Acceptance as a Success Factor for Planning Wireless Network Infrastructure

Alexander Engels, Melanie Neunerdt, and Rudolf Mathar
Institute for Theoretical Information Technology
RWTH Aachen University
D-52056 Aachen, Germany
Email: {engels, neunerdt, mathar}@ti.rwth-aachen.de

Harnan Malik Abdullah
Thai-German Graduate School of Engineering
King Mongkut's University of Technology North Bangkok
10800 Bangkok, Thailand
Email: malik@ti.rwth-aachen.de

***Abstract*—Availability of ubiquitous wireless services is taken for granted by most of the people. Therefore, network operators have to deploy and to operate large radio networks that, particularly, support broadband services and applications. One effect is a growing cell density, i.e., the number of required base stations increases. On the other hand, there are people that are afraid of getting harmed by electromagnetic radiation emitted by base stations or there are people that just dislike the prevalence of base station antennas. Both types of people's attitude refer to the field of user acceptance. A high deficiency in acceptance might lead to public disputes, political disputes, and negative economical consequences. To counteract such trends preventively, we propose a mathematical optimization model that allows for planning wireless network infrastructure with respect to user acceptance. While keeping technical and economical aspects as primarily considered planning criteria, we propose a multi-objective optimization model that takes into account user acceptance as an objective. Numerical results demonstrate effects of this approach compared to application of a conventional planning model.**

***Index Terms*—Radio network planning, technology acceptance, multi-objective optimization.**

I. INTRODUCTION

While present usage of wireless services can already run radio networks to the limit of their capacity, future demand for traffic-intensive applications such as video conferencing and online gaming is supposed to exceed network capacity significantly. Therefore, operators are permanently enhancing the performance capabilities of their wireless networks by either deployment of more base stations (BS), utiliztion of advanced transmission techniques, or launching fourth generation (4G) mobile networks such as LTE communication systems. LTE-based systems benefit from usage of sophisticated concepts such as OFDMA, adaptive coding and modulation schemes, and multi-antenna transmission [1], [2]. However, taking full advantage of the system capabilities requires optimal placement of base stations in the deployment phase and selection of optimal system configuration in the operational state.

Basically, the considered *Key Performance Indices (KPIs)* for network deployment and configuration are coverage, capacity, and economical performance [3], [4], [5]. Optimization with respect to more than one of these KPIs generally leads to multi-objective optimization problems [6]. Besides technical and economical aspects, electromagnetic compatibility (EMC) is an important issue. Although all relevant compatibility acts are met for deployment of system components, there remains still uncertainty of possible negative effects to health. Comprehensive studies and investigations were carried out to find and to verify scientifically reasonable threshold values that ensure harmlessness of electromagnetic impact to health [7], [8], [9]. However, there are still controverse discussions on that topic and particularly web 2.0 platforms are often used by scared people to distribute negative propaganda that might influence other people. On the other hand, user acceptance evidently is one of the key issues for successful launching of technical innovations such as new technical devices, services, and large scale technologies: Potential users that do not accept the innovation will never become supporters and customers for it [10], [11]. Therefore, operators might take care of acceptance aspects for planning and operating wireless networks either to avoid negative perception or to benefit from potential competitive advantages.

In this paper, we propose a mathematical model to consider user acceptance as an objective component in optimization models for deployment and configuration of wireless networks. Since the resulting optimization problems typically are of multi-objective nature, we further suggest an approach to deal with that kind of problem extension. We apply the proposed model and methods to an exemplary planning scenario for deployment of an LTE-based radio network and demonstrate effects by numerical evaluation.

The rest of this paper is organized as follows. In Section II, we discuss related work in the field of user acceptance modeling and radio network planning. We present an approach to assess user acceptance regarding wireless network infrastructure in Section III, before we introduce the considered network planning model and its acceptance-sensitive extension in Section IV. In Section V, we carry out numerical evaluation of an exemplary application scenario. Finally, we conclude this paper and discuss future work in Section VI.

II. RELATED WORK

In the field of information technology acceptance, there exist two widely considered models. First, the *Technology Acceptance Model (TAM)* [10] and its extensions *TAM2* [12] and *TAM3* [13]. And second, the *Unified Theory of Acceptance and Use of Technology (UTAUT)* [14]. While TAM mainly considers two key constructs, the perceived ease of use and the perceived usefulness, UTAUT considers four relevant determinants of user acceptance and results from a review and consolidation of earlier proposed models. However, both approaches are developed on the basis of empirical investigations regarding a special context. For instance, TAM particularly describes usage on the job situations. Therefore, utilization of both models for assessment of user acceptance regarding wireless networks and their infrastructure is at least questionable [11].

Optimal planning and configuration of wireless communication networks is discussed with respect to different technologies (GSM, UMTS, WiMAX, LTE), for instance, in [15], [3], [16], [17]. Sophisticated algorithms and heuristics have beed developed to cope with complexity of relevant optimization problems that, generally, belong to the class of NP-hard problems [15], [18]. The approaches in [4], [17] particularly tackle optimization problems that consider multiple KPI objectives. Regarding health risk issues in radio network optimization, it is a quite intuitive and trivial approach to formulate constraints that ensure the signal power level to stay below a certain threshold at critical points. However, this is not a suitable approach to consider user acceptance. Moreover, to our knowledge there exist no models to explicitly consider acceptance of wireless networks infrastructure in the planning process.

III. MODELING USER ACCEPTANCE

To overcome the problems mentioned in Section II, the *HUMIC* project group aims at developing models and methods to integrate user acceptance into the radio network planning process [19]. Generally, integration of acceptance into technical processes requires the ability of assessing user-specific acceptance. Since user acceptance can not be directly measured but is rather affected by other directly measurable variables, a suitable model is needed to quantify acceptance. A common approach to cope with this type of problem is the application of statistical methods such as *Structural Equation Modeling (SEM)* and multiple regression. We apply an SEM variant, the *Partial Least Squares (PLS)* approach that, in addition to standard regression models, allows for modeling causal relations between multiple components [20]. Based on a sufficiently large set of user data, a factor analysis is performed to determine the basic components (constructs) of the acceptance model, i.e., measurable variables, not directly measurable (latent) variables, and the relations between both. Afterwards, the acceptance model is completed by finding reasonable relations between constructs. Particularly, the developed model and all its components have to satisfy statistical evaluation requirements. Figure 1 exemplarily shows the construct *perceived risk* that serves as variable in the developed PLS-based user acceptance model.

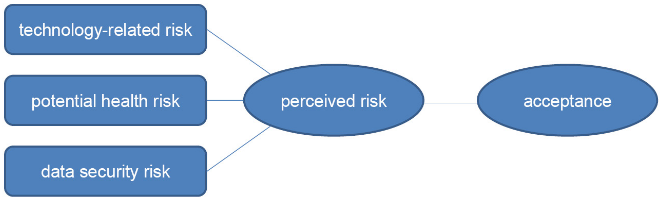


Figure 1. *Perceived risk* as an exemplary construct for modeling acceptance.

Utilizing the developed acceptance model, we apply the *Finite Mixture PLS (FIMIX-PLS)* approach, discussed in [20], to identify user groups that differ in acceptance behaviour regarding wireless network infrastructure. The FIMIX-PLS approach allows for jointly performed estimation of model parameters and identification of clusters that correspond to heterogeneous subsets in the underlying data set. Thus, we obtain different clusters and their model parameters. Each cluster might be associated with a particular user group, e.g., old people who rarely use mobile communication systems and are sceptical in general or parents that are scared of negative effects possibly applied to their children.

A considerable survey has been carried out to gather suitable data for acceptance modeling and parameter estimation. The survey was based on questionaires that were designed with respect to the particular purposes. Furthermore, web mining techniques are used to cross-validate key findings of acceptance modeling against user behaviour according to relevant user discussions on web 2.0 platforms.

IV. WIRELESS NETWORK PLANNING

We first introduce the considered optimization model for planning 4G wireless networks. Subsequently, we present the acceptance-sensitive variant of this optimization model. The proposed concept is applicable to a wide range of further network optimization models. However, it has to operate on the same variables and corresponding parameters as the original model.

A. Network Planning Model

According to [15], [17], [21], and Table I, we consider the optimization model

$$\max \left[\lambda_{\text{basic}} \sum_{(s,t)\in\mathcal{S}*\mathcal{T}} z_{st} + \lambda_{\text{rate}} \sum_{(s,t)\in\mathcal{S}*\mathcal{T}} w_t z_{st} - \sum_{s\in\mathcal{S}} c_s x_s \right]$$

subject to

$$\sum_{s\in\mathcal{S}_t} z_{st} \le 1 \qquad \forall\, t\in\mathcal{T} \tag{1}$$

$$z_{st} \le x_s \qquad \forall\,(s,t)\in\mathcal{S}*\mathcal{T} \tag{2}$$

$$\sum_{t\in\mathcal{T}_s} \frac{w_t}{e_{st}} z_{st} \le b_s x_s \qquad \forall\, s\in\mathcal{S} \tag{3}$$

$$x_s + x_{s'} \le 1 \qquad \forall\,(s,s')\in\mathcal{C} \tag{4}$$

where the sets $\mathcal{S}*\mathcal{T}$, $\mathcal{S}_t$, and $\mathcal{T}_s$ are defined as

$$\mathcal{S}*\mathcal{T} = \{(s,t)\in\mathcal{S}\times\mathcal{T} \mid e_{st}\ge e_{\text{min}}\},$$
$$\mathcal{S}_t = \{s\in\mathcal{S} \mid (s,t)\in\mathcal{S}*\mathcal{T}\}, \mathcal{T}_s = \{t\in\mathcal{T} \mid (s,t)\in\mathcal{S}*\mathcal{T}\}.$$

Table I
INPUT PARAMETERS AND VARIABLES.

Symbol & domain	**Parameter** description
$\mathcal{S} = \{1, \ldots, N_S\}$	Index set of BS candidates
$\mathcal{T} = \{1, \ldots, N_T\}$	Index set of traffic nodes (TN)
$s \in \mathcal{S}, t \in \mathcal{T}$	Representative indices
$c_s \in \mathbb{R}_{\geq 0}$	BS costs
$w_t \in \mathbb{R}_{\geq 0}$	Rate demand of TN
$b_s \in \mathbb{R}_{\geq 0}$	Total transmission bandwidth at BS
$e_{st} \in \mathbb{R}_{\geq 0}$	Link quality between BS and TN
$e_{\text{min}} \in \mathbb{R}_{>0}$	Required minimum quality to establish a link
$\mathcal{C}$	Set of conflicting BS pairs due to potential inter-cell interference
Symbol & domain	**Variable** description
$x_s \in \{0, 1\}$	BS deployment indicators
$z_{st} \in \{0, 1\}$	Coverage indicators

For appropriately chosen parameters λ_{basic} and λ_{rate}, the objective leads to maximization of operator profit [17]. For the revenue gained by potential users that are modeled by traffic nodes (TNs), we distinguish basic fee λ_{basic} and traffic dependent fee λ_{rate}. Each TN t can be covered ($z_{st} = 1$) by at most one deployed BS s, see (1) and (2). The rate demand of each covered TN is fulfilled. This is ensured by constraint (3) that forces the accumulated amount of required resources, i.e., the assigned transmission bandwidth, to meet BS resource limtation b_s. The amount of resources required to serve demand w_t by BS s depends on the link quality, i.e., on the spectral efficiency e_{st} the link supports. If there is no interference, spectral efficiency is determined by the modulation and coding scheme available for the given signal-to-noise ratio (SNR) according to system link budget specification [2]. The required amount of transmission bandwidth is then given by w_t/e_{st}. Here, we ensure interference to stay below a significant level by applying OFDM transmission (no intra-cell interference) and by prohibiting joint deployment of interfering BSs (no inter-cell interference). The latter approach is modeled by constraint (4) and the predefined set $\mathcal{C}$ of potentially interfering BSs.

B. Acceptance-Sensitive Model

Introducing additional parameters and variables according to Table II, we extended the original objective to

$$\max \left[\lambda_{\text{basic}} \sum_{(s,t) \in \mathcal{S} * \mathcal{T}} z_{st} + \lambda_{\text{rate}} \sum_{(s,t) \in \mathcal{S} * \mathcal{T}} w_t z_{st} - \sum_{s \in \mathcal{S}} c_s x_s - \lambda_{\text{acp}} \sum_{a \in \mathcal{A}} w_a y_a \right]$$

and add constraint

$$\sum_{s \in \mathcal{S}} p_{as} x_s - n_a \leq N_S y_a \qquad \forall\, a \in \mathcal{A}\ . \tag{5}$$

While the first three objective components are the same as before, the fourth one describes the effect induced by activated *acceptance patterns* (APs). Via its relevant BSs, an AP a refers to a certain location or area. A relevant BS s is indicated by $p_{as} = 1$. In contrast to model acceptance by constant BS penalty factors, APs also allow for triggering penalties depending on deployment of certain BS subsets. According to (5) and due to the negative influence of active APs to the objective, AP a stays inactive ($y_a = 0$) as long as the number of deployed BSs that are relevant for a does not exceed the maximal tolerated number n_a. If the threshold n_a is exceeded by a solution, the AP affects the objective negatively and weighted according to its impact factor w_a. Furthermore, the parameter λ_{acp} controls the influence of the acceptance-related component to the overall objective.

Table II
ACCEPTANCE-RELATED INPUT PARAMETERS AND VARIABLES.

Symbol & domain	**Parameter** description
$\mathcal{A} = \{1, \ldots, N_A\}$	Index set of acceptance patterns (AP)
$a \in \mathcal{A}$	Representative index
$w_a \in \mathbb{R}_{\geq 0}$	Impact (weight) of AP
$(p_{a1}, \ldots, p_{aN_S}) \in \{0, 1\}^{N_S}$	Indication vector to select BSs relevant for AP
$n_a \in \mathbb{N}_0$	Maximal number of relevant BSs tolerated by AP
Symbol & domain	**Variable** description
$y_a \in \{0, 1\}$	AP activity indicators

Applying the proposed extensions, it is possible to model the following desires by appropriately chosen AP a and w_a:

1) *Deployment of certain BSs is not appreciated*: Set relevant entries $p_{as} = 1$ and $n_a = 0$. Deployment of one or more relevant BSs activates AP a. If the acceptance-related effect increases with the number of relevant BSs, create separate APs for them.
2) *Deployment of at most n BSs out of a certain set is tolerated*: Create indication vector as before and set $n_a = n$.
3) *The total number of deployed BSs should be limited*: Set all entries of the indication vector to one and n_a to the tolerated limit.

APs are created according to a socio-economic analysis of the considered planning area and with respect to potentially affected user groups (clusters) identified by the PLS-based acceptance model from Section III. Typically but not necessarily, the BSs in the direct neighborhood of the AP-associated user group are the relevant ones for the AP. Impact factors w_a are derived from the acceptance model (relative weightings) and the assumed influence of the affected AP user group. A reasonable choice for control parameter λ_{acp}, however, is a critical point and an open problem, see Section VI for further discussion.

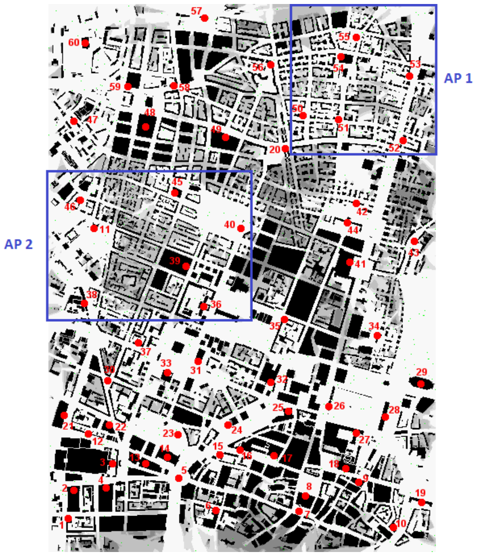


Figure 2. 60 BS location candidates in Munich city and two exemplary AP-related areas. Maximal achievable signal levels are colored pointwise from white (strong) to dark grey (weak), buildings are colored black, and indoor signal levels are not shown.

Table III
PLANNING SCENARIO SETUP.

Scenario component	Setup
Area	Munich city, 3.4 km × 2.4 km [22]
Number of BS candidates	60
Number of TNs	1000, uniformly distributed, 80% indoor TNs
TN demand profile	Data: 10 − 20 % at 512 − 2000 kbps Web: 20 − 40 % at 128 − 512 kbps VoIP: [40 − 70 %] at 64 kbps
Carrier frequency	2 GHz
Available DL bandwidth	10 MHz
BS monthly cost	1800 €
BS Tx average power	43 dBm
BS / TN antenna gain	14 dBi / 0 dBi
BS / TN noise figure	5 dB / 9 dB
Shadowing standard deviation	8 dB
Path loss model	CORLA ray-optical model [23], omnidirectional antenna pattern
Spectral efficiency lookup table	LTE UE reference sensitivity specification [2]

Table IV
EVALUATION RESULTS.

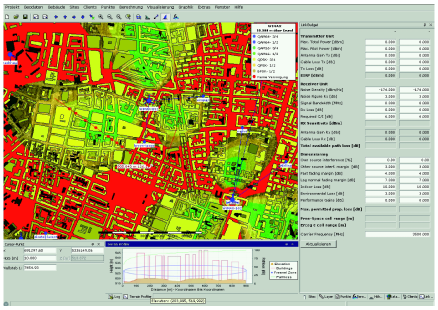
λ_{acp}	#BS	#AP	#TN	Profit [€]	Profit loss [%]
0	16	6	1000	170800	–
100	16	2	1000	170800	0
1000	16	1	995	169802	0.6
5000	14	0	919	158232	7.4

V. NUMERICAL EVALUATION

The following planning scenario serves as example to demonstrate effects of acceptance-sensitive BS deployment compared to application of the conventional model according to Section IV-A. We consider BS location planning for an LTE-based wireless network in an urban area as depicted in Figure 2 and according to the parameter setup from Table III. We keep the term BS instead of eNB which would be the proper one in context of LTE. As objective we consider monthly operator profit [17]. We assume monthly BS cost of 1800 € covering site rental, leased line rental, air-conditioning, and maintenance [5]. Furthermore, we choose $\lambda_{\text{basic}} = 50$ € and $\lambda_{\text{rate}} = 0.5$ €/$kbps$ to describe monthly fee paid to the operator. TN rate demand is modeled as superposition of service-related rates where each rate is multiplied with its service-specific request probability. Service-specific rates and probabilities are generated randomly and uniformly distributed over the intervals listed in Table III. Note, that probability for VoIP service follows from substraction of generated probabilities for data and web services from one. Since a TN typically represents 3 to 5 users, the suggested parameter selection appears reasonable. However, for practical applications the parameter selection is done by the operator that has substantial knowledge about reasonable parameters.

Based on a socio-economic analysis of the considered planning area, we derive APs that model people's disaffirmation of BSs potentially deployed in certain spots. We assume that those BS candidates are relevant for an AP that are located in the neighborhood of the AP-associated user group. In Figure 2, the related areas of two exemplary APs are depicted: While the first AP refers to a district where many elder and wealthy people live, the area associated with the second AP covers serveral preschooles. Particularly the second AP is a typical example where people generally do not appreciate a high BS density. Eight more APs are derived accordingly and an 11th AP reflects the citizens' attempt to keep network size in the city area below 15 BSs.

As mentioned in Section IV-B, parameter λ_{acp} controls the impact of the acceptance component to the overall objective. We vary this control parameter to gain an insight into impact intensity. Table IV shows the results for different control parameter settings. Each optimization instance is solved optimally utilizing *Gurobi Optimizer* (www.gurobi.com) as solving engine. The solution for $\lambda_{\text{acp}} = 0$ does not consider any acceptance aspects and serves as reference solution obtained by conventional planning. In the reference solution, all 1000 TNs are covered by 16 deployed BSs. However, it also activates 6 APs. For $\lambda_{\text{acp}} = 100$, acceptance-sensitivity leads to a reduction of active APs while keeping the remaining results as before. When λ_{acp} is raised by one magnitude to 1000, previously optimal BSs are substituted by less benefiting BSs and the primary objective starts to degrade. The degradation further increases to 7.4% for having all APs deactivated. The trigger for this solution is the 11th AP, i.e., network size limitation due to citizens' desires. Nevertheless, the question if full acceptance of the deployed network is worth the degradation, also in terms of 8% less covered TNs, stays open.



X 691297.60 Y 5336149.06

0G [m] 10.000 Z [m] 518.672

Maßstab 1: 7454.93

Link Budget	-	-
Transmitter Unit		
Max. Total Power [dBm]	0.000	0.000
Max. Pilot Power [dBm]	0.000	0.000
Antenna Gain Tx [dBi]	0.000	0.000
Cable Loss Tx [dB]	0.000	0.000
Tx Loss [dB]	0.000	0.000
EIRP [dBm]	0.000	0.000
Receiver Unit		
Noise Density [dBm/Hz]	-174.000	-174.000
Noise Figure Rx [dB]	3.000	3.000
Signal Bandwidth [MHz]	0.000	0.000
Rx Loss [dB]	0.000	0.000
Required C/I [dB]	6.000	6.000
RX Sensitivity [dBm]		
Antenna Gain Rx [dBi]	0.000	0.000
Cable Loss Rx [dB]	0.000	0.000
Total available path loss [dB]		
Dimensioning		
Own source interference [%]	0.00	0.00
Other source interf. margin [dB]	3.000	3.000
Fast fading margin [dB]	4.000	4.000
Log normal fading margin [dB]	7.000	7.000
Indoor Loss [dB]	10.000	10.000
Environmental Loss [dB]	3.000	3.000
Performance Gains [dB]	0.000	0.000
Max. permitted prop. loss [dB]		
Free-Space cell range [m]		
Erceg C cell range [m]		
Carrier Frequency [MHz]	3500.000	

Figure 3. GUI of WiMAP-4G, a professional software tool for planning 4G wireless networks (www.wimap-4g.com).

VI. CONCLUSIONS AND FUTURE WORK

Consideration of acceptance aspects in planning radio network infrastructure is a potential success factor for operators in terms of positive publicity and might serve as strong argument when it comes to discussions with people or organizations that feel themselves affected by network BSs.

We proprose an approach to integrate acceptance aspects into network planning models by introducing N_A additional variables and N_A additional constraints for consideration of N_A acceptance patterns. Using a predefined interface, the presented models can be embedded into professional software for wireless network planning, e.g., WiMAP-4G (www.wimap-4g.com), see Figure 3. Acceptance patterns are created according to user group interests that are identified by application of a PLS-based acceptance model. Evaluation of an exemplary application shows that the acceptance-sensitive planning approach can lead to degradation of conventional KPIs. On the other hand, it also demonstrates that there can be potential to improve user acceptance at no price by selecting suitable alternatives.

By varying the weighting factor λ_{acp} for the acceptance term in the optimization objective, it is possible to control the impact of acceptance aspects to the overall objective, e.g., to keep economical aspects as primary deployment trigger. However, due to the reasons mentioned above it might be more benefical to consider acceptance aspects at least in a certain proportion, e.g., as long as the potential profit is not degraded by more than five percent. This strategy would implicitly determine the selection of control parameter λ_{acp}. As a more general guideline for choosing λ_{acp} properly is preferable, present research of the HUMIC research group concentrates on trade-off analysis considering acceptance, technical desires, and economial interest. By means of *conjoint analysis*, a method from marketing research, we investigate user group specific trade-off factors between the different aspects. The findings are expected as future results.

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