LTE Access Network Planning and Optimization: A Service-Oriented and Technology-Specific Perspective

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***Abstract*— With the emergence of new technologies and services, it is very important to accurately identify the factors that affect the design of the wireless access network and define how to take them into account to achieve optimally performing and cost-efficient networks. Till now, most existing efforts have been focused the basic access capability. This article describes a way to deal with the trade-offs generated during the LTE Access network design, and presents a service-oriented optimization framework that offers a new perspective for this process with consideration of the technical and economic factors of this kind of networks. We propose a mixed integer programming model with the use of the method of the Pareto front and Multiobjective Tabu Search. An example of deployment is presented.**

I. INTRODUCTION

Long Term Evolution (LTE) describes the standardization work by the *Third Generation Partnership Project (3GPP)* to define a new high-speed radio access method for mobile communication systems [1].

In order to successfully compete to other existing and future wireless, cellular and wire-line services, the network designers need to fully consider the technical constraints that influence the whole design process of this kind of networks. The number of combinations of network elements and parameters that can be configured (e.g. antenna tilt, azimuth, base station location, power) constitutes the solution space of the design process. The size of this space determines the degree of complexity of finding appropriate solutions. In *Wireless Metropolitan Area Network (WMAN)* scenarios like LTE, the number of options is high, so it is very unlikely that the optimal network configuration can be found using a manual method [2].

Base station (BS) location, antenna azimuth and tilt optimization has been widely investigated as main part of advanced network planning and optimization tools, especially in the case of UMTS, CDMA based networks [3][4][5][6] and also mobile WiMAX [2]. They focus on special cases and no works specialized on LTE have been found. In addition, the existing literature does not consider a precise formulation and computationally efficient methodology on multiobjective problems. Until now, most existing efforts have been focused on an access-oriented design, which may not be a good solution because of the following reasons. Some of these designs may not be efficient for areas with high number of users and with different service demands, which often result in a bottleneck for the rest of the network. In addition, for many existing designs that are developed to gain basic access, the customer may not be able to obtain the desired *quality-of-service (QoS)*. Also, the access-oriented design may not be fair to the provider who develops the infrastructure, because the service provider only earns the access fee, which is usually paid monthly and is relatively low compared to the deployment cost.

With the increasing need of supporting new services and applications for different scenarios or multiple objectives, the problem of wireless network architecture design becomes too large in scope to be handled efficiently with a single technique. This article presents a service-oriented optimization framework that provides a clear and comprehensive description of different options and solutions to achieve an optimal network configuration. Section I, explains the impact of the LTE physical technology on the network architecture design. Then and insight on the network planning and optimization process is given within a LTE context, and we give an economic perspective to the calibration of the factors in the cost function. Third, we describe a way to deal with the trade-offs generated during the network architecture design. Finally, an example of deployment cost analysis and performance evaluation is given.

II. LTE PHYSICAL TECHNOLOGY

LTE uses new multiple access schemes on the air interface: *OFDMA (Orthogonal Frequency Division Multiple Access)* in downlink and *SC-FDMA (Single Carrier Frequency Division Multiple Access)* in uplink. OFDMA is a physical technology that supports several key features necessary for delivering broadband services, for example, scalable channel bandwidths, high spectral efficiency, interference and multipath tolerance due to subcarrier orthogonality and long symbols. SC-FDMA is a new single carrier multiple access technique which has similar structure and performance to OFDMA. It uses single carrier modulation and orthogonal frequency multiplexing using DFT-spreading in the transmitter and frequency domain equalization in the receiver.

In both cases, subcarriers are grouped into *resource blocks (RBs)* of 12 adjacent subcarriers with an intersubcarrier spacing of 15 kHz [1]. Each RB has a time slot duration of 0.5 milliseconds, which corresponds to 6 or 7 symbols. The smallest resource unit that a scheduler can assign to a user is a *scheduling block (SB),* which consists of two consecutive RBs, spanning a subframe time duration of 1 millisecond. One LTE

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radio frame consist of 10 ms. All SBs belonging to a single user can be assigned to only one *modulation and coding scheme (MCS)* in each scheduling period.

Establishing a reliable connection for the users in LTE is not as easy as just assigning enough transmission power for each SB. The reason is that there will probably be a certain level of interference between users depending on the position and the number of BSs and the resources available for each of them. Within the same frequency band, some users interfere each other and some others do not. This particular matrix interference model of LTE should be taken into account when planning and optimizing a network.

III. Network Planning and Optimization

In general, the network design process consists of two parts, *planning* and *optimization*, represented in Figure 1. The concept of planning involves finding the quality of the network performance for a given configuration, whereas optimization refers to finding the configuration for which the network quality is optimal. There are several methods and algorithms in the existing literature to perform the latter task. The cellular network optimization problem is NP-hard as it is very difficult to find a theoretical optimum in polynomial time [3]. Meta-heuristic algorithms seem a common approach, since they can provide close to optimal solutions in reasonable time [3][4][5].

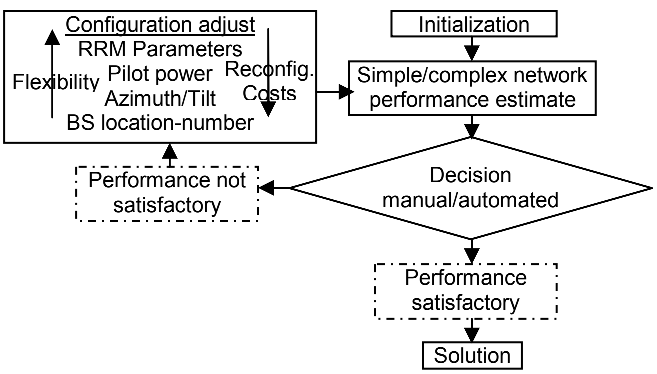

Figure 1. Network Planning and Optimization.

The process of Figure 1 may be differently implemented depending on the network deployment stage. The first stage is the actual *definition of the network*, where different criteria is defined, including description of the expected traffic, services pilot power, deployment scenarios, and system capacity requirements. Then, a first manual network adjustment based on data collection and propagation model tuning can be done.

A following *detailed network planning and optimization phase* normally makes use of a tool for capacity calculation to predict the network performance of each configuration tested for different parameters with high reconfiguration costs e.g. site location-number, tilt or azimuth, which is the case evaluated in this work. The tool should support traffic, propagation, *Radio Resource Management (RRM)* models, and other parameters. The objective of this tool is to calculate *Key Performance Indicators (KPI)* that can represent the quality of a certain LTE network configuration. Monte Carlo simulation is often used in cellular network planning and optimization due to the high computational load that dynamic simulation would require in an iterative process that may need thousands of simulations [2].

Let us model an LTE network as a set of candidate *N* sectors $S = \{S_0, S_i, S_j \ldots S_{N-1}\}$ with users associated to each of them ($MS_i = \{0, m \ldots M_i - 1\}$). During simulation, a *channel quality indicator (CQI)* helps to set the adequate MCS for communication in order to fulfill the service requirements of each user. It represents a feedback of the *Mobile Station (MS)* in previous iterations. Link level simulation results are imported in the form of *Look Up Tables (LUT)* for throughput calculation, which should include effects of different wireless channels and effects like fading. The throughput of the sector is calculated, as shown in (1), from the number of subcarriers per SB, η_s (12 in this case), and the bearer efficiency $\eta_{B(CQIm)}$ in terms of bits/subcarrier. Each bearer corresponds to a certain MCS (see Table). T_{frame} is the frame duration (10ms).Then, the LUT provides the *BLER (Block Error Rate)* values which is a function of the bearer B used and the CINR level of the studied resource r from the given set of available *SB {1, 2,…,R}*. The integer variable s_i indicates if sector S_i is selected in the solution, and $v_{m,r}$ represents the LTE matrix-like interference model by indicating if MS *m* is using SB *r*.

$$T_i = \sum_{m=1}^{M_i} \sum_{r=1}^{R} \left(\frac{\eta_s \cdot \eta_{B(CQI_m)}}{T_{frame}} \cdot \left(1 - BLER_{(B(CQI_m),CNIR_r)}\right) \right) \cdot v_{m,r} \cdot s_i \tag{1}$$

Table 1 LTE Profiles

Radio Bearer index	Modulation	Channel Coding Rate	Bearer Efficiency, η_B (bits/subcarrier)	CINR Threshold (dB)
1	QPSK	0.0761719	0.1523	-6.5
2	QPSK	0.117188	0.2344	-4
3	QPSK	0.188477	0.377	-2.6
4	QPSK	0.300781	0.6016	-1
5	QPSK	0.438477	0.877	1
6	QPSK	0.587891	1.1758	3
7	16QAM	0.369141	1.4766	6.6
8	16QAM	0.478516	1.9141	10
9	16QAM	0.601563	2.4063	11.4
10	64QAM	0.455078	2.7305	11.8
11	64QAM	0.553711	3.3223	13
12	64QAM	0.650391	3.9023	13.8
13	64QAM	0.753906	4.5234	15.6
14	64QAM	0.852539	5.1152	16.8
15	64QAM	0.925781	5.5547	17.6

The way resources are reused in the technology studied play an important role in the network design process. This should be represented in the cost function to be minimized by the optimization algorithm, and it is described next section.

The processes described in the detailed planning and optimization phase are considered *off-line* since the optimization loop does not include the real network. Simulation is used instead as it would be unfeasible to iteratively reconfigure some parameters that need physical changes. A third *operation and maintenance phase* can make use of *on-line* optimization by using real measurement data, and optimize parameters that can be reconfigured by software, such as RRM.

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A. Service-Oriented Network Design – An Economic View

An economic perspective can be given to the design activity as follows:

$$Profit = ProfitEst - CostAdj \quad (1)$$

In this model, some expected profits can be estimated during the network definition phase, and represented in *ProfitEst* in (1). This factor includes ideal estimations for the profit in a business case and it considers license acquisition costs, and installation and maintenance costs of the core network. The optimization process tries to minimize a cost adjustment factor, *CostAdj*, which includes access network costs (F_{costs}) and some penalty costs for the performance of a particular network configuration (F_{pen} see (2)). These penalties balance the ideal estimations done in *ProfitEst*. This model gives a picture of the possible real profit for the operator.

The optimization algorithm test different configurations for different parameters - e.g. BS location from a set of candidate sites, antenna tilt or azimuth - that need to be discrete, and the resolution chosen will determine the size of the solution space. The algorithm stops when the cost function based on the infrastructure costs and the a series of penalty functions based on some criteria $(G = \{G_0, G_h,\ldots G_{H-1}\})$, meet the needs of the service provider (See (2)).

$$\min\{CostAdj\} = \min\{F_{costs}, \sum_{h=0}^{H-1} F_{pen_h}\} \quad (2)$$

The different criterion values are evaluated over all the users, which may be penalized differently. A binary variable d_h^m in {0, 1} indicates if user m is evaluated by the cost function related to criterion (3). For example, the MSs will be either in transmission UL or reception DL state and the designer may want to penalize differently these two states.

$$F_{pen_h} = \sum_{i=0}^{N-1}\sum_{m=0}^{M_i-1} f_{pen_h}^m \cdot d_h^m \quad (3)$$

A threshold-based function avoids the excessive influence of very good or very bad users. Maximal penalty is applied when the value of the criterion t_h^m from user m is smaller than a lower bound T_{min} and no penalty exists when it is higher than a threshold T_{max}. In between these two values the function is linearly decreasing as (4) indicates.

$$f_{pen_h}^m = f_{pen_h}^m(t_h^m) = \begin{cases} 0 & if(T_{\max_h}^m < t_h^m); \\ f_{\max_h}^m \cdot \left(\dfrac{t_h^m - T_{\max_h}^m}{T_{\min_h}^m - T_{\max_h}^m}\right) & if(T_{\min_h}^m < t_h^m \le T_{\max_h}^m); \\ f_{\max_h}^m & if(t_h^m \le T_{\min_h}^m); \end{cases} \quad (4)$$

Furthermore, the different criteria can be grouped according to the main KPIs. We consider infrastructure costs, CINR (C), throughput (T) in a three objective minimization problem as shown in (5). Different subsets of criteria $(G', G'' \subset G)$ related to the particular KPI nature will determine different constraints to the problem, e.g. different throughput in services or channel profiles, which are shown in (6-8) and described below.

$$\min\{\sum_{i=0}^{N-1} f_{costs}^i \cdot s_i,\ \sum_{i=0}^{N-1}\sum_{m=0}^{M_i-1}\sum_{h'=0}^{H'-1} f_{pen(C)}^m \cdot d_{h'}^m,\ \sum_{i=0}^{N-1}\sum_{m=0}^{M_i-1}\sum_{h''=0}^{H''-1} f_{pen(T)}^m \cdot d_{h''}^m\} \quad (5)$$

subject to:

$$1 < \sum_{h'=0}^{H'-1} d_{h'}^m \le 2 \qquad \forall m \quad (6)$$

$$1 < \sum_{h''=0}^{H''-1} d_{h''}^m \le 2 \cdot Ser_{\max} \qquad \forall m \quad (7)$$

$$s_i, d_{h'}^m, d_{h''}^m \in \{0,1\} \qquad \forall m, s_i, h', h'' \quad (8)$$

- F_{costs} represents the aggregate of *CapEx (Capital Expenditure)* and *OpEx (Operational Expenditure)* in an LTE access network and no special penalty function is applied. This method represents a financial model over suitable return periods. One example for 5 years used for our numerical results is shown in Table 2. This economic study has been done for a typical BS costs found in [2] and [7].

TABLE 2 EXAMPLE OF INFRASTRUCTURE COSTS

Year		1	2	3	4	5
Site (k€)	CapEx	20	17.72	15.70	13.82	12.16
	OpEx	0.75	0.75	0.75	0.75	0.75
Sector (k€)	CapEx	1.5	1.33	1.18	1.06	0.95
	OpEx	0.48	0.48	0.48	0.48	0.48

- $F_{pen(C)}$ represents the wireless connection by penalizing the effective CINR perceived by the MSs over all SBs. The thresholds T_{min} and T_{max} can be set to the CINR thresholds for the minimum and maximum MCS in the LUTs (Table 1). The assumptions about the expected users made by the network provider in the network definition, such as the user profile and speed, influence the final network design. Different MSs profiles may require different costs for the system due to the different channel conditions. Therefore the network designer may penalize each of them differently (note that different LUTs will apply with different thresholds). Table 3 shows the T_{min} and T_{max} thresholds for three different user profiles.

TABLE 3 CINR THRESHOLDS

Modulation	CINR (dB) Fixed user	CINR (dB) Pedestrian user	CINR (dB) 50K/h user
QPSK1/12	-6.5	-4.3	-1.7
64QAM11/12	17.6	19.3	22.6

Since in a Monte Carlo simulation each user will be in UL or DL (or both) and in certain channel conditions at each snapshot, constraint (6) indicates that a maximum of two penalty functions are applied per user. The maximum penalty F_{max} can be set in economic terms related to users. For example, in a user with low CINR, a penalty related to the user connection tariff and annual subscription is applied (Table 4).

TABLE 4 USER ECONOMIC PARAMETERS

Year	1	2	3	4	5
Annual subscription (€)	500	440	386	337	293
Connection Tariff (€)	50	45	41	37	33
Mb allowance (€)	500	450	410	380	360
Other charges (€)	62	56	50	45	41

Different users can have the same "connectivity", by having similar average CINR over their set of SBs, but they may require different number of SBs and thus, different final throughput. A separate *Quality of Service (QoS)* indicator is needed in the cost function.

• $F_{pen(T)}$ is the penalty function for the MSs throughput. T_{min} and T_{max} can be set to the maximum and minimum throughput request for each service (e.g. in Table 5). The use of this factor in the cost function provides a more flexible network design in which different business plans, based on certain services for some areas, can be applied. Constraint (7) indicates that the MS will use at least one service DL or UL, and a maximum of services, Ser_{max} (4 in this case) in both UL and DL which can be penalized in different ways.

TABLE 5 SERVICE REQUIREMENTS THRESHOLDS

Name	Maximum Throughput (DL) (kbps)	Minimum Throughput (DL) (kbps)	Maximum Throughput (UL) (kbps)	Minimum Throughput (UL) (kbps)
Web	128	64	64	32
FTP	1,000	0	100	0
Video	64	64	64	64
VoIP	12.2	12.2	12.2	12.2

The maximum penalty F_{max} can be set to user economic parameters, e.g. a bad QoS will be reflected in losses in the Mb allowance and other charges related to services (See Table 4).

B. Multiobjective Perspective

The optimization problem can be solved by using the solutions of the Pareto front [8], where the network provider must select a posteriori the most appropriate ones according to some policies. Each one of the obtained solutions will represent a certain optimal trade-off between the different factors in the cost function. Figure 2 illustrates the solutions in an example of a two-objective minimization problem.

The solutions are iteratively calculated by an optimization algorithm in three main stages:

• Search front expansion. The algorithm searches for neighbor solutions in the current search front. In this work, a neighbor solution is obtained by removing/changing the position of one BS, or by changing the antenna azimuth/tilt.

• Update of the optimal Pareto front. The non-dominated solutions of the neighborhood are selected.

• Selection of the new search front. This is done according to the optimization algorithm methodology. In this work we use Multiobjective Tabu Search. This algorithm maintains two lists, one with forbidden moves previously performed (Tabu List), and other list with the neighbor solutions that helps finding the optimal front of solutions [2] [8].

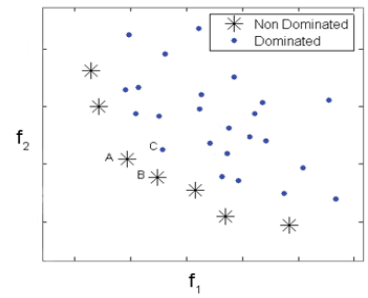

Figure 2. Example of pareto front.

IV. EXPERIMENTAL EVALUATION

An example of LTE network design process has been performed over a rectangular area of (5km × 4km). Three different types of traffic pattern have been used to simulate the uneven distribution of the users across the scenario in a dense urban, urban and suburban traffic: with a density of 80 $user/km^2$, 40 $user/km^2$ and 10 $user/km^2$, respectively that account for aproximately 700 users per snapshot. The rest of parameters are shown in Table 6.

TABLE 6 SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
Candidate Sectors	60	CPE Antenna Gain	0dBi
Carrier Frequency	2GHz	CPE Antenna Pattern	Omni
Channel Bandwidth	10MHz	CPE Noise Figure	5dB
BS TX Power	43dBm	CPE Cable Loss	0dB
BS Antenna Gain	18dBi	σ(Shadow Fading)	8dB
BS Noise Figure	4dB	Intra BS correlation	0.7
BS Cable Loss	3dBm	Inter BS correlation	0.5
CPE Tx Power	23dBm	Path Loss Model	RayTrace

The MSs have different service requirements (Web browsing, FTP download, VoIP and H.263 video) and their profile is generated as stationary, pedestrian or 50 km/h users.

Different configurations are searched by a Tabu Search, which gets optimal values for Sector position and number, antenna tilt and azimuth - in intervals of 10^0 -. The Tabu list size is chosen empirically during the initial tuning. The economic parameters have been set to the ones presented I Section II-A. The exception are the sites/sectors CapEx and OpEx, which may vary with the area e.g. establishment fee or maintenance. A final set of ten representative solutions is selected for the three-objective scenario, and shown in Table 6.

TABLE 6. THE 5 MOST REPRESENTATIVE SOLUTIONS OF THE PARETO FRONT

Solution	*Number of sectors*	F_{costs} *(100k€)*	$F_{pen(C)}$ *(100k€)*	$F_{pen(T)}$ *(100k€)*
1	10	3.56	2.41	1.29
2	12	4.60	1.15	2.67
3	9	3.02	2.27	1.96
4	8	2.24	3.59	3.86
5	12	5.40	1.87	1.95

Figure 3 shows which users fulfill the service requirements in a single snapshot in solution 1. In this solution, a low number of sectors results in medium infrastructure costs and low throughput penalties. Dense urban areas and indoor coverage benefit from this configuration. On the other hand, there are a number of MSs with low CINR levels concentrated at the edge of the coverage areas, where they may have a poor channel and also high interference. This solution can be a suitable option for service providers that plan a future expansion of the network according to the real user demands.

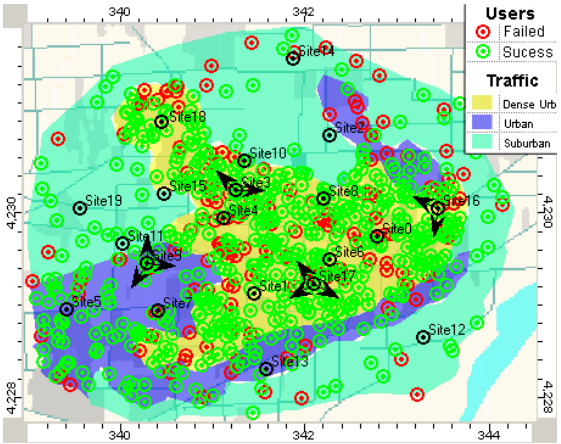

Figure 3. Snapshot in solution 1. Traffic maps and candidate sites are shown.

Note that the penalization is performed in different ranges and values, and depends on the network provider criteria as some objectives can be given more or less preference. Due to this fact diverse situations can be created.

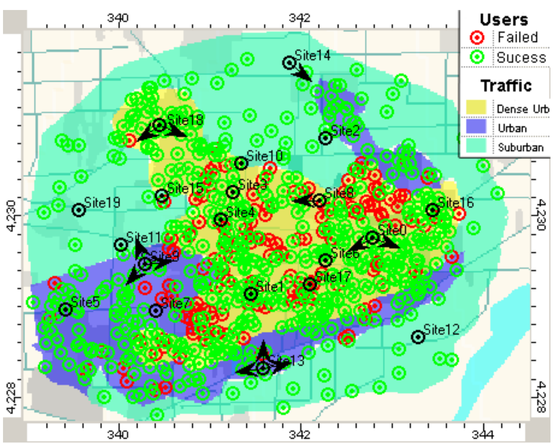

Figure 4. Snapshot in solution 2. Traffic maps and candidate sites are shown.

In solution 2 (Figure 4) some new users can gain connection to the network because of the addition of more sectors, and therefore some penalty values related to connection tariff or annual subscription are reduced. Note also that more sites are used. On the other hand, the throughput per user decreases specially in the MSs that are in dense urban area. Users that require services that are bandwidth consuming are more penalized and thus, this option would be suitable for network providers that prefer to ensure connectivity to as many users as possible than providing services with high bit rates.

Solution 1 represents a throughput enhancement strategy, while solution 2 characterizes a coverage extension strategy. Other solutions in Table 6 represent other tradeoffs. For example Solution 3 and 4 can reduce infrastructure costs at the expense more penalties in "connection" values, or even more degraded performance in the latter case. Solution 5 shows the best user performance, but with high infrastructure costs.

In order to fully understand the differences between solution 1 and 2, Table 7 shows the distribution of users in CINR levels. We can observe that the number of users that cannot access MCS for communication (CINR < -6.5dB) is slightly lower in solution 2. However, the main difference with solution 1 is the high number of users that have low CINR levels that only allow low MCSs. These users need more SBs to fulfill their service requirements and the frame is filled faster, thus, leaving other users with the same situation with lower throughput levels (higher penalties in throughput).

TABLE 7 NUMBER OF USERS AT DIFFERENT REFERENCE CINR

Solution	CINR < -6.5 dB	CINR >= -6.5 dB	CINR >= 6.6 dB	CINR >= 11.4 dB	CINR >= 17.5 dB
1	130	157	149	138	113
2	122	179	146	132	108

V. CONLUSIONS

This article presents a service-oriented optimization framework that offers the service provider a comprehensive, detailed and clear description of different scenarios during the network architecture design process so that the most suitable solution can be found.

The results of the LTE scenario analyzed in this article highlight the benefits of the described optimization framework, as it can provide valuable help to the service provider even in medium sized scenarios. The accuracy of the results relies on a network simulation tool and a previous economic study of several factors. Nevertheless, a multiobjective perspective can provide a good assistance when choosing a solution in any case by showing the trends of different configurations. We are working on extending the formulation of the optimization procedure for multihop communications.

REFERENCES

[1] "3GPP; Technical Specification Group Radio Access Network; Requirements for E-UTRA and E-UTRAN", 3GPP, March. 2008. [Online]: http://www.3gpp.org/ftp/Specs/html-info/36-series.htm.

[2] F. Gordejuela-Sanchez and J. Zhang, "Practical design of IEEE 802.16e networks: A mathematical model and algorithms," presented in *Global Communications Conference (GLOBECOM'08)*, 2008.

[3] E. Amaldi, A. Capone, and F. Malucelli, "Planning UMTS base station location: Optimization models with power control and algorithms," *IEEE Trans. Wireless Commun.*, vol. 2, no. 5, September 2003.

[4] S. Hurley, "Planning Effective Cellular Mobile Radio Networks," *IEEE Trans. Veh. Technol.*, Vol.51, No.2, pp. 243-253, March 2002.

[5] A. Eisenblätter, H. F. Geerdes, T. Koch, A. Martin, and R. Wessly, "UMTS radio network evaluation and optimization beyond snapshots," *Mathematical Methods of Operations Research*, vol. 63, pp. 1–29, 2005.

[6] I. Siomina, P. Värbrand, and D. Yuan. Automated optimization of service coverage and base station antenna configuration in UMTS networks. *IEEE Wireless Communications*, vol. 13. pp. 16-25, 2006.

[7] A.Hoikkanen, "Economics of 3G Long-Term Evolution: the Business Case for the Mobile Operator" in WOCN'07 pp 1-5, 2007.

[8] K. Jaffres-Runser, J. Gorce, and S. Ubeda, "QoS constrained wireless LAN optimization within a multiobjective framework," *IEEE Wireless Communication,* vol. 13, no. 6, pp. 26–33, December 2006.

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