IEEE Vehicular Technology Conference, Budapest, Hungary, May 2011

A Joint Optimization of Antenna Parameters in a Cellular Network Using Taguchi's Method

Ahmad Awada and Bernhard Wegmann
Nokia Siemens Networks
Munich, Germany
Emails: {ahmad.awada.ext; bernhard.wegmann @nsn.com}

Ingo Viering
Nomor Research GmbH
Munich, Germany
Email: viering@nomor.de

Anja Klein
Technische Universität Darmstadt
Communications Engineering Lab
Darmstadt, Germany
Email: a.klein@nt.tu-darmstadt.de

***Abstract*—One of the primary aims of radio network planning is to place and configure the transmit antennas of the base stations such that the deployment achieves the required quality of service. Long term evolution (LTE) systems are operated with frequency reuse one and, therefore, a proper configuration of the antenna azimuth orientations and tilts is essential to mitigate the inter-cell interference. Various algorithms have been proposed to adjust these two antenna parameters, but only a few are exploiting the mutual dependencies that exist between them. In this paper, we propose a new algorithm based on Taguchi's method that jointly optimizes the antenna azimuth orientations and tilts. LTE downlink simulations show that the joint optimization of the two antenna parameters outperforms the independent optimization methods. Moreover, the joint optimization reduces the computational complexity by a factor of two.**

***Index Terms*—LTE, Taguchi's method, nearly orthogonal array, antenna parameters, joint optimization method.**

I. INTRODUCTION

Long term evolution (LTE) is a new broadband wireless communication system which is based on orthogonal frequency division multiple access (OFDMA) and provides high data rate services [1]. Moreover, LTE adopts a frequency reuse one where each cell utilizes the whole available bandwidth to serve its user equipments (UEs). In an OFDMA system, UEs allocated to the same channel simultaneously receive co-channel interference (CCI) from neighboring cells which causes degradation in the performance, especially for cell edge users. A promising approach to increase the coverage and capacity in the network is the adjustment of the tilt of the antennas and their azimuth orientations [2].

Taguchi's method has been applied to radio network optimization in [3], however adjusting the tilts and azimuth orientations independently. Taguchi's method is a well-known optimization approach in manufacturing processes [4]. Herein, orthogonal array (OA), which is not to be confused with orthogonal antenna array, is used to select a reduced set of representative parameter combinations to be tested from the full search space. The number of parameter combinations determines the number of experiments being carried out and evaluated against a performance measure to find the maximum. In our case, an experiment corresponds to a simulation run in the network planning environment. Using all the experiments' results, a candidate solution is found and the process is repeated until a desired criterion is fulfilled.

The major advantage of Taguchi's method over other optimization algorithms is the ability to consider the interactions existing among the configuration parameters. Moreover, it explores the search space in a scientifically disciplined manner unlike metaheuristic methods such as local search algorithms. On the other hand, the main limitation of Taguchi's method is the need of constructing an OA having number of columns equal to the number of configuration parameters which may not be possible in practice if the number of parameters is quite large.

In this paper, a nearly orthogonal array (NOA) is proposed to be used in Taguchi's method for the first time instead of OA. NOA is easier to construct and has statistical properties comparable to those of OA. NOA does not only offer more flexibility regarding the number of configuration parameters and experiments, but also allows a joint optimization of the parameters which is the main focus in this work.

The paper is organized as follows. The cellular network optimization problem is presented in section II and the iterative optimization procedure based on Taguchi's method using NOA is explained in section III. In section IV, the LTE downlink system model is discussed and the proposed optimization approach is evaluated in section V. The paper is then concluded in section VI.

II. CELLULAR NETWORK OPTIMIZATION PROBLEM

In this section, the optimization problem is presented along with the configuration parameters and optimization function. The optimization is carried out offline in a network planning environment.

Consider a cellular LTE network where the antenna tilt Θ_c and azimuth orientation Φ_c of each sector $c = 1, \ldots, C$ need to be optimized. Hence, the total number of configuration parameters is $2 \cdot C$. Let the variable x_t where $t = 1, \ldots, 2 \cdot C$ designate one of the configuration parameters and γ_c be any performance measure for cell c. Without loss of generality, γ_c is defined in this work to be the 5%-tile of the cumulative distribution function (CDF) of UE throughput in a cell c denoted by $\gamma_{c,5\%}$. This is a quite common criterion to evaluate the cell edge user performance [1].

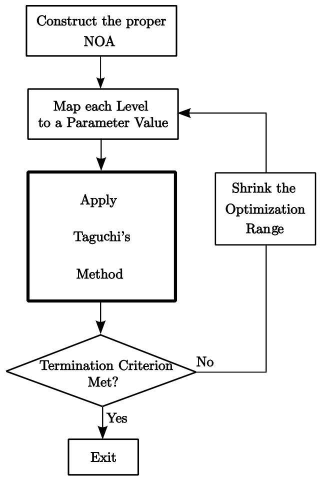

Fig. 1. The modified iterative optimization procedure based on Taguchi's method using NOA rather than OA.

To account for the interactions among the configuration parameters, the performance measures of all cells are bundled into one optimization function $y(\gamma_1, \ldots, \gamma_C)$. The optimization problem is to find jointly the antenna tilt and azimuth orientation of each sector c maximizing $y(\gamma_1, \ldots, \gamma_C)$ and is formulated as

$$\{x_1^{(\text{opt})}, \ldots, x_{2\cdot C}^{(\text{opt})}\} = \underset{x_1,\ldots,x_{2\cdot C}}{\arg\max}\; y(\gamma_1, \ldots, \gamma_C). \qquad (1)$$

The definition of the function $y(\gamma_1, \ldots, \gamma_C)$ has a prominent role in achieving the desired network performance. The aim of the optimization is to improve the performance measure $\gamma_{c,5\%}$ for each cell c while keeping fair user experience (outage probabilities) among cells. For this reason, $y(\gamma_1, \ldots, \gamma_C)$ is defined as in [3] to be the harmonic mean (HM) of $\gamma_{c,5\%}$ in a cell as

$$y(\gamma_1, \ldots, \gamma_C) = \text{HM}(\gamma_{c,5\%}) = \frac{C}{\sum_{c=1}^{C} \frac{1}{\gamma_{c,5\%}}}. \qquad (2)$$

The choice of HM rather than arithmetic mean is because HM mitigates more the impact of outliers and provides a more homogeneous user experience in the network. For more details, the reader is referred to [3].

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

In this section, the iterative optimization procedure based on Taguchi's method which is followed in [3], [6] is modified to include NOA rather than OA. The new proposed optimization approach is depicted in Fig. 1 and will be discussed in details in the following.

A. Construct the proper NOA

Originally, Taguchi's method uses a so-called OA which is an array containing a reduced set of N parameter combinations to be tested from the full search space [5]. 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 subsection III-B). Each parameter combination $i = 1, \ldots, N$ is tested in an experiment i where the function $y(\gamma_1, \ldots, \gamma_C)$ 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. However, constructing an OA with the latter property is challenging and might be computationally impossible if the number of configuration parameters $2 \cdot C$ is large. For this reason, the OA is replaced by a NOA which relaxes this property in the construction. In a 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. A NOA can be constructed for any number $2 \cdot C$ of parameters and number N of experiments at the expense of considering partially the interactions among the configurations parameters.

TABLE I
An illustrative NOA$(8, 4, 3)$ with the measured responses and their corresponding SN ratios.

Experiment	x_1	x_2	x_3	x_4	Measured Response	SN Ratio
1	1	1	2	3	y_1	SN_1
2	1	2	1	1	y_2	SN_2
3	2	3	2	1	y_3	SN_3
4	2	1	1	2	y_4	SN_4
5	3	2	2	2	y_5	SN_5
6	3	3	1	3	y_6	SN_6
7	1	1	3	1	y_7	SN_7
8	1	2	3	2	y_8	SN_8

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 network, the total number of configuration parameters is $k = 2 \cdot C$. Thus, a NOA having $2 \cdot C$ columns should be constructed with a predefined number of experiments N and levels s. The first C columns can be used for the azimuth orientation parameters and the rest for the antenna tilt parameters. For clarity, an example of a small NOA$(8, 4, 3)$ having $N = 8$ which is approximately 9 times smaller than $3^4 = 81$ possible experiments, $k = 4$ parameters and $s = 3$ levels is shown in Table I. In this case, we have four configuration parameters represented by $x_1, \ldots, x_4$ where each is tested at level $\ell = 1, 2, 3$. The impact of the number of experiments N and levels s on the performance of the proposed algorithm is studied later in the simulation section.

Various algorithms exist for constructing NOA. In this work, all NOAs are built using the algorithm described in [7].

B. Map each level to a parameter value

Let $\min_t$ and $\max_t$ be the minimum and the maximum feasible values for parameter x_t. In the first cycle $m = 1$, the center value of the optimization range for parameter x_t is defined as

$$V_t^{(m)} = \frac{\min_t + \max_t}{2}. \quad (3)$$

In any cycle m, the level $\ell = \lceil s/2 \rceil$ is always 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

$$\beta_t^{(m)} = \frac{\max_t - \min_t}{s+1}. \quad (4)$$

In cycle m, the mapping function $\mathrm{f}_t^m(\ell)$ for a level ℓ to a dedicated value of the parameter x_t can be described as follows

$$\mathrm{f}_t^m(\ell) = \begin{cases} V_t^{(m)} - (\lceil s/2 \rceil - \ell) \cdot \beta_t^{(m)} & 1 \le \ell \le \lceil s/2 \rceil - 1 \\ V_t^{(m)} & \ell = \lceil s/2 \rceil \\ V_t^{(m)} + (\ell - \lceil s/2 \rceil) \cdot \beta_t^{(m)} & \lceil s/2 \rceil + 1 \le \ell \le s. \end{cases} \quad (5)$$

For instance, consider an antenna tilt parameter x_1 having a minimum value $\min_1 = 0^\circ$ and a maximum $\max_1 = 15^\circ$. If x_1 is tested with three levels, i.e., $s = 3$, level 2 is mapped in first cycle to $(0^\circ + 15^\circ)/2 = 7.5^\circ$, level 1 to $7.5^\circ - \beta_1^{(1)} = 3.75^\circ$ and level 3 to $7.5^\circ + \beta_1^{(1)} = 11.25^\circ$. The values of $V_c^{(m)}$ and $\beta_c^{(m)}$ are updated at the end of each cycle if the termination criterion (see section III-E) is not met.

C. 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 signal-to-noise ratios (SNRs) of the received signals. The SN ratio is computed for each experiment i as

$$\mathrm{SN}_i = 10 \cdot \log_{10}(y_i^2) \text{ [dB]}. \quad (6)$$

Then, the average SN ratio is computed for each parameter and level. In the example of Table I, the average SN ratio of x_2 at level $\ell = 1$ is computed by averaging in dB the SN ratios of the experiments where x_2 is tested at level 1, i.e., $\mathrm{SN}_1, \mathrm{SN}_4$ and SN_7. The best level of each parameter is the level having the highest average SN ratio. According to the mapping function $\mathrm{f}_t^m(\ell)$, the best setting of a parameter x_t in cycle m is found and denoted by $V_t^{(\mathrm{best},m)}$.

D. Shrink the Optimization Range

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

$$V_t^{(m+1)} = V_t^{(\mathrm{best},m)}. \quad (7)$$

It may happen that the best value of a parameter x_t found in cycle m is close to $\min_t$ or $\max_t$. In this case, there is 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 $\xi < 1$:

$$\beta_t^{(m+1)} = \xi \beta_t^{(m)}. \quad (8)$$

E. Check the Termination Criterion

With every cycle, the optimization range is reduced and the possible values of a parameter are 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 and parameter-specific threshold ϵ_t, i.e.,

$$\beta_t^{(m)} < \epsilon_t \ \forall t. \quad (9)$$

IV. LTE System Model

The LTE downlink system model is considered for evaluation. A static system level simulator is used to generate the results in the following.

A. Layout and Parameters

The cellular network is composed of $C = 33$ cells located in an area of 4×4 km, see Fig. 2. This network layout has been proposed in [8]. Every cell c is served by one of the three sectors of an enhanced Node B (eNodeB). The maximum eNodeB transmission power is 40 W or equivalently 29 dBm per physical resource block (PRB), i.e., 10 MHz system bandwidth with 50 PRBs. The path loss offset and exponent are set to 128.1 dB and 3.76, respectively. The penetration loss is assumed to be 20 dB and the thermal noise power is -114 dBm on a single PRB. The standard deviation of the shadowing is set to 8 dB and the de-correlation distance to 50 m. The transmit antennas of eNodeBs are mounted at height $h_{\mathrm{BS}} = 30$ m whereas a UE is assumed to be located at ground, i.e., UE height is zero. Moreover, the number of UEs is assumed to be 50 per cell irrespective of the cell size. The transmit antenna pattern of an eNodeB is modeled in 3-

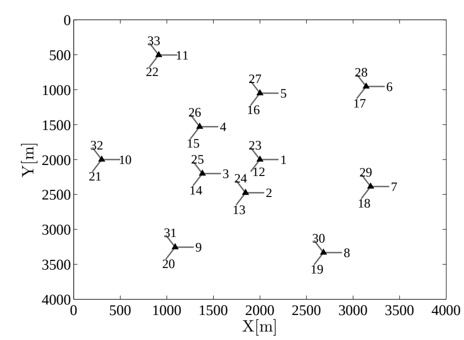

Fig. 2. Heterogeneous network with cells of different coverage areas.

dimensions (3D). It is approximated using the model defined in [9] by summing up the azimuth and vertical patterns. The antenna parameters are according to those recommended by 3GPP in [1] and summarized in Table II.

B. Calculation of UE throughput

We assume a resource fair scheduler where each UE is served using a single PRB. The signal-to-interference-noise ratio (SINR) of a UE is computed assuming a full load system where a UE receives interference from every other neighboring

TABLE II
ANTENNA MODEL AND PARAMETERS.

Parameter	Model
Azimuth pattern	$B_\phi(\phi) = -\min\left\{B_0, 12\cdot\left(\frac{\phi-\Phi}{\Delta_\phi}\right)^2\right\}$ $B_0 = 25$ dB, $\Delta_\phi = 70^\circ$ and Φ: azimuth orientation
Elevation pattern	$B_\theta(\theta) = -\min\left\{B_0, 12\cdot\left(\frac{\theta-\Theta}{\Delta_\theta}\right)^2\right\}$ $B_0 = 25$ dB, $\Delta_\theta = 9^\circ$ and Θ: tilt
3D antenna pattern	$B(\phi,\theta) = -\min\{-\left[B_\phi(\phi)+B_\theta(\theta)\right], B_0\}$
Antenna gain	14 dBi

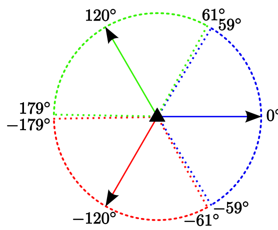

Fig. 3. Optimization range for each of the three transmit antennas of a single eNodeB.

cell [3]. The throughput R of a UE can be approximated using Shannon's equation as

$$R = W_{\text{eff}} \cdot B \cdot \log_2\left(1 + \frac{\text{SINR}}{S_{\text{eff}}}\right) \text{ [kbps]} \quad (10)$$

where $W_{\text{eff}} = 0.88$ and $S_{\text{eff}} = 1.25$ are the bandwidth and SINR efficiency factors [10], respectively, and $B = 180$ kHz is the bandwidth occupied by one PRB. The metric $\gamma_{c,5\%}$ is computed by taking the 5%-tile of R distribution in cell c.

V. SIMULATION RESULTS

The joint optimization of the antenna azimuth orientation and tilt is solved using the modified optimization procedure applying NOA. Moreover, the proposed solution is compared to the one obtained by optimizing the azimuth orientation and tilt independently in two subsequent runs using the same procedure.

A. Algorithm parameters

To cover the full range of the azimuth orientation of one 120° sector, i.e., 3 sector site, the maximum and minimum values of the azimuth orientation Φ of an antenna are determined by adding and subtracting 59° from its default setting as depicted in Fig. 3. For the tilt Θ, the minimum value is set to 0° and the maximum value to 15°. Moreover, the reduction factor ξ is set to 0.85 as a trade-off between performance and complexity, and ϵ_t is set to 0.01 for each optimization which is low enough to allow convergence of the results.

B. NOA Versus OA

In principle, OA considers more than a NOA the interactions existing among all parameters. However, in our optimization problem, it is enough to consider the interactions among the sector of interest and its close neighbors that are more influential than others. Thus, though a NOA considers partially the interactions among parameters, it is expected to have statistical properties that are good enough for the optimization problem and comparable to those of OA. This is illustrated in Fig. 4 which displays the CDFs of the 5%-tile $\gamma_{5\%}$ of the UE throughput distribution in a cell obtained by optimizing the tilts only using an OA and a NOA having the same number of experiments and levels, i.e., the azimuth orientations are kept to default settings as in Fig. 2. The HM($\gamma_{c,5\%}$) achieved by using an OA and a NOA are 73.83 kbps and 73.33 kbps, respectively. Therefore, NOA and OA yield almost to the same performance. This is also seen in Fig. 4 that shows a slight degradation in performance if NOA is used rather than OA.

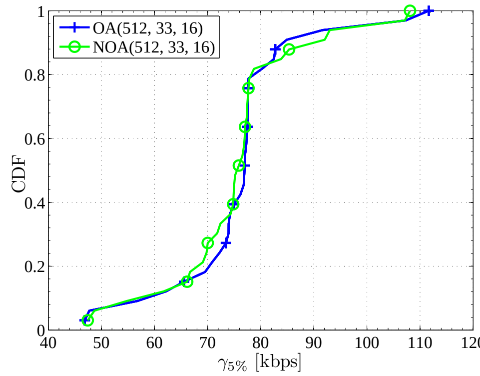

Fig. 4. CDFs of $\gamma_{5\%}$ obtained by optimizing the tilts of the sectors using an OA and a NOA having same parameters.

C. Performance Versus Complexity of the Algorithm

In the following, we will consider the joint optimization of both azimuth and tilt. The performance of the proposed algorithm depends on the NOA used. As the computational complexity is proportional to the number of carried-out experiments, we define the complexity metric of the algorithm to be the number N of experiments. In addition, we define an accuracy metric to be the number of times that each level is tested in one cycle for any parameter x_t. Since the NOAs are constructed using an algorithm that uses balanced columns [7], i.e., each level is tested the same number of times in the considered NOAs, the accuracy of the algorithm is computed by taking the ratio between N and the number of levels s.

Fig. 5 shows the HM($\gamma_{c,5\%}$) obtained by jointly optimizing the antenna azimuth orientations and tilts as a function of the complexity of the algorithm. For fixed $s = 9$, the performance of the algorithm tends to improve as the complexity of the algorithm increases. Interestingly, the HM($\gamma_{c,5\%}$) achieved by the NOA$(288, 66, 9)$ is higher than those obtained by NOA$(522, 66, 9)$ and NOA$(1044, 66, 9)$ though it has a lower complexity metric. Moreover, to compare the performance between NOAs having different number of levels, we pick up NOA$(288, 66, 9)$ and NOA$(512, 66, 16)$ as they have the same accuracy metric equal to $288/9 = 512/16 = 32$. For the same accuracy metric, a slightly higher performance is achieved using the NOA having 9 levels instead of 16.

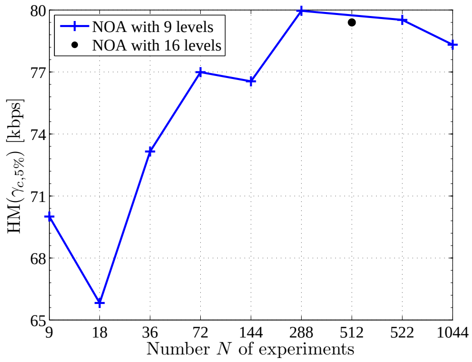

Fig. 5. Comparison between the performance of different NOAs having various complexity and accuracy metrics.

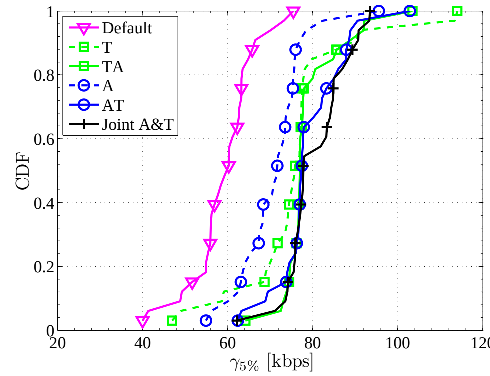

Fig. 6. CDFs of $\gamma_{5\%}$ for various optimization methods.

D. Joint Versus Independent Optimization

The joint optimization of both antenna parameters and the independent optimization of each of them have the same number of experiments, and therefore, same complexity. However, in case of joint optimization, the algorithm is running once using a NOA having $2 \cdot C$ columns rather than twice with a NOA having C columns. Hence, the joint optimization reduces the computational complexity by a factor of two as the complexity is binded to the number of experiments rather the number of configuration parameters. Moreover, the joint optimization explores the dependencies among the antenna parameters. To visualize the gain achieved by the joint optimization, denoted by "Joint A&T", we will compare its antenna configurations acquired using NOA$(288, 66, 9)$ to those obtained by optimizing the tilt and azimuth independently using NOA$(288, 33, 9)$.

Let us denote the optimization of the tilts assuming default azimuth orientations, see Fig. 2, by "T" and the optimization of the azimuth orientations given the optimized tilts by "TA". Similarly, we denote the optimization of the antenna azimuth orientations assuming a tilt of $4°$ for all sectors by "A" and the optimization of the tilts given the optimized azimuths by "AT". Moreover, we denote the default azimuth orientations depicted in Fig. 2 and optimal constant tilt of $4°$ by "Default".

The CDFs of $\gamma_{5\%}$ in a cell are depicted in Fig. 6 for various optimization methods. The HM($\gamma_{c,5\%}$) values of optimization methods "Default", "T", "TA", "A", "AT" and "Joint A&T" are 58.1 kbps, 73.8 kbps, 78.2 kbps, 70.01 kbps, 78.3 kbps and 80.0 kbps, respectively. Therefore, the joint optimization provides a gain of around 2.2% if compared to "TA" and "AT", and around 8.5% if compared to "T". Moreover, the joint optimization has half the computational complexity of "TA" and "AT" as the antenna azimuth orientations and tilts are optimized at the same time.

VI. Conclusion

In this paper, we have presented an iterative algorithm based on Taguchi's method that jointly optimizes the antenna azimuth orientations and tilts of eNodeBs. The method uses NOA instead of OA as it provides more flexibility regarding the number of configuration parameters and experiments and has statistical properties that are comparable to OA. Simulation results in LTE downlink have shown that an additional user throughput gain can be achieved if both antenna parameters are optimized jointly rather than independently. Moreover, the joint optimization reduces the computational complexity by a factor of two if compared to the independent optimization methods. As the proposed optimization algorithm allows any kind of parameter combinations, it can easily be extended to optimize different cell-specific radio network parameters jointly such as the power control parameter P_0 used to control the SNR target of a UE in uplink and the path loss compensation coefficient α.

References

[1] 3GPP, "Physical layer aspects for evolved universal terrestrial radio access (UTRA)," TR 25.814, Sophia-Antipolis, France, Tech. Rep., 2006.

[2] O. N. C. Yilmaz, S. Hämäläinen, and J. Hämäläinen, "Analysis of antenna parameter optimization space for 3GPP LTE," in *IEEE Vehicular Technology Conference*, Anchorage-Alaska, September 2009.

[3] A. Awada, I. Viering, B. Wegmann, and A. Klein, "Optimizing radio network parameters of Long Term Evolution systems using Taguchi's method," *submitted to IEEE Transactions on Vehicular Technology*, October 2010.

[4] R. Roy, *A Primer on the Taguchi Method.* Society of Manufacturing Engineers, 1990.

[5] A. S. Hedayat, N. Sloane, and J. Stufken, *Orthogonal Arrays: Theory and Applications*. New York:Springer-Verlag, 1999.

[6] W.-C. Weng, F. Yang, and A. Elsherbeni, "Linear antenna array synthesis using Taguchi's method: A novel optimization technique in electromagnetics," *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 3, pp. 723–730, March 2007.

[7] H. Xu, "An algorithm for constructing orthogonal and nearly-orthogonal arrays with mixed levels and small runs," *American Statistical Association and the American Society for Quality*, vol. 44, no. 4, Technometrics, November 2002.

[8] J. Turkka and A. Lobinger, "Non-regular layout for cellular network system simulations," in *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, September 2010.

[9] R. Hoppe, "Comparison and evaluation of algorithms for the interpolation of 3D antenna patterns based on 2D horizontal and 2D vertical patterns," AWE Communications GmbH, V 1.0, Tech. Rep., 2003.

[10] P. Mogensen, W. Na, I. Kovacs, F. Frederiksen, A. Pokhariyal, K. Pedersen, T. Kolding, K. Hugl, and M. Kuusela, "LTE capacity compared to the shannon bound," in *IEEE Vehicular Technology Conference*, 2007, pp. 1234–1238.