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Joint Optimization of Uplink Power Control Parameters in LTE-Advanced Relay Networks

Ömer Bulakci[1,2], Ahmad Awada[1,3], Abdallah Bou Saleh[1,2], Simone Redana[1], Jyri Hämäläinen[2], Bernhard Wegmann[1], Bernhard Raaf[1], and Ingo Viering[4]

***Abstract*—Relaying is a promising enhancement to existing radio access networks and is currently being standardized in 3GPP to be part of the LTE-Advanced Release 10. Relays promise to alleviate the limitations of conventional macrocell-only networks such as poor indoor penetration and coverage holes in a cost-efficient way. Yet, to fully exploit the benefits of relaying, the inter-cell interference which is increased due to the presence of relays should be mitigated. Besides, a high receiver dynamic range should be avoided to retain the orthogonality of the SC-FDMA system. In this manner, uplink power control is an effective tool to address such challenges. However, in order to enhance the overall system performance, power control optimization should be jointly done on all links, i.e. on eNB-relay node, eNB-UE and relay node-UE links. In this paper, we propose a joint optimization strategy of power control parameters based on Taguchi's method that exploits the mutual dependencies of the different links without a priori knowledge. The proposed joint parameter optimization is compared with a reference study that comprises a four-step optimization. The evaluation of the optimization strategies within the LTE-Advanced uplink framework is carried out by applying the standardized LTE Release 8 power control scheme both at eNBs and relays. Simulations show that the proposed optimization yields similar or better performance relative to the reference strategy depending on the considered performance metric.**

***Keywords-* LTE-Advanced; relay; uplink; power control; joint optimization; Taguchi's method**

I. INTRODUCTION

RELAYING is considered an integral part of the Fourth Generation (4G) radio access networks, namely IEEE 802.16m and 3GPP Long Term Evolution Release 10 and beyond (LTE-Advanced). The motive behind choosing relaying as an enhancement technology to current radio access networks has been well elaborated in literature. According to previous technical studies, relay nodes (RNs) promise to increase the network capacity and to better distribute resources in the cell, or alternatively, extend the cell coverage area [1], [2]. Relaying is also regarded a cost efficient technology [3].

Relay deployments require a more detailed dimensioning and planning than conventional single-hop networks. RN-served user equipments (relay-UEs) can create severe inter-cell interference in particular when a large number of RNs are deployed in the cell with a reuse factor of one. Consequently, power control (PC) becomes a vital means in the uplink (UL) not only to compensate for channel variations, but also to mitigate the interference and to increase the cell edge and system capacities. Furthermore, PC decreases the deviation between received power levels of different nodes in the same cell ensuring that the receiver dynamic range does not exceed a predetermined level above which intra-cell interference occurs [4]. Besides, in contrast to evolved Node B (eNB)-only networks, PC is necessary for the relay link (eNB-RN) because the end-to-end (e2e) throughput (TP) of relay-UEs depends on the qualities of both the access (RN-UE) and relay links.

In [5], a four-step PC parameter optimization is suggested where the parameters are tuned in each step according to the results obtained in the preceding step. We take this work as a reference for performance comparisons and propose a joint PC parameter optimization based on Taguchi's method. The PC parameters on the direct (eNB-UE), access, and relay links are tuned jointly. Taguchi's method uses originally a so-called orthogonal array (OA) [6]. An OA selects a reduced set of parameter combinations to be tested from the full search space. The number of selected combinations determines the number of experiments being carried out and evaluated against a performance measure. Using all the experiments' results, a candidate solution is found and the process is repeated till a desired criterion is fulfilled. Herein, we use the optimization procedure based on Taguchi's method applying a nearly OA (NOA) rather than an OA, as an NOA can be constructed for any number of experiments and in turn the complexity of the algorithm can be reduced. NOAs were used in [7] to optimize antenna parameters in eNB-only deployment within the LTE Release 8 (Rel. 8) framework. In this work, evaluation is carried out by applying standardized LTE Rel. 8 PC scheme in simulations conducted within the LTE-Advanced UL context.

The remainder of the paper is organized as follows. Section II provides the background information. In Section III, the optimization problem is outlined along with the proposed and reference optimization strategies. The system model and simulation assumptions are given in Section IV. In Section V, detailed performance evaluation and analysis are carried out. Section VI concludes the paper.

II. BACKGROUND AND DEFINITIONS

In this section, we briefly recall the fractional power control (FPC) scheme of LTE Rel. 8. The definitions of the

[1] Nokia Siemens Networks, St.-Martin-Straße 76, 81541, Munich, Germany, {omer.bulakci, abdallah.bousaleh}@ieee.org, {ahmad.awada.ext, simone.redana, bernhard.wegmann, bernhard.raaf}@nsn.com.
[2] Aalto University School of Electrical Engineering, P.O. Box 13000, FIN-00076 Aalto, Finland, jyri.hamalainen@aalto.fi.
[3] Technische Universität Darmstadt, Communications Engineering Lab, Merckstr. 25, 64283, Darmstadt, Germany.
[4] Nomor Research GmbH, Brecherspitzstrasse 8, 81541, Munich, Germany, viering@nomor.de.

performance metrics are presented afterwards.

A. UL Open-Loop Power Control

The main task of PC mechanisms is to compensate the long-term channel variations and to limit the amount of generated inter-cell interference. Yet, the receiver dynamic range[1] of eNBs and RNs should also be adjusted via PC. Large dynamic range may lead to reduced orthogonality between time-frequency resources within a cell and cause intra-cell interference [4]. To fulfill the aforementioned objectives, FPC [8] is used for the Physical Uplink Shared Channel (PUSCH) to determine the UE transmit power. In this work, FPC is also employed for the relay specific PUSCH (R-PUSCH). Accordingly, the transmit power of a node u (UE or RN) that employs open-loop FPC, is given in dBm as:

$$P_u = \min\{P_{\max}, P_0 + 10 \cdot \log_{10} M_u + \alpha \cdot L\}. \qquad (1)$$

In this equation,

- $P_{\max}$ is the maximum allowed transmit power which has an upper limit of 23 dBm for UE power class 3 and 30 dBm for RN transmissions for urban scenarios [9],
- P_0 is the power offset comprising cell-specific and node-specific components and it is used for controlling the received signal-to-noise-ratio (SNR) target that can be set from -126 dBm to $P_{\max}$ with a step size of 1 dB,
- M_u is the number of physical resource blocks (PRBs) allocated to node u,
- α is a 3-bit cell-specific path loss compensation factor that can be set to 0.0 and from 0.4 to 1.0 with a step size of 0.1,
- L is the downlink path loss estimate calculated at the node.

Open-loop PC compensates slow channel variations, i.e. path loss changes including shadowing, while limiting the inter-cell interference. If α is set to one in (1), the path loss is fully compensated and the resulting scheme is called full compensation power control (FCPC). For a given P_0 value, FCPC improves the cell-edge user performance at the cost of increased inter-cell interference due to higher transmit power levels. Yet, the inter-cell interference can be reduced by using values smaller than one, which can increase the cell-center performance at the cost of penalizing the cell-edge performance [10][11]. Moreover, one important motivation to study the applicability of the existing FPC for the relay enhanced cells is the desired backward compatibility between LTE Rel. 8 and LTE-Advanced terminals.

B. Performance Metrics

The paper utilizes the following key performance metrics:

- $\Gamma_{5\%}$: The *5^{th}%-ile level of the user TP CDF* reflects the cell-edge bit rate or equivalently the cell coverage performance.
- Γ_{HM}: The *harmonic mean (HM) of the user TP levels* in the cell prioritizes the performance of cell edge UEs and thus an optimization using this metric leads to a more homogeneous user experience in the network [12].

[1] The receiver dynamic range is defined as the difference in dB between the 5^{th}%-ile and 95^{th}%-ile of the cumulative distribution function (CDF) of the total received power.

III. Optimization Problem and Methods

In this section, we first introduce the relay scenario and the optimization problem to be addressed. We then outline the proposed optimization strategy and give a brief explanation of the reference optimization strategy.

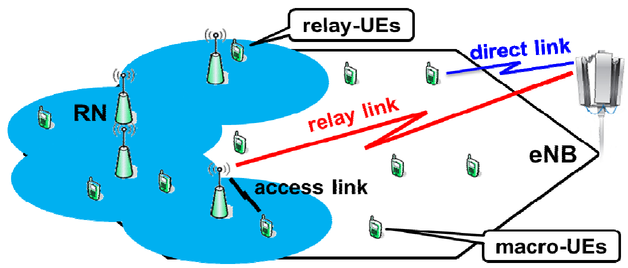

Figure 1. One-tier relay deployment shown in a sector. 4 RNs are deployed at the cell-edge.

The considered relay deployment along with the links is depicted in Fig. 1. Cell selection for the UEs is based on the strongest downlink received signal power, whereas RNs are connected to the overlaying macrocell. As can be seen in Fig. 1, relay-UEs are mostly those at the macrocell edge, whereas, macro eNB-served UEs (macro-UEs) are generally located in the cell center. Accordingly, in order to enhance overall system performance, the PC parameter optimization should be done on all links considering the interdependencies. Tuning $P_{\max}$, P_0, and α on these links simultaneously is a challenging task - given the possible parameter range discussed in Section II-A. Therefore, a brute-force approach becomes infeasible due to high computational complexity. A reasonable optimization approach should take into account the mutual dependencies of relay and access links, where e2e performance is determined by the qualities of both links.

A. Four-step Optimization

In [5], interdependencies between different links are addressed via a four-step strategy. The parameter tuning in each step is done according to the performance results of the preceding step. Namely, the four steps are:

1. Simulations are carried out to optimize PC parameters for eNB-only scenario.
2. Relay scenario is adopted and parameters resulting from Step 1 are applied at both eNBs and RNs. Simulation results of this step are used as a starting point for Steps 3 and 4.
3. PC parameters are optimized in RN cells.
4. Keeping PC parameters fixed at RNs, the PC parameters at eNBs are optimized.

In contrary to the four-step optimization, Taguchi's method inherently takes into account the interdependencies and yields the optimized parameter setting in one simulation run. Since the main focus of the relay deployment at the cell edge is to increase coverage, we consider FCPC as described in Section II-A. The goal is to optimize P_0 values on all links jointly, i.e. $P_0^{\text{direct link}}$, $P_0^{\text{access link}}$, and $P_0^{\text{relay link}}$. Moreover, it is known from [5] that $P_{\max}$ of relay-UEs ($P_{\max}^{\text{relay-UEs}}$) can be also tuned to further enhance the system performance. Therefore, $P_{\max}$ tuning for the relay-UEs is considered as well.

B. The Optimization Procedure Based on Taguchi's Method Using NOA

We start by defining the configuration parameters. Let x_t be a configuration parameter where index t = 1,2,3,4 refers to as one of the four configuration parameters, i.e.,

$$x_1 = P_0^{direct\ link},\ x_2 = P_0^{access\ link},\ x_3 = P_0^{relay\ link},\ x_4 = P_{\max}^{relay-UEs}.$$

Besides, we denote the optimization target function as y and it can be set either to 5%-ile user TP or HM metric, see Section II-B.

Let us next introduce Taguchi's method [7][12]. The optimization approach is depicted in Fig. 2 and will be discussed in details in the following.

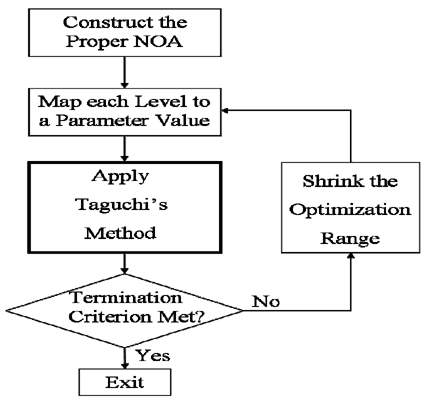

Figure 2. The iterative optimization procedure based on Taguchi's method using NOA .

1) Construct the proper NOA

Originally, Taguchi's method uses an OA which contains a reduced set of N parameter combinations from the full search space [6]. Every parameter x_t has a set of testing values corresponding to a set of levels, i.e., level 1 is mapped to the first testing value of a parameter, level 2 to the second value and so on (see Section III-B-2). Each of the N parameter combinations is tested in a corresponding experiment i where the function y is evaluated resulting in a measured response y_i. In an OA, each testing value of a parameter x_t is tested at least once with every other value of parameter $x_{j\neq t}$. This property of the OA accounts for the interactions that might exist between the configuration parameters. To reduce the number of experiments, an OA is replaced by a nearly orthogonal array (NOA) [7]. Considering an NOA, each testing value of a parameter x_t is not necessarily tested with every other value of parameter $x_{j\neq t}$. Hence, NOA considers only partially the interactions among the parameters and is easier to construct. An NOA can be constructed for any number of parameters and number N of experiments at the expense of considering partially the interactions among the configurations parameters.

The first step in the optimization procedure is to construct a proper NOA. For this purpose, the number of configuration parameters has to be determined. In our case, the total number of configuration parameters is k = 4. Thus, an NOA having 4 columns should be constructed with a predefined number of experiments N and levels s. In this work, we construct an NOA having N = 36 experiments and s = 9 levels, see Table I, using the algorithm described in [13]. Using this NOA, each parameter will be tested with 9 different values in each iteration of the algorithm. Every column of the NOA corresponds to a configuration parameter. For example, the first column can be assigned to x_1, the second to x_2 and so on.

Having constructed the required NOA, the levels of each parameter should be mapped to parameter values in order to conduct the experiments. In each iteration, the levels of each parameter are assigned to different set of values depending on the candidate solution found in the previous iteration. This process is repeated until the levels of each parameter are mapped to values that are close enough to each other. The mapping function is explained in the next subsection.

TABLE I. AN NOA HAVING K=4 CONFIGURATION PARAMETERS, N=36 EXPERIMENTS, S=9 LEVELS WITH THE MEASURED RESPONSES AND THEIR CORRESPONDING SN RATIOS.

Experiment # i	x_1	x_2	x_3	x_4	Measured Response	SN Ratio
1	1	1	9	6	y_1	SN_1
2	1	2	7	1	y_2	SN_2
3	1	3	4	9	y_3	SN_3
4	1	4	1	8	y_4	SN_4
5	2	5	9	1	y_5	SN_5
6	2	6	7	2	y_6	SN_6
7	2	7	1	5	y_7	SN_7
8	2	8	5	4	y_8	SN_8
:	:	:	:	:	:	:
36	9	9	2	2	y_{36}	SN_{36}

2) Map each level to a parameter value

Let $\min\{x_t\}$ and $\max\{x_t\}$ be the minimum and the maximum feasible values for parameter x_t. In the first iteration, m =1, the center value of the optimization range for parameter x_t is defined as

$$V_t^{(m)} = \frac{\min\{x_t\} + \max\{x_t\}}{2}. \tag{2}$$

In any iteration m, the level $\ell = \lceil s/2 \rceil$ is mapped to $V_t^{(m)}$. The other s-1 levels are distributed around $V_t^{(m)}$ by adding or subtracting a multiple integer of a step size $\beta_t^{(m)}$. For m =1, the step size is defined as

$$\beta_t^{(m)} = \frac{\max\{x_t\} - \min\{x_t\}}{s+1}. \tag{3}$$

In iteration m, the mapping function $f_t^{(m)}(\ell)$ for a level ℓ to a dedicated value of the parameter x_t can be described as:

$$f_t^{(m)}(\ell) = \begin{cases} V_t^{(m)} - (\lceil s/2 \rceil - \ell)\cdot \beta_t^{(m)} & 1 \le \ell \le \lceil s/2 \rceil - 1 \\ V_t^{(m)} & \ell = \lceil s/2 \rceil \\ V_t^{(m)} + (\ell - \lceil s/2 \rceil)\cdot \beta_t^{(m)} & \lceil s/2 \rceil + 1 \le \ell \le s \end{cases}. \tag{4}$$

For instance, consider the parameter $x_4 = P_{\max}^{\text{relay-UEs}}$ having a minimum value of $\min\{x_4\}$ = 7 dBm and a maximum $\max\{x_4\}$ = 23 dBm. If x_4 is tested with 9 levels, i.e., s = 9, level $\ell = 5$ is mapped in first iteration to (7 + 23) / 2 = 15 dBm, level 4 to 15 - $\beta_4^{(1)}$ =13.4 dBm, level 6 to 15 + $\beta_4^{(1)}$ = 16.6 dBm and so on. As the power setting x_t cannot be decimal, the mapped value $f_t^{(m)}(\ell)$ of a level ℓ is further quantized to the nearest integer. The values of $V_t^{(m)}$ and $\beta_t^{(m)}$ are updated at the end of each iteration if the termination criterion, see Section III-B-5, is not met.

3) Apply Taguchi's method

To interpret the experimental results, Taguchi's method converts the measured responses to signal-to-noise (SN) ratios which are not to be confused with the SNRs of the received signals. The SN ratio is computed for each experiment *i* as

$$SN_i = 10 \cdot \log_{10}(y_i^{\,2}) \ . \tag{5}$$

Then, the average SN ratio is computed for each parameter and level. In the example of Table I, the average SN ratio of x_1 at level $\ell = 1$ is computed by averaging the SN ratios of the experiments where x_1 is tested at level 1, i.e., SN_1, SN_2, SN_3 and SN_4. The best level of each parameter is the level having the highest average SN ratio. According to the mapping function $f_t^{(m)}(\ell)$, the best setting of a parameter x_t in iteration *m* is found and denoted by $V_t^{(\text{best},m)}$.

4) Shrink the optimization range

At the end of each iteration, the termination criterion is checked. If it is not met, the best values found in iteration *m* are used as center values for the parameters in the next iteration *m*+1:

$$V_t^{(m+1)} = V_t^{(\text{best},m)} . \tag{6}$$

It may happen that the best value of a parameter x_t found in iteration *m* is close to $\min\{x_t\}$ or $\max\{x_t\}$ In this case, there is a need for a procedure to consistently check if the mapped value of a level is within the optimization range. Moreover, the optimization range is reduced by multiplying the step size of each parameter x_t by a reduction factor $\xi < 1$:

$$\beta_t^{(m+1)} = \xi \cdot \beta_t^{(m)} . \tag{7}$$

5) Check the termination criterion

With every iteration, the optimization range is reduced and the possible values of a parameter get closer to each other. Hence, the set used to select a near-optimal value for a parameter becomes smaller. The optimization procedure terminates when all step sizes of the parameters are less than a predefined threshold ε, i.e.

$$\beta_t^{(m)} < \varepsilon \ \forall \ t . \tag{8}$$

In this work, the algorithm ends when the mapped values of levels 1 and 9 do not differ by more than 1 dB for each parameter. To this end, ε is set as a rough approximation to 1/(*s*-1) =1/8.

IV. System Model

A. Resource Sharing

A resource fair round robin (RR) scheduling is applied for all UEs. Besides, the performance of relay-enhanced networks depends significantly on the resource allocation strategy. For relay-UEs, the experienced e2e TP depends on the qualities of both the access and relay links. That is

$$TP_{e2e} = \min\left(TP_{eNB-RN}, TP_{RN-UE}\right), \tag{9}$$

where e2e throughput is obtained as a minimum over throughputs on the relay and access links.

As depicted in [9], the backhaul subframes are reserved for relay link transmissions and thus a data transmission gap is experienced on the access link. During the transmission gaps relay-UEs are not scheduled. For the resource allocation on the backhaul subframes and access link, we utilize the scheme in [14], referred to as hop-optimization model. In this model, the resource shares of the RNs on the relay link are determined proportional to the number of attached relay-UEs. The available capacity on the relay link is then distributed among relay-UEs utilizing max-min fairness. Moreover, the number of backhaul subframes to be allocated to RNs is chosen such that the overall system performance is optimized.

B. Simulation Parameters

The simulated network is represented by a regular hexagonal cellular layout with 19 tri-sectored sites, i.e. 57 cells. RNs admit regular outdoor deployment at the sector border and indoor users are assumed, where 25 uniformly distributed UEs are dropped per sector and the full buffer traffic model is applied. In total, 50 user drops (or snap-shots) are simulated using a system level semi-static simulator, where results are collected from the inner most sector only, to ensure proper modeling of interference (two tiers of tri-sector sites). Simulation parameters follow the latest parameter settings agreed in 3GPP [9] and are summarized in Table II.

A frequency reuse factor of one (full reuse scheme) is considered in the network. All available resources in a cell are assumed to be used and hence a rather pessimistic interference modeling is considered at the access link.

TP is computed from signal-to-interference-plus-noise ratio (SINR) using the Shannon approximation similarly as described in [15]. An overhead of 25% is assumed, which accounts for control symbols and pilots.

Relay site planning is assumed as modeled in [9]. Directional antennas are utilized at the RNs for backhaul transmission, while omni-directional antennas are assumed for the access link transmission. Log-normal shadow fading is as well modeled and applied for NLOS propagation conditions.

V. Performance Evaluation and Analysis

The performance evaluation is carried out assuming the 3GPP urban scenario (ISD 500 m) where 4 RNs are deployed per cell. The number of backhaul subframes is set to two [14]. This setting is found to optimize the overall system performance along with relatively more homogeneous user experience over the whole cell area. The cell capacity-oriented setting with P_0 = -55 dBm and α = 0.6 (FPC) [5] is applied for the eNB-only deployment. Recall that the eNB-only deployment is taken as a benchmark to determine the relative gains of different optimization strategies. Besides, for the four-step optimization the cell coverage-oriented setting is used for the relay scenario. Furthermore, in order to maximize the cell edge user performance α is set to one (FCPC).

TABLE II. SIMULATION PARAMETERS

Parameter	Value
System Parameters	
Carrier Frequency	2 GHz
Bandwidth	10 MHz
Number of PRBs	48 for data transmission
Highest MCS	64-QAM, $R = 9/10$
Penetration Loss	20 dB on eNB-UE and RN-UE links
Thermal Noise PSD	-174 dBm/Hz
SINR lower bound	-7 dB
eNB Parameters	
Transmit Power	46 dBm
Elevation Gain	14 dBi
Antenna Configuration	Tx-2, Rx-2
Noise Figure	5 dB
Antenna Pattern (Horizontal)	$A(\theta) = -\min[12\,(\theta/\theta_{3dB})^2, A_m]$ $\theta_{3dB} = 70^o$ and $A_m = 25$ dB
UE Parameters	
Maximum Transmit Power	23 dBm
Antenna Configuration	Tx-1, Rx-2
Noise Figure	9 dB
Relay Node Parameters	
Maximum Transmit Power	30 dBm
Antenna Configuration	Tx-2, Rx-2
RN-eNB Elevation Gain	7 dBi
RN-UE Elevation Gain	5 dBi
Relay Link Antenna Pattern (Horizontal)	$A(\theta) = -\min[12\,(\theta/\theta_{3dB})^2, A_m]$ $\theta_{3dB} = 70^o$ and $A_m = 20$ dB
Access Link Antenna Pattern	Omni-directional
Noise Figure	5 dB
Channel Models	
Distance	R [km]
Direct Link (eNB – UE) PL(LOS): $103.4 + 24.2\log_{10}(R)$, PL(NLOS): $131.1 + 42.8\log_{10}(R)$ Prob(LOS) = $\min(0.018 / R, 1)\,(1-\exp(-R / 0.063))+\exp(-R / 0.063)$ **Access Link (RN – UE)** PL(LOS): $103.8 + 20.9\log_{10}(R)$, PL(NLOS): $145.4 + 37.5\log_{10}(R)$ Prob(LOS) = $0.5 - \min(0.5, 5\exp(-0.156/R)) + \min(0.5, 5\exp(-R/0.03))$ **Relay Link (eNB – RN)** {a & b account for the site planning gain} PL(LOS): $100.7 + 23.5\log_{10}(R)$, PL(NLOS): $120.2 + 36.3\log_{10}(R)$-b Prob (LOS) = $1-(1-(\min(0.018./R,1)(1-\exp(-R/0.072))+\exp(-R/0.072)))^a$ a=3 & b=5 towards donor eNB, whereas, a=1 & b=0 towards other eNBs.	
Shadowing	
Shadow Fading	Log-normal
Standard Deviation	8 dB (direct link), 10 dB (access link) 6 dB (relay link)
De-correlation Distance	50 m
Correlation Factor	0.5 between sites
	1 between sectors

The rest of this section is organized as follows. First, the numerical results for joint P_0 optimization are analyzed. To perform this joint optimization, it is enough to drop the column of $x_4 = P_{\max}^{\text{relay-UEs}}$ from the NOA and follow the optimization algorithm as described in Section III. Second, the results are presented for joint P_0 and $P_{\max}$ optimization. In addition, the ranges of [-113, -83] dBm and [7, 23] dBm with a step size of 1 dB are considered for P_0 and $P_{\max}^{\text{relay-UEs}}$ values, respectively.

A. Joint P_0 Optimization

The P_0 values on all links are jointly optimized while fixing $P_{\max}$ of UEs and RNs to the upper bounds. Both $\Gamma_{5\%}$ and Γ_{HM} are used as performance metrics. In Fig. 3, the convergence of the proposed optimization procedure is shown with respect to the number of iterations for both performance metrics. Note that a complexity and optimality analysis can be found in [12].

Obtained parameter settings are tabulated in Table III and the corresponding user TP CDFs are plotted in Fig. 4. It can be observed that the four-step optimization and the proposed optimization using HM metric yield similar performances as well as similar parameter settings. On the other hand, using the 5%-ile TP metric, the proposed method outperforms the four-step optimization on a wide range of CDF levels. Yet, slight performance degradation can be seen at the very low percentiles (below 5%-ile). Compared to eNB-only deployment, the proposed method with 5%-ile TP metric achieves 129% and 54% gains at 5%-ile and 50%-ile CDF levels, respectively. Note that the 50%-ile user TP gain reads as 42% for the four-step optimization and the proposed method with HM metric.

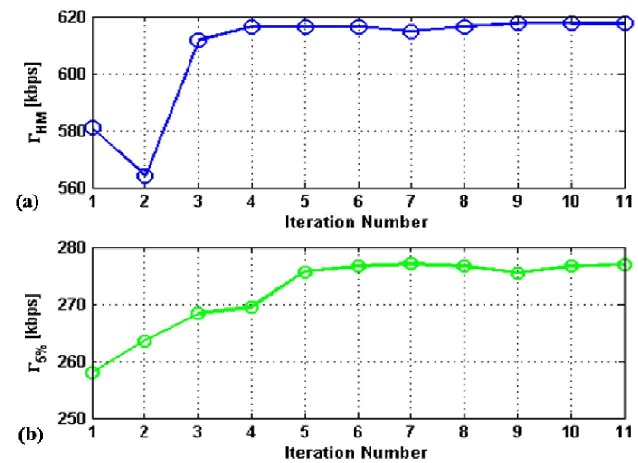

Figure 3. The convergence of the proposed optimization; (a) using Γ_{HM} and (b) using $\Gamma_{5\%}$ as performance metrics in joint P_0 optimization.

TABLE III OPTIMIZED PARAMETER CONFIGURATIONS

Parameters	4-Step Optimization			Proposed Optimization (Metric: 5%-ile user TP)			Proposed Optimization (Metric: HM of user TPs)		
	eNBs	*RNs*	*Relay Link*	*eNBs*	*RNs*	*Relay Link*	*eNBs*	*RNs*	*Relay Link*
P_0 [dBm]	-95	-101	-83	-90	-102	-85	-95	-102	-90
α	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$P_{\max}$ [dBm]	23	23	30	23	23	30	23	23	30

B. Joint P_0 and $P_{\max}$ Optimization

In conjunction with P_0 values, the parameter $P_{\max}^{\text{relay-UEs}}$ is also jointly tuned by the proposed optimization method. Furthermore, $P_{\max}$ of macro-UEs and RNs are set to the upper bounds. We adopt $\Gamma_{5\%}$ performance metric as it has shown a

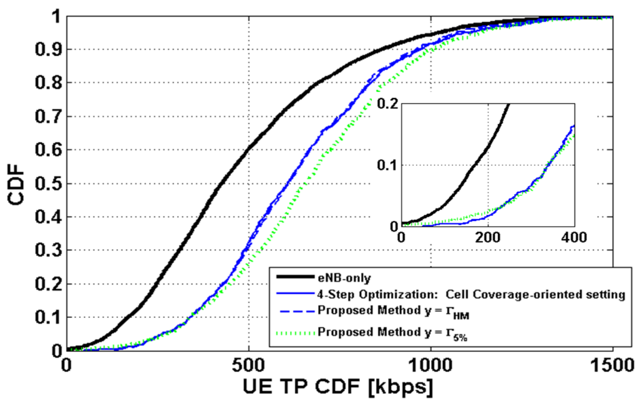

Figure 4. UE TP CDFs for different approaches for joint P_0 optimization.

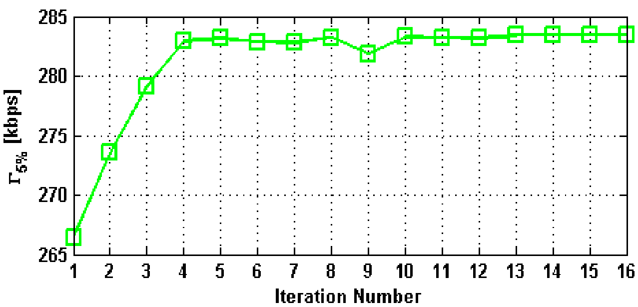

Figure 5. The convergence of the proposed optimization using $\Gamma_{5\%}$ as the performance metric for joint P_0 and P_{max} optimization.

superior performance relative to adopting Γ_{HM}. The convergence of the method is depicted in Fig. 5.

For the four-step optimization $P_{max}^{relay\text{-}UEs}$ is found to be 15 dBm. The P_0 and α values are tabulated in Table III. For the proposed method the P_0 values -98, -108 and -90 dBm are obtained for direct, access and relay links, respectively. Besides, $P_{max}^{relay\text{-}UEs}$ is tuned to 9 dBm. All other parameters are the same as given in Table III. The resultant user TP CDF plots are shown in Fig. 6. The four-step optimization and the proposed joint P_0 and P_{max} optimization yield similar results. As compared to joint P_0 optimization, these settings result in better performance at low CDF percentiles. However, the joint P_0 optimization shows better performance at high percentiles.

VI. CONCLUSION

We have proposed a joint power control parameter optimization strategy for relay enhanced LTE-Advanced networks based on Taguchi's method that exploits the mutual dependencies of the different links.

The impact of using different performance metrics as optimization functions has been investigated. It is presented that joint P_0 optimization using 5%-ile user throughput level as the optimization target function yields a better performance on a wide probability range when compared to the case where harmonic mean was used as a metric and to the reference four-step optimization. Between joint P_0 optimization and joint P_0 and P_{max} optimization, it has been shown that joint P_0 optimization can improve the performance at higher CDF percentiles. On the other hand, joint P_0 and P_{max} optimizations can improve the performance in the low throughput regime at

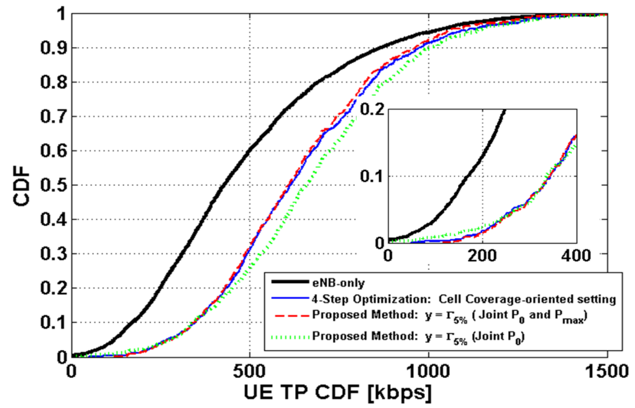

Figure 6. UE TP CDFs for different optimization approaches in case of joint P_0 and P_{max} optimization.

the cost of decreased performance at higher CDF percentiles.

After applying the proposed power control optimization strategy with 5%-ile user throughput metric in urban scenarios, it was found that relay deployment achieves 129% and 54% gains relative to macrocell-only deployment at 5%-ile and 50%-ile user throughput CDF levels, respectively.

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