Power Efficient Pilot Symbol Power Allocation under Time-variant Channels

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***Abstract*—Current Multiple Input Multiple Output (MIMO) Orthogonal Frequency Division Multiplexing (OFDM) based systems for wireless communications enable to adjust power radiated at the pilot symbols. Under time-invariant channels, a power increase at the pilot symbols results in improved quality of the channel estimate. However, under time-variant channels, this is not necessarily the case. Due to the decreased temporal channel correlation, the channel estimation performance becomes saturated. If under time-variant channels more power is assigned to the data symbols, such approach increases inter-layer interference due to the imperfect channel knowledge at the receiver. In this paper, we show how to distribute power among data and pilot symbols in a power efficient way. Using our proposed method, up to 50% of the transmit power can be saved in a 4×4 Long Term Evolution (LTE) downlink transmission at a Signal to Noise Ratio (SNR) of 20 dB.**

***Index Terms*—LTE, Power distribution, OFDM, MIMO.**

I. Introduction

Current systems for cellular wireless communication are designed for coherent detection. Therefore, channel estimation is a crucial part of a receiver. UMTS Long Term Evolution (LTE) provides the possibility to change the power radiated at the pilot subcarriers relative to that of the data subcarriers. Clearly, this additional degree of freedom in the system design provides potential for optimization.

A. Related Work

Many researchers have realized, that the power assigned to the pilot symbols has significant influence on the system's performance [1, 2]. There has been many attempts to answer the arising question of how to distribute the available power between data and pilot symbols. However, many of these attempts are limited only to a certain modulation alphabet [2], or specific channel estimators [3].

The authors of [4] derived the optimal power distribution between pilot and data symbols for time-invariant channels under imperfect channel knowledge. The optimal distribution of power turned out to be independent of the Signal to Noise Ratio (SNR) and channel realizations. In [5], the work of [4] was extended to multi eNodeB scenarios where the interference from neighboring eNodeBs was included. Due to the LTE pilot symbol design, the pilot symbols from neighboring eNodeBs are overlapping with the data symbols in the eNodeB of interest, which complicates the optimization problem. In [6], this work has been extended to answer the question of how to optimally distribute power between pilot and data symbols under time-variant channels. The authors showed that performance of Least Squares (LS) and Linear Minimum Mean Square Error (LMMSE) channel estimators saturates with increasing Doppler spread. Therefore, it might seem that with increasing Doppler spread, more power should be assigned to the data symbols. This is not true, because this would increase the inter-layer interference of the Multiple Input Multiple Output (MIMO) system caused by the imperfect channel knowledge.

B. Contribution

In this paper, we relax our previous constraint of a fixed transmit power [4–6] and introduce only a higher bound for the maximum available transmit power. By doing so, the optimization problem becomes more complicated, but allows to decrease the total transmit power while keeping the system's performance almost unchanged. A novel formulation of the optimization problem delivers a power efficient solution for the power distribution among pilot and data symbols under time-variant channels. As with our previous work, all data, tools, as well implementations needed to reproduce the results of this paper can be downloaded from our homepage [7].

In this paper, we analytically solve the optimization problem of power efficient optimal power allocation for a MIMO system with a Zero Forcing (ZF) equalizer under imperfect channel state information. In contrast to [4–6], we utilize the actual transmission power as the cost function instead of the post-equalization Signal to Interference and Noise Ratio (SINR), that is used as a bound for defining a solution of interest.

The remainder of the paper is organized as follows. In Section II, we describe the mathematical system model for transmitting pilots and data over a MIMO channel. In Section III, we briefly describe the post-equalization SINR expression for ZF equalizers with imperfect channel knowledge. We formulate the optimization problem for optimal pilot symbol

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power allocation in Section IV. Finally, we present LTE simulation results in Section V and conclude our paper in Section VI.

II. System Model

In this section, we briefly point out the key aspects in the LTE standard that are relevant to this paper and introduce a transmission model suitable for our further derivation.

A received Orthogonal Frequency Division Multiplexing (OFDM) symbol in the frequency domain at the n_r-th receive antenna can be written as

$$\tilde{\mathbf{y}}_{n_\mathrm{r}} = \sum_{n_\mathrm{t}=1}^{N_\mathrm{t}} \tilde{\mathbf{H}}_{n_\mathrm{t},n_\mathrm{r}} \mathbf{x}_{n_\mathrm{t}} + \tilde{\mathbf{n}}_{n_\mathrm{r}}, \tag{1}$$

where $\tilde{\mathbf{H}}_{n_\mathrm{t},n_\mathrm{r}} \in \mathbb{C}^{N_\mathrm{sub} \times N_\mathrm{sub}}$ represents the channel matrix in the frequency domain between the n_t-th transmit and n_r-th receive antennas. The transmitted signal vector is referred to as $\mathbf{x}_{n_\mathrm{t}}$, the received signal vector as $\tilde{\mathbf{y}}_{n_\mathrm{r}}$. The vector $\tilde{\mathbf{n}}_{n_\mathrm{r}} \in \mathbb{C}^{N_\mathrm{sub}\times 1}$ denotes additive white zero mean Gaussian noise with variance σ_n^2 on antenna n_r. In case of a time-invariant channel, the channel matrix $\tilde{\mathbf{H}}_{n_\mathrm{t},n_\mathrm{r}}$ appears as a diagonal matrix, whereas a time-variant channel forces the channel matrix $\tilde{\mathbf{H}}_{n_\mathrm{t},n_\mathrm{r}}$ to become non-diagonal. These non-diagonal elements indicate that the subcarriers are not orthogonal anymore, leading to the so-called Inter Carrier Interference (ICI). The vector $\mathbf{x}_{n_\mathrm{t}}$ has N_sub entries, corresponding to the number of non-zero subcarriers. Let us denote the number of pilot symbols and the number of precoded data symbols by N_p and N_d, respectively.

Specifically, the vector $\mathbf{x}_{n_\mathrm{t}} \in \mathbb{C}^{N_\mathrm{sub}\times 1}$ in Equation (1) comprises the precoded data symbols $\mathbf{x}_{\mathrm{d},n_\mathrm{t}} \in \mathbb{C}^{N_\mathrm{d}\times 1}$ and the pilot symbols $\mathbf{x}_{\mathrm{p},n_\mathrm{t}} \in \mathbb{P}^{N_\mathrm{p}\times 1}$ from the set of all possible pilot symbols $\mathbb{P}$ defined in LTE, at the n_t-th transmit antenna placed by a suitable permutation matrix $\mathbf{P}$

$$\mathbf{x}_{n_\mathrm{t}} = \mathbf{P}\, \left[\mathbf{x}_{\mathrm{p},n_\mathrm{t}}^\mathrm{T}\; \mathbf{x}_{\mathrm{d},n_\mathrm{t}}^\mathrm{T}\right]^\mathrm{T}. \tag{2}$$

On subcarrier k of the data symbol vector $\mathbf{x}_{\mathrm{d},n_\mathrm{t}}$, the precoding process can be described as

$$\left[x_{\mathrm{d},1,k} \cdots x_{\mathrm{d},N_\mathrm{t},k}\right]^\mathrm{T} = \mathbf{W}_k \left[s_{1,k} s_{2,k} \cdots s_{N_\mathrm{l},k}\right]^\mathrm{T}, \tag{3}$$

where $x_{\mathrm{d},n_\mathrm{t},k}$ is a precoded data symbol at the n_t-th transmit antenna port and the k-th subcarrier, $\mathbf{W}_k \in \mathbb{C}^{N_\mathrm{t}\times N_\mathrm{l}}$ is a unitary precoding matrix at the k-th subcarrier and $s_{n_\mathrm{l},k} \in \mathbb{D}^{1\times 1}$ is the data symbol of the n_l-th layer at the k-th subcarrier. Here, $\mathbb{D}$ is the set of available modulation alphabets. In LTE, three different sets can be used, namely 4 Quadrature Amplitude Modulation (QAM), 16 QAM and 64 QAM. In order to obtain data symbol vectors $\mathbf{x}_{\mathrm{d},n_\mathrm{t}}$, one has to stack data symbols $x_{\mathrm{d},n_\mathrm{t},k}$ obtained via Equation (3) at a specific antenna n_t into a vector.

For the derivation of the post-equalization SINR, we will use a MIMO input-output relation at the subcarrier level, given as:

$$\mathbf{y}_k = \mathbf{H}_{k,k}\mathbf{W}_k\mathbf{s}_k + \mathbf{n}_k + \underbrace{\sum_{l\neq k} \mathbf{H}_{k,l}\mathbf{W}_l\mathbf{s}_l}_{\mathrm{ICI}}. \tag{4}$$

Matrix $\mathbf{H}_{k,l} \in \mathbb{C}^{N_\mathrm{r}\times N_\mathrm{t}}$ denotes the MIMO channel matrix between the k-th and l-th subcarrier. This matrix is obtained by means of the Fourier transformation of the physical channel in the time domain. In this work, we assume Jake's spectrum model. In LTE, the precoding matrix can be chosen from a finite set of precoding matrices [8]. The vector $\mathbf{s}_k$ consists of the data symbols of all layers at the k-th subcarrier. Vector $\mathbf{n}_k$ represents additive white zero mean Gaussian noise with variance σ_n^2 at subcarrier k. We denote the effective channel matrix by

$$\mathbf{G}_{k,k} = \mathbf{H}_{k,k}\mathbf{W}_k. \tag{5}$$

Furthermore, the average power transmitted on each of the N_l layers is denoted by σ_s^2. The total power transmitted on one data position is σ_d^2, while that on one pilot position is σ_p^2. When the power is evenly distributed between the data and pilot symbols, we have:

$$\sigma_s^2 = \mathbb{E}\left\{\|s_{l,k}\|_2^2\right\} = \frac{1}{N_\mathrm{l}}, \tag{6}$$

$$\sigma_\mathrm{d}^2 = \frac{1}{N_\mathrm{d}} \sum_{n_\mathrm{t}=1}^{N_\mathrm{t}} \mathbb{E}\left\{\|\mathbf{x}_{\mathrm{d},n_\mathrm{t}}\|_2^2\right\} = 1, \tag{7}$$

$$\sigma_\mathrm{p}^2 = \frac{1}{N_\mathrm{p}} \sum_{n_\mathrm{t}=1}^{N_\mathrm{t}} \mathbb{E}\left\{\|\mathbf{x}_{\mathrm{p},n_\mathrm{t}}\|_2^2\right\} = 1, \tag{8}$$

where N_d denotes the number of data symbols, N_p the number of pilot symbols and N_l the number of layers.

III. Post-equalization SINR

In this section, we consider a time-variant scenario and briefly describe an analytical expression for the post-equalization SINR of a MIMO system using a ZF equalizer based on imperfect channel knowledge. More details can be found in our previous work [6].

If perfect channel knowledge is available at the equalizer, the ZF estimate of the data symbol $\mathbf{s}_k$ is given as

$$\hat{\mathbf{s}}_k = \left(\mathbf{G}_{k,k}^\mathrm{H}\mathbf{G}_{k,k}\right)^{-1}\mathbf{G}_{k,k}^\mathrm{H}\mathbf{y}_k. \tag{9}$$

The data estimate $\hat{\mathbf{s}}_k$ defined in Equation (9) results in a post-equalization SINR of the m-th layer given as [9, 10]

$$\gamma_m = \frac{\sigma_s^2}{\left(\sigma_n^2 + \sigma_\mathrm{ICI}^2\right)\mathbf{e}_m^\mathrm{H}\left(\mathbf{G}_{k,k}^\mathrm{H}\mathbf{G}_{k,k}\right)^{-1}\mathbf{e}_m}, \tag{10}$$

where the vector $\mathbf{e}_m$ is an $N_\mathrm{l}\times 1$ zero vector with a one on the m-th element. This vector extracts the signal on the corresponding layer m after the equalizer. The variable σ_ICI^2 represents the ICI power, that is

$$\sigma_\mathrm{ICI}^2 = \mathbb{E}\left\{\sum_{l\neq k}\|\mathbf{H}_{k,l}\mathbf{W}_l\mathbf{s}_l\|_2^2\right\}. \tag{11}$$

Let us proceed to the case of imperfect channel knowledge. We define the perfect channel as the channel estimate plus the error matrix due to the imperfect channel estimation

$$\mathbf{H}_{k,k} = \hat{\mathbf{H}}_{k,k} + \mathbf{E}_{k,k}, \tag{12}$$

where the elements of the matrix $\mathbf{E}_{k,k}$ are random variables, statistically independent of each other each with variance σ_e^2. Inserting Equation (12) in Equation (4), the input-output relation changes to

$$\mathbf{y}_k = \left(\hat{\mathbf{H}}_{k,k} + \mathbf{E}_{k,k}\right)\mathbf{W}_k\mathbf{s}_k + \mathbf{n}_k + \sum_{l\neq k}\mathbf{H}_{k,l}\mathbf{W}_l\mathbf{s}_l. \quad (13)$$

Since the channel estimation error matrix $\mathbf{E}_{k,k}$ is unknown at the receiver, the ZF solution is given again by Equation (9) with channel matrix $\mathbf{H}_{k,k}$ replaced by its estimate $\hat{\mathbf{H}}_{k,k}$, that is known at the receiver [11]

$$\hat{\mathbf{s}}_k = \left(\hat{\mathbf{G}}_{k,k}^{\mathrm{H}}\hat{\mathbf{G}}_{k,k}\right)^{-1}\hat{\mathbf{G}}_{k,k}^{\mathrm{H}}\mathbf{y}_k, \quad (14)$$

with matrix $\hat{\mathbf{G}}_{k,k}$ being equal to $\hat{\mathbf{H}}_{k,k}\mathbf{W}_k$.

Applying a ZF equalizer, Equation (14) leads to the SINR on the m-th layer [6]

$$\gamma_m = \frac{\sigma_s^2}{\left(\sigma_n^2 + \sigma_{\mathrm{ICI}}^2 + \sigma_e^2\sigma_{\mathrm{d}}^2\right)\mathbf{e}_m^{\mathrm{H}}\left(\hat{\mathbf{G}}_{k,k}^{\mathrm{H}}\hat{\mathbf{G}}_{k,k}\right)^{-1}\mathbf{e}_m}. \quad (15)$$

Note, that in practice variables $\sigma_s^2, \sigma_{\mathrm{d}}^2$, σ_{ICI}^2, and σ_n^2 need to be replaced by their estimates.

IV. Power Allocation

In this section, we show how to distribute available power among data and pilot symbols in power efficient way under time-variant channels. In contrast to [4–6], in the optimization problem formulation, we relax the constraint of a fixed transmit power and define only a higher bound for it. This enables to optimize the amount of consumed power while keeping the system's performance almost unchanged. Although the provided results are shown in the context of the current LTE standard, the presented concept can be applied to any MIMO OFDM based system. Furthermore, we will limit our discussion only to an LS channel estimator. Note, that based on the results shown in [6], all concepts can be easily applied also to an LMMSE channel estimator.

We introduce power adjusting factors c_{p}^2 and c_{d}^2 for the pilot and data symbols, respectively. A variable p_{off} is defined as the power offset between the power of the pilot symbols and the data symbols, denoted by

$$c_{\mathrm{d}}^2 = p_{\mathrm{off}}c_{\mathrm{p}}^2. \quad (16)$$

If we increase the power at the pilot symbol by c_{p}^2, the noise and ICI dependent parts of the Mean Square Errors (MSEs) of an LS channel estimator decreases by the same factor c_{p}^2. Therefore, the new MSE after power adjustment can be stated as

$$\tilde{\sigma}_e^2 = c_e\frac{\left(\sigma_n^2 + \sigma_{\mathrm{ICI}}^2\right)}{c_{\mathrm{p}}^2} + d, \quad (17)$$

where c_e and d are real constants that determine the performance of the channel estimators [6]. Plugging the variables c_{d}^2 and c_{p}^2 into Equation (15), we obtain the SINR expression at layer m with adjusted power of the pilot symbols

$$\gamma_m = \frac{\sigma_s^2 c_{\mathrm{d}}^2}{\left(\sigma_n^2 + \sigma_{\mathrm{ICI}}^2 + \tilde{\sigma}_e^2\sigma_{\mathrm{d}}^2 c_{\mathrm{d}}^2\right)\mathbf{e}_m^{\mathrm{H}}\left(\mathbf{G}_{k,k}^{\mathrm{H}}\mathbf{G}_{k,k}\right)^{-1}\mathbf{e}_m}. \quad (18)$$

Inserting Equation (17) into Equation (18) and simplifing the expression, we obtain the SINR:

$$\gamma_m = \frac{1}{N_{\mathrm{l}}\left(\sigma_n^2 + \sigma_{\mathrm{ICI}}^2\right)\mathbf{e}_m^{\mathrm{H}}\left(\mathbf{G}_{k,k}^{\mathrm{H}}\mathbf{G}_{k,k}\right)^{-1}\mathbf{e}_m\left(f\left(c_{\mathrm{p}}^2, c_{\mathrm{d}}^2\right) + \tilde{d}\right)}, \quad (19)$$

for which the power allocation function $f\left(c_{\mathrm{p}}^2, c_{\mathrm{d}}^2\right)$ is given as

$$f\left(c_{\mathrm{p}}^2, c_{\mathrm{d}}^2\right) = \frac{1}{c_{\mathrm{d}}^2} + \frac{c_e}{c_{\mathrm{p}}^2}. \quad (20)$$

The constant $\tilde{d}$ is proportional to the channel saturation coefficient d and is given as

$$\tilde{d} = \frac{d}{\sigma_n^2 + \sigma_{\mathrm{ICI}}^2}. \quad (21)$$

Note, that Equation (20) is independent of channel realization, noise variance, ICI power and even user velocity. Let us focus on the term $\tilde{d}$ in Equation (19). This term is always positive. It thus becomes obvious that it causes the overall limitation of the post-equalization SINR.

Let us consider a situation for the moment when $\tilde{d} \gg f\left(c_{\mathrm{p}}^2, c_{\mathrm{d}}^2\right)$. In this case, the post-equalization SINR is mainly determined by the value of $\tilde{d}$, and almost independent of the choice of c_{p}^2 and c_{d}^2. Therefore, a formulation of the optimization problem similar to [6] does not lead to power efficient values of power distribution among pilot and data symbols:

$$\begin{aligned} \underset{c_{\mathrm{p}}^2, c_{\mathrm{d}}^2}{\text{minimize}} \quad & f\left(c_{\mathrm{p}}^2, c_{\mathrm{d}}^2\right) \\ \text{subject to} \quad & c_{\mathrm{p}}^2 N_{\mathrm{p}} + c_{\mathrm{d}}^2 N_{\mathrm{d}} \leq N_{\mathrm{d}} + N_{\mathrm{p}} \end{aligned} \quad (22)$$

In this paper, in contrast to the previous approach we rather try to minimize the actual transmit power while keeping the power allocation function small enough, so that it does not worsen the post-equalization SINR compared to the case when the whole available power is used. The optimization problem can be defined as follows:

$$\begin{aligned} \underset{c_{\mathrm{p}}^2, c_{\mathrm{d}}^2}{\text{minimize}} \quad & c_{\mathrm{d}}^2 N_{\mathrm{d}} + c_{\mathrm{p}}^2 N_{\mathrm{p}} \\ \text{subject to} \quad & f\left(c_{\mathrm{p}}^2, c_{\mathrm{d}}^2\right) < a\tilde{d} + f\left(\tilde{c}_{\mathrm{p}}^2, \tilde{c}_{\mathrm{d}}^2\right) \\ & 0 < c_{\mathrm{p}}^2 < \frac{N_{\mathrm{d}} + N_{\mathrm{p}}}{N_{\mathrm{p}}} \\ & 0 < c_{\mathrm{d}}^2 < \frac{N_{\mathrm{d}} + N_{\mathrm{p}}}{N_{\mathrm{d}}} \\ & c_{\mathrm{p}}^2 N_{\mathrm{p}} + c_{\mathrm{d}}^2 N_{\mathrm{d}} \leq N_{\mathrm{d}} + N_{\mathrm{p}} \end{aligned} \quad (23)$$

The first condition from Equation (23) constrains the power allocation function, so that it does not become larger than the variable $\tilde{d}$ multiplied by a real constant a plus a power allocation function evaluated at $\tilde{c}_{\mathrm{p}}^2$ and $\tilde{c}_{\mathrm{d}}^2$, which are the optimal values derived in [6]. The purpose of the constant a is to ensure that the value of the power allocation function is much smaller than the variable $\tilde{d}$ in case of channel estimator saturation $f\left(c_{\mathrm{p}}^2, c_{\mathrm{d}}^2\right) \ll \tilde{d}$. The second and third conditions from Equation (23) warrant, that at least some power is assigned to the pilot and data symbols, respectively. At the same time, the power assigned to the data and pilot symbols is not larger than the maximum available power. The last condition upper bounds the sum transmit power of the pilot and data symbols by the maximum available power. We also assumed, that $N_{\mathrm{p}}+N_{\mathrm{d}}$ is constant. This assumption is fulfilled in common systems for wireless communications. Due to the simplicity of the cost function, the stated problem was solved using a full search method. Figure 1 displays an example of

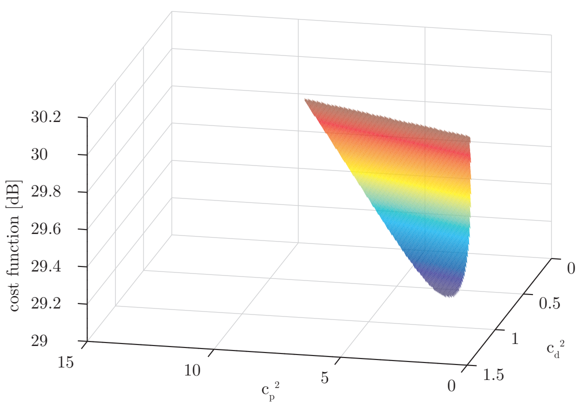

Fig. 1. Cost function $c_{\mathrm{d}}^2 N_{\mathrm{d}} + c_{\mathrm{p}}^2 N_{\mathrm{p}}$ for a SISO system applying an LS channel estimator at a user velocity of 500 km/h and SNR = 20 dB.

a cost function $c_{\mathrm{d}}^2 N_{\mathrm{d}} + c_{\mathrm{p}}^2 N_{\mathrm{p}}$ for SISO transmission scheme utilizing an LS channel estimator at user speed of 500 km/h and SNR = 20 dB. In this case, by the solving optimization problem defined in Equation (23), variables c_{p}^2 and c_{d}^2 were chosen by algorithm as $c_{\mathrm{p}}^2 \approx 2.6$ and $c_{\mathrm{d}}^2 \approx 0.7$, which results in $p_{\mathrm{off}} \approx 5.6\,dB$ and actual transmit power saving of around 20%. In this example, we set $a = \frac{1}{16}$, this warranties post-equalization SINR loss of maximum 0.26 dB.

V. Simulation Results

In this section, we present simulation results and discuss the performance of LTE system using different pilot symbol powers. All results are obtained with the LTE Link Level Simulator version "r1089" [12, 13], which can be downloaded from www.nt.tuwien.ac.at/ltesimulator. The Vienna LTE simulator is a Matlab implementation of all physical layer procedure like coding, rate matching [14], synchronization [15, 16], timing estimation [17] etc. All data, tools and scripts are available online in order to allow other researchers to reproduce the results shown in the paper [7]. Table I shows the most important simulator settings.

Figure 2 shows throughput over user velocity for various number of utilized antennas for user velocity at SNR= 20 dB.

TABLE I
Simulator settings for fast fading simulations

Parameter	Value
Bandwidth	1.4 MHz
Number of transmit antennas	1, 2, 4
Number of receive antennas	1, 2, 4
Receiver type	ZF
Transmission mode	Open-loop spatial multiplexing
Channel type	ITU VehA [18]

The blue dashed line depicts an LTE system with no power distribution among pilot and data symbols. The red continuous line represents a system with our novel proposed power efficient power distribution among pilot and data symbols. The amount of used power when utilizing our proposed power efficient power distribution is shown in Figure 3. In case when no power distribution is applied, the whole available transmit power is utilized. For example, considering a 4×4 transmission system at a user speed of 500 km/h, when using our proposed power distribution algorithm more than 50% of the total transmit power can be saved compared to a system with no power distribution, while achieving the same throughout. For the simulated curves we calculated the 95% confidence intervals, which are plotted in gray color. Their size indicates a high quality of the simulation results. At lower user velocities, the system utilizing power distribution outperforms the system without any power distribution. This is consistent with results from [4–6]. At higher user velocities the system with power efficient power distribution experiences small throughput loss, at the same time utilizes less transmit power than the system not utilizing power distribution. Note, that the throughput loss can be further decreased by changing the variable a in the first condition of Equation (23). In the shown simulation we set $a = \frac{1}{16}$, this warranties post-equalization SINR loss of maximum 0.26 dB. If no SINR loss is desired, the variable a has to be set to zero, in this case, no power savings are achieved.

Figure 3 depicts the actual transmit power for various antenna setups over user velocity at SNR = 20 dB when using our proposed solution. With increasing user velocity also the amount of power used for the transmission decreases. This behavior can be explained by the fact, that the performance of the channel estimators with increasing Doppler spread become saturated due to the low temporal channel correlation. Therefore, less power is radiated at the pilot symbols and at the same time the power at the data pilots is limited, since it would only increase the inter-layer interference caused by the imperfect channel knowledge.

In the previous problem formulation [6], the whole available power had to be used, however by increasing the power radiated at the data symbols, inter-layer interference would be increased, therefore the power radiated at the pilot symbols is increased, with no effect on the quality of the channel estimate due to the saturation effect with increasing user velocity. The saturation effect is more relevant with increasing SNR, therefore the transmit power is lower with increasing SNR.

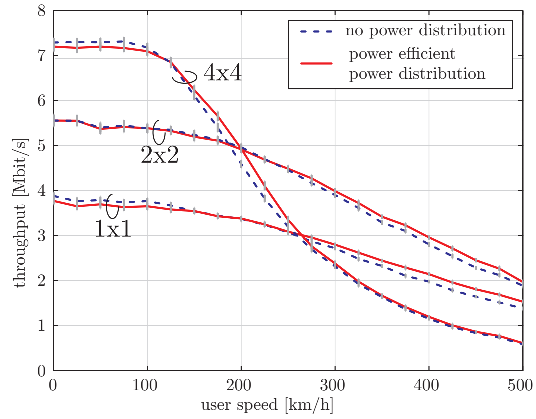

Fig. 2. Throughput comparison of various LTE systems without any power distribution and with power efficient power distribution at SNR = 20 dB over user velocity.

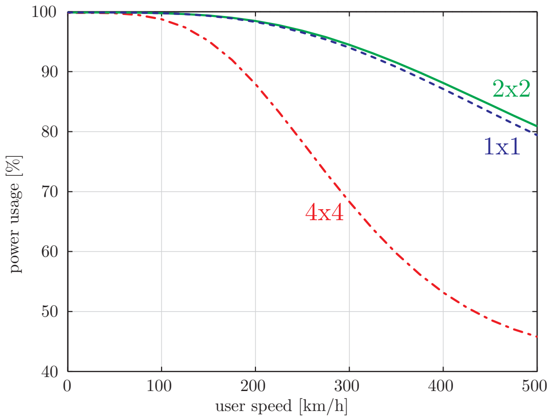

Fig. 3. Percentage of power used for the transmission of LTE system for various numbers of transmit antennas plotted over user velocity utilizing our proposed power efficient power distribution at SNR=20 dB.

VI. Conclusion

In this paper, we answered the question of how to distribute available power among pilot and data symbols under time-variant channels in an power efficient way. Compared to the previous work, instead of utilizing the post-equalization SINR as the cost function, in this paper, we utilized the total consumed power as the cost function and the post-equalization SINR as one of the conditions of the optimization problem. Up to 50% of the radiated power can be saved using 4×4 MIMO LTE downlink transmission system at SNR = 20 dB. This power saving can be explained by the saturation effect of the state-of-the-art channel estimators (e.g., LS, LMMSE) under time-variant channels. It simply does not pay off to radiate more power at the pilot symbols at high Doppler spread since the state-of-the-art channel estimators show saturation effects at high user velocities. At the same time, increased power at data subcarriers would lead to increased inter-layer interference due to the imperfect channel knowledge.

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