Measuring Galileo's Channel — the Pedestrian Satellite Channel

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Abstract

This paper discusses the results of experiments investigating the environment of satellite navigation receivers for pedestrian applications, where reflections from buildings decrease the accuracy of the positioning.

1. 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 [Reference 1]) had clearly shown that the synchronization 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 becomes 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) [Reference 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 and suburban scenarios. This paper presents the first preliminary results and conclusions for typical pedestrian applications.

2. Channel Measurement

The satellite was simulated by a Zeppelin NT operating at distances of up to 4,000 m from the receiver. We transmitted a special measurement signal with 10 W 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 under the airship (see Figure 1). The image taken by the camera was transmitted via a wireless radio link to a monitor on 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 successful in terms of the operational requirements.

Figure 1. Measurement setup

In addition, the Zeppelin transmitted an 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 conducted. For the pedestrian channel the focus was on:

- Urban channels (large city — Munich, including a shopping street)
- Suburban channels (small town — Fürstenfeldbruck).

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

3. Channel Characteristics

During the measurements the whole range of elevations to the “satellite” from 5° to 90° was covered. As an example some measurement results for the urban pedestrian channel are presented as the receiver moved along a narrow shopping street (see Figure 2) in the centre of Munich. 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. Figures 3, 4 and 5 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 grey-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.

In Figure 3, for very low elevations, many strong reflections are visible. Their excess delays decrease as soon as the pedestrian 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. These reflections appear and disappear. This situation can best be modelled by a Markov state model. In other cases a clearly increasing power level is detected when the antenna approaches the reflector. There is also strong fading in the LOS path which is caused by the fact that a pedestrian cannot carry the receiver antenna in perfectly horizontal alignment. In the last 30 m of the measurement, beyond 170 m, the team moved into a side street where the Zeppelin was out of view. As a consequence there is no LOS signal traceable, but there are surprisingly strong reflections. Most of the echo power is within the delay range of one chip. Therefore these reflected signals will directly cause an error in the receiver’s DLL (Delay Locked Loop). Only excess delays larger than a chip length (e.g., 1 ms for the GPS C/A code) do not affect the propagation delay measurement of the receiver. Compared with lower elevations, the approaching reflections become less powerful at elevations of 40° (Fig. 4). The echo power becomes concentrated within a relative delay of 0.25 µs. Because the channel has a Rician characteristic, there is

Figure 2. Measurement location in Munich

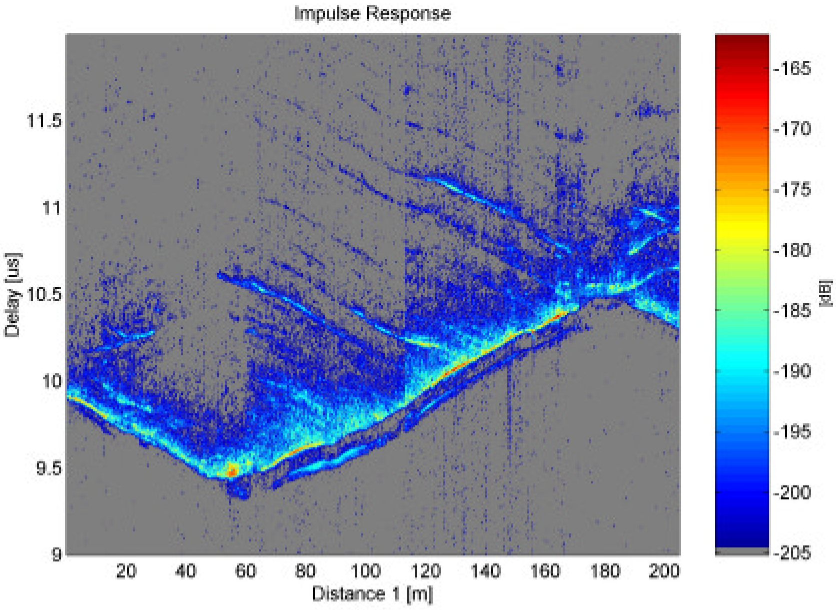

Figure 3. Urban pedestrian channel, 10° elevation

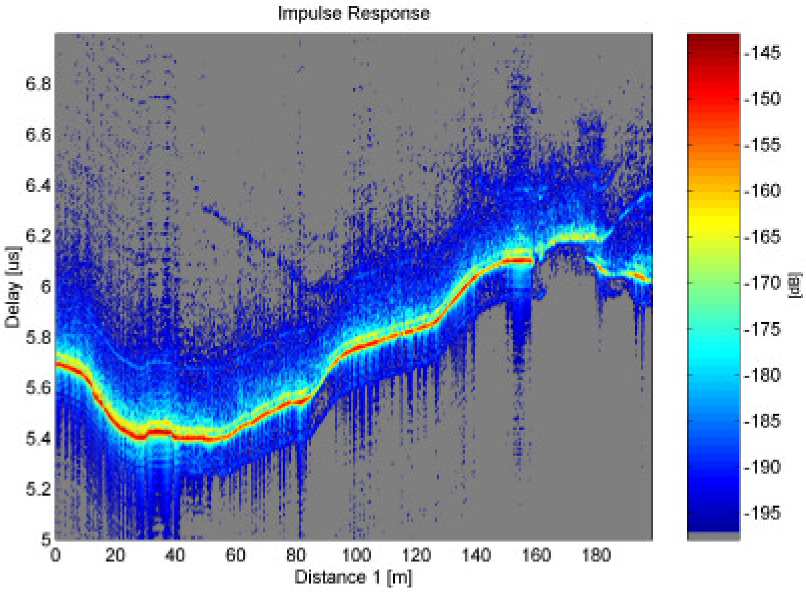

Figure 4. Urban pedestrian channel, 40° elevation

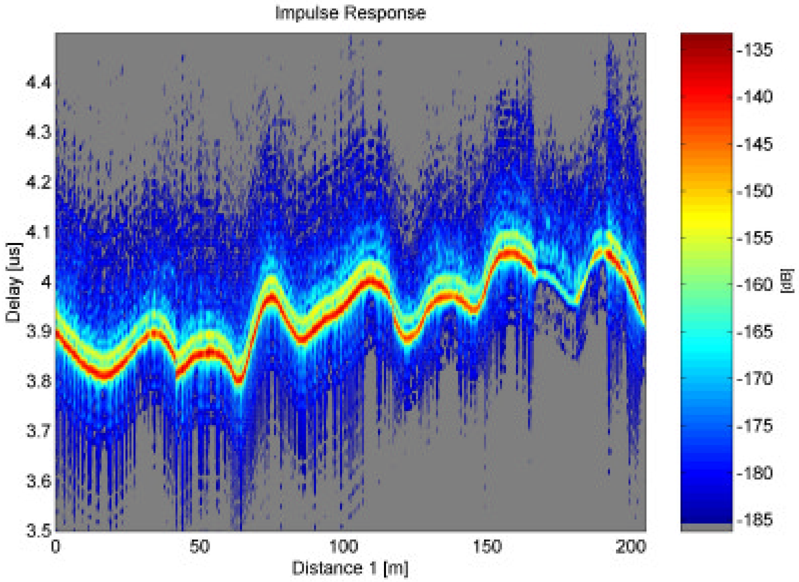

Figure 5. Urban pedestrian channel, 80° elevation

some remaining fading in the LOS signal. For the last part of the measurement the direct path becomes clearer. In Figure 5, for very high elevations the Zeppelin could be seen during almost all the measurement. Even without the LOS signal some very short delayed reflections indicate the line-of-sight distance. The reflecting structures are close to the receiver, and echoes with constant excess delay have replaced the approaching ones. Looking into the details reveals that the constant delays indicate the distance between the houses and the receiver. A delay of 100 ns (0.1 µs) corresponds to a distance of 30 m.

Another example for the pedestrian channel was measured in Fürstenfeldbruck, a small town near Munich (see Figure 6). Again the same track was measured for elevations between 5° and 90° (Figure 7 and 8). In the first 200 s of the measurement the receiver moved more or less orthogonal to the Zeppelin´s position. Therefore the absolute distance stayed nearly constant, and the echoes kept a constant excess delay. But this constant delay again depends on elevation. While there are sometimes echoes at excess delays of about 150 ns for low elevations, there is a strong static echo at an excess delay of about 40 ns at high elevations, as can be seen in detail in Fig. 8. This is explained by reflections from the city hall, located at the end of the road where the measurements were made (see Fig. 6).

Figure 6. Measurement location in Fürstenfeldbruck

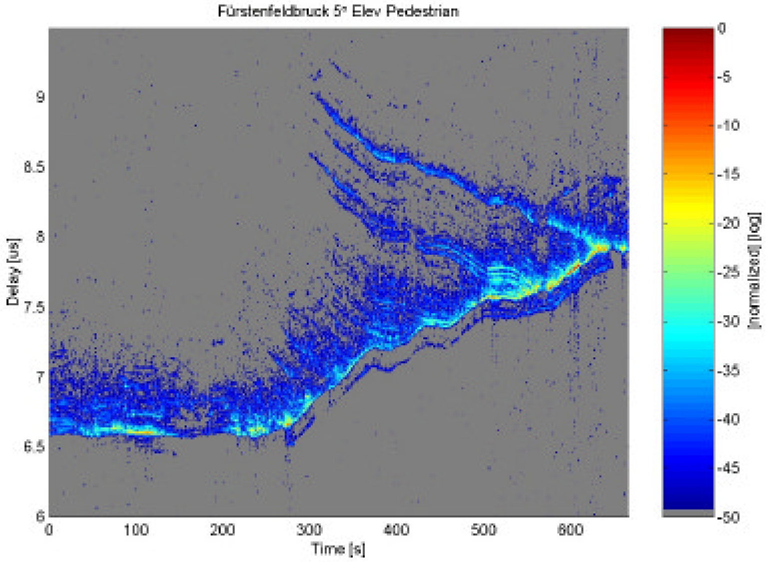

Figure 7. Suburban pedestrian channel, 5° elevation

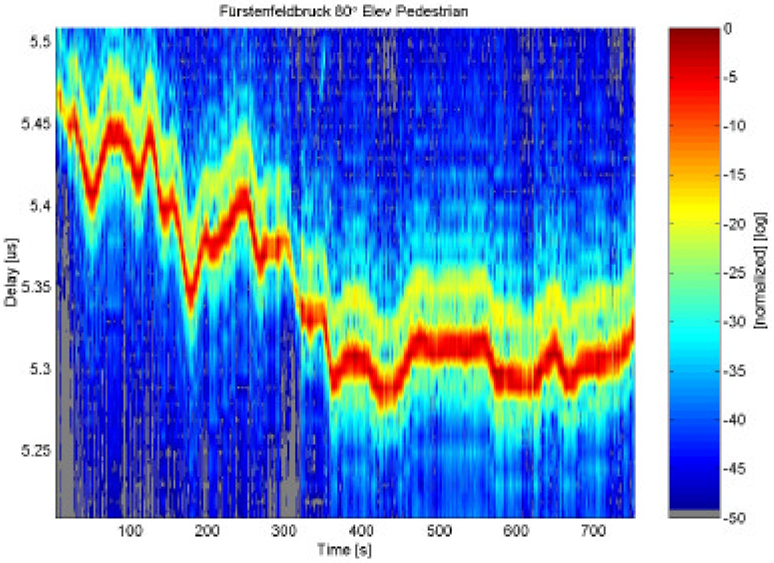

Figure 8. Suburban pedestrian channel, 80° elevation

For more details on the measurement campaign as well as the first results of urban, suburban, and rural car channels we refer to References 2 and 4. The impact of short delayed slowly varying reflections on the positioning error was simulated and has been presented [Reference 5].

4. Conclusion

A high time resolution satellite navigation channel measurement campaign was performed to investigate critical multipath scenarios. There is a very high probability of strong, short delayed echoes causing very large positioning errors. Especially, slowly varying echoes in pedestrian applications lead to errors of several tens of meters. A clear elevation dependency of constant delayed and “approaching” reflections characterizes the power delay profiles of the measured channels. From the obtained data we will derive multipath models which will be used by system designers as well as receiver developers to improve the performance of future systems and to allow accurate positioning even in the presence of reflecting structures.

References

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