Planung und Modellierung von WLAN/WiMAX-Netzwerken
(Planning and Modelling of WLAN/WiMAX Networks)

Research Paper

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Abstract

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*Zielstellung:*

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Introduction

Research motivation and aim

This research thesis was made in the context of the “Computer Aided Network Design Utility” (CANDY). The project runs at the institute of computer science at the Technical University of Dresden. It is dedicated to the development of a tool that enables also non-network-experts to configure a network by themselves. The programme will include different tools. One part is dealing with the special requirements of radio networks. In order to guarantee interoperability amongst the tools a new language has been worked out which is called “Network Design Modelling Language” (NDML). NDML is based on XML grammar. In order to meet the special requirements of radio networks RadioNDML was suggested.

The task of this thesis was to analyse the functionality of existing network design programmes and to develop a concept for a radio network planning tool.

Structure

This thesis deals with the planning and modelling of wireless networks. The first section is about the basics of network planning. It is supposed to give an impression of all necessary steps of radio network planning and therefore of the software requirements.

In the second part an overview above the specifications of the IEEE 802.11 and IEEE 802.16 standards shall be presented.

The third and forth chapter will give an overview about current wave propagation and visualisation models. The aim is to find a suitable model for all applications and wireless standards in the radio network part of the CANDY project.

Furthermore already existing WLAN design tools are to be examined. Therefore a closer look towards the options that are nowadays provided by those tools is taken. The section will finish with a table naming the advantages and disadvantages of each programme.
In the sixth part of this thesis a concept for the radio network design tool that will be needed in the CANDY project is suggested. Hence the knowledge about the previously examined tools is combined with the facts about network design and special requirements of CANDY in order to achieve a concept how the radio network tool might work.

The seventh section will suggest some extensions to RadioNDML.

The last part gives an outlook about future development.
1 Basic knowledge in radio network planning

Network planning consists of several tasks. At the beginning an initial proposition of the hardware - like antennas and base stations - is to be found. The next steps are the optimisation of cost, capacity, coverage, complexity and the signal-to-noise-ratio. Unfortunately one cannot be done without neglecting another. If the capacity of the network is for example supposed to be rather high the complexity and the costs of the system will increase. Therefore it is important to define one’s priorities before starting to plan a network.

Also network planning cannot be done simply at a computer since all the calculations are just estimations of the real world. Hence it is necessary to do a radio frequency survey after the radio network simulation. This means that there has to be a temporary installation of the selected hardware solution in the environment at the predetermined location.

1.1 Fresnel Zone

The Fresnel Zone covers the area around the line of sight (LOS) in which radio waves are propagated after they left the transmitting antenna. It describes several elliptical areas. In radio networks normally just the first elliptical area is considered to be the most important one. There are also the 2nd, 3rd and .... Fresnel Zone. All odd numbers represent the amplifying signal superposition and all even numbers the weakening signal superposition. It can be calculated with the following formula:

\[ r = 17.32 \times \sqrt{\frac{d}{4f}} \]

- \( r \) radius in metres
- \( d \) distance in kilometres
- \( f \) frequency in GigaHertz
Either this region is obstacle free – which means that less than 20% of the Fresnel Zone is affected by obstacles like buildings or trees, - or the signal strength and therefore the data rate at the receiver will be weakened. If there are obstacles in the Fresnel Zone reflection may occur. These reflections can either cause a total wave cancellation in the case that the signals are exactly 180° out of phase or distorted signals at the receiver if the phase differentiates in more or less than 180°. Those effects are called multipath interferences.

If the Fresnel Zone is totally obstacle free the received signal strength can be calculated with the Free Space Loss (FSL) formula. This means that the attenuation is exclusively depending on the frequency of the signal and the distance between transmitting and receiving station.

\[ FSL = 20 \log(f) + 20 \log(d) + 36.6 \]

d distance in miles  
f frequency in MegaHertz

The Clearance model is dedicated to radio frequency calculation for large distances since the curvature of the earth needs to be considered. The minimum height of the antennas can be calculated so that the disturbances are decreased.
1.2 Coverage area

To determine the special requirements of each coverage area, maps have to be used. Topographical, building drawings and blueprints are useful in order to calculate the Fresnel Zone since they provide a three dimensional view on the region. Unfortunately morphological and territorial data is very much depending on future development. There might be for example the construction of other buildings in the way between transmitter and receiver after the network has been planned. It might also occur that trees grow in the LOS connection between transmitter and receiver. This will weaken the signal strength and makes it impossible to provide a final network design in many cases.

\[
h = \frac{d^2}{8} + 17.32 \cdot \sqrt{\frac{d}{4 \cdot f}}
\]

\(h\) minimale Höhe der Antennen in Meter
\(d\) Entfernung der Antennen in Meter
\(f\) Frequenz in GHz

If a large area has to be covered with a radio network there are different frequency channels which can be used. Each additional frequency channel provides the opportunity to increase the number of users. But it has to be considered that adjacent segment do use interference free channels. There is also a difference between the theoretical, ideal and real coverage of an
area. In the theoretical assumption hexagonal segments are usually taken which do not exist in reality. In reality the segments are determined by obstacles and physical effects such as attenuation and shadowing – as can be seen in figure 2 at the very right.

In order to determine the coverage area there has to be interference management and frequency reuse. When the area is large or there are many users several base stations have to be used. Therefore a frequency reuse plan is needed. Reuse patterns of 1, 3, 4, 7, 9, 12 and 21 are commonly in use – in figure 2 a frequency reuse plan of 3 is shown.

There are problems with unlicensed frequencies in multi-storey buildings because those frequencies are free to everyone. The signals propagate and interfere through different storeys. Therefore the use of very high gain directional antennas is recommended since they can concentrate their transmitting power into the direction where it is most needed.

For the radio network design it is important where the base stations are mounted. For the coverage of a building it is possible to either place the antenna inside a building, at the roof top or at a mast. When the site for the antenna is to be chosen it is important to make sure that the site provides radio frequency coverage for the entire area. On the other hand the coverage should not be too intense outside the aspired area for security reasons.

1.3 Antenna

Antennas play a very important role in network design. Their parameters determine the size and power of each radio network. In order to determine the antenna that is best for the application it is essential to ask some questions about the distance between transmitter and receiver, the needed fade margin, the building attenuation and whether the client’s devices will be mounted outside and so on. With all this gathered information the antennas can be chosen. There are different types of antennas:

- Omni directional antenna
- Sector antenna
- Unidirectional antenna.
For indoor use there are several base station locations possible. If an omni-directional antenna is in use it is best to install the antenna in the middle of the room at the ceiling. Directional antennas can be placed in the corners of the room or at the walls. A combination of these methods is possible. Waves usually do not propagate inside of building the way they do it outside due to the multiple reflections and attenuations. Therefore metal or cement walls, elevator shafts and utility wall (walls that do have many pipes and cables) have to be considered as special obstacles to the wave propagation characteristics of antennas.

Preferably directional or so called smart antennas should be used since there are strict limitations considering power. This enables interference and range control. The user device though is recommended to employ an omni-directional antenna since it is usually necessary to find the access point with the best serving qualities.

Antenna characteristics can be divided into:

- antenna height above ground level
- type of antenna
- exact working frequency
- azimuth
- transmit power
- receive density
- antenna gain
- horizontal patterns
- electrical and mechanical downtilt

Abbildung 3: Downtilt Calculation
Formula for inner radius distance in metres:

\[ d_{ir} = \frac{H}{\tan\left(\frac{A + \frac{BW}{2}}{2}\right)} \]

H  height of antenna in metres
BW vertical beam width in °
A  downtilt antenna in °

Formula for outer radius distance in metres:

\[ d_{or} = \frac{H}{\tan\left(\frac{A - \frac{BW}{2}}{2}\right)} \]

H  height of antenna in metres
BW vertical beam width in °
A  downtilt antenna in °

The mechanical downtilt is the sloping downward of the antenna meaning that the main beam is mounted aslope. On the other hand there is the electrical downtilt which causes the sloping downward of the main beam by electrical control.

For directional antennas common horizontal patterns are 180, 120, 90, 60, 45, 30 and 15°. Vendors usually give certain values so that the antenna that is to be used can be evaluated in a better way:

dBi  antenna gain referenced with an isotrope antenna
dBd  antenna gain referenced with an dipole antenna.

The planning of wireless networks is requiring the knowledge of different national laws. There are differences even in Austria and Germany regarding to:

- Transmitting power – signal strength
1.4 **Number of users and required data rates**

The theoretical possible number of users can differentiate widely from the number of current users that actually work with the network at a time. Anyways the worst case has to be considered in the calculations so that the user is always in possession of a certain minimum data rate level. That means that there has to be a definition of peak capacity requirements of users. This leads to the conclusion that not only the coverage area but also the number of users is important to network design.

The required data rate differentiates a lot between the possible applications. Whilst for example simple HTML-site access is also possible with a relatively small data rate, video conferences require much higher data rates. Hence the network designer has to consider whether a rather high or low signal strength at the work space of the user is required. In the optimisation phase of the network design this will become an important question.

Therefore the question of how many dB of radio path loss are still acceptable for the system without loosing functioning is very difficult to answer. The solution depends on the applications that are about to be used. So in order to calculate the bandwidth requirements an average usage per user has to be defined. It is an interesting parameter to know the total number of users per base station. The bandwidth per user can then be calculated by the radio information throughput divided by the number of user. It is furthermore recommended to adjust the data rate per base station by eliminating the overhead. A fade margin should always be budgeted since the radio networks are normally about to grow in the future.

The calculation of the maximum attenuation under which the system still works is given by the link budget.

\[
L_{\text{dB}} = P_{\text{tx}}[\text{dBm}] + G_{\text{tx}}[\text{dBi}] - P_{\text{rx}}[\text{dBm}] + G_{\text{rx}}[\text{dBi}] + G_{\text{dv}}[\text{dBi}] - M[\text{dB}]
\]

\(L\) link budget in dB
Ptx transmit power
Prx receiver sensitivity
M fading margin
Gtx antenna gain transmit site (antenna + coax cables + connectors)
Grx antenna gain receive site (antenna + coax cables + connectors)
Dfv diversity gain

The uplink and the downlink connection are unbalanced because the base station has higher transmission power than the client. Therefore a different link budget calculation per antenna needs to be made.

1.5 Costs

By defining a radio network system it might be also interesting to set an upper limit of costs. The cost factor usually includes capital expenses and operating expenses. For a complete cost overview about a network the costs that will appear after the initial installation need to be calculated as well.

Radio network planning includes more than just radio frequency aspects. First of all an important aim is to design a cost effective network. The costs can be reduced by choosing the right equipment. But there are also hidden costs that might be forgotten at first sight like the construction, interconnection, power and maintenance costs.

The capital expenses are rather easy to find. They contain all the one-time costs that are most likely to find at the beginning of the radio network planning. They contain the capital equipment, the construction, the design and the planning costs.

The operating expenses on the other hand are month-to-month costs meaning that they contain the leases, maintenance and utilities.
2 Wireless Standards

The Institute for Electrical and Electronic Engineers (IEEE) developed the 802 standard to deal with the physical and data link layers of the OSI model. Interoperability within the standard is guaranteed by the transparency to upper levels of the OSI model. Therefore it is of no importance for the functionality of the upper levels if a wired or a wireless network is used. For wireless communications the IEEE group defined the standard 802.16 for wireless metropolitan area networks, 802.11 for wireless local area networks and 802.15 for wireless personal area networks. The software for the CANDY project is dedicated to IEEE 802.11 and IEEE 802.16 networks.

2.1 IEEE 802.11

The IEEE 802.11 standard is referred to as an industrial standard for wireless network communications – wireless Ethernet - and is also known as WLAN (Wireless Local Area Network). LANs are characterised by their local limitation to less than a few hundred metres radius of the coverage area. The standard has been adopted in 1997. It defines several physical signalling techniques and interface functions that are controlled by IEEE 802.11 MAC. The operation of any IEEE 802.11 conformant device is possible in a WLAN. Also standards for privacy, security and authentication are delivered. The Wi-Fi forum was created by the industry in order to assure equipment interoperability to the IEEE 802.11 standard.
The different sub-standards can be differentiated by attached letters (IEEE 802.11a, IEEE 802.11b...). The most common standards nowadays are IEEE 802.11a, b and g. The sub-standards are using different frequencies and transmission techniques. Whilst IEEE 802.11a and the still to be adopted IEEE 802.11n standard are sending their signals on 5 GHz ISM frequency band (industrial-scientific-medical), which is a licensed band and is using a rather large 405MHz frequency band, the IEEE 802.11b and IEEE 802.11g standard are operating on the 2.4 GHz ISM frequency band with a rather small frequency band of lower than 100 MHz. The IEEE 802.11 b and IEEE 802.11g standard show interoperable characteristics. Since this frequency is licence-exempt, there are possible interferences with other transmitters like bluetooth, microwave ovens and baby-phones.

WLANs can be used in the infrastructure or the ad hoc mode. The infrastructure mode means that they can have a base station and several receivers that are communicating exclusively with this access point as in the infrastructure mode. The ad hoc mode operates with an installation without an access point thus making the communication directly between the partners. Anyhow the infrastructure mode is much more common and is the one that is furthermore regarded in this thesis.

### 2.1.1 IEEE 802.11a

IEEE 802.11a is using the 5 GHz ISM frequency band which is different from the one for IEEE 802.11b and IEEE 802.11g. Therefore those standards are not compatible but coexist. IEEE 802.11a works with the OFDM (Orthogonal Frequency Division Multiplex) which is a multiple carrier signal technique. Data transfer rates up to 54 Mbps are possible. Because the standard is incompatible with IEEE 802.11b and IEEE 802.11g devices it is not as widespread as the others which were introduced to the market much earlier. The number of channels is 34, 38, 42 or 46.

### 2.1.2 IEEE 802.11b

The IEEE 802.11b standard is still a widespread standard due to the compatibility with IEEE 802.11g. It was published in 1999 and operates at the 2.4 GHz ISM frequency band. A data
transfer rate lower than 11 Mbps is possible which is why this standard has been mainly replaced by the 802.11g standard. The standard supports just certain intervals of speed, which are 1, 2, 5.5 or 11 Mbps on the same hardware.

There are 11 channels in the USA and 13 channels in Europe, except France and Spain, but only 3 can be used at a time because of interference problems which occur when channels are overlapping. Each channel covers 20 MHz from 2.4 to 2.487 GHz with 5 MHz distance to the next channel. Interference problems mean that there will be inter-carrier interference which will enlarge the noise in the system.

### 2.1.3 IEEE 802.11g

This standard is an improvement to 802.11b. It employs the same frequency band but instead of Direct Sequence Spread Spectrum (DSSS), that is used for IEEE 802.11b, it works with the same modulation standard namely OFDM as IEEE 802.11a. This allows a data transfer rate of up to 54 Mbps which is equal to the one of IEEE 802.11a but has the advantage of being backward compatible with 802.11b. The coverage distance depends highly on the obstacles that are in the line of sight.

### 2.1.4 IEEE 802.11n

The IEEE 802.11n standard is a new amendment to the 802.11 standard and is yet to come. There are no final specifications so far but the theoretical data throughput is assumed to be 540 Mbps and the distance ranges are supposed to be larger then the IEEE 802.11a,b or g standards. The standardization process is expected to be completed in the later 2006.

IEEE 802.11n employs OFDM and MIMO (multiple-input multiple-output) which uses multiple transmitter and receiver antennas to enable increased data throughput. That is done by spatial multiplexing. It also increases the range by exploiting the spatial diversity.
<table>
<thead>
<tr>
<th>Standard</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11</td>
<td>Original standard, 2,400-2,485 GHz (unlicensed); 1-2 Mbit/s; Out of date; Not in broad use any more (1997)</td>
</tr>
<tr>
<td>802.11a</td>
<td>Enhancement of physical layer; 5 GHz; 54 MBit/s; minor (1999)</td>
</tr>
<tr>
<td>802.11b</td>
<td>Enhancements to 802.11 to support 5.5 and 11 Mbit/s (1999)</td>
</tr>
<tr>
<td>802.11c</td>
<td>Bridge operation procedures; included in the 802.11d standard (2001)</td>
</tr>
<tr>
<td>802.11d</td>
<td>International (country-to-country) roaming extensions (2001)</td>
</tr>
<tr>
<td>802.11e</td>
<td>Enhancements: QoS, including packet bursting (2005)</td>
</tr>
<tr>
<td>802.11f</td>
<td>Inter-Access Point Protocol (2003)</td>
</tr>
<tr>
<td>802.11g</td>
<td>54 Mbit/s, 2.4 GHz standard (backwards compatible with b) (2003)</td>
</tr>
<tr>
<td>802.11h</td>
<td>Spectrum Managed 802.11a (5 GHz) for European compatibility (2004)</td>
</tr>
<tr>
<td>802.11i</td>
<td>Enhanced security (2004)</td>
</tr>
<tr>
<td>802.11j</td>
<td>in Japan; 4.9-5 GHz</td>
</tr>
<tr>
<td>802.11k</td>
<td>Radio resource measurement enhancements</td>
</tr>
<tr>
<td>802.11l</td>
<td>(reserved, typologically unsound)</td>
</tr>
<tr>
<td>802.11m</td>
<td>Maintenance of the standard; odds and ends</td>
</tr>
<tr>
<td>802.11n</td>
<td>Higher throughput improvements</td>
</tr>
<tr>
<td>802.11o</td>
<td>(reserved, typologically unsound)</td>
</tr>
<tr>
<td>802.11p</td>
<td>WAVE - Wireless Access for the Vehicular Environment (such as ambulances and passenger cars)</td>
</tr>
<tr>
<td>802.11q</td>
<td>(reserved, typologically unsound, can be confused with 802.1q VLAN trunking)</td>
</tr>
<tr>
<td>802.11r</td>
<td>Fast roaming</td>
</tr>
<tr>
<td>802.11s</td>
<td>ESS Mesh Networking</td>
</tr>
<tr>
<td>802.11t</td>
<td>Wireless Performance Prediction (WPP) - test methods and metrics</td>
</tr>
<tr>
<td>802.11u</td>
<td>Interworking with non-802 networks (e.g., cellular)</td>
</tr>
<tr>
<td>802.11v</td>
<td>Wireless Network Management</td>
</tr>
<tr>
<td>802.11w</td>
<td>Protected Management Frames</td>
</tr>
</tbody>
</table>

Tabelle 1: IEEE 802.11 standards
2.2 IEEE 802.16

The IEEE 802.16 standard is a wireless protocol which focuses on last-mile-applications of wireless technology for broadband access. As well as IEEE 802.11 it is normalizing the layers 1 and 2 of the OSI model.

Its most commonly know subcomponent is IEEE 802.16a, also called WiMAX (worldwide interoperability for metropolitan access) and is an improvement to WLAN-technologies in regard to the coverage area and data rate. Currently some licensed frequency bands of the frequency regions 2-11 GHz for non line of sight connection (NLOS) and 10-66 GHz for line of sight connections (LOS) are used. But it is planned to use the both licensed and un-licensed frequency bands. All frequencies above 6 GHz require a LOS connection.

WiMAX has another advantage. The standards are developed by the WiMAX Forum which is a cooperation of numerous large companies like Nokia, Deutsche Telekom, Alcatel and so on. Therefore the standard requirements are definitively used by the industry and the customers do not have a manufacture-depended solution. The IEEE 802.16 standard is also fully inter-operational with the IEEE 802.11 standard assuring that users do not need to buy new equipment to use the technology.

It is noted that the coverage area might be up to 50 kilometres and the maximum data transfer rate is up to 109 Mbps if there is a LOS connection between transmitter and receiver which is much larger than the bandwidth transmission facilities of WLAN.

WiMAX is supposed to be an alternative to DSL for Metropolitan Area Networks (MAN) in those regions where there is too much traffic or cabling is too expensive. Up to now the last mile of radio communications was always cabled which hand plenty of disadvantages like the diminution of the high speed due to cable losses that would normally have been possible with radio networks. But there are problems like the relatively high transmitting power and the radio frequencies which are partly allocated by another radio technique called “Wireless Local Loop” that did not succeed so far. Also the unlicensed radio frequencies provide some problems since they are free to everyone including amateur radio operators who have a “primary” right to the allocated frequency band. That means that in the worst case they are even allowed to override the band. There is also the problem of interference.
The radio network technology is a very fast changing technology which is why although the IEEE 802.16 standard was just introduced there are already out-of-date subcomponents. The first time that IEEE 802.16 was introduced to the market was in late 2003. The initial standard does not provide high speed wireless communication for mobile users but IEEE 802.16e is offering high speed connectivity for vehicles with up to 150 kilometres per hour.

Current standards:
- IEEE 802.16-2004
- IEEE 802.16.2-2004
- IEEE 802.16/Conformance01-2003
- IEEE 802.16/Conformance02-2003
- IEEE 802.16/Conformance03-2004

Future standards:
- IEEE Draft 802.16e
- IEEE Draft 802.16f

Out-of-date standards:
- IEEE 802.16-2001
- IEEE 802.16a-2003
- IEEE 802.16c-2002
- IEEE 802.16.2-2001

The following table shall give a survey of the currently most used standard IEEE 802.16a and the yet to come IEEE 802.16 standard comparing their characteristics.
<table>
<thead>
<tr>
<th>Completion date</th>
<th>2001</th>
<th>2003/2004</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range</td>
<td>10 – 66 GHz</td>
<td>2 – 11 GHz</td>
<td>2 – 6 GHz</td>
</tr>
<tr>
<td>LOS / NLOS</td>
<td>LOS</td>
<td>NLOS</td>
<td>NLOS</td>
</tr>
<tr>
<td>Bit rate in Mbps</td>
<td>32 - 134</td>
<td>75</td>
<td>15</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM, 64QAM</td>
<td>QPSK, 16QAM, 64QAM, QFDM 256</td>
<td>QPSK, 16QAM, 64QAM</td>
</tr>
<tr>
<td>Channel bandwidth in MHz</td>
<td>20 ; 25 and 28</td>
<td>1.25 – 20</td>
<td>20 ; 25 and 28</td>
</tr>
<tr>
<td>Cell radius in miles</td>
<td>1 – 3</td>
<td>3 – 5</td>
<td>1 – 3</td>
</tr>
</tbody>
</table>

Table 2: comparison IEEE 802.16 standards

2.3 Conclusion

The requirements for the wave propagations models are determined by coverage area and frequency. The frequency range of the wave propagation coverage area theoretically needs to be from 2 up to 66 GHz ISM frequency band but since the WiMAX technique is just about to be taken over in practical purposes it is definitely enough to concentrate on the frequencies that are nowadays in use. The selection of the frequency the system is operating with will determine the range, the capacity and the spectrum that is available as well as the costs of the technology and the link quality. The most widespread spectral allocations today are:

- 2.4GHz
- 3.5 GHz
- 5 GHz
- 5.8 GHz.

Also the coverage area is very important. It is very unrealistic that the cell radius is larger than 30 kilometres and even that number is still high. Therefore the wave propagation model needs to be valid for a distance from 0 up to 30,000 meters from the transmitting to the receiving antenna.
The frequencies are subdivided into a certain number of frequency ranges. In case of WLAN and WiMAX those are:

<table>
<thead>
<tr>
<th>Frequencies (in GHz)</th>
<th>Free-space Wavelength (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra High Frequency (UHF)</td>
<td>0.3 – 3</td>
</tr>
<tr>
<td>Super High Frequency (SHF)</td>
<td>3 – 30</td>
</tr>
<tr>
<td>Extremely High Frequency (EHF)</td>
<td>30 - 300</td>
</tr>
</tbody>
</table>

**Tabelle 3: frequency ranges**

Finally I will emphasise the similarities and differences of IEEE 802.11 and 802.16 in a comparison.

<table>
<thead>
<tr>
<th></th>
<th>802.11</th>
<th>802.16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>Cell size 100 m ; ~ 1 km distance range</td>
<td>Cell size 1-10 km; 50 km distance range</td>
</tr>
<tr>
<td>Coverage</td>
<td>Indoor environment</td>
<td>Outdoor environment</td>
</tr>
<tr>
<td>Scalability</td>
<td>Channel bandwidth: 20 MHz</td>
<td>Channel Bandwidth: 1.25 – 20 MHz</td>
</tr>
<tr>
<td>Max. Bit rate</td>
<td>54 Mbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>QoS</td>
<td>802.11e</td>
<td>QoS integrated in each standard</td>
</tr>
</tbody>
</table>

**Tabelle 4: comparison IEEE 802.11 and IEEE 802.16**
3 Wave Propagation Models

The propagation models are an opportunity to evaluate the coverage of a radio network system without temporarily installing the hardware equipment first. Nevertheless it is still necessary to do a physical survey before finally installing the network because the wave propagation models are just giving an estimation of the signal strength.

In this section some planning methods for the determination of electromagnetic field strength in any point of the wireless network considering the distance to the access point are presented. At the end the use of each single method for the planning of WLAN and WiMAX networks in the CANDY project shall be evaluated.

The frequencies in wireless networks do have similar wave propagation characteristics as light. In a disturbance-free environment they are broadcasted directly and evenly in all directions from the antenna. Due to the fact that such a free space propagation does not exist in real environments radio waves show one or more of the following characteristics:

- Attenuation
- Reflection
- Diffraction
- Diffusion
- Shadowing effects.

A further result might be multiple path propagation. If frequencies above 10GHz are used for the transmission also the following factors can cause additional attenuation. The attenuation of those effects increase the higher the frequency is.

- Ground waves
- Ionosphere
- Atmospheric attenuation
- Rain fade.

In case of discrete frequencies which correspond with the natural frequency of the molecules that exist in the atmosphere, resonance absorption by oxide and hydrogen occurs.
The examined wave propagation models are subdivided into empirical models, that employ statistical formulas and are not considering the real environment, and analytical models, that consider the characteristics of wave propagation like attenuation and diffraction and the environment.

Abbildung 5: Classification Wave Propagation Models

3.1 Fully empirical

Fully empirical wave propagation models employ the statistical evaluation of many measurements. After choosing an appropriate approximation formula an estimation of real-world propagation of the expected signal strength at a certain point is given.

Different models have been developed for the GSM networks but they are suitable for neither WiMAX nor WLAN networks because of their frequency range. They usually range up to 1.8 GHz and sometimes up to 2 GHZ. But since the formulas were developed by the statistical analyses of measurements there is no chance to use those models in the planning of WLAN or WiMAX networks. Such are:

- Okumara-Hata
- COST-Hata
- Log-Distance-Path-Loss
- CCIR-Model.

3.1.1 Longley-Rice
The Longley-Rice model has been developed by Anita Longley and Phil Rice in 1968. It is known under the names Longley-Rice Model or Irregular Terrain Model. The frequency range of the model ranges from 20 MHz up to 20 GHz. It can be applied to a large variety of engineering problems. The model, which is based on electromagnetic theory and on statistical analyses of both terrain features and radio measurements, predicts the median attenuation of a radio signal as a function of distance and the variability of the signal in time and in space. The distance that can be covered with this algorithm ranges from 0.1 up to 2000 kilometres which makes the algorithm useful in outdoor environments. It even considers the climate.

The Longley-Rice Model was accepted by the Federal Communications Commission (FCC) as a wave propagation model. This fact ensures a certain reliability of the algorithm. Unfortunately I could not find the algorithm but an agency of the U.S. Government - the NTIA/ITS – provides a C++ source code which is implementing the formula under http://flattop.its.bldrdoc.gov/itm/ITMDLL.cpp.

3.2 Semi empirical

Semi empirical wave propagation models employ theoretical approaches like the estimation of diffraction attenuation by multiple-knife-edge models or the dual beam theory which will be combined with empirical corrections. Examples for this type of model are:

- Okumura-Hata and Knife-edge
- COST-Hata and Knife-edge
- Walfisch-Bertoni
- Walfisch-Ikegami
- COST-Walfisch-Ikegami

Unfortunately they were developed for frequencies up to 2 GHz which means that they cannot be used for neither WLAN nor WiMAX networks.

3.2.1 Simple Diffraction Models
Simple diffraction models are a special type of semi empirical models. The above mentioned problem, that they are not suitable for frequencies above 2 GHz, occurs here as well. Another problem is that they only apply diffraction as an effect although reflection might be the more effective problem in some cases.

- Epstein-Petersen
- Deygout
- Giovaneli
- Cascaded-Cylinder.

### 3.3 Ray optical

The ray optical wave propagation model searches all relevant wave propagation paths under consideration of cultivation and relief variations. The transmission behaviour of each single path is calculated. The receiving power is calculated by the utilization of all the parameters of all the propagation paths. Ray optical models can either be in 2D or in 3D.

![Abbildung 6: Multipath Propagation And Separation Into Single Paths](image)

It has been shown that in radio networks some simplifications can be made since the effects are caused by objects that are rather large in comparison with the wavelength (>5λ). The most important methods are:
- Geometrical Theory of Diffraction (GTD) and Uniform Theory of Diffraction (UTD)
- Physical Optics (PO)
- Physical Theory of Diffraction (PTD) and Method of Equivalent Currents (MEC).

As can be seen in the following figure the wave propagation in reality is much more complicated than the empirical models which are taking just one single path – the direct path between transmitter and receiver – into consideration. Therefore effects like reflection and diffraction are given a higher priority in the ray optical models in order to give a more precise simulation of the reality. As can be seen in figure 6 the illumination in point A differentiates a lot from the illumination in position B although there are not more walls in the direct path between transmitter and receiver. Especially at higher frequencies it seems to be important to use more exact algorithms.

Abbildung 7: Ray Optical Model

In order to use the ray optical algorithms in network design programmes it is better to concentrate on the 2 or 3 main rays between transmitter and receiver that carry about 90% of the energy. Therefore special models have been developed. One major model is the “Dominant Path Model”.

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3.3.1 Dominant Path Model

The dominant path model for indoor use was developed by G. Wölfle and F. M. Landstorfer.

To start with the algorithm the building blueprint needs to be taken. All the rooms on one floor are numbered in the way that the room with the transmitter is always room number 1.

Afterwards all the interior walls get each one a unique letter.

The following step is to develop a so-called “room tree”.
The root of the tree is always the room with the transmitter. For every wall that is adjacent to the tree there is a new branch with the indication of the letter for the wall and the room where it leads to. Each new branch is now treated with the same procedure – all coupling walls indicate a new branch – but if the wall is already used in that branch it is not taken a second time. For example: From room number 1 it is possible to pass wall A to come to room 2 where else from room number 2 the ray can just pass wall B since wall A was already used in that branch. Since this algorithm is deterministic and finite. As a result there are all possible ways the rays can take as a leaf of the tree.

The last step is the selection of the minimum–loss dominant path (MLDP). For each leaf the total attenuation is calculated. It is composed by:

\[ L = w_{FS} \cdot L_{FS} + w_{T} \cdot L_{T} + w_{I} \cdot L_{I} \]

- \( L \): total attenuation
- \( w_{FS} \): weighting factor
- \( L_{FS} \): free space loss
- \( w_{T} \): weighting factor
- \( L_{T} \): transmission loss
- \( w_{I} \): weighting factor
- \( L_{I} \): interaction loss

With the Free Space Loss that is calculated by:
Another part of the total attenuation is the transmission loss:

\[ L_T = \sum_{i=1}^{N_T} L_i \]

The interaction loss is calculated with the following formula:

\[ L_i = \frac{1}{\alpha_L} * \sum_{i=1}^{N_i} \alpha_i \]

angle, changes in direction of path

In order to find the path with the minimum loss the results of the leaves with the same receiver position are compared. It is even possible to take 2 or more paths together.

In the case that the aim is to calculate the attenuation of a path inside one room which might be obstructed by interior walls the algorithm works similar. First of all the corners get numbered and as a result the corner tree is developed. Next step is to discover the leaf with the least attenuation by diffraction.
3.4 Field theoretical

The field theoretical wave propagation models are based on the direct numerical solution of the Maxwell equations with integral or differential equation systems. Indoor wave propagation or wave propagation in town need very much calculation time and memory space since the entire simulation area needs to be discretised into $1/10^{th}$ of the wave length.

- Integral Equation Method
- Parabolic Equation Method
- Finite Element Method
- Finite Difference Time Domain

3.5 Conclusion

Although field theoretical models deliver the most exact results they are not the optimal solution for the CANDY project because of their extremely high calculation time and requirements for memory. Empirical models on the other hand do not give results that match with the reality. The problem in this case is the fact that the architecture of a building is not at all considered in the calculation of the field strength which makes those models useless in indoor calculations. Since microwaves are used already items at the size of the wave length are hindering the waves from their direct dispersion. With the high frequencies as are used in WLAN and WiMAX already small items can be seen as problems if they are obstructing the line of sight between transmitter and receiver.
My recommendation is to implement ray optical wave propagation model “Dominant Path Model” for all indoor applications due to their compromise of a relatively high accuracy in comparison with empirical models and their minor calculation time compared with field theoretical models.

It might be useful though to compare the results of the empirical Longley-Rice model with the ray optical one of the same spot. It is possible that environment plays an important role like in climate zones but it is difficult to give an exact opinion since there are no comparing results so far.

<table>
<thead>
<tr>
<th></th>
<th>Empirical &amp; Semi-Empirical</th>
<th>Ray Optical</th>
<th>Field Theoretical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marginal Checking</td>
<td>No</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>Longley-Rice</td>
<td>Ok</td>
<td>Ok</td>
</tr>
<tr>
<td>Distance Range</td>
<td>Nothing near the transmitting antenna</td>
<td>Ok</td>
<td>Few meters</td>
</tr>
<tr>
<td>Application Area</td>
<td>All</td>
<td>All</td>
<td>Inside buildings</td>
</tr>
<tr>
<td>Systematic Errors</td>
<td>High</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Simplicity</td>
<td>Simple</td>
<td>Large scale</td>
<td>Very Large scale</td>
</tr>
<tr>
<td>Needed Input</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Calculation Cost / Computing Power</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Precision</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Resolution</td>
<td>Low</td>
<td>High</td>
<td>Very high</td>
</tr>
</tbody>
</table>

Tabelle 5: Comparison Wave Propagation Models
4 Visualisation and Positioning Algorithms

4.1 Multi Colour Ink Spot Model

The multi colour ink spot model has been published by A. Geitmann. It is supposed to find the optimal coverage within a WLAN depending on the number of users and their behaviour. The model takes into account the number of users and the minimum bandwidth the user needs.

The building blueprint is not scanned but inserted by the user himself. There is a class called “room” in which an ID of the room, 2 coordinates of the room and the number of users must be given. The walls are getting specific attenuation parameters.

The number of access point is simply depending on the number of users and the bandwidth they need.

\[ P = \frac{B_{b_{\text{min}}}}{B_{b_{\text{max}}}} \sum_r n_r \]

- \( P \) number of access points
- \( B_{b_{\text{min}}} \) minimum bandwidth in Mbps
- \( B_{b_{\text{max}}} \) maximum bandwidth in Mbps
- \( N_r \) number of users in room \( r \)

The increasing and respectively decreasing of colour intensity is depending on the distance to the access point. The access point itself and the nearest surrounding gets the darkest colours. The colour is calculated by the following formula:

\[ C'_r(x, y) = \frac{1}{\sum w_i + w_{\text{air}}} \cdot \frac{B_{b_{\text{max}}}}{D'(x, y)^2} \cdot n'_r \]

- \( B_{b_{\text{max}}} \) maximum bandwidth in Mbps
\[ C_i^r(x,y) \] colour intensity in room with access point i

\[ n_i^r \] number of users in room r that are belonging to access point i

\[ D^i(x,y) \] distance to access point i in metres

\[ w_1 \] wall attenuation

\[ w_{air} \] air attenuation

Abbildung 14: Multi Colour Ink Spot Model

The advantage of the algorithm is that it provides a first overview about the possible coverage area of all the access points (APs). Since the algorithm is empirical there is a high probability of getting the falsified results.

Another disadvantage is that the rooms can only be rectangles. Attenuation of walls is considered but the algorithm does not deliver exact results. As we can see in the figure above the attenuation does not look like in reality. AP1 cannot have the same illumination in room 2 like in room 1. Phenomena like reflection or diffraction of signals are not considered. And there is another weakness of the algorithm. The APs take the weakest signal in their coverage area to determine the modulation technique that they will use. So taking always the maximum bandwidth that the access point offers under best circumstances is not useful.

In my opinion the inkspot model itself as a visualisation is a good idea but we need to exchange the bandwidth totally. Instead the signal strength should be used. Since many vendors even offer with their product a table wherein the data rate can be determined by looking at the signal strength it is better to determine the signal strength and do the backward
calculation. In this algorithm no hardware is considered. There is neither a determination of the frequency nor any antenna gain.

### 4.2 Standort Finder

T. Fahnert developed the model last year. He suggested a formula which is relying on the Friis Lost Space Model.

\[
P_E = P_S - 20 \log \left( \frac{4 \pi f}{c} \sqrt{\left(\frac{h_d - h_t}{d}\right)^2 + d^2} + G_s + G_E - D_W - P_{\text{Sicher}} \right)
\]

- \(P_E\): received signal strength
- \(P_S\): transmitting power
- \(f\): frequency in Hz
- \(c\): speed of light
- \(G_s\): antenna gain transmitter
- \(G_E\): antenna gain receiver
- \(D_W\): attenuation factor
- \(P_{\text{Sicher}}\): security factor

The advantage of this model is the simple calculation due to the fact that this is an empirical model. It is an improvement to the Friis Lost Space Model in regard to the distance calculation.

But there are several disadvantages. First the Friis Lost Space Model is limited in regard to the frequency range which has to be lower than 2 GHz. It is also mainly a model for far field regions and is not particularly suitable for small distances. This means that Friis assumed for example an unobstructed path. Although the algorithm corrects the results by introducing a new attenuation factor \(D_w\) it is not likely that the equation works. For example: If there are two adjacent rooms the signal might either pass through the wall or be reflected in the hallway. Therefore the signal strength might be much higher in reality than the calculated signal.
Another problem is that up to now there are no measurements which are either proving or disproving the correctness of the equation. It might be interesting to run a few tests if the formula can be used.

In the research thesis he also suggested an algorithm to find an initial placement for access points inside a building. The area that needs to be covered is separated in as many smaller regions as necessary in order to reach a possible theoretical coverage of each spot in the area. Then the first AP is placed in the middle of the first area. If the position is outside the building the algorithm is switching the position into the nearest border of the area. After that the algorithm is checking if the entire area has coverage. If not the regions are furthermore subdivided.

This algorithm is actually pretty interesting because it delivers a possible initial positioning of the antennas. There is of course the problem that the neither the users nor their needed bandwidth or signal strength are considered. If too many users are about to be allocated to a certain base station, the area could be subdivided into square grids. Each of those square grids is supposed to get a base station.

And the algorithm might deliver another difficulty concerning security. Since the access point are moved to the border of each region if they are not placed properly in the first time it might occur that many access points are near walls which allows snooping outside the building.

4.3 Heightmap Model

This model was developed by A. Dorawa and is dedicated to WiMAX – especially the standard IEEE 802.16a. It is combining several wave propagation models into a hybrid model with empirical and ray optical background.

In order to find an appropriate description of the environment the model works with a 3D height map. The algorithm needs to know 2 points with their coordinates and the highest as well as the lowest point. Afterwards the height is interpolated and given a certain grey value.
Subsequently an area can be high lightened where the antenna is supposed to be placed and the algorithm is proposing the best position.

Afterwards the Fresnel Zone is calculated. As described earlier the Fresnel Zone is subdivided into several ellipses in which the first is the most important and has to be almost obstacle free in the best case. Afterwards the algorithm suggests a comparison if there is any obstacle in the direct path between transmitter and receiver by checking the air-line distance. If there are less than 20% of the Fresnel Zone penetrated the signal strength at each point will be calculated with the Free Space Loss formula. From the transmitter every possible angle – in steps of $1^\circ$ - is analysed. The algorithm terminates if the signal strength fall below a certain level.

The disadvantage for this algorithm is that it is not suitable if there is any obstacle in the way because the formula that is used does not work for those cases. Anyhow the algorithm is an interesting idea but will most likely not be used in practise.

### 4.4 Conclusion

After the analyses of those different visualisation and positioning models one important fact needs to be noted. The algorithm needs to be fast. Therefore it is recommended to use the “Standort Finder” in the first place to place the equipment and afterwards do the optimisation by adding the number of users and their behaviour. The number of APs can be calculated with the formula of the ink spot model:

$$P = \frac{B_{b_{\text{min}}}}{B_{b_{\text{max}}}} \sum_{r} n_r.$$

The maximum bandwidth that is provided can be determined by the signal strength. My recommendation is that for the indoor case the signal strength in each room can be calculated with the Dominant Path algorithm – by starting at the very left and upper point of the map and then move on. Afterwards the result is compared with the bandwidth table of the vendor. The formula can be applied to determine the number of needed access points.
For the visual part the ink spot model was actually quite useful if the standard is IEEE 802.11b. In case of IEEE 802.11a there are 19 channels available. It is therefore necessary to employ a different model.

The signal strength can be indicated with the same colour for each value. Maybe there could be 4 values of signal strength for each room. The intervals of signal strength should not be taken too small since the result will still be just an estimation of the real world.
5 Design tools

5.1 Ekahau Site Survey

Ekahau Site Survey is a tool that graphically indicates the radio propagation and can be used for both analysis of already existing networks and WLAN simulation. Whilst for the analysis there needs to have at least a temporary installation of all network components the simulation employs just a manually parameterised map. Therefore the user scans a map and accumulates it in the drawing tool with details like windows and walls with a certain attenuation factor.

The analysis is basically walking through the spot with a computer that is able the measure constantly the network parameters like signal strength and noise. As result a map is presented where the signal strength, overlapping areas and the borders of the network are shown. If no building blueprint is scanned the evaluation will be done in tables. All the access points can be parameterised with speed, packet loss and channels in use.

For the simulation the user needs to place the access points himself in the scanned map. The results will be signal strength, signal-to-noise-ratio (SNR), overlapping areas and the borders of the network. As with the analysis the results can be saved or printed. A report in .html is possible as well.

It is possible to recognise access points in reach of the measurement position and to show the signal strength, the channel noise and the signal to noise ratio. There is also GPS integrated in the tool so that users can be localised in the network.

The tool is designed so far exclusively for the 802.11 a, b and g standard. There are several modules which might enhance the programme like the module “Planner” that is calculating the optimal position of access points and the module “Reporter” that produces reports in .xml. The maps can be imported as images or CAD files.

Unfortunately there was no possibility to find out, which wave propagation models has been used.
5.2 **CISCO Wireless Control System (WCS)**

CISCO Wireless Control System was programmed to simplify the planning, configuration and maintenance of WLAN systems. It provides radio frequency (RF) prediction, policy provisioning, network optimization, troubleshooting, user tracking, security monitoring, and management of wireless LAN systems. Cisco WCS runs on a server platform with an embedded database. The software provides integrated RF prediction tools that can be used to create a detailed wireless LAN design, including lightweight access point placement, configuration, and performance or coverage estimates. Real floor plans can be imported into Cisco WCS and assign RF characteristics to building components to increase design accuracy. Graphical heat maps help to visualize anticipated wireless LAN behaviour. The tool also provides a portal into the real-time RF management capabilities including channel assignments and access point transmit power settings.

Cisco WCS collects important network information, such as noise levels, signal-noise ratio, interference, signal strength, and network topology, so that the network administrator can easily isolate and resolve problems at all layers of a wireless network. The programme can automatically discover individual devices within a wireless network which will eliminate the need for manual database configuration and maintenance, and provides accurate information for capacity planning and troubleshooting purposes. The output is given in images and several reports in order to document network activity and system information. This includes client statistics, radio utilization data, 802.11 counters, RF management configuration history, and alarms.

5.3 **Airespace Control System**

The Airespace Control System is a simulation tool which needs to be installed on a server. The programme is using a database that enables a simpler management of all APs and other hardware devices. The Airespace Control System functionality ranges from the calculation of radio frequency propagation to the optimisation of networks. It is also possible to localise
snooping since there is a tool that can determine the position of each user. That increases the security in the network.

The input is done with graphical user interfaces. It is possible to import building blueprints and enhance them with walls, windows and certain attenuation factors.

### 5.4 AirMagnet Surveyor

AirMagnet Surveyor makes the analysis and simulation of 802.11a, b and g wireless network possible. AirMagnet Surveyor is the only solution that performs active surveys, which means that it is associating to specific access points or Service Set Identifiers (SSID) to gather actual end user performance information -and multi-storey site surveys. This software automatically gathers critical RF information from the network using multiple data collection methods and generates detailed maps of the results for easy network deployment, provisioning and optimization.

The programme also determines the optimal access point placements and their power settings. Another feature is that it analyses any sources of interference or noise. If there is any outdoor activity the GPS device will automatically know where the user is and automatically record data, without the need for the user to manually map locations during the survey.

One advantage of the software is the multi-storey survey where up to four floors can be integrated into one structure. This means that the signals of the access points can actually pass through into other storeys and the user can see the effects and prevent interference zones. The output is either in report form or graphically which makes the analysis much simpler.

The system allows passive as well as active survey. In the passive survey the Surveyor collects all the information from the hardware whilst active survey provides a reality check with packet loss, connection speed, package retry rates and so on. Those results can be combined in the reports. The reports include Signal, Noise, SNR, Frame Speeds, Retry Rates, and Packet Loss.
5.5 Airopeek

Airopeek is a network analysing software for Wireless Ethernet LAN based on the IEEE 802.11b standard. It is collecting wireless Ethernet packages. Therefore it is necessary to install a Wireless Ethernet PC Card which supports AiroPeek with a special driver.

AiroPeek NX was developed for Windows 95/98/ME/NT/2000/XP. Additionally to the information for the Ethernet Packages the software also measures signal strength, data throughput, the channel that is currently used and the evaluation of the radio cell quality.

5.6 EMF Visual

This simulation software has been developed by Antennessa and uses a ray optical wave propagation model which enables the software to deliver very exact results especially in the close area to the antennas that are used in radio networks like GSM and UMTS. This tool provides the opportunity to compare the calculated with the measured results. Its reach is limited to a few hundred metres.

A 3D graphical interface allows the user to model realistic scenes. There are already 3D models of the model ground, buildings, indoor objects etc. in an object library available. There is an antenna library with all the current antennas that are used in GSM and UMTS networks. The calculation is based on ray tracing. The tools also considers national recommendations like safety distance.

5.7 Radio Plan Survey

Radio Plan Survey is appropriate for indoor and outdoor applications. The user can determine several level of detail depending on the environment. The software is specialised for UMTS frequencies.

This software employs the COST231-Walfisch-Ikeami, the COST231-Multi-Wall-Model and ray tracing simulation that means that effects like attenuation, reflection and diffraction can be
considered. A hybrid simulation is possible. The fundament of the software is a road map which can be enhanced with several details like the height of buildings and so on. The simulation can be made either in 2D or in 3D. The advantage of the programme is that it uses a simple version of CAD that is implemented in the programme. Therefore all file formats of CAD are accepted. The results can be given in CAD files or ASCII.

The results of the programme are coverage, indication of areas that are not well served and tables with the maximum signal strength, all base stations in the reach and so on for the single receivers.

5.8 Radio Mobile Deluxe

This simulation freeware of a radio network by Roger Coudé is based on the irregular terrain model by Longley and Rice (see above in chapter 3). Since it is using an empirical model it is not calculating with actual morphology (no location of buildings, trees, roads) but adds several morphological factors. Therefore the prediction is based on average morphology density. The accuracy of the model and therefore the software increases in environments where there is basically no multipath propagation. It is not suitable for indoor wave propagation prediction. Radio Mobile Deluxe was developed for Windows 95/98/ME/NT/2000/XP.

5.9 Wireless Insite

Wireless Insite is a radio propagation programme for the frequency ranges for GSM 900, GSM 1800 and UMTS and was developed by Remcom. It is based on the ray optical wave propagation model and provides the opportunity to model a 3D simulation environment. It is suitable for indoor use as well. The results are not given as field strength at a certain position but as received power by the antenna. That means that in order to get a 3D model with the signal strength in an area a large number a receiver antennas needs to be positioned.

The parameters that the user needs to provide like the parameters of the antennas and the morphological information can be either imported in the programme or generated in the programme itself.
5.10 Quickplan

Quickplan is a simulation software for terrestrial cellular network and has been developed by TeS Teleinformatica e Sistemi s.r.l. This programme is based on the ray optical model. All parameters that are necessary for the calculation like type of antenna, building blueprints, etc. are filed in an Oracle database that is integrated in the software. A surface calculation for signal strength and received power is possible.

The programme is valid for the frequency ranges of GSM 900, GSM 1800 and UMTS and it is also designed to be used in far field regions. There are several possible environments that can be simulated like rural, sub-urban and urban regions but the programme is not suitable for indoor projects.

5.11 Empire and Feko

Empire was developed by IMST GmbH and is based on the field-theoretical model with the FDTD method. It is solving the time and space discrete Maxwell equations directly.

Feko is also based on the field theoretical method with the “Moment Method”. This method allows to calculate the surface currents on conducting surfaces as well as electrical and magnetic surface currents on dielectric materials. If the current distribution is known parameters like the near field, the far field and input impedance of antennas can be determined. Since Feko is integrating asymptotic methods like “Physical Optics” and “Uniform Diffraction Method” it is a hybrid programme.

The calculation time and memory requirements are rather high for both programmes. Therefore it is necessary to narrow down the region of interest. It is also important to know the electrical and geometrical characteristics of each antenna very detailed in order to get an exact modelling. The advantage of both programmes is that once the user fed in all the parameters the detailed results are very precise.
6 Concept of network planning tool

6.1 Description

The aim of the software is to support radio network designers. The user shall be able import maps, mark the regions of interest and configure the radio network with the menu driven software. Afterwards the user shall get an impression of a possible configuration by a suggested initial installation of the network components where the covered regions are highlighted. Subsequently the user shall be able to decide if he wants to optimise the network under certain aspects like costs, coverage and so on.

6.2 Requirements

By summing up the facts that were collected until here a specific list of requirements for the network planning design tool can be made.

First of all the programme needs to be platform free which would indicate the usage of JAVA as programming language. The software shall also have a simple graphical user interface at its disposal. The user is supposed to understand the programme at first sight even though he might not be an expert. Therefore a menu driven application serves best. It aims to enable the user to mark the regions of interest on the map and without further input of any value get the result with a mouse click. In case that the user wants to compare several simulations the programme could offer a multi-window solution with the original solution on the right side and the improved solution on the other.

Secondly we need a propagation model that fits our requirements meaning that it should not be too voluminous considering the calculation time but delivers exact results at the very same time. I suggest that the propagation model depends on the coverage area. The coverage area should be divided into indoor and outdoor where else outdoor should be further subdivided into rural and urban. If there is a need for indoor planning the ray optical models do have the advantage, that they deliver results which are exact enough. If we use outdoor models in contrast it might be easier to go with the empirical Longley-Rice model at least in the rural
environments. Of course it is hard to say which model fits the requirements best since there have been no comparing tests so far.

It is furthermore interesting to provide a certain database with material depending attenuation measurements which might be altered by the user. Maybe another database could contain the data of the most used antennas.

The planning tool needs to be able to calculate the needed number of access points for the specific application as well as to find an initial position for the access points. This task might be done with the “Standort Finder” since this is a first attempt for AP positioning. Afterwards the network planning tool should be able to give several simulations of the network and save the results. The several simulations can be run with different AP positions. It should be possible to optimise the costs of the network as well as optimising the signal strength at any particular point.

The tool must be able to import graphics and support different formats – at least jpg, png and drawings from CAD. It should be possible to use pictures that were taken from satellites or road maps as well as building maps.

The result of the network planning tool should be provided first in RadioNDML in order to simplify the next simulation step if necessary and a graphic format to give the user a visual about the suggested network. It might be also helpful to create a database e.g. in SQL with all the important parameters like AP positions and particular costs to facilitate the tasks for the user if he has to decide between two or more possible offers.

6.3 Input

In order to meet the requirements for the tool it is necessary to get specific information about the particular environment by the user. Those can be divided into 2 groups in which one is filled with geographical data like building information and height information and the other group consists of specific data about the base station like height and type of antenna.
First of all it is necessary to know the exact coordinates of coverage area with length, width and height of the building. The building blueprint can be taken from satellite pictures or the land survey register. The height information is contained in so called ground surface models e.g. the digital ground surface model DGM5. Another way to determine the size and the particular extend of the area the user should scan some map material which is preferably one of the following: png, jpg, dxf or xml. Accurate information about the terrain and the morphology is needed as well which is why the highest resolution terrain data available is necessary.

Secondly the base station information is needed. As described in section 1 paragraph 3 the antenna height above ground level, the type of antenna, number of channels, exact working frequency, transmitting power of amplifier, the cable loss and the azimuth of both – transmitter and receiver - are necessary information. It is also important to know the downtilt, transmit power and receive density as well as the required safety distance. Furthermore the base station and far end antenna pattern and antenna gain might be of interest.

The user should also decide which IEEE standard he wants to employ for his application. In that case there could be a questionnaire as the very first step of the programme asking some facts about the coverage area and level of security and if it is supposed to be an indoor or and outdoor application. The system might then suggest the user the best suitable wireless standard for his application.

### 6.4 Output

One major result of the programme should be the determination of number of access points, the radio frequencies and number of channels that are needed for this specific network. It is furthermore an aim to minimise the number of access point and optimise the frequency channels. In order to fulfil this task the programme has to calculate the coverage area of each access point and keep under surveillance the number of adjacent access points. Those access points have to work under different frequency channels. In multi-storey buildings it is also possible that the signal passes through the floor disturbing other networks. For this reason the software should be able to handle multi-storey simulations. After fulfilling this task another
important factor can be the optimisation of hardware parameters, e.g. characteristics of antenna – direction, height, transmitting power.

The software should also deliver a forecast of quality of the radio network. This is best shown in a map where the regions with the same level of signal strength should be presented in the same colour. Multiple covered areas could be high lightened because clients in those zones are bouncing between the base stations which might cause information loss and the slowdown of those base stations. Especially in industrial environments it is very likely that interferences might occur. An interference forecast of the entire area and the potential source of interference might be interesting for the user. For each client a best server prediction could be made.

### 6.5 Steps for planning of radio networks

The first step will always be to get a map. Maps can be for example ground plots of buildings or xml files. In any case the entire walls should be represented and – as far as possible- the material that was used for the construction as well as the thickness of the obstacles. Especially for higher frequencies all the items in a room can be seen as obstacles. Therefore it is useful to drawn in as well all the items that will not be moved in a long time like book shelves. In addition to that it is normally also know if there are carpets in a room.

During the next step several access points are suggested in an original, not yet ideal position by an algorithm like “Standort Finder” by Thomas Fahnert. The illumination efficiency of each point in the map will be calculated. The calculation will never be exact due to the fact that also humans or plants inside a room will change the wave propagation. It is also important to the signal strength whether a door is left open or closed.

Especially in establishments of industries and larger residential areas there are possibly already existing radio networks which might cause interference with the network that is about to be planned. So before the actual planning starts it is necessary to detect possible sources of interference. Also the surrounding environment may have an influence on the wave propagation. If there is a forest near the signal propagation path there can be a weakening of signal strength.
6.6 Functionality

After gathering all the facts about the software a list with all the functionalities can be arranged. This can be seen as a customer requirement specification.
1. Presentation of the map before and after the simulation ⇒ multi window solution

2. File management with
   a. Open file
   b. Save file
   c. Save file as
   d. Print
   e. Send to
   f. Close

3. Image transformation
   a. Insert obstacles
   b. Delete obstacles
   c. Insert APs
   d. Delete APs
   e. Insert Network equipment
   f. Standort Finder

4. Simulation
   a. Dominant Path Algorithm
   b. Longley-Rice
   c. Free Space Loss
   d. start
   e. stop

5. Options / Preferences
   a. Path settings
   b. Edit / no edit mode

6. Help
   a. Online-Help
   b. Tool-Help

7. language: English; German

8. status line with information

9. high-lighting of transformed region

10. handling of software via graphical user interface

11. click on the right mouse opens context menu
Abbildung 16: GUI - UML
7 Radio NDML

In order to meet the specific requirements for radio networks the Network Design Markup Language (NDML), which was implemented for the CANDY project, was being expanded into RadioNDML by Thorsten Haase. NDML is an XML based language to describe network topologies and is supposed to present networks in a standardised way in order to simplify network planning.

Although the language itself seems to fulfil already the needs I would like to add some characteristics.

First of all the tag <antenna> in <devices> does consist of just 5 attributes: a unique ID, a name, a horizontal angle of beam spread, the antenna gain and cost. I think that the downtilt of the antenna in degree should be another attribute since it can influence the signal strength a lot. Another attribute might be the working frequency in GHz that is used since not all antennas can be used for all frequencies and therefore industrial standards. As described earlier there are limitations to antenna height in metres and transmit power depending on national regulations. If the antennas are about to be used in either indoor or outdoor environments it is interesting to know if they are or are not weatherproof.

<devices>

   <product id = "p01" type = "Accesspoint" name = "WRT54g" vendor = "Linksys" bandwidth = "54" technology = "802.11g">
       <transmitpower>15</transmitpower>
       <height>2</height>
       <downtilt>3</downtilt>
       <frequency>2.4</frequency>
       <costs id = "c03">
           <unit_price>60.00</unit_price>
           <price>60.00</price>
       </costs>
   </product>

</devices>
Secondly the user types are described by 6 attributes: an id, Name and further attributes to
describe his traffic: percentage of attendance, proportion of internal and external traffic,
which is given by first the total internal and second the total external traffic, and the
minimum, maximum and average traffic in kbps. I personally think that in enterprise
networks the percentage of attendance of the employees is most likely 100% which makes
this attribute not so important.
8 Outlook

This research thesis focused on the technical basics of radio network planning especially the wave propagation models. In my opinion it is very important to check on the wave propagation models that are used. Because those models are the basis of the calculation they need to be as exact as possible. It is highly recommended that the models are about to be analysed if they deliver the correct result by actually temporarily installing a network with hardware equipment and do some measuring. The next step will be to implement the suggested algorithms and the GUI.
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## List of Acronyms

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<tr>
<td>AP</td>
<td>Access Point</td>
</tr>
<tr>
<td>CANDY</td>
<td>Computer Aided Network Design Utility</td>
</tr>
<tr>
<td>DSL</td>
<td>Digital Subscriber Line</td>
</tr>
<tr>
<td>FCC</td>
<td>Federal Communications Commission</td>
</tr>
<tr>
<td>FSL</td>
<td>Free Space Loss</td>
</tr>
<tr>
<td>GHz</td>
<td>GigaHertz</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile Communications</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronic Engineers</td>
</tr>
<tr>
<td>ISM</td>
<td>Industrial Scientific Medical</td>
</tr>
<tr>
<td>LOS</td>
<td>Line of Sight</td>
</tr>
<tr>
<td>MAN</td>
<td>Metropolitan Area Network</td>
</tr>
<tr>
<td>MBPS</td>
<td>Megabyte Per Second</td>
</tr>
<tr>
<td>MHz</td>
<td>MegaHertz</td>
</tr>
<tr>
<td>MLDP</td>
<td>Minimum Loss Dominant Path</td>
</tr>
<tr>
<td>NLOS</td>
<td>Non Line of Sight</td>
</tr>
<tr>
<td>NDML</td>
<td>Network Design Modelling Language</td>
</tr>
<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
</tr>
<tr>
<td>QAM</td>
<td>Quadrature amplitude modulation</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>QPSK</td>
<td>Quadrature Phase Shift Keying</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal to Noise Ratio</td>
</tr>
<tr>
<td>WiMAX</td>
<td>Worldwide Interoperability for Microwave Access</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
</tr>
</tbody>
</table>
List of references

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Eidesstattliche Erklärung

Hiermit versichere ich, die vorliegende Arbeit selbständig, ohne fremde Hilfe und ohne Benutzung anderer als der von mir angegebenen Quellen angefertigt zu haben. Alle aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als solche gekennzeichnet. Die Arbeit wurde noch keiner Prüfungsbehörde in gleicher oder ähnlicher Form vorgelegt.

Annett Ihlefeld

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