INVESTIGATION OF MULTIPATH DETECTION ALGORITHMS BASED ON SCATTER PLOTS IN GALILEO CBOC SIGNALS

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ABSTRACT

In this paper we address the issue of multipath propagation of the Galileo CBOC signal, using carrier phase investigation approaches. While the multipath estimation problem has been widely addressed, the multipath detection has not been so much investigated so far, especially with Galileo signals. The detection of the multipath propagation situations is of particular interest because it can mitigate the positioning errors. We propose two methods of multipath propagation detection that exploit the properties of the generic patterns encountered in scatter diagrams of the ACF and we define two measures of the scatter spread: one based on projections, and a second one based on eigen-value decomposition.

Keywords: *Composite Binary Offset Carrier modulation (CBOC), Galileo, multipath detection, scatter diagram.*

1. BACKGROUND AND MOTIVATION

Galileo, the future European Global Navigation Satellite System (GNSS), is planning to transmit signals for five navigation and location services in four sub-bands within the L band. Binary-Offset-Carrier (BOC) modulation is a spread-spectrum modulation technique that is currently proposed to be used in Galileo Open Services and Global Positioning System modernized signals. The Sine BOC (further referred to as BOC) modulation splits the signal spectrum in two components, symmetrically placed around the carrier frequency, by multiplying the pseudorandom code with a rectangular subcarrier [12]. The typical notation is BOC(f_{sc} , f_c) or BOC(m,n), with $m= f_{sc} / f_{ref}$ and $n= f_c / f_{ref}$, where f_c is the chip rate, f_{sc} is the sub-carrier frequency and f_{ref} is the reference frequency (generally f_{ref} =1.023 MHz). The Power Spectral Density of Multiplexed-BOC (MBOC) is a combination of BOC(1,1) spectrum and BOC(6,1) spectrum. One method of generating the MBOC spectrum is that of using Composite BOC (CBOC) time waveforms. The CBOC method is based on a weighted sum (or difference) of BOC(1,1) and BOC(6,1)- modulated code symbols [13, 14].

A GNSS receiver calculates its position by precisely timing the signals sent by the GNSS satellites, orbiting above the Earth, using the concept of time of arrival. Each satellite continually transmits messages containing the time the message was sent and its precise orbital position. The receiver measures the transit time of the messages and, by multiplying it with the speed of light, computes the distance to each satellite (pseudorange). Geometric multilateration is used to combine these distances with the location of the satellites to determine the receiver's position. Signals from at least four satellites are required in order to obtain a precise fix and to eliminate the errors introduced by the imprecise receiver clock. If more than four satellites are available and if some of the pseudorange measurements are affected by multipaths, then it could be beneficial to use only those satellites with clear Line Of Sight (LOS) visibility. That is why the detection of the situations with multipaths versus single path (or LOS only) has a particular significance in a Galileo receiver design, in order to improve multipath mitigation solutions.

While the multipath estimation problem has been widely addressed, e.g., in: [1-7], the multipath detection has not been so much investigated so far, especially with Galileo signals. An innovative approach based on carrier phase has been first proposed in [8] and further investigated in [9-11]. This approach is the basis of our proposed methods. Our methods do use as a starting point the carrier phase information proposed in [8-11], by converting it into a scatter plot diagram and by further defining two measures of the scatter 'spread': one based on projections, and a second one based on eigen-value decomposition. The novelty of our methods consists in this analysis of the scatter diagram spread and in its mapping, via thresholding, into two detection regions: a region of single path (or LOS only) and a region of multipaths (or NonLOS components).

2. SCATTER PLOTS FOR GALILEO CBOC SIGNALS

Our multipath detection methods are based on the properties of the complex output of the autocorrelation function (ACF) between the received CBOC signal and the locally generated CBOC signal. Generic examples of the scatter diagram of the real and imaginary parts of the ACF are illustrated by the blue dots in Figures 1 and 2. Most of the scatter points obtained in the single path case, shown in the first plot, are approximately aligned across a straight axis, while, in the multipath case shown in next Figure, the points are arranged on the perimeter and inside a polygon. Thus, by using these patterns, the presence of multipath propagation can be detected.

3. MULTIPATH DETECTION ALGORITHMS

We developed and tested two algorithms for the detection of multipath, by exploiting the scatter patterns previously described. The first method (denoted as the projection method) relies on the mean distance between each scatter point and the axis of the pattern, which is equal to the distance between the point and its projection on the axis. The axis is plotted as a red segment in Figures 1 and 2. The equation of the axis is obtained by connecting the two scatter points which possess the minimum/maximum sum of coordinates ($x+y$). For each scatter point, we compute the distance to the axis, given by the length of the segment [AD] in Figure 2, by expressing the area of the triangle ABC with two equivalent formulas (Heron's and the semiproduct of height and base), as the in the following expression:

$$h = \frac{2\sqrt{p(p-a)(p-b)(p-c)}}{a} \qquad (1)$$

where h=height=length of [AD], p is the semiperimeter of the triangle ABC, a is the length of [BC], b is the length of [AC], c is the length of [AB]. Further, the arithmetic mean (over all the points) of this distance is compared to a threshold. As it can be seen from the previously mentioned two Figures, in the multipath case most points are visibly further away from the axis than in the single path case. Therefore, the projection height h may be used as an indicator of the multipath presence, and, if it exceeds the threshold, then multipath propagation is declared. Otherwise, we consider the propagation as having a single path.

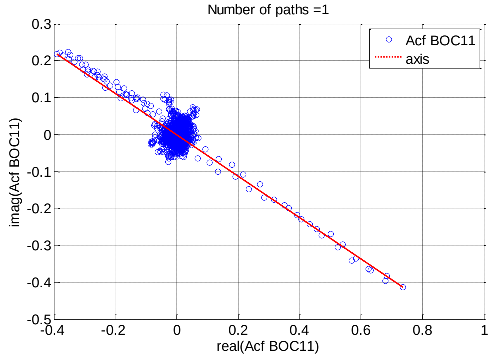

Figure 1: *Scatter diagram for single path (LOS only).*

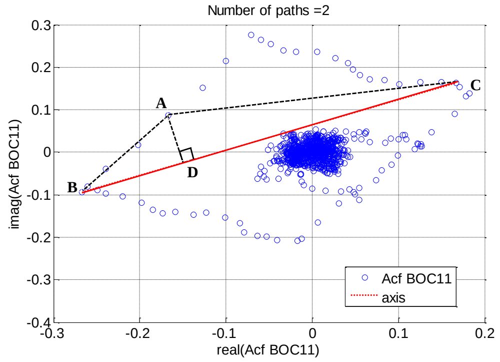

Figure 2: *Scatter diagram for multipath.*

The second method (named as the eigen-value decomposition method) uses as measure (for the scattering of the points) the square root of the ratio of the eigen-values (also known as proper values) of the estimated covariance matrix between the real and imaginary parts of the ACF. The blue ellipses plotted in the Figures 3 and 4 are obtained by using the eigen-vectors and eigen-values and centred on the mean coordinates of the scatter points. It can be noted that visibly more points are contained by the ellipse in the single path case, then in the multipath situation. Therefore, the more 'circular' the ellipse shape is, the more likely it is that we are in a multipath situation. This algorithm also compares the measure against a threshold and declares multipath propagation if it is not exceeded.

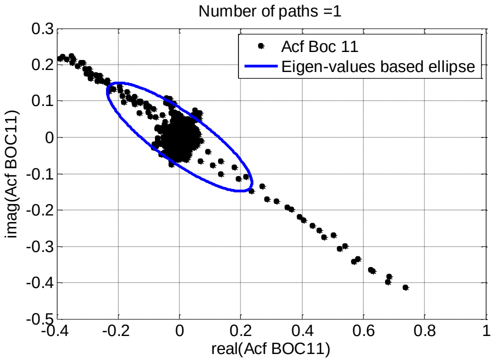

Figure 3: *Scatter diagram for single path (LOS only).*

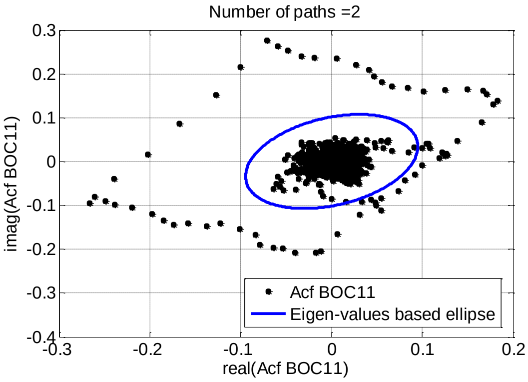

Figure 4: *Scatter diagram for multipath.*

Figures 5 and 6 show the histograms of the measures used in the two detection methods, obtained during initial test simulations for the purpose of calibrating the detection threshold according to particular carrier to noise density ratio C/N_0 conditions. The values of the measures are classified in multipath or single path according to the known propagation conditions modelled by the radio channel (single or multipath). In every case, the threshold was chosen in order to obtain the best detection performances. It is to be noted that a further topic of investigation is to build such a threshold adaptively, without any a priori knowledge about the channel paths. The approach in here is purely theoretical, and meant to illustrate the maximum achievable performances with these methods. Figure 5 illustrates best the behaviour of the projection algorithm: the more scattered the points are, the more increases the mean distance to the axis and thus the probability of a multipath environment. A similar conclusion can be drawn from Figure 6, with the difference that the ratio of the eigen-values increases inverse proportional with the number of propagation paths.

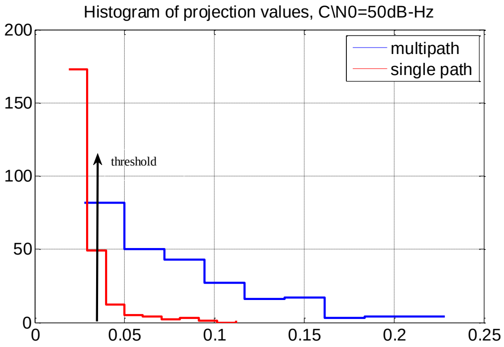

Figure 5: *Histogram of projection values.*

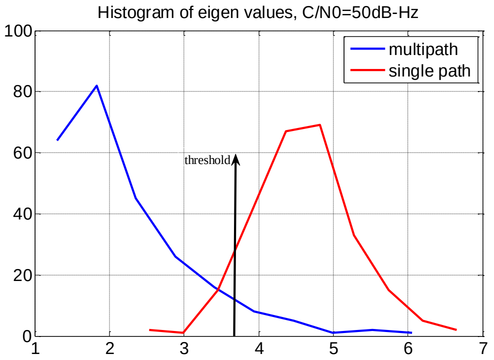

Figure 6: *Histogram based on eigen-values function.*

The variations of the thresholds are shown in Figure 7. We can notice that, while the threshold for the first method decreases with the C/N_0, the threshold for the eigen-values algorithm increases with the C/N_0.

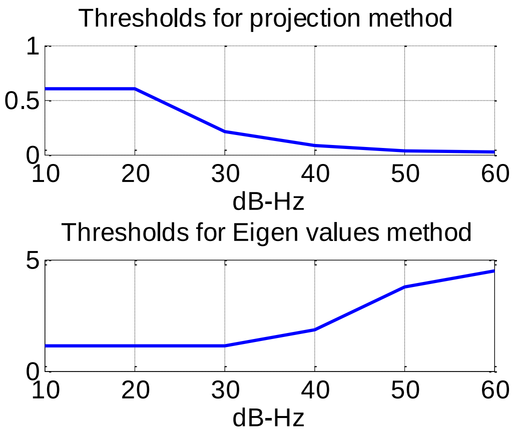

Figure 7: Thresholds used for detection vs. C/N_0.

4. SIMULATION RESULTS

Extended simulations were run using Mathworks Matlab for a C/N_0 covering the [10, 60] dB-Hz interval, with the simulation parameters enumerated in Table 1. No navigation data was used, assuming for example that pilot channels are available for the multipath detection purpose. Before being fed to the correlator, the generated CBOC signal is passed through a radio channel modelled with Additive White Gaussian Noise and with a Doppler effect corresponding to a ground speed of the receiver of 4 km/h. This signal is also affected by multipath, in a controlled manner. The channel paths were uniformly distributed between 1 and 10, with half of the cases set to LOS only, and the other half having between 2 and 10 channel paths, with power decay profile with a coefficient of 0.5 samples.

Parameter	**Value**
Channel model	fading, uncorrelated, Nakagami-m=0.8
Path spacing	min=0, max=0.35 chips
Oversampling factor	48
Filter type	infinite bandwidth (no filtering)
Coherent integration time	16 ms
Noncoh. integration time	1 ms
Initial delay error (coming from acquistion)	0 chips

Table 1: *Values of the simulation parameters.*

The final output of the simulations is represented by the Detection probability P_d and the False Alarm probability P_{fa}. The detection probability is defined as the ratio between the number of correct detections of single paths and the total number of simulated single path propagations. False Alarm probability is expressed by the number of false multipath detections, divided by the total number of simulated single path propagations. The resulting plots of P_d and P_{fa} are displayed in Figures 8 and 9. From the previous bar plots, it can be said that the performances of the multipath detection algorithms degrade with the decrease of the C/N_0 (as expected). Also the eigen-values method proves to be more robust than the projection method, because it maintains a relatively low P_{fa} at lower C/N_0. Both methods seem to be very sensitive to low C/N_0, which signals the fact that, without additional enhancements, they are more suitable to outdoor rural

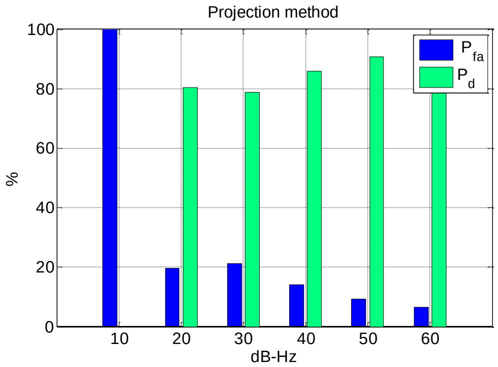

Figure 8: *P_d and P_{fa} (for LOS only detection) vs. C/N_0, projection method.*

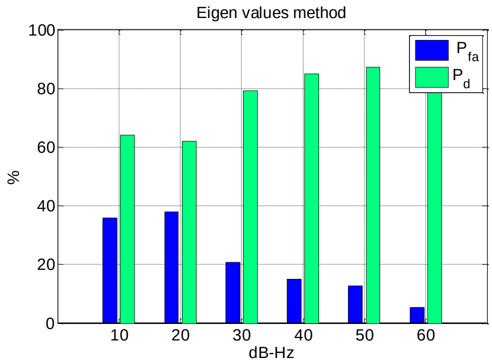

Figure 9: P_d and P_{fa} (for LOS only detection) vs. C/N_0, eigen-values method

situations, and not too suitable to heavy urban areas or indoor propagation.

5. CONCLUSIONS

In this paper we address the issue of multipath detection for a Galileo CBOC navigational signal, using carrier phase investigation approaches. We propose two methods of multipath propagation detection that exploit the properties of the generic patterns encountered in scatter diagrams of the correlation function at the received side. We define two measures of the scatter spread: a low complexity one based on projections, and a second one based on eigen-value decomposition. At high C/N_0, both algorithms present good performance (high P_d and low P_{fa}), but, as the C/N_0 decreases, the eigen-values method (which is more computationally-complex) proves to be more robust that the first technique. Our current results are limited to good C/N_0 situation (outdoor conditions), but we plan to further investigate indoor and urban situations, which are of interest because of their low-to-moderate C/N_0 conditions.

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