Multipath detection using SNR values for Galileo satellites

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Introduction

Effect of signal multipath still remains one of the biggest unresolved problem in GNSS positioning. It plays an important role in basic navigation tasks as well as in precise geodetic applications. In code measurements, effect strongly depends on quality of receiver technology and may significantly vary from decimeter level (geodetic grade receivers) up to several meters in case of navigational receivers.
Effect plays significant role also in phase measurements. It can take values up to quarter of wavelength (approximately 5 centimeters) in raw phase measurement and even more when phase combinations are used. There is no complex mathematical model in GNSS processing which could deal with multipath effect.
Galileo satellite system offers from its beginning unique opportunity to access more signals than any other GNSS have. It can be beneficial for multipath detection methods which rely on combination of different carrier's measurements. This poster presents method based on idea of Strode and Groves (Strode and Groves, 2016), which utilizes Signal-to-Noise values. This method is possibly suitable even for real-time applications due its relative simplicity. In original article, method has been tested for GPS block II-F satellites which also transmit signals on three different frequencies. In this presentation we want to show its applicability for Galileo system. Poster shows estimation of critical detection values for Galileo satellites based on calibration measurement in low multipath environment. Several approaches with different weighting schemes will be used and detection performance in urban environment will be evaluated on skyplot images.

Relation between phase multipath and SNR values

Connection between signal quality measurement SNR and carrier phase multipath can be shown on phasor diagram (Fig. 1). The phase lock loop attempts to track a composite signal which is the vector sum of all phasors (direct plus one or more multipath signals). According to this, the SNR then becomes a measurement of composite signal amplitude, $SN^R \approx A_c$ (Bilich and Larson, 2008). Using the law of cosines and geometric relationships expressed in the phasor diagram, composite SNR due to the direct signal plus one multipath reflection can be expressed as:

$$SN^R \approx A_c^2 = A_d^2 + A_r^2 + 2A_dA_r\cos\Delta\Phi_{d,r}$$

This equation shows how parameters of reflected signal ($A_r, \Delta\Phi_{d,r}$) influence multipath contaminated SNR values. As it is schematically shown in (Lau and Cross, 2006), maximal differences of SNR values compared to its nominal values (corresponding only to direct signal) is when relative phase $\Delta\Phi_{d,r} = 0°$ or $\Delta\Phi_{d,r} = 180°$, alternatively minimal differences compared to SNR nominal values are for $\Delta\Phi_{d,r} = 90°$ and $\Delta\Phi_{d,r} = 270°$ as it is visible on the following figure.

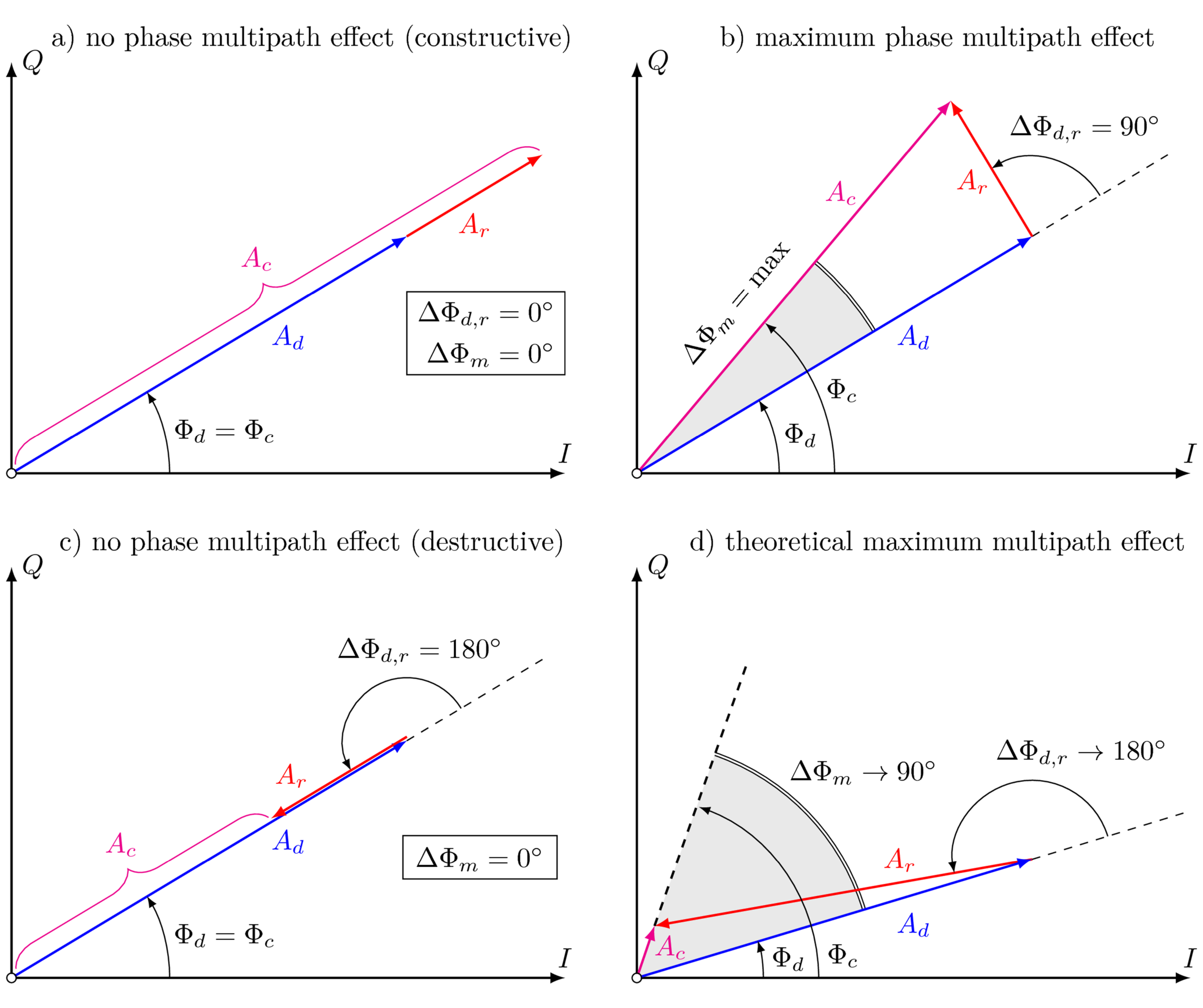

Fig. 1: Phase multipath effect on amplitude of tracked composite signal

Relative phase $\Delta\Phi_{d,r}$ depends on path delay Δd and used carrier wavelength λ. If we compute relative phases $\Delta\Phi_{d,r}$ for different carriers (e.g. E1, E5a), they will be different, because of not equal wavelength magnitudes. Relation between path delay and relative phase on carrier λ_i is:

$$\Delta\Phi^i_{d,r} = \left(\frac{\Delta d - n\lambda_i}{\lambda_i}\right)\cdot 360°$$

Because of different relative phases there will be subsequently also different effect on multipath error and also SNR values at each carrier frequency. This finding is the precondition for definition of detection statistic based on combination of SNR values at different carriers.

Methodology

Finding that the presence of phase multipath has a different impact on SNR measurements at each of tracked carrier frequency, exploded Strode and Groves in (Strode and Groves, 2016). In general terms they proposed a detection algorithm which computes a test statistic from a set of current SNR measurements and then compares it with threshold that marked the limit of the system's normal performance. Exceeding test statistic over the threshold indicates the presence of multipath. SNR measurements at three different carrier frequencies are used to compute test statistic S_s^a, thus only utilization of GPS Block II-F and Galileo satellites is possible:

$$S_s^a = \sqrt{\left(SNR_a^{s,E1} - SNR_a^{s,E5^a} - \Delta\hat{C}_{15a}(\theta_a^s)\right)^2 + \left(SNR_a^{s,E1} - SNR_a^{s,E5^b} - \Delta\hat{C}_{15b}(\theta_a^s)\right)^2}$$

where eg. $SNR_a^{s,E1}$ denotes SNR measurement on Galileo E1 carrier frequency between antenna a and satellite s, $\Delta\hat{C}_{15a}$ are predicted E1 – E5a, respectively E1 – E5b SNR differences acquired in low-multipath environment modeled as a function of satellite elevation θ_s^a. Function are modeled as polynomials and their coefficients have to be estimated in low multipath environment. Measurement campaign to determine coefficients of $\Delta\hat{C}_{15a}$ and $\Delta\hat{C}_{15\,b}$ was performed in low-multipath environment, in different words in environment where no objects are in close vicinity of antenna and no reflections are expected. This measurement campaign we can name as calibration measurement, because it will further represent reference for multipath detection. For this purpose an open field with low vegetation growth near Bratislava, Slovakia has been chosen. Combined geodetic GNSS receiver Trimble R8 Model 3 was used with tracking capability of GPS, Galileo and GLONASS systems at 1 s sampling.

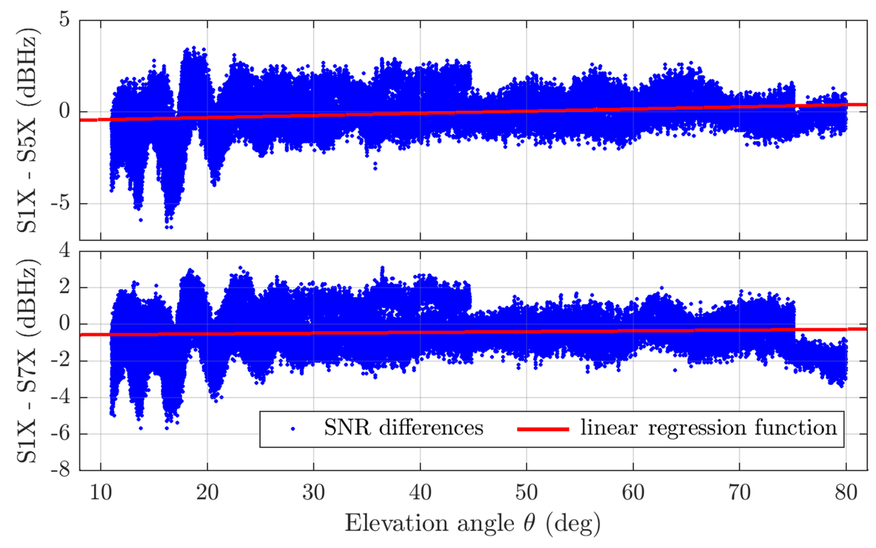

Fig. 2: Galileo signals SNR differences from calibration measurement. These values were used to estimate coefficients of linear functions $\Delta\hat{C}_{15a}$ and $\Delta\hat{C}_{15b}$.

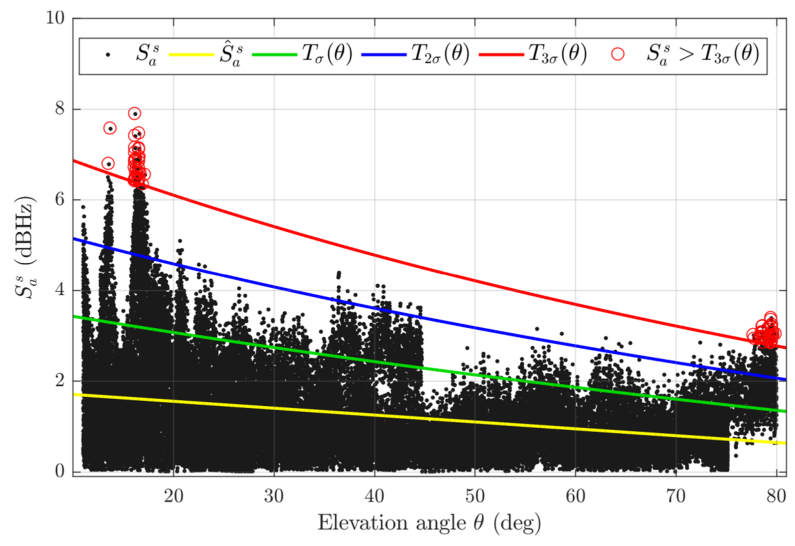

Fig. 3: Detection statistic S_s^a from calibration measurement. Exponential weighting was used to establish the multipath detection criterion (red).

Results and conclusions

To test introduced method of multipath detection we made two experimental GNSS static measurements in complex urban environments. As first site we chose Slovak University of Technology principal residence. There is the open courtyard inside building block as it is shown on Fig. 4 (left side). Big walls of surrounding, up to 25 m high buildings, should introduce many reflections. Measurement on this site last 16 hours. Second test site was located in courtyard of flat residence complex in Bratislava city center (Fig.4, right side). In this case view of sky was less obscured than at first test site and surrounding buildings have simpler geometry. Measurement at second site last approximately 4 hours. For verification purposes we used zenith-pointing image panorama taken at sites. Panoramas were created from the series of images with given orientation in free photo stitching software Hugin.

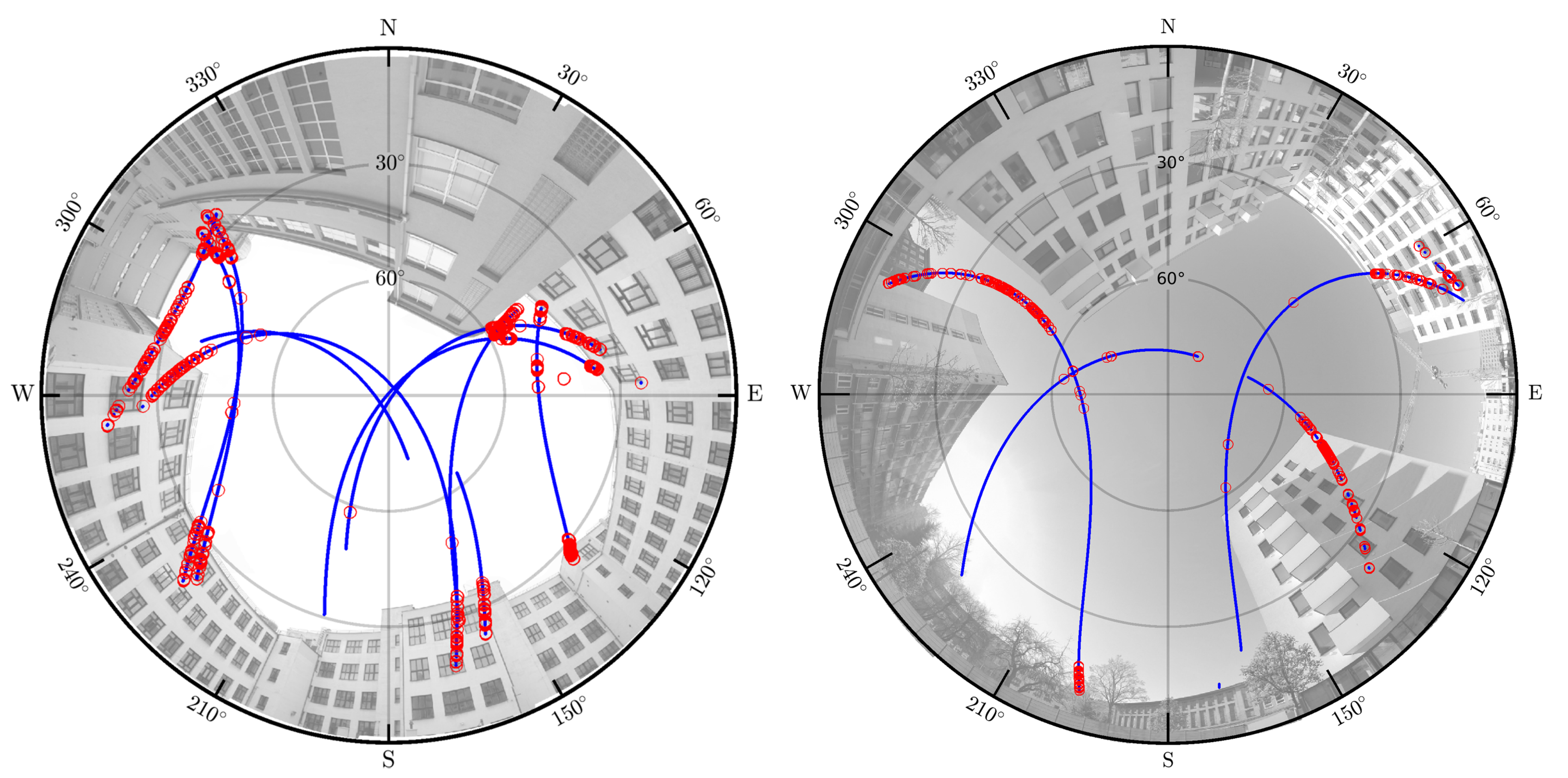

Fig. 4: Skyplot graphics of test measurement multipath detection results for Galileo. Blue dots represent satellite positions with complete set of measurements, red circles are detected multipath events.

In case of first test site we can see that method correctly identify non-line-of-sight (NLOS) measurements, but almost none measurements on "clear" sky, even in places where multipath is expected (opposite to building's walls). At second test site, method also correctly identify NLOS measurements covered by buildings, but also measurements for satellite E09 in approximate azimuth 300°. Satellite E09 is in opposite direction to building at south-east. Specular reflection for E09 is expected. Correct identification of multipath signal for E09 is promising for further investigation. For future work we suggest to perform new calibration measurement with more Galileo satellites in environment more similar to urban conditions (e.g. concrete parking lot).

References:

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