Ray-Tracing Approach for Multipath Characterization - Including Multiple Rays

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Motivation

Multipath propagation has a major contribution to the total GNSS error budget. Site-dependent characteristics, unknown geometry, dynamic nature and the dependency on many other factors, like e.g. reflection/diffraction properties, weather conditions and antenna and/or receiver design make multipath mitigation very challenging. In our study, the results of a novel ray-tracing approach are used for understanding and characterizing multi-multipath propagation process. Based on a 3D model of the physical environment of the antenna, measured by a terrestrial laser scanner, ray tracing simulations are performed. Rays that arrive at the receiving antenna by paths other than the direct are identified. Based on the geometric and electromagnetic characteristics of the identified rays, phase and code errors caused by superimposition of all rays are calculated.

Our investigation showed

- 90° shift between code and phase errors, which occurs for errors caused by a single multipath component, is not valid in the case of multiple multipath components
- 90° shift may be valid only when a dominate component exist
- Constructions shorter and/or a few meters higher from the receiving antenna cause edge diffraction even from high elevation satellites
- First results of simulated DD measurements are in very good agreement with real measurements both in amplitude and frequency
- Multipath relative amplitude and normalized C/N0 values can be model analytically, with an approximate knowledge of the antenna pattern

Ray-Tracing Simulations - Input parameters

Fig. 1: Laboratory Network at the rooftop.

The physical description of the environment in which the receiving antenna is placed (scenario) is one of the fundamental inputs for the channel estimation. In this case, the scenario is the rooftop of the geodetic institute (GIH) of the University of Hannover, which is a typical environment for GNSS reference stations (Figure 1). A 3D terrestrial laser scanning of the rooftop was performed in order to derive the input, to the ray-tracing, scenario model. Due to the large number of planes (more than 900) of the initial scenario, it was decided that at first a simplified version of it will be used for the simulations.

Apart from the scenario model and in order to completely characterize the satellite-to-earth channel, the coordinates of the transmitter and receiver are needed as well as the receiving and transmitting 3D antenna diagrams for both orthogonal polarizations.

Ray tracing Simulations - Channel estimation

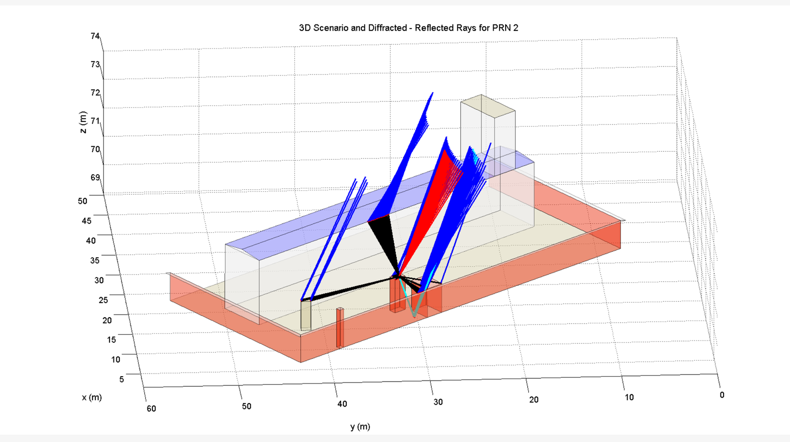

Fig. 2: Visualization of the scenario and the identified multipath rays of PRN2 for one hour observational period.

Based on the input information:

- Firstly a geometrical ray path searching is perfomed
- Then the physical and electromagnetic properties of each ray are calculated (Liso et al. 2011)

The visualization of the scenario and the identified multipath rays of PRN2 for one hour observational period are plotted in Figure 2. The line-of-sight (LOS) rays is in red color, the incident rays in blue and the diffracted ones in black, last but not least the ground reflected one is plotted in cyan color.

Tab. 1: Overview of the identified multipath components by the Ray-Tracing tool.

Multipath component	Type	Identification time [h]	Duration [sec]	Mean Extra Path [m]
1	Edge diffraction	14:100	3661	11.586
2	Edge diffraction	14:100	3661	0.816
3	Edge diffraction	14:596	550	3.878
4	Edge diffraction	14:546	502	4.329
5	Edge diffraction	14:100	3661	1.600
6	Edge diffraction	14:100	3661	2.861
7	Edge diffraction	14:100	191	1.594
8	Edge diffraction	14:100	2560	0.928
9	Ground reflection	14:100	1114	1.8826

Multipath caused error in phase and code observations due to each component separately

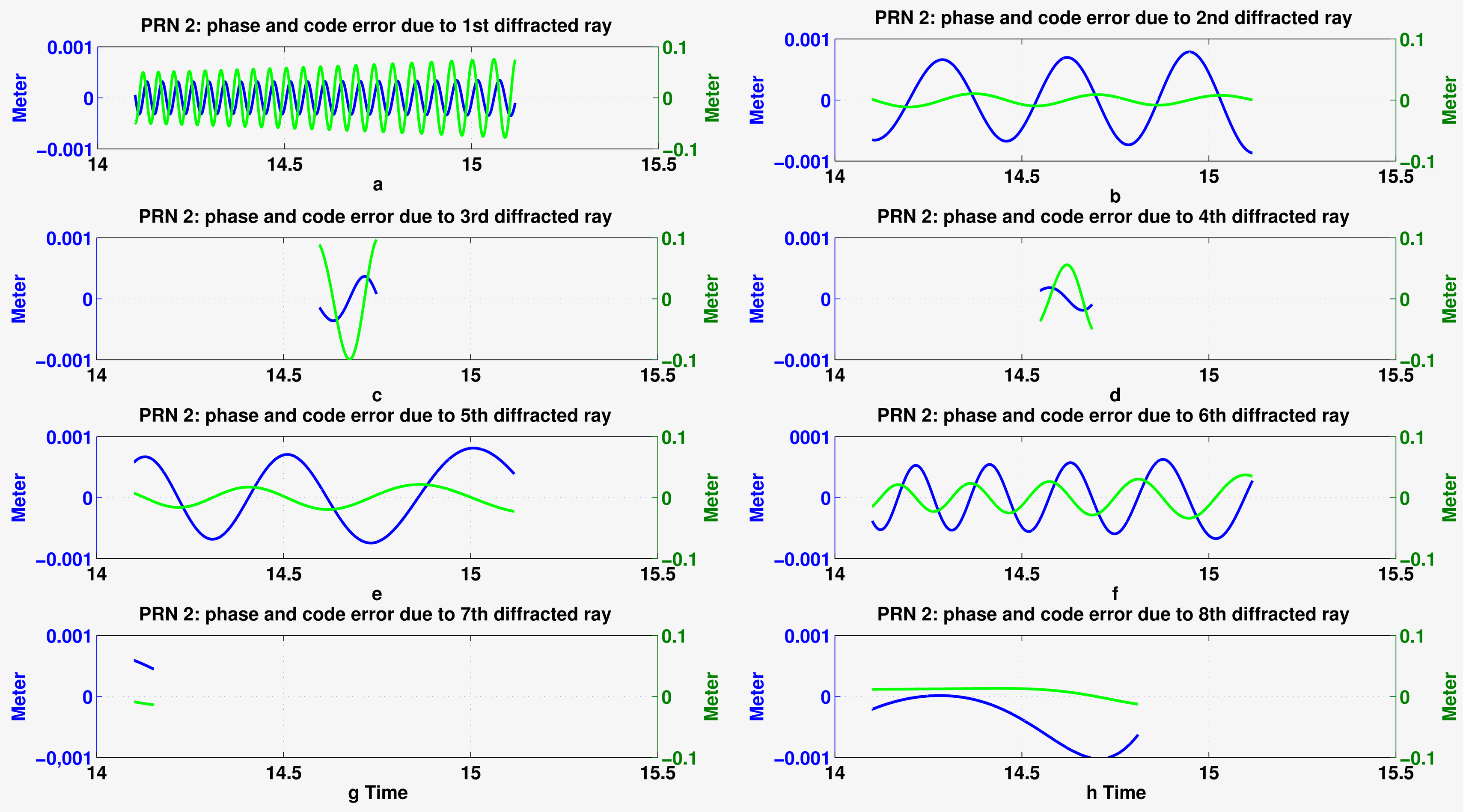

Fig. 3: Phase and Code errors caused by each diffracted ray separately, looking at Figure 3 it can be stated that for each MPC, the error characteristics are as expected from multipath theory. First of all, there is a 90° shift between code and phase errors. Moreover, phase errors are oscillating around zero, while code errors are not. The last comment is not so obvious from the plots. This is because of the very small relative amplitude of the diffracted/reflected rays.

Multipath caused error in phase and code observation due to more than one multipath component (MPC)

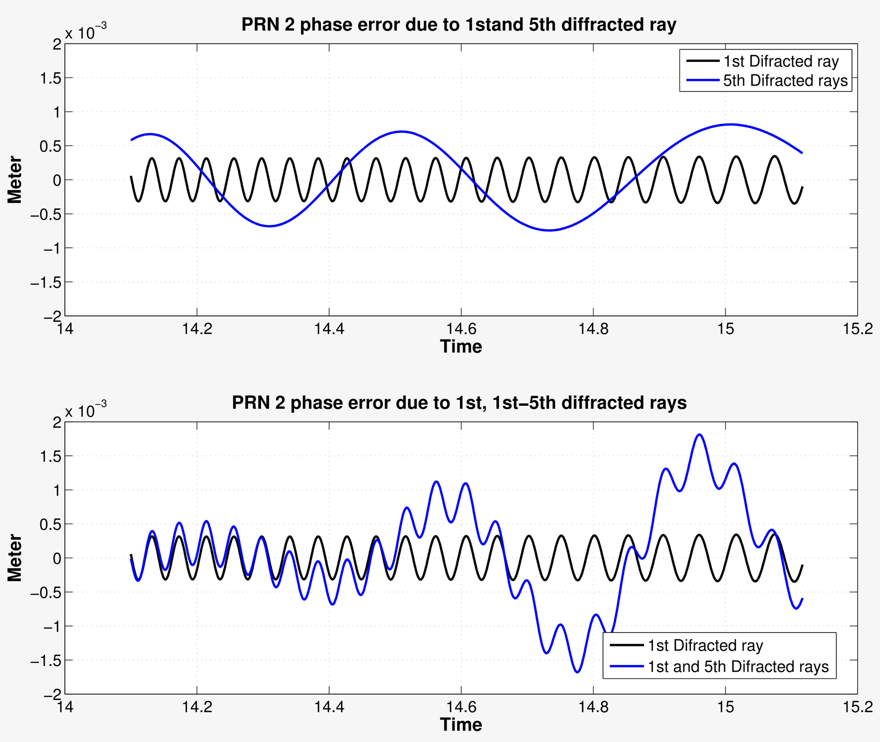

Fig. 4: Upper plot: Phase errors caused by two diffracted rays. Lower plot: the phase error due to the first diffracted ray is plotted in black color and the phase error due to the first and fifth rays in blue. It can be seen in this plot, that the impact of the fifth diffracted ray is dominating, especially in the last half of the plotted time series. So it can be stated that when a dominating MPC exists, which has a significant larger magnitude that all the other components, it is dominating and moreover the overall phase error and multipath frequency can be well model just by modeling the impact of the dominating MPC. The 90° shift between code and phase error in the presence of a dominating MPC still occurs as well as the oscillation around zero for the phase error.

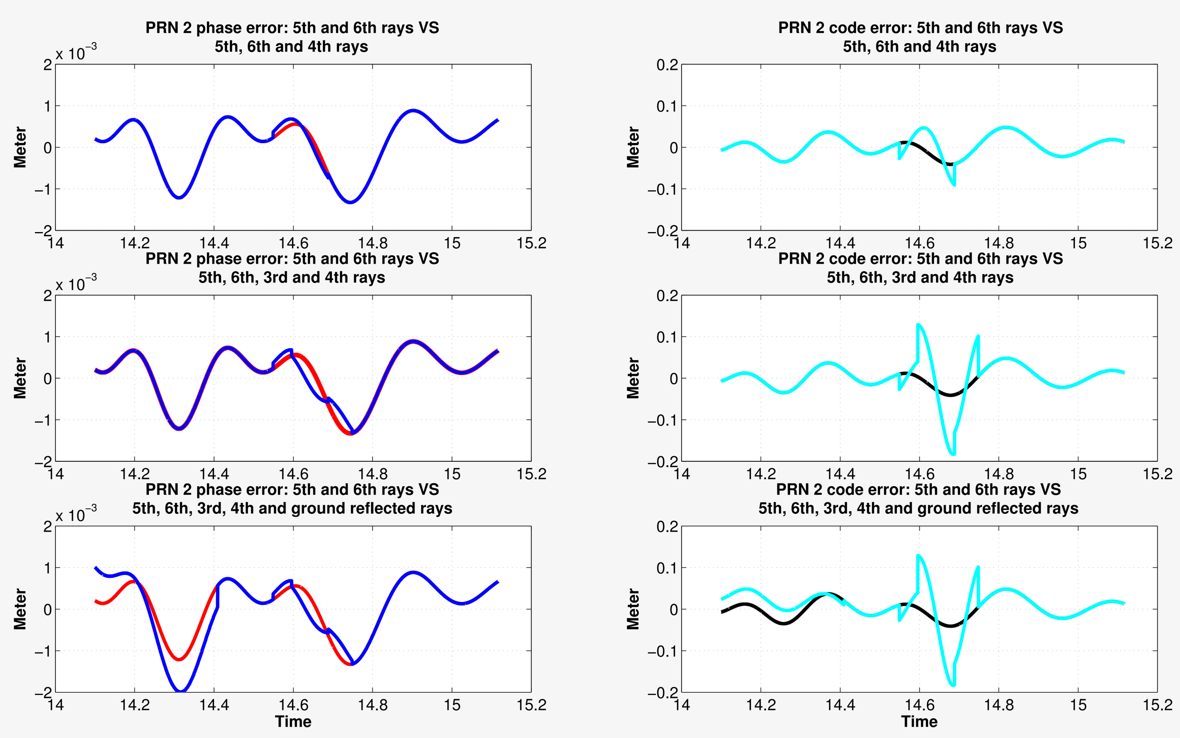

Fig. 5: First column: the phase error due to the 5th and 6th rays is plotted in red against phase errors calculated by these two rays plus other short duration MPCs that appear (or disappear) later on in the time series. Second column: the code error of the same two rays is plotted in black against code errors compute by more than these two MPCs in cyan color. Due to the very small phase error magnitude, there is a very small change in the trend of the two time series (red and blue). In the case of code error, the error magnitude is causing a visible change between the two time series (In this case the error magnitude is a function of the extra path delay also).

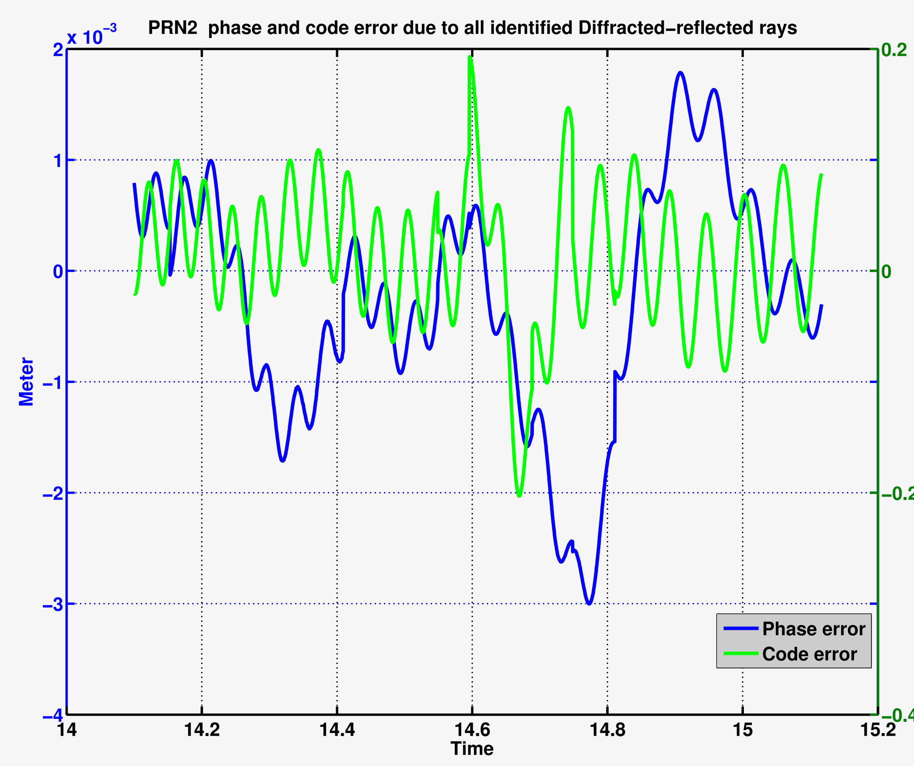

Fig. 6: Combined by all identified multipath components, phase and code errors. It can be clearly seen that the 90° shift between the phase and code errors is not present and neither code nor phase errors oscillate around zero. Furthermore, the sharp changes in magnitude due to the appearance (or disappearance) of another MPC are clearly visible. When the error magnitude is well above the noise of the code and/or phase observations, these epochs can be identified

First Results of an analytical modeling of multipath relative amplitude and phase DDs

(a) (b)

Fig. 7: Experimental setup for ground multipath modeling in PTB, Braunschweig (a) and Leica AX1202GG antenna used for data capture (b).

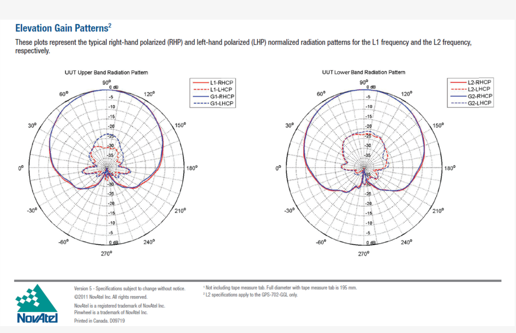

Fig. 8: Gain pattern of NOV702GG (source: http://webone.novatel.ca/assets/Documents/Papers/GPS701_702GG.pdf)

- controlled environment at PTB antenna Test Facility with an area of 50 m×60 m and special reflection material
- antenna gain pattern of a NOV702GG depicted in Figure 8 as azimuthal cut, LEIAX1202GG antennas were considered similar to NOV702GG
- gain patterns (both RHCP and LHCP) were used for modeling the receiving antennas

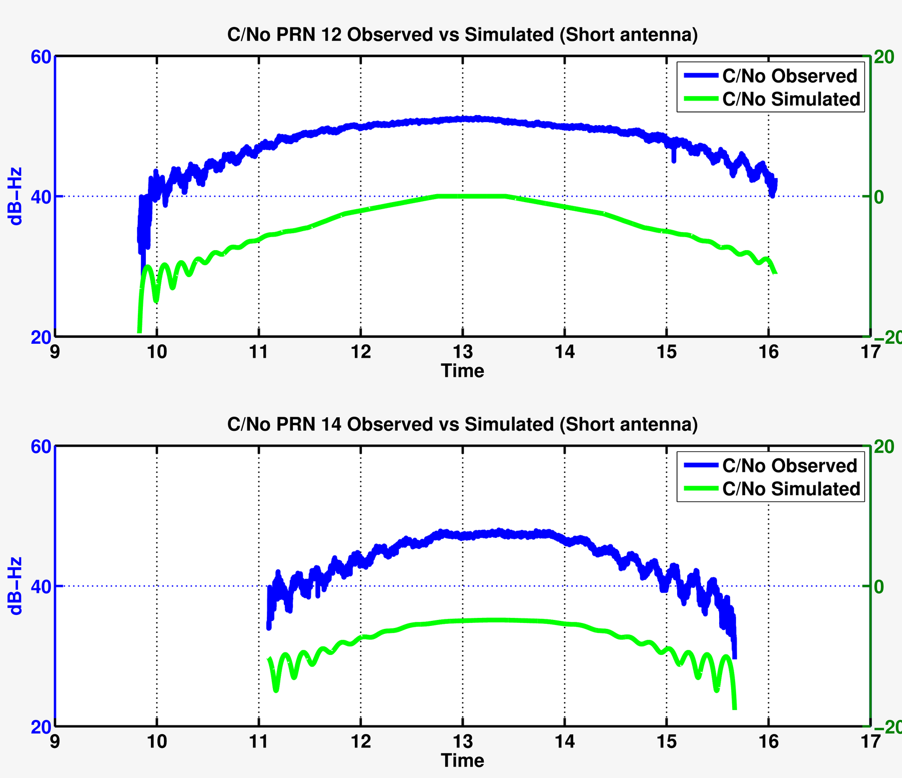

Fig. 9: Direct and reflected signals were model using geometric optics approximation and the normalized C/N0 values were calculated as a function of the normalized antenna gain pattern, the geometry and the material properties of the ground reflector. In this figure, the observed C/N0 values for PRN 12 and 14 (in blue) are plotted together with the simulated (in green) ones.

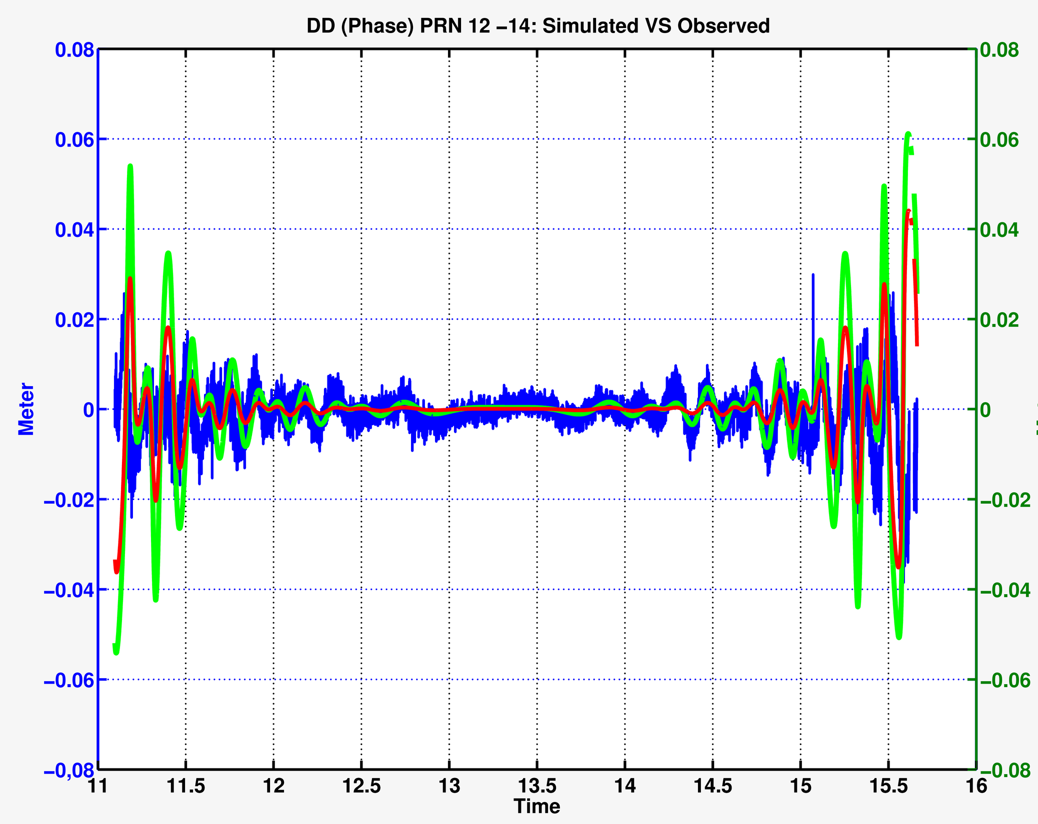

Fig. 10: Double differencies (DD) formed by PRN 12 and 14 of the short baseline (21.292 m) measured at PTB Braunschweig. In blue is the time series of the observed values for about 5 hours observational period. In green and red colors are the simulated DD phase errors, where the relative amplitude of each multipath components was calculated analyticaly and varies as geometry change. In green curve no reflection loss was concidered and in red, the material properties of a concrete reflector were used.

References

Liso, Marcos et al. (2011). Basic Concepts for the Modeling and Correction of GNSS Multipath Effects using Ray Tracing and Software Receivers. In: *IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications*, 12-16 Sept. 2011, Torino, Italy, pp. 890-893.

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