The Influence of Multipath on the Positioning Error

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1 Abstract

Both GPS and the future European satellite navigation system GALILEO are CDMA based systems. Due to the spreading both systems are capable of reducing the influence of echoes caused by the multipath propagation channel. Nevertheless, measurements have shown that in critical environments the reflections are causing positioning errors of several ten meters. In times after SA and of well performing ionospheric models, these echoes have become the dominant error source. Especially, reflections close to the receiver significantly decrease the performance. The position error becomes worse if the reflection is strong and slowly varying over time.

This paper describes the mechanism of multipath signals causing errors in a standard receiver. A simple channel model is used to investigate the influence of certain system parameters on the multipath performance. It will be shown that the resolution of existing channel models is not sufficient for accurate multipath modelling. For this reason a highly accurate channel measurement campaign was performed by DLR in 2002.

2 Introduction

A CDMA system is able to cancel echoes whose delays are larger than the chip rate. That means that by increasing the bandwidth of the spread spectrum system the multipath sensitivity can be reduced. Due to bandwidth limitations, the goal of designing a satellite navigation system is to maximize the suppression of reflected signals for a given system bandwidth.

Many parameters have an influence on the multipath sensitivity of a satellite navigation system. Especially the power delay profile of the channel is highly relevant for the performance. Another essential point is the pulse shape of the used spreading sequence.

In a receiver the received signal is correlated with the spreading code with the chiprate 1/ T_C. In absence of noise and multipath this results in the undisturbed autocorrelation function. The propagation delay τ is tracked by a DLL (Delay Locked Loop) [1], shown in

Figure 1. An early and a late copy of the code (shifted by $\pm T_C/2$) are correlated with the incoming signal. The difference of these two correlation functions results in the Loop S-curve. This signal is lowpass filtered and steers the VCO (Voltage Controlled Oscillator) which acts as the clock of the code generator. The DLL locks to the zero crossing of the loop S-curve. Noise and echoes larger than the loop bandwidth are filtered, whereas slow varying signals are tracked by the DLL.

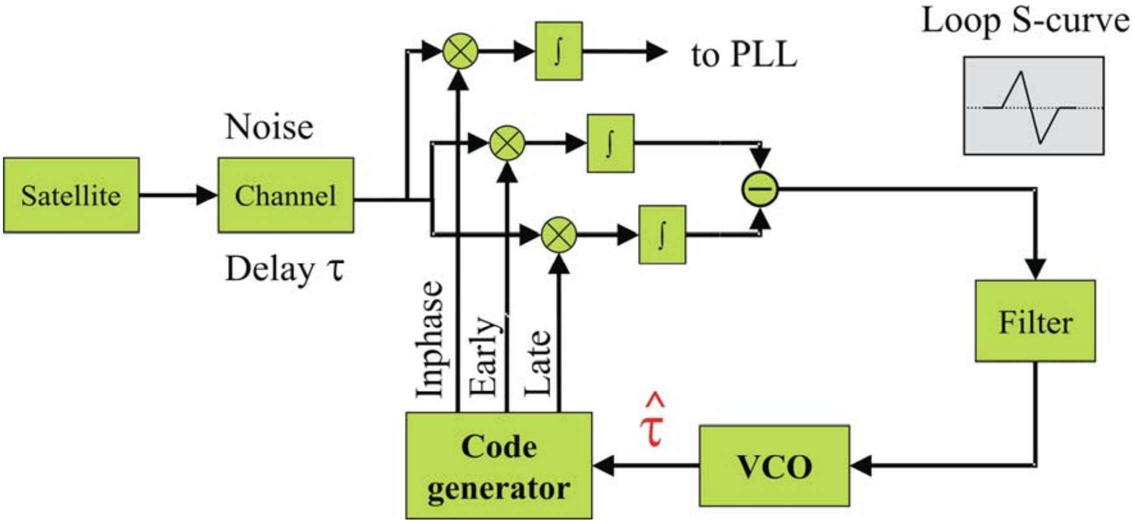

Figure 1: Delay Locked Loop

3 Simulation

In absence of noise and multipath the zero crossing of the loop S-curve of a standard receivers DLL locks to the correct propagation delay τ. To investigate the effects of multipath propagation, we look at a simple channel model where we have a direct signal and one discrete reflection (see Figure 2). The reflected signal experiences a certain attenuation γ, phase shift φ and delay $\Delta\tau$.

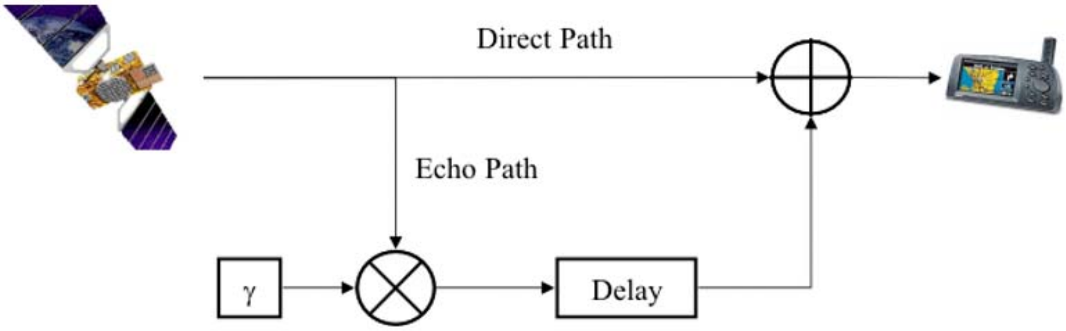

Figure 2: Simple multipath model

If such a signal is applied to a standard receiver, the zero crossing of the loop S-curve will be displaced even without noise. Both the direct and the reflected signal will we correlated with the code in the receiver resulting in an overlaying S-curve caused by the

reflected signal in addition to the wanted loop S-curve of the direct signal. Thus the receiver will detect a wrong propagation delay which results in a positioning error.
Depending on the delay and phase we simulated the DLL's offset for different chip pulse shapes [2]. In the following example we assume the reflected path to be 10 dB below the direct signal:

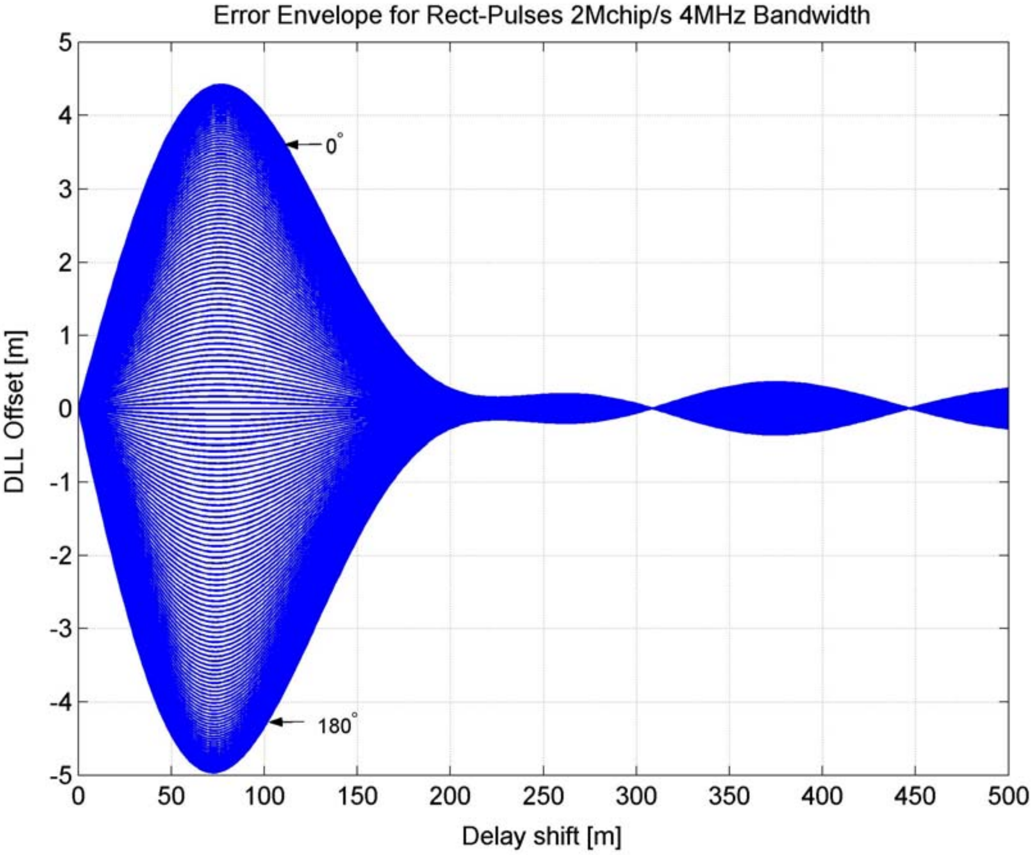

Figure 3: DLL Error for Rectangular Chip [2]

In Figure 3 the DLL's offset is already converted to meters, indicating the positioning error. It is easily visible that the largest offsets occur for phase 0 and 180 degrees. For all other phases the positioning error is less. We also note that echoes with delays less than 200 ns which corresponds to detour path lengths of about 60 meters have the largest impact. This simulation is valid for static and slow varying reflections. If a reflection experiences a Doppler shift due to a relative movement of the reflector or it has a large Doppler bandwidth, it will be filtered by the DLL's loop filter. On the other hand, we can expect strong influence in scenarios like a walking pedestrian or a car at low speed in a traffic jam. Reflections on the car chassis itself, as well as from other slow moving cars or structures cannot be filtered by the DLL.

In addition the offset strongly depends on the chip pulse shape. Figure 4 shows the upper bound (error envelope) for a rectangular and a root-raised-cosine signal (roll of factor 0.2) for a given system bandwidth of 4 MHz.
The maximum error for the rectangular pulse is higher than for the RRC pulse, but the DLL is less sensitive to reflections in a medium delay range. That is, the RRC is preferable in scenarios with only short delayed echoes, whereas the rectangular signal

performs better if there are reflections between 150 and 350 ns delay. Thus, the total influence on the performance in a multipath scenario depends strongly on the power delay profile of the channel.

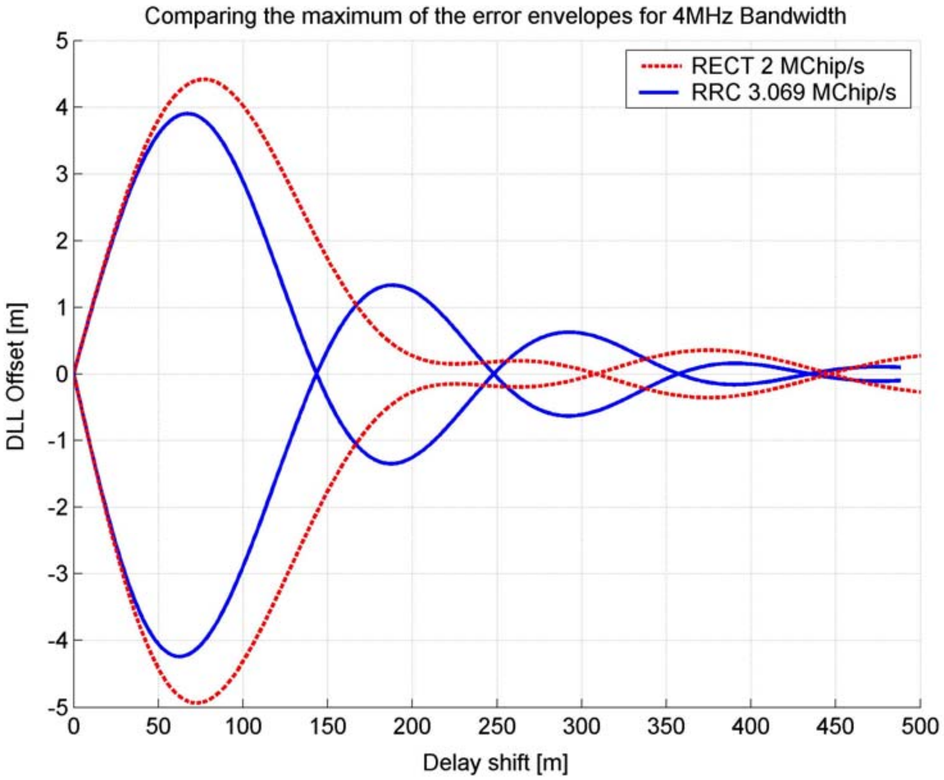

Figure 4: Error envelope [2]

4 Channel measurement

The simulation results in the last chapter clearly show that existing multipath models with a time accuracy of 50 ns are not sufficient for modelling the positioning error. For this reason we carried out a broadband channel measurement campaign in and around Munich in autumn 2002.

Several rural, suburban and urban scenarios were measured for land mobile as well as pedestrian applications with an time accuracy of 10 ns. By applying an ESPRIT ("Estimation of Signal Parameters via Rotational Invariance Techniques") based super resolution algorithm this can be increased to 1 ns for the final model.

Typical urban power delay profiles can be seen in Figure 5, where we plotted the channels impulse responses in an absolute delay range of 9-12 μs over the measured track length. For this scenario a pedestrian was carrying a receiver antenna with a typical characteristic in a narrow shopping street in the city of Munich. The transmitter (mounted on a Zeppelin NT) was to be seen at an elevation of 10 degrees.

The dark line indicates the LOS path. Note that many of the reflections are within a chip length (500 ns for the C/A-code) and that there are many strong reflections close to the direct path. It can be clearly seen that there are specific reflector structures. When approaching this reflectors the corresponding echo delay decreases and appears as a line in Figure 5. For more details on the channel measurement campaign and on first results for all measured scenarios we refer to [3] - [5].

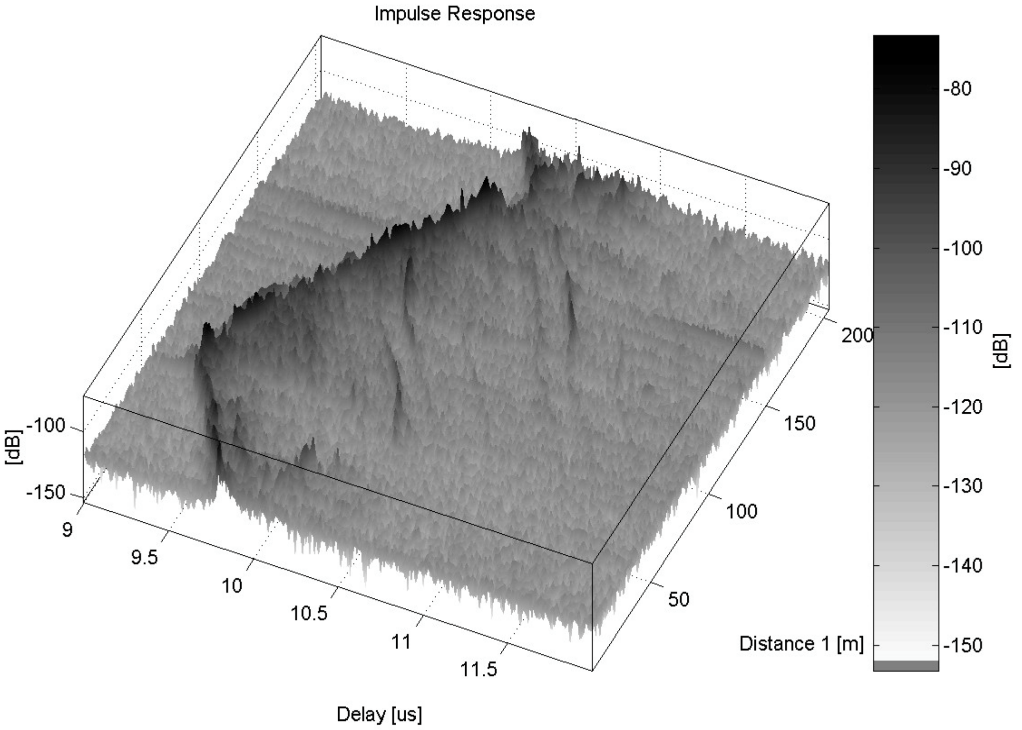

Figure 5: Typical urban channel

5 Conclusion

The positioning error of a navigation receiver in multipath scenarios strongly depends on the channels power delay profile. Especially strong short delayed echoes cause large positioning errors. Using a high time resolution model the actual multipath error can be simulated to find optimal signal structures for GALILEO as well as to define most critical environments.

References

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