

Results and Analysis of Using the MEDLL Receiver as a Multipath Meter

by

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BIOGRAPHY

Bryan Townsend received his Bachelors of Science in 1989 and Masters of Science in 1993 from the Department of Geomatics Engineering at the University of Calgary. Since then he has worked in several areas of GPS including GPS surveying, and GPS receiver design. Currently he is working with wide area reference systems such as WAAS and EGNOS.

Jonathan Wiebe received a Bachelors of Mathematics in Applied Mathematics from the University of Waterloo in 1995. He completed his Masters of Science at the University of Calgary in Geomatics Engineering in 1998. His research interests included Synthetic Aperture Radar texture analysis and speckle filtering. He is currently employed at NovAtel Inc. as a GPS (Global Positioning System) Engineer.

Andy Jakab received his B.Sc. in 1997 from the Geomatics Engineering department at the University of Calgary and is currently pursuing a masters degree part time. After receiving his undergraduate degree, he joined NovAtel and has worked on receiver testing and end user software. Andy is currently GPS Systems Engineer for the Aviation group working on receiver certification and development activities including evil waveform research.

ABSTRACT

The Multipath Estimating Delay-Lock-Loop (MEDLL) is a method for mitigating the effects due to multipath within the receiver tracking loops. Recently the MEDLL receiver was modified to output the multipath parameters, hence the name 'Multipath Meter'. These parameters include the delay, relative amplitude, and phase of the multipath signal along with the residual values for each correlator. The multipath parameters are estimated by the MEDLL and the residuals indicate the quality estimation process.

This paper investigates how the Multipath Meter can be used in real-time monitoring of the GPS signal. Using a GPS simulator the MEDLL receiver is tested to determine how accurately the multipath parameters can be measured. Also, data is collected from an antenna location on the roof of the NovAtel facility at Calgary, Alberta, Canada. Two specific situations are focused on: short delay and long delay multipath. Results show that the Multipath Meter is useful for signal quality monitoring and reference site surveys.

INTRODUCTION

The Multipath Estimating Delay-Lock-Loop (MEDLL) is a method for mitigating the effects of GPS signal multipath within the receiver tracking loops. The MEDLL does this by separating the signal into its line-of-sight and multipath components. The line-of-sight component is then used for computing the tracking error. The MEDLL receiver performance, in mitigating the effects of multipath on C/A code pseudorange and carrier phase measurements, has been demonstrated in previous papers [2, 3, and 7].

The MEDLL receiver was modified to output the multipath parameters. The name 'Multipath Meter' come from the fact that it 'measures multipath'. The parameters output include the delay, relative amplitude, and phase of the multipath signal, along with the residual values for each correlator. The multipath parameters are estimated by the MEDLL and the residuals indicate the quality estimation process.

GPS MULTIPATH

The term multipath is derived from the fact that a signal transmitted from a GPS satellite can follow a 'multiple' number of propagation 'paths' to the receiving antenna. This is possible because the signal can be reflected back

to the antenna off surrounding objects, including the earth's surface. Figure 1 illustrates this phenomena for one reflected signal.

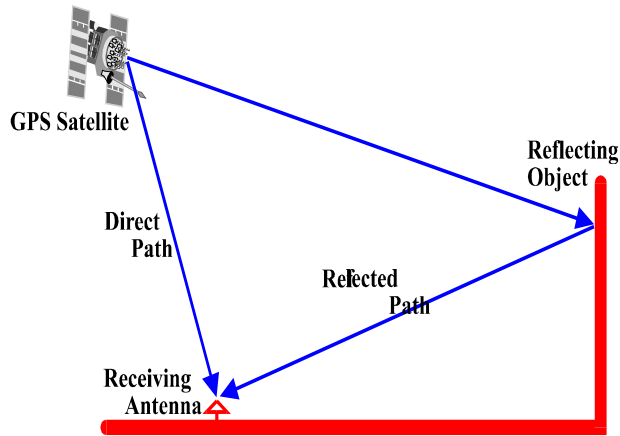


Figure 1: Direct Path and Multipath (Reflected Path) Signals

Some important characteristics of multipath are as follows [4]:

- i) The multipath signal will always arrive after the direct path signal because it must travel a longer distance over the propagation path.
- ii) The multipath signal will normally be weaker than the direct path signal since some signal power will be lost from the reflection.
- iii) If the delay of the multipath is less than two PRN code chip lengths, the internally generated receiver signal will partially correlate with it. If the delay is greater than 2 chips the correlation power will be negligible.

MEDLL

In the presence of multipath propagation, the received signal at the input of a direct-sequence spread-spectrum receiver can be written as:

$$r(t) = \sum_{m=0}^{M-1} a_m p(t - \tau_m) \cos(\omega t + \theta_m) + n(t) \quad (1)$$

where,

- M = number of signals
- t = time
- p(t) = the spread-spectrum code
- n(t) = white Gaussian noise
- a_m = component signal amplitude

- τ_m = component signal delay
- θ_m = component signal phase

For a positioning system like GPS, the parameters of interest are the direct path signal delay and phase. In order to estimate these parameters, the direct path correlation function needs to be determined. The MEDLL approach used here involves the decomposition of the correlation function into its direct path and reflected path components.

The MEDLL estimates the amplitude, delay, and phase of each multipath component using maximum likelihood criteria. Each estimated multipath correlation function component is in turn subtracted from the measured correlation function. The result is an estimate of the direct path correlation function. A standard early-late DLL is applied to the direct path component of the correlation function giving a 'multipath free' estimate of the code loop tracking error.

THE MULTIPATH METER CONCEPT

The multipath meter concept involves taking the signal parameters output from the MEDLL algorithms and using them for quality monitoring of the GPS signal. These parameters are the delay, relative amplitude, and phase of the multipath signal along with the residual values for each correlator.

The multipath meter output is used for real-time signal quality monitoring. It can also be used for reference station site surveys to determine if a location is suitable for a GPS reference station.

Of the signal parameters output, the amplitude of the multipath is of most interest because it will indicate the presences of multipath even if it is not causing any pseudorange error. This would be the case is the relative phase of the multipath is 90 or 270 degrees.

THEORETICAL PERFORMANCE

Figure 2 shows a plot of the pseudorange error due to multipath for MEDLL and Narrow Correlator tracking. The light colored line is the MEDLL and the dark colored line is the Narrow Correlator. The multipath signal has an amplitude (a_m) of 0.5 relative to the direct path signal. The delay is varied from 0 to 1.1 chips. The plot appears almost solid because the multipath varies in phase as the delay is varied. One carrier phase cycle is 1/1540 chips and as the delay varies over one cycle the phase of the multipath signal relative to the direct path signal varies over 360 degrees. The multipath error is at its maximum positive value at 0 degrees phase and at its maximum

negative value at 180 degrees phase. The error is 0 at 90 and 270 degrees.

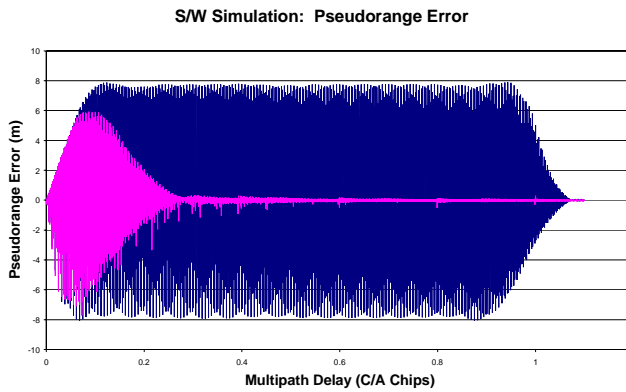


Figure 2: Theoretical pseudorange multipath error for MEDLL and Narrow Correlator ($a_m = 0.5$)

It should be mentioned here that the MEDLL receiver has a pre-correlation bandwidth of 8 MHz and the Narrow Correlator receiver has a 16 MHz pre-correlation bandwidth. This was done to simulate the NovAtel WAAS receiver which is used in the next section for live signal tests. The MEDLL was implemented in the WAAS receiver using an OEM2 hardware platform and the Narrow Correlator is implemented using an OEM3 hardware platform. The two platforms use different RF decks.

For the same multipath scenario as in Figure 2, the corresponding measured multipath power is shown in Figure 3.

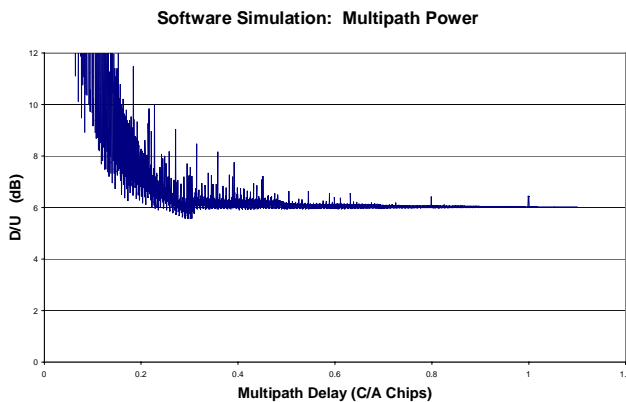


Figure 3: Theoretical D/U values for 0.5 amplitude signal

The multipath power is plotted in D/U (desired signal power over undesired signal power) in decibels (dB). The D/U is calculated using the equation,

$$D/U = 20 \cdot \log(a_{direct} / a_{multipath}) \quad (2)$$

The plot shows that the D/U converges to 6 dB as the delay of the multipath is increased. 6 dB corresponds to a relative multipath power of 0.5. For delays less than 0.2 the D/U becomes less accurate. This is expected since the accuracy of the MEDLL is limited by the BW of the GPS receiver RF deck and the GPS signal itself.

GPS SIGNAL SIMULATOR TESTS

The next step in our analysis is to repeat the scenario from the previous section using the GPS signal simulator. The test setup consisted of the Global Navigation Satellite System (GSS) GPS signal simulator and NovAtel WAAS receiver.

Figure 4 shows a plot of the code minus carrier for the MEDLL receiver. There is a offset that hasn't been removed however error distribution compares well with the theoretical values compute in Figure 2.

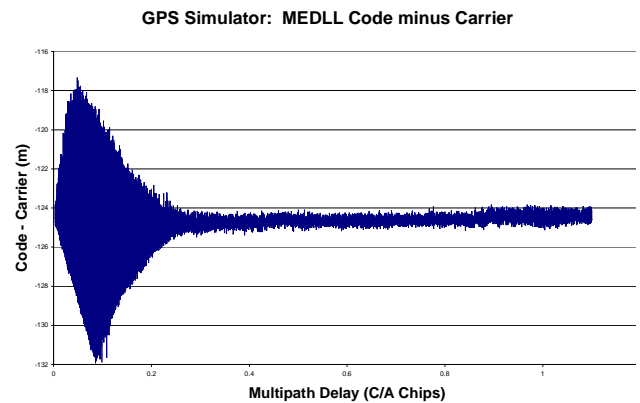


Figure 4: MEDLL code minus carrier, GPS simulator, $a_m = 0.5$

Figure 5 shows D/U output from the MEDLL receiver. Once again the plot compares well with the theoretic plot in Figure 3. There a is wider distribution of points but this is expected since there is measurement noise in that is not present in the software simulations.

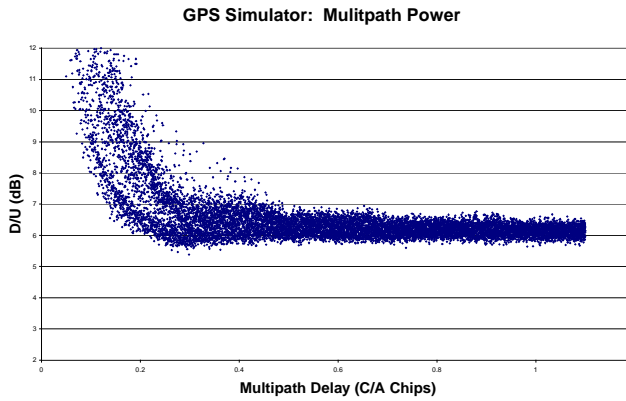


Figure 5: D/U, GPS simulator, $a_m = 0.5$

Another check of how well the MEDLL algorithms are performing is to look at the size of correlator residuals. A correlator residual is calculated by taking the measured correlator value and subtracting off the computed direct path and multipath correlator values. The direct path and multipath correlator values are calculated using a pre-determined reference correlation function. Based on equation (1) the correlator residual is represented by,

$$C_{res} = C_{meas} - \sum_{m=0}^{M-1} a_m C_{ref}(x - \tau_m) \cos(\theta_m) \quad (3)$$

where,

- C_{res} = correlator residual
- C_{meas} = measured correlator value
- C_{ref} = reference function correlator value
- M = number of signals
- x = correlator position
- a_m = component signal amplitude
- τ_m = component signal delay
- θ_m = component signal phase

Figure 6 is a plot of the RMS of the normalized residuals for the simulator test. As expected the RMS residuals are quite small with the majority of the values less than 1%. This shows that the MEDLL algorithms are converging and the modeling is good.

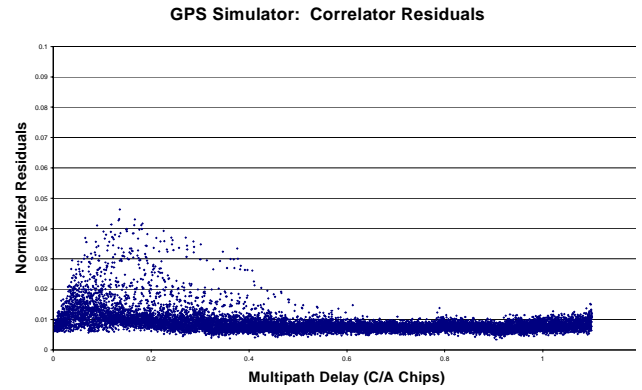


Figure 6: RMS of correlator residuals, GPS simulator, $a_m = 0.5$

ANALYSIS OF LIVE SIGNAL DATA

The next step in our analysis was to look at data collected from tracking live satellites. For this purpose the NovAtel WAAS receiver was set up to collect data at NovAtel's facility in Calgary, Alberta, Canada. Figure 7 shows a picture of part of the antenna array on the roof of the NovAtel building. The roof was designed to be a low multipath environment and, as can be seen, the area is reasonably clear of objects that could reflect multipath signals. For the data collection, a non-choking antenna was used in order to try to induce more multipath.



Figure 7: Antenna array on the roof at NovAtel Inc.

Figure 8 shows a plot of the code minus carrier residuals for the Narrow Correlator receiver and Figure 9 shows the corresponding code minus carrier plot for the MEDLL receiver. The data was collected for a 24 hour period

starting from approximately 6:00 in the evening. L1 and L2 carrier phase measurements were used to remove the ionospheric trend and the initial bias has been removed so that the plot is centred about zero.

For most part the code minus carrier residuals are small indicating a low multipath environment. There are, however, some large excursions. Two of these are labeled in the figure by 'PRN 3' and 'PRN 8'. These two satellites were selected for closer investigation because they represent short delay (< 0.2 chips) and long delay (> 0.2) multipath.

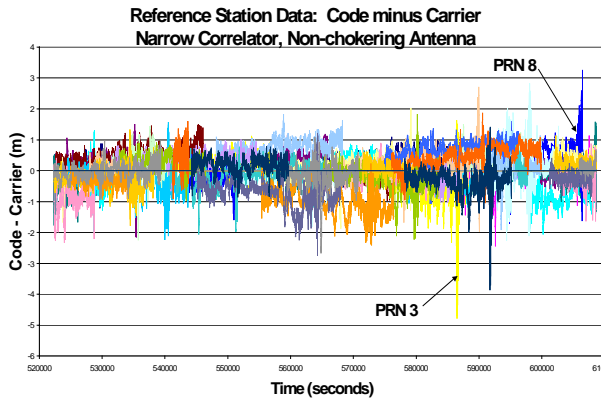


Figure 8: Narrow correlator code minus carrier, NovAtel roof, non-choking antenna, 24 hours

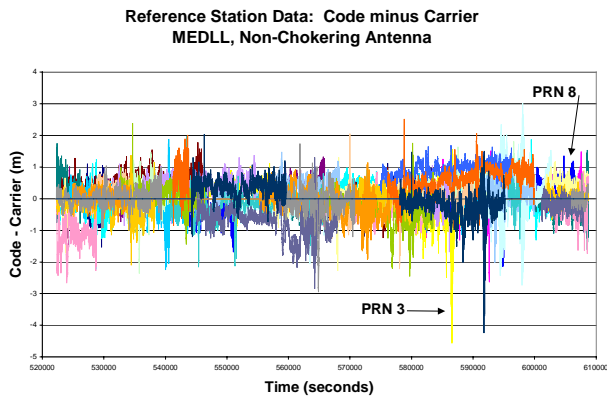


Figure 9: MEDLL code minus carrier, NovAtel roof, non-choking antenna, 24 hours

AN EXAMPLE OF LONG DELAY MULTIPATH

Figure 10 shows a close-up of the spike seen in Figure 7 plot for PRN 8. In this case the MEDLL is able to mitigate the effects of the multipath signal. The satellite is setting so it is being effected by low elevation multipath.

We can also summarize that the delay of the multipath is greater than 0.2 chips because the MEDLL is accurately solving for it. Indeed the measured delay in this case is ~0.67 chips.

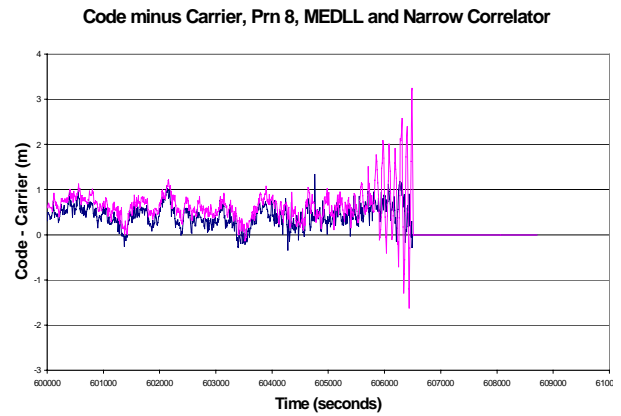


Figure 10: Code minus carrier, PRN 8, Dark colored = MEDLL, Light colored = Narrow Correlator

Figure 11 shows the measured D/U for PRN 8 during the same period. As can be seen the multipath power increase has the same trend as the pseudorange error. The D/U decreases indicating the multipath power is increasing and at the same time pseudorange error for the Narrow Correlator receiver increases.

This shows a good example of how the D/U can be used for signal quality monitoring (SQM). The D/U is a scalar quantity and a simple threshold test could be used to alert the user of the presence of excess multipath. It could also be used to scale the accuracy of the pseudorange and carrier phase measurements.

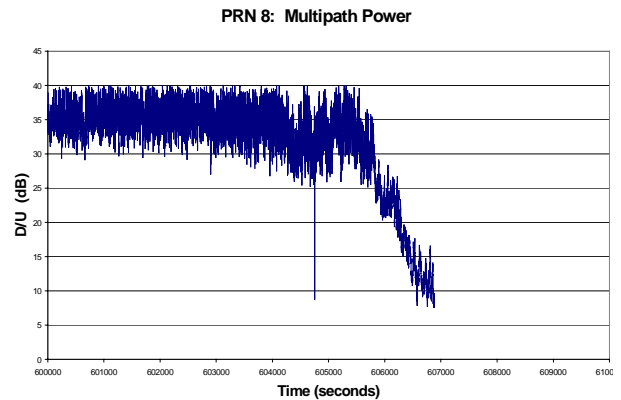


Figure 11: D/U for PRN 8

By contrast the multipath phase and delay are not as useful for SQM. The phase rotates between $-\pi$ and $+\pi$

radians and can not be directly correlated to pseudorange and carrier phase error due to multipath. Figure 12 shows plot of the multipath phase for PRN 8 during the same period. The phase in the first part of the plot is quite noisy but as the multipath starts to gain in power the phase starts to follow a sinusoid like curve. The frequency of which would be the relative doppler of the multipath signal to the direct path.

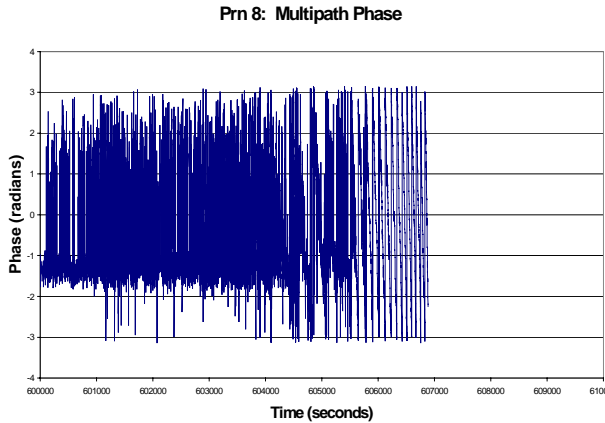


Figure 12: Estimated Phase of Multipath for PRN 8

The delay has similar problems in that if the multipath power is low the delay estimate is very noisy. When the MEDLL is able to estimate the multipath delay well it can not be directly correlated to measurement error. The delay does however help in a site survey because it gives an indication of how far away a reflecting object is away from the antenna.

The phase and delay have some limited value but it is pointless to use them unless the D/U shows the presence of multipath at the antenna.

AN EXAMPLE OF SHORT DELAY MULTIPATH

Figure 13 shows a close-up of the spike seen in the code minus carrier plot for PRN 3. In this case the MEDLL and the Narrow Correlator are effect in the same way by the effects of multipath.

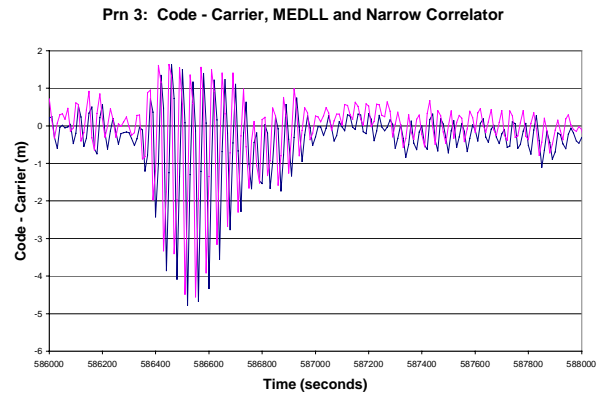


Figure 13: Code minus carrier, PRN 3, Dark colored = MEDLL, Light colored = Narrow Correlator

In contrast to the previous example, the multipath occurred at a higher elevation angle. From the plot it can be seen that the multipath fades in for a while and then disappears. This is a classic case of short delay multipath.

Figure 14 shows the D/U estimates for PRN 3.

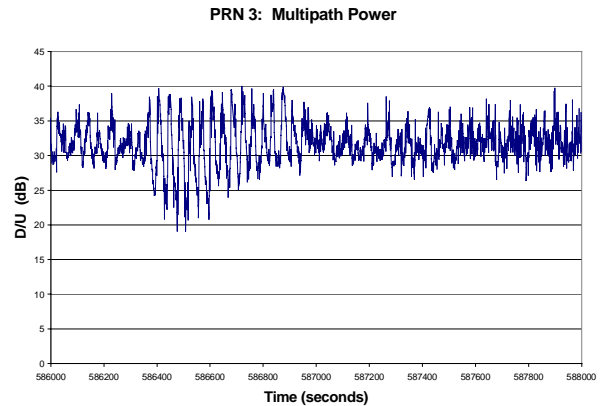


Figure 14: D/U for PRN 3

During the multipath event the D/U values oscillates as the multipath goes in and out of phase. In the case of short delay multipath the MEDLL cannot estimate the signal parameters accurately. As a result, a simple threshold test on the D/U would not work as well for SQM. If the threshold was set at 25 dB the D/U would only trigger it part of the time. A more sophisticated test using the trend of the D/U would be required in this case but it would not be any more onerous than using code minus carrier.

CONCLUSIONS

The result from this analysis show that the Multipath Meter can useful for signal quality monitoring and reference site surveys. For SQM the D/U gives the best indication of the presence of multipath signals and their severity. Short delay multipath is not detected as easily as long delay multipath and will require a more elaborate detection mechanisms.

Future work on the Multipath Meter will investigate antenna locations with more severe multipath environments with multiple reflected path signals.

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