GPS L2C Signal Quality Analysis

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BIOGRAPHIES

Liliána Sükeová is an M.Sc.E student in the Department of Geodesy and Geomatics Engineering, University of New Brunswick. She graduated from the Slovak Technical University, Bratislava in 2005.

Marcelo Santos is an associate professor in the Department of Geodesy and Geomatics Engineering at UNB. He holds a M. Sc. in geophysics from the National Observatory in Rio de Janeiro, and a Ph.D. in geodesy from UNB. He has been involved in research in the fields of space and physical geodesy, GNSS, and navigation. Dr. Santos is currently the president of the Geodesy Section of the Canadian Geophysical Union and chair of the International Association of Geodesy Working Group on the use of Numerical Weather Models for Positioning.

Richard Langley is a professor in the Department of Geodesy and Geomatics Engineering at the University of New Brunswick in Fredericton, Canada, where he has been teaching and managing research since 1981. He has a B.Sc. in applied physics from the University of Waterloo and a Ph.D. in experimental space science from York University, Toronto. Professor Langley has been active in the development of GPS error models since the early 1980s and is a contributing editor and columnist for GPS World magazine. He is a fellow of The Institute of Navigation (ION) and was a co-recipient of the ION Burka Award for 2003. He is also a fellow of the International Association of Geodesy and an associate fellow of the Royal Institute of Navigation.

Rodrigo Leandro is a Ph.D. candidate of the Department of Geodesy and Geomatics Engineering, University of New Brunswick (UNB), Canada, where he has been a student since 2004. Mr. Leandro is also a research and development engineer of Trimble Terrasat, Germany. He holds an M.Sc.Eng. in civil engineering from the University of São Paulo, in São Paulo, Brazil, and has been involved in research in the fields of geodesy and satellite positioning. Mr. Leandro has received a best student paper award from the Canadian Geophysical Union and a student paper award from The Institute of Navigation, both in 2004. In 2006 Mr. Leandro has also received a best presentation award from The Institute of Navigation.

Okwuchi Nnani is an M.Eng student in the Department of Geodesy and Geomatics Engineering at the University of New Brunswick. He received a B.Sc degree in Surveying, Geodesy and Photogrammetry in 1992 from the University of Nigeria, Nsukka. He has over 13 years work experience as a surveyor in Nigeria and Jamaica. He is currently working under Marcelo C. Santos

Felipe Nievinski is an M.Sc.E student and research assistant in the Dept. of Geodesy and Geomatics Engineering, University of New Brunswick. At the end of 2004 he received his degree in geomatics engineering from the Federal University of Rio Grande do Sul, Brazil. He is a member of The Institute of Navigation, the American Geophysical Union, and the Society for Industrial and Applied Mathematics.

ABSTRACT

A new generation of Global Positioning System (GPS) satellites, called Block IIR-M, has been launched since December of 2005. These satellites are part of the modernization effort that the GPS is undergoing. The signals transmitted by these satellites contain a new civilian code superimposed on the L2 carrier, called the L2C code. Research into the characteristics of the L2C code is based on an International GNSS Service (IGS) L2C dedicated Test Network. This network is composed of both existing stations as well as newly established ones with receivers capable of tracking the L2C signal. The IGS L2C Test Network is composed only of Trimble receivers.

The University of New Brunswick (UNB), Fredericton Campus, Department of Geodesy and Geomatics Engineering (GGE), obtained a Trimble R7 and a Trimble NetR5 receiver on loan from Cansel, a Canadian distributor of Trimble products. Both receivers are capable of tracking the L2C code. The Trimble R7 receiver was collocated with IGS station UNB1 (now station UNBJ), sharing the same antenna, and has become a part of the L2C signal tracking network since January 2006. From November 2006 we have replaced the R7 receiver by the NetR5.

This paper presents results of our analysis on the L2C data collected by the L2C Test Network. Our

investigation starts with an examination of the signal-to-noise ratio (SNR) on the L1 and L2 frequencies. The range of the SRN values on the L1 frequency is similar for all satellites, whilst the range of the SRN on the L2 frequency for the three modernized satellites is higher than those for all other satellites. This indicates an improvement in the SNR of the L2C signal over the P(Y) code. It follows with a study on the multipath and noise levels of C/A and L2C code pseudorange for PRN 17 in the Trimble R7 receiver. These values were calculated and compared. A typical standard deviation of the C/A and L2C code noise and multipath is 0.27 m and 0.61 m, respectively. The difference between the standard deviations is caused by issues in the firmware versions 2.26 and 2.28, which were used in the Trimble R7 receiver during the observation period.

Further, we have analyzed the C/A and L2C code multipath and noise levels based on the L2C global Test Network. We chose four stations (FAIC, UNAC, UNB3 and GANP) to be used in this analysis The first two stations use a Trimble NetRS receiver; while the last two stations use a Trimble NetR5 receiver

Standard deviations of multipath and noise values were computed over the entire 24-day period and each day separately for each elevation angle bin, each modernized satellite, each four stations and code (C/A and L2C).

After examining the results from the stations using Trimble NetR5 receiver we realized that the standard deviations of the C/A and L2C codes were similar in the case of all modernized satellites. However, stations using Trimble NetRS receiver had higher standard deviations for the L2C code then for the C/A code. This can be also explained by the firmware versions used in the receivers.

INTRODUCTION

The United States has started an extensive modernization program to provide better service to Global Positioning System (GPS) users. This modernization program includes the launching of modernized GPS satellites. The first block of these new satellites is called Block IIR-M, where “R” stands for replenishment and “M” for modernized. In this modernization process, GPS has gained a new open civil signal (called L2C), centered on the L2 frequency. Currently there are three fully operational modernized satellites in orbit broadcasting the L2C signal (Sükeová et al., 2007).

The first modernized satellite, PRN17, was launched on 25 September 2005 and the new L2C signal was made fully available from 15 December 2005. The second Block IIR-M satellite, PRN31, was launched on 25 September 2006 and became fully operational from 12 October 2006. PRN12 was launched on 17 November 2006 and was set healthy on 12 December 2006.

The third frequency band L5 (centered at 1176.55 MHz) will arrive with the Block IIF (“F” for follow-on) satellites, now scheduled to start to be launched in 2008 or 2009.

From the time PRN17 was placed in orbit, the L2C signal became an issue of worldwide interest to the GPS research community. Receivers capable of tracking the modernized L2C signal have been developed and provided by a number of manufacturers, such as Trimble, NovAtel, Septentrio, Leica and Topcon. The International GNSS Service (IGS) has organized a network of L2C signal tracking stations, hereinafter referred to as L2C Test Network which has been established in different places in the world.

Cansel, the Canadian distributor of Trimble Navigation Ltd products provided to us on loan a Trimble R7 and a Trimble NetR5 receiver, both capable of tracking the L2C signal. The Trimble R7 receiver was connected to the same antenna used by IGS station UNB1 (now UNBJ) and became part of the L2C Test Network in January 2006. This receiver was later replaced by the Trimble NetR5 receiver.

The main objective of the investigation reported in this paper is to analyze the L2C signal, which is currently transmitted by modernized IIR–M satellites. This includes an analysis of the signal-to-noise ratios and of the multipath and noise level of the observations. Other objectives of the investigation are to maintain an L2C-capable station using Trimble R7, Trimble NetR5, or other receivers and to test the receivers’ firmware versions in terms of L2C signal tracking capabilities.

This paper uses as a reference work a paper published by Simsky [2006]. Simsky compares the tracking noise and multipath characteristics of L2C and C/A codes tracked by a PolarRx2C receiver. His results were in agreemnet with the expections; that is, avarage amplitudes of multipath and tracking noise for the C/A code and L2C were found to be about equal.

DATA COLLECTION AT UNB

The major focus of this paper is on the L2C signal analysis involving the global Test Network of L2C tracking stations. It also includes a description of the L2C data collection using the Trimble R7 receiver, as follows.

After initial testing procedures the Trimble R7 receiver was connected to the same antenna used by former IGS station UNB1 (currently UNBJ), by means of an antenna splitter. The Trimble R7 was in operation from 11 January

2006 to 10 October 2006. It was replaced by the Trimble NetR5, which was installed on 2 November 2006 and has been operational to date (4 May 2007). The Trimble R7 station was called UNB3 and became one of the L2C Test Network stations. The same name (UNB3) remained for Trimble NetR5 as well.

The UNB3 RINEX files for Trimble R7 contain the following observables: C1, C2, P2, L1, L2, S1 and S2. C1 stands for C/A code, C2 for L2C code, P2 for P2(Y) code measurements, L1 and L2 for carrier-phase measurements on the L1 and L2 frequencies, respectively, and S1 and S2 are the signal-to-noise ratio (SNR), for each satellite (Sükeová et al., 2007).

Because RINEX 2.1 format didn't have an observable code for L2C, a new observable column was introduced to accommodate L2C observations (C2's column) in version 2.11.This column is populated only for IIR-M satellites (such as PRN17, PRN 31 and PRN 12), and there are no P2 observations for these satellites if the receiver is not able of tracking simultaneous P2 and C2 (such as NetRS and R7 receivers using the firmware currently available). In case of NetR5 receivers, both columns might be populated for IIR-M satellites. In the case of satellites of other blocks, C2 column remains empty and P2 column is filled with P2 code observations

As said before, the Trimble R7 receiver was replaced by the Trimble NetR5. One of the advantages of Trimble NetR5 over Trimble R7 is that both P2 and C2 measurements are tracked simultaneously for the modernized satellites, therefore P2 code observations are available in addition to the L2C measurements.

L2C TEST NEWORK

The L2C Test Network (as of 22 December 2006) is illustrated in Figure 1. The date was chosen in order to show all of the stations involved in the L2C Test Network at the time of the data collection for this investigation. Table 1 summarizes the receiver and antenna types used at each station.

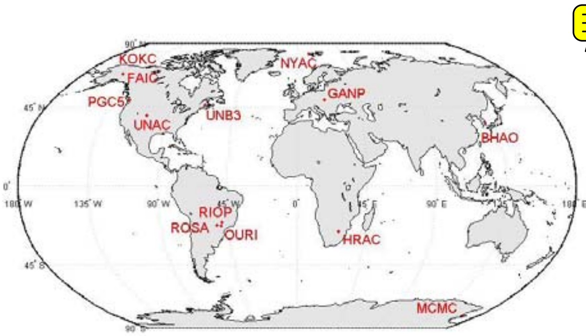

Figure 1 L2C tracking Test Network

Table 1 Receiver and antenna types used in the L2C tracking Test Network

Station name	Receiver Type	Antenna type
FAIC	Trimble NetRS	TRM29659.00
HRAC	Trimble NetRS	TRM29659.00
KOKC	Trimble NetRS	TRM29659.00
MCMC	Trimble NetRS	AOAD/M_T
NYAC	Trimble NetRS	AOAD/M_B
PGC5	Trimble NetRS	TRM29659.00
UNAC	Trimble NetRS	TRM29659.00
UNB3	Trimble NetR5	JPSREGANT_DD_E
GANP	Trimble NetR5	TRM55971.00
BHAO	Trimble NetRS	TRM29659.00
OURI	Trimble NetRS	TRM41249.00
RIOP	Trimble NetRS	TRM41249.00
ROSA	Trimble NetRS	TRM41249.00

L2C Test network contributors have uploaded daily and hourly compact RINEX files containing the L2C measurements at 30 seconds sampling rate to the ftp server of the Crustal Dynamics Data Information System (CDDIS) at NASA's Goddard Space Flight Center. Data from all stations in the IGS L2C Test Network can be found at: ftp://cddis.gsfc.nasa.gov/gps/data/l2ctest/hourly/2007/ and ftp://cddis.gsfc.nasa.gov/gps/data/l2ctest/daily/2007/.

In this paper a one-day observation file was analyzed for station UNB3 (Trimble R7) on day 16 January 2006. Data from 1 December 2006 to 24 December 2006 was analyzed for stations UNB3 and GANP (Trimble NetR5) and for stations FAIC and UNAC (Trimble NetRS).

METHODOLOGY

The objective of this section is to show the calculation method of the C/A and L2C code multipath and noise level.

A pseudo-observable which contains only receiver noise and multipath effects was created by differencing the raw pseudorange measurement, given by equation (1), and the raw carrier-phase measurement, given by equation (2), both of them with their ionospheric delay removed. This procedure follows the steps given by Langley [1998]. This section will explain how to remove the ionospheric delay from the raw carrier-phase and pseudorange observations, and how to obtain the code noise plus multipath pseudo-observable.

At first, we will look at the pseudorange and carrier-phase measurement simplified equations, which are both expressed in length units:

$$p_i = \rho + c(dT - dt) + d_{ion\,i} + d_{trop} + mp_{p_i} + \varepsilon_{p_i}, \qquad (1)$$

where i stands for the L1 or L2 frequency, p_i is the measured pseudorange on the L1 or L2 frequency, ρ is the geometric distance between the receiver and satellite antennas, dT and dt represent the receiver and satellite clock offsets relative to GPS Time (GPST), respectively, $d_{ion\,i}$ and d_{trop} are the ionospheric and tropospheric propagation delays, respectively, mp_{p_i} represents the effect of multipath and ε_{p_i} the noise term.

The carrier-phase measurement equation reads:

$$\Phi_i = \rho + c(dT - dt) + \lambda_i N_i - d_{ion\,i} + d_{trop} + mp_{\Phi_i} + \varepsilon_{\Phi_i}, \quad (2)$$

where λ_i is the carrier wave length and N_i represents the carrier-phase ambiguity. The other terms in the carrier-phase observations equation stand for the same effects as in the pseudorange observation explained above. Other terms such as satellite and receiver hardware delays have been ignored.

The ionospheric delays on the two different frequencies can be related as follows:

$$d_{ion_2} = d_{ion_1} \frac{f_1^2}{f_2^2} \quad (3)$$

where f_1 and f_2 are the carrier frequencies on L1 and L2. By forming the difference between the carrier-phase measurements on L1 and L2, the ionospheric delay on L1 can be computed with an additive constant (mainly caused by carrier-phase ambiguities) and with multipath and noise contributions as:

$$\Phi_2 - \Phi_1 = d_{ion_1} - d_{ion_2} + \lambda_2 N_2 - \lambda_1 N_1 + mp_{\Phi_2} - mp_{\Phi_1} + \varepsilon_{\Phi_2} - \varepsilon_{\Phi_1}. \quad (4)$$

Solving for d_{ion_1} gives:

$$d_{ion_1} = \left(\frac{f_2^2}{f_1^2 - f_2^2}\right)\begin{pmatrix}\Phi_1 - \Phi_2 + \lambda_2 N_2 - \lambda_1 N_1 \\ + mp_{\Phi_2} - mp_{\Phi_1} + \varepsilon_{\Phi_2} - \varepsilon_{\Phi_1}\end{pmatrix}. \quad (5)$$

The measure of the L1 ionospheric delay could be used to correct both code and carrier-phase measurements, if we knew the carrier-phase multipath, the noise values and the integer ambiguities. At best, we can compute a relative ionospheric delay d^* which includes a constant contribution from the integer carrier-phase ambiguities, the multipath and noise terms (Langley, 1998):

$$d^*_{ion_1} = \left(\frac{f_2^2}{f_1^2 - f_2^2}\right)(\Phi_1 - \Phi_2). \quad (6)$$

Although the estimate of the ionospheric delay from carrier-phase measurements is biased by the ambiguities, when we use it to correct carrier-phase and pseudorange observations (by removing the relative ionospheric delay from both measurements) and difference the result we get (Langley, 1998):

$$\left[p_1 - \left(\frac{f_2^2}{f_1^2 - f_2^2}\right)(\Phi_1 - \Phi_2)\right] - \left[\Phi_1 + \left(\frac{f_2^2}{f_1^2 - f_2^2}\right)(\Phi_1 - \Phi_2)\right] = p_1 - \left(\frac{f_1^2 + f_2^2}{f_1^2 - f_2^2}\right)\Phi_1 + \left(\frac{2 f_2^2}{f_1^2 - f_2^2}\right)\Phi_2. \quad (7)$$

If we assume, that the geometric distance, ρ, the receiver clock offset dT; and the satellite clock offset, dt, are the same for L1 and L2 carrier phase and pseudorange measurements, we arrive at the following equation:

$$p_1 - \left(\frac{f_1^2 + f_2^2}{f_1^2 - f_2^2}\right)\Phi_1 + \left(\frac{2f_2^2}{f_1^2 - f_2^2}\right)\Phi_2 = mp_{p_1} + noise_{p_1} - \left(\frac{f_1^2 + f_2^2}{f_1^2 - f_2^2}\right)(\lambda_1 N_1 + mp_{\Phi_1} + noise_{\Phi_1}) + \left(\frac{2f_2^2}{f_1^2 - f_2^2}\right)(\lambda_2 N_2 + mp_{\Phi_2} + noise_{\Phi_2}). \quad (8)$$

The right-hand side of the equation (8) contains the pseudorange and carrier-phase multipath and noise and the ambiguity term. Since the carrier-phase measurement multipath and noise is insignificant in comparison with code multipath and noise, the right-hand side of the equation (8) gives the multipath and noise of the code measurement, offset by a constant component due to the carrier-phase ambiguities. Terms such as satellite and receiver hardware delays have been absorbed by the ambiguity parameters.

RESULTS AND THEIR ANALYSIS

In this section the results are presented and analyzed. We start with the signal-to-noise ratio values (SNR) as directly provided by the receivers. Following we make use of equation (8) to compute multipath and noise from Trimble R7, NetR5 and NetRS receivers' data.

Signal-to-noise Ratio

An attempt to gain a better understanding of the SNR of the new signal as compared to the legacy signal was done. SNR values on the L1 and L2 frequencies for all satellites are illustrated in Figures 2 and 3, respectively. The values refer to day: 17 December 2006 for station MCMC. The date and the station were chosen randomly as the SNR values could be taken from any other station at any other date in the L2C tracking Test Network.

The range of the SNR values on the L1 frequency (Figure 2) is approximately from 23.75 to 50.25 dB-Hz for all satellites. The range of the SRN values on the L2 frequency (Figure 3) is approximately 12.5 to 49 dB-Hz for all satellites except the three modernized satellites: PRN 17, PRN 31 and PRN 12. By comparing the SNR levels on each frequency we can see that the SNR of the modernized satellites on L2 are higher than those for all other legacy satellites, reaching similar values of the SNR on the L1 frequency. This indicates an improvement of L2C signal's SNR over the L2 P(Y) code.

Table 2 summarizes the minimum and maximum elevation angles for satellites PRN 17, PRN 31 and PRN 12, the maximum SNR values on both frequencies and the time when the maximum value occurred.

Table 2 Summary of the maximum SNR values and elevation angles for PRN 17, PRN 31 and PRN 12

Sat.	Max. SNR on L1 (dB-Hz)	Max. SNR on L2 (dB-Hz)	Max. SNR occurred appr. at:	Elevation angle min. – max. (deg)
PRN17	50	52.75	12h 38m	1.26 – 59.20
PRN31	49	51.50	3h 12m	0.20 – 56.25
PRN12	49.25	51.25	14h 20m	1.31 – 52.76

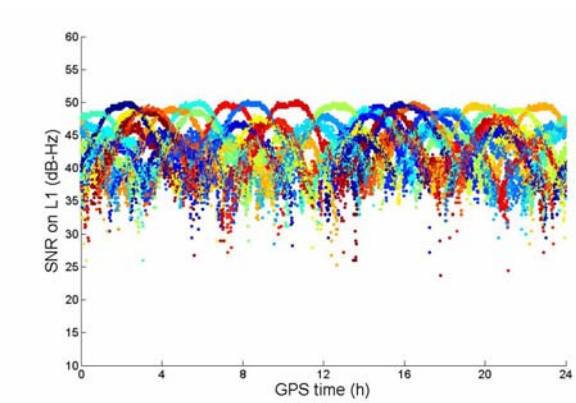

Figure 2 Signal-to-noise ratio on L1

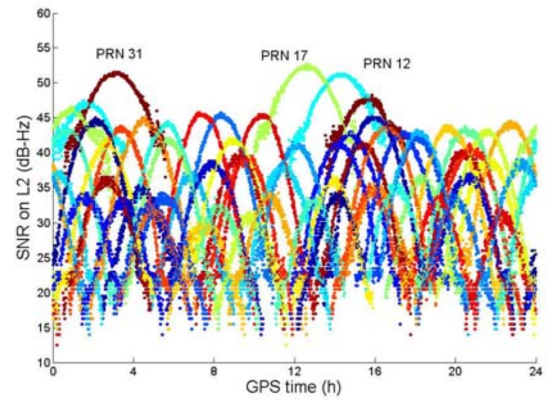

Figure 3 Signal-to-noise ratio on L2

Code multipath and noise level analysis using a Trimble R7 receiver

In this sub-section the multipath and noise level of C/A and L2C codes for PRN 17 and PRN 11 are analyzed using the Trimble R7 receiver. The noise plus multipath values referred to frequencies L1 and L2 were computed using the approach described above, equations (1) to (8).

In order to better illustrate the noise level and the multipath, the mean of the computed values was removed. As the computed results were biased by the carrier-phase ambiguities, sections between each cycle-slip were identified during the implementation procedure and the mean value corresponding to each section was removed.

Multipath and noise values with their mean removed for C/A code as of 16 January 2006 are illustrated in Figures 4 and 6 for PRN 17 and PRN 11, respectively.

From equation (8) the multipath and noise of the L2C and P2 codes can be derived by taking into account that the ionospheric delay on L2 is different from that on L1 (see equation (3)). The resulting multipath and noise levels for L2C (PRN 17) and P2 codes (PRN 11) are illustrated in Figures 5 and 7, respectively, with their mean value removed. The standard deviations of C/A, L2C and P2 code multipath and noise levels are summarized in Table 3. The maximum elevation angles of PRN 17 and PRN 11 are 80 and 70 degrees, respectively.

Table 3 suggests that the C/A-code multipath and noise level of PRN 17 is slightly smaller than for PRN 11. This difference is expected because PRN 17 is observed at slightly higher elevation angles compared to PRN 11. Even though one might expect to see also smaller noise levels for L2C from PRN 17 compared to P2 from PRN 11, it can be noticed that the L2C noise level for PRN 17 is actually higher than for P2, as observed for PRN 11. The causes of this behavior are discussed next.

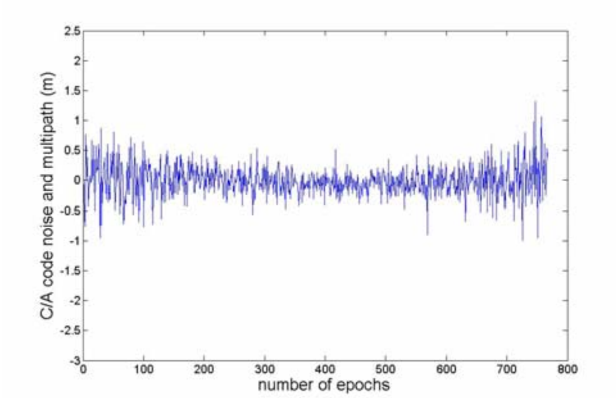

Figure 4 Noise and multipath level of C/A code, PRN 17

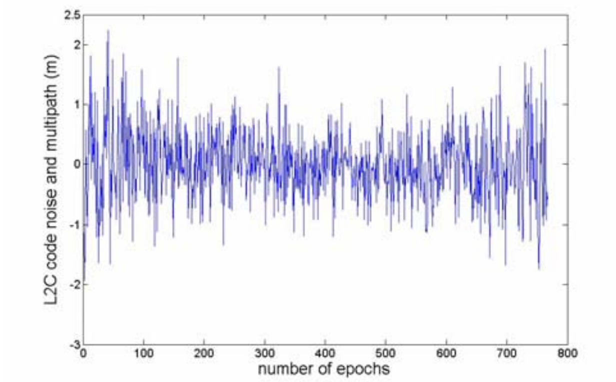

Figure 5 Noise and multipath level of L2C, PRN 17

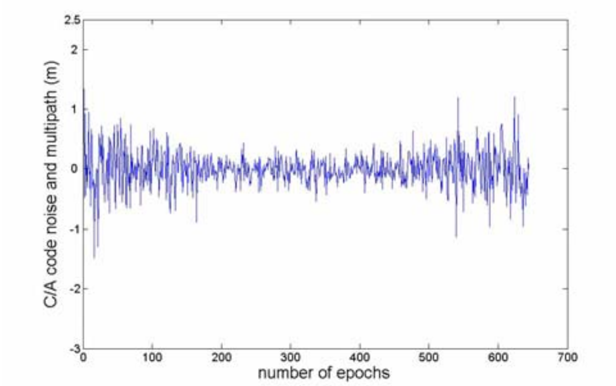

Figure 6 Noise and multipath level of C/A, PRN 11

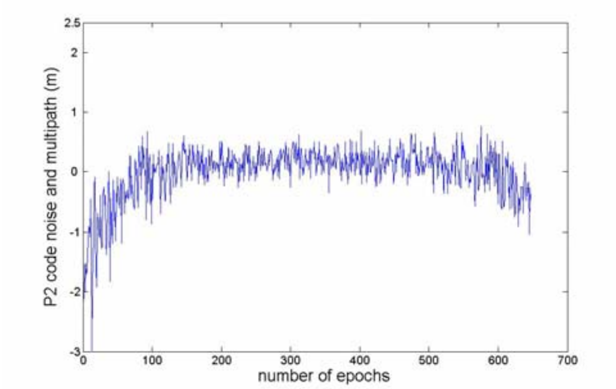

Figure 7 Noise and multipath level of P2, PRN 11

Table 3 Standard deviations noise and multipath for PRN 17 and PRN 11

	PRN 17		PRN 11	
	L2C	C/A	P2	C/A
Standard deviation (m)	0.611	0.270	0.438	0.315

The L2C code has a chipping rate of 1.023MHz. For noise and multipath performances, the L2C code behaves similarly to a BPSK modulation at 1.023MHz. This means, that the same level of noise and multipath is expected on C/A and L2C (Simsky et al., 2006).

Our results show a contrast with this expectation as the standard deviation of the noise level of L2C signal is 0.611 m, while it is 0.270 m for the C/A code. Therefore, according to our results, the noise level of the L2C code is higher than the noise of the C/A code. Why is there a contrast between the expected multipath and noise level and the obtained results? An explanation for the higher noise and multipath on the L2C code is found in the firmware of the Trimble R7 receiver used during the data collection (v. 2.26 and v. 2.28), since Everest (Trimble's multipath mitigation algorithm) was not enabled for L2C tracking. As pointed out by Mallen [2007] there were also some residual tracking issues which slightly increased the noise on the L2C observable. The differences seen in noise level therefore came mainly from the different treatment given to the observations, rather than purely signal quality. Both issues were fixed in Trimble R7 firmware version 2.30 which was released on 21 September 2006 (Sükeová et al., 2007).

If we compare Figure 4 to 6, and Figures 5 and 7 we can see that the P2 code performance at low elevation angles on the multipath and noise is different from that of the other codes. This trend can be explained by firmware issues which, according to the manufacturer, have been fixed in v.2.30 (Mallen, 2007). This trend also causes the higher standard deviation of 0.438m on P2 code.

Code multipath and noise level analysis based on the L2C global Test Network

Four stations have been chosen from the global L2C Test Network to be used in this analysis. They are stations FAIC, UNAC, UNB3 and GANP (see Figure 1). The first two stations use a Trimble NetRS receiver; while the last two stations use a Trimble NetR5 receiver (see Table 1). Similar analysis as with the Trimble R7 receiver has been done for the chosen four stations. The objectives of this investigation are to analyze the L2C code quality, to test the receivers' firmware versions in order to demonstrate that Trimble's multipath mitigation algorithm (Everest) is enabled on both L1 and L2 frequencies and how Everest influences the resulting multipath and noise values.

As many as 24 days of data have been analyzed for the four stations from 1 December 2006 until 24 December 2006. Multipath and noise values for each observation have been computed using the methodology described above.

The standard deviations of multipath and noise values have been calculated for each of:

- 10-degree elevation angle bins, from 0 to 90 degrees (9 bins);
- the four stations from the global L2C Test Network (FAIC, UNAC, UNB3 and GANP);
- the modernized satellites; and
- C/A and L2C codes

in two ways:

- for each day separately (i); and
- for the entire 24-days period as a whole (ii).

In Tables 4 to 7 we give the standard deviations for the entire 24-days period (ii) for a particular station (UNB3, GANP, FAIC or UNAC), for all modernized satellites (PRN17, PRN31 and PRN12), each elevation angle bin and each code (C/A and L2C). The empty blocks in Tables 4 to 7 indicate that for those elevation angle bins there were no observations for the particular satellite.

Figures 8 to 13 illustrate the standard deviations representing the entire 24-days period (ii) for each one of to the elevation angle bins as dots. The standard deviation of (i) is represented by an error bar superimposed on each standard deviation and expanded twice its initial magnitude.

Each figure represents the solution for two stations grouped according to the receiver type, a particular satellite (PRN17, PRN31 or PRN12) and each code (C/A and L2C). The vertical axis stands for the standard deviation in meters for C/A or L2C code and the horizontal axis represents the lower limit of the elevation angle bin (i.e. 0 stands for the elevation angle interval from 0 to 10 degrees, 10 represents the bin from 10 – 20 degrees, etc.).

We would like to call the attention to the fact that the standard deviations decrease with the increase in elevation angle, and also that the standard deviations for C/A and L2C are similar for those stations using NetR5 (UNB3, GANP) but different for those using NetRS (FAIC, UNAC).

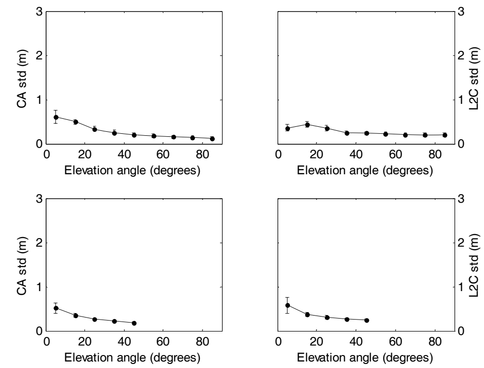

Figure 8 C/A and L2C code multipath and noise standard deviation, PRN 17, stations UNB3 (top) and GANP (bottom)

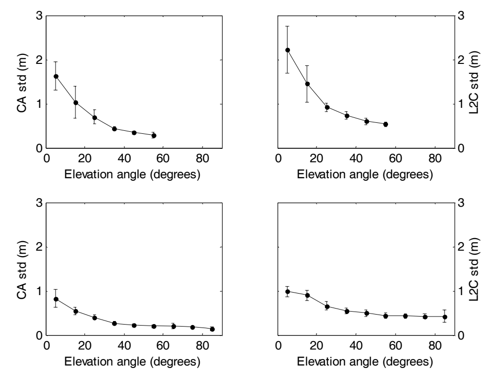

Figure 9 C/A and L2C code multipath and noise standard deviation, PRN 17, stations FAIC (top) and UNAC (bottom)

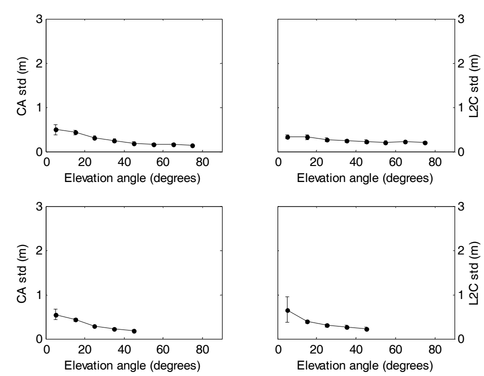

Figure 10 C/A and L2C code multipath and noise standard deviation, PRN 31, stations UNB3 (top) and GANP (bottom)

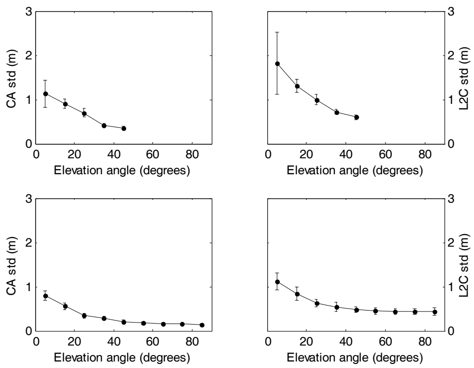

Figure 11 C/A and L2C code multipath and noise standard deviation, PRN 31, stations FAIC (top) and UNAC (bottom)

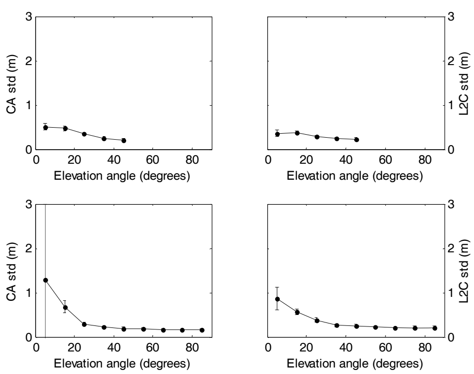

Figure 12 C/A and L2C code multipath and noise standard deviation, PRN 12, stations UNB3 (top) and GANP (bottom)

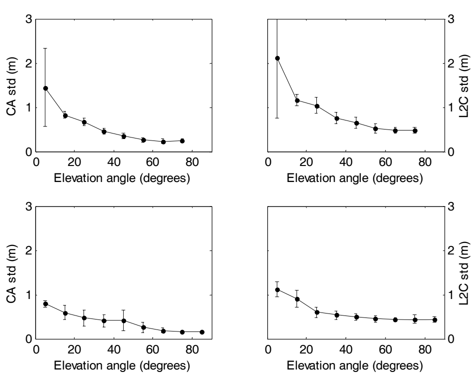

Figure 13 C/A and L2C code multipath and noise standard deviation, PRN 12, stations FAIC (top) and UNAC (bottom)

From Figures 8 to 13 we corroborate the elevation angle dependence of the standard deviations, i.e. at low elevation angle intervals the variance is higher than at higher elevation angle bins, as expected.

In most of the cases the error bars at the first elevation angle bin are higher than for the other bins seen in Tables 4 to 7. This can be explained by the fact that a particular satellite has not been tracked under the same initial elevation angle each day during the 24-day period. Therefore when the satellite was tracked in higher initial elevation angle, the resulting standard deviation (i) for that particular day was determined from a smaller number of observations. Also at lower elevation angles the satellite's speed is higher with respect to the receiver's position; therefore less data can be collected in a 0-10 degrees elevation bin in comparison with the other elevation angle bins within a day. This explains the higher error bars in the first elevation angle bin.

Another issue of our particular interest which has been investigated in this project is the Trimble's Multipath Mitigation Algorithm. As mentioned before the same multipath and noise level is expected on C/A and L2C. From our previous analysis with the Trimble R7 receiver we concluded, that the expected results have not been reached because Everest was not enabled on the L2 frequency.

To further analyze if Everest is enabled on both frequencies for both types of receivers used in the L2C tracking Test Network the same four stations have been used.

Let us examine first the Trimble NetR5 receiver (stations UNB3 and GANP). From Tables 4 to 7 we can see that the standard deviations for stations GANP and UNB3 have similar values on the L1 and L2 frequencies for all satellites (expect the first elevation angle bin, which has been explained above). This demonstrates that the Everest is enabled on both frequencies.

On the other hand, having a closer look at stations FAIC and UNAC one can realize that the standard deviations of the L2C multipath and noise level are higher than for the C/A code for all satellites. This indicates that the Everest was not enabled on the L2 frequency in the Trimble NetRS receivers.

The Trimble NetRS receivers' firmware version used during the analyzed 24 days was v.1.1-5 released on 13 January 2006. This version was the last released firmware version for the Trimble NetRS receivers at the time of the data collection.

Table 4 C/A and L2C code standard deviations for PRN 17, PRN 31 and PRN 12 – station UNB3

Elevation angle bins (deg)		0 -10	10 - 20	20 -30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90
PRN 17	Std.CA (m)	0.602	0.491	0.338	0.251	0.210	0.175	0.150	0.136	0.127
	Std. L2C (m)	0.358	0.427	0.353	0.252	0.239	0.222	0.209	0.201	0.194
PRN 31	Std.CA (m)	0.492	0.429	0.309	0.241	0.185	0.163	0.155	0.129	
	Std. L2C (m)	0.335	0.328	0.270	0.235	0.227	0.208	0.218	0.206	
PRN 12	Std.CA (m)	0.510	0.471	0.347	0.255	0.207				
	Std. L2C (m)	0.356	0.379	0.283	0.250	0.229				

Table 5 C/A and L2C code standard deviations for PRN 17, PRN 31 and PRN 12 – station GANP

Elevation angle bins (deg)		0 -10	10 - 20	20 -30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90
PRN 17	Std.CA (m)	0.513	0.355	0.268	0.230					
	Std. L2C (m)	0.577	0.364	0.309	0.258					
PRN 31	Std.CA (m)	0.551	0.426	0.284	0.221	0.184				
	Std. L2C (m)	0.656	0.384	0.302	0.276	0.231				
PRN 12	Std.CA (m)	1.286	0.679	0.294	0.220	0.190	0.179	0.163	0.161	0.160
	Std. L2C (m)	0.863	0.557	0.377	0.255	0.251	0.222	0.209	0.211	0.209

Table 6 C/A and L2C code standard deviations for PRN 17, PRN 31 and PRN 12 – station FAIC

Elevation angle bins (deg)		0 -10	10 - 20	20 -30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90
PRN 17	Std.CA (m)	1.6211	1.030	0.698	0.431	0.341	0.285			
	Std. L2C (m)	2.230	1.451	0.917	0.733	0.599	0.533			
PRN 31	Std.CA (m)	1.133	0.906	0.701	0.420	0.356				
	Std. L2C (m)	1.811	1.311	0.997	0.717	0.599				
PRN 12	Std.CA (m)	1.442	0.829	0.670	0.450	0.356	0.255	0.229	0.240	
	Std. L2C (m)	2.113	1.162	1.042	0.757	0.659	0.528	0.471	0.485	

Table 7 C/A and L2C code standard deviations for PRN 17, PRN 31 and PRN 12 – station UNAC

Elevation angle bins (deg)		0 -10	10 - 20	20 -30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90
PRN 17	Std.CA (m)	0.824	0.538	0.404	0.272	0.217	0.192	0.199	0.175	0.140
	Std. L2C (m)	0.981	0.894	0.659	0.549	0.490	0.443	0.428	0.422	0.421
PRN 31	Std.CA (m)	0.794	0.561	0.341	0.288	0.205	0.178	0.168	0.155	0.147
	Std. L2C (m)	1.121	0.839	0.631	0.550	0.477	0.452	0.439	0.429	0.429
PRN 12	Std.CA (m)	0.794	0.594	0.473	0.412	0.414	0.259	0.188	0.153	0.159
	Std. L2C (m)	1.116	0.896	0.599	0.532	0.489	0.457	0.440	0.439	0.436

CONCLUSIONS

The L2C modernized civil signal has been collected at UNB from 11 January 2006 until 10 October 2006 using a Trimble R7 receiver. Several analyses have been made on the L2C signal based on them.

The signal-to-noise ratio of all satellites has been compared on the L1 and L2 frequencies. The conclusion from this comparison is that the signal-to-noise ratio of L2C signals is higher than the signal–to-noise ratio of P2 code, and reaches similar values as those of the SNR of the C/A code on the L1 frequency.

The noise level of the L2C and C/A code was calculated and analyzed for the Trimble R7 receiver. From the comparison of the multipath and noise of the two codes it can be seen that the noise level of the L2C code was higher than the noise of the C/A code, which was against the expectation of having similar noise and multipath levels for both L2C and C/A code. However, this can be explained by issues in the firmware versions 2.26 and 2.28, which were used in the Trimble R7 receiver during the observation period. Those issues have been fixed in the new firmware release, version 2.30 (Mallen, 2007).

Similar analysis has been made for four stations in the global L2C tracking Test Network in order to analyze the quality of the L2C signal, to test the receivers' firmware versions and investigate how it influences the C/A and L2C code multipath and noise levels. The chosen stations were FAIC, UNAC (which use Trimble NetRS), UNB3 and GANP (which use Trimble NetR5). Standard deviations of multipath and noise values were computed over the entire 24-day period and each day separately for each elevation angle bin, satellite, station and code.

After examining the results from the stations using Trimble NetR5 receiver we realized that Everest was enabled on both frequencies i.e. the standard deviations of the C/A and L2C codes were similar in the case of all modernized satellites. Stations using Trimble NetRS receiver had higher standard deviations for the L2C code then for the C/A code. That indicates that the Everest in not enabled on the L2 frequency.

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