Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

UMTS COVERAGE MEASUREMENTS

Nice, May 2007

EXECUTIVE SUMMARY

This report describes a method to measure UMTS coverage. Because actually measuring along every possible route throughout the country would require extremely high effort and time, a method is introduced that basically verifies coverage prediction models calculated from the network planning. Using this approach, it is sufficient to measure across border lines separating areas that are predicted to be covered from those predicted not to be covered with UMTS service.

For proper function of UMTS equipment it is not only sufficient to provide enough field strength. One other critical parameter is the E_C/I_0 that can be compared to the signal to noise ratio in other communication systems. Experience shows, however, that, at the coverage borders, measuring a parameter comparable to the field strength (in UMTS expressed as RSCP) is sufficient to evaluate coverage.

The report uses the coverage measurement equipment and findings from measurements done in Germany as an example. It does not imply a recommendation for this particular set of equipment.

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UMTS coverage measurements

1 BASICS, TERMS AND DEFINITIONS

Unlike most others, the Universal Mobile Telecommunication System (UMTS) is based on a technology that spreads the RF energy over a wide band, resulting in higher occupied bandwidth. The disadvantage of not using as less bandwidth as possible is compensated by the advantage that multiple UMTS stations can transmit on the same frequency at the same time while still maintaining the possibility to separate the different transmissions on the receiver side. This method is called Code Division Multiple Access (CDMA). To allow the separation, the user data is first "modulated" onto a binary code (key) before it is transmitted. For a data bit 1, the negative binary code is transmitted, for a data bit 0, the code itself is transmitted. If, for example, the code is 4 digits long, the data rate to be transmitted and the resulting RF bandwidth is four times higher than it would be without spreading.

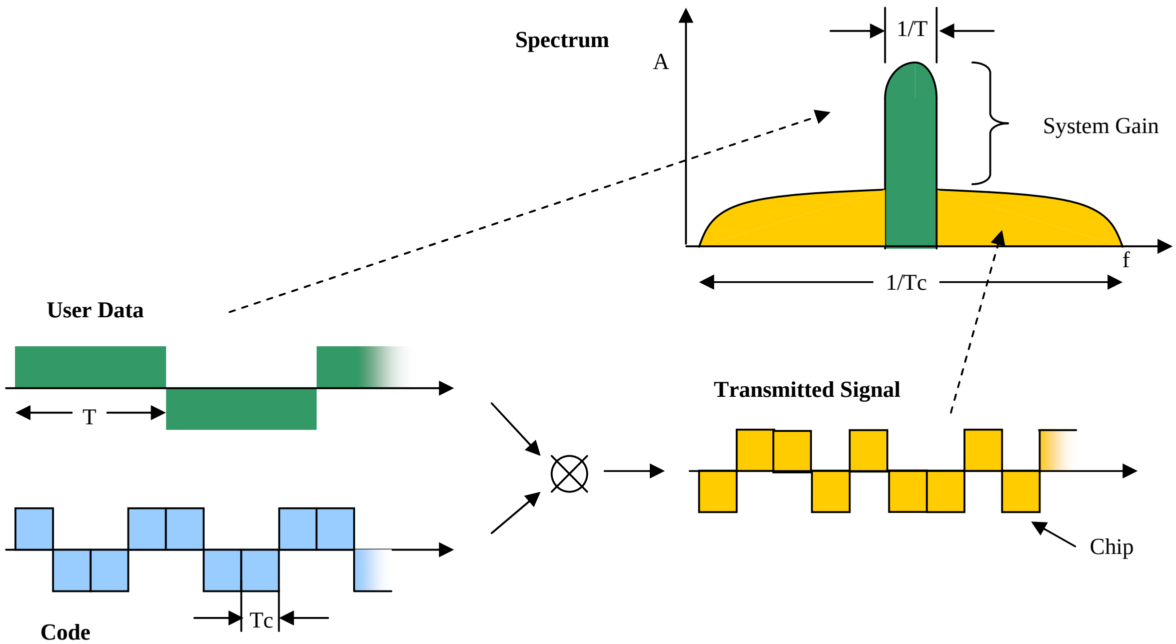

Figure 1: Principle of spectrum spreading

The codes used in UMTS have a pseudo random bit sequence, making the transmitted signal noise like (pseudo noise or PN), regardless of the original user data. To prevent mixing up with user data, each bit of the code is called a chip. Hence the actually transmitted data rate is the chip rate rather than the data rate.

The receiver performs a correlation process with the received signal and the known code. Comparison of every four received bits (in our example) with the code followed by a time integration retrieves the original useful data with a very high confidence. Even if some of these bits are destroyed due to interfering emissions from other UMTS stations on the same frequency, the original data can be filtered out. Physically, the RF energy spread over a wide bandwidth is "collected" by the receiver and reduced to a narrow band by the correlation process. This concentration suppresses any narrow and wideband interferers by the so-called "system gain", resulting in much higher resistance against interference.

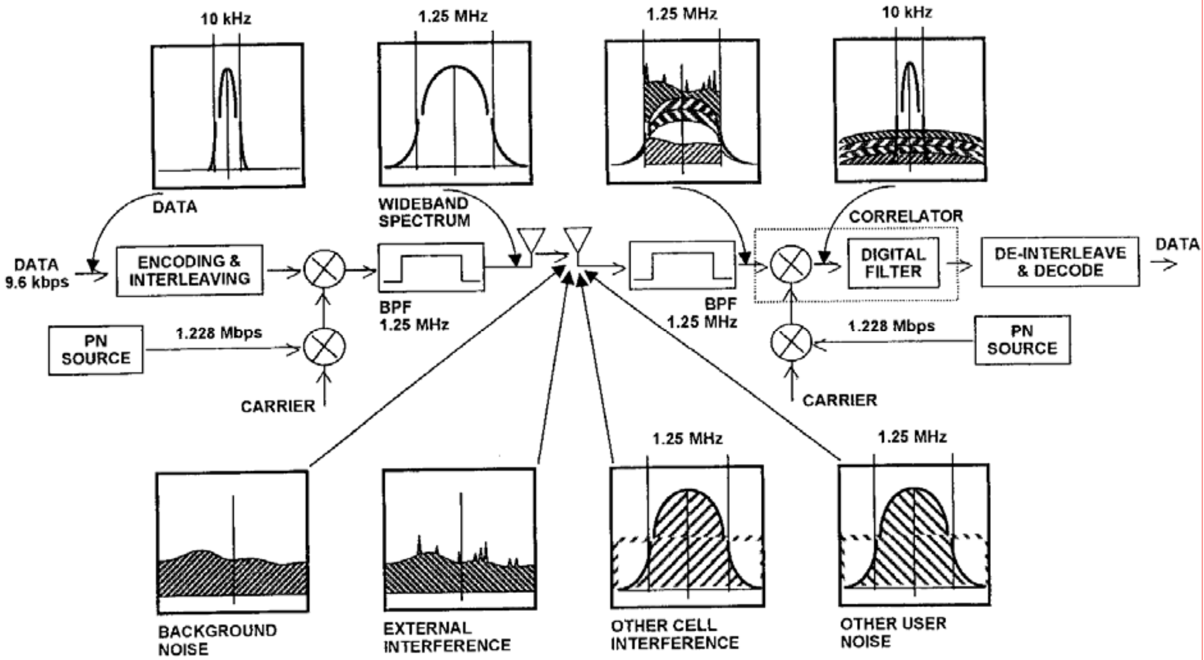

Figure 2: Used and interference spectra at different stages of the transmission process (example from IS-95)

Commercial receivers in UMTS are called user equipment (UE). Among other functional units, the UE includes the actual RF receiver, correlation stages, and demodulator.

2 MEASURED PARAMETERS

2.1 Network Coverage Definition

To define the term “network coverage”, it is important to agree on what is expected from the user equipment. Like in GSM networks, there are different assumptions for a successful operation of the UE:

- Logging in to the network
- Starting a call
- Maintaining a call that is already set up
- Reaching a specific data rate in data transmission

If the reception quality gets poorer, the following effects are observed:

- Data rate decreases
- Call that has been established is disconnected (“dropped call”)
- New call can not be started
- Equipment is logged out of the network (“network disconnection”)
- Equipment can not be logged into the network (“network access”)

In various measurements done in Germany it has been found that the above effects or equipment states have the following dependency with regard to the reception quality:

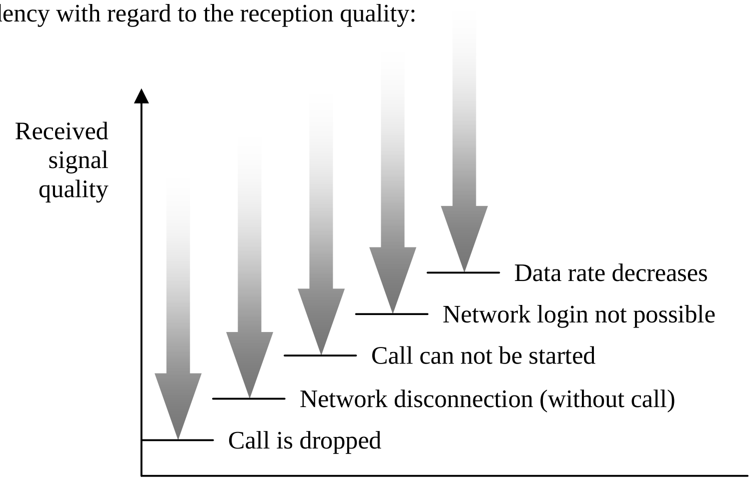

Figure 3: Minimum receive quality for certain equipment stages

In Germany it was not mandatory that for all covered locations a certain data rate is provided. The user data rate in UMTS not only depends on the reception quality but also on things like number of active users in a cell, whether users are entitled to high data rates, current capacity of the backbone network and so on. Therefore, the available data rate doesn't seem to be a good indicator of the reception quality and coverage.

The next critical aspect is the ability to log on to the network. This is an absolute requirement to use any of the UMTS services and therefore the most appropriate indicator of network coverage. Once the equipment is logged onto the network, calls can be started and maintained, even if temporarily the reception quality decreases further.

It is therefore necessary to establish one or more technical parameter values that allow the UE to log onto the network. Network access (to be able to log into the network) is the proper criteria to decide whether a location is covered or not.

2.2 RSCP

The "Received Signal Code Power" (RSCP) is the collected RF energy after the correlation / descrambling process, usually given in dBm. Because this process already "filters out" the signal with the correct code (the code meant for the specific UE), the RSCP can not be calculated back to the total received RF power that a normal monitoring receiver or spectrum analyzer measures. Instead, a correlation receiver has to be used and the RSCP has to be measured for the specific code only, in the code domain. Only this code power is of interest for the following receiver stages when judging on the quality of the reception.

A commercial UMTS receiver has to know the code that is transmitted for it in order to perform the correlation process. With monitoring equipment, however, we want to measure UMTS emissions with any code. Therefore, special measurement receivers and equipment are necessary for UMTS measurements. These receivers have to try and correlate the received pseudo-noise-like signal with every possible code. This process is called PN scanning. Only after the receiver has found a match, the descrambling can take place, followed by measurement of the RSCP in the code domain.

2.3 E_c/I_0

This is the ratio of the received energy per chip (= code bit) and the interference level, usually given in dB. In case no true interference is present, the interference level is equal to the noise level. However, in a UMTS network the UE normally receives signals from multiple base stations, all transmitting on the same frequency. Therefore it is possible that even at a location close to a base station, with a high RSCP, no logon is possible, due to high interference levels from a second nearby base station. This effect is called "pilot pollution" and network planners try to avoid too close spacing of base stations to minimize regions where it can occur.

Because also the chip energy can only be measured after the descrambling in the code domain, the same special measurement equipment is needed as described in 2.2.

Because of the system gain (see 1), the interference level can be higher than the wanted signal level. Therefore, at the coverage border, the value of E_c/I_0 is usually negative.

2.4 RSSI

The Received Signal Strength Indicator (RSSI) is a value that takes into account both RSCP and E_c/I_0. It is usually given in dBm and can be calculated as follows:

$$RSSI\ [dBm] = RSCP\ [dBm] - E_c/I_0\ [dB] \qquad (1)$$

As with RSCP and E_c/I_0, it can only be measured in the code domain and needs the special monitoring equipment as described above.

2.5 Critical Parameter Values

Looking at the definitions of the three parameters RSCP, Ec/I0 and RSSI above, the RSSI seems to be the most sensitive parameter to observe. However, UMTS network planners mostly design their network to provide certain RSCP and E_c/I_0 values. In Germany a large number of measurements have been made to find out the minimum values for all three parameters.

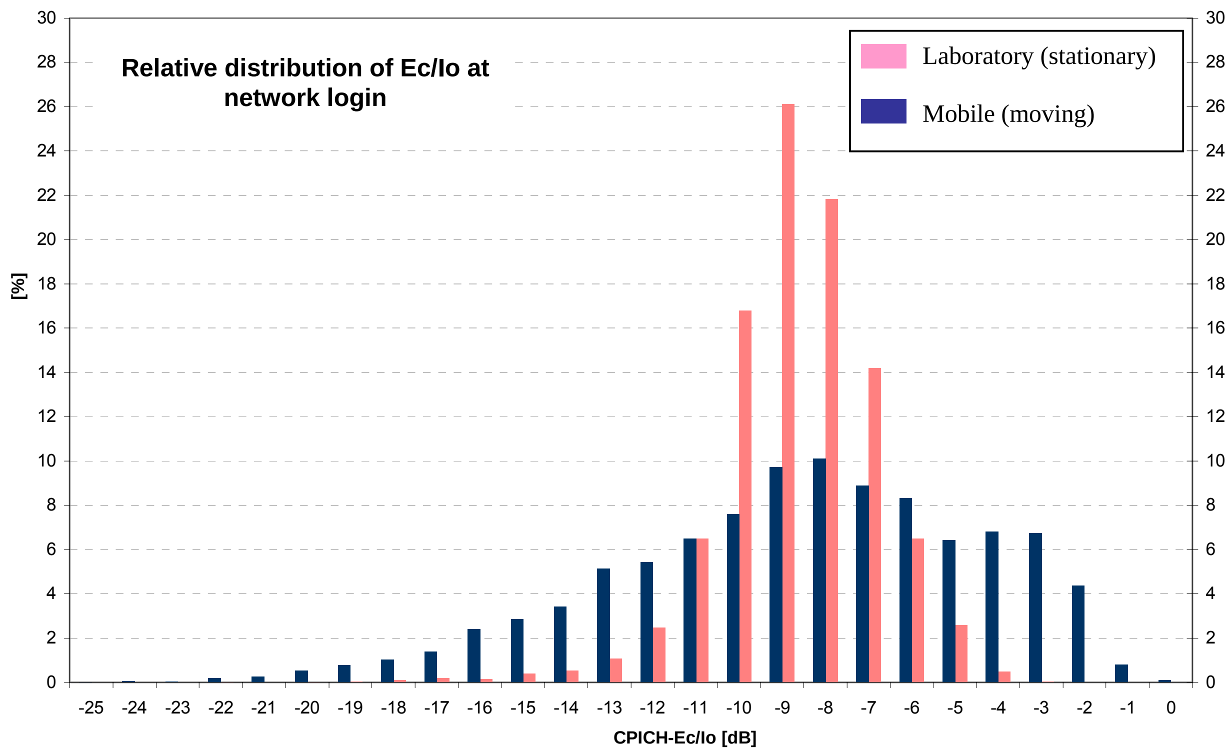

Figure 4: Ec / Io values at network login

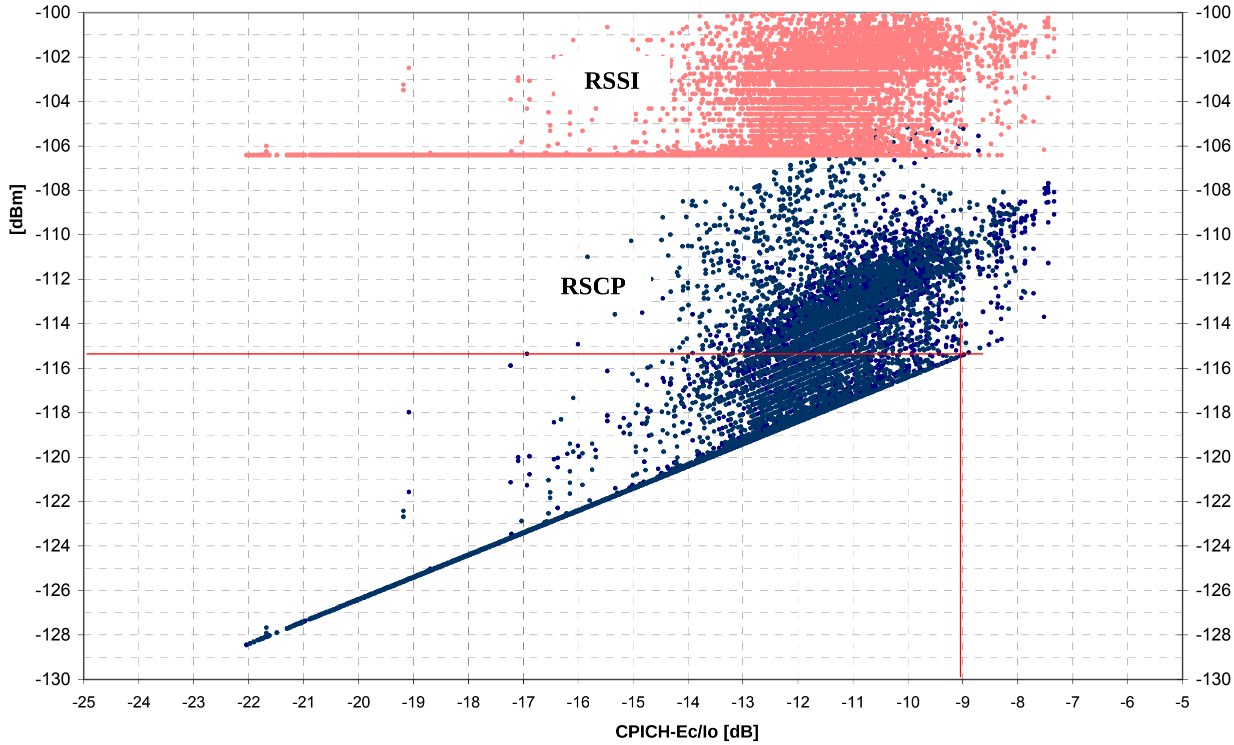

Figure 5: RSSI and RSCP over Ec/Io values at network login

The "signal-to-interference-ratio" (E_c/I_0) in UMTS is a fixed value and set by physical constraints of the correlation process. Inside well covered regions, the interference part is dominated by the receive level of nearby other UMTS stations. Therefore, the minimum RSCP can be much higher as the receiver sensitivity in these areas. However, at the rim of the coverage area it can be assumed that the serving base station is the last in reach of the mobile and therefore the only emission on the frequency. In this case, the receiver noise takes over the part of "interference" and the E_c/I_0 becomes equal to the signal-to-noise ratio. Consequently, from the measurements shown above it can be assumed that the minimum RSSI of -106 dBm is the true receiver sensitivity.

It has been found that the following values just allow to log onto the network:

- E_c/I_0 > -9 (maximum value in Fig. 4)
- RSCP > -114 dBm (minimum value at E_c/I_0 of -9 dB in Figure 5, including a fading margin of 1 dB between actual login and measurement)
- RSSI > -106 dBm (minimum value at E_c/I_0 of -9 dB in Figure 5)

Note that all values are levels at the receiver input (or after the descrambling process) and not field strength. In UMTS network planning this is an agreed practice and all prediction tools are also based on input level. It is assumed that a standard matched monopole antenna is used. The height of the receiving antenna is assumed to be at 2 m above ground (car roof level).

3 COVERAGE PREDICTION

Since network planning today is computer-based, the operators can provide exported coverage prediction graphs from their planning tools, taking into account things like antenna heights and directivity, pilot pollution and topography of the terrain. The predicted coverage area is always based on a certain value of RSCP or E_c/I_0. To compare prediction with measurements, the network operator has to provide a graphic file in a format that can be read into the map software used by the monitoring service (in Germany MapInfo). Most important is the possibility to geo-reference the map. The file is basically a map of the country with covered areas presented in one colour and uncovered areas shown in another colour.

4 MEASUREMENT CONCEPT

It is usually not possible to measure the actual coverage along every route for every area of the whole country because this would require in a tremendous amount of manpower and time. Instead, coverage is only verified in certain reference areas. In Germany, these reference areas were squares of 10 x 10 km and were selected around 10 more densely populated regions of the country.

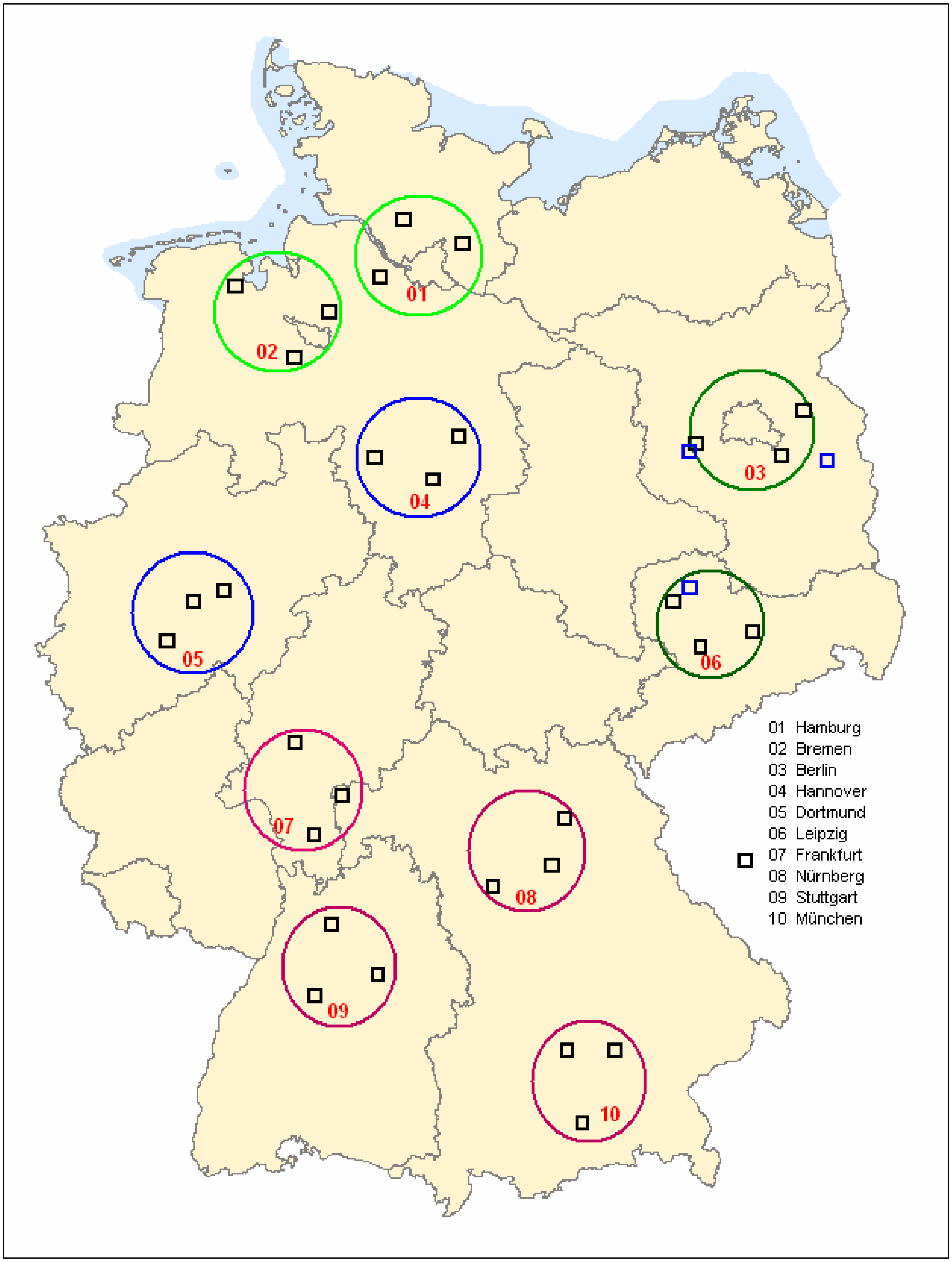

Figure 6: Population centres and reference areas

Because what we actually measure is the conformity of the prediction with actual coverage rather than the coverage itself. This allows us to extrapolate from the reference area results to the coverage throughout the country. In other words, if we find that the predictions closely match the actual coverage in the reference areas, we can say that the prediction tool used by the network operator is correct, which means that it will be accurate throughout the country.

To verify the accuracy of the prediction, it is important to place the reference areas at the borders between covered and uncovered regions. Ideally, 50% of the reference area is predicted to be covered, the other half is predicted not to be covered by UMTS.

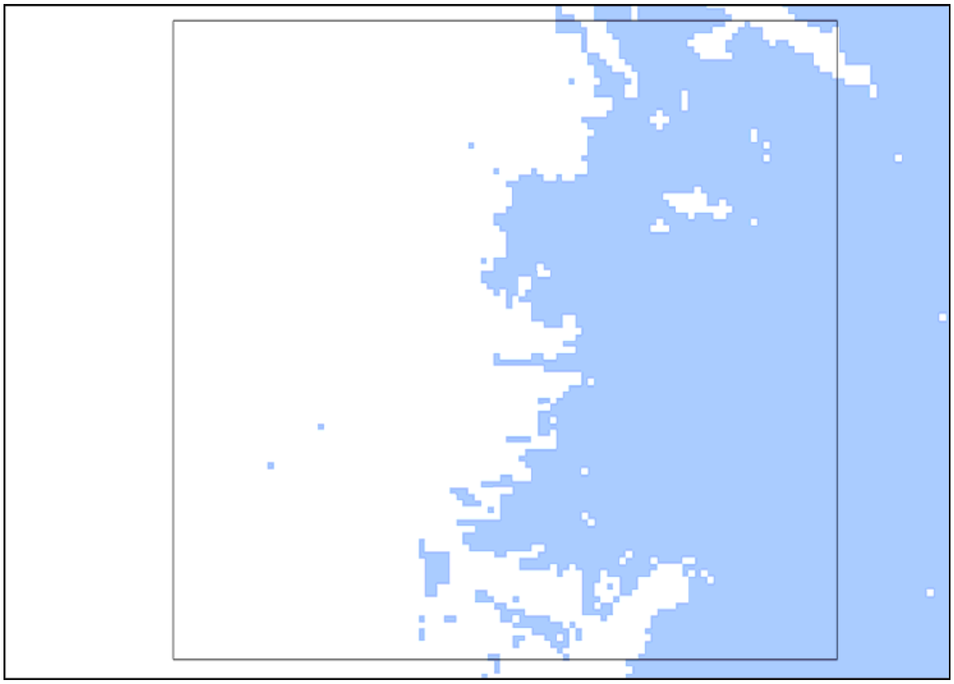

Figure 7:Coverage prediction inside a reference area

Using the measurement equipment specified above, the value of RSCP is then measured while driving along many routes inside the reference area. When selecting roads to drive it should be aimed the about 50% of the driving distance is inside and 50% outside the predicted coverage area. In addition, as many transitions from covered to uncovered and back should be included.

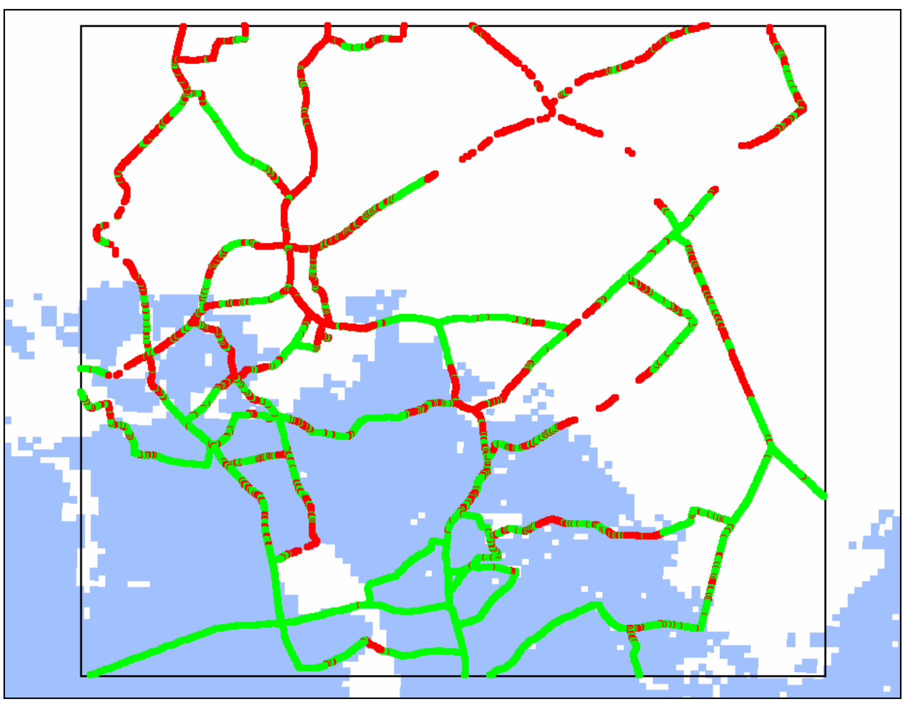

Figure 8: Sample measurement route inside a reference area. Green indicates RSCP better than -114 dBm (network login possible)

Using special software, the measured RSCP values can be compared with the coverage prediction at the exact same geographical coordinate to establish the degree of concurrency between prediction and measurement.

If the measurement shows equal or more coverage than the prediction, the graphical file with all covered areas according to the prediction is placed over a graphical file showing the population density. From this comparison, the percentage of population covered with UMTS service can be established.

5 EXAMPLE MEASUREMENT SETUP

The following measurement setup is used in Germany to measure UMTS coverage:

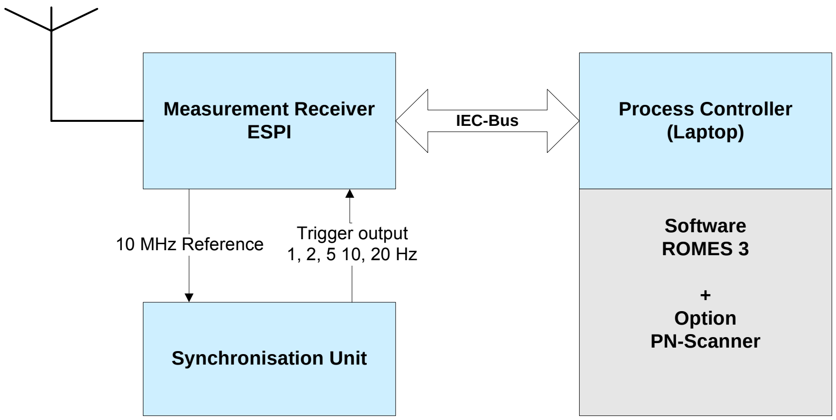

Figure 9: Hardware setup used in Germany

Figure 10: Hardware setup used in Germany

The PN scanning process is done by the spectrum analyzer (using a special software option). The measurement programme measures all parameters available in the code domain such as scrambling code, RSCP and Ec/I0. A GPS receiver connected to the laptop allows attachment of the geographical coordinates to each measurement result. During the measurement, the current data can be seen on the laptop screen.

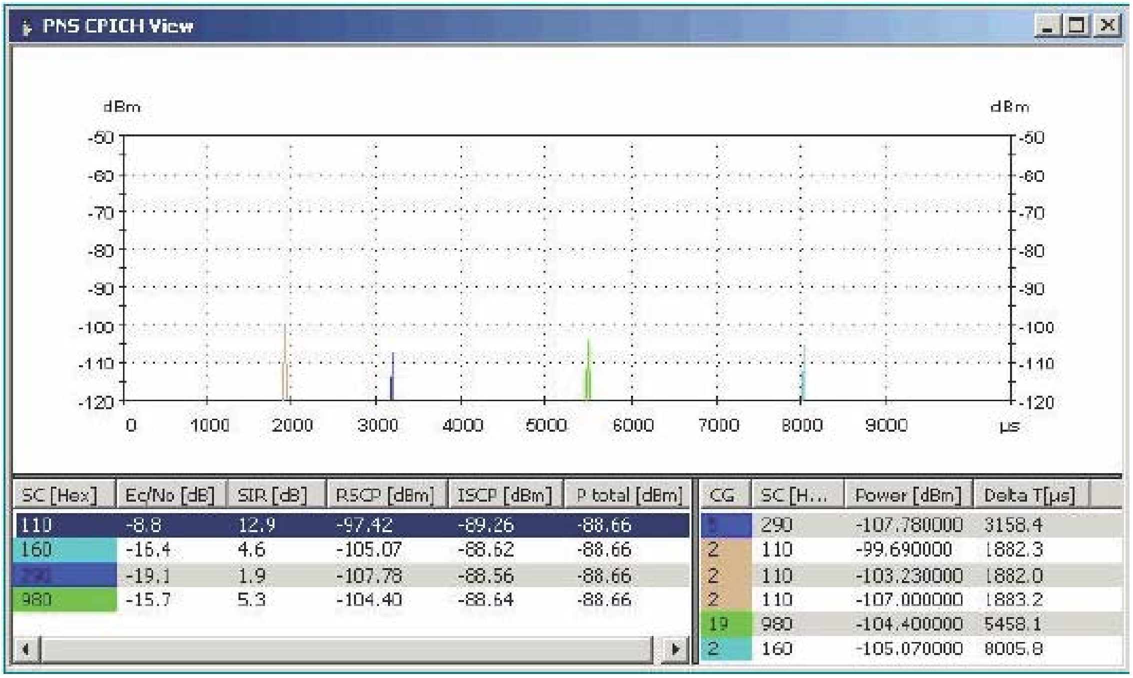

Figure 11: Sample screen display during measurements. The four lines in the bottom left window indicate that at this location, 4 different base stations can be received

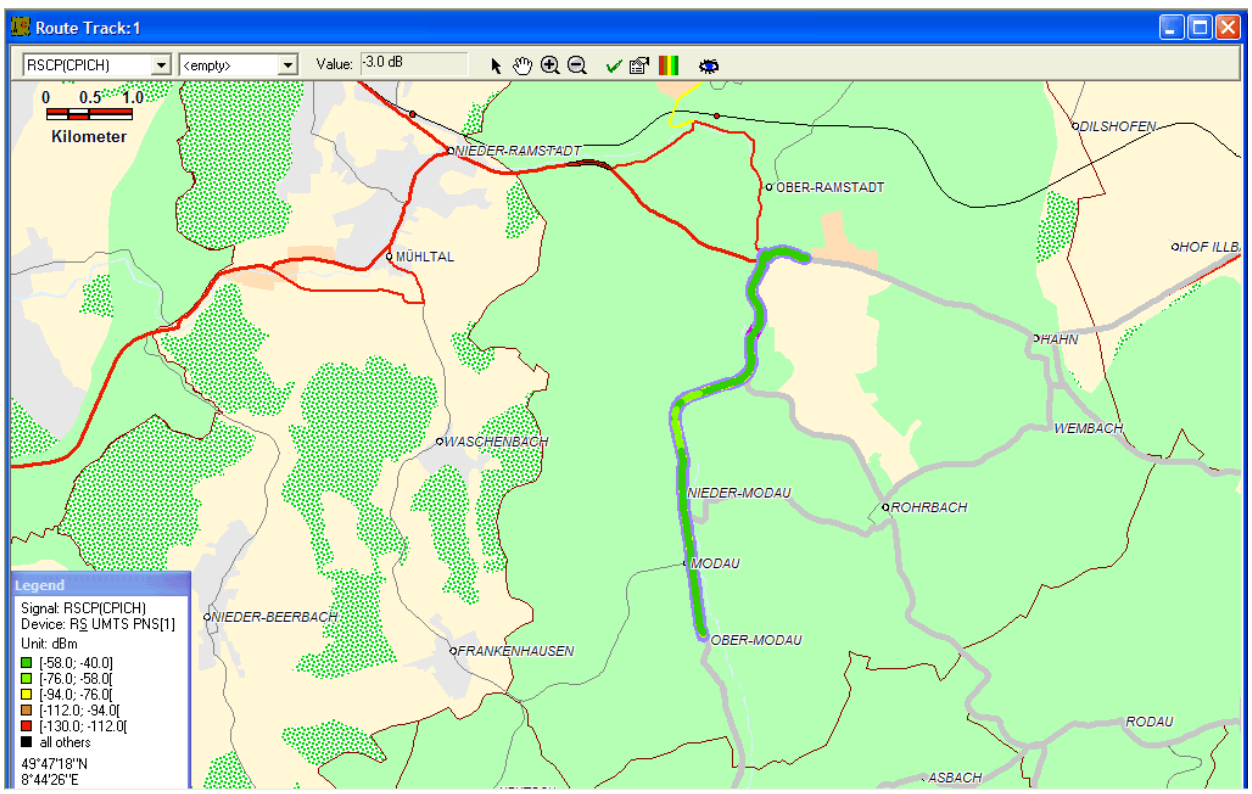

Figure 12: Sample display of route driven during measurement

6 RESULT PRESENTATION

Using a special software, the resulting RSCP values, together with geographical coordinates of the measurement vehicle, are presented in a map, together with the coverage prediction (see figure 13).

With this form of presentation, the correlation factor between prediction and measurement can only roughly be judged manually which may not be accurate enough. One of the major problems in this subjective method is the fact that sometimes areas that are predicted to be covered are in fact not covered while in other areas it is just the other way around. To be correct, both “discrepancies” have to be counted against each other so that in the end the overall covered area can still be as large as predicted.

In Germany, a special software has been developed where the prediction data and measured data are imported as geo-referenced bitmaps. The programme then compares the colour of each pixel from the prediction along the driven route with the measurement result at the same geographical coordinate to decide whether or not both values match.

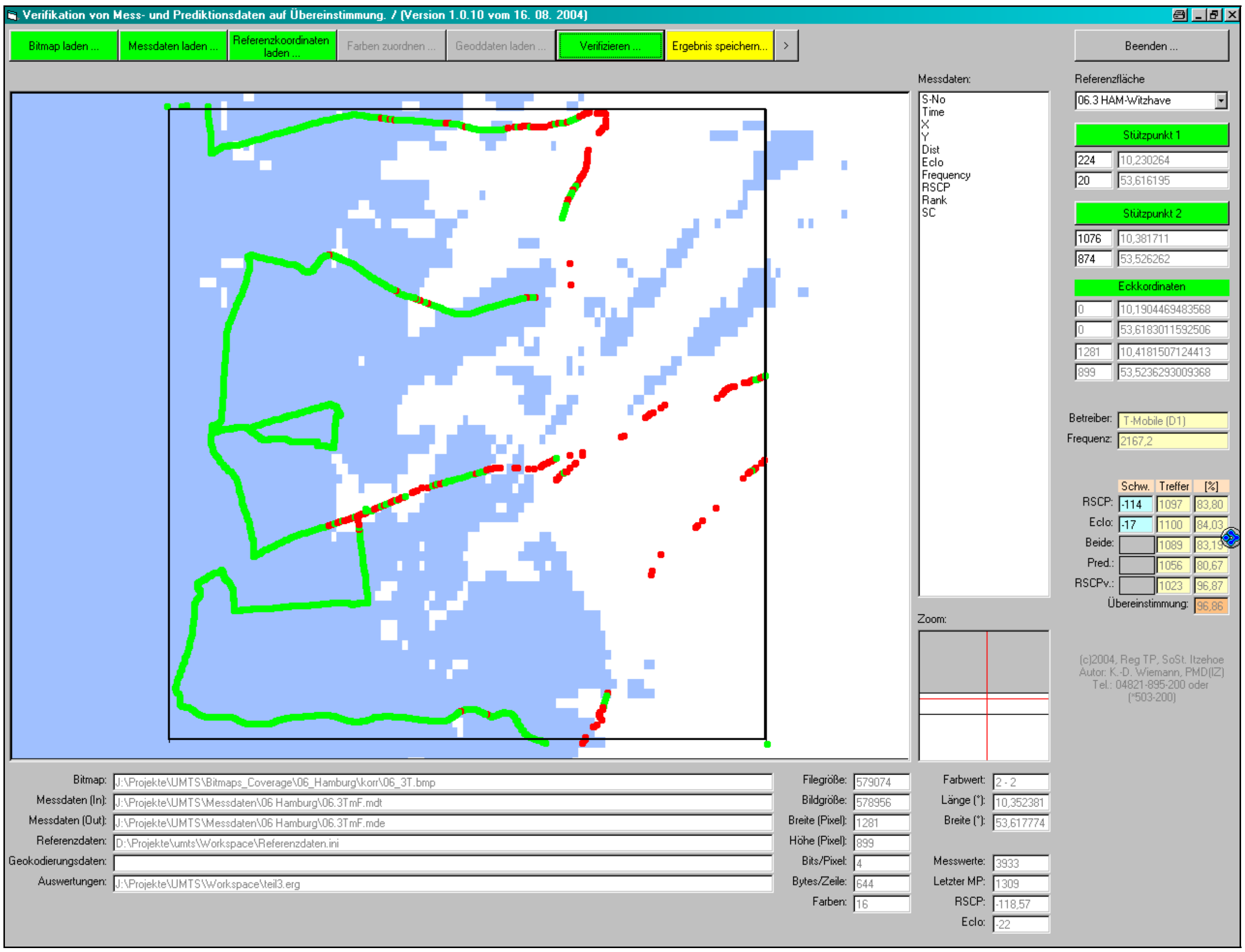

Figure 13: Sample screen of sotftware that compares measured data with predicted data inside a reference area

The result of the comparison is exported as a text file which can be used in a spreadsheet programme like Excel to draw the following graphs:

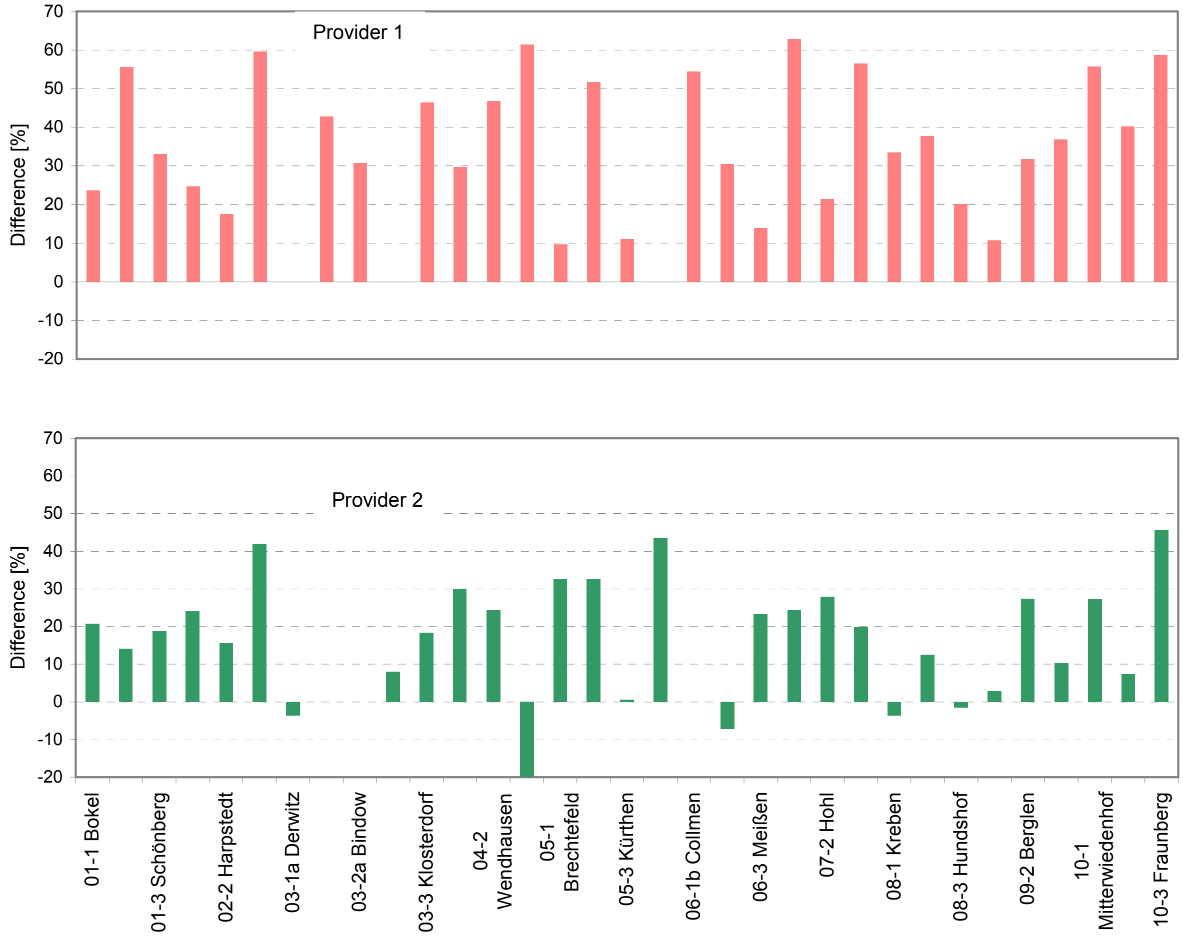

Figure14: Comparison between prediction and measurement inside reference areas for the complete measurement route. Positive bar means that more area is covered than predicted, negative bars indicate that actual coverage area is smaller than predicted

In Germany if it was required in the UMTS licence that a certain percentage of the <u>population</u> is covered instead of a certain percentage of the <u>area.</u>

In this case, if the measured coverage is equal to or more than predicted, the prediction graph from the network operator can be placed over a map containing the population density to see whether the necessary percentage of population is covered.

7 MEASUREMENT ACCURACY AND UNCERTAINTY FACTORS

Since we measure in the code domain, we have to wait for the PN scanner to perform the correlation process under constantly changing reception conditions. Even with fast processors this is a time consuming task involving many calculations. With the measurement setup described we can get about 1 measurement value every two seconds. With practical vehicle speeds between 50 and 80 km/h, we get one sample every 26 to 44 m. The wavelength at 2 GHz is about 15 cm. So it becomes evident that we can never fulfil the LEE criteria required for field strength measurements along a route.

To keep the amount of calculations reasonable, the resolution of the coverage prediction graphs is 100 x 100 m per pixel. So, what we actually get is 2 to three measured values inside a pixel square, which is far from being representative for the field strength. However, due to the extremely large amount of total measurement samples, errors will tend to cancel out so that the overall result is still representative.

Another factor also influences accuracy of the described method: As mentioned above, pilot pollution can prevent successful operation of the UE even inside areas well covered according to the prediction. Because we have only placed our reference areas at the coverage borders, we won’t notice this effect and rely on the network operators to avoid this phenomenon by carefully placing their base stations.

On the positive side (increasing accuracy), we have calculated the result in the following way: If locations <u>inside</u> the predicted coverage area are in fact <u>not</u> covered, they are counted against locations <u>outside</u> the predicted coverage area that are in fact covered.

Due to all these unknown factors influencing the results, we can not calculate the accuracy of the described method. Instead, it has been tried to minimize their negative effects as much as possible.

8 CONCLUSION

In Germany the described method has proved to be an adequate tool to evaluate UMTS coverage predictions and provides sufficient accuracy while still keeping the required manpower at a reasonable level. It has been used twice to evaluate a 25% and 50% population coverage and has so far not been questioned by the network operators.