Planning Cordless Business Communication Systems*

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A new tool optimizes the placement of base stations for local wireless communications at company sites. It uses the latest in constraint-based programming technology.

1 Introduction

People in their cars, people in the street, people at work, people at home - communicating through their mobile phones. Wireless communications is maybe *the* trend of the nineties, and it definitely means big business for the telecommunication industry. In Germany, for example, every third phone sold today is mobile. In the US, 20 million subscribers to cellular phone services will be reached soon. In the second half of the nineties, 20 to 30 percent of phones sold worldwide are expected to be wireless (see fig. 1) [Sie94].

With the introduction of the European standard for digital cordless telecommunication, DECT, cordless local area networks are possible. Mobile communi-

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‡Work was done while at SIEMENS, ZFE, Munich, Germany, as part of the Master thesis at the Aachen University of Technology, Germany

§Work was done while at ECRC, Munich, Germany cations comes to company sites. No cabling is required and the employees can be reached at any time at any place. However, planning of wireless digital networks is quite different from planning traditional wire-based systems. The specifics of radio wave propagation at the installation site have to be taken into account. Computer-aided planning promises to ease some of the difficulties encountered.

In this article, we describe POPULAR (Planning of Picocellular Radio), the tool prototype resulting from a collaboration of industry and research institutions in Germany: The Siemens Research and Development Department, the Siemens Personal Networks Department (PN), the European Computer-Industry Research Center (ECRC) and the Institute of Communication Networks at the Aachen University of Technology. POPULAR uses the latest in constraint-based programming technology to optimize the placement of base stations (transmitters) for local wireless communications at company sites.

1.1 The DECT Standard

In 1992, the Digital European Cordless Telecommunications (DECT) standard was published by the European Telecommunications Standards Institute (ETSI) [ETS92]. The DECT standard allows for a cellular structure of the radio network. A cell is the space that is covered by a transmitter (base station). The size of a cell is usually in the tens of meters. For buildings, multi-cellular systems are required, because walls and floors absorb part of the radio signal. The network organizes itself in a decentralized manner on a per-communication basis with seamless hand-overs.

The standard integrates a number of telecommunication services. The wireless services include the Telepoint service (wireless public phones in cities), wireless Local Area Networks (LAN) for data transfer and wireless Private Automatic Branch Exchange (PABX) for in-house communication. The PABX service is the one we are concerned with in this article.

PABX systems (fig. 2) have turned out to be a major market which is growing even faster than the wireless communication market in general. PABX enables the installation of Cordless Business Communication Systems (CDBS). The major vendors of PABX systems based on the DECT standard are Alcatel (Alcatel 4220/4000), Ericsson (Freeset) and Siemens (Hicom Cordless 300). Of course, selling such systems is not enough, the service that comes with it makes the difference. A vendor will also plan, install and maintain the system. Especially the planning phase is of importance, since a vendor that can offer to cover a company site with a smaller number of base stations will be ahead of its competition.

1.2 POPULAR - Innovation in Planning

Today, the number and positioning of base stations is estimated by an experienced sales person. To help the sales person, Siemens has compiled a set of

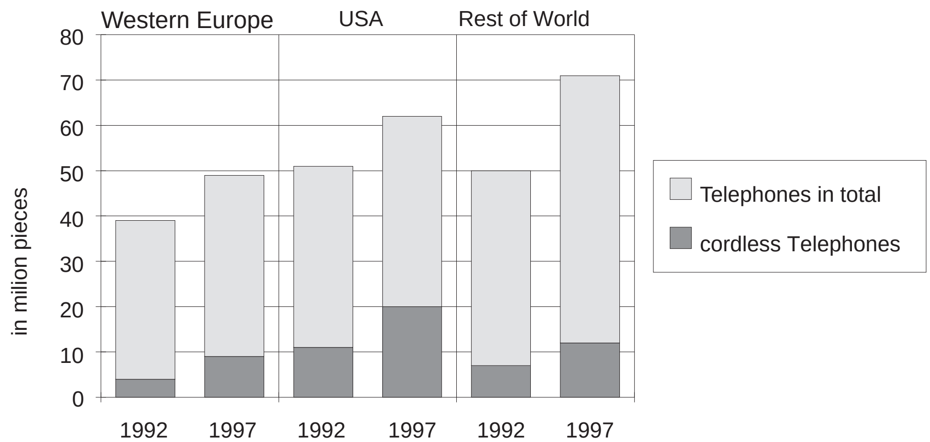

Figure 1: Phone Sales (in millions)

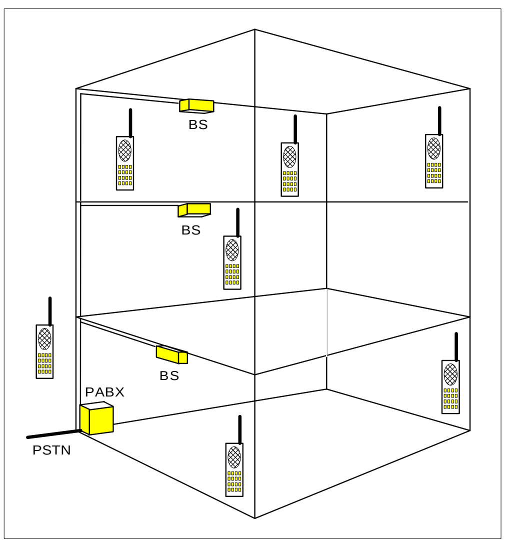

Figure 2: Wireless Private Automatic Branch Exchange (PABX) with Base Stations (BS) and Public Switched Telephone Network (PSTN)

guidelines based on typical scenarios. However, a scenario may not always apply and the approach does not work well when it comes to position the base stations.

The next step to improve costumer satisfaction and to minimize sales costs is computer-aided planning. The idea is straightforward: Given a blue-print of the building or company site, compute the minimal number of base stations and their location by simulation and subsequent optimization.

In the next section we describe how picocellular radio transmission and buildings are modeled for the simulation. Then we describe planning with POPULAR. Last we evaluate the prototype developed.

2 Modeling Picocellular Radio

Radio wave propagation suffers from the following effects:

- attenuation (weakening) of the signal due to the distance,
- shadowing (absorption) through obstacles,
- multipath propagation due to reflection and diffraction,
- interference with other transmitters,
- motion in the radio field (doppler effect).

To describe indoor radio propagation at a macroscopic level a path loss model is suitable. [Has93] writes:

> Path loss information in indoor environments are essential in determination of the size of the coverage area for radio communications systems, and in selecting optimum locations for base antennas. Obtaining three-dimensional propagation contour plots using a building's blue-print and the knowledge of its construction material is a challenging job which requires detailed and reliable path loss models.

In the rest of this section we describe the path loss model and propose an extension that takes the effect of fading and antenna directivity into account. Interference and Doppler effects are neglegible due to the systems inherent properties.

2.1 Path Loss Model

In the COST[1]-Subgroup "Propagation Models" the following path loss model was proposed [COS90]:

[1]European Cooperation in the field Of Scientific and Technical research

$$L_P = L_{1m} + 10\, n\, \log_{10} d + \sum_i k_i\, F_i + \sum_j p_j\, W_j \tag{1}$$

where L_P : total path loss in dB,
L_{1m}: path loss in 1 m distance from transmitter,
n : propagation factor,
d : distance between transmitter and receiver,
k_i : number of floors of kind i in the propagation path,
F_i : attenuation factor of one floor of kind i,
p_j : number of walls of kind j in the propagation path,
W_j : attenuation factor of one wall of kind j.

The model is based on the power balance of wireless transmission. It combines a distance dependent term with correction factors for extra path loss due to floors and walls of the building in the propagation path. In [Kee90] it was found that the following parameters gave the best fit to actual data. The propagation factor for the indoor channel is $n = 2$ as in free space. A carrier frequency of $1.728 GHz$ resulted in a path loss of $L_{1m} = 38 dB$. Figure 3 shows an example of the resulting path loss over distance on logarithmic scale. At $6m$ and $9m$ walls are weakening the signal.

The walls and floors are characterized by their attenuation factors. The attenuation not only consists of the loss due to the material, but also includes the loss caused by the limited dimensions of a wall or floor, by doors, windows, inhomogeneous materials used, etc. The overall loss is called insertion loss (see table 1 and table 2 for some examples).

2.2 Extensions

The introduced path loss model does not take reflection and hence multipath effects into account. Even with sufficient receiver sensitivity a radio link could fail due to fading and too many bit errors that result from it. Thus a *fading reserve* (fade margin) is introduced. Investigations about the bit error probability in dependence of multipath effects show good behaviour of a DECT multi-carrier system in comparison with a single-carrier system, [Lop91, Sch92]. Accordingly, the fading reserve is chosen.

Antennas do not beam with the same energy in every direction. A descriptor for the directional effect of an antenna is its gain G. The *antenna gain* is defined as the ratio of maximal radiation density to the radiation density of a isotropic sphere antenna. The radiation density is dependent on the polar angles ϱ and φ and adapted to the maximal density, it is usually expressed as directional diagram, $S(\varrho, \varphi)/S_{max}$. For the directivity of a antenna, $G(\varrho, \varphi)$, follows:

$$G(\varrho, \varphi) = G \cdot \frac{S(\varrho, \varphi)}{S_{max}} \tag{2}$$

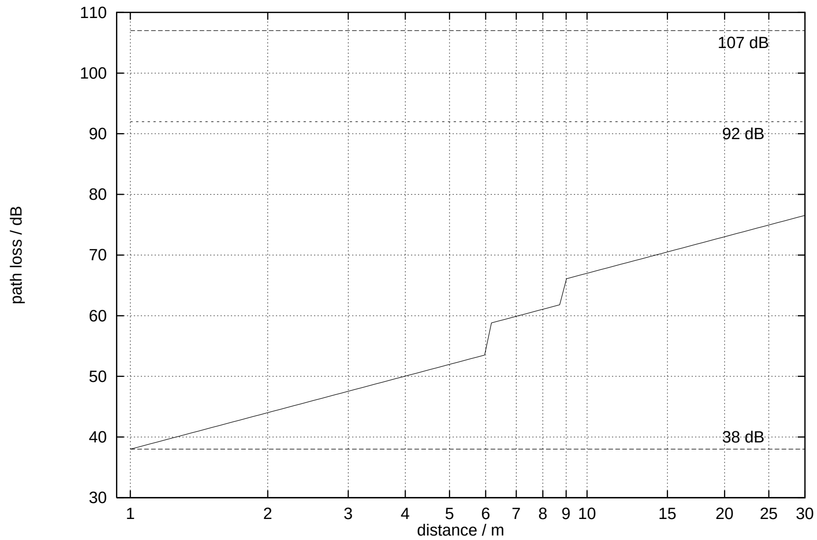

Figure 3: Typical path loss with additional attenuation in $6m$ and $9m$ distance due to walls

Walls	L_{ins}/dB
Soft system wall	2–3
Glass	2
Reinforced glass	8
70 cm brick	4–5
100 cm brick	9
10 cm concrete, indoor	6
20 cm concrete, large windows	5–6
40 cm concrete, indoor	17
Steel, large reinforced windows	10

Table 1: Insertion loss of walls [COS90]

Ceiling	L_{ins}/dB
Reinforced concrete	6–9
Tiles and metal mesh	15
Reinforced concrete on steel frame	12–16

Table 2: Insertion loss of ceilings [COS90]

In our extended path loss model, equations 1 and 2 are combined:

$$L_{P'} = L_P + L_{FadingReserve} - 10\,\log_{10}(G) - 10\,\log_{10}\left(\frac{S(\varrho,\varphi)}{S_{max}}\right) \tag{3}$$

3 Planning in POPULAR

POPULAR [Mol94] (fig. 4) was implemented by P. Brisset and J.-R. Molwitz in a constraint-based programming environment, ECLiPSe, within one man-year. The ECRC Constraint Logic Programming System (ECLiPSe) [B*94] is basically a rule-based knowledge based system. Constraints are used to express partial information and pre- and post-conditions on rules. For a survey on constraint logic programming see [JaMa94]. ECLiPSe 3.4 includes an implementation of Constraint Handling Rules (CHRs), which was essential in implementing POPULAR. Constraint handling rules (CHRs) [Fru95] are a high-level language extension to implement arbitrary constraint systems.

Given some basic information about the building or company site (a blueprint and the materials used for walls and ceilings), we compute the minimal number of base stations and their location by simulation and subsequent optimization.

First, the characteristics of the building are computed using a grid of test points. Each test point represents a possible receiver position. Under the assumption that the radio channel is reciprocal, we can interchange transmitter and receiver. In this way we can calculate the radio coverage area, called the "radio cell". In order to cover a test point, a transmitter (base station) has to be placed inside its radio cell. If the grid is sufficiently small, we can expect that if two neighbouring test points are covered, the space inbetween - hence the whole building - can also be covered.

In the optimization phase, it is made sure that there is at least one transmitter inside each radio cell. The resulting opimization problem is solved by intersecting radio cells to find common locations for transmitters so that the number of transmitters is minimized.

3.1 Simulation of Radio Cells

The test points are placed on a 3-dimensional grid inside the volume that should be covered. The horizontal distances of the test points are chosen by the user. It is in the meter range. At each floor of the building, there is one such layer of test points (fig. 5).

The radio cell of each test point is calculated using path tracing with a low resolution. In the current implementation, 128 discrete unit vectors are used as directions. To get to the point of minimal sensitivity (i.e. maximal permissible path loss), each path must be followed through the whole building (fig. 6). The

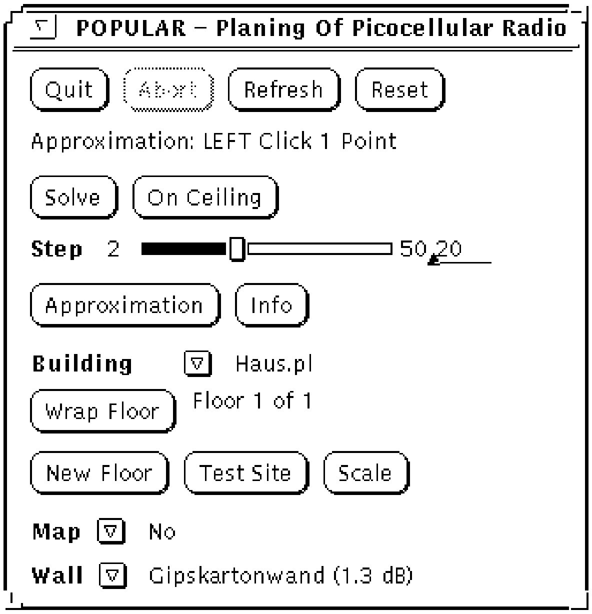

Figure 4: Control panel of POPULAR

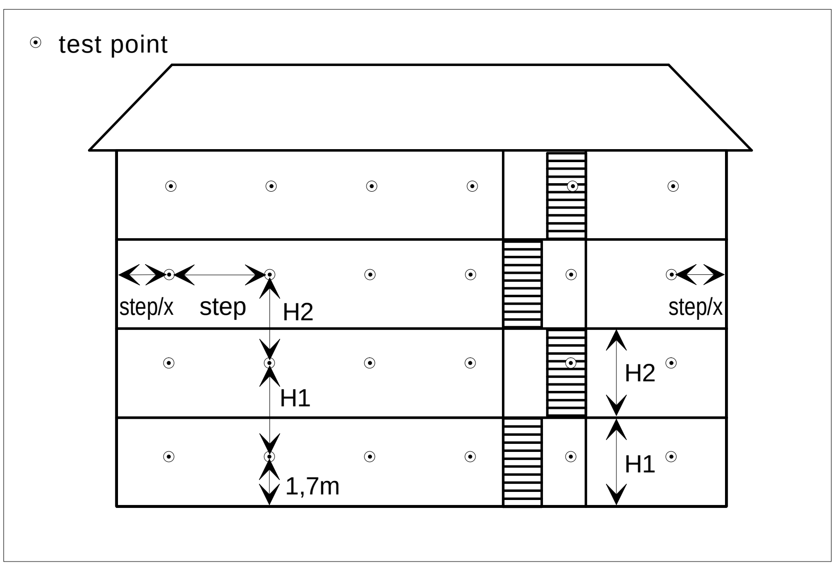

Figure 5: Grid of test points in a building

values of antenna attenuation in the direction of the path, the path loss due to the distance and the insertion losses due to intersections of the path with walls and floors are added up to the maximal permissible path loss. The resulting end points are used to describe the hull of the radio cell.

In practice, the base stations are installed at the same height from the floor on the ceilings or on the walls. This means that on each floor, the possible space of locations for a base stations is on a single plane. This plane is intersected with the radio cells, reducing them from a polyeder to a series of connected planes (one for each floor) (fig. 7).

3.2 Constraint-Based Optimization

The optimization problem is solved using constraint-based programming. For each radio cell (i.e. its set of planes) a constraint (condition) is set up that there must be (at least) one location of a base station (geometrically speaking, a point) somewhere in that area. Then, we try to find locations that are in as many radio cell planes at the same time as possible. Thus the possible locations are constrained to be in the intersections of the radio cell planes covered. In this way, a first solution is computed. To minimize the number of base stations, we use a *branch-and-bound* method. It consists in repeatedly searching for a solution with a smaller number of base stations until the minimal number is found. The solving of the geometric constraints and the search are provided by the implementation language ECLiPSe. The details of the implementation are the topic of a forthcoming paper.

3.3 Example

Currently, to get a description of a building we scan in a blue-print (fig. 8). From the scanned image, the walls and ceilings are redrawn. Each wall and ceiling gets its own attenuation factor. Also, the test site is defined, that is the volume of the building that has to be completely covered by base stations.

The single-floor building shown in figure 8 is an actual building in the Netherlands. The size of the building is about $15m * 49m$, its height is about $3m$. The inside walls are soft system walls with an attenuation of $2.3dB$, except for the walls to the aisle, which are stronger with an attenuation of $8dB$.

To solve this planning problem, a grid size of $4m$ is chosen. The size was estimated from the dimensions of the rooms in the building. Base stations are constrained to be installed on walls only. POPULAR places a single base station near the center of the building. Figure 9 shows the possible locations on the walls as dotted lines. POPULAR has chosen the position indicated by the circle for the base station.

In a slightly different scenario we assume that all walls have the same, stronger attenuation. As figure 10 indicates, the building cannot be covered by one base station anymore. In the figure, the radio cell is shown as it would

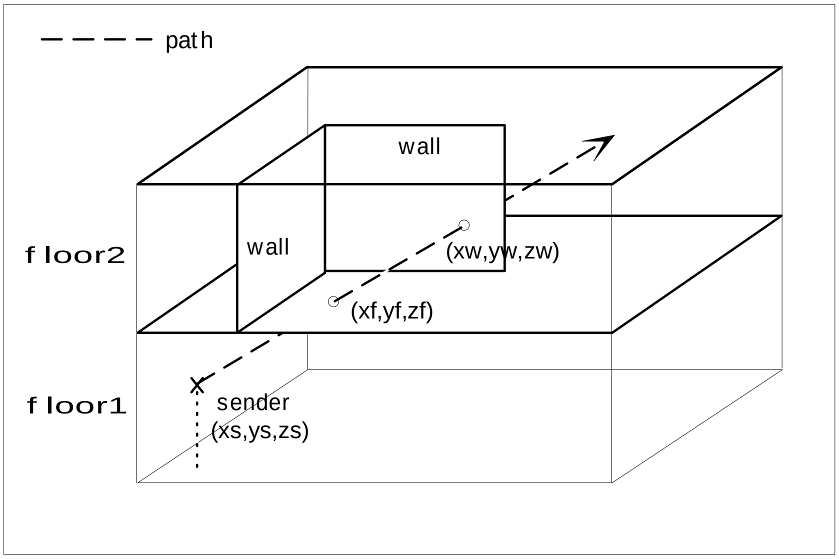

Figure 6: Path from transmitter intersecting a ceiling and a wall

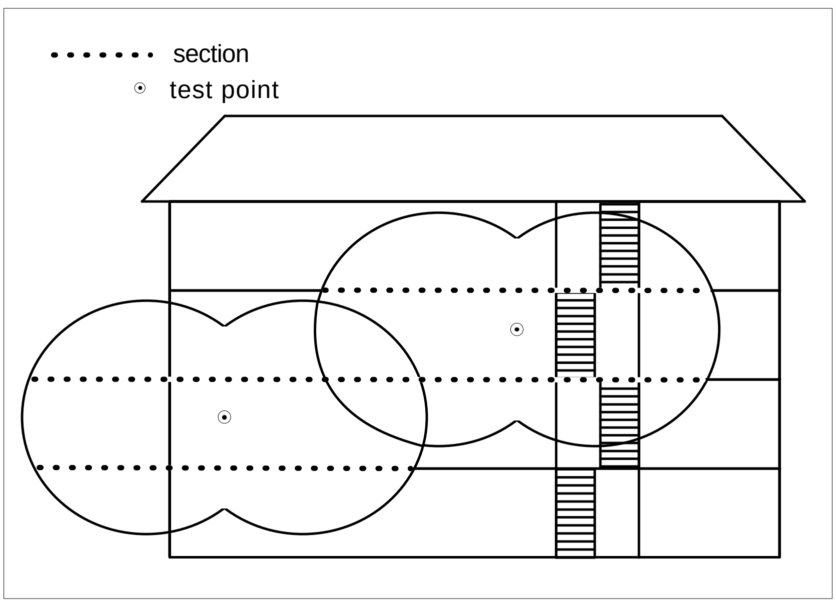

Figure 7: Typical radio coverage areas in a building

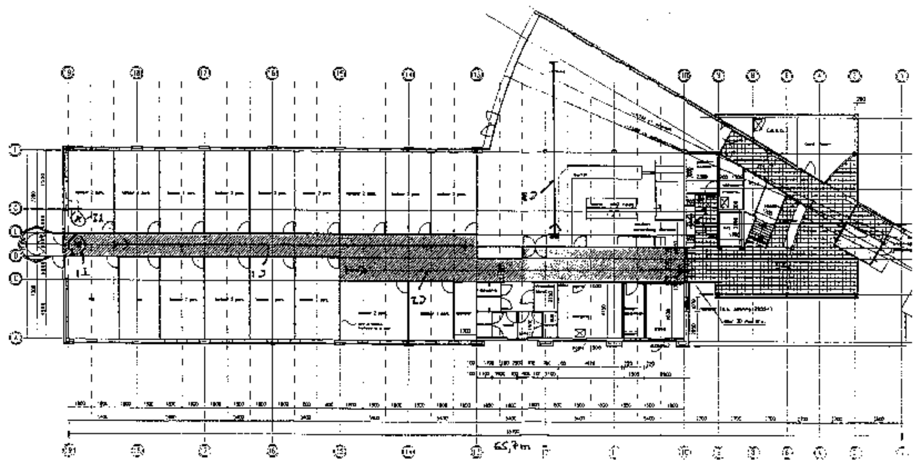

Figure 8: Blue-Print of a building in the Netherlands

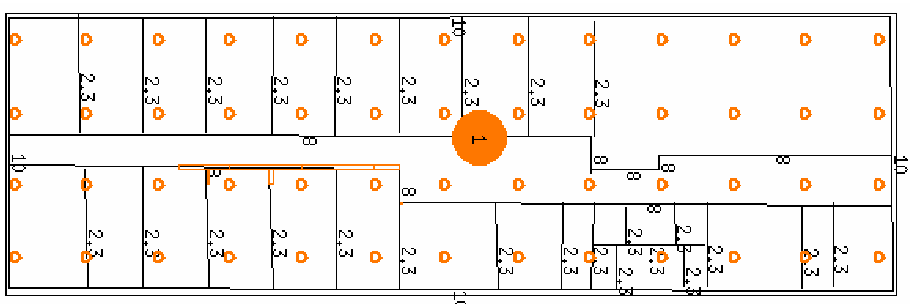

Figure 9: Solution with test point grid size of $4m$, possible and chosen positions of base station

have been computed in the simulation phase - composed of small triangular segments. Along each line drawn from the base station, the sensitivity has been computed up to the point of maximal permissible path loss.

Figure 11 shows a solution with to the revised scenario using two base stations. The middle of the building is covered by both base stations. In figure 11, a radio cell extends only as long as its base station provides the strongest signal so that the area actually covered by each of the base stations is accurately visualised.

4 Evaluation

In this section we review the tool POPULAR, i.e. the adequacy of model on which it is based and the performance of the planning algorithm.

4.1 Precision of the Extended Path Loss Model

The Siemens departments of Public and Personal Networks did experiments concerning "Last Mile" applications of DECT based telecommunication systems. The standard deviation between the actual measurements and the prediction based on the standard path loss model was $4dB$. Similar results are reported in the literature, e.g. by [Kee90].

The reasons for the imprecision of the path loss model are signal fading and the imprecision of the insertion attenuation. Taking reflection into account would complicate the model considerably and introduce new sources of imprecision. Since we introduced a fading reserve in our extended path loss model, the worst case due to the above imprecisions can be accounted for.

The precision of a blue-print is usually sufficient, since the main source of imprecision is due to modeling radio transmission as described before. Since a wall and ceiling can only have a single degree of attenuation, buildings with rather heterogeneous walls and ceilings may have to be approximated piecewise.

4.2 Performance of POPULAR

While the simulation phase has linear complexity in the number of test points, the optimization phase has a theoretical exponential complexity. Our practical experience shows, however, that the actual complexity is much lower. The implementation benefits from heuristics that take the geometric nature of the problem into account. We performed some measurements with POPULAR running on a SUN SPARCStation 10. The average run-time was almost linear in the number of walls and test points, with about $25ms$ per wall and per test point. For larger buildings this results in times which are in the minute range. Hence the speed of the prototype is satisfactory.

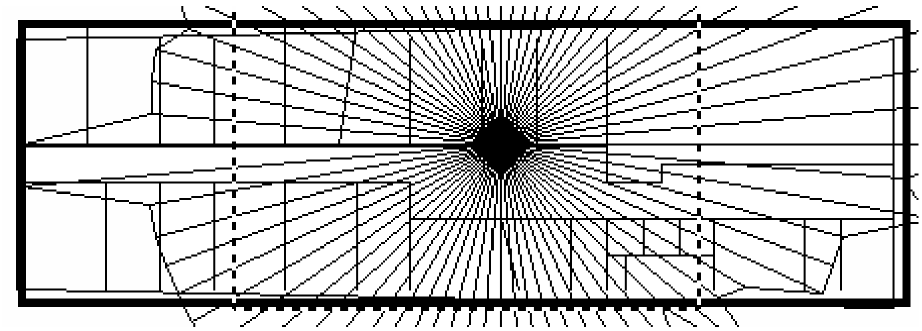

Figure 10: Radio area of one base station if the walls have stronger attenuation

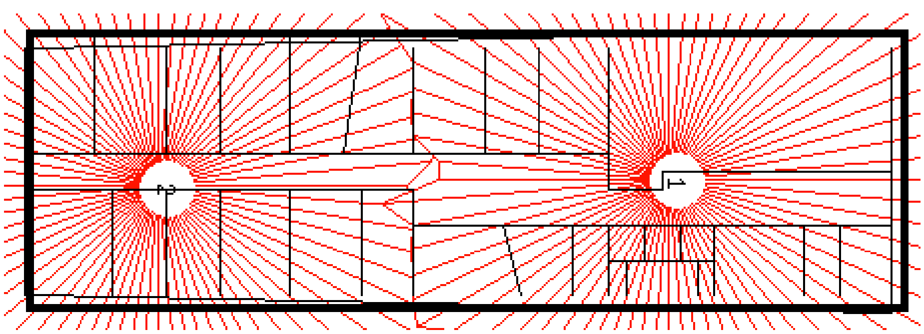

Figure 11: Radio areas of two base station covering the building with stronger walls

5 Conclusions

In this article, we described POPULAR (Planning of Picocellular Radio), a tool prototype developed at ECRC and SIEMENS with the Institute of Communication Networks at the Aachen University of Technology to optimize the placement of base stations for local wireless communications at company sites based on information about buildings.

POPULAR was implemented within a year in the ECRC Constraint Logic Programming System (ECLiPSe), which includes the latest in constraint technology. In particular, the constraint handling rules library allowed for a rapid, flexible and efficient implementation of the geometric constraints that appear in this placement problem.

The optimization of the base station placement is based on a description of the building, that is a simple blue-print showing the walls at each floor and information about the materials used for walls and ceilings to determine the attenuation factors. An optimal placement is found within a few minutes at most.

We found that the overall quality of the solutions produced by POPULAR is comparable to those of a human expert. More field tests are necessary to see if the solutions computed by POPULAR are always optimal in the number of base stations.

The precision of our extended path loss model is in the range of a few meters. While this seems satisfactory, multipath propagation effects should be taken into consideration in more detail. This would allow to estimate the bit error rates and thus could refine the computation of the radio cells.

Current work aims at making the generation of the test points more flexible and automatic. So far, the right grid size (the coarsest one that still leads to good results) has to be found by trial and error by the user. The idea is to generate test points automatically depending on the architecture of the building.

Authors

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