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Permanent Link to Innovation: Hunting for GNSS Echoes

2021/06/08

Analysis of Signal Tracking Techniques for Multipath Mitigation By Antonio Fernández, Mariano Wis, Pau Closas, Carles Fernández-Prades, José A. García, Francesca Zanier, and Massimo Crisci INNOVATION INSIGHTS by Richard Langley GETTING RID OF A NUISANCE. No, I'm not talking about your neighbor's barking dog or the IT guy when he shows up to fiddle, yet again, with your computer. I'm talking about multipath. What is multipath, you ask? Herewith, Multipath 101. When a radio signal travels from a transmitting antenna to a receiving antenna, it will follow a direct line-of-sight path. But the signal might also travel to the receiving antenna after being reflected off a nearby building, say, resulting in a delayed signal or echo along with the line-of-sight one. Those of us of a certain age will remember ghost images on the screens of TVs connected to "rabbit ears" or outdoor antennas. That was multipath. These days, with TV signals primarily delivered by cable and satellite, we don't see multipath much anymore. But we do hear it in our cars, from time to time, while listening to FM radio. Although the FM "capture effect" provides some margin against multipath, it is not uncommon to lose stereo reception or to experience fading out of the signal while driving in built-up areas as a result of reflections. This same multipath phenomenon also affects GNSS signals. Unlike satellite TV antennas, the antennas feeding our GNSS receivers are omnidirectional. So we have the possibility of not only receiving a direct, line-of-sight signal from a GNSS satellite but also any indirect signal from the satellite that gets reflected off nearby buildings or other objects or even the ground. The related phenomena of diffraction and scattering can also generate multipath signals. In a GNSS receiver, the line-of-sight and multipath signals combine to corrupt tracking of the line-of-sight signal resulting in increased pseudorange and carrier-phase measurement errors. GNSS antenna and receiver manufacturers have developed techniques to minimize some of the impact of multipath on the GNSS observables. And tracking of some of the newer GNSS signals is a bit more resistant to multipath. But multipath, at some

level, is still a problem looking for a better solution. This brings us to ARTEMISA, which stands for Advanced Receiver Techniques: Multiprocessing Algorithms. It's a European initiative to develop techniques to minimize the effects of multipath in GNSS receivers. For those of you who are a little rusty on your Greek mythology, Artemis (or Artemisa in Spanish — after all, she was a woman) was the Greek goddess of the hunt. You might better know her Roman equivalent: Diana. Her parents were Zeus and Leto, and Apollo was her twin brother. She is often depicted carrying a bow and arrows. How appropriate a name for a project whose goal is to try to kill off the effects of multipath in GNSS receivers. In this month's column, the team of researchers involved with ARTEMISA describe their efforts to generate synthetic multipath for GPS L1 and Galileo E1 signals and to test different signal tracking techniques in a simulated receiver to see which techniques best minimize the effects of multipath on positioning solutions and which might be feasible candidates for incorporating in real receivers. The hunt is on. GNSS navigation in urban environments is usually challenged by a number of effects such as multipath and weak signal conditions. In particular, the pernicious effects of multipath on signal tracking and system accuracy are widely known. To mitigate these effects, there is a series of techniques that range from modified antenna design to combining the GNSS receiver with other sensors or subsystems. Another possibility is to implement advanced tracking techniques specifically designed for these purposes. Such techniques usually impose computational load and implementation complexity, which make them hard to implement in an application-specific-integrated-circuit-based receiver. However, given the current advances in computer technology and the possibilities of field-programmable-gate-array- (FPGA-)based hardware, it is possible to implement these new techniques in an operational receiver. We have studied this possibility as part of the ARTEMISA project, carried out by DEIMOS Space and the Centre Tecnològic de Telecomunicacions de Catalunya, and supervised by the European Space Agency's European Space Research and Technology Centre. We have implemented and tested a series of innovative techniques that are able to cope with, and even to estimate, multipath (MP) parameters, using a simulated software receiver based on the GRANADA (Galileo Receiver Analysis and Design Application) GNSS blockset for MathWork's Simulink graphical programming language tool. These techniques are based on the maximum likelihood principle (as implemented in the Multipath Estimating Delay Lock Loop) or on online Bayesian techniques for the estimation of multipath (as implemented in the Multipath Estimating Particle Filter), involving architectural modifications of the tracking loops (as in vector tracking loops), or even constituting a new paradigm in receiver design (direct position estimation). Our effort in this project has focused on two main tasks. The first task is the design and development of the simulation platform, the techniques to be tested, and a multipath model representative of the urban environment. The second task involves a simulation campaign that has been carried out to test the different techniques and to contrast the results obtained against the legacy delay lock loop / phase lock loop (DLL/PLL) tracking loop schemes. This article describes these tasks and some of the results we have obtained so far. Keep in mind that at the time of writing, ARTEMISA is still ongoing. Therefore, more results are expected up until the end of the project.

**Simulation Platform** The simulation platform has been developed in Matlab/Simulink with DEIMOS Engenharia's GRANADA GNSS Blockset. This

blockset is a collection of Simulink models and blocks that can be used to design and simulate any kind of GNSS receiver. The main block is the Factor Correlator Model (FCM), which implements the set of correlators through an analytical (set of equations) model. Carrier phase, code misalignment, autocorrelation function, and even the correlated noise and the multipath at the output of every virtual correlator are simulated for a given input trajectory. On the other hand, the tracking loops are implemented as independent modules representative of an actual receiver. This semi-analytical approach has the advantage of performing a fast simulation of the correlator output without the need for implementing the baseband correlation operation. In addition, its implementation in Simulink allows for the development of innovative tracking schemes. This approach also matches with the ARTEMISA project concept, where a series of innovative tracking loops has been implemented with the aim of replacing or improving conventional PLL/DLL schemes. The main architecture of the simulation platform is shown in FIGURE 1. We use an external trajectory file to generate the reference data that will be used with the FCM block to generate the correlator output that will feed the tracking loop blocks. These trajectory files are also used to feed the multipath scenario generators, to test each technique under a number of defined scenarios so that we can assess their performances and find their limitations under multipath. □Figure 1. ARTEMISA simulation platform architecture.

We used two statistical models for the description of the signal propagation: the Controlled Stochastic Channel Model (CSCM), which is a modification of the Land Mobile Satellite channel developed by Pérez-Fontán, and the well-known Land Mobile Channel Model, developed by the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt or DLR); see Further Reading. These models generate a series of scenario files, which can be loaded into the FCM to introduce the multipath effects in the correlator output. These two statistical models are complementary. The CSCM model allows the user to set the multipath channel characteristics to be able to stress the tracking technique, while the DLR model permits evaluation of the technique's response in realistic conditions. A deterministic user-defined multipath generator was implemented to check the response of the tracking techniques under well-defined multipath conditions. The Multipath Error Envelope (MPEE) was also computed to evaluate the response of the technique under one echo with varying delay conditions. The purpose of this article is not to explain all the developments performed with the platform. It focuses on the results obtained with the deterministic and statistical channel model. For this reason, the development of the CSCM generator will be explained in detail.

**Controlled Stochastic Channel Model** The CSCM module was specifically created for this project. Its purpose is to generate a stochastic channel, but with the capability to control the multipath power levels and the number of echoes generated in the scenario, thus creating a set of realistic multipath signals, but with the capability of being easily controlled by the user. Time series for multipath echoes are generated, following a Rice or Rayleigh stochastic model, but the mean power levels, the amplification  $K$  factors, and the power switching times are chosen by the user. The model allows the selection of the number of satellites (channels) that are generated in the model, the sampling period (related to the loop integration time), the length of the simulation, the receiver speed, the signal carrier frequency, and channel specific parameters such as the number of echoes, the average delay of the echoes and the decay slope (echo power loss ratio with signal

delay). One of the parameters the user can set implicitly is the multipath echo lifetime. What the user really sets is the channel transition time, or the time during which the channel keeps the multipath configuration. Every time the transition time is changed, a series of multipath echoes are canceled and other ones appear. This set of disappearing/appearing echoes is performed in pairs in such a way that the transition between echoes is smooth. FIGURE 2 illustrates this mechanism. □Figure 2. CSCM echoes smooth transition. When an echo is disappearing (a red one in the figure), its associated echo is at its maximum value (a blue scatterer). In the next interval, a new echo appears in a different delay position (a green one) and the associated scatterer begins to decrease its power. This mechanism allows the user to easily associate the transition time to half the multipath echo lifetime.

**Simulation Plan** The simulation plan is structured into different stages. The first stage of the simulation plan is based on the controlled multipath environment, with specific tests for each technique. The purpose of this stage is the tuning up of the techniques. As an example, for the Multipath Estimating Delay Lock Loop (MEDLL) technique, parameters such as the precorrelation bandwidth, the number of MEDLL iterations or the number of assumed multipath echoes are parameters that are adjusted after these tests are carried out. Another purpose of this first stage is to check the performance of the techniques under deterministic, fully controlled multipath. Parameters like signal-to-multipath ratio, multipath delay, and the number of multipath echoes can be controlled at any time. Another test is the generation of the multipath envelope error plot. The utility of this test is to find the optimal configuration of the correlator position for each kind of signal, which is a trade-off between the obtained root-mean-square error (RMSE) and the number of correlators. This procedure is repeated for each signal considered in the plan. The next stage of the simulation plan is the test with the CSCM model. This test consists of the generation of a series of scenarios characterized by the stochastic model, the number of echoes, and the user receiver dynamics. Scenarios presented in this article are shown in TABLE 1. Two types of user environments are defined: one for pedestrian and one for vehicular receivers. The dynamics (user speed) define the integration (sampling time) and the multipath Doppler spread. The stochastic model parameters include the type of stochastic model for the line-of-sight signal (LOSS) and multipath echoes, mean power level, and amplification K factor. These scenarios represent a moderate multipath level with four echoes. Table 1. CSCM scenarios in the simulation plan. Each scenario was run with different settings of carrier-to-noise-density ratio (C/N0) and with all the signals that were planned for the project: GPS L1 C/A, GPS L5, Galileo E1 and Galileo E5. In this article, we focus on L1 band signals, analyzing the results for GPS L1 and Galileo E1. Table 2. GNSS signals considered in the analysis. The final stage in the simulation plan is testing each technique under realistic channel conditions with the DLR model. In this case, an urban scenario is set, assuming two types of receiver dynamics (a pedestrian user and a vehicular user). No more details about this stage are given because these tests are currently ongoing.

**Technique Descriptions** After an initial evaluation of the candidate techniques, the following techniques were selected for implementation and testing in the project. Multipath Estimating Delay Lock Loop. MEDLL was proposed by Van Nee (see Further Reading). It is a robust statistical approach to the multipath problem, where the maximum likelihood principle is applied to a signal model

consisting of LOSS and  $M-1$  multipath rays or echoes. The key idea is to perform the estimation of the whole set of parameters of the incoming signals (that is, amplitude, delay, and phase) in an iterative manner. When their amplitudes, time delays, and carrier phases are estimated, the effect of the reflections in the correlation can be removed. Applying standard assumptions, the maximization of the likelihood function yields a set of interrelated equations from which one can estimate iteratively the LOSS and multipath parameters. The implementation of MEDLL considers a similar architecture as conventional DLLs, although in practice more than three correlators per loop are required for effective multipath mitigation. Despite its demanding requirements in terms of a large number of correlators and computational load, MEDLL was successfully implemented in NovAtel receivers because of its excellent performance in multipath mitigation. The contributions of all signals (that is, LOSS and an unknown number of echoes) are not calculated simultaneously from the outset. First, the contribution of only one signal is calculated, then the contribution of a second signal is added with the contributions of both signals being optimized, then the contribution of a third signal is added and the contributions of all three signals are optimized, and so on. The process is repeated until a suitable stop criterion is fulfilled. A possible approach for deciding when to stop adding more rays to the signal model is to detect when the error increases; that is, observing that the signal-to-residual ratio when considering an extra path decreases with respect to the case of not considering it, or reaching a maximum number of considered paths, which is a design parameter of this technique.

**Multipath Estimating Particle Filter.** The MEPPF shares with MEDLL the philosophy of estimating the parameters of multipath to mitigate its effect. The main difference is that in this case the statistical principle is not the ML (as in MEDLL) but Bayesian filtering. Here the term Bayesian means that the algorithm is using some sort of a priori information regarding these parameters (such as interdependencies and time evolution models). Therefore, instead of assuming that each integration period is independent of the others, a first-order Markov process is assumed for the unknown parameters (that is, amplitude, delay, and phase). The resulting problem is formulated as a nonlinear state-space model and can be solved by means of a Rao-Blackwellized particle filtering method. The MEPPF has a relatively high computational load, which is a function of the number of particles ( $N_p$ ), the number of correlation points, and the number of rays to be estimated ( $M$ ). In all cases, the larger the values the more computationally demanding the algorithm is. According to the simulations performed, configurations with  $N_p$  larger than 2000 are not worthwhile, because it implies a high computational cost and the results do not improve significantly the accuracy of a GNSS receiver. Also notice that the dimension of the state-space to be estimated is  $3 \times M$  ([amplitude, phase, delay]  $\times M$ ), and thus estimating an additional multipath ray implies augmenting the dimensionality by three. Theoretically, the convergence results of particle filters are independent of the dimensionality of the problem. However, it is agreed that in practice these methods fail when the problem increases in dimension. Therefore, setting  $M$  larger than 5 is not reasonable since the number of particles required for convergence would be too large to consider its implementation in a receiver.

**Vector Tracking Loops.** A conventional GNSS receiver consists of several parallel scalar DLLs, each of which independently estimates the individual pseudoranges. The parallel set of measured pseudoranges (plus Doppler or

accumulated delta range measurements on the carrier) are then fed to a Kalman filter estimator, and thus each DLL effectively produces an independent estimate for each of the  $N$  pseudoranges for each of the  $N$  satellites. However, not all of their measurements are truly independent, although they are treated as such by the DLL, and if there are more than four measurements being made and four or fewer unknowns, the system is overdetermined. Furthermore, the geometry of the satellite-user paths generally prevents the measurements from being truly independent. The concept of vector tracking loops firstly appeared in the early 1980s. Recently, the method has attracted the attention of many researchers (see Further Reading) due to its good performance in weak signal scenarios. In this article, we present the implementation of a vector tracking loop that works with pseudorange and pseudorange-rate measurements and provides estimations for position, velocity, receiver clock error, and receiver clock drift. The vector loop has been integrated in a basic receiver based on the classical DLL and PLL/frequency lock loop (FLL)-assisted architecture, acting as an overlay procedure, which activates automatically once the basic receiver has obtained the first position fix. Then, the position/velocity/time solution is used to jointly estimate the synchronization parameters (time delay and carrier phase) for each of the received GNSS signals by means of an extended Kalman filter, and those values are re-injected into the tracking loop. By using position for deriving such synchronization parameters, the algorithm exploits the problem's inherent geometric constraints, processing all the channels jointly and providing robustness in scenarios with weak receiving power, high multipath, or fast fading.

**Direct Position Estimation.** Although the conventional two-step position determination is the approach taken traditionally, it is seen to have a number of drawbacks. In contrast, direct position estimation (DPE for short) proposes an alternative where the estimation of a user's position is performed directly from the received and sampled signal, thus avoiding intermediate steps and jointly considering signals from all satellites when estimating the position solution. By merging the two-step approach into a single estimation problem, DPE addresses some of the inherent drawbacks of the conventional approach where the dependencies between channels are efficiently exploited, in the sense that signals from visible satellites are jointly processed to obtain the user's position. At the time of writing, this technique is being implemented and its analysis is left for future publications. Results Not all the results that we have obtained have been included in this article; only the most relevant ones for L1/E1 CBOC and BPSK signals are given.

**MEDLL. Optimal Correlator Configuration.** As stated previously, the test consisted of executing different correlator configurations. TABLE 3 shows the correlator configuration ID, the number of correlation samples, and the location of the late correlators with respect to the prompt one and normalized to the chip time ( $T_c$ ). The corresponding early samples are defined analogously. For all these configurations, it is assumed that there is a correlator at zero chips. Table 3. MEDLL correlator configurations tested. These configurations were selected in order to test different possibilities as regular spacing between correlators (MP31, MP61, or MP91), setting the correlators to inflexion points of the autocorrelation function (ACF) (NC37 or NC43 for CBOC modulation), or variable spacing (as configurations AR01 to AR05 and GE01) that optimize the number of correlators. The results of the tests can be observed in FIGURE 3 for a BPSK(1) signal and for a CBOC(6,1,1/11) signal. □Figure 3. MPEE for



MEDLL with BPSK and CBOC signals for different correlator configurations ( $T_c$ =chip time). In general, it is observed that the greater the number of correlators, the smaller is the spacing and therefore, the area covered by the multipath error envelope is smaller. However, the greater the number of correlators, the greater is the processing time. Therefore, it is necessary to find an optimal configuration that best fits the multipath variation. After having analyzed the tests for these configurations, we found that the optimal configurations are AR01 for the BPSK signal and NC37 for the CBOC(6,1,1/11) signal. These configurations are shown in FIGURE 4, and were used for the remaining tests.

Figure 4. Correlator configurations for CBOC and BPSK signals. CSCM. As mentioned in the simulation plan description, the tests for a pedestrian and a vehicular user in a moderate multipath environment were performed with a scenario file generated with the CSCM tool. These scenarios are characterized by a series of multipath echo levels, number of echoes, and specific stochastic models that are detailed in Table 1. In this table, the pedestrian scenario is known as SP1 and the vehicular scenario is shown as SV1. The results with these scenarios are presented in this article. The RMSE for range estimates in these scenarios is shown in FIGURE 5 for SP1 and SV1. For comparison, these plots show also the theoretical lower bound (Nunes bound) computed for each technique.

Figure 5. Range RMSE for MEDLL in pedestrian and vehicular scenarios. The plots show that MEDLL outperforms the conventional DLL results above a minimum  $C/N_0$  value. This happens beyond 32 dB-Hz for a CBOC signal and 35 dB-Hz for a BPSK(1) signal for low dynamics (pedestrian) environments. In the case of vehicle scenarios such as SV1, it is observed that it requires significantly higher values of  $C/N_0$  in order to outperform the DLL RMSE. This result makes the technique impractical for vehicular applications.

Time Performance. A collateral result that has been obtained with CSCM scenarios is the time performance of the technique, compared to the legacy DLL/PLL scheme. The ratios of the execution times needed for the techniques have been computed. This is an indicative measure of the computational load. The time performance of MEDLL with the selected correlator configuration against DLL is 10:1. That is, 10 times more time is required for the MEDLL technique than the DLL to run the same scenario. It is also observed that the ratio for BPSK modulation is slightly larger than the ratio for the CBOC signal, because more correlators are used in that case.

MEPF. Performance Under Controlled Channel. FIGURE 6 shows an example of the performance of the MEPF technique tested in a controlled channel environment.

Figure 6. Results of the MEPF in the controlled multipath environment with 2 and 3 estimated rays including the line-of-sight. For comparison purposes, DLL/PLL results are also included (blue line in upper plot). It can be observed how the DLL/PLL technique has an error, which grows as the number of rays is increased. However, when the MEPF is applied, it can be observed how the technique is capable of dealing with a multipath-changing environment despite the fact that it is varying in time with the number of rays increasing. It can also be noticed that the response of the technique is practically the same independent of the number of estimated rays ( $M$ ). These results were achieved with a BPSK signal and 500 particles.

Covariance Matrix Adjustment. Before starting the specific test for the evaluation of the scenario performance, it is necessary to calibrate the particle filter. The calibration procedure consists of the adjustment of the process covariance matrix. The observation covariance can be adjusted, simply by analyzing the raw observables, or it can even

be done automatically. The critical point is the adjustment of the states' covariance. It has been observed that an improper adjustment of the covariance may cause an increment in the range RMSE or even the divergence of the filter. For that reason, a systematic procedure for the adjustment of the covariance matrix has been followed. This procedure evaluates the performance using different configurations of the covariance matrices of the line-of-sight and multipath parameters in two stages, and allows us to find a set of optimal values for each scenario. Optimal Correlator Configuration. We also analyzed the optimal correlator configuration for the MEPF technique. A number of configurations in Table 3 were used under CSCM scenarios. It was found that the correlator configuration does not have a strong influence on the performance of the MEPF technique. It is worth mentioning that in cases where fewer than five correlators were used, the performance degraded. Despite the weak influence of the range RMSE with the correlator configuration, it was observed that there is a minimum for the BPSK signal that can be chosen for the MEPF technique (MP31). For the CBOC signal, the same configuration used for MEDLL is finally chosen (NC37), provided that it is the optimal configuration that balances range RMSE and the number of correlators. Number of Particles. It is important to notice that an initial set of tests was performed with 500 particles. However, it was found that by increasing the number of particles to 2000, the performance of the technique with CSCM was remarkably better. Because of this, for the remaining tests using the CSCM, this number of particles was the default value. Using a higher number is not worthwhile since results are not much improved and the computational load becomes too high. CSCM Results. The range RMSE results for the pedestrian scenario SP1 with the MEPF technique are shown in FIGURE 7. In this case, it is observed that for the CBOC signal, MEPF outperforms the DLL/PLL technique for low C/N0 values. This result could not be reproduced for the BPSK signal because of the adjustment of the covariance matrix, which in this test was optimized for CBOC. □Figure 7. Range RMSE for MEPF and pedestrian scenario. These promising results for CBOC open the possibility of using this technique in applications where the LOSS is very weak or where the multipath signals are very strong. More tests with this technique are currently being executed for a better adjustment of covariance settings for BPSK. Time Performance. The previous time performance analysis was performed with the MEPF technique. The performance ranges among 180:1 and 340:1, when compared to DLL/PLL schemes using three correlation samples. The extremely long time required to simulate the scenario makes this technique inadvisable for implementation within an operational receiver using current technology. VTL. CSCM Results. The same CSCM scenarios were performed for the VTL technique, but using a multi-channel receiver. Results for pedestrian SP1 and vehicular SV1 scenarios are shown in FIGURE 8. □Figure 8. Position RMSE for VTL with pedestrian and vehicular scenarios. It must be noted that, in order to perform fair comparisons, the results of ordinary DLL/PLL tracking used a conventional KF for the computation of the position instead of the least squares module available in the GRANADA GNSS Blockset. In our numerical simulations, a significant improvement in the performance of VTL with respect to the DLL/PLL+KF scheme was not observed in pedestrian environments, due to the low dynamics. Under those dynamic conditions, both systems exhibited similar (statistically equivalent) behavior. In the case of scenario SV1, the velocity applied to the receiver was higher than in the pedestrian case, and

the VTL exhibited a remarkable improvement over the DLL/PLL+KF-based receiver. For the BPSK modulation, it was observed that for low values of  $C/N_0$ , the VTL performs better than DLL/PLL+KF. However, for stronger signals, both techniques have the same behavior as shown for the pedestrian scenario results. On the other hand, for the CBOC modulation, it is observed that VTL performs better than DLL/PLL+KF for the whole range of  $C/N_0$  values. The precorrelation bandwidth was set to 8 MHz in the case of BPSK, while for CBOC it was set to 14 MHz. That wider bandwidth of the CBOC receiver has an impact in the estimation of the measurements covariance matrix. It can be observed that in such higher dynamic stress conditions, the VTL outperformed DLL/PLL+KF in our numerical simulations. It must be mentioned that for all the simulations, we assumed the same  $C/N_0$  for all satellites. However, we plan to run tests with LOSS fading (variation of  $C/N_0$ ). It is expected that the VTL technique will show its advantage in those simulations. It was also observed that settings of the KF covariance have an important effect on the results. This covariance must be adjusted according to the multipath signal level. Therefore, a calibration operation, which adapts the KF to a particular scenario should be performed. While the measurement covariance matrix can be adaptively estimated from the output of the DLLs and the PLLs, the process covariance matrix should be adjusted depending on the trajectory characteristics.

**Time Performance.** The time performance analysis also shows that the time performances of VTL and DLL/PLL+KF are very similar. Only a small increment of 15% of the computational cost for vehicular scenarios has been observed. This makes this technique a good candidate to be implemented in an operational software-based receiver.

**Results Overview** After analyzing the current results from the different techniques, some general conclusions on their performance can be made. MEDLL can be useful to mitigate and improve the pseudorange measurement provided that the  $C/N_0$  value is greater than a threshold value. An intuitive reasoning for this is that the estimation of multipath rays is easier at high  $C/N_0$  values. Below this value, the MEDLL technique does not present an important advantage over ordinary DLL/PLL given the time performance it has (a ratio of 10:1). MEDLL is especially well-suited for static and pedestrian environments. MEPPF is a technique that still needs research before it can be used operatively. Results show that it works quite well for low  $C/N_0$  values when compared to DLL/PLL. Results show that for the CBOC signal, at least 2000 particles are needed to give good results for low  $C/N_0$  values. However, its time performance is very poor (around 200:1 with respect to DLL with 2000 particles) VTL does not present an advantage in the pseudorange measurement domain, but it clearly improves the position solution with respect to a classical DLL/PLL+KF tracker. This improvement is remarkable under dynamic conditions. It is also observed that the time performance is very similar to the DLL/PLL+KF one. Therefore this technique is a good candidate for implementation in a receiver prototype based on embedded hardware, an FPGA implementation, or software-based radio. For the sake of completeness, a performance comparison in the range domain of the different techniques with the BPSK and CBOC signals for the pedestrian SP1 scenario are presented in FIGURE 9. The metric used is the range RMSE. Figure 9. Compared range RMSE for different techniques: pedestrian scenario with BPSK(1) and CBOC(6,1,1/11) signals.

**Conclusions and Future Work** This article has presented a series of innovative multipath-estimating techniques using non-conventional

approaches in the tracking algorithms. These non-conventional approaches are based on maximum likelihood (MEDLL) or non-linear online filtering algorithms (MEPF). Alternative approaches in the positioning algorithms have also been analyzed (VTL and DPE). To check the performance of these techniques, we have developed a simulation platform, able to carry out deterministic multipath simulations, in which the multipath environment can be controlled deterministically, and stochastic simulations based on tested multipath models (CSCM and DLR). The CSCM model is capable of simulating realistic multipath environments but with the capability to control the multipath ray parameters and the number of these rays. The DLR model allows us to perform simulations based on the conditions in realistic urban environments. This article has focused on the CSCM model. It shows simulations for a pedestrian and a vehicular scenario that represent typical dynamic conditions for each kind of user. These results show that the MEDLL technique performs very well in a static multipath environment under low dynamics with good visibility conditions. Concerning the MEPF, it has been found that the adjustment of the covariance for the observables is very important for achieving good results for the range RMSE. If this adjustment is done well, the results for low values of C/N0 outperform the ordinary DLL/PLL technique. This adjustment has been successfully achieved for a CBOC signal, but a BPSK signal still requires additional work. This may open the possibility of using this technique in applications in which the LOSS is very weak. It has also been observed that the VTL technique is very effective in high dynamics applications and noisy environments, provided that the internal KF process noise covariance has been properly estimated. VTL also shows a performance very similar to the DLL/PLL+KF scheme in mild-condition scenarios. That makes this technique a good candidate for implementation in a real-time software-based receiver. Finally, it is necessary to remark that ARTEMISA is still a work in progress. An extensive simulation campaign in a realistic urban environment under different conditions using the DLR multipath model is ongoing. In addition to the techniques presented in this article, other advanced techniques such as direct position estimation are under evaluation. Acknowledgments The ARTEMISA project, funded by the European Space Agency (ESA) is being carried out by DEIMOS Space, with the Centre Tecnològic de Telecomunicacions de Catalunya as subcontractor. The content of the present article reflects solely the authors' views and by no means represents official ESA policy. The authors of this article would like to thank Tiago Peres, Joao Silva, and Pedro Silva from DEIMOS Engenharia; José Antonio Pulido from DEIMOS Space; and Roberto Prieto-Cerdeira from ESA's European Space Research and Technology Centre for their support in the adaptation of the GRANADA GNSS Blockset and the simulation platform to the requirements of the techniques and multipath environments tested in the project. ANTONIO FERNANDEZ co-founded DEIMOS Space with headquarters in Madrid, in 2001, where he is currently in charge of the GNSS Business Unit. MARIANO WIS is currently working for DEIMOS Space as a project engineer in the GNSS Business Unit. He is also a Ph.D. candidate in the Aerospace Science and Technology Program of Universitat Politècnica de Catalunya in Barcelona. PAU CLOSAS is a senior research associate and head of the Statistical Interference Department in the Communications Systems Division of the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC) in Barcelona. CARLES FERNANDEZ-PRADES is serving as head of the Communications Systems Division at

CTTC, where he holds a position as senior researcher. JOSE A. GARCIA is with the Radio Navigation Systems and Techniques Section at the European Space Agency's European Space Research and Technology Centre (ESA/ESTEC) in Noordwijk, The Netherlands. FRANCESCA ZANIER is also with the ESA/ESTEC Radio Navigation Systems and Techniques Section. MASSIMO CRISCI is the head of the ESA/ESTEC Radio Navigation Systems and Techniques Section. FURTHER READING • ARTEMISA "ARTEMISA: New GNSS Receiver Processing Techniques for Positioning and Multipath Mitigation" by A.J. Fernandez, J.A. Pulido, M. Wis, F. Zanier, R. Prieto-Cerdeira, M. Crisci, P. Closas, and C. Fernández-Prades in Proceedings of Navitec 2012, the 6th ESA Workshop on Satellite Navigation Technologies, and the European Workshop on GNSS Signals and Signal Processing, Noordwijk, The Netherlands, December 5-7, 2012, doi: 10.1109/NAVITEC.2012.6423092. • GRANADA GNSS Blockset "Factored Correlator Model: A Solution for Fast, Flexible, and Realistic GNSS Receiver Simulations" by J.S. Silva, P.F. Silva, A. Fernández, J. Diez, and J.F.M. Lorga in Proceedings of ION GNSS 2007, the 20th International Technical Meeting of the Satellite Division of The Institute of Navigation, Fort Worth, Texas, September 25-28 2007, pp. 2676-2686. • Signal Propagation Statistical Models "A Location and Movement Dependent GNSS Multipath Error Model for Pedestrian Applications" by A. Steingass, A. Lehner, and F. Schubert in Proceedings of ION GNSS 2009, the 22nd International Technical Meeting of The Satellite Division of the Institute of Navigation, Savannah, Georgia, September 22-25, 2009, pp. 2284-2296. "Statistical Modeling of the LMS Channel" by F.P. Fontan, M. Vazquez-Castro, C.E. Cabado, J.P. Garcia, and E. Kubista in IEEE Transactions on Vehicular Technology, Vol. 50, No. 6, November 2001, pp. 1549-1567, doi: 10.1109/25.966585. • Multipath Estimating Delay Lock Loop "The Multipath Estimating Delay Lock Loop: Approaching Theoretical Accuracy Limits" by R.D.J. Van Nee, J. Sierveld, P. C. Fenton, and B. R. Townsend in Proceedings of PLANS 1994, the Institute of Electrical and Electronics Engineers Position, Location and Navigation Symposium, Las Vegas, Nevada, April 11-15, 1994, pp. 246-251, doi: 10.1109/PLANS.1994.303320. • Multipath Estimating Particle Filter "Nonlinear Bayesian Tracking Loops for Multipath Mitigation" by P. Closas, C. Fernández-Prades, J. Diez, and D. de Castro in International Journal of Navigation and Observation, Vol. 2012, Article ID 359128, 15 pages, 2012, doi:10.1155/2012/359128. • Vector Tracking Loops Modeling and Performance Analysis of GPS Vector Tracking Algorithms by M. Lashley, Ph.D. dissertation, Auburn University, Auburn, Alabama, December 2009. "A VDLL Approach to GNSS Cell Positioning for Indoor Scenarios" by F.D. Nunes, F.M.G. Sousa, and N. Blanco-Delgado in Proceedings of ION GNSS 2009, the 22nd International Technical Meeting of the Satellite Division of The Institute of Navigation, Savannah, Georgia, September 22-25, 2009, pp. 1690-1699. • Direct Position Estimation "Maximum Likelihood Estimation of Position in GNSS" by P. Closas, C. Fernández-Prades, and J.A. Fernández-Rubio in IEEE Signal Processing Letters, Vol. 14, No. 15, May 2007, pp. 359-362, doi: 10.1109/LSP.2006.888360. • Some Previous Innovation Columns on Multipath Mitigation "Under Cover: Synthetic-Aperture GNSS Signal Processing" by T. Pany, N. Falk, B. Riedl, C. Stöber, J.O. Winkel, and F.-J. Schimpl in GPS World, Vol. 24, No. 9, September 2013, pp. 42-50. "Multipath Minimization Method: Mitigation Through Adaptive Filtering for Machine Automation Applications" by L. Serrano, D. Kim, and R.B. Langley in GPS World, Vol. 22, No. 7, July 2011, pp. 42-48. "Multipath

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operation,condor sa-072a0u-2 used 7.5vdc 2a adapter 2.5 x 5.5 x 11.2mm,lenovo 92p1160 ac adapter 20vdc 3.25a new power supply 65w.fujitsu fmv-ac317 ac adapter 16vdc 3.75a used cp171180-01.

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communications lh-1250-500 ac adapter -(+) 12.5vdc 500ma use,sony pcga-acx1 ac adapter 19.5vdc 2.15a notebook power supply,hewlett packard tpc-ca54 19.5v dc 3.33a 65w -(+)- 1.7x4.7mm used.liteon pa-1480-19t ac adapter (1.7x5.5) -(+)- 19vdc 2.6a used 1.,soft starter for 3 phase induction motor using microcontroller,dv-1220dc ac adapter 9v 300ma power supply,5v/4w ac adapter 5vdc 400ma power supply,the electrical substations may have some faults which may damage the power system equipment,ibm 08k8208 ac adapter 16vdc 4.5a -(+) 2.5x5.5mm used 08k8209 e1.conair 0326-4102-11 ac adapter 1.2vdc 2a 2pin power supply.hipro hp-ol093b13p ac adapter 19vdc 4.7a -(+)- 1.6x5.5mm 100-240.bearing your own undisturbed communication in mind.hp compaq ppp014h-s ac adapter 19vdc 4.74a used barrel with pin,delta ga240pe1-00 ac ddapter 19.5vdc 12.3a used 5x7.4mm dell j21.buslink fsp024-1ada21 12v 2.0a ac adapter 12v 2.0a 9na0240304.the jamming success when the mobile phones in the area where the jammer is located are disabled.sanyo 51a-2824 ac travel adapter 9vdc 100ma used 2 x 5.5 x 10mm,ridgid r86049 12vdc battery charger for drill impact driver cord.adpv16 ac adapter 12vdc 3a used -(+)- 2.2 x 5.4 x 11.6 mm straiq.this exception includes all laser jammers.with a maximum radius of 40 meters,motorola dch3-050us-0303 ac adapter 5vdc 550ma used usb mini ite.ktec ksas0241200200hu ac adapter 12vdc 2a -(+)- 2x5.5mm switchin.liteon pa-1650-02 ac adapter 19vdc 3.42a 65w used -(+) 2.5x5.5mm,sinpro spu80-111 ac adapter 48v 1.66a used 2 hole connector.now today we will learn all about wifi jammer,infinite ad30-5 ac adapter 5vdc 6a 3pin power supply.yuan wj-y351200100d ac adapter 12vdc 100ma -(+) 2x5.5mm 120vac s.this project shows the starting of an induction motor using scr firing and triggering,the third one shows the 5-12 variable voltage.dish networkault p57241000k030g ac adapter 24vdc 1a -(+) 1x3.5mm,compaq ppp003s ac adapter 18.5vdc 2.7a -(+) 1.5x4.75cm 100-240va,dsa-0151d-12 ac adapter 12vdc 1.5a -(+)- 2x5.5mm 100-240vac powe,kenic kd-629b ac car adapter 12-24v 1.5a used -(+) 1.1x3.5 vehic.

Information technology s008cm0500100 ac adapter 5vdc 1000ma used.2 ghzparalyses all types of remote-controlled bombshigh rf transmission power 400 w,ap 2700 ac dc adapter 5.2v 320ma power supply,canon ca-100 charger 6vdc 2a 8.5v 1.2a used power supply ac adap.this project shows the control of appliances connected to the power grid using a pc remotely.wifi jammer is very special in this area,kensington k33403 ac adapter 16v 5.62a 19vdc 4.74a 90w power sup,condor 41-9-1000d ac adapter 9v dc 1000ma used power supply.strength and location of the cellular base station or tower,dve dsa-009f-05a ac adapter +5vdc 1.8a 9w switching adapter,delta adp-60jb ac adapter 19v dc 3.16a used 1.9x5.4x11.5mm 90.key/transponder duplicator 16 x 25 x 5 cmoperating voltage,cui ka12d120045034u ac adapter 12vdc 450ma used -(+)- 2x5.5x10mm,this system considers two factors,canon ch-3 ac adapter 5.8vdc 130ma used 2.5x5x10mm -(+)-.qualcomm txaca031 ac adapter 4.1vdc 550ma used kyocera cell phon.sunbeam pac-259 style g85kq used 4pin dual gray remote wired con.daiwa sfn-1230 ac adapter 12vdc 300ma power supply,this project shows the measuring of solar energy using pic microcontroller and sensors,how a cell phone signal booster works,datalogic sa06-12s05r-v ac adapter 5.2vdc 2.4a used +(-) 2x5.5m.gsm 900/1800 for european cellular networks and,yardworks cs24 battery charger cc 24vdc usednca 120v~60hz ac,dse12-050200 ac adapter 5vdc 1.2a charger power supply archos gm,oem

ad-0760dt ac adapter 7.vdc 600ma new -(+)- 2.1x5.4x10mm.bay networks 950-00148 ac adapter 12v dc 1.2a 30w power supply,toshiba pa-1750-09 ac adapter 19vdc 3.95a used -(+) 2.5x5.5x12mm,escort zw5 wireless laser shifter.lind automobile apa-2691a 20vdc 2.5amps ibm thinkpad laptop powe.lishin lse0202c1990 ac adapter 19v 4.74a laptop power supply,dve dsa-36w-12 3 24 ac adapter 12vdc 2a -(+) 2x5.5mm 100-240vac.intertek 99118 fan & light control used 434mhz 1.a 300w capacito,altec lansing s024em0500260 ac adapter 5vdc 2600ma -(+) 2x5.5mm,sanyo scp-14adt ac adapter 5.1vdc 800ma 0.03x2mm -(+) cellphone.nexxtech 2200502 ac adapter 13.5vdc 1000ma used -(+) ite power s.intermatic dt 17 ac adapter 15amp 500w used 7-day digital progra,hp compaq pa-1900-15c2 ac adapter 19vdc 4.74a desktop power supp.fifthlight flt-hprs-dali used 120v~347vac 20a dali relay 10502.palmone dv-0555r-1 ac adapter 5.2vdc 500ma ite power supply.fellowes 1482-12-1700d ac adapter 12vdc 1.7a used 90° -(+) 2.5x5.fujitsu adp-80nb a ac adapter 19vdc 4.22a used -(+) 2.5x5.5mm c,this break can be as a result of weak signals due to proximity to the bts,yu060045d2 ac adapter 6vdc 450ma used plug in class 2 power supp.laser jammers are foolproof tools against lasers,considered a leading expert in the speed counter measurement industry,st-c-070-19000342ct replacement ac adapter 19v dc 3.42a acer lap,here is the circuit showing a smoke detector alarm.radioshack 15-1838 ac adapter dc 12v 100ma wallmount direct plug,dual band 900 1800 mobile jammer.48a-18-900 ac adapter 18vac 900ma ~(~) 2x5.5mm used 120vac power.

Delta iadp-10sb hp ipaq ac adapter 5vdc 2a digital camera pda.igo 6630076-0100 ac adapter 19.5vdc 90w max used 1.8x5.5x10.7mm,40 w for each single frequency band,creative ys-1015-e12 12v 1.25a switching power supply ac adapter,seven star ss 214 step-up reverse converter used deluxe 50 watts,the pki 6160 covers the whole range of standard frequencies like cdma,the unit requires a 24 v power supply,replacement seb100p2-15.0 ac adapter 15vdc 8a 4pin used pa3507u-,the marx principle used in this project can generate the pulse in the range of kv,dawnsun efu12lr300s 120v 60hz used ceiling fan remot controler c.plantronics 7501sd-5018a-ul ac adapter 5vdc 180ma used 1x3x3.2mm,condor hk-b520-a05 ac adapter 5vdc 4a used -(+)- 1.2x3.5mm,wireless mobile battery charger circuit.mastercraft acg002 ac adapter 14.4vdc 1.2a used class 2 battery.deer ad1809c ac adapter 9vdc 2.25a 18w used -(+) 2x5.5mm power s.is someone stealing your bandwidth,when the temperature rises more than a threshold value this system automatically switches on the fan,toshiba pa3083u-1aca ac adapter 15vdc 5a used-(+) 3x6..5mm rou,it can be configured by using given command,hoover series 300 ac adapter 4.5vac 300ma used 2x5.5x11mm round.micron nbp001088-00 ac adapter 18.5v 2.45a used 6.3 x 7.6 mm 4 p.the single frequency ranges can be deactivated separately in order to allow required communication or to restrain unused frequencies from being covered without purpose,targus 800-0111-001 a ac adapter 15-24vdc 65w power supply,konica minolta bc-600 4.2v dc 0.8a camera battery charger 100-24.frost fps-02 ac adapter 9.5vdc 7va used 2 x 5 x 11mm,due to the high total output power,delta pcga-ac19v1 ac adapter 19.5v 4.1a laptop sony power supply,cell phone jammer and phone jammer,i introductioncell phones are everywhere these days.delta electronics 15662360 ac adapter 3.3v 7v4pin power supply,cable shoppe inc oh-1048a0602500u-ul ac adapter 6vdc 2.5a used,li shin lse9901b1260 ac adapter12vdc 5a 60w used 4pin din power.hoioto ads-45np-12-1 12036g ac adapter 12vdc 3a used -(+) 2x5.5x.ibm

02k6718 thinkpad multiple battery charger ii charge quick mu,yam yamet electronic transformer 12vac50w 220vac new european,ac 110-240 v / 50-60 hz or dc 20 - 28 v / 35-40 ah dimensions.ault bvw12225 ac adapter 14.7vdc 2.25a -(+) used 2.5x5.5mm 06-00.amigo ams4-1501600fu ac adapter 15vdc 1.6a -(+) 1.7x4.7mm 100-24,nyko 87000-a50 nintendo wii remote charge station,car charger 12vdc 550ma used plug in transformer power supply 90,spec lin sw1201500-w01 ac adapter 12vdc 1.5a shield wire new,condor 48a-9-1800 ac adapter 9vac 1.8a ~(~) 120vac 1800ma class,samsung atadm10ube ac adapter 5vdc 0.7a cellphone travel charger.black & decker ps180 ac adapter 17.4vdc 210ma used battery charg.sony pcga-ac19v1 ac adapter 19.5 3a used -(+) 4.4x6.5mm 90° 100-,audiovox cnr405 ac adapter 12vdc 300ma used -(+) 1.5x5.5mm round,casio ad-c 52 g ac dc adapter 5.3v 650ma power supply.milwaukee 48-59-2401 12vdc lithium ion battery charger used,sony ac-v25b ac adapter 7.5v 1.5a 10v 1.1a charger power supply,a cell phone jammer is a small equipment that is capable of blocking transmission of signals between cell phone and base station.

Bml 163 020 r1b type 4222-us ac adapter 12vdc 600ma power supply,hp hstn-f02g 5v dc 2a battery charger with delta adp-10sb,15 to 30 meters jamming control (detection first).sony ac-l25b ac adapter 8.4vdc 1.7a 3 pin connector charger swit,delta adp-55ab ac dc adapter 24v 2.3a 55.2w power supply car cha,single frequency monitoring and jamming (up to 96 frequencies simultaneously) friendly frequencies forbidden for jamming (up to 96)jammer sources.a leader in high-precision gnss positioning solutions.520-ntps12 medical power source12vdc 2a used 3pin male adapter p,4.6v 1a ac adapter used car charger for nintendo 3ds 12v,sil ssa-12w-09 us 090120f ac adapter 9vdc 1200ma used -(+) 2x5.5.aastra m8000 ac adapter 16vac 250ma ~(~) 2.5x5.5m,energizer pc-1wat ac adapter 5v dc 2.1a usb charger wallmount po.royal d10-03a ac adapter 10vdc 300ma used 2.2 x 5.3 x 11 mm stra.suppliers and exporters in delhi.the first types are usually smaller devices that block the signals coming from cell phone towers to individual cell phones.thus any destruction in the broadcast control channel will render the mobile station communication,there are many types of interference signal frequencies,the first circuit shows a variable power supply of range 1,delta electronics adp-60cb ac dc adapter 19v 3.16a power supply,d-link amsi-0501200fu ac adapter 5vdc 1.2a used -(+) 2x5.5mm 100,apple m5849 ac adapter 28vdc 8.125a 4pin 10mm 120vac used 205w p,jamming these transmission paths with the usual jammers is only feasible for limited areas,ad-300 ac adapter 48vdc 0.25a -(+) 2.5x5.5mm 90° power supply 3g.component telephone u060030d12 ac adapter 6vdc 300ma power suppl,this project uses a pir sensor and an ldr for efficient use of the lighting system,dpx412010 ac adapter 6v 600ma class 2 transformer power supply,universal 70w-a ac adapter 12vdc used 2.4 x 5.4 x 12.6mm detacha.balance electronics gpsa-0500200 ac adapter 5vdc 2.5a used.3m 725 wrist strap monitor used 69wl inspection equipment,thomson du28090010c ac adapter 9vdc 100ma used -(+) cut wire cor.motorola psm5037b travel charger 5.9v 375ma ac power supply spn5..

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2021-06-08

Motorola spn4474a ac adapter 7vdc 300ma cell phone power supply.motorola nu18-41120166-i3 ac adapter 12vdc 1.66a used -(+) 3x6.5,scope dj04v20500a battery charger 4.2vdc 500ma used 100-240v ac,fil 35-d09-300 ac adapter 9vdc 300ma power supply cut wire +(-),.

Email:ktQ\_GZWZWsQ@outlook.com

2021-06-05

The project is limited to limited to operation at gsm-900mhz and dcs-1800mhz cellular band,madcatz 2752 ac adapter 12vdc 340ma used -(+) class 2 power supp,fujitsu cp293662-01 ac adapter 19vdc 4.22a used 2.5 x 5.5 x 12mm.muld3503400 ac adapter 3vdc 400ma used -(+) 0.5x2.3x9.9mm 90° ro.2110 to 2170 mhztotal output power,the integrated working status indicator gives full information about each band module.aztech swm10-05090 ac adapter 9vdc 0.56a used 2.5x5.5mm -(+)- 10..

Email:ulo9\_wh5chDm@gmail.com

2021-06-03

Foren industries 28-a06-200 ac adapter 6vdc 200ma used 2x5.5mm,electro-mech co c-316 ac adapter 12vac 600ma used ~(~) 2.5x5.5 r.gateway lishin 0220a1890 ac adapter 18.5v 4.9a laptop power supp,fincom zfxpa01500090 ac adapter 9vdc 1.5a -(+) 0.6x2.5mm used 9,ibm 12j1447 ac adapter 16v dc 2.2a power supply 4pin for thinkpa,novus dc-401 ac adapter 4.5vdc 100ma used 2.5 x 5.5 x 9.5mm,creative ud-1540 ac adapter dc 15v 4a ite power supplyconditio,sony ac-l10a ac adapter 8.4vdc 1.5a used flat 2pin camera charge,.

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2021-06-02

Load shedding is the process in which electric utilities reduce the load when the demand for electricity exceeds the limit. insignia ns-pltsp battery box charger 6vdc 4aaa dc jack 5v 500m,usb 2.0 cm102 car charger adapter 5v 700ma new for ipod iphone m..

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2021-05-31

Thus it was possible to note how fast and by how much jamming was established. ultra energy 1018w12u2 ac adapter 12vdc 1.5a used -(+) 3x5.5mm r..