MBOC vs BOC(1,1): multipath comparison based on GIOVE-B data

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BIOGRAPHIES

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Wim De Wilde received a M.Sc. in Electrical Engineering from the University of Ghent, Belgium. Upon graduation, he joined the research team at Alcatel Bell. Since 2002 he has worked as an R&D engineer at Septentrio. His area of research includes digital signal processing, multipath mitigation and receiver design.

Dr. Martin Hollreiser works for the ESA Galileo Project where he is responsible for the Ground Mission and Test User Segment development. Since graduation in 1983 his R&D activities have been focusing on integrated CDMA transceiver design, on GPS/GLONASS and Galileo receiver design and on payload signal processing and related VLSI implementation. Martin holds a Master’s and Ph.D. degree in Electrical Engineering. He is a Senior Member of the IEEE and a member of the ION.

Dr. Massimo Crisci has a Ph.D. in Automatics and a Master’s degree in Electronics Engineering. He is working as Radio Navigation and Signal Processing Engineer for ESA (TEC/ETN), part of the Galileo/GIOVE Ground and System Engineering team. His main focus is on the Galileo system design and performance verification activities, and he is part of the ESA team coordinating the GIOVE experimentation. He is currently in charge of the procurement of the PRS and Non-PRS Ground Receiver Chains part of the Ground Mission segment.

ABSTRACT

One of the purposes of the GIOVE-B mission activity is to verify the multipath performance improvement achieved by replacing the Galileo L1BC-BOC(1,1) modulation with MBOC, implemented either as CBOC, a superposition of BOC(1,1) and BOC(6,1), or as TMBOC, a time-division-multiplex of BOC(1,1) and BOC(6,1). This paper contains first experimental results for the multipath performance of both BOC(1,1) and MBOC modulations based on the analysis of live GIOVE-B measurements. The data were collected with the use of the GETR receiver at the Septentrio’s antenna site in Leuven, Belgium. The comparison of the two signals has shown that MBOC outperforms BOC(1,1) by 20-25%. This difference is mainly due to the reduction of high-frequency part of the error (characteristic time less than 10 sec), which consists of tracking noise and long-range multipath. As to the low-frequency short-range multipath (characteristic time greater than

100 sec), the performance of both signals is similar and tends to equalize for characteristic times greater than about 600 sec.

INTRODUCTION

The GIOVE-B satellite, a second experimental Galileo satellite was launched on April 27, 2008 and started the transmission of ranging signals on May 07, 2008. Unlike its predecessor, GIOVE-B is meant to be a real prototype of future Galileo satellites: signal generation and clocks are very close to what shall be used by Galileo. GIOVE-B is transmitting all the foreseen Galileo signals in all frequency bands: L1BC, E1A, E5a, E5b, E6A, and E6BC. Although the transmitter of GIOVE-B is capable of transmitting in all the Galileo frequency bands at a time, at this early phase of the testing the all-frequency transmission has not yet occurred.

One of the main points of attention with GIOVE-B signals is the performance of the new L1-MBOC modulation, an improved alternative to L1-BOC(1,1), an Open Service signal on E1. The L1-BOC(1,1) was foreseen in the initial Galileo signal plan and was transmitted by GIOVE-A, while L1-MBOC was discussed as possible replacement. The analysis of the GIOVE-A data [1-3] has confirmed that the multipath performance of L1BC-BOC(1,1) was the worst among all the Galileo modulations. Due to the evident importance of the E1 signal as basis for all the single-frequency and multi-frequency positioning techniques, green light was given to the implementation and testing of the L1-MBOC on GIOVE-B.

The description of the L1-MBOC signal and the discussion thereof can be found in [4-6]. With the MBOC modulation, the multipath suppression is improved by adding a higher-frequency BOC(6,1) modulation on top of BOC(1,1) either by a way of algebraic addition (CBOC) or by time multiplexing (TMBOC). The discussion in [5, 6] circles around the cost/benefit analysis of the replacement of BOC(1,1) with MBOC. Now, when the actual data is available, the real value of the benefits as well as implementation costs can be appreciated.

In this paper we present the first results for the actual multipath of MBOC and evaluate the improvement relative to BOC(1,1) using the data collected at our antenna site in Leuven. The pseudorange and phase measurements were logged on the GETR receiver connected to a wide-band Space Engineering antenna.

GIOVE-B can transmit three versions of the L1BC signal: BOC(1,1), CBOC, and TMBOC. At the time of this writing only BOC(1,1) and CBOC have been observed. Although our experimental results are based only on the CBOC data, they are also applicable to TMBOC because the multipath performance of both versions of MBOC is expected to be practically identical [4].

MORE DETAILS ABOUT CBOC

According to the general definition, CBOC signals contain about 10% of power in the BOC(6,1) component, which is added to the main BOC(1,1) modulation. This general definition allows for multiple possible implementations. The implementation of CBOC in GIOVE-B (and in future Galileo) can be described as a single modulation with a 4-level spreading symbol shown in Figure 1. The CBOC is the first signal in the GNSS history with this kind of combined modulation, which opens new possibilities for tracking and multipath suppression algorithms.

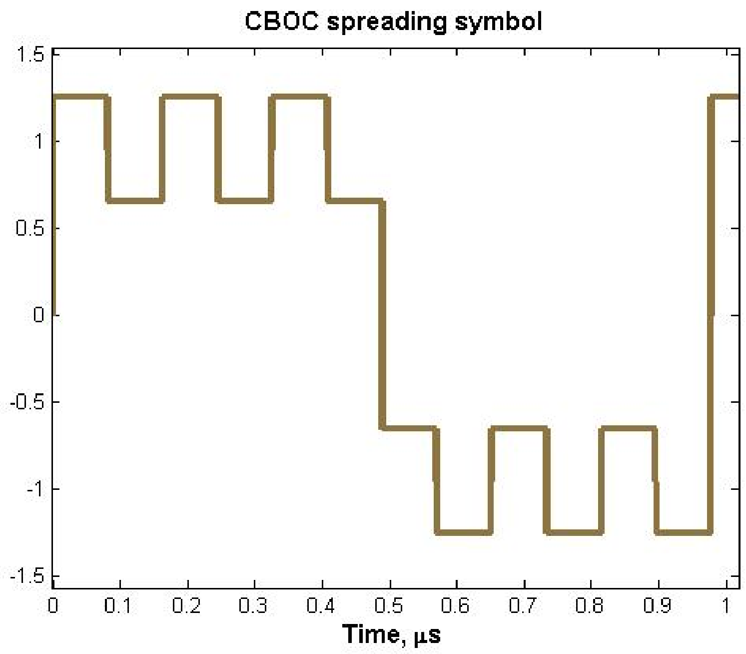

Figure 1. The spreading symbol of CBOC is made by algebraic addition of BOC(1,1) and BOC(6,1) spreading symbols.

Multipath error envelopes for both BOC(1,1) and CBOC are compared in Figure 2. The MBOC modulation clearly reduces multipath errors for delays greater than 25 m. The magnitude of reduction depends upon the spectra of multipath delays for individual antenna sites.

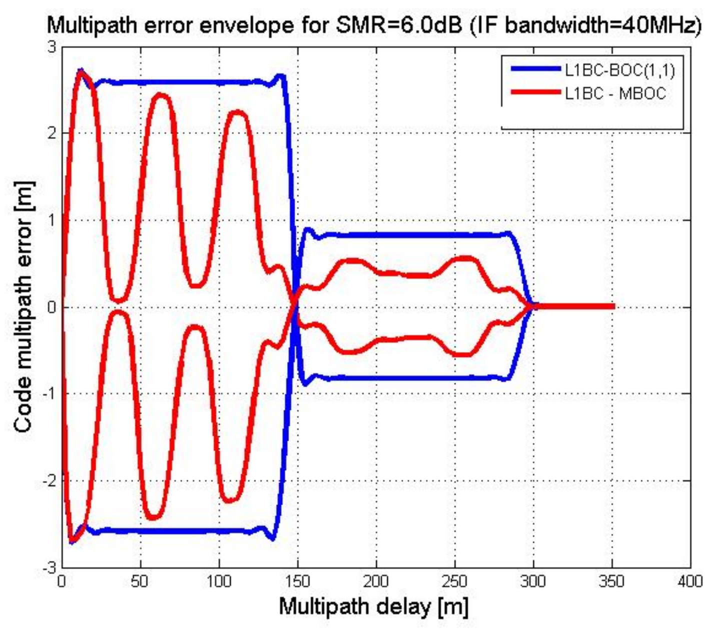

Figure 2. Multipath error envelopes of MBOC versus BOC(1,1) computed at a signal/multipath ratio of 6 dB.

The GETR receiver has the unique ability to track the CBOC in a genuine CBOC mode and also in a legacy BOC(1,1) mode. The GETR can be configured to track the CBOC signal in both modes simultaneously on two different channels. In this way direct simultaneous comparison of BOC(1,1) and CBOC is possible.

The comparison of BOC(1,1) and CBOC multipath was carried out in two ways, which give equivalent results:

a) The BOC(1,1) multipath can be computed for the periods of time when BOC(1,1) is transmitted by GIOVE-B and compared statistically to the CBOC multipath computed for the periods when CBOC is transmitted.
b) The multipath of both CBOC and BOC(1,1) can be estimated based only on the CBOC signal tracked either as CBOC or as BOC(1,1) on two different channels.

Only method (b) allows for direct simultaneous comparison of multipath time series.

CODE MULTIPATH OF CBOC VS BOC(1,1)

The code multipath was computed by using a well-known formula:

$$M_i = P_i - \Phi_i + 2\lambda_i^2 \frac{\Phi_j - \Phi_i}{\lambda_j^2 - \lambda_i^2} \qquad \textbf{(1)}$$

where M_i is the estimate of the code multipath error on a pseudorange P_i, while Φ_i and Φ_j are the carrier phase observables (in units of length) for wavelengths λ_i and λ_j for the same satellite. *j* represents any band which is different than *i*. Formula (1) estimates the sum of multipath and tracking errors, but the multipath component is dominant.

Standard deviations of the multipath errors observed at our Leuven were averaged for 10-degree bins of elevation angles. Results are presented in Figure 4. The multipath errors by CBOC as compared to BOC(1,1) are lower by about 20-25%.

It is also evident that the L1BC-CBOC shows multipath performance comparable to most other Galileo modulations (except for high-performance E5AltBOC). The fact that the improved E1BC signal does not fall out any more from the performance point of view relative to the other signals is a good news for future Galileo users.

Figure 3. Space Engineering antenna mounted on the rooftop of the Septentrio office in Leuven.

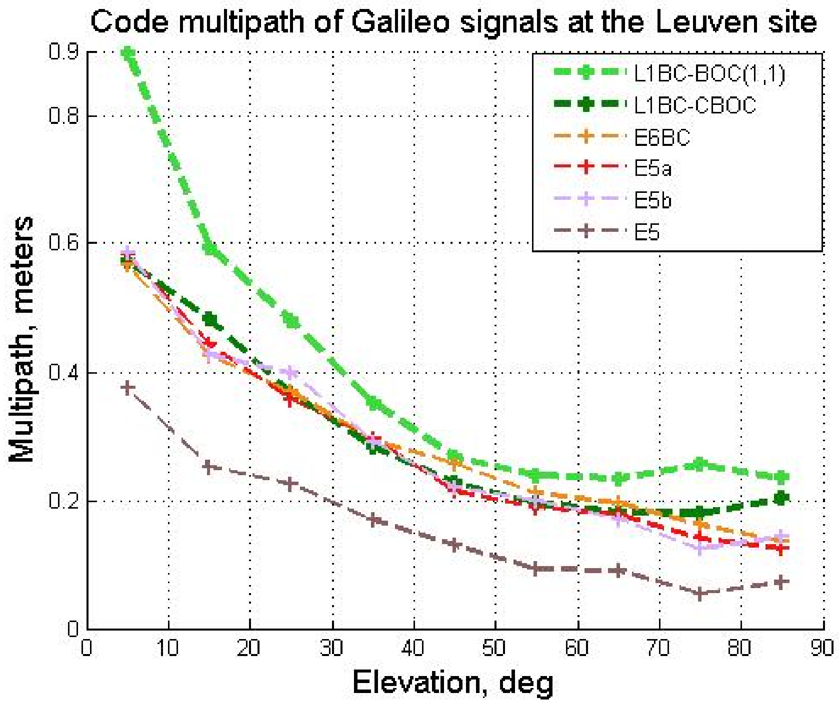

Figure 4. STD of code multipath for Galileo signals transmitted by GIOVE-B. The two thicker lines indicate L1BC modulations: BOC(1,1) and CBOC.

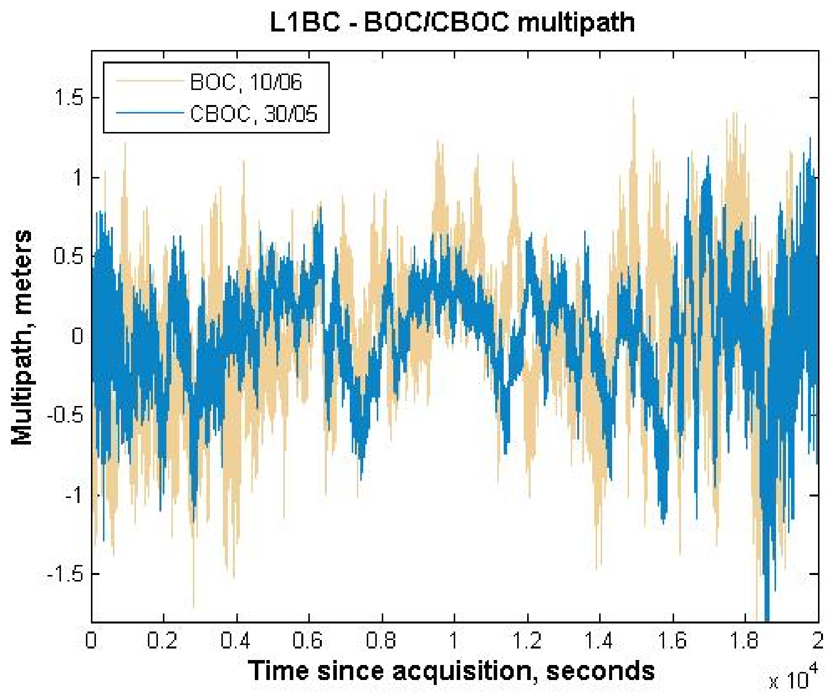

Figure 5. Multipath time series for L1BC for May 23, when BOC(1,1) was transmitted, are compared to June 10, when CBOC was transmitted (comparison by method (a)).

Time series of multipath are compared in Figure 5 by using method (a) and in Figure 6 by using method (b). The lower amplitudes of CBOC multipath errors compared to BOC(1,1) are quite visible.

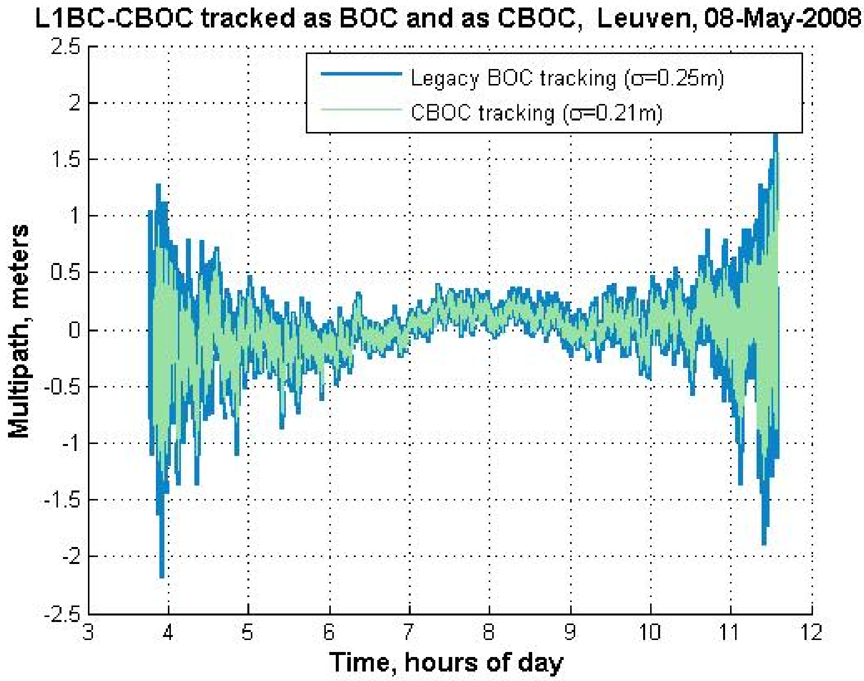

Figure 6. Simultaneous multipath time series of BOC(1,1) (blue) and CBOC (green) obtained by the tracking of CBOC in two modes (comparison method (b)).

The reduction of range errors with the CBOC relative to BOC(1,1) occurs in the tracking noise and the high-frequency multipath component, which is due to long-range multipath and is dominant at low elevations. The slowly changing component, which is due to the short-range multipath and is visible at high elevations, is practically the same for both modulations. This can be directly observed in Figure 6. More elaborate data processing, which was performed at the ESA based on the data from multiple GESS stations, allowed to quantify the frequency content of the range errors. The left side of Figure 7 shows the ratio between the errors of CBOC and BOC(1,1) as a function of the elevation angle for different values of filtering window. The ratio clearly tends to 0 with longer filtering. The plot on the right side of Figure 7 directly shows that for filtering windows longer than 600 seconds the performance of both signals is equivalent.

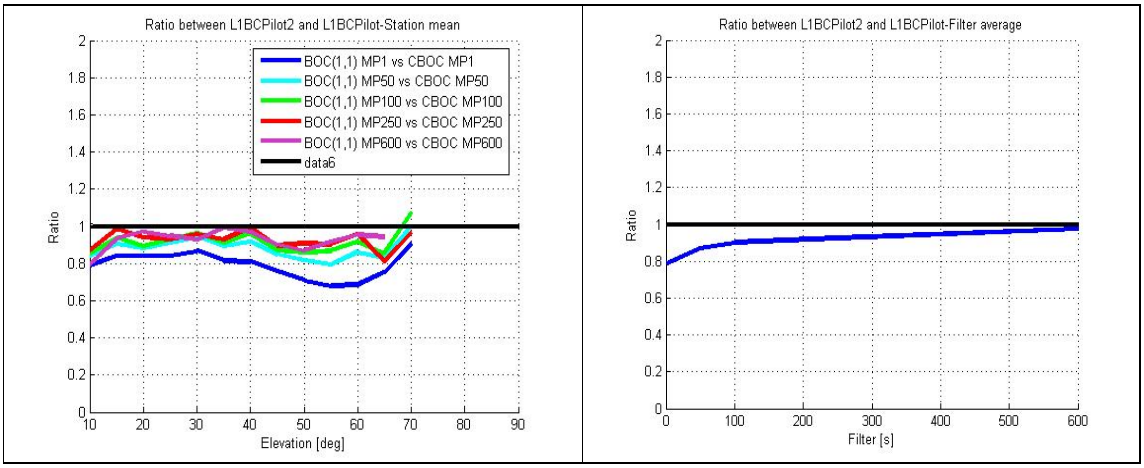

Figure 7. Left side: ratio of the range error STD ratio of CBOC/BOC(1,1) as a function of the elevation angle for various filtering windows (1,50,100,250, 600s). Right side: total standard deviation as a function of the filtering window.

CONCLUSIONS

Field experience with GIOVE-B signals tracked by the GETR receiver has confirmed the advantage of the MBOC modulation compared to BOC(1,1). At the Leuven antenna site the average multipath errors of MBOC were about 20-25% lower than with BOC(1,1). The multipath level of MBOC appears to be of the same order of magnitude as with most other Galileo signals. In this paper only static data have been discussed.

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