PUBLIC

IST R&D. FP6-Priority 2.
SPECIFIC TARGETED RESEARCH PROJECT
Project Deliverable

SUIT Doc Number	SUIT_279_WP2_D2.5_Network Capacity
Project Number	IST-4-028042
Project Acronym+Title	SUIT- Scalable, Ultra-fast and Interoperable Interactive Television
Deliverable Nature	Report
Deliverable Number	D2.5
Contractual Delivery Date	31 Sept 07
Actual Delivery Date	31 Oct 07
Title of Deliverable	Network Capacity
Contributing Workpackage	WP2
Project Starting Date; Duration	01/02/2006; 27 months
Dissemination Level	PU
Author(s)	Alexander Schertz (IRT), Alois Zistler (IRT), Moti Goldshtein (Runcom), A. Navarro (IT), C. Liew (UniS), S. Worrall (UniS), X. Shi (UniS)

Abstract

This report features the coverage simulation for derivation of Network Capacity of WiMAX and DVB-T for the city of Munich. It is used for estimation of system performance, i.e. coverage and capacity, before the WiMAX field test planned by IRT for the autumn of 2007. The conditions set for the simulation are mostly identical with the basic conditions of the field test so that the results can be used for the planning of the field test. In the first section of the report detailed descriptions of the software tool FRANSY and the field strength prediction models used for the study are given. After that the conversion of field test results to throughputs of the system for various receiving conditions (mobile, portable outdoor, portable indoor, directed roof antenna) for WiMAX is described. The results of WiMAX downlink simulation show a sufficient coverage for the planned WiMAX field tests. DVB-T simulations are only carried out for portable outdoor and mobile conditions. However, when VoD services are offered to WiMAX subscribers, it is not possible to provide SD resolution video via WiMAX alone, i.e., using BSTs directly to feed houses. Finally the report outlines the results of the WiMAX uplink simulations for the portable outdoor transmission condition. They are more favourable than the results of the downlink simulations.

Keyword list: WiMAX, DVB-T, downlink, uplink, broadcast mode, coverage analysis, mobile reception, portable indoor reception, portable outdoor reception, roof antenna reception, FRANSY, IRT prediction models, 2D prediction model, 3D prediction model

Network Capacity

SUIT_279

31 October 2007

Table of Contents

1 INTRODUCTION...5

2 INTRODUCTION TO FRANSY 7

2.1.1 IRT field-strength prediction method 8
2.1.2 Application of IRT_2D- and IRT_3D models for City of Munich....................................11

3 SIMULATION OF WIMAX DOWNLINK COVERAGE/BANDWIDTH CAPACITY...............13

3.1 RECEIVING CONDITIONS OF THE COVERAGE ANALYSIS..13
3.1.1 Relation between received power P and field strength E 13
3.1.2 Receiving conditions and conversion tables..15
3.2 RESULTS OF THE COVERAGE ANALYSIS 18
3.2.1 Results for the field test area...19
3.2.2 Results for the area of Munich 21
3.3 DISCUSSION OF COVERAGE ANALYSIS RESULTS...28

4 SIMULATION OF DVB-T DOWNLINK BROADCAST IN MUNICH 29

4.1 CONVERSION TABLE 29
4.2 RESULTS OF THE COVERAGE ANALYSIS 30

5 SIMULATION OF WIMAX UPLINK SCENARIO IN MUNICH 38

6 COMBINED DVB-T AND WIMAX COVERAGE ANALYSIS 43

7 SUMMARY 44

8 REFERENCES...45

1 Introduction

This deliverable's objectives are to present the performance study coverage and capacity of DVB-T/H and WiMAX systems using the IRT Fransys coverage analysis software. The SUIT architecture, shown in Figure 1, will first be reviewed. SVC coded MDC videos are streamed over a microwave link to the remote co-located DVB and WiMAX base stations. The two MDC video descriptions are then sent over the DVB and WiMAX links respectively (using the switch device). Receiving either description from DVB or WiMAX allows the reconstruction of video with good quality, but if both descriptions are received, enhanced video quality can be expected.

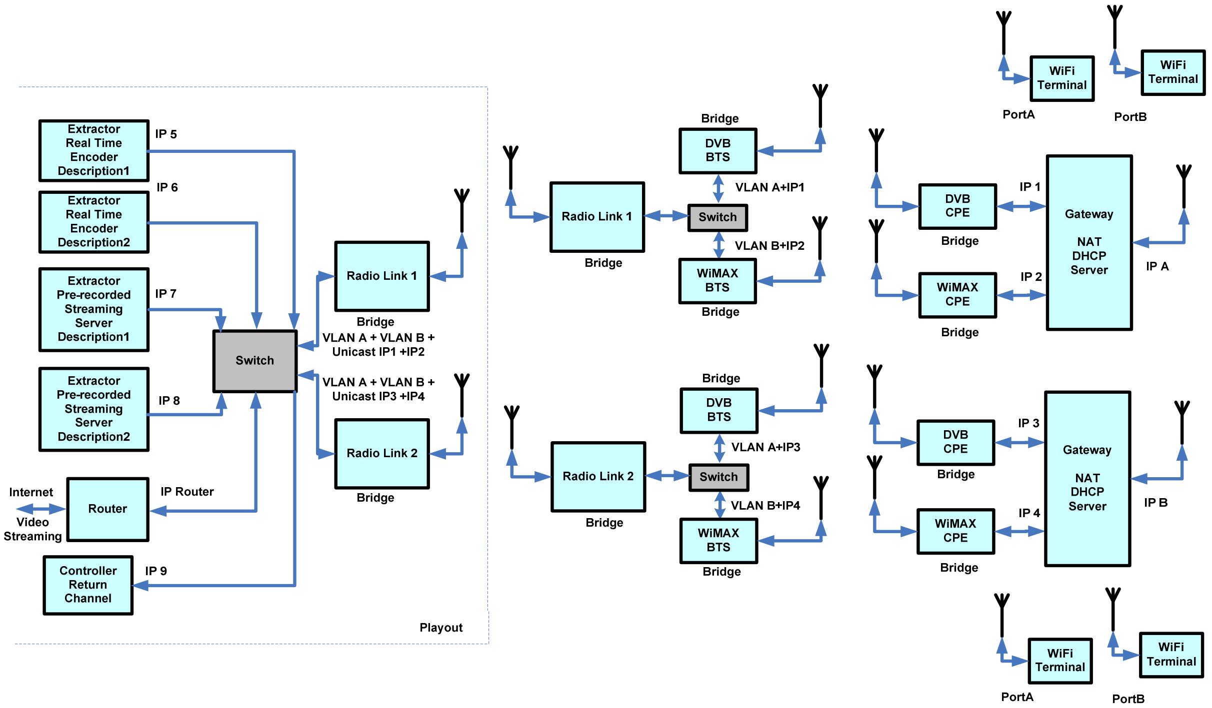


Figure 1: Block diagram of the home network scenario

As can be seen in the figure, the supported capacities at the DVB-T/H and WiMAX interfaces have a significant effect on video quality (i.e. more bit rate allows better video quality) as well as the number of services supported by the systems. This deliverable features capacity and coverage analysis for the city of Munich, where WiMAX field trials will be carried out. The reference network scenarios for trials are available in Deliverable 1.4 [23]. Although DVB-T trials will not be held in Munich, the DVB-T coverage analysis is carried out for Munich so that the two systems can be compared. The reader can refer to D6.4 to find simulations of Aveiro, where the final field trials are to take place.

The study is useful from two angles. First. it will allow the estimation of system equipment requirements (e.g. antenna gain and amplifier specifications) as well as system parameters (e.g. total transmit power) for a given pre-set system performance for the trial. Or in reverse, it can be used to estimate the system performance for a given specified equipment capability and system parameters. In either case, it will be a prerequisite before the field trials to predict the system performance (e.g. coverage and capacity) which gives indications of the kind of field test / service scenario possible for the trial. The estimated capacity at the interfaces can be translated into the estimated video quality and number of services supported beforehand.

The rest of the deliverable is structured as follows: Section 2 describes the FRANSY frequency planning software tool used for the coverage analysis, Section 3 contains details and results from the WiMAX downlink analysis, Section 4 examines DVB-T downlink broadcast coverage, and Section 5 describes the analysis of the WiMAX uplink performance. Section 6 compares the results for DVB-T and WIMAX to investigate how the converged systems are likely to operate. Finally Section 7 concludes the deliverable.

2 Introduction to FRANSY

FRANSY is the frequency planning software tool for coverage analysis for all public broadcasters in Germany. It allows for complete coverage analysis, network planning and optimization using the relevant field strength prediction models using data for terrain, morphography and population density. The IRT field strength prediction method implemented in FRANSY was initially developed for field-strength predictions in the VHF and UHF range allocated to terrestrial broadcasting services and has continuously been modified, improved and extended for other frequencies and applications. The most important improvement in recent years was the inclusion of scattered and reflected waves, especially regarding applications for terrestrial digital wide-band systems such as DAB (Digital Audio Broadcasting) and DVB (Digital Video Broadcasting). Two different approaches were developed: version IRT_2D only takes into account reflections behind the receiver site propagating in the vertical plane through transmitter (T_x) and receiver (R_x), while version IRT_3D is capable to consider three-dimensional propagation paths outside this vertical plane. IRT_3D is a discrete ray launching method, i.e. from the reflecting surface a certain number of rays is sent out.

Extensive field-strength measurements have been carried out by IRT for frequencies between 80 MHz and 1500 MHz in different types of terrain and for different services. Measurements were done in smooth undulating terrain as well as in rough mountainous terrain, e.g. in Black Forest or in the Alps, for stationary reception (10m receiving antenna height) and for mobile reception (4m and 1.5m receiving antenna height), in open, forested and in urban areas. Based on comparisons of these measurements with different field-strength prediction models the IRT started to develop its own method, using algorithms that were found to be most suitable and accurate.

FRANSY allows for complete coverage analysis, network planning and optimization using the relevant field strength prediction models using data for terrain, morphography and population density. At any point of the coverage area, it is possible to interrogate a multitude of parameters that help the planner to interpret the complex situation at the receiver location. The summarized features of Fransy are:

- Planning of digital (DVB-T, T-DAB) and analogue (analogue-TV, FM-radio) SFNs and MFNs, considering wanted and unwanted transmitters
- Coverage calculations
- Various ways of choosing sets of transmitters
- Several field strength prediction models:
    - "path specific", i.e. IRT2D and IRT3D model
    - "path general", i.e. ITU-R recommendation 1546
- Many SFN analysis modes (several synchronisation strategies and accumulation methods)
- Utilisation of digital elevation models, population density and land cover data
- SFN-Network Optimisations: transmitter delay and receiving antenna characteristics
- Transparency of results provided by various tools:
    - field strength delay spectrum
    - terrain profile
    - map display
    - display of coverage information at receiver position

- Built-in database system (HSQLDB) for transmitter data, support for different external database systems for the transmitter data base (Oracle, MS Access)

2.1.1 IRT field-strength prediction method

2.1.1.1 Introduction

Extensive field-strength measurements have been carried out by IRT for frequencies between 80 MHz and 1500 MHz in different types of terrain and for different services. Measurements were done in smooth undulating terrain as well as in rough mountainous terrain, e.g. in Black Forest or in the Alps, for stationary reception (10m receiving antenna height) and for mobile reception (4m and 1.5m receiving antenna height), in open, forested and in urban areas. Based on comparisons of these measurements with different field-strength prediction models [1, 2] the IRT started to develop its own method, using algorithms that were found to be most suitable and accurate.

The IRT-method was initially developed for field-strength predictions in the VHF and UHF range allocated to terrestrial broadcasting services and has continuously been modified, improved [3, 4] and extended for other frequencies [15, 16, 17] and applications [19, 21, 22]. The most important improvement in recent years was the inclusion of scattered and reflected waves, especially regarding applications for terrestrial digital wide-band systems such as DAB (Digital Audio Broadcasting) and DVB (Digital Video Broadcasting). Two different approaches have been developed: version IRT_2D only takes into account reflections behind the receiver site [5] propagating in the vertical plane through transmitter (T_x) and receiver (R_x), while version IRT_3D is capable to consider also three-dimensional propagation paths outside this vertical plane [6, 7].

2.1.1.2 General elements of IRT prediction method

2.1.1.2.1 Diffraction

The IRT prediction method is based on a slightly modified calculation [8] of the multiple knife-edge diffraction loss after Deygout [9] and empirically gained attenuation correction terms. A maximum of seven diffraction loss contributions are considered, either originating from obstacles above the line-of-sight between transmitter T_x and receiver R_x or from obstructions within the first Fresnel zone. Optional the number of contributing knife-edges can be limited to a maximum of three, e.g. for interference calculations.

As an option spherical surface loss [10] may be used to calculate the diffraction loss, in case that T_x and R_x do not have a common horizon. This option may be useful for smooth surfaces, in particular for waves propagating over sea paths. Nevertheless the multiple knife-edge diffraction approach used in our method was found to give realistic predictions also for rather smooth terrain, and hence it is used as a general method for all kinds of terrain. A similar approach is proposed in Recommendation ITU-R P.526.

2.1.1.2.2 Empirical correction

Empirically gained attenuation correction terms were derived by comparison of calculated and measured field-strength values, the latter resulting from extensive measurement campaigns. The corrections are necessary to take account of effects which only may be caught in a statistical manner due to the lack of detailed information, e.g. effects of ground reflections in front of the receiving antenna. In general the correction leads to an additional reduction of the predicted field strength which is increasing with distance. The slope of this correction, respectively the increase with distance, depends on the frequency as well as on the so-called equivalent effective transmitter antenna height [4]. This height is defined as the median height of the line-of-sight above ground between T_x and first obstacle, respectively R_x in case of an unobstructed line-of-sight. Thus, for low transmitting antennas the empirical correction becomes greater than for rather high transmitting antennas.

The correction due to the equivalent effective transmitter antenna height is necessary in particular for antennas situated at relative low height above the surrounding area. The empirical corrections have been derived from measurements for transmitting antenna heights greater than 50 m above ground. For lower equivalent effective transmitter antenna heights the corrections are evaluated by extrapolation. In order to verify the applicability of the corrections for these low T_x antenna heights, further comparisons with measurements may be necessary.

2.1.1.2.3 Ground cover

If the ground cover along the profile or at least at the R_x location is known, e.g. from a ground cover data bank, additional optional corrections of the received field strength can be applied. One rather simple correction was taken from an ITU-Recommendation [11] considering only the ground cover type at the receiver location, receiving antenna height and polarisation. This approach was tested against measurements and showed suitable results, however, a disadvantage of this method is that only the ground cover at the receiver site is taken into account.

Optional, another approach based on the so-called effective ground cover height [21] can be used. In this case the ground cover along the whole profile is considered and added to the terrain height. However, the assumed effective height of the ground cover depends on the frequency and is different from the “real” ground cover height. This approach is essentially based on the fact that e.g. forest becomes less opaque for lower frequencies and, hence, this is simulated by reducing the effective height of the forest. This method has some advantages in particular for low transmitting antenna heights, in urban areas and also for prediction of indoor coverage [21].

Several other possibilities to consider ground cover effects at the receiver location are available (optional), depending on the installed version of the IRT method.

2.1.1.2.4 Wanted and interfering signal

In order to allow predictions of the wanted field strength as well as of interfering fields, calculations for different time percentages (1% - 99 %) can be done. Anomalous tropospheric propagation situations are considered by assuming different refractive indices of the troposphere, which are modelled by modified effective earth radii.

Tropospheric scattering and ducting effects (super-refraction) similar to Recommendation ITU-R P.452-7 [12] are incorporated in our models for predictions for time percentages less than or equal 50 %. However, the application of the ducting approach is limited to land paths in Central Europe. We do not yet have evidence from own measurements whether these approaches are reliable or not, but long-term measurements are carried out at IRT in order to get the necessary information.

2.1.1.2.5 Urban areas

The IRT, supported by Bayerischer Rundfunk (public Bavarian Broadcaster) and with allowance of Städtisches Vermessungsamt München (municipal land surveying office of Munich), developed a digital city model for a large area of Munich. These data are stored in raster form (pixel), similar to topographic data, and contain information on streets, trees and building heights. We extended our IRT-method, in particular IRT_3D, in order to use these detailed city data for predictions in urban areas. Essentially an additional urban propagation loss [13] was incorporated, taking into account the attenuation due to diffraction over a number of buildings obstructing the first Fresnel zone.

If the term „urban propagation loss“ is used in the following descriptions, we assume that digital city data in raster format with a resolution in the order of 1-10 m is available, containing detailed information on streets and individual building heights.

2.1.1.3 Multi-path propagation (optional)

This optional extension of the prediction method can be used for all aforementioned purposes respectively services, like FM-Sound Broadcasting (VHF), analogue TV (VHF, UHF), T-DAB (VHF, L-Band) and DVB-T (VHF, UHF).

Two different approaches to take account of reflected and scattered waves were developed at the IRT:

IRT_2D considers only waves propagating within the vertical plane through T_x and R_x. Optional also reflections behind the receiver site [5] propagating in this vertical plane may be considered. The 2D-approach [5] needs obviously less computational effort, because only two-dimensional propagation paths are investigated. The influence of reflections will be caught only for very particular terrain configurations, e.g. if the terrain is significantly rising behind the receiver location. Nevertheless, the predictions will be much better than without consideration of any reflected waves [5]. Also in urban areas, where nearly everywhere reflections from buildings behind the mobile receiver location will occur, predictions with IRT_2D gave much better results [14, 15] compared to those achieved by the IRT-method not taking account of reflections.

Note: This method has not been modified and fully tested in recent years, because further developments are concentrated on the 3D-approach that gives much better predictions.

IRT_3D takes into account three-dimensional propagation paths outside the vertical plane through T_x and R_x [6, 7]. This approach may lead to very time consuming computations, but especially in mountainous terrain [16, 17, 18] or in urban areas [14, 15] the prediction accuracy may be improved significantly.

IRT_3D is a discrete ray launching method, i.e. from the reflecting surface a certain number of rays is sent out. The computation time as well as the prediction accuracy depends largely on the number and angular resolution of the scattered rays. Optional, a ray tracing algorithm is available (test phase), however, this method takes much more computation time. The result of the 3D-calculation is the field strength at the receiver location, either using power sum of incoming signals (e.g. DAB) or taking into account interference of direct and reflected signals (e.g. analogue TV). Optional, a number of reflections (default 10) can be stored for every receiver location, providing information on field strength, delay time and arrival angle. A suitable algorithm is used in order to store the most significant (e.g. strongest) reflections.

The essential elements of the 3D-multi-path approach are:

- various options to consider reflection and scatter loss
- power sum of all signals
- interference between direct and reflected waves (optional)

- consideration of directional receiving antennas
- forward scatter (optional)
- ray tracing (test phase)

The most important parameter for calculation of reflected and scattered waves is the reflection loss. Several different models to consider the reflection loss were described in previous papers [5, 6, 7, 14, 15, 16, 17, 18, 19, 20] and may be used for the predictions.

In order to make the 3D-method fast and to achieve results within an acceptable time the IRT_3D method makes use of a number of simplified assumptions [6, 7, 14, 19], e.g. :

- specular reflection
- cosine distribution of scattered wave around specular reflected ray
- constant reflection loss or constant surface roughness
- no multiple reflections
- limitation to low receiving antenna heights (< 10m)
- (optional) only reflections from surfaces with unobstructed line-of-sight to T_x

The IRT prediction method (VHF, UHF, L-Band, T-DAB, DVB-T) is written in FORTRAN 77 and can easily be incorporated in existing program modules, because the interface is similar to other two-dimensional prediction methods based on topographic data. In order to use the IRT_2D extension considering two-dimensional reflections, a profile extending behind R_x is needed, in order to check whether reflections from behind the R_x location may occur.

IRT_3D searches for three-dimensional propagation paths and, hence, many different profiles originating from the reflecting surfaces are needed. Therefore a reconfiguration of data handling within prediction methods may be necessary for the installation of IRT_3D.

2.1.2 Application of IRT_2D- and IRT_3D models for City of Munich

The application of the IRT_3D model makes sense if reflections play an important role and can be taken into consideration. For cities reflections are important indeed because reflections improve the receiving conditions for shadowed parts of streets. But a detailed city model with high resolution (about 10 m) is required for this type of calculation. Such data are not always available because they are very expensive. The IRT owns such a model for an important part of Munich (Figure 2). Two types of calculations can be done for the downlink analysis:

a) Calculations for the (smaller) area where field trials will take place using the IRT_3D model and the high resolution city model data (resolution: 10 m)

b) Calculations for the whole area of Munich using the IRT_2D model and lower resolution (100 m) topographic and morphographic data

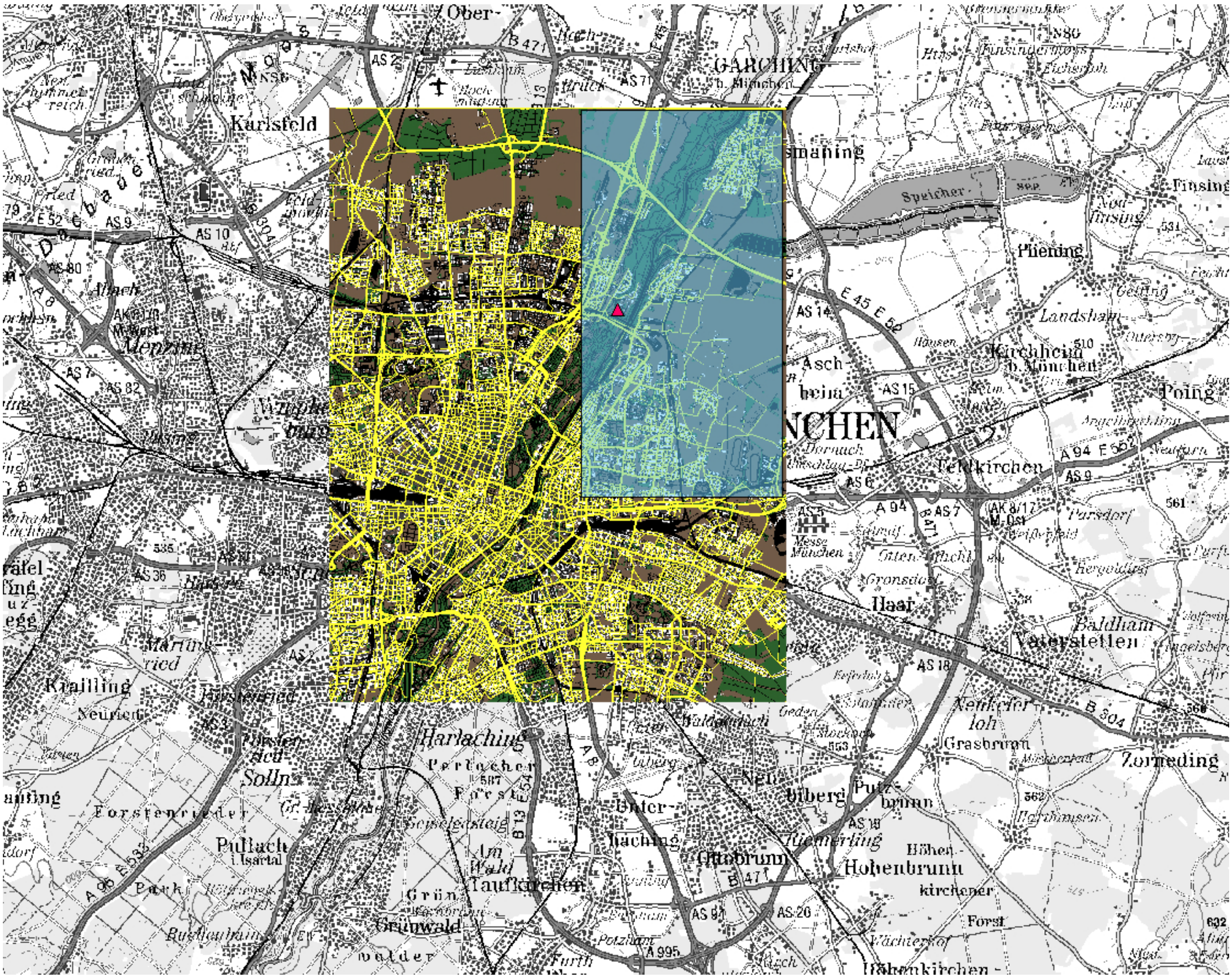


Figure 2 Map of Munich (grey), area of IRT city model (coloured), area of field tests (blue) and position of the transmitting antenna for field tests (red triangle)

3 Simulation of WiMAX Downlink coverage/bandwidth capacity

This section will present the simulation of the coverage and capacity of parts of the city of Munich by a WiMAX downlink. The coverage analysis was done for the conditions of the WiMAX field tests planned by the IRT in the framework of the SUIT project. On the one hand this contribution is meant to support the planning of the field tests, on the other hand it shall give an idea of the size of the area covered by WiMAX on certain conditions.

The following data were defined for the WiMAX field tests of the IRT:

- Position of the transmitting antenna: 11E 37’ 39.2’’, 48N 11’ 16.5’’ (Figure 2)
- Height of transmitting antenna location above sea level: 498 m
- Height of transmitting antenna above ground level: 90 m
- Transmitter power: 100 W (EIRP)
- Polarization of transmitter antenna: vertical

The WiMAX downlink simulations were carried out for the physical situation defined by these data. A spherical antenna diagram was assumed for the calculations. Consequently in the field tests only a sector of the coverage calculated by the simulation can be expected. More calculations will be done taking into account the real antenna diagram as soon as the exact orientation of the transmitting antennas for the field tests have been defined.

3.1 Receiving conditions of the coverage analysis

The coverage analysis was carried out for various receiving conditions. The results of the FRANSY calculations on these conditions were field strength data (dBµV/m), but what is needed is the throughput (Mbit/s) coverage. As WiMAX is deploying with adaptive modulation and coding (ACM), a table has been provided by Runcom giving the relationship between throughput (Mbit/s) and receiving power (dBm) for its receiver . Consequently two steps had to be done:

(1) Determination of the relation between the received power and the field strength

(2) Generation of tables linking the field strength to the throughput for the various receiving conditions

3.1.1 Relation between received power P and field strength E

3.1.1.1 <u>Step 1: from power to voltage</u>

If the surge impedance of the cable connected to the aerial is 50 Ohm, the relation between the received power P (dBm) and the voltage (dBµV) is:

$U = P + 107$

3.1.1.2 Step 2: From voltage to field strength for a dipole antenna

The voltage U produced by a field strength E is proportional to that field strength. Consequently for a logarithmic calculation the relation between the voltage U (dBµV) and the field strength E (dBµV/m) is the following:

$E = U + c$ (c: constant)

If the surge impedance of the aerial is 50 Ohm, the constant c is derived from the frequency in the following way:

$c = -31.9 + 20 * \lg(f)$ (lg: common logarithm)

f: frequency / MHz

3.1.1.3 Step 3: Taking into consideration the antenna gain compared to a dipole antenna

The field strength E (dBµV/m) required to produce the voltage U (dBµV) is reduced by the antenna gain G_d (compared to a dipole antenna):

$E = U + c - G_d$

The relation between the antenna gain G_d compared to a dipole antenna and the antenna gain G_i compared to an isotropic emitter is:

$G_d = G_i - 2.15$

3.1.1.4 Step 4: Combination of the previous results to a formula for the conversion of thresholds of received power (dBm) to thresholds of field strength (dBµV/m)

Consequently, the conversion formula for the given problem is as follows:

$E = U + c - G_d$

$= U + c - G_i + 2.15$

$= P + 107 - 31.9 + 20 * \lg(f) - G_i + 2.15$

$= P + 20 * \lg(f) - G_i + 77.25$

f = 2500 MHz

$G_i = 0$ (information from SUIT partner Runcom: Gte = Antenna gain CPE side = 0 dBi)

Consequently:

E (/dBµV/m) = P (/dBm) + 145.21

3.1.2 Receiving conditions and conversion tables

The coverage analysis was carried out for four different receiving conditions. For each case the conversion from field strength data (dBµV/m) yielded by the FRANSY calculations to the throughput (Mbit/s) was different. Based on the information provided by Runcom (table linking received power and throughput) and the formula for the conversion from received power P to field strength E derived in chapter 3.1.1, the following conversion tables could be produced for the various receiving conditions.

Tables linking received power and throughput (provided by Runcom) for 60km/h and 120km/h

Bandwidth: 10 MHz - WiMAX

Modulation	Code Rate	RSSI (BER=10^-5) dBm	CINR (BER=10^-5) dB	Throughput Mbit/sec
Down Link Using channel model Veh A at 60Km/h				
QPSK	1/2	-83	16	4.32
QPSK	3/4	-80	19	6.48
16QAM	1/2	-78	21	8.64
16QAM	3/4	-72	27	12.96
64QAM	1/2	-73	26	12.96
64QAM	2/3	-67	32	17.28
64QAM	3/4	-65	34	19.44
64QAM	5/6	-63	36	21.60
Up Link Using channel model Veh A at 60Km/h				
QPSK	1/2	-83	16	2.16
QPSK	3/4	-80	19	3.24
16QAM	1/2	-78	21	4.32
16QAM	3/4	-72	27	6.48

*See comments below

Modulation	Code Rate	RSSI (BER=10^-5) dBm	CINR (BER=10^-5) dB	Throughput Mbit/sec
Down Link Using channel model Veh A at 120Km/h				
QPSK	1/2	-82.7	16.3	4.32
QPSK	3/4	-79.5	19.5	6.48
16QAM	1/2	-77.5	21.5	8.64
16QAM	3/4	-71.4	27.6	12.96
64QAM	1/2	-72.0	26.7	12.96
64QAM	2/3	-66.3	32.7	17.28
64QAM	3/4	-64.2	34.8	19.44
64QAM	5/6	-62.8	36.2	21.60
Up Link Using channel model Veh A at 120Km/h				
QPSK	1/2	-82.8	16.2	2.16
QPSK	3/4	-79.5	19.5	3.24
16QAM	1/2	-77.3	21.7	4.32
16QAM	3/4	-71.8	27.2	6.48

*Comments:

1. BW=10MHz
2. FFT=1K
3. frame =5msec
4. Channel model according to WiMAXVehicular A @120km/h
   Fade margin is included.
5. throughput calculation is according to

DL

As an example for QPSK1/2

Log4*1/2*720*30*200=2*1/2*720*30*200=4.32Mbit/sec
The log is log base 2
720 useable carriers for data
30 symbols in 1 frame for DL
Frame duration=5msec-→200 frames/sec

As an example for 64QAM2/3

Log64*2/3*720*30*200=6*2/3*720*30*200=17.28Mbit/sec

UL

Same as in DL but 15 symbols in 1 frame for UL
As an example for 16QAM3/4
Log16*3/4*720*15*200=4*3/4*720*15*200=6.48Mbit/sec

Receiving condition A: Mobile reception in a car running at a speed of 60 km/h

Receiving aerial height: 2 m

Receiving aerial gain: 0

Loss by movement: 2 dB

Modulation	Code Rate	Field strength dBμV/m	Throughput Mbit/sec
QPSK	1/2	62.21	4.32
QPSK	3/4	65.21	6.48
16QAM	1/2	67.21	8.64
16QAM	3/4	73.21	12.96
64QAM	1/2	72.21	12.96
64QAM	2/3	78.21	17.28
64QAM	3/4	80.21	19.44
64QAM	5/6	82.21	21.60

Receiving condition B: Portable Outdoor

Receiving aerial height: 1.5 m

Receiving aerial gain: 0

Modulation	Code Rate	Field strength dBµV/m	Throughput Mbit/sec
QPSK	1/2	60.21	4.32
QPSK	3/4	63.21	6.48
16QAM	1/2	65.21	8.64
16QAM	3/4	71.21	12.96
64QAM	1/2	70.21	12.96
64QAM	2/3	76.21	17.28
64QAM	3/4	78.21	19.44
64QAM	5/6	80.21	21.60

Receiving condition C: Portable Indoor

Receiving aerial height: 1.5 m

Receiving aerial gain: 0

Attenuation by building: 9 dB

Modulation	Code Rate	Field strength dBµV/m	Throughput Mbit/sec
QPSK	1/2	69.21	4.32
QPSK	3/4	72.21	6.48
16QAM	1/2	74.21	8.64
16QAM	3/4	80.21	12.96
64QAM	1/2	79.21	12.96
64QAM	2/3	85.21	17.28
64QAM	3/4	87.21	19.44
64QAM	5/6	89.21	21.60

Receiving condition D: Directional roof antenna

Receiving aerial height: 10 m (additional calculations for 4, 6 and 8 m)

Receiving aerial directional gain: 16 dB

Modulation	Code Rate	Field strength dBµV/m	Throughput Mbit/sec
QPSK	1/2	44.21	4.32
QPSK	3/4	47.21	6.48
16QAM	1/2	49.21	8.64
16QAM	3/4	55.21	12.96
64QAM	1/2	54.21	12.96
64QAM	2/3	60.21	17.28
64QAM	3/4	62.21	19.44
64QAM	5/6	64.21	21.60

3.2 Results of the coverage analysis

All coverage calculations (WiMAX 802.16e) are performed under the following parameters:

Frequency: 2500 MHz
Bandwidth: 10 MHz
Antenna height: 90 m above ground
Transmission power: 100 W (EIRP)

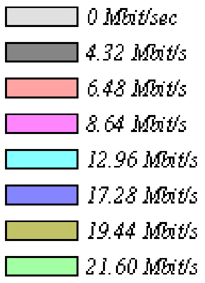
Remark: All calculations have been performed assuming isotropic transmission. Consequently, exact antenna orientation / elevation needs not to be considered.

3.2.1 Results for the field test area

Field strength prediction method: IRT_3D

Morphographic Data: IRT’s City model

Resolution: 10 m



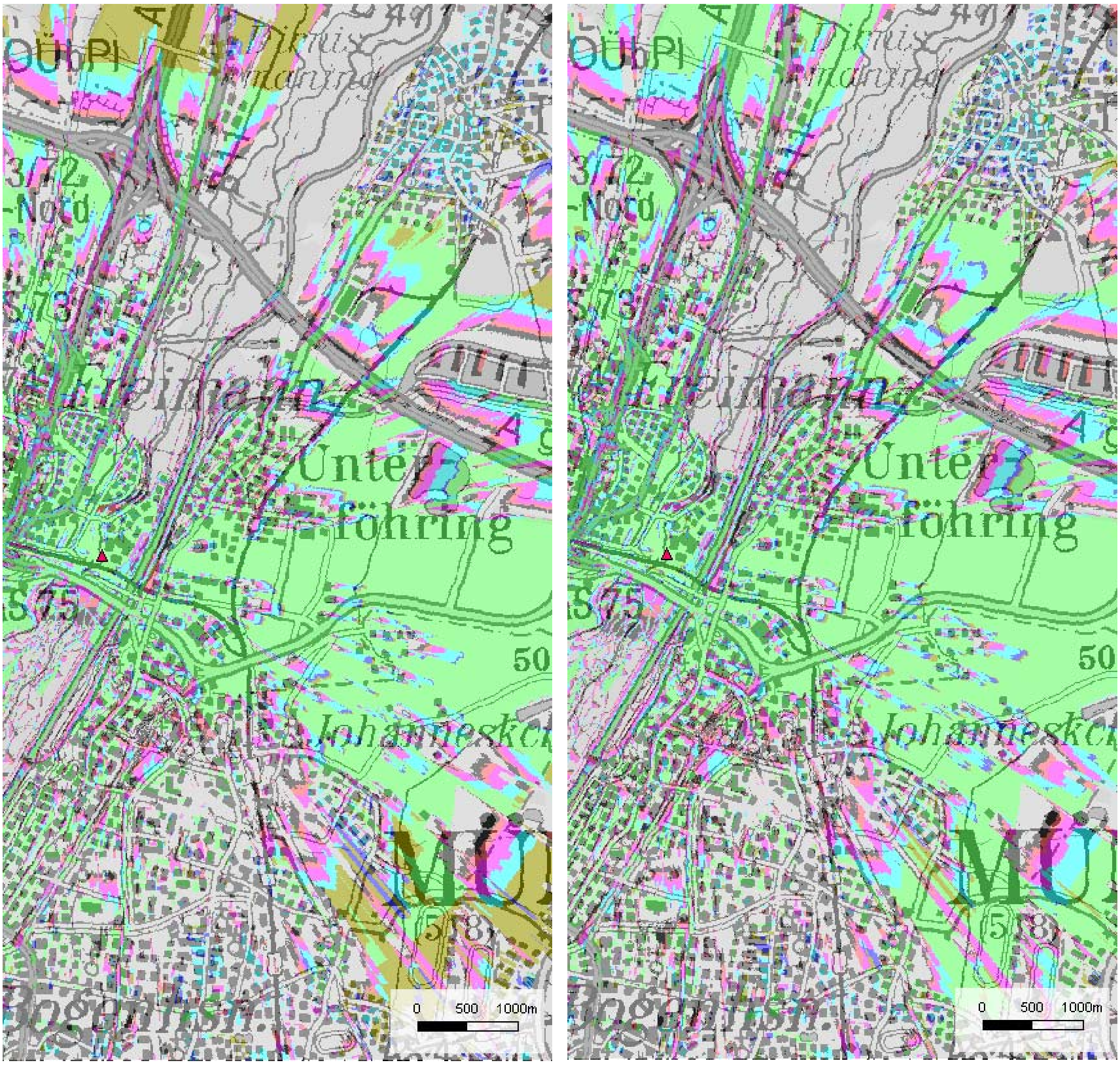
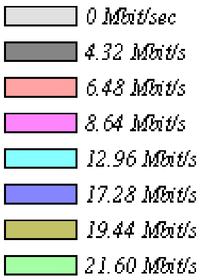


Figure 3 Coverage analysis results for conditions A (Mobile at 60 km/h) on the left side and B (Portable Outdoor) on the right side

Field strength prediction method: IRT_3D

Morphographic Data: IRT’s City model

Resolution: 10 m



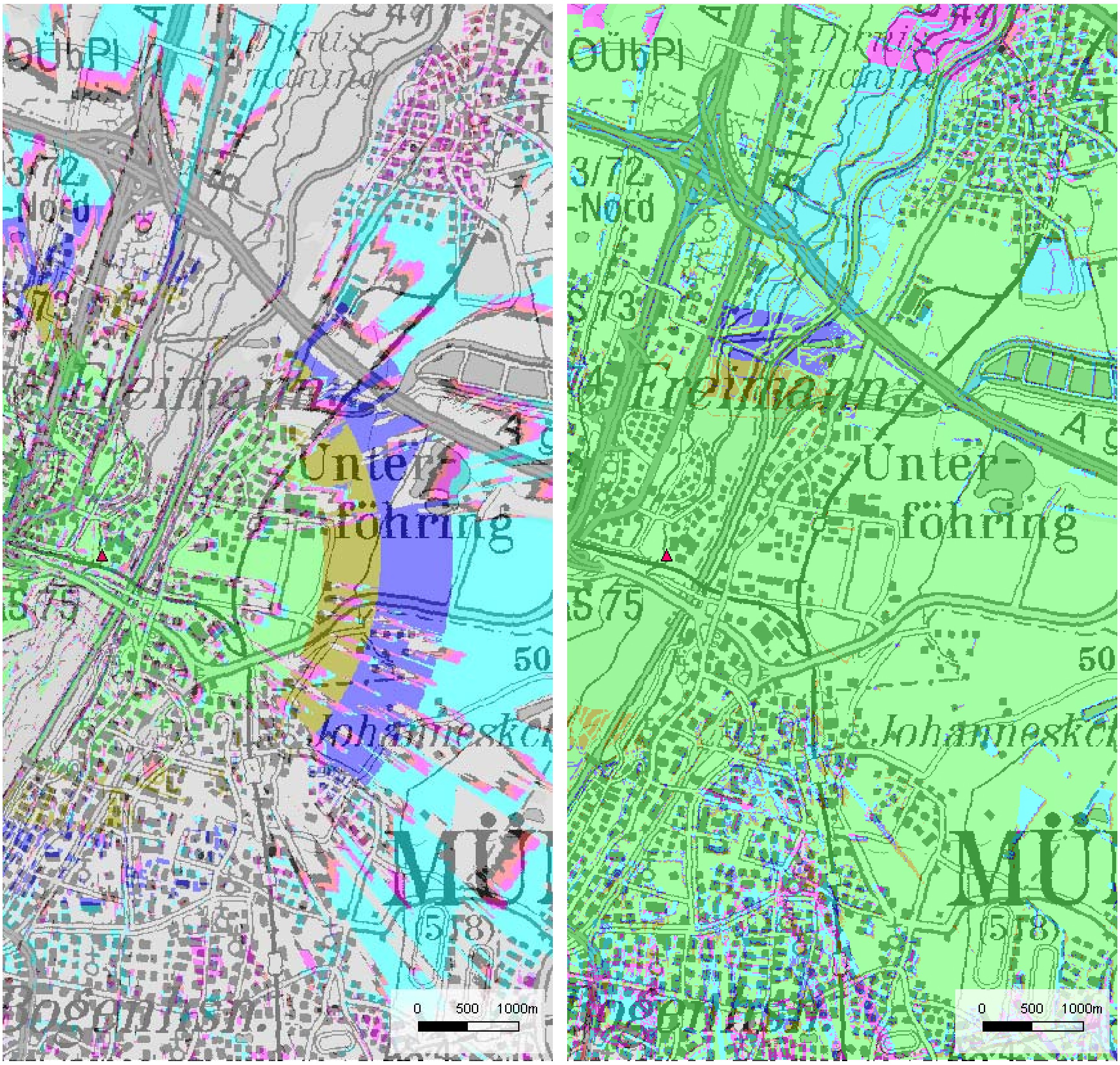


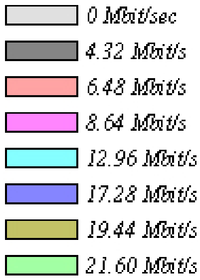
Figure 4 Coverage analysis results for conditions C (Portable Indoor) on the left side and D (directional roof antenna) on the right side

3.2.2 Results for the area of Munich

Field strength prediction method: IRT_2D

Morphographic data: Morpho IRT

Resolution: 100 m



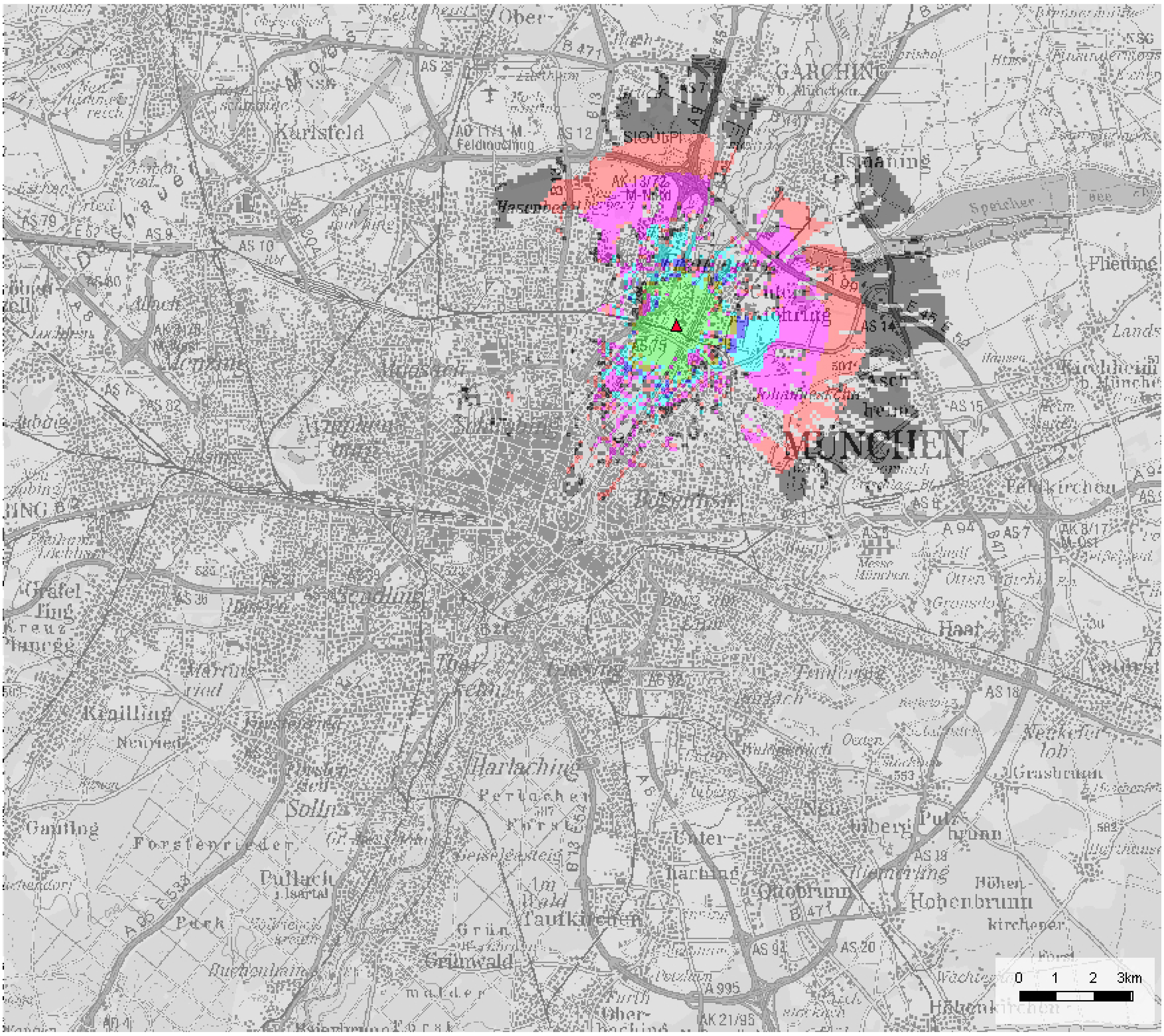
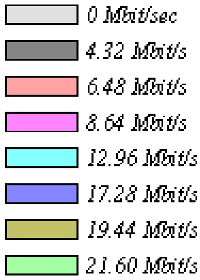


Figure 5 Coverage analysis results for condition A (Mobile at 60 km/h)

Field strength prediction method: IRT_2D

Morphographic data: Morpho IRT

Resolution: 100 m



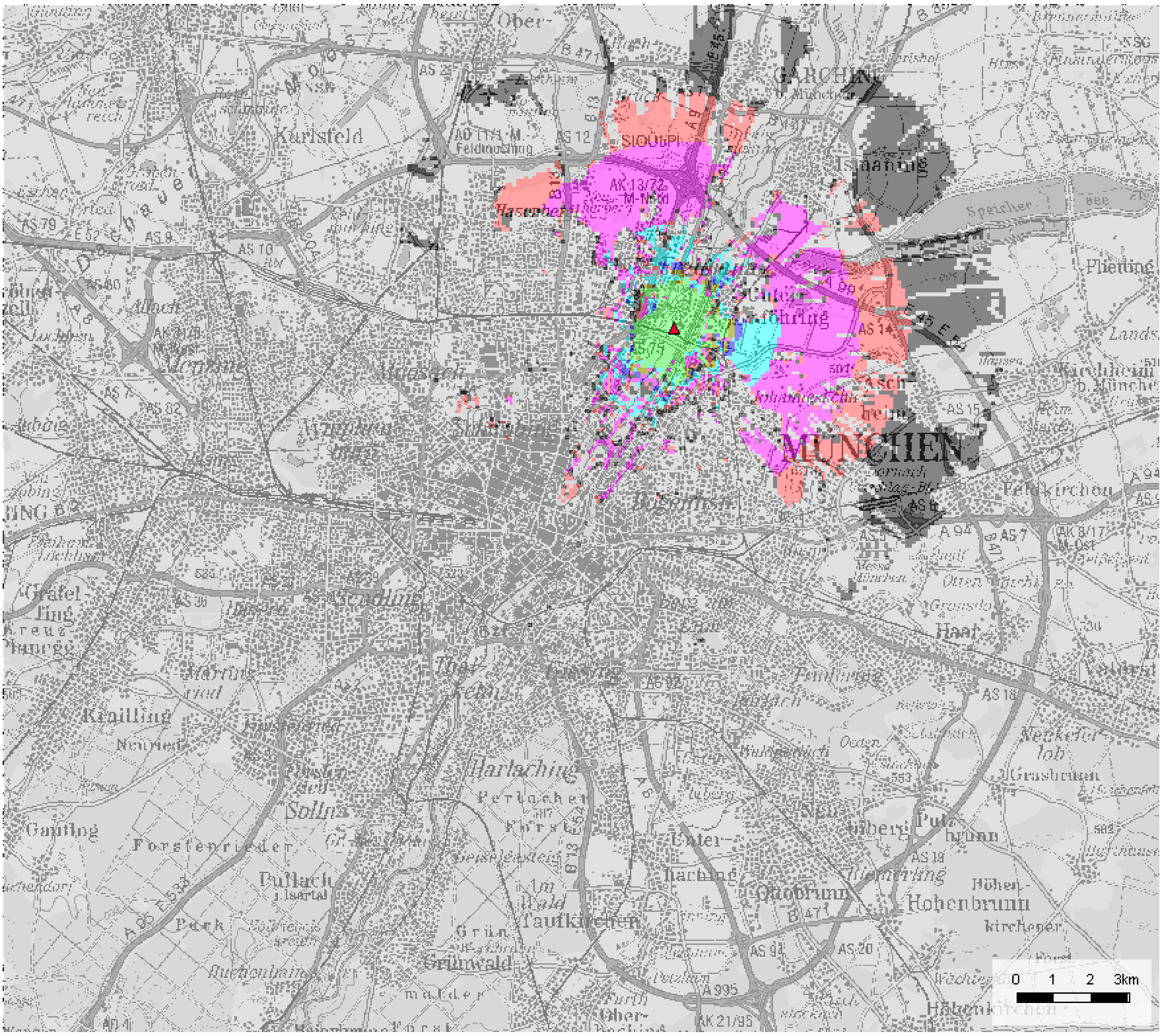


Figure 6 Coverage analysis results for condition B (Portable Outdoor)

Field strength prediction method: IRT_2D

Morphographic data: Morpho IRT

Resolution: 100 m

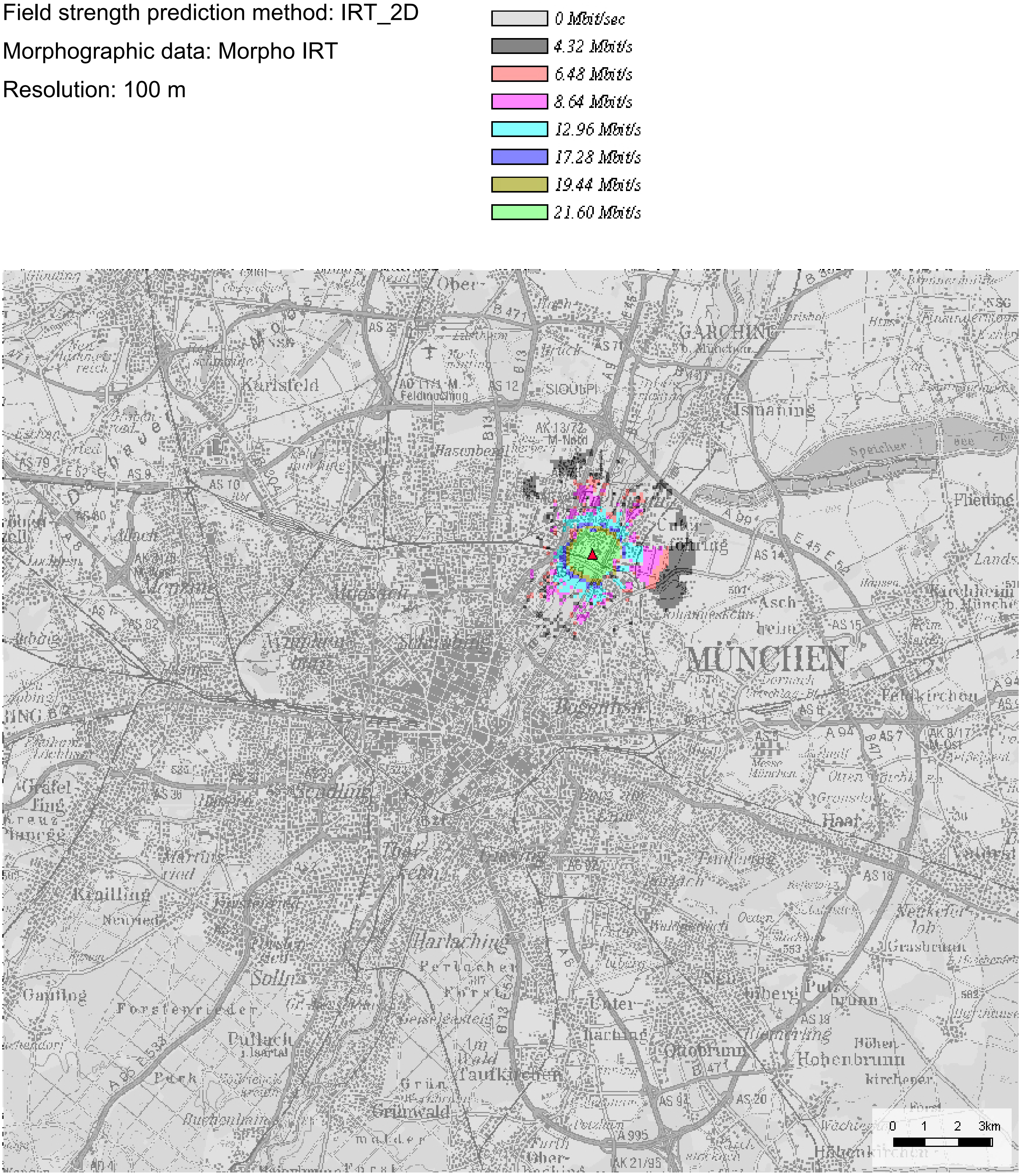
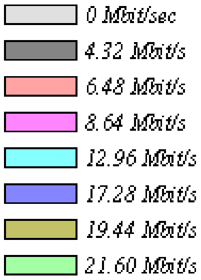


Figure 7 Coverage analysis results for condition C (Portable Indoor)

Field strength prediction method: IRT_2D

Morphographic data: Morpho IRT

Resolution: 100 m



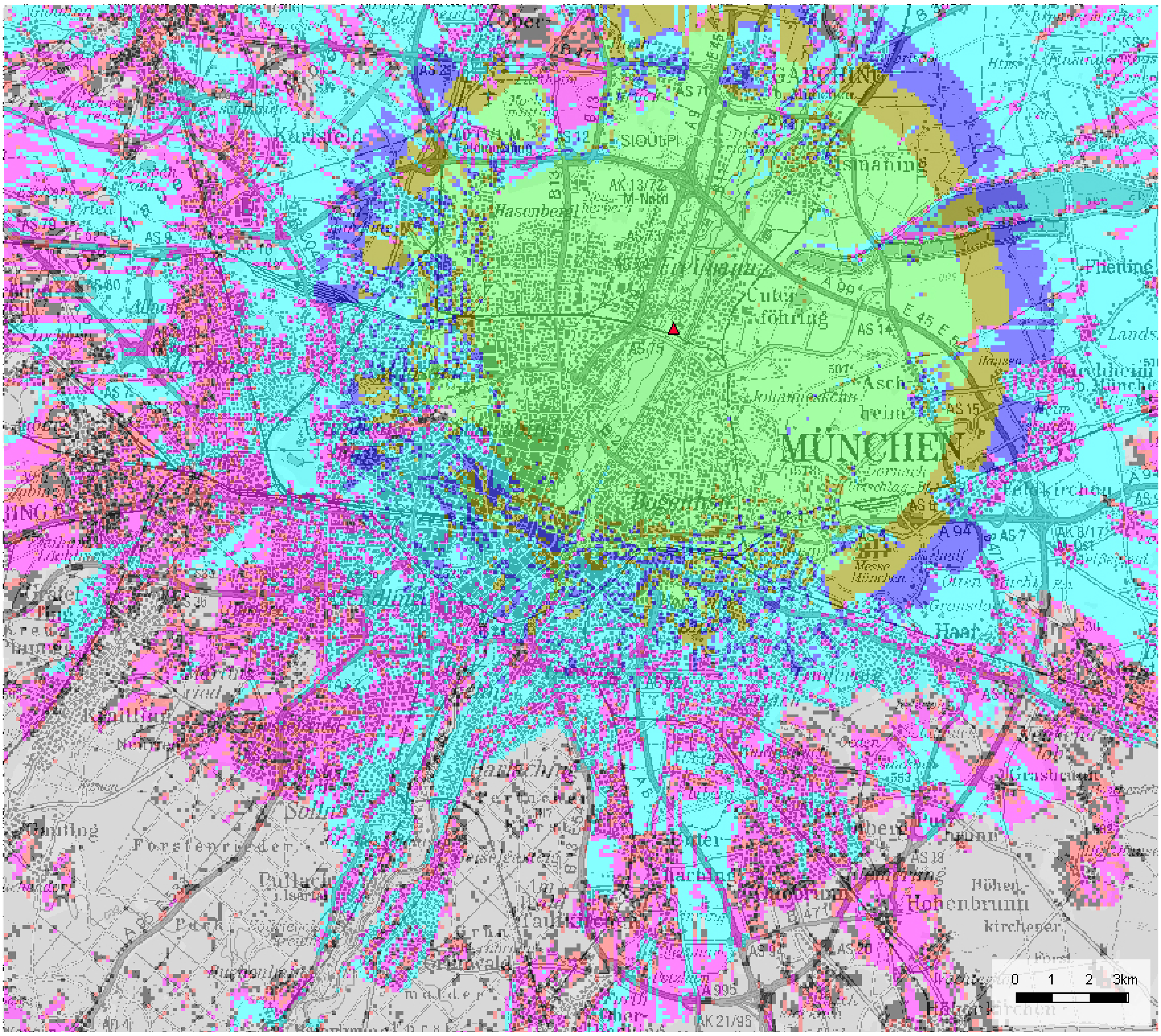
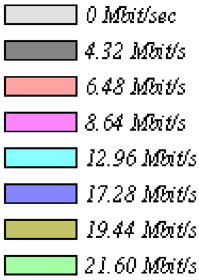


Figure 8 Coverage analysis results for condition D (directional roof antenna; antenna height: 10 m)

Field strength prediction method: IRT_2D

Morphographic data: Morpho IRT

Resolution: 100 m



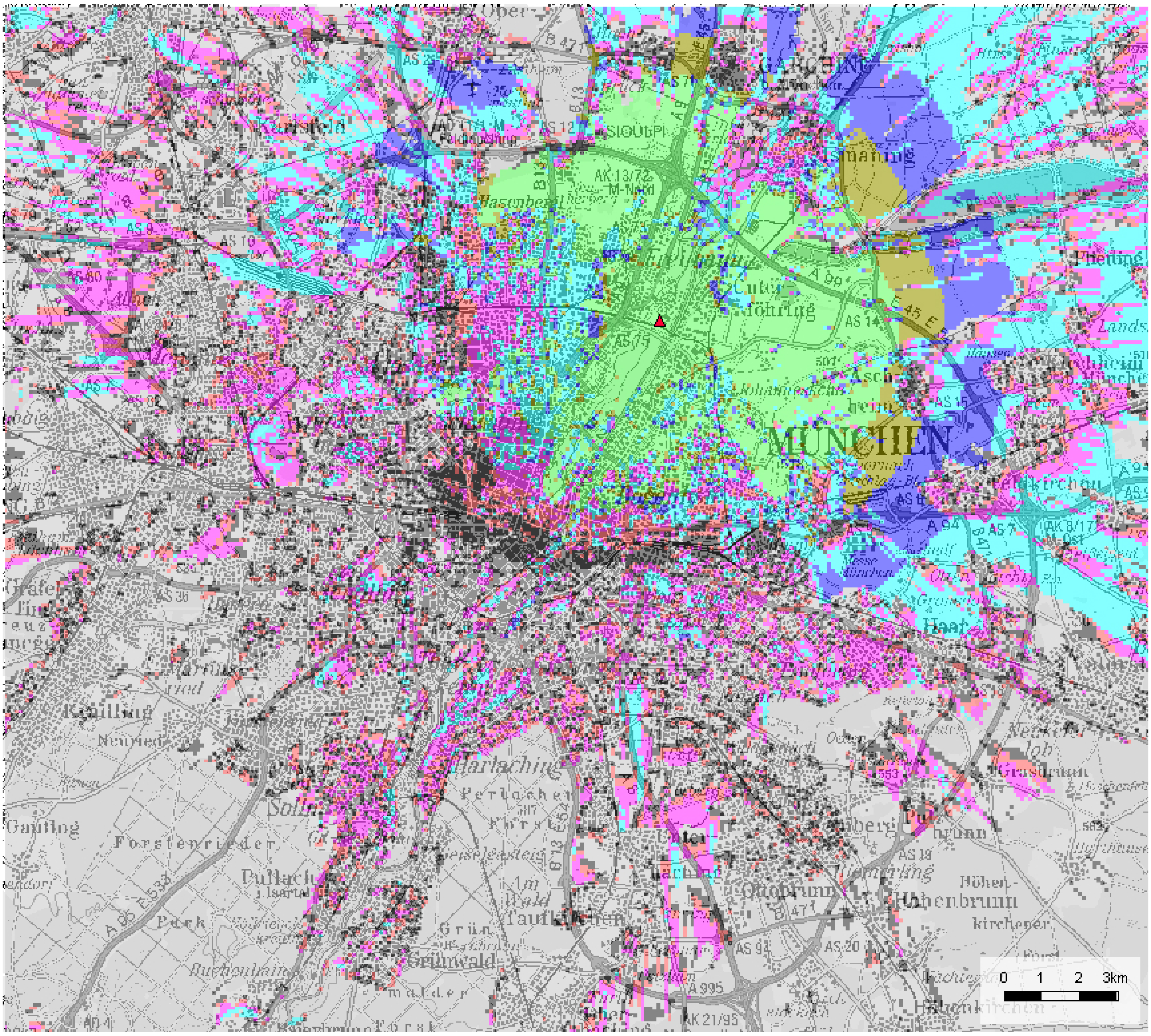
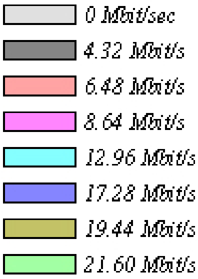


Figure 9 Coverage analysis results for condition D (directional roof antenna); antenna height: 4 m

Field strength prediction method: IRT_2D

Morphographic data: Morpho IRT

Resolution: 100 m



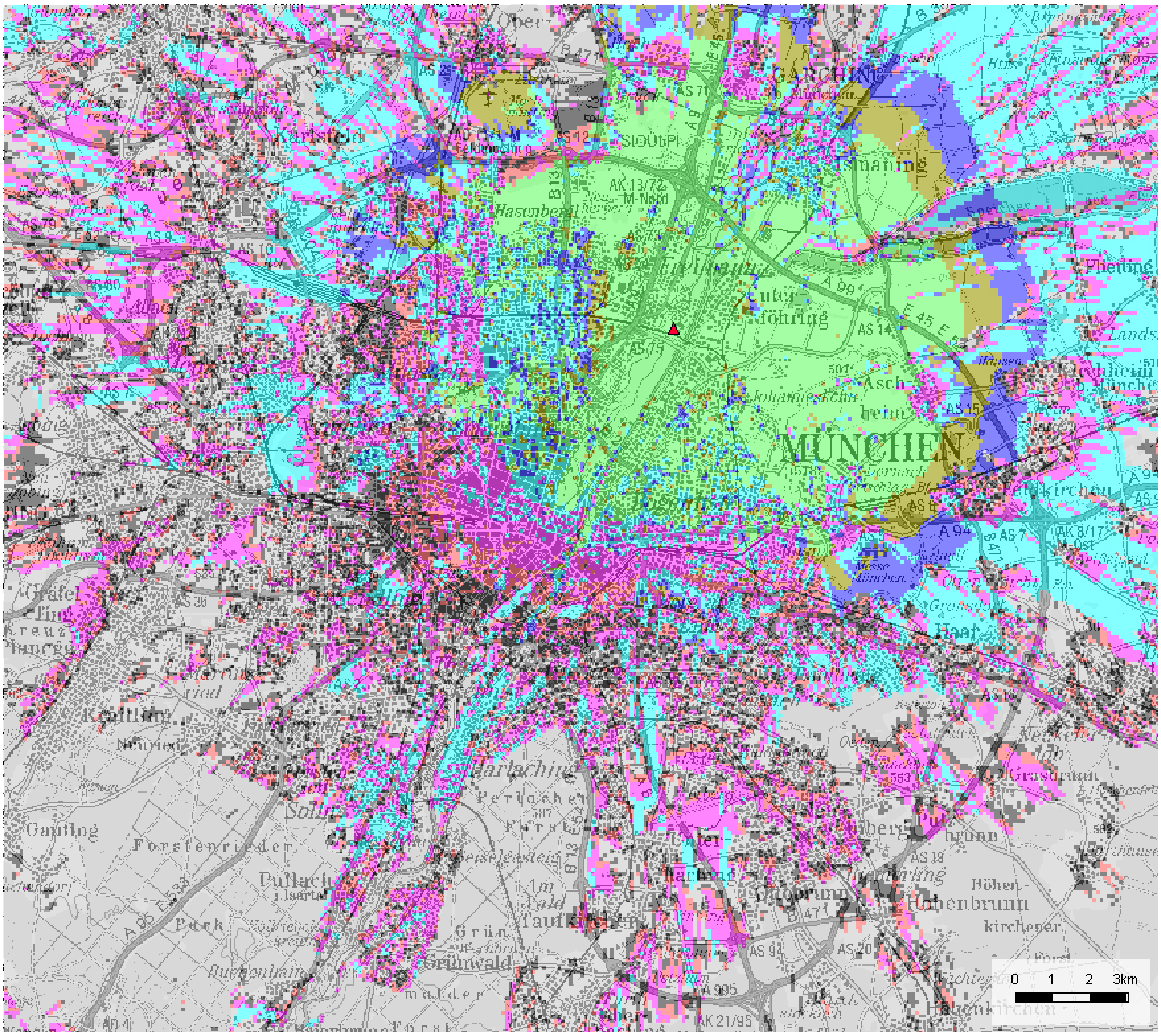
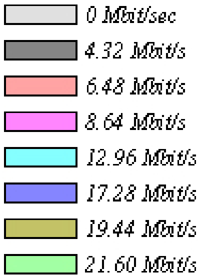


Figure 10 Coverage analysis results for condition D (directional roof antenna); antenna height: 6 m

Field strength prediction method: IRT_2D

Morphographic data: Morpho IRT

Resolution: 100 m



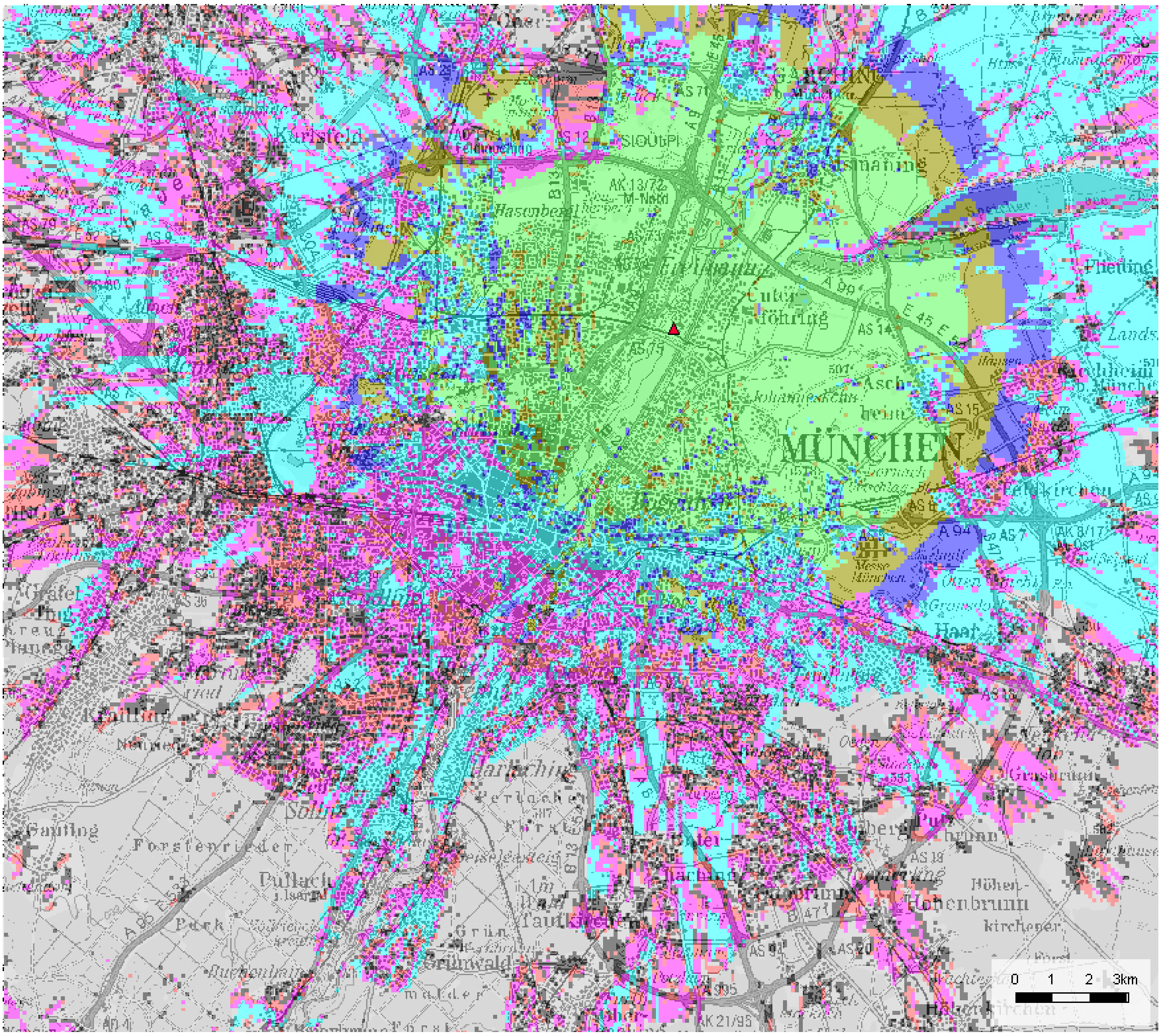


Figure 11 Coverage analysis results for condition D (directional roof antenna); antenna height: 8 m

3.3 Discussion of coverage analysis results

The results of the analysis for the field test area (Figure 3, Figure 4) show that a reasonable coverage for the tests can be expected. For a mobile terminal with a speed of 60 km/h (condition A), a data rate of 21 Mbits/sec can obtained for a coverage circle of approximately 8km with the recommendation of IRT_3D prediction method and IRT's city morphographic data model, as shown in Figure 3. However, this coverage range falls to approximately half (4 km) for guaranteed 21 Mbits/sec data rate, when the IRT_2D prediction method is used as shown in Figure 5. the green area on the map shows the reception data rate of 21.60 Mbits/sec.

A comparison of these results with the results of the calculations for the whole area of Munich (Figure 5 -Figure 11) shows that the latter predictions are less optimistic except for condition D (reception by directional roof antenna). The difference in resolution is the key reason of this discrepancy. Certain parameters of the IRT_2D and the IRT_3D models which play a role for averaging are optimized for frequencies up to 1.5 GHz. In the case at hand the models were applied to transmission at 2.5 GHz. Consequently a certain deviation of these parameters from the optimum has to be reckoned with. This systematic deviation is more important for calculations at a lower resolution because the influence of averaging on the final results is more important. But why is condition D an exception? Two points have to be taken into account to explain this. On the one hand the dependence of the averaging parameters on the frequency depends itself on the antenna height. On the other hand the 3D model incorporates reflections which improve the reception in shadowed streets which are neglected by the 2D model and this effect depends on the antenna height. It is weaker for 10 m than for 1.50 or 2 m.

Even though the results of the calculations at higher resolution using the 3D model are more reliable than the other ones, the results at lower resolution were included in this report as well because they give at least a qualitative idea of the coverage of the city of Munich as a whole on the given conditions.

4 Simulation of DVB-T Downlink Broadcast in Munich

This section will present the simulation of the coverage and capacity of parts of the city of Munich by a DVB-T downlink in broadcast mode.

4.1 Conversion table

The following tables, linking received power and throughput was provided by Runcom. They show results for simulations at 60km/h and 120km/h.

*See comments below

DVB-T/RCT

Modulation	Code Rate	RSSI (BER=10^-4) dBm	CINR (BER=10^-4) dB	Throughput Mbit/sec
Down Link Using channel model cost231with mobile adaptation at 60Km/h				
QPSK	1/2	-85	16	6.03
QPSK	2/3	-83	19	8.04
QPSK	3/4	-82	16	9.05
QPSK	5/6	-81	19	10.05
QPSK	7/8	-80	19	10.56
16QAM	1/2	-79	21	12.06
16QAM	2/3	-77	23	16.09
16QAM	3/4	-75	25	18.10
16QAM	5/6	-74	26	20.11
16QAM	7/8	-72	27	21.11
64QAM	1/2	-71	26	18.10
64QAM	2/3	-68	32	24.13
64QAM	3/4	-66	34	27.14
64QAM	5/6	-64	36	30.16
64QAM	7/8	-63	36	31.67
Up Link Using channel model cost231with mobile adaptation at 60Km/h				
QPSK	1/2	-84	16	5.6
QPSK	3/4	-82	19	8.4
16QAM	1/2	-78	21	9.2
16QAM	3/4	-75	27	14.0

*Comments:

6. BW=8MHz
7. FFT=2K
8. frame =1.2msec
9. Channel model according to WiMAXcost231 with mobile adaptation @60km/h
   Fade margin is included.
5. GI=1/32

#See comments below

Modulation	Code Rate	RSSI (BER=10^-4) dBm	CINR (BER=10^-4) dB	Throughput Mbit/sec
Down Link Using channel model cost 231with mobile adaptation at 120Km/h				
QPSK	1/2	-84.8	16.2	6.03
QPSK	2/3	-82.8	19.2	8.04
QPSK	3/4	-81.7	16.3	9.05
QPSK	5/6	-80.6	19.4	10.05
QPSK	7/8	-79.5	19.5	10.56
16QAM	1/2	-78.5	21.5	12.06
16QAM	2/3	-76.8	23.2	16.09
16QAM	3/4	-75.6	24.4	18.10
16QAM	5/6	-73.2	25.8	20.11
16QAM	7/8	-71.8	27.2	21.11
64QAM	1/2	-70.5	27.5	18.10
64QAM	2/3	-65.2	32.4	24.13
64QAM	3/4	-63.2	34.4	27.14
64QAM	5/6	-62.2	36.0	30.16
64QAM	7/8	-62.2	36.0	31.67
Up Link Using channel model cost 231with mobile adaptation at 120Km/h				
QPSK	1/2	-83.0	17.0	5.6
QPSK	3/4	-81.4	19.6	8.4
16QAM	1/2	-76.0	23.0	9.2
16QAM	3/4	-72.0	27.0	14.0

#Comments:

10. BW=8MHz
11. FFT=2K
12. frame =1.2msec
13. Channel model according to cost 231 with mobile adaptation @120km/h
    Fade margin is included.
5. GI=1/32

4.2 Results of the coverage analysis

The coverage calculations (DVB-T) were performed under the following parameters:

Frequency:	650 MHz (channel 43)
Bandwidth:	8 MHz
Modulation:	16 QAM
Code rate:	2/3

Guard interval: 1/4

Transmission antenna height: 90 m above ground

Transmission power: 100 W (EIRP)

Receiving antenna height: 1.50 m for portable outdoor

2 m for mobile

Position of the transmitting antenna: 11E 37’ 39.2’’, 48N 11’ 16.5’’ (DVB-T simulation alone)

11E 40’ 45’’, 48N 7’ 0’’ (combined with WiMAX)

The combination (16 QAM, CR=2/3, Guard interval=1/4) is prevailing in Germany because it is a good compromise between data rate and robustness.

DVB-T coverage calculations were carried out for the mobile (60 km/h) and the portable outdoor reception condition. According to the table above the RSSI value for such a system is -77 dBm. From the formula in chapter 3.1.1.4 the corresponding minimum field strength for the mobile reception condition can be derived:

$$E = P + 20*\lg(f) + 77.25$$

$$= 56.51 \text{ dB}\mu\text{V/m}$$

If a difference of 2 dB is assumed between the minimum field strength values for mobile and portable outdoor reception, the minimum field strength for the latter condition is 54.51 dBµV/m.

In agreement with the WiMAX coverage calculation procedure, the IRT-3D model was applied for a smaller area at a resolution of 10 m whereas the IRT-2D model was used for a wider area covering the whole city of Munich at a resolution of 100 m. The results for the portable outdoor condition are presented in Figure 12 - Figure 16.

In Figure 14 the WiMAX and the DVB-T results for portable outdoor as calculated by the 2D model are shown side by side. It is evident that the area covered by DVB-T is much larger than the area covered by WiMAX at a similar bitrate.

The field strength differences between the WiMAX and the DVB-T portable outdoor coverage (antenna height: 1.50 m) are shown in Figure 15 (3D calculation for smaller area) and Figure 16 (2D calculation for larger area).

A combined coverage of WiMAX and DVB-T for the mobile (60 km/h) reception condition is presented by Figure 17 (position of the WiMAX transmitting antenna: 11E 37’ 39.2’’, 48N 11’ 16.5’’). Because the presentation of the DVB-T coverage in this figure is semitransparent, it is evident where the areas of coverage are overlapping and which WiMAX zones are covered by DVB-T as well.

Field strength prediction method: IRT_3D

Morphographic Data: IRT's City model

Resolution: 10 m

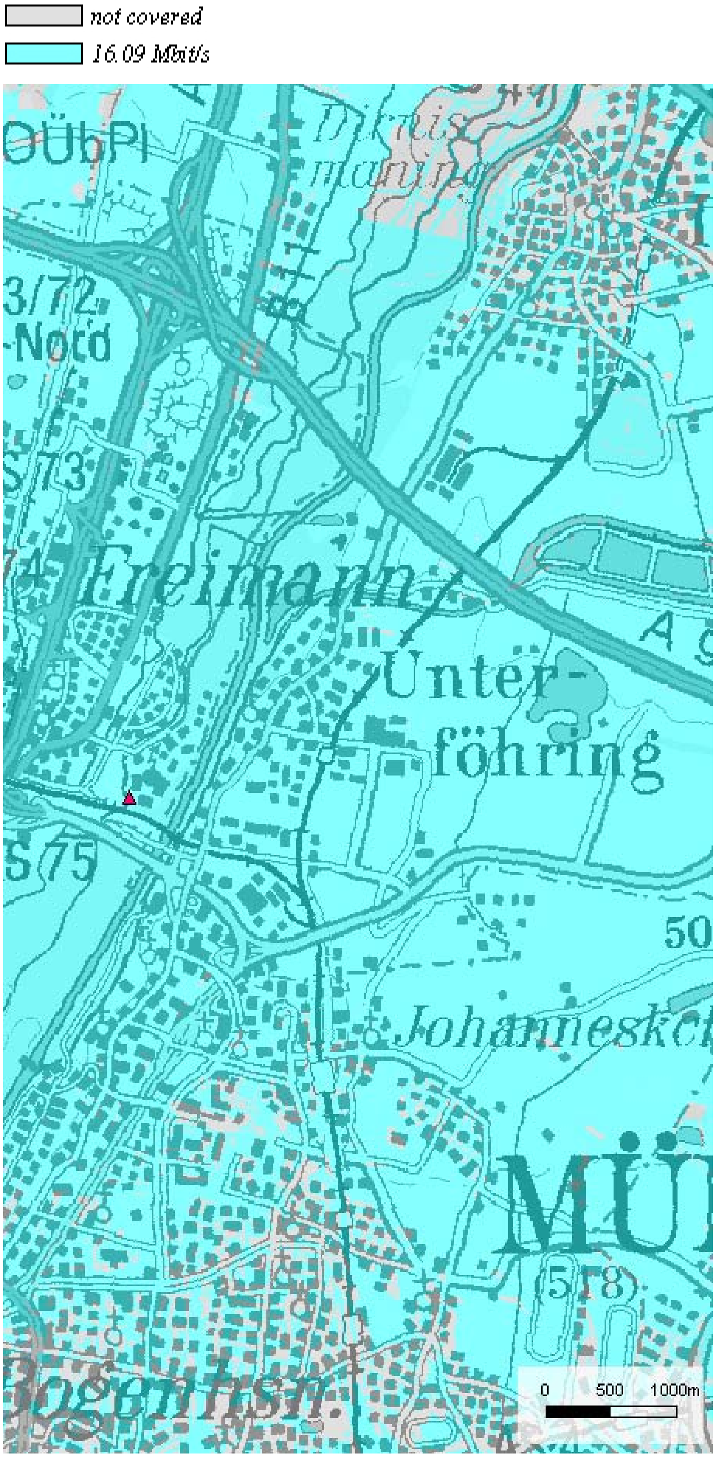


Figure 12 DVB-T coverage analysis results for Portable Outdoor receiving condition (3D model)

Field strength prediction method: IRT_2D

Morphographic data: Morpho IRT

Resolution: 100 m

not covered

16.09 Mbit/s

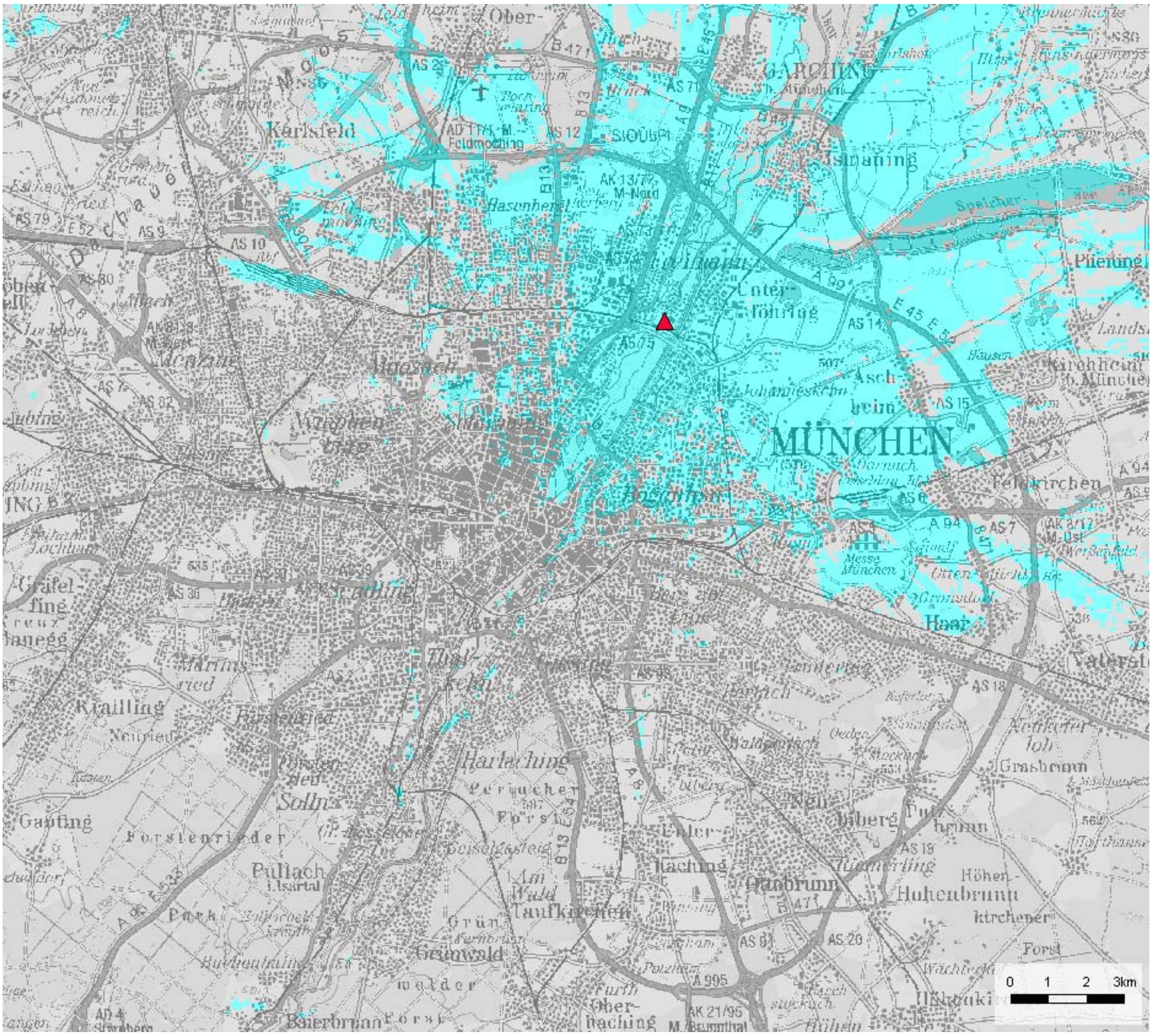


Figure 13 DVB-T coverage analysis results for Portable Outdoor receiving condition (2D model)

Figure 14 Comparison of WiMAX (left side) and DVB-T coverage (right side) for Portable Outdoor receiving condition (2 D model)

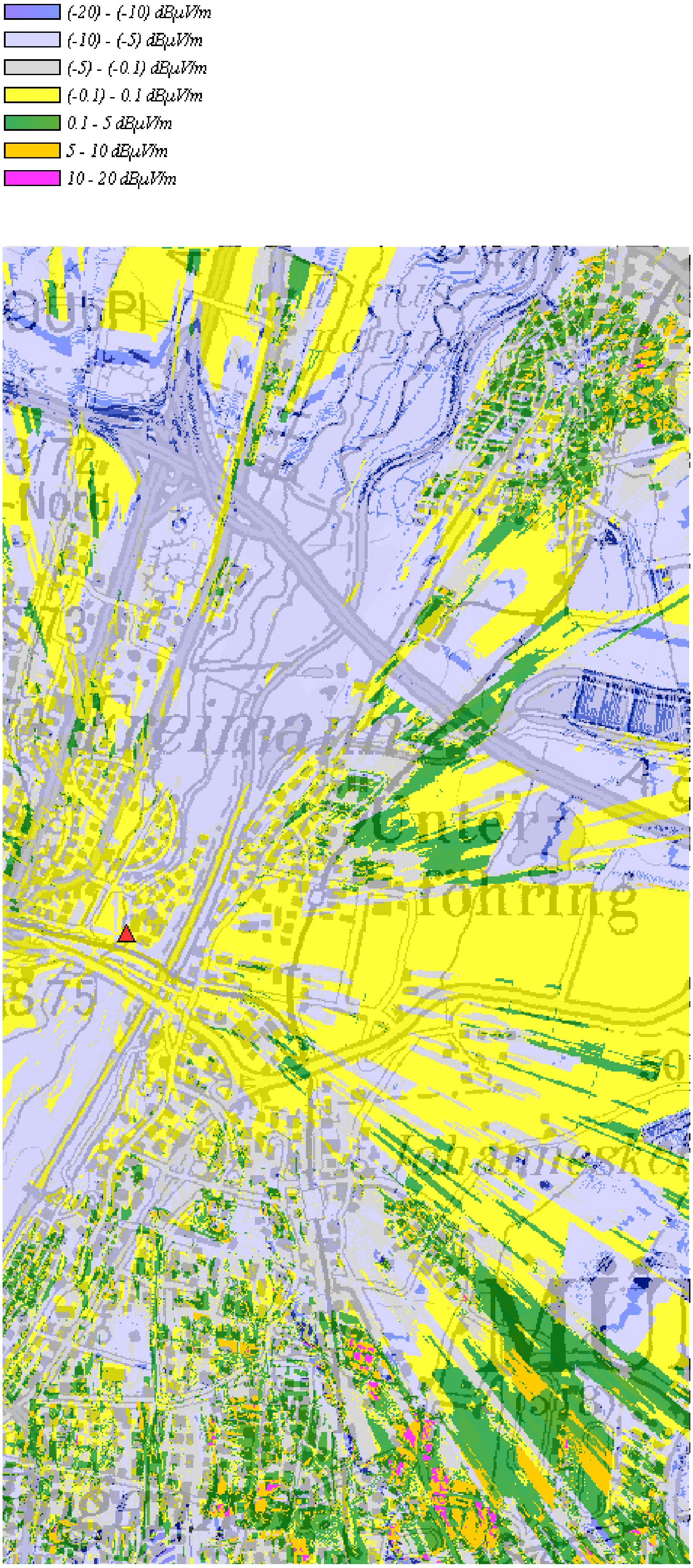


Figure 15 Difference in coverage analysis results:
(WiMAX) – (DVB-T) for Portable Outdoor condition (3D model)

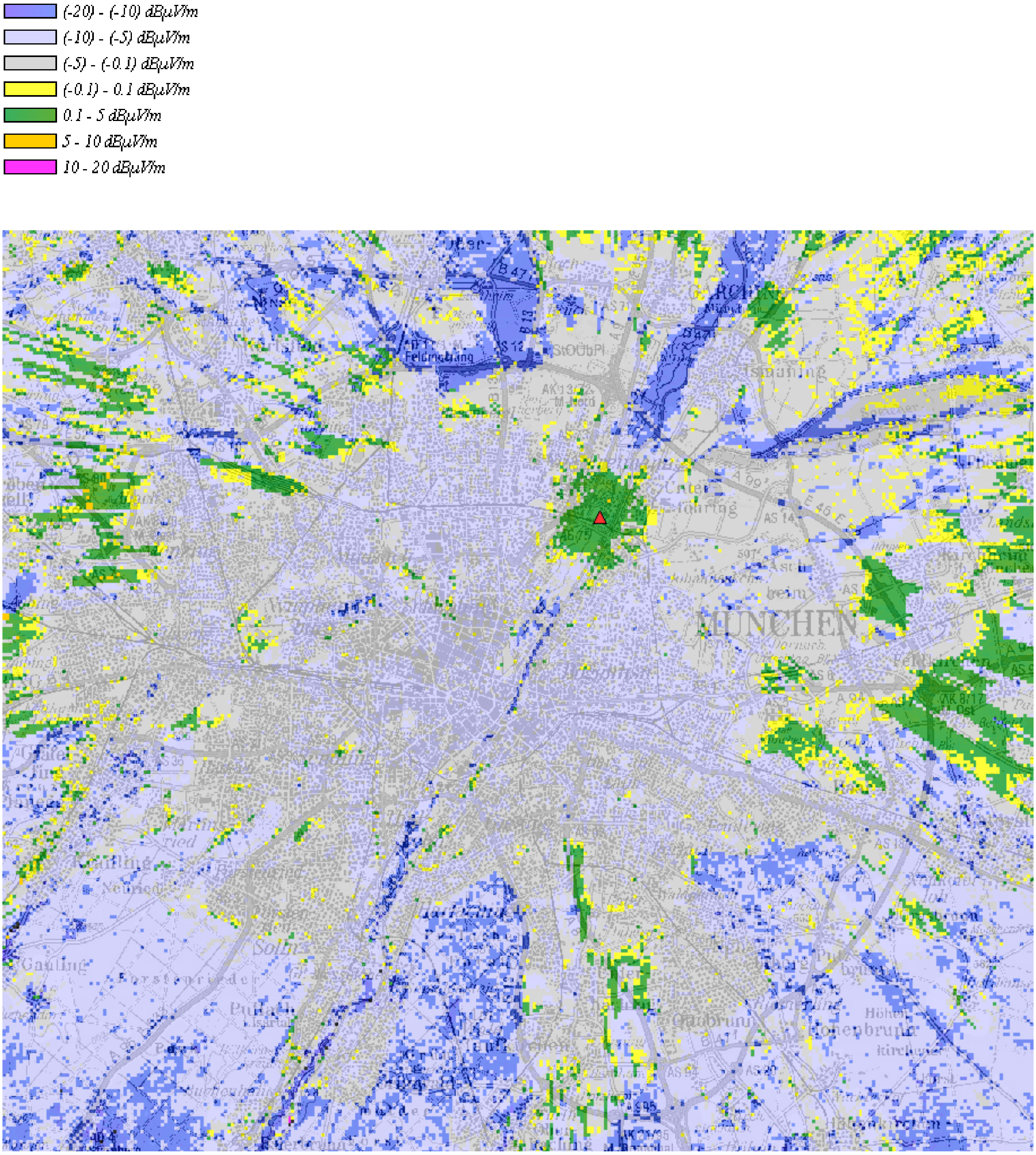


Figure 16 Difference in coverage analysis results:(WiMAX) – (DVB-T) for Portable Outdoor condition (2D model)

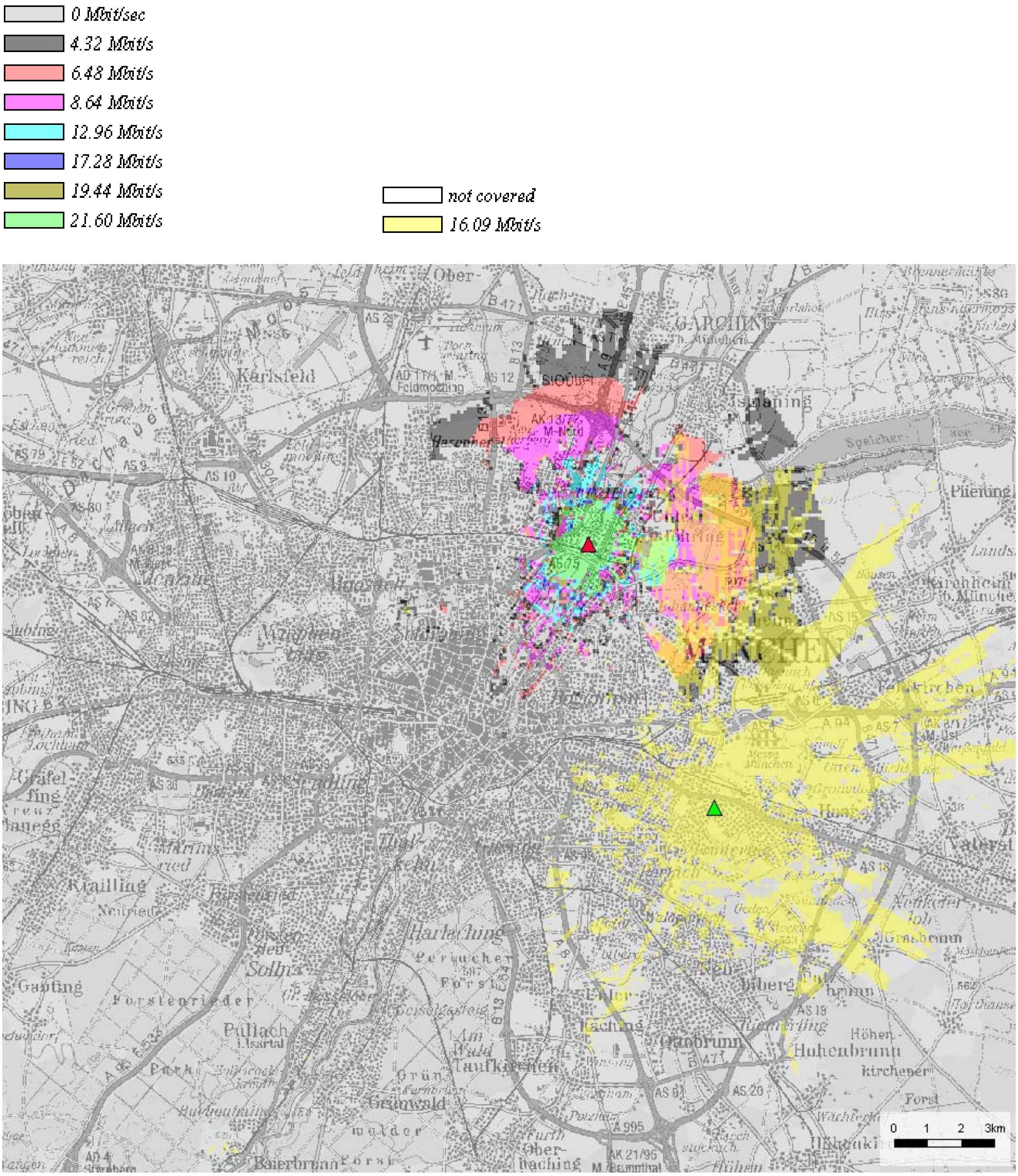


Figure 17 Combined WiMAX (transmitter: red) and DVB-T (transmitter: green) coverage for the mobile (60 km/h) reception condition

5 Simulation of WiMAX Uplink scenario in Munich

This section will present the simulation of the coverage of parts of the city of Munich in respect of a WiMAX uplink ENG (Electronic News Gathering) system for events applications. The WiMAX coverage calculations were only carried out for the portable outdoor reception condition. The resulting coverage/throughput maps give information about maximal uplink rates (e.g. to a studio) to be expected for any position.

The coverage calculations were performed for the following parameters:

Frequency:	2500 MHz
Bandwidth:	10 MHz
Polarization of transmitter antenna:	vertical
Position of the receiving antenna:	11E 37' 39.2'', 48N 11' 16.5'' (Figure 2)
Receiving antenna height:	90 m above ground
Receiving antenna gain:	23 dB
Transmission antenna height:	1.50 m
Transmission power:	200 mW
Transmission antenna gain:	14 dB (taken into consideration below)
Uplink/downlink ratio	1/3:2/3 (14 frames : 30 frames)

Remark: In an ENG uplink scenario it is common that directivity antennas are used. Consequently, the position of the reception antenna has to be known by the journalist in the field in order to correctly adjust his transmission antenna.

Physically there is no difference between a transmission from a 1.50 m antenna somewhere in Munich to the antenna in Freimann and the procedure in the opposite direction. Consequently, the uplink simulation could be done by a coverage calculation for the fixed 90 m antenna as transmitter and the 1.50 m antenna at various positions as receiver and interpreting the results the other way around. Accordingly the antenna gain of the 90 m antenna (23 dB) was taken into consideration for the transmission power which yielded:

Transmission power: $10^{(23/10)} * 200$ mW = 39.9 W ≈ 40 W (EIRP)

The coverage analysis was carried out only for the portable outdoor transmitting condition. This is also due to the directivity of the used antenna in the field. Based on the information provided by Runcom (table linking received power and throughput) and the formula for the conversion from received power P to field strength E derived in chapter 3.1.1, the following conversion table could be produced for this transmitting condition:

Modulation	Code Rate	Field strength dBµV/m	CINR (BER=10^-5) dB	Throughput Mbit/sec
Up Link Using channel model Veh A at 60Km/h				
QPSK	1/2	62.22	16	2.16
QPSK	3/4	65.22	19	3.24
16QAM	1/2	67.22	21	4.32
16QAM	3/4	73.22	27	6.48

The required minimum field strength values are further reduced taking into consideration

- no movement (at 60 km/h): - 2 dB
- antenna gain of the 1.50 m antenna: - 14 dB

Consequently, the table is transformed to:

Modulation	Code Rate	Field strength dBµV/m	CINR (BER=10^-5) dB	Throughput Mbit/sec
QPSK	1/2	46.22	16	2.16
QPSK	3/4	49.22	19	3.24
16QAM	1/2	51.22	21	4.32
16QAM	3/4	57.22	27	6.48

Additionally, a so-called “processing gain” is enabled in WiMAX by not using the whole bandwidth. In case that only one of the 35 sub-channels is used, there result a processing gain of 15,4 dB, however at the price of correspondingly throughput reduction.

The “processing gain” is expressed by following formula:

10 * log(35/(number of used subchannels)

As the throughput is reduced accordingly to the non-used subchannels, the lowest throughput resulting is about 64kbit/s solely sufficient for a pure audio connection or a slow file-contribution to the studio.

The processing gain can be calculated for each combination of modulation and code rate. However, in order to restrict the number of possible combinations, the calculations have been performed for some chosen number of subchannels. The corresponding processing gain values have been considered in the following table by reduced field strength values:

Modulation	Code Rate	Number of subchannels	Field strength dBµV/m	CINR (BER=10^-5) dB	Throughput Mbit/sec
QPSK	1/2	1	30.78		0.062
QPSK	1/2	5	37.77		0.309
QPSK	1/2	20	43.79		1.23
QPSK	1/2	35	46.22	16	2.16
QPSK	3/4	35	49.22	19	3.24
16QAM	1/2	35	51.22	21	4.32
16QAM	3/4	35	57.22	27	6.48

In agreement with the approach to the WiMAX downlink and the DVB-T simulations before, the calculation was carried out for a smaller part of Munich using the IRT 3D model and for the whole area of this city using the IRT 2D model. The results are presented in Figure 18 and Figure 19.

It is evident that nearly in the whole area of the 3D simulation (where the IRT field test will take place) transmission at the highest possible uplink data rate is possible, which is also due to the additional antenna gain in the field. So it can be concluded that the uplink transmission conditions are even more favourable than the downlink conditions.

Field strength prediction method: IRT_3D

Morphographic Data: IRT's City model

Resolution: 10 m

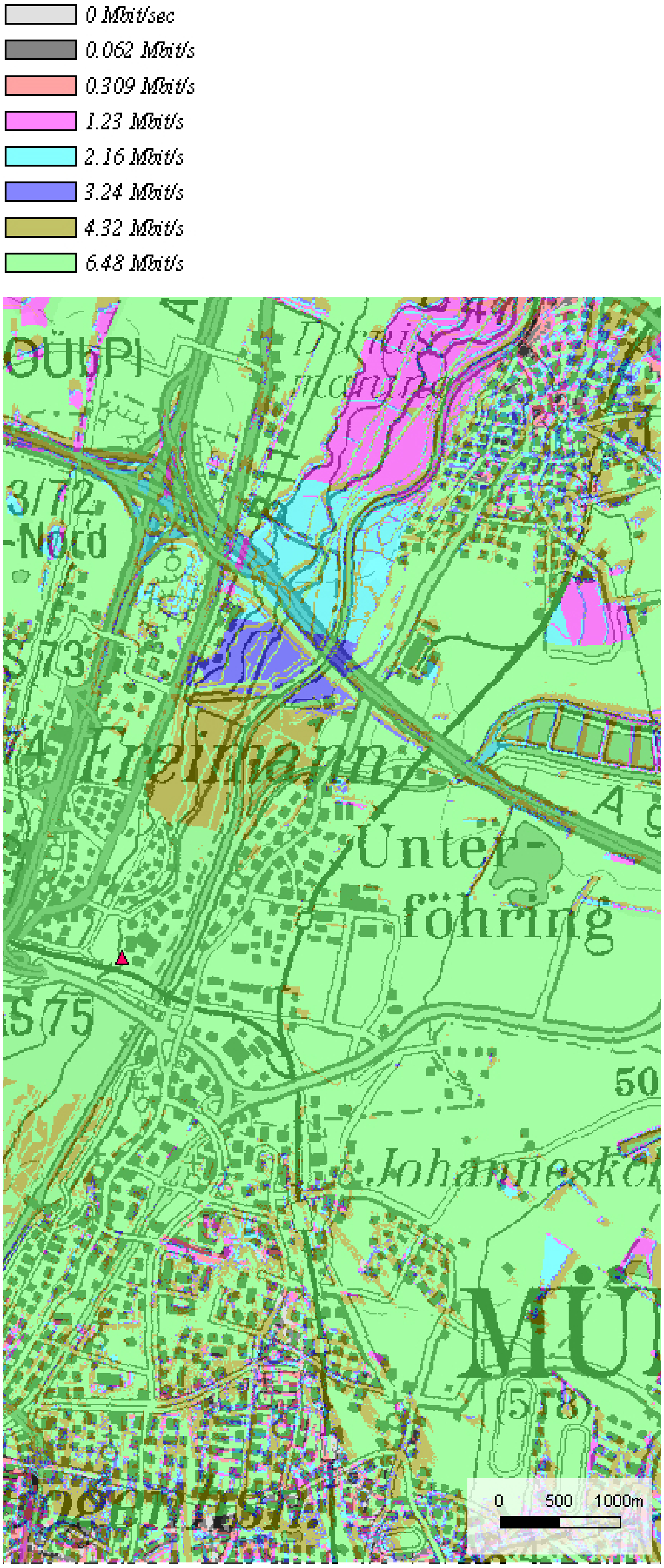


Figure 18 WiMAX uplink coverage analysis results for Portable Outdoor transmitting condition (3D model)

Field strength prediction method: IRT_2D

Morphographic data: Morpho IRT

Resolution: 100 m

- 0 Mbit/sec
- 0.062 Mbit/s
- 0.309 Mbit/s
- 1.23 Mbit/s
- 2.16 Mbit/s
- 3.24 Mbit/s
- 4.32 Mbit/s
- 6.48 Mbit/s

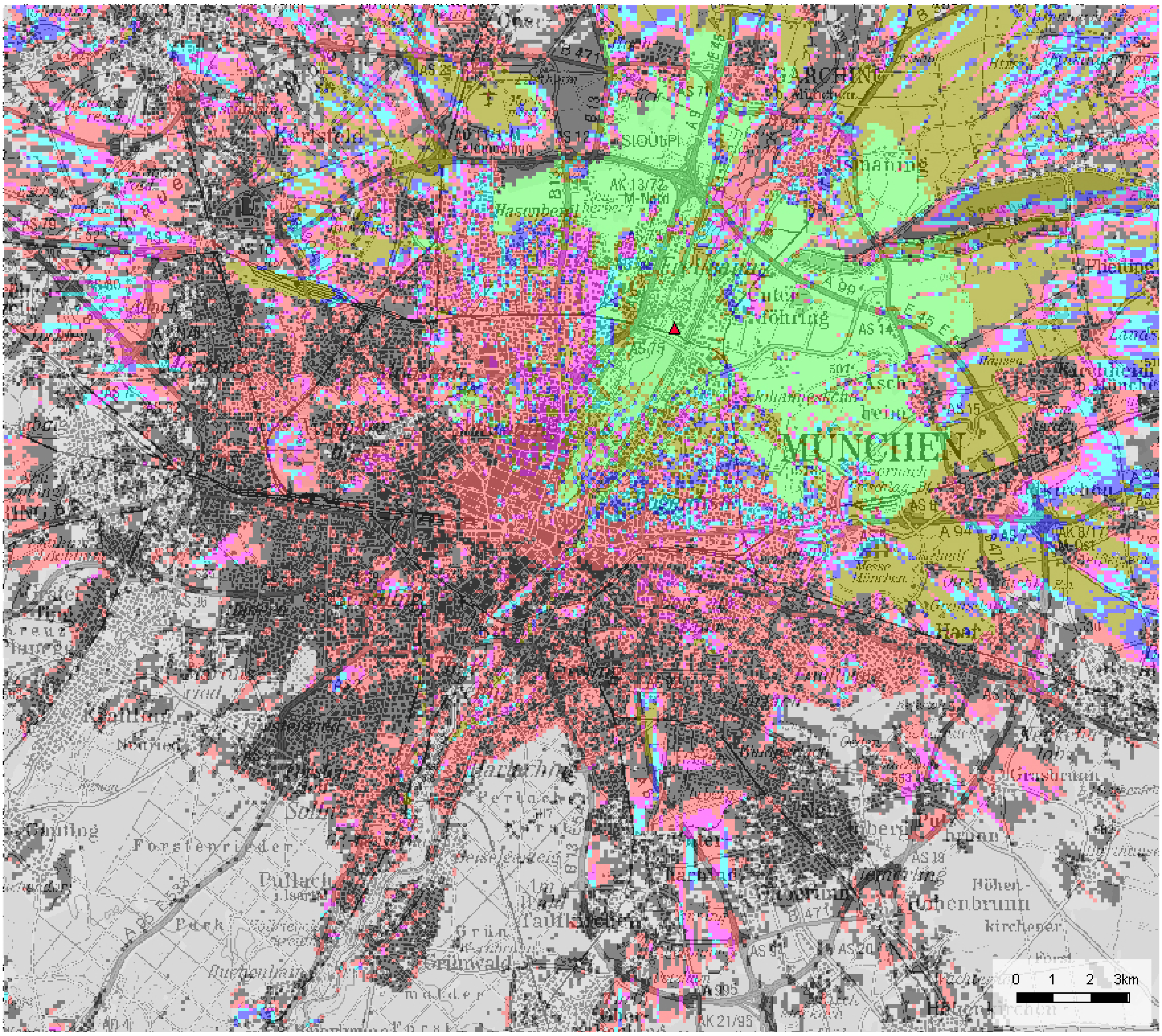


Figure 19 WiMAX uplink coverage analysis results for Portable Outdoor transmitting condition (2D model)

6 Combined DVB-T and WiMAX Coverage Analysis

This section of the report compares results for DVB-T and WiMAX, so that conclusions can be drawn about the requirements and the potential performance of the SUIT architecture. To achieve this, the WIMAX and DVB-T results are compared for the portable scenario.

In Figure 14 the WIMAX and the DVB-T results as calculated by the 2D model are shown side by side. The same colour (cyan) is used for similar data rates (WIMAX: 12.96 Mbit/s, DVB-T: 13.27 Mbit/s). It is evident that the area covered by DVB-T at 13.27 Mbit/s is very similar to the area covered by WIMAX at 12.96 Mbit/s or a higher data rate. The field strength differences between the WIMAX and the DVB-T coverage are shown in Figure 15Figure 15 (3D calculation for smaller area) and Figure 16Figure 16 (2D calculation for larger area).

Although the bit rates are the same for WIMAX and DVB-T, in SUIT the WIMAX system is used for providing web services, and streaming video, alongside the broadcast of video. This means that the quoted bit rate must be shared amongst multiple subscribers. To get a better idea of the true situation, a simple calculation can be performed. First, some assumptions can be made to estimate the number of WIMAX subscribers using the system at a time:

Population density of Munich: 4353 km^{-2}

Assume 4 people per household

4353/4 = 1088 households/km^2

If 30% of those households are subscribers, and 10% of those subscribers are using WIMAX at once, then 1088x0.3x0.1 = **32 users/km^2** should be supported

The highest bit-rates supported in the coverage simulations is 20Mb/s. If we assume that the coverage area shown in the simulations is around 1km^2 then each user could be provided with a capacity of approximately 0.6 Mb/s.

This shows that unless WIMAX is used to broadcast only video, it cannot support Standard Definition (SD) video under the conditions used in the coverage simulations. Using the simulations shown in this deliverable, a number of conclusions can be drawn about how the trial should be set-up:

1. Mobile WIMAX has limited coverage, and so the base station should be situated close to the road for the trial;
2. WIMAX can only provide CIF resolution 0.5 Mb/s video. This means that the Multiple Description Coding used in SUIT will need to be heavily unbalanced;
3. Only DVB-T can support HD video;
4. Around three WIMAX base stations would be needed to support the same area covered by one DVB-T transmitter.

For the field trials in Aveiro, points 2 and 4 above, may differ slightly. As Aveiro has a lower population density, and a different landscape, it may be possible to provide more bit-rate to users, or to use fewer base stations by turning up the power. However, it is unlikely that there will be enough capacity provided by WIMAX for SD video (1.5-2 Mb/s).

As Munich has 310.6 km2 and a population of 1.2 Million habitants, it would require around 300 BSTs! Clearly, the SUIT building profile can overcome this difficulty by providing VoD for households whereas WiMAX can provide SD VoD in vehicles. See deliverable D1.4.5, D6.4 and D6.5 for more information namely capacity simulations for a less dense populated city, Aveiro.

7 Summary

This deliverable features the downlink and uplink coverage and capacity analysis for Munich city using the IRT Fransy software for WiMAX and DVB-T. For the WiMAX downlink simulations, various reception conditions were simulated, including mobile reception in a car travelling at 60 kmph, portable indoor and portable outdoor reception, and finally directional roof antenna reception. Results show that reasonable system coverage and capacity can be expected for the trial. However, one thing to note is that the results were obtained for 2.5 GHz while the actual path loss models used were estimated for frequencies 0.8 – 1.5 GHz. Hence, an additional margin will probably be needed. WiMAX uplink transmission simulation showed that uplink transmission at a data rate of 6.48 Mbit/s should be possible nearly everywhere in the area of the planned IRT WiMAX field tests. The DVB-T DL coverage ensured 16 Mbps in a 1.5 km radius, despite the field strength extended to a greater distance in all directions except in the west part of the city.

The most interesting results come from the comparison of the WIMAX and DVB-T coverage simulations. When multiple services are provided by WIMAX (i.e. Internet, streaming video), then it is clear that WIMAX cannot support as good quality video as DVB-T. In fact, it is recommended that WIMAX video is limited to CIF resolution, and a bit rate of 0.5Mb/s. In addition, some simple estimations are used to show that around three WIMAX base stations are needed to cover the same area as a single DVB-T transmitter. The conclusions drawn in this deliverable can be used in the design of the field trials in Aveiro. However, it is necessary to remember that Aveiro has a lower population density and presents a different environment to Munich. Nevertheless, many of the basic conclusions drawn for Munich are still expected to be valid for Aveiro. See Deliverables D7.1.5 and D6.4 for further information about Aveiro.

Other very interesting conclusion is the increased coverage area obtained from the superposition of DVB-T signal and WiMAX (see Figure 17). This figure proves the most important objective of SUIT, network diversity, where CIF resolution in WiMAX can be selected by the Gateway and afterwards enlarged by the Terminal emulating SD or HD.

8 References

[1] Grosskopf, R.: Comparison of different methods for the predictions of the field strength in the VHF-range, IEEE Transactions on Antennas and Propagation 35 (1987), 7, pp. 852-859

[2] Grosskopf, R.: Comparison of field-strength prediction methods in the UHF range, EBU Review 229 (1988), pp. 102-110

[3] Grosskopf, R.: Feldstärkevorhersage im VHF-Bereich mit Hilfe topografischer Daten, Rundfunktechnische Mitteilungen 30 (1986), 4, pp. 176-182

[4] Grosskopf, R.: Dämpfungszuschläge für Feldstärkevorhersagen im VHF- und UHF-Bereich in Abhängigkeit von einer äquivalenten effektiven Sendeantennenhöhe, Technischer Bericht Nr. B 112/90 des Instituts für Rundfunktechnik, 1990

[5] Grosskopf, R.: Verbesserte Feldstärkevorhersage in Tallagen durch Berücksichtigung von Reflexionen hinter dem Empfangsort, Rundfunktechnische Mitteilungen 35 (1991), 3, pp. 129-134

[6] Grosskopf, R.: Feldstärkevorhersage mit Berücksichtigung von Mehrwegeausbreitung, Rundfunktechnische Mitteilungen 33 (1989), 4, pp. 155-161

[7] Grosskopf, R.: Field strength predictions in the VHF and UHF range including multipath propagation, 7. International Conference on Antennas and Propagation (ICAP 91), York, Conf. Publ. No. 333, Vol. 2, IEE, London 1991, pp. 965-967

[8] Meeks, M.L.: VHF propagation over hilly, forested terrain, IEEE Transactions on Antennas and Propagation 31 (1983), 3, pp. 483-489

[9] Deygout, J.: Multiple knife-edge diffraction of microwaves, IEEE Transactions on Antennas and Propagation 14 (1966), 4, pp. 480-489

[10] Causebrook, J.H. et al: Computer prediction of field strength - A manual of methods developed by the BBC for LF, MF, VHF and UHF bands, Engineering Division, BBC

[11] Recommendation ITU-R P.1146: The prediction of field strength for land mobile and terrestrial broadcasting services in the frequency range from 1 to 3 GHz, ITU-R Recommendations, Geneva, 1997, P Series – Part 1, pp.

[12] Recommendation ITU-R P.452-7: Prediction procedure for the evaluation of microwave interference between stations on the surface of the earth at frequencies above about 0.7 GHz, ITU, Geneva (1995)

[13] Sharples, P.A. and Mehler, M.J.: An integrated terrain and urban diffraction model for system planning, 7th Int. Conf. on Antennas and Propagation (ICAP 91), York, Conf. Publ. No. 333, vol. 2, IEE London, pp. 808-811, 1991

[14] Grosskopf, R.: Prediction of Urban Propagation Loss, IEEE Transactions on Antennas and Propagation 42 (1994), 5, pp. 658-665

[15] Grosskopf, R.: A Propagation Model for Digital Broadcast Systems in Urban Areas, Beyond Line-of-Sight Conference, The University of Texas at Austin, Austin, USA, 1994

[16] Grosskopf, R.: Investigation of a terrestrial DAB single frequency network for Nordrhein-Westfalen, 8. Int. Conf. on Antennas and Prop. (ICAP 93), Edinburgh, Conf. Publ. No. 370, Vol. 1, IEE, London 1993, pp. 462-465

[17] Grosskopf, R.: Vergleich verschiedener Feldstärkevorhersagen mit Messungen im DAB-Gleichwellennetz in Bayern, Rundfunktechnische Mitteilungen 39 (1995), 3, pp. 102 - 114

[18] Grosskopf, R.: Vergleich verschiedener Feldstärkevorhersagen im 1,5 GHz-Bereich mit Messungen im DAB-Gleichwellennetz der Deutschen Telekom AG bei Offenburg, Rundfunktechnische Mitteilungen 40 (1996), 1, pp. 14 - 23

[19] Grosskopf, R.: Ausbreitungsuntersuchungen im Stadtgebiet von München im 1,5-GHz-Bereich, Technischer Bericht Nr. B 154/97 des Instituts für Rundfunktechnik, 1997

[20] Grosskopf, R.: Terrestrial DAB at 1.5 GHz - Comparison of Predictions and Measurements, 10. Int. Conf. on Antennas and Propagation (ICAP 97), Edinburgh, Conf. Publ. No. 370, Vol. 1, IEE, London (1997), pp. 2.347-2.352

[21] Grosskopf, R.: Inhaus-Versorgung der DVB-T Sender in München, Technischer Bericht Nr. B 168/99, Institut für Rundfunktechnik, München, 1999

[22] Grosskopf, R: Field-Strength Prediction Method for Urban Micro Cells, 17th International Conference on Applied Electromagnetics and Communications, ICECom 2003, 1-3 October 2003, Dubrovnik, Croatia, pp. 213-216

[23] A. Zistler, C. Dosch, M. Goldstein, F. Enrich, A. Navarro, “Architecture and Reference Scenarios“, SUIT Deliverable 1.4, December 2006.