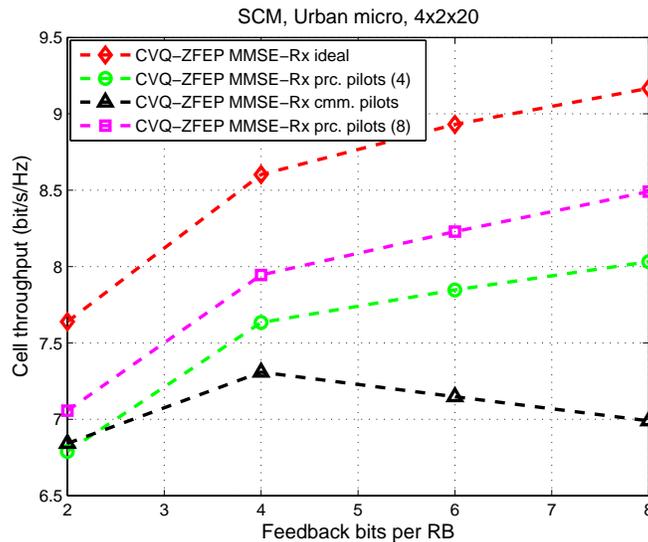


Fig. 4. Average system throughput corrected by signalling/pilot overhead versus codebook size used for UE feedback. 4 Tx antennae, 2 Rx antenna, 20 users per cell.

Fig. 5 shows a histogram of the system throughput achieved by the two estimation methods, with 3 different receiving antenna array sizes and a DFT codebook of 4 bits.

By comparing the bars for 8 precoded pilots and (8) common pilot cases in Fig. 5 we see that as the number of receive antennae increases the gap with the ideal throughput becomes wider for the common pilots, despite the fact that the granularity of pilots is the same for both cases and in fact the interpolation in frequency is more accurate for the common pilots as pointed out earlier on. This is a confirmation of the fact that the explicit signalling scheme suffers from error propagation effects when multiplying the estimated channel $\hat{\mathbf{H}}$ by the precoding matrix \mathbf{G} , which become increasingly evident as the involved matrices gets larger in size.

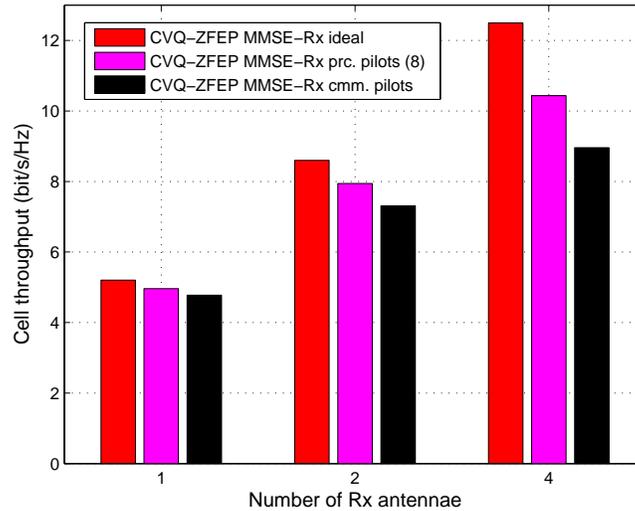


Fig. 5. Average system throughput corrected by signalling/pilot overhead versus number of receive antennae for a 4-bit DFT codebook. 4 tx antennae, 20 users per cell.

4. Conclusion

In this contribution we have considered two methods of indicating the precoding matrix used by the Node B to the terminals: precoded pilots and explicit control signalling. We have considered two precoded pilot patterns with different granularity, namely 4 and 8 pilot symbols per time slot, while the common pilot pattern is the one described in the TS document [7]. Along with good system throughput performance, precoded pilots also provide a clear advantage in terms of extra flexibility in deciding the precoding matrix at the Node B and in enabling beamforming techniques like the one described in [1]. These benefits suggest that precoded pilots are preferable to explicit control signalling for the indication of the precoding matrix.

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