Selection of the Coordination Strategy in the Network MIMO Downlink

Sebastian Stern and Robert F.H. Fischer
Institut für Nachrichtentechnik, Universität Ulm, Ulm, Germany
Email: {sebastian.stern, robert.fischer}@uni-ulm.de

Abstract—Network MIMO or distributed MIMO is one promising strategy to increase the data rates in future cellular communication systems. However, well-known schemes like linear pre-equalization or Tomlinson-Harashima precoding for handling the multiuser interference assume full coordination (via some centralized processing) between the base stations. This approach causes significant traffic in the (wired) backhaul. In this paper, decentralized strategies with partial coordination are considered. A selection algorithm is presented, which, given the actual MIMO channel, automatically chooses the amount of coordination which is necessary to achieve a predefined performance. The trade-off between the achievable reduction in backhaul signaling and the required signal-to-noise ratio to not exceed a tolerated bit error rate is discussed. The proposed strategies are covered by means of numerical simulations.

I. INTRODUCTION

Over the last years, the principle of network multiple-input/multiple-output (network MIMO) has gained significant popularity in multiuser communication, e.g., [7]. Employing network MIMO, several user equipments (UEs) located within a service area are jointly supplied by a group of base stations (BSs). In our paper, we concentrate on the network MIMO downlink [9], i.e., uncoordinated UEs are served by coordinated BSs (where the coordination is realized via wired backhaul).

Meanwhile, a variety of strategies to handle multiuser interference in network MIMO has been proposed in the literature. In particular, linear pre-equalization (LPE) or the better-performing Tomlinson-Harashima precoding (THP), e.g., [3], [4], [6], [13], are of interest. Recently, these techniques have been extended to incorporate additional optimization criteria, for instance per-antenna/BS power constraints or a performance balancing among the UEs, e.g., [12], [14], [11], [5].

However, for all of the abovementioned schemes it is assumed that precoding takes place at some central instance. If the data to be transmitted to each UE initially arrives at its dedicated BS—as usual in uncoordinated wireless communication—the wired backhaul is burdened with a large amount of coordination traffic. To relieve this situation, we have recently proposed a strategy for a decentralized network MIMO processing [8]. After an initial, centralized computation of required precoding matrices, the encoding procedure is completely performed by direct signaling between BSs. Since this signaling can be conducted in a hierarchical way, the amount of backhaul traffic can be significantly reduced when tolerating only a small decrease in error rate performance.

Yet, still the question remains for which actual channel situations hierarchical coordination is sufficient to ensure a desired performance. If the current MIMO channel is very bad, a fully-coordinated precoding (or even an exclusion from transmission, i.e., declaring an outage) is advisable. In contrast, if good conditions are present, there is the chance to guarantee performance requirements without any or only little coordination effort. To this end, in this paper, we propose a selection algorithm which automatically switches between a fully- or hierarchically-coordinated scheme, or even deactivates coordination dependent on the actual MIMO channel. Thereby, a required performance is guaranteed while reducing the backhaul signaling as much as possible. Numerical simulations cover the effectiveness of the derived approach.

The paper is organized as follows: in Sec. II, a geometrical channel model for network MIMO scenarios is briefly reviewed. Sec. III discusses THP-type precoding schemes with different levels of coordination. An automated selection algorithm for these schemes is derived in Sec. IV. A short summary and conclusion can be found in Sec. V.

II. SYSTEM MODEL

The geometrical network MIMO model shown in Fig. 1 is the basis for the considerations throughout the paper. All BSs are placed on a hexagonal grid with inter-site distance \( r_{\text{BS}} = 500 \text{ m} \), where \( N_B = 3 \) BSs are combined to supply \( N_U = 3 \) single-antenna UEs jointly. The UEs are uniformly distributed within the service area (dark gray shaded in Fig. 1). UEs located outside this region are served by another triple of BSs leading to an identical scenario. The model is taken from [9], [5], [8], however, UEs located close to BSs are not omitted (\( r_{\text{min}} = 0 \)).

A. Channel Model

For the abovementioned geometrical model, the respective discrete-time (symbol interval \( T \)) complex baseband
MIMO system model can be defined.\(^1\) The MIMO system model from BSs to UEs in vector/matrix notation for one time step then reads\(^2\)

\[
y = H x + n ,
\]

where \(x = [x_1, \ldots, x_{N_U}]^T\) denotes the vector of transmit symbols which are radiated from the BSs and \(y = [y_1, \ldots, y_{N_U}]^T\) the vector of receive symbols at the UEs. The vector \(n\) represents complex-valued zero-mean mutually uncorrelated white Gaussian noise at the receivers, i.e., \(n = [n_1, \ldots, n_{N_U}]^T\) and \(E\{nn^H\} = \sigma_n^2 I\). The noise variance of each component is given as \(\sigma_n^2 \equiv N_0/T\), with \(N_0\) as the one-sided noise power spectral density.

The channel matrix

\[
H = [h_{u,b}]_{u=1,\ldots,N_U}^{b=1,\ldots,N_B}
\]

is assumed to be constant over some transmission burst (block-fading channel). The complex channel coefficient \(h_{u,b}\) models the connection between BS \(b\) and UE \(u\) and is given as\(^3\)

\[
h_{u,b} = 10^{-L_{an}(r_{u,b})/20} \cdot 10^{A_{hb}(\theta_{u,b})/20} \cdot h_{u,b,i.i.d} .
\]

For the details see [1], [2], [5].

\(^1\)The channel model contains pulse-shaping at the transmitter, the radio-frequency channel, as well as matched filtering and sampling at the receiving UE. For instance, this model is suited for per carrier radio-frequency channel, as well as matched filtering and sampling at the receiving UE.

\(^2\)Notation: \(E\{\cdot\}\): expectation. \(A^T\): transpose of matrix \(A\). \(A^H\): Hermitian of matrix \(A\). \(I\): identity matrix. \(\text{diag}(\cdot)\): diagonal matrix with given elements. \(\text{mod}(\cdot)\): symmetrical modulo operation; interval depends on context.

\(^3\)Here, the factor \(L_{an}(r_{u,b})\) is composed of \(L_{dB}(r_{u,b}) = D_{\text{dB}} + 37.6 \log_{10}(r_{u,b} / \text{[km]}) + S_{\text{dB}}, \) where \(D_{\text{dB}}\) represents the basic channel attenuation, the second quantity the path loss \(r_{u,b}\) is the distance between UE \(u\) and BS \(b\), cf. Fig 1); and the Gaussian zero-mean random variable \(S_{\text{dB}}\) (in dB, 8 dB standard deviation) shadowing effects. The factor \(h_{u,b,i.i.d.}\) is a zero-mean uncorrelated random variable to model fast fading. Finally, \(A_{hb}(\theta_{u,b}) = \min\{12(\theta_{u,b}/70^\circ)^2, 20\}\) is assumed as antenna pattern, with \(\theta_{u,b}\) denoting the angle between UE \(u\) and BS \(b\), cf. Fig 1).
III. COORDINATION STRATEGIES FOR DECENTRALIZED PROCESSING

In the literature on network MIMO usually a central processing unit (CU) fulfilling two different tasks is expected: i) assuming perfect channel knowledge and bursty transmission, the CU initially computes the precoding matrices for the specific scheme which are valid for one transmission frame; ii) subsequently, in each time step of this burst, the CU is responsible for calculating the transmit symbols $x$ from the actual data symbols $a$.

For the case that each data symbol is present at one (previously assigned) BS—a situation relevant in practice—significant data traffic in the wired backhaul is caused. All data symbols have to be transmitted to the CU in order to perform the precoding; the CU then returns the transmit symbols. If we measure the coordination effort by the number (denoted as $\beta$) of complex symbols to be communicated via the backhaul in each discrete time step, for classical CU processing, we have $\beta = 6$.

In contrast, a strategy for decentralized processing has been presented in [8], where the CU is just responsible for the initial computation of the precoding matrices. The calculation of the transmit symbols takes place separately in each BS, hence, the encoding is realized via a direct communication between the BSs without any CU. In the following, THP-type precoding for decentralized encoding employing different levels of coordination (no, hierarchical and full coordination) is assessed, as illustrated in Fig. 3.

A. No Coordination

If all UEs possess good channel conditions (usually when all UEs are located near their assigned BS), each BS may individually supply its UE. In that case, interference caused by other BSs does not significantly lower the performance. Consequently, there is a chance to avoid backhaul traffic completely ($\beta = 0$; cf. Fig. 3 left), and the data symbols directly constitute the transmit symbols,$^4$ i.e., $x = a$.

The performance largely depends on the assignment from data symbols to BSs. For non-coordinated (NC) transmission, there are $N_B! = 6$ different assignments, i.e., six column permutations $HP_B$ of the channel matrix.

The end-to-end cascade from data to receive symbols thus reads $C_{\text{NC}} = [c_{u,b}^{\text{NC}}] = HP_B$. For uncoordinated transmission, the $\text{signal-to-interference-plus-noise ratio (SINR)}$—the relevant quantity for the BER performance—is then given as ($\zeta \equiv \sigma_d^2/\sigma_a^2$ is the inverse SNR)

$$\text{SINR}_{u}^{\text{NC}} = \frac{|c_{u,u}^{\text{NC}}|^2}{\zeta + \sum_{i \neq u} |c_{u,i}^{\text{NC}}|^2}. \quad (7)$$

Since the overall BER performance is dominated by the worst-case user, it is convenient to maximize the minimum SINR over all users, like proposed in [12], [14], [11], [5] (min SINR criterion). Hence, the optimization task reads

$$\text{minSINR}_{u}^{\text{NC}} \triangleq \min_{u=1,...,N_U} \text{SINR}_{u}^{\text{NC}} \rightarrow \max. \quad (8)$$

This strategy requires only a very low initial computation effort, as the SINRs are directly obtained from the permutations of $H$. Noteworthy, the power constraints (4) and (5) are immediately fulfilled.

B. Hierarchical Coordination

In [8], we have proposed a THP-type precoding scheme for a hierarchical distribution of knowledge with successive encoding; this strategy is shown in Fig. 3 (middle). BS 1 only knows its data symbol $a_1$ and calculates $\tilde{x}_1 = a_1$ and $x_1 = f_1, \tilde{x}_1$. The precoded symbol $\tilde{x}_1$ is communicated to BS 2, which, together with its data symbol $a_2$ calculates $\tilde{x}_2 = \text{mod}(a_2 - b_2, \tilde{x}_1)$ and $x_2 = f_2, \tilde{x}_1 + f_2, \tilde{x}_2$. Finally, both precoded symbols, $\tilde{x}_1$ and $\tilde{x}_2$, are sent to BS 3, which calculates $\tilde{x}_3 = \text{mod}(a_3 - b_3, x_1, x_2)$ and $x_3 = f_3, \tilde{x}_1 + f_3, x_2 + f_3, x_3$. This directly corresponds to a lower triangular feedforward matrix $F$. In summary, only $\beta = 3$ symbols have to be communicated via the backhaul.

Again, it is of importance which data symbol is communicated to which BS (permutation matrix $P_B$). However, in addition, here the ordering of the successive encoding also has to be optimized. As in conventional THP, this ordering can be described by a row permutation matrix $P_U$. In summary, $N_U!N_B! = 36$ permutations $P_UHP_B$ are possible in case of hierarchical coordination (HC). The end-to-end cascade is now given as $C_{\text{HC}} = [c_{u,b}^{\text{HC}}] = P_UHP_BF$, and the optimization task according to the min SINR criterion reads

$$\text{minSINR}_{u}^{\text{HC}} \triangleq \min_{u=1,...,N_U} \text{SINR}_{u}^{\text{HC}} (P_U, P_B) \rightarrow \max. \quad (9)$$

$^4$Regarding Fig. 2, this can be seen as THP with feedforward and feedback matrix $F = I, B = I$. At the receiver scaling via $G = \text{diag}(\{c_{1,1}^{\text{NC}}\}^{-1},\ldots,\{c_{3,3}^{\text{NC}}\}^{-1})$ is performed.
where the SINR calculates to [5], [8]
\[
\text{SINR}^{(HC)}_u \equiv \frac{\zeta + \sum_{i > n_U} |c_{u,i}^{(HC)}|^2}{\sum_{i = 1}^{n_U} |c_{u,i}^{(HC)}|^2}.
\] (10)

The computation of \( F \) and \( B \) obeying the power constraints (4) and (5) can be performed using a second-order cone program, cf. [11, Algorithm 2] (numerically implementable via [10]). Regrettably, the precoding matrices have to be computed for all 36 possible permutations in order to find the best solution. To lower the initial calculation effort, in [8], a heuristic strategy for restricting the set of permutation pairs \((P_U, P_B)\), for which the optimization is carried out, has been presented. In the present paper, we employ this preselection strategy\(^5\) and only test 6 permutation pairs.

### C. Full Coordination

When one or several UEs suffer from bad channel conditions, the employment of fully-coordinated precoding is advisable. In this case of classical THP, all precoded symbols \(x_1, x_2, \) and \(x_3\) have to be known at all BSs; the respective coordination effort amounts to \(\beta = 6\), cf. Fig. 3 (right). As known from conventional THP, here only the precoding order is of importance; the \(N_U! = 6\) row permutations \(P_U \rightarrow H\) lead to different SINRs. The end-to-end cascade for full coordination (FC) precoding reads \(C^{(FC)} = [c_{u,b}^{(FC)}] = P_U \cdot H F\) and the optimization task is given as

\[
\min\text{SINR}^{(FC)}_u \equiv \min_{u=1,\ldots,N_U} \text{SINR}^{(HC)}_u \cdot \frac{P_{\text{max}}}{P_{\text{max}}} \rightarrow \max,
\] (11)

where \(\text{SINR}^{(FC)}_u\) is defined in (10), replacing the subscript “HC” by “FC”.

For FC precoding, the BLAST algorithm yields the (nearly) optimum encoding order [13]. Using the associated permutation \(P_U\) the precoding matrices are again computed via second-order cone program obeying (4) and (5) [5].

\(^5\)Although the channel model in this paper has slightly changed compared to [8] (no exclusion of UEs located near to BSs), the empirically obtained probabilities, based on which the permutations are chosen, are almost the same as in [8].

### D. BER Performance and Comparison

For a comparison of the achievable performance of the abovementioned coordination strategies, Fig. 4 shows the BER curves over the SNR. In the Monte Carlo simulations 50000 channel realizations were considered; each one for a burst of 50000 data symbols.\(^6\) Different levels of coordination; for comparison, the result for the optimized version of LPE [5] is given.
Noteworthy, even hierarchical precoding significantly outperforms fully-coordinated ($\beta = 6$) linear preequalization.

IV. AUTOMATED SELECTION OF THE COORDINATION STRATEGY

In this section, the possibility of an automated selection of the coordination effort is discussed. Depending on the current channel, our objective will be the reduction of the backhaul traffic, ensuring a predefined transmission quality (BER demand).

A. SINR Statistics

As already discussed in the last section, regardless of the specific precoding strategy, the minimum SINR is determining the BER performance. Consequently, we are interested in the distribution of this quantity. Fig. 5 depicts the empirically determined probability density function (pdf) of $\min\text{sINR}^{\left(\frac{1}{2}\right)}$ in dB for all considered precoding strategies. For comparison, Gaussian distributions with the same mean value and the same standard deviation are shown (black lines). Additionally, Fig. 6 illustrates the resulting mean values $\mu_{\text{dB}}$ and standard deviations $\sigma_{\text{dB}}$ over the SNR (each in dB).

As can be seen, for uncoordinated transmission the SNR only has a minor impact on the pdf (interference-limited regime). This behavior explains the hardly decreasing BER curve in Fig. 4. Just in a few cases, the uncoordinated scheme results in an acceptable transmission quality. In contrast to that, the statistics of hierarchical coordination do not differ a lot from the ones for full coordination. Especially in the high-SNR regime full coordination shows its advantage; in double-logarithmic scale, expectation and standard deviation linearly increase over the SNR for FC, whereas some residual interferences are still present in HC.

Particularly in the case of fully-coordinated THP (optimized according to the min SINR criterion), the pdfs of the minimum SINR are very well approximated by a log-normal one, i.e.,

$$\text{pdf}(\min\text{sINR}^{(\text{FC})}) = \frac{1}{2\pi\sigma_{\text{dB}}^2} \exp\left(-\frac{(10\log_{10}(\min\text{sINR}^{(\text{FC})}) - \mu_{\text{dB}})^2}{2\sigma_{\text{dB}}^2}\right). \quad (12)$$

This fact is subsequently used to develop an adequate selection model.

B. Selection Algorithm

Since fully-coordinated THP is the best-performing precoding strategy (among that considered in this paper), for an automated selection, its average BER curve (cf.

\begin{itemize}
  \item \text{In dependency of } $\zeta = \frac{\sigma^2}{\sigma_n^2}$, these parameters are well approximated by $\mu_{\text{dB}} = 9.47 + 10\log_{10}(\zeta^{-1}) - 4.15$ [dB] and $\sigma_{\text{dB}} = 0.16 + 10\log_{10}(\zeta^{-1}) + 4.28$ [dB] for fully-coordinated precoding.
  \item Since interference is handled, $\text{SINR}_{\text{u}}^{\left(\text{FC}\right)} \approx \left| c_{u,\alpha} \right|^2 \cdot \frac{\sigma^2}{\sigma_n^2}$.
\end{itemize}

Fig. 4) can be seen as a reference. In turn, to each SNR value $E_{\text{b}}/N_0$, a corresponding SINR value, which is minimally required, is associated. If, for the actual channel, uncoordinated transmission or hierarchical precoding are able to achieve a $\min\text{sINR}^{(\text{FC})}$ at least as large as the required one, these schemes are sufficient to guarantee the desired performance but with lowered backhaul traffic.

In addition, performance can be increased by discarding “poor” channel realizations, hence causing an outage.

For an automated selection, still the question has to be answered of how to specifically choose the required SINR (for a given SNR) for which uncoordinated or hierarchical transmission, respectively, are accepted. To this end, we consider that value of $\min\text{sINR}^{(\text{FC})}$, de-
noted as minSINR_{\text{req}}(p_e), which (relying on the log-normal model) is exceeded with a given probability \( p_e \in [0, 1] \). Mathematically, minSINR_{\text{req}}(p_e) corresponds to the \((1 - p_e)\)-quantile of the minSINR_{\text{FC}} distribution, i.e., the inverse of the cumulative distribution function \(\text{cdf}\) at probability \(1 - p_e\). For the log-normal distribution at hand, these quantiles are determined as

\[
\text{minSINR}_{\text{req}}(p_e) = 10^{(\mu_{\text{dB}} + \sigma_{\text{dB}} \sqrt{2} \text{erf}^{-1}(1 - 2p_e))/10},
\]  

(13)

where \(\text{erf}^{-1}(\cdot)\) is the inverse of the error function.

Algorithm 1 Automated selection of coordination strategy

Require: channel matrix \( \mathbf{H} \), inverse SNR \( \zeta \), exceedance probability \( p_e \) and no-outage probability \( p_{\text{no}} \)

1: \( \text{minSINR}_{\text{req}} \) := \( 10^{(\mu_{\text{dB}} + \sigma_{\text{dB}} \sqrt{2} \text{erf}^{-1}(1 - 2p_e))/10} \);
2: \( \text{minSINR}_{\text{out}} \) := \( 10^{(\mu_{\text{dB}} + \sigma_{\text{dB}} \sqrt{2} \text{erf}^{-1}(1 - 2p_{\text{no}}))/10} \);
3: \( \text{Check if non-coordinated transmission sufficient} 
\) \( P_B := \text{optimizeNC}(\mathbf{H}, \zeta) \) // cf. (8)
4: \( \text{if minSINR}_{\text{req}}(\mathbf{H}P_B, \zeta) \geq \text{minSINR}_{\text{req}} \) then
5: \( P_U := \mathbf{I} \); \( F := \mathbf{I} \); \( B := \mathbf{I} \);
6: \( \text{return } P_U, P_B, F, B; // \text{Return if successful} \)
7: end if
8: \( \text{Check if hierarchical coordination sufficient} 
\) \( [F, B, P_U, P_B] := \text{optimizeHC}(\mathbf{H}, \zeta) \) // cf. (9)
9: \( \text{if } \text{minSINR}_{\text{HC}}(P_U \mathbf{H}P_B F, \zeta) \geq \text{minSINR}_{\text{req}} \) then
10: \( \text{return } P_U, P_B, F, B; // \text{Return if successful} \)
11: end if
12: \( \text{Check if full coordination sufficient} 
\) \( [F, B, P_U] := \text{optimizeFC}(\mathbf{H}, \zeta) \) // cf. (11)
13: \( \text{if } \text{minSINR}_{\text{FC}}(P_U \mathbf{H}F, \zeta) \geq \text{minSINR}_{\text{out}} \) then
14: \( P_B := \mathbf{I} \);
15: \( \text{return } P_U, P_B, F, B; // \text{Return if successful} \)
16: else
17: \( \text{return } \text{FAIL}; // \text{Declare outage} \)
18: end if

hold. Subsequently, a suited choice of the probabilities \( p_e \) and \( p_{\text{no}} \), respectively, or corresponding thresholds minSINR_{\text{req}}(p_e) and minSINR_{\text{out}}(p_{\text{no}}), is discussed in detail.

From the above theoretical considerations, we are able to state an automated selection algorithm for reducing the backhaul traffic while guaranteeing the desired performance, see Algorithm 1. As input quantities, the algorithm demands for the actual channel matrix \( \mathbf{H} \), the inverse SNR \( \zeta \), and a proper choice of the exceedance probability \( p_e \) and the no-outage probability \( p_{\text{no}} \). First, the thresholds minSINR_{\text{req}} and minSINR_{\text{out}} are calculated from \( p_e \) and \( p_{\text{no}} \), respectively (cf. (13)). Then, it is tested whether non-coordinated transmission suffices, i.e., if minSINR_{\text{FC}} is above the threshold. If this is the case, the algorithm can already be terminated. Otherwise, it is tested whether hierarchical THP suffices, i.e., if minSINR_{\text{HC}} is above the threshold. Fully-coordinated precoding is the fall-back option. Alternatively, if outage is allowed \( (p_{\text{no}} < 1) \) it is tested whether fully-coordinated precoding fulfills the set demand.

C. Numerical Results

For the numerical evaluation of the selection algorithm, we again examine 50000 different channel realizations, where each channel matrix is constant over a burst of 50000 symbols. First, we restrict to the case when the exclusion of channels is turned off \( (p_{\text{no}} = 1) \); then, we study the effect of allowing outage.

1) Selection without Outage: Fig. 8 depicts the average BER over all users and channel realizations over the SNR...
The fully-coordinated scheme is the reference, increasing strategies selected by the algorithm. Fig. 9 illustrates system operates determine the ratio of the coordination performance (loss of coordinated precoding. In contrast, when selecting \( p \) since the BER performance is nearly equivalent to fully-coordinated precoding (cf. Fig. 4) is shown as reference.

Obviously, both \( p_c \) and the SNR at which the MIMO system operates determine the ratio of the coordination strategies selected by the algorithm. Fig. 9 illustrates each strategy’s percentage of usage for \( p_c = 0.99 \). Since the fully-coordinated scheme is the reference, increasing the SNR lowers the tolerated BER and hence increases the required SINR. Non-coordinated transmission is selected only for very low SNRs, which coincides with the conclusions obtained from Fig. 5. In the low- to mid-SNR range, HC precoding is sufficient for most of the channel realizations. Only in the high-SNR regime (low BER requirements), full coordination becomes important as there the superiority of FC over HC is more pronounced (cf. Fig. 5 or 6).

Since the ratio of each coordination strategy directly determines the (average) traffic in the backhaul, both the SNR and \( p_c \) influence the number \( \beta \) of complex symbols to be transmitted per discrete time step. In Fig. 10, \( E\{\beta\} \) is visualized in dependency of these two quantities. Again, increasing the SNR lowers the tolerated BER and hence FC is more and more preferred. Consequently, an increase in average coordination effort is visible over the SNR. This effect also holds for lowering \( p_c \), as the acceptance ratio of NC and HC is decreased, too.

If we select \( p_c = 0.9 \) (which is a good choice in the low-SNR regime, cf. Fig. 8), the traffic can be lowered from \( \beta = 6 \) for FC to \( E\{\beta\} \approx 3 \ldots 4 \). The gains of the selection become even more pronounced in the high SNR region. Here, \( p_c = 0.99 \) is reasonable and the average coordination effort \( E\{\beta\} \) can be kept below 3.5. In summary, using the proposed selection strategy, without noticeable loss in BER performance, the backhaul traffic can almost be halved.

The trade-off between the backhaul traffic and the SNR required for guaranteeing a desired target BER (here \( BER = 10^{-4} \)) is depicted in Fig. 11. Again, for the moment, no outage is allowed (\( p_{\text{no}} = 1 \), red curve). Obviously, the lowest required SNR in order to achieve the target BER is obtained by restricting to FC precoding (i.e, \( p_c = 0 \) or \( \min\text{SINR}_{\text{req}} = \infty \)) which results in the worst-case backhaul traffic of \( \beta = 6 \). When enabling the automated selection by increasing \( p_c \) (lowering
min\text{SINR}_{\text{req} \{\beta\}}, E\{\beta\} decreases significantly almost without any increase in required SNR. Employing a probability $p_\text{e}$ beyond approximately 0.99 does provide only very little additional gains in $E\{\beta\}$ but significantly increases the required SNR; the curve flattens out at $E\{\beta\} = 3$. Hence, $p_\text{e} \approx 0.99$ is a good compromise between the amount of coordination and SNR requirements.

2) Selection with Outage: Finally, we investigate the influence of allowing an outage, i.e., the effects when “bad” channels are excluded from transmission. To this end, we again consider the trade-off between backhaul traffic and SNR required for guaranteeing a desired target BER (here $BER = 10^{-4}$), see Fig. 11. The no-outage probability is chosen to $p_{\text{no}} = 0.999$, 0.99, and 0.9, i.e., for the 0.1, 1, and 10% worst performing channels according to the Gaussian model an outage is declared.

As expected, the exclusion of channels with poor conditions in general leads to lower required SNRs. The trade-off curves basically exhibit the same characteristics (L shape) as in the case of no outage. However, the specific values of $p_\text{e}$ for the optimum trade-off depend on the actual value $p_{\text{no}}$. Remarkably, even the exclusion of only the 1% worst performing channels can lower the required SNR by about 2 dB. As already explained, only $p_\text{e} \leq p_{\text{no}}$ is reasonable. Hence, the curves end at $p_\text{e} = p_{\text{no}}$. Beyond this point (visualized by the dashed line) the precoding strategy selected by the algorithm always performs better than the desired target BER.

V. SUMMARY AND CONCLUSION

In this paper, an approach for the automated selection of coordination strategies in network MIMO scenarios has been presented. To this end, different precoding strategies (no coordination, hierarchical precoding, conventional fully-coordinated precoding) have briefly been reviewed and assessed. A straightforward selection algorithm has been proposed, which classifies the current channel situation and activates only that coordination strategy which guarantees a desired performance with the lowest amount of backhaul signaling. For that purpose, a log-normal model for the minimum SINR over the users achievable with fully-coordinated precoding has been employed.

Numerical simulations have revealed that the selection is able to nearly halve the amount of backhaul traffic without any noticeable negative impact on the BER performance. By adjusting the free parameter (exceedance probability or minimally required SINR) a trade-off between required SNR and signaling is enabled. Finally, we have assessed the exclusion of bad-performing channels. Allowing an outage, the required SNR can be lowered significantly.

In summary, the automated selection of the degree of cooperation is a promising technique for future network MIMO scenarios. For the vast majority of channel realizations, fully-cooperated precoding (classical THP) is not required at all; very often the hierarchical scheme proposed in [8] is sufficient. Consequently, only the amount of backhaul traffic really needed should be invested.

REFERENCES