Land Mobile Satellite Navigation - Characteristics of the Multipath Channel

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BIOGRAPHY

Alexander Steingass was born in Mettmann, Germany in 1969. He received his Dipl. Ing. diploma in Electrical Engineering in 1997 (University of Ulm, Germany). Since then he has been a reseach scientist at the German Aerospace Centre DLR – Institute of Communications and Navigation. He has been involved in several projects in the area of satellite navigation and location dependent mobile services. In 2002 he was promoted Dr. Ing. at the University of Essen.
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ABSTRACT

In this first results of the 2002 measurement campaign are discussed, investigating the environment of satellite navigation receivers for land mobile applications, where reflections from e.g. buildings decrease the accuracy of the positioning.

INTRODUCTION

An important point in the choice of the signal format for the Galileo System is the multipath transmission channel. Studies concerning the signal structure (e.g. ESA Signal Design Study [1]) have clearly shown that the synchronisation performance of a specific signal strongly depends on reflections from the environment. Especially, short delayed reflections significantly decrease the performance of the receiver. The positioning error gets even worse if these reflections are strong and slowly varying over time, which is predominant in pedestrian applications. Although narrow-band channels like GSM (COST 207 [2]) or UMTS channels have been measured in the past, it became necessary to analyse the wide-band navigation channel to minimize multipath effects in future highly accurate receivers. For these reasons we measured the channel from a simulated satellite to a receiver in critical urban, suburban and rural scenarios. This paper will presents the first preliminary results and conclusions for typical car and pedestrian land mobile applications.
Please note that due to a cable recalibration slightly different results are shown here in comparison to earlier publications [3-5].

CHANNEL MEASUREMENT

The satellite was simulated by a Zeppelin NT operating at distances of up to 4000 m from the receiver. We transmitted a special measurement signal with 10W and a bandwidth of 100 MHz. The transmitted signal had a rectangular shaped line spectrum consisting of several hundred single carriers. This guaranteed a time resolution of 10 ns for the channel impulse response. A very high resolution is necessary for the planned wide-band services of Galileo using BOC (Binary Offset Coding) signal structures. By applying an ESPRIT (Estimation of Signal Parameters via Rotational Invariance Techniques)-based super resolution algorithm, the time resolution for the final model will be increased to 1 ns. To achieve this high time resolution we used specially assembled rubidium clocks with an Allan variance of 10^{-11} s over an integration time of 1 s, as references for the measurement devices.
For accurate positioning the Zeppelin was filmed by a camera station situated on the ground directly beyond the airship (see **Figure 1**). The image taken by this camera was transmitted via a wireless radio link to a monitor at the airship, enabling the captain to hold its position. During the measurement the position of the Zeppelin was kept within a radius of about 20 m, which was sufficient in terms of the operational requirements.

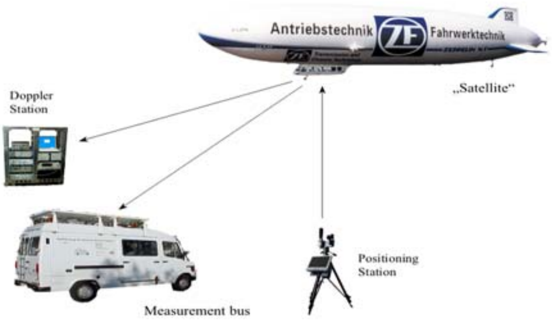

Figure 1: Measurement setup

In addition, the Zeppelin transmitted a 18.8 GHz carrier whose Doppler shift was logged by a ground station in order to measure the airship's movement which is comparable with the movement of a pedestrian. These data are necessary to calculate the Doppler spreads caused by the receiver and its environment. For the measurements, a team member simulating the average pedestrian carried the receiver antenna in his hand while walking along the sidewalks. He was accompanied by a special measurement bus equipped with the channel sounder receiver, wheel sensors, laser gyros, audio and video system, data recording and GPS sensors.
During the campaign 60 scenarios each lasting from 10 to 20 minutes were measured. For the land mobile channel the focus was on:

- Urban car channels (Large city – Munich including a drive along a motorway)
- Urban pedestrian channels (Large city – Munich including shoping street)
- Suburban car and pedestrian channels (Small town – Fürstenfeldbruck)
- Rural car channels (Motorway and country roads)

An antenna showing the characteristics of a navigation system receiver antenna was used throughout the measurements to guarantee a realistic modelling.

URBAN CHANNEL – LARGE CITY

During the measurements the whole range of elevations to the "satellite" from 5° to 90° was covered. For the urban car channel two very typical scenarios are illustrated in **Figure 2** and **Figure 3**. A wide through street with tree-lined allies and mid high buildings, and a very narrow street canyon with low visibility typical for a city centre. To characterize the propagation channel of a navigation signal, we "sounded" the channel by sending an impulse-like signal which was detected at the receiver after a certain absolute delay as a direct signal followed by reflections of this signal from the environment. **Figure 5**, **7** and **8** show the channels impulse responses over the distance of the same track for a satellite at elevations of 10°, 40°, and 80°. The received signal power is color-scale coded in dB. The strongest line indicates the direct signal. The "echoes" arrive with larger delay (shown in microseconds) and are less powerful. The multipath channel can be described by the excess delay of the reflections relative to the direct signal, their power and their phases. **Figure 4** shows the track for the car channel measurements in the centre of Munich. Starting on the Lindwurmstrasse, which is one of the main roads of the capital of the German Federal state of Baveria, the track led us through narrower roads, street canyons and large city squares. In **Figure 5** the measured channel impulse response is plotted over the measurement time of about 1000 s. As an example let us look at a time stamp of about 150 s after start. The direct signal is received with an absolute delay of 8.6 μs, followed by a strong reflection with an excess delay of about 500 ns. For very low elevations, many strong reflections are visible. Their excess delays decrease as

Figure 2: Urban car channel, Munich, wide street

Figure 3: Urban car channel, Munich, street canyon

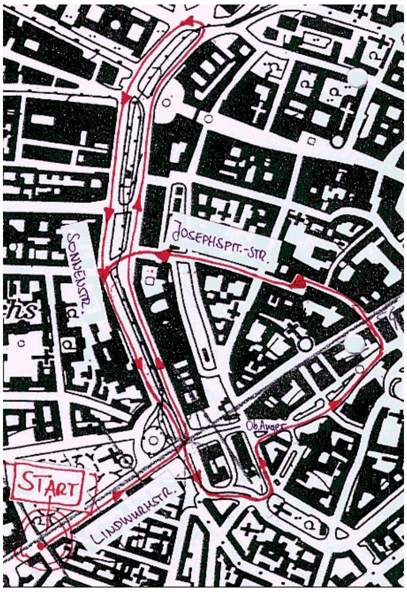

Figure 4: Measurement area “Lindwurmstrasse” in Munich

soon as the car approaches a reflecting structure. Note that in this configuration the LOS (line of sight) signal might already be attenuated by the receiving antenna pattern which has a masking angle of about 10°, typical for a GPS antenna to filter low-elevation signals which cause larger positioning errors. For this low elevation the visibility of the satellite is naturally quite low as well. In comparison to a visible satellite in the zenith the power is attenuated about –30 dB. In some areas during the measurement the power comes up to about –20 dB. When the satellite is at this low elevation very “long” echoes occur. It is very typical for a situation like this when a car is driving towards a reflector (buildings etc.), that the reflection comes closer and closer to the shortest path and finally matches it. This “low elevation building echo” is very typical for this low elevation. In **Figure 6** multiple reflection can be seen. During this part of the measurement the bus moved along a wide through street heading orthogonally to the line bus - Zeppelin which was blocked by high buildings (only a weak LOS signal due to diffraction can be seen). Starting with an excess delay of about 200 ns, which corresponds to about 60 m, multiple reflections from the other side of the road are received.

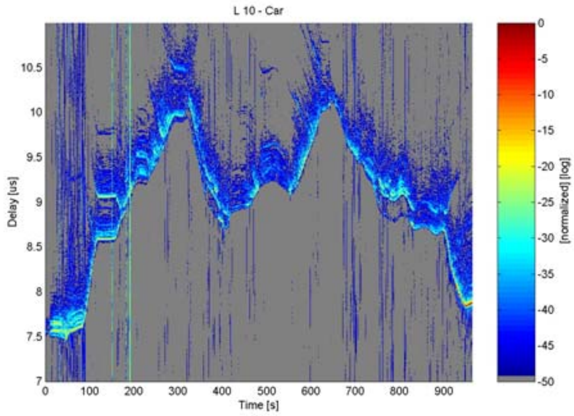

Figure 5: Urban car channel, Munich 10° elevation

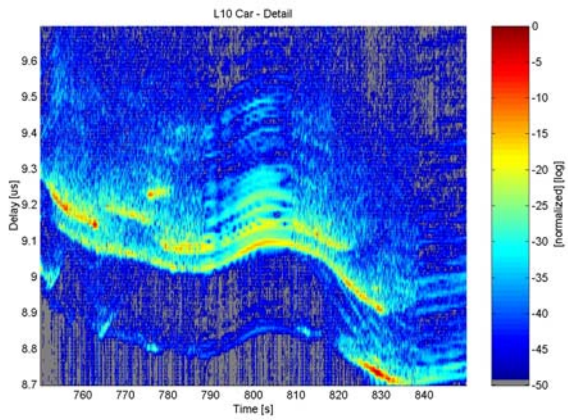

Figure 6: Urban car channel, Munich, 10° elevation - Detail from **Figure 5**

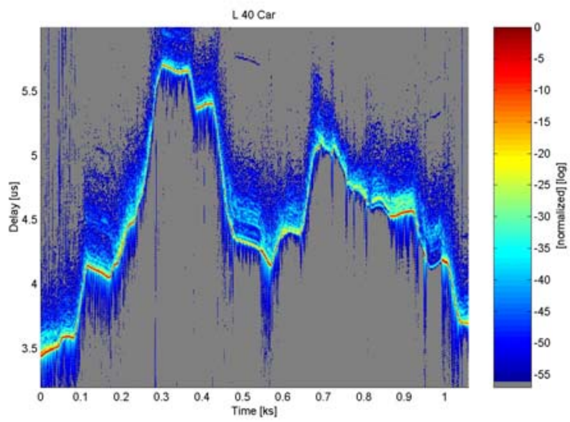

Figure 7: Urban car channel, Munich, 40° elevation

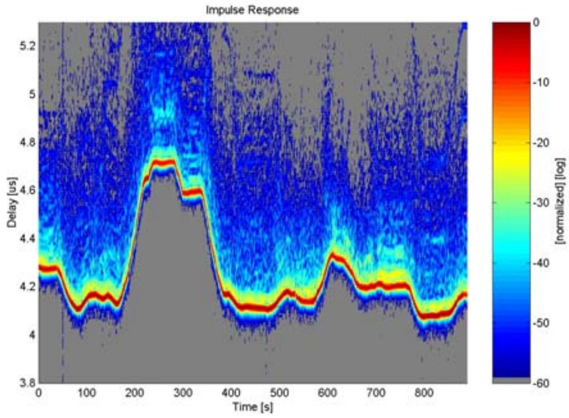

Figure 8: Urban car channel, Munich, 80° elevation

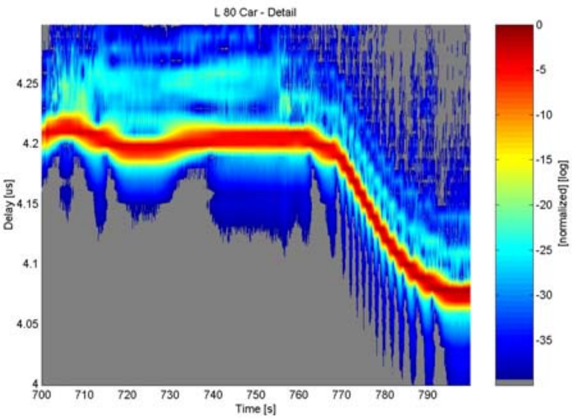

Figure 9: Urban car channel, Munich, 80° elevation – Detail from **Figure 8**.

Figure 7 shows the same measured track through the centre at 40 degrees elevation. In this situation the visibility increases dramatically. The tendency for long echoes is reduced. Unfortunately another characteristic comes up. As the elevation increases, a very constant short delayed reflection can be seen during almost all the time. Very likely this reflection occurs with a delay matching the distance between buildings and the bus. The power of this reflection is quite high and reaches values around –15 to –20 dB. **Figure 6** shows the same track with the Zeppelin at 80 degrees elevation. There the visibility is very high. The echoes tend to be short and strong. The detail in **Figure 9** shows the very short delayed "building echo". Note that there is some variation when the bus moves orthogonally to the trajectory bus - Zeppelin (the part where the absolute delay stays constant).
One can notice that by approaching or receding towards or from the airship the delay and power is very constant.

With all elevations one can find the "flashing reflectors" caused by small objects passing by quickly. The small reflection surface and the relatively high vehicle speed keeps their survival time short.

SUBURBAN CHANNEL – SMALL TOWN

The following measurements were performed in the small town of Fürstenfeldbruck near Munich. **Figure 10** gives an impression of the measurement area. In comparison to the city of Munich the buildings of Fürstenfeldbruck are significantly lower (usually only three floors) and the streets are wider.

Figure 10: City of Fürstenfeldbruck

Similar to the effects we described for the Munich measurements we can see many approaching reflectors as well as constant delays (see Figure 11 to **13**). But due to lower buildings and wider streets delays are usually larger. Furthermore the more open gaps in the sky lead to a slightly better visibility than in the town centre in Munich. Again for the low elevation the dominant effect is the "low elevation building echo". In contrast to a large city multiple reflections in urban channels are less likely.

Increasing the elevation to 40 degrees again improves the visibility of the satellite. Once more an echo at a constant delay appears. It is as well correlated with the width of the street. But again the more open sky becomes important. The received power level is higher than in the presence of urban canyons.

Increasing the elevation to 80 degrees enforces the presence of a near constant echo. Figure 13 depicts the 80 degree measurement in Fürstenfeldbruck. Like in Munich the visibility incenses to its most. The direct path is now nearly always followed by a quite close reflection. Beside this the only important reflections are caused by small reflectors appearing often with a short lifetime. These flashing reflectors can be found in all elevations.

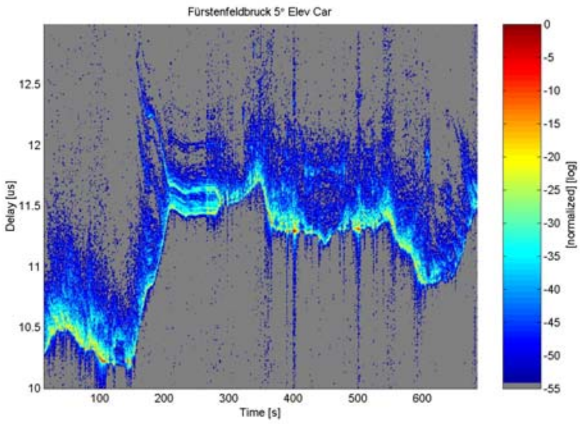

Figure 11: Urban car channel, Fürstenfeldbruck, 5° elevation

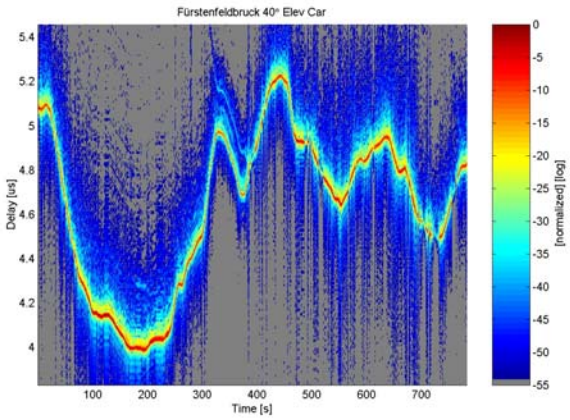

Figure 12: Urban car channel, Fürstenfeldbruck, 40° elevation

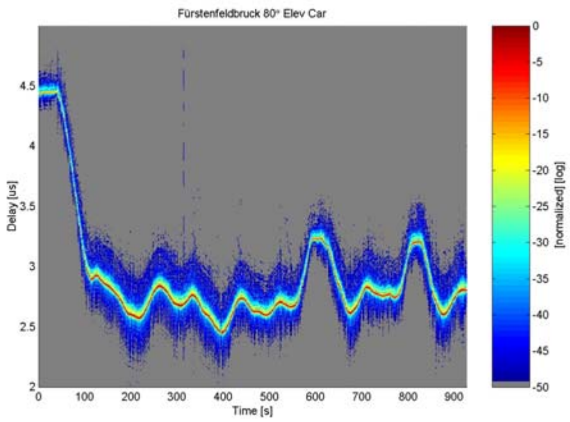

Figure 13: Urban car channel, Fürstenfeldbruck, 80° elevation

RURAL CHANNEL – MOTORWAY

Another important application for a navigation system is a drive on the motorway (car navigation systems). Figure 16 shows the measurement for low elevation (10-30 degrees). We started with an elevation of 10 degrees at the beginning, 30 degrees were reached in the middle of the measurement passing by the hovering Zeppelin then decreasing to 10 degrees at the very end again. At first this channel seemed not to be very exciting. On closer viewing the constant characteristic of the channel we recognized a continuos ground reflection in a certain distance. When the Zeppelin is aside the vehicle other reflections from traffic signs, trees or side walls are most likely present.

The constant ground echo can be seen very clearly in **Figure 17** which depicts an excerpt of **Figure 16**. Furthermore a very strong reflection appears. This was caused by a large, glazed building which was located directly beside the motorway. Please note the often mentioned “cosine shaped” delay.

Increasing the elevation towards 80 degrees the channel shows a strong correlation to the low elevation. Only the ground reflection is being moved and the building reflection disappeared.

It was certainly no surprise that no signal was detectable inside the tunnel.

Figure 14: Motorway seen from the Zeppelin

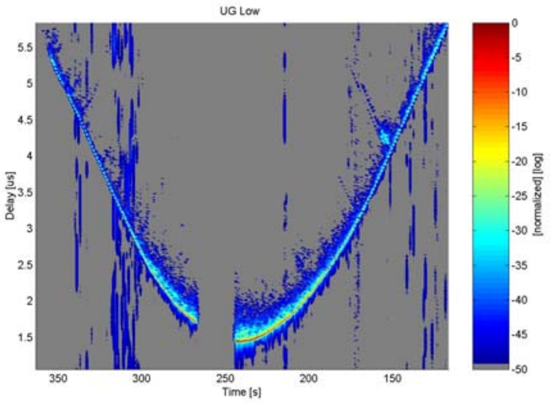

Figure 15: Motorway Low Elevation

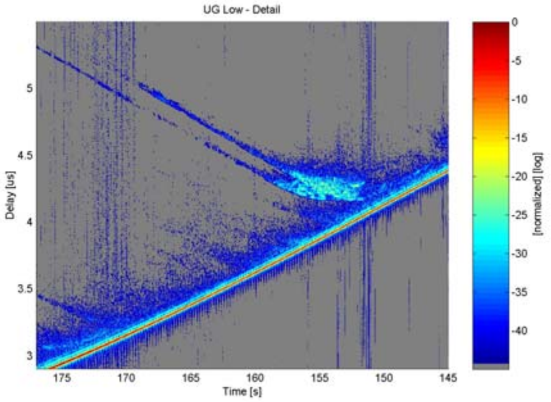

Figure 16: Motorway Low Elevation – Detail

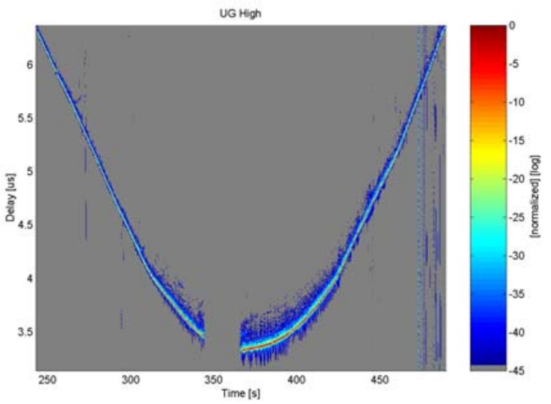

Figure 17: Motorway High Elevation

RURAL CHANNEL – COUNTRY ROAD

Different from the broad motorway without any trees close to the road, on a country road the signal is blocked more often. **Figure 18** shows the measurement in this scenario at a low elevation (10-30 degrees). The ground reflection in this application is less sharp and scattered over a wide delay range. Furthermore the presence of approaching reflectors is obvious. This is indicated again by the diagonal lines approaching in **Figure 18**. This effect can best be seen in the excerpt of the measurement depicted in **Figure 19** where the trip lead through an alley of trees. On this low elevation these trees caused distict reflections. The line of site signal was sometimes blocked by the trees.

Increasing the elevation up to 30 degrees (**Figure 20**) reduces the tree reflection dramatically. But now the direct path is affected by the treetops. It seems that these treetops are opaque which affects the line of sight power even more than at a low elevation.

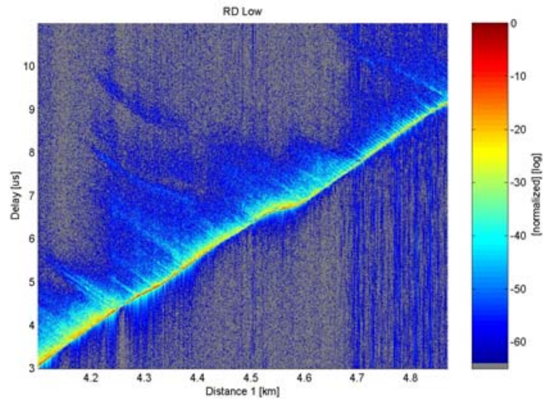

Figure 18: Country Road Low Elevation

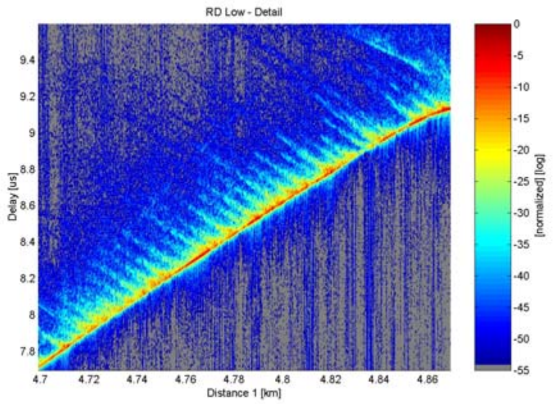

Figure 19: Country Road Low Elevation - Detail

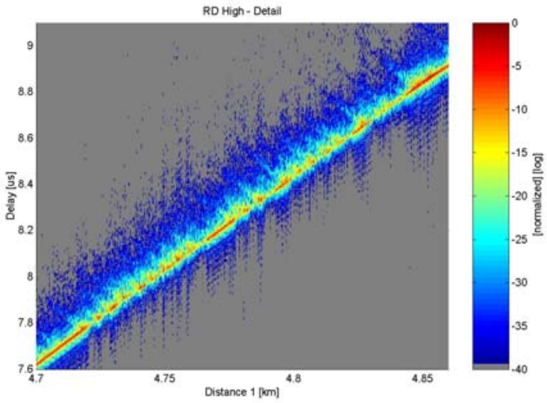

Figure 20: Country Road High Elevation - Detail

CONCLUSIONS

To evaluate the reflections in urban, suburban and rural environments a measurement campaign in Autumn 2002 was performed. The main outcome is the strong elevation dependency of the channel. For the navigation application it is very important that many short delayed echoes occur. This adverse characteristic of the measured channel must be taken into account in the design phase of new systems and receivers. It could explain the lack of performance in critical situations.

ACKNOWLEDGEMENTS

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