Propagation Measurements for the Characterization of a Hybrid Mobile Channel in S-band

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Abstract- **The mobile hybrid satellite/terrestrial channel for the SDMB system in the IMT2000 band has been measured and analyzed. During the first of two measurement campaigns within the MAESTRO project (IST-2003-507023, [1]), data have been collected to characterize the wideband mobile radio channel. The trials took place in Monaco in November 2004.**
Outdoor and indoor measurements were carried out in an experimental hybrid network comprising a satellite emulator and an on-channel repeater, both transmitting in an IMT2000 frequency block in S-band. The power received and the complex base band signal were recorded during a number of drives through Monaco. Recordings were done in two transmitter configurations, satellite signal only and hybrid network. The outdoor and indoor data are analysed for important channel parameters such as signal distribution characteristics. In addition, channel delay profiles are extracted from the outdoor recordings. This paper presents first results from the field trials in Monaco.

Keywords: **Hybrid channel, mobile propagation channel, IMT2000 measurements, S-band, indoor tests**

I Introduction

The MAESTRO project aims at studying the technical implementations of innovative mobile satellite system concepts while striving for the integration of and interaction with 3G and beyond 3G mobile terrestrial networks at the same time. MAESTRO intends to specify and validate the most critical services, features and functions of satellite system architectures and to achieve the highest possible degree of integration with terrestrial infrastructures.
As a first objective, the second work package of MAESTRO defines the so called SDMB physical layer based in 3GPP UTRA W-CDMA (FDD-mode) standard for optimized transmission performance in various mobile environments.
The physical channel as defined in [2] implements a W-CDMA modulation scheme at a chip rate of 3.84 Mcps with roll-off factor 0.22, resulting in an active band width of 4.65 MHz. Using the UMTS licence of Monaco Telecom, a hybrid network was installed in Monaco. This allows the use of the same frequency band as it will be used for the future SDMB service.
The results of these measurements are used to calibrate the Radio Network Planning Tool (RNPT) by AWE Communications [3]. The tool predicts the path loss and the channel delay profile through 3-D ray tracing in suburban and urban areas and by empirical models outside cities.
This paper is structured as follows: Firstly, the measurement method will be explained. Secondly, the first results taken from the analysis of the recorded outdoor data will be presented. Thirdly, results from the indoor measurements will be presented. This paper will end with a conclusion of the results and a description of future tasks in order to characterize the propagation channel.

II Measurement Method

The transmitter set-up includes a satellite emulator and a commercial on-channel repeater from Andrews Corp. The satellite emulator used for the field trials (figure 1) comprises standard commercial signal generators and amplifier equipment by Rohde&Schwarz and Amplifier Research. The emulator's transmitter site at Jardin Exotique has an elevation of 10 to 15° in the main coverage area. The centre frequency of the transmitted signal is 2117.5 MHz. A circular polarized transmit antenna is used.
A **test sequence** compatible to the 3GPP specification [2] is transmitted by the AMIQ arbitrary waveform player. The test sequence contains all physical channels like P-SCH and P-CPICH to be compatible to the repeater and it is known on a chip-by-chip basis. It is used to correlate the received (and recorded) IF signal for obtaining key channel parameters like the channel impulse response or the Doppler spread.

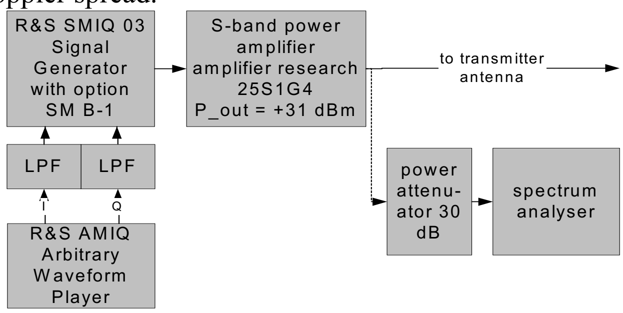

figure 1: Monaco transmitter set-up

The transmit antennas of the satellite emulator and the repeater are pointed towards Monaco's harbour (figure 2). They cover a representative urban area of Monte Carlo marked out by street canyons, different direction in relation to the transmitter and the various heights of the surrounding buildings.

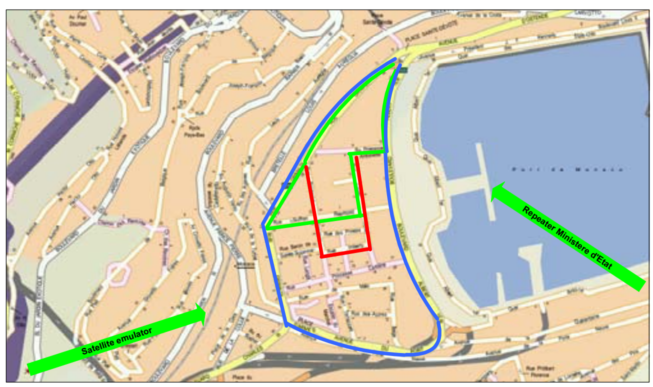

figure 2: General direction of satellite emulator antenna (left arrow) and repeater antenna (right arrow). Main urban test drives are indicated in blue, red and green.

The mobile **receiver set-up** mounted in a SUV Landrover car is essentially made up of two subsystems:

- Set-up A: Equidistant sampling of the signal power received carried out by a R&S ESVB test receiver, triggered by the measurement car's wheel sensor that generates a pulse every 2 cm. That distance is short enough to sample the small scale fading variations of the channel in an urban environment (Set-up: see figure 3).
- Set-up B: Recording of the received complex signal at tuner's IF stage (figure 4). The signal is sampled with a fast two-channel ADC board at a multiple of the UMTS chip frequency (6 * 3.84 MHz). The board contains 256 MB on-board memory, allowing samples up to 3 sec of the real-time signal.

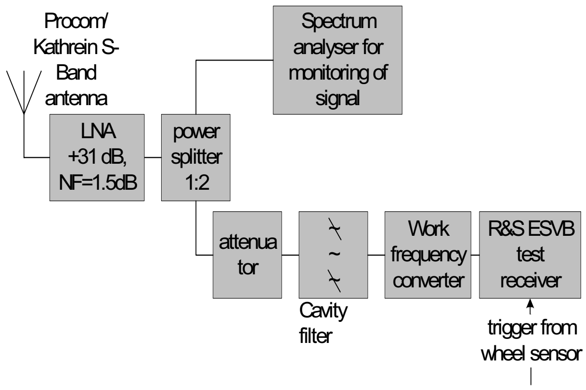

figure 3: Mobile receiver set-up A – equidistant sampling of field strength triggered by a wheel sensor

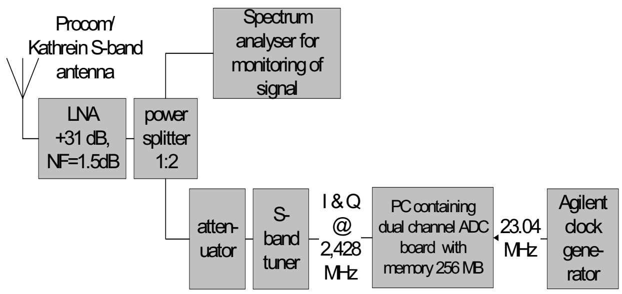

figure 4: Mobile receiver set-up B – fast complex sampling of IF signal

In both set-ups, unidirectional linear dipole antennas (UMTS antennas from Procom and Kathrein) were used. The antennas were calibrated before in the antenna chamber of our institute. The measurement's results will be presented in the next two chapters.

III Results – Outdoor

A Measured Received Power

With set-up A, measurements of the received power have been performed for the two network configurations 'satellite reception only' and 'hybrid satellite / terrestrial reception'.

Derived from the recordings of the measurement set-up A, plots of the received power are extracted, all plots shown here are from the same 'green' route referred to figure 2.

figure 5 and figure 9 illustrate the received power of a S-UMTS system without a repeater network. In a pure satellite system, the received power has deeper fades due to deep shadowing. The absolute attenuation of the large scale fading signal compared with Line-of- Sight (LoS) reception is up to 25 dB.

The power received during the same drive was analysed for the K-factor, which is defined as the ratio of the average power of the dominant multi-path component and the average fading power received over the non-dominant paths. The method as described in [4] was used for the analysis. The analysis result in figure 7 show that during the drive, most of time the Ricean factor K was around 5 to 10 dB in areas of high attenuation of the signal. However, higher values of up to 15 dB of K in streets with lower attenuation indicate that a diffracted and attenuated LOS signal is received, while the power of the scattered components remains the same.

In figure 8, the cumulative density function and the level histogram is presented. For 99% percent of way, the attenuation is below 28 dB, for 90% of the way below 26 dB.

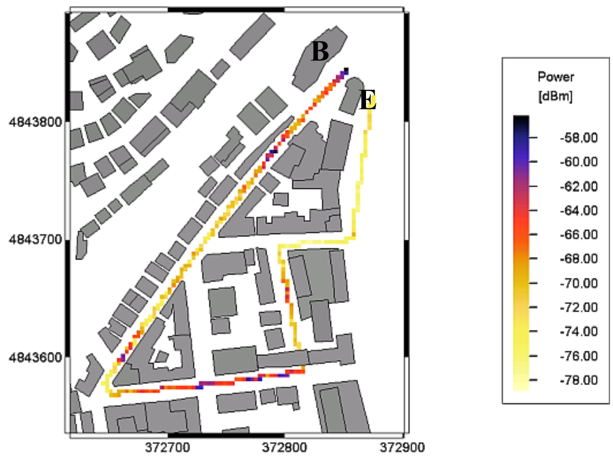

figure 5: Diagram of measured received power from the satellite during a drive through Monaco ('green' route of figure 2). Low attenuation with strong echoes on the north and south end of the route, high attenuation on the east side due to blockage of high buildings.

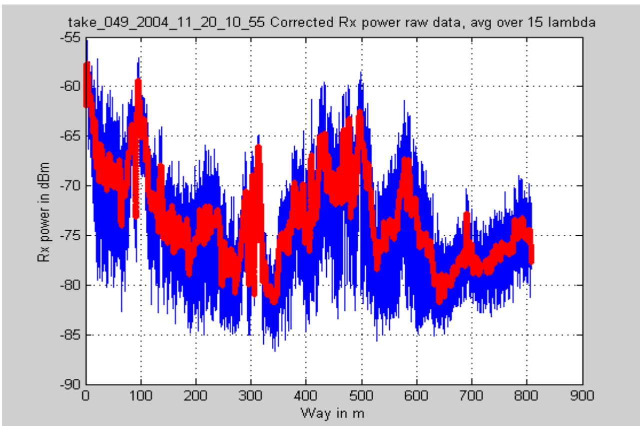

figure 6: Satellite reception: Absolute power received vs. way for the same drive as in figure 5. No direct LoS signal was received during the drive. Red: large scale fading signal averaged over 15 * wavelength

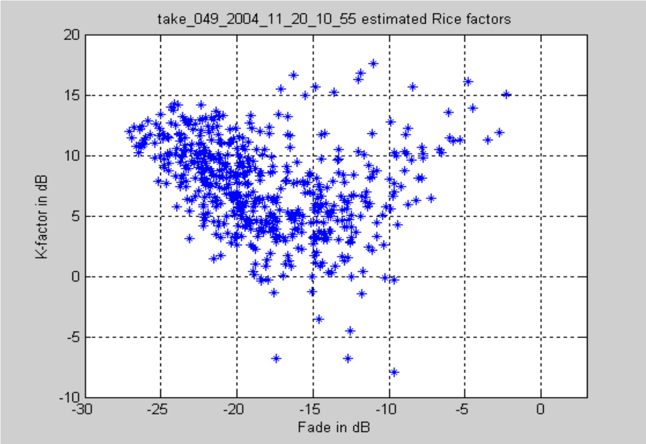

figure 7: Satellite reception: Ricean factor vs. fade depth (compared to LoS level). Most of K values are concentrated at 5 to 10 dB at areas with high attenuation.

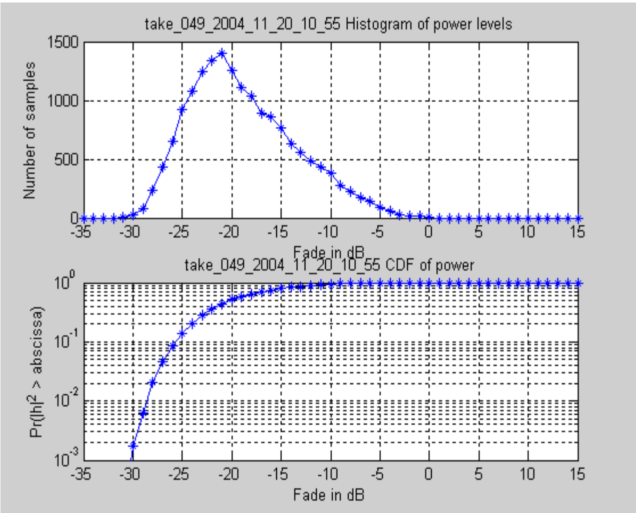

figure 8: Satellite reception: Cumulative density function and level histogram, normalized to LoS level.

figure 9, figure 10 and figure 11 show plots of the received power for the same route with **hybrid network** configuration. The signal level at the begin and the end is quite high due to LoS or diffracted LoS of the repeater signal. Now, during 90% of the way, the combined signal power is higher than the satellite LoS signal attenuated by 11 dB.

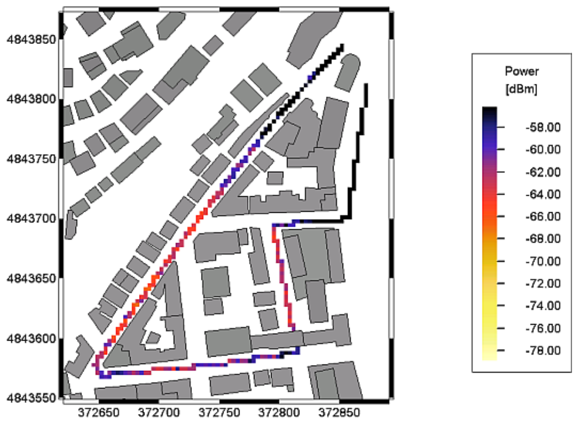

figure 9: Diagram of measured hybrid power received from the satellite and the repeater during a drive through Monaco. The repeater signal 'fills' the sections with weak satellite reception on the east side.

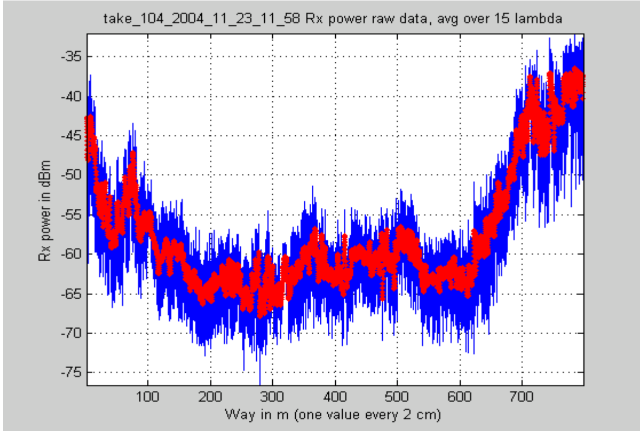

figure 10: Hybrid reception: Absolute received power vs. way for the same drive as in figure 9.

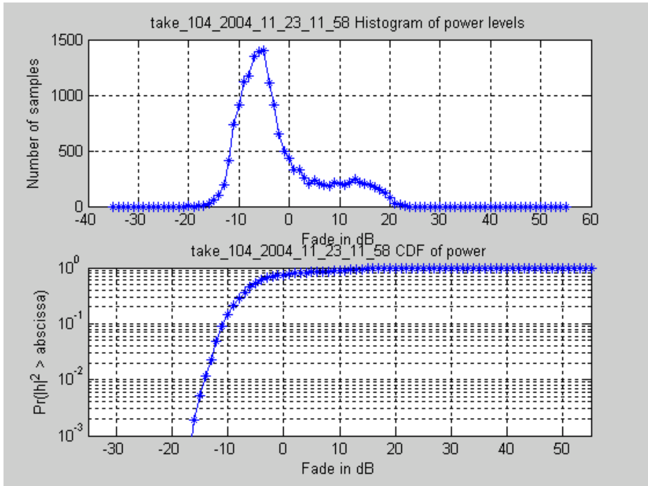

figure 11: Hybrid reception: Cumulative density function and level histogram, normalized to LoS level of satellite.

B *Extracted Channel Delay Profiles*

Representative channel delay profiles are derived from the RNPT within the MAESTRO project for three purposes:

- For the SDMB end-to-end simulation set-up,
- for the laboratory test bed with a channel simulator,
- for the definition of conformance tests for the future user equipment.

The channel characterization measurement as described in this paper are intended to verify the channel delay profiles derived from the RNPT.

Analysis of the complex base band signal recorded with set-up B has been done to extract channel delay profiles for the two configurations of the network, 'satellite reception only' and 'hybrid satellite / terrestrial reception'.

Delay profiles are derived from the recorded signal by applying the maximum likelihood estimation approximation (MLEA) algorithm.

Two representative channel delay profiles observed in the field are summarised in the following two tables. Since the paths from satellite and repeater can be resolved due to repeater processing delay of 8 µs, all tables display the channel impulse responses (CIR) for hybrid reception. table 1 shows non-LoS satellite reception with long satellite echoes (up to 2 us). The longer measured delay is in contrary to the shorter delay spreads as reported from L-band measurements in [9]. From the repeater, many scattered components within 2 us are received, no far echoes are received. table 2 is derived from a recording at the harbour. The CIR shows a strong satellite signal without echoes. Terrestrial reception is characterized by two dominant receiving paths and several echoes.

Delay [us]	Attenuation [dB]	Type	Source
0	-10.5	Direct/Scatter	Sat
0.347	-14.8	Echo/Scatter	Sat
0.694	-19.8	Echo/Scatter	Sat
0.954	-19.7	Echo/Scatter	Sat
2.04	-20.1	Echo/Scatter	Sat
9.81	-20.4	Echo/Scatter	Repeater
10.11	-30.6	Echo/Scatter	Repeater
10.46	-30.5	Echo/Scatter	Repeater
10.89	-24.0	Echo/Scatter	Repeater
11.07	-23.5	Echo/Scatter	Repeater
11.46	-33.5	Echo/Scatter	Repeater

table 1: Measured channel delay profile for hybrid reception in Rue Grimaldi (take 108, no LoS, repeater processing delay is 8 µs). Satellite attenuation is normalized to satellite LoS level and repeater attenuations normalized to repeater LoS level.

Delay [us]	Attenuation [dB]	Type	Source
0	-3.1	LoS	Sat
8.90	-7.1	Direct/Scatter	Repeater
9.24	-6.9	Direct/Scatter	Repeater
9.59	-14.6	Echo/Scatter	Repeater
9.90	-17.4	Echo/Scatter	Repeater
10.20	-18.2	Echo/Scatter	Repeater
10.98	-16.5	Echo/Scatter	Repeater

table 2: Measured channel delay profile for hybrid reception in Blvd Albert at the harbour (take 112, repeater processing delay is 8 µs, same normalization as is previous table).

In general, the measurements confirm the channel delay profiles derived from the Radio Network Planning Tool (RNTP). Our measurements showed a few number of differences to the delay profiles predicted by the RNTP for urban environment:

- For satellite non LoS state, many rays spread over 400 ns are predicted. In this state, the only difference of the measured profile is a higher delay spread of the received satellite signal of up to 2 us.
- Different terrestrial channel delay profiles are predicted by the RNPT for one and more repeaters. In principal, the measured and predicted delay spread and the power of the received path is similar. The difference of the measured data is the higher number of paths received within the first few µs (6 in both presented profiles, 7 in other measured profiles, 4 predicted in the RNPT).

IV Results – Indoor

Indoor reception quality, especially satellite reception quality, is another interesting field as the future SDMB terrestrial repeater network will not cover all rural and suburban buildings.

First indoor measurements in Monaco were performed in the Hotel Hermitage with and without repeater signal and in rooms with different orientation towards the transmitter. The elevation of the satellite emulator was 6.5°. The next figure 12 illustrates the relative direction of the rooms to the transmitters.

Several tests were done with the measurement set-up A described in section 'Measurement method' above. Instead of a trigger from the wheel sensor, a clock generator was used to initiate a measurement 20 times a second. Due to the low speed of the antenna during the dynamic tests, a spatial resolution better than 0.1 wavelength is reached.

Static and dynamic indoor measurements were performed to simulate user behaviour. The results achieved in a room which was oriented towards the satellite emulator proof that indoor reception from a satellite without a repeater signal is possible.

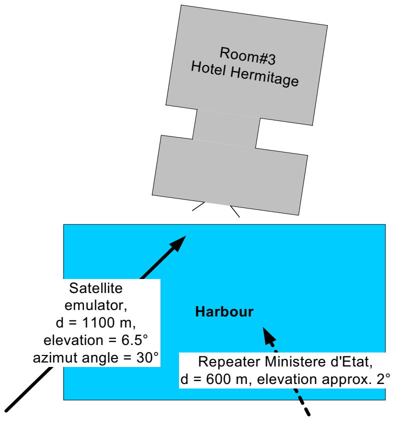

figure 12: Direction of transmitters and room during indoor measurements

However, a strong influence due to the attenuation of the windows could be observed. People moving in the room have a strong effect, too, even if they do not stand in between antenna and window. Variations of 15 dB have been observed with a static antenna 0.4 m away from the window (h=1.0 m) and two people walking behind the antenna (figure 13). The standard deviation of the levels is approx. 3 dB, the mean value is 0.5 dB lower than observed during the measurement without people moving (figure 14). This is in contrary to observations according to [6] and needs further investigation. The measured signal amplitude seems to follow a lognormal distribution, which confirms the measurements reported in [6].

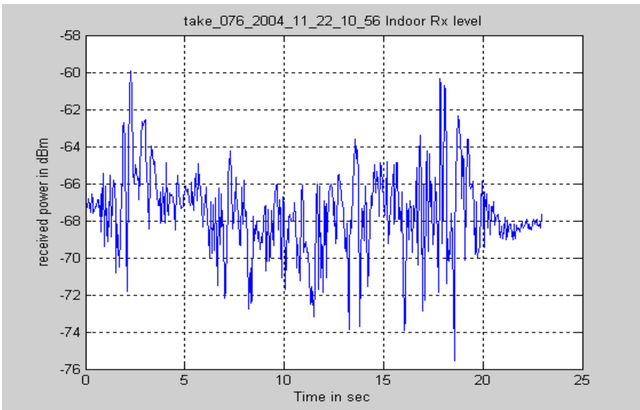

figure 13: Variations of power received with static antenna next to window and two people moving behind antenna.

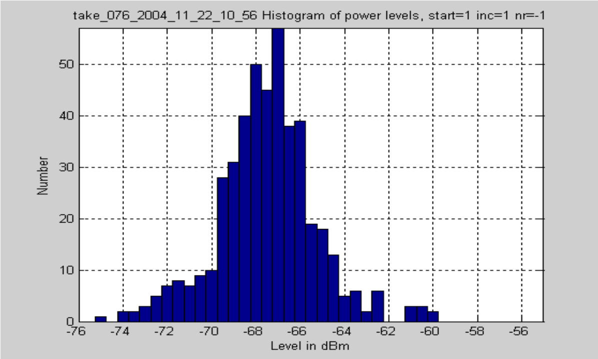

figure 14: Histogram of the sampled power as shown in figure 13. The measured fades in dB follow roughly a normal distribution; the signal is then log-normally distributed, and not Raleigh as in statistics outside of buildings.

One plot of the power received in room#3 is shown in the next figure (figure 15). The antenna was mounted on a ground plane and was moved from the window 1.6 m inside the room. The overall attenuation of the signal when windows are opened is ranging from 6 dB (diffraction, no LOS) to 22 dB. The average attenuation is around 15 dB (right part of the diagram). The attenuation of the window has been measured to 10 dB (single glass), and in another room with thermal isolated double glass to 18 dB. This is consistent with the additional loss of 15 dB introduced by coated glass referred to [6].

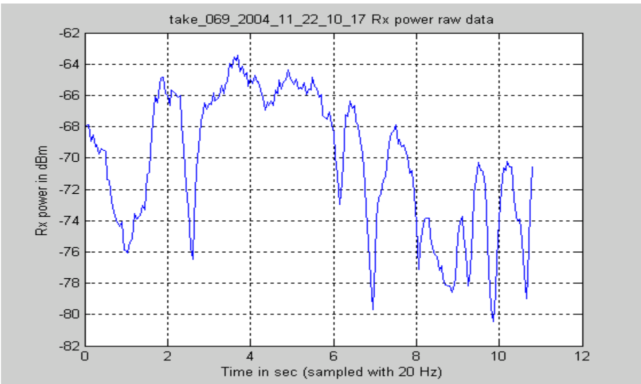

figure 15: Plot of the received power measured without repeater signal while walking with the antenna away from the window (left) straight inside the room 1.6 m (right); windows open; LOS power was –58 dBm. A metal balcony is the reason for the low power (left) directly at the window.

The plot of the received power demonstrates that the signal is varying rapidly within 0.15 * wavelength. Previous measurements of signal reception at low elevations in terrestrial networks according to literature were done with much lower resolutions (e.g. [7] 0.8 * wavelength), but obviously the coherence length of the indoor satellite propagation channel is much shorter. In [5] and [6], a higher resolution of 5 cm is chosen for the measurements with satellite emulators emitting in frequency ranges from 700 to 1800 and 500 to 3000 MHz.

V Conclusion

The trials in Monaco in the hybrid prototype S-UMTS network were very useful for a first qualification of the mobile SDMB propagation channel.
The outdoor measurements with the R&S test receiver were used to characterize the power received in a pure satellite system and in a hybrid network. The power received was presented including the cumulative density functions and the Rice factors.
The extracted channel delay profiles in general confirm the predicted ones from the RNPT: For satellite reception, longer echoes were measured. Tests with elevations similar to the future commercial system will be performed during the second measurement campaign of the MAESTRO project. Results from the measurements with terrestrial repeater show more paths received as predicted in the RNPT.
First meaningful results were obtained by the indoor test in Monaco. However, the results were influenced by various parameters like window attenuation and moving of people. Therefore, more detailed tests will be conducted in the next trials period within MAESTRO, varying in the type of room, the direction of the room relative to the signal source, elevation etc. The indoor results are also of interest for future navigation services like GALILEO, which is based on LMS channel, too, in a near frequency band.
Additional results from the measurements are available in the public deliverable D2-2.2 [8].

VI Acknowledgement

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