Evaluation of Multipath Effects on Interference Cancellation in GNSS using Space-Time based Array Processing

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Abstract

Space-time adaptive processing is a powerful tool for interference rejection. However, its performance may significantly degrade in the presence of multipath. Due to the coherence between the multipath of the interference, adaptive methods are not able to satisfactorily remove the interference. In this paper, we present a simulation study to quantify the degradation of a common adaptive method in different multipath scenarios. Both spread-spectrum and narrowband interference sources are considered. Particularly, performance analyses versus the angular and delay separations between the line of sight and multipath components of the interference are investigated. Insightful conclusions are drawn.

1. Introduction

Since the introduction of GPS, the first modern constellation of Global Navigation Satellite System (GNSS), one of the aims in the navigation society is to implement satellite-based navigation for all phases of flight, i.e. en-route, terminal, approach, and surface navigation, replacing the conventional ground-based aeronautical navigation equipments, such as DME, TACAN, etc.

The navigation satellite link budget, which determines the signal power spectrum density level received by a normal omni-directional antenna is well below the thermal noise floor. A GNSS receiver has to rely on despreading techniques to boost the signal power. The existing GNSS systems are therefore inherently vulnerable to Radio-Frequency Interference (RFI). Adaptive antenna array and Space-Time Adaptive Processing (STAP) are promising and powerful methods to deal with interferences.

Beside the direct path of the interference, the multipath components also introduce unwanted interference power to the GNSS antenna array. For GNSS equipments, the negative effect is not only the extra interference power due to interference multipath, but also the distorted spatio-temporal covariance matrix of the received signal due to the correlation between the different paths of the interference. This causes degradation of the performance of STAP and hence the interference power would be less effectively cancelled.

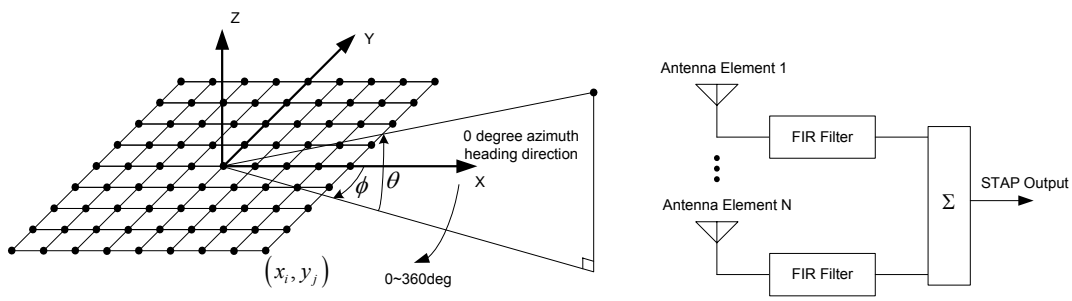
For a general aviation vehicle, the multipath components could be generated by aircraft wings, tails, fuselage, ground and building reflections [1]. So both the desired satellite signal and the interference could experience multipath propagation. Multipath components of the desired signal may cause significant degradation of positioning accuracy. The latter is generally not affected by whether the interference experiences multipath propagation or not [2]; only the total power of the interference is a factor. However, the ability of STAP to reduce the interference power is undermined by multipath propagation. The aim of this paper is to investigate this issue by quantifying the degradation of STAP in different scenarios. Previous work on this issue can be found in [3] and [4], where the multipath is generated using a few symmetrically and uniformly distributed scatterers, and the impact of multipath was mainly studied with respect to system bandwidth.

In this paper, the antenna array based interference suppression scheme is analysed for different types of interference signals. The performance of STAP is quantified for different values of the angular and delay separation between the LOS and NLSO components. One of the widely used adaptive algorithms, Eigenvalue beamforming, is chosen to illustrate our results. The interference types studied here are continuous wave (CW), or narrowband, interference and spread spectrum interference. The typical interference for ground-based aeronautical navigation equipments, such as DME and TACAN system, is a pulse narrowband signal. The pseudolite which transmits

navigation satellite like signals, deployed near the airport, would cause spread spectrum interference of increasing power when the aircraft approaches landing.

2. System and Signal Model Description and Multipath Effect

In Figure 1(a), the geometry and element definition of a conventional antenna array is shown. To have good performance of wide-band noise cancellation and multipath immunity, STAP is deployed as shown in Figure 1(b). The antenna array setup used in our simulation is a 5-by-5 planar array with half wavelength inter-element separation and a 4-tap FIR filter is associated with each antenna.



(a) (b)

Figure 1 (a) Antenna Array Geometry and Element Definition (b) Space-Time Adaptive Antenna Array Structure

To obtain the desired antenna gain, optimization methods could generally be divided into two categories, constraint optimization [3][5] and unconstraint optimization [5]. In [4], the comparison between constraint and unconstraint optimizations is provided. In this paper, the unconstraint method of minimum overall power is used to evaluate the multipath effects. In this method, the optimal STAP coefficient vector, w_o, minimizes the Rayleigh quotient [5]

$$w_o = \arg\min_{w} \frac{w^H R w}{w^H w} \tag{1}$$

where R is the spatio-temporal covariance matrix and ^{H} denotes Hermitian transpose. The solution is given by the eigenvector associated with the smallest eigenvalue of the R.

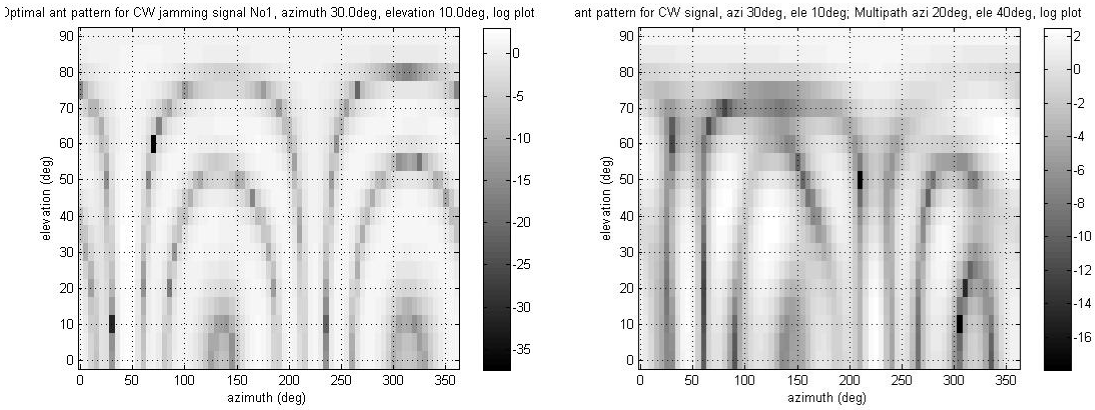
It is worth pointing out that prior to dispreading, the GNSS signal has a much lower SNR than the interference, and has therefore no impact on the operation of STAP. Thus, by choosing the STAP to minimize the overall power, only the interference will be suppressed. The distortion of the desired signal due to the STAP based on the above unconstraint optimization was shown to be at an acceptable level in some situations [4].

The signal model for the unwanted interference and its multipath components at the ith antenna element and n^{th} tap of the FIR filter is given as follows:

$$x_i(t,n) = s(t-\tau_i-nT)e^{j\omega_0(t-\tau_i-nT)} + \sum_{k=1}^{P}\alpha_k s(t-\tau_{ik}-d_k-nT)e^{j\omega_0(t-\tau_{ik}-d_k-nT)} \tag{2}$$

where $s(t)$ is a Pseudo-Random Number modulation code in the case of spread-spectrum interference and $s(t)=A_c$ (a constant) in the case of CW, τ_i is the delay associated with the ith antenna (which depend on the antenna array geometry) of the LOS, T is the FIR filter tap delay, ω_0 is the carrier angular frequency, P is the number of multipath components, α_k is the complex attenuation (with respect to LOS) of the kth multipath component, and τ_{ik} is the delay associated with the kth multipath component at the ith antenna.

In the case where the two types of interference coexist, simulation in Figure 2(a) shows that the DSSS from 70° Azimuth 60° Elevation and the CW coming from 30° Azimuth 10° Elevation are both suppressed. Figure 2(b) shows the degradation due to the multipath components coming from 50° Azimuth 40° Elevation for DSSS and 20° Azimuth 40° Elevation for CW, both with 6dB less power than LOS.



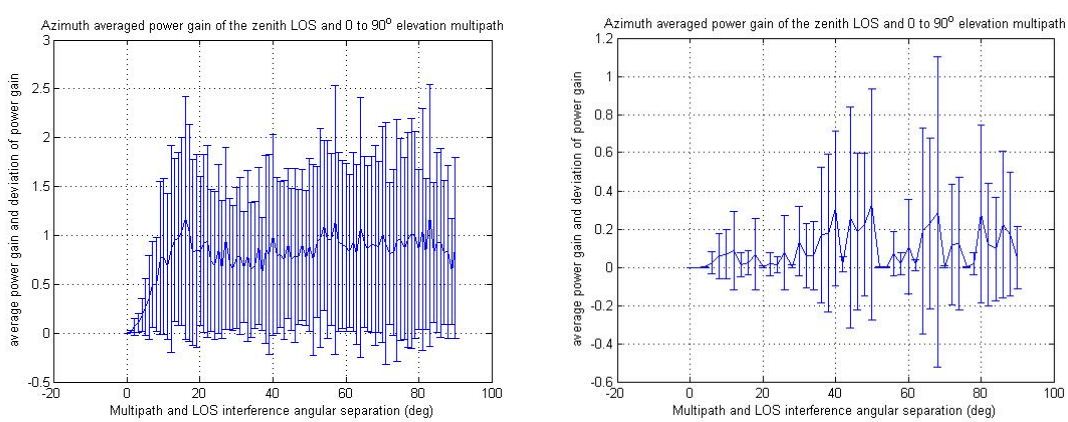
(a) (b)

Figure 2 (a) Antenna Pattern for DSSS Signal and CW Signal; (b) Antenna Pattern for DSSS Signal, CW Signal and their Multipath components

3. Performance versus angular and delay spreads

In order to study the effects of the angular spread of the interference on STAP-based interference cancellation, we focus on the two path scenario: one is the LOS signal fixed at the zenith angle, and the other one is a reflected path with 6dB less power and fixed elevation, whereas its azimuth angle varies within a complete cycle. Since performance is angle dependent, we evaluate the mean and standard deviation of the power gain, which is used as a performance figure of merit. For the spread spectrum case, the delay difference between the two paths is much smaller than the inverse of the signal bandwidth.

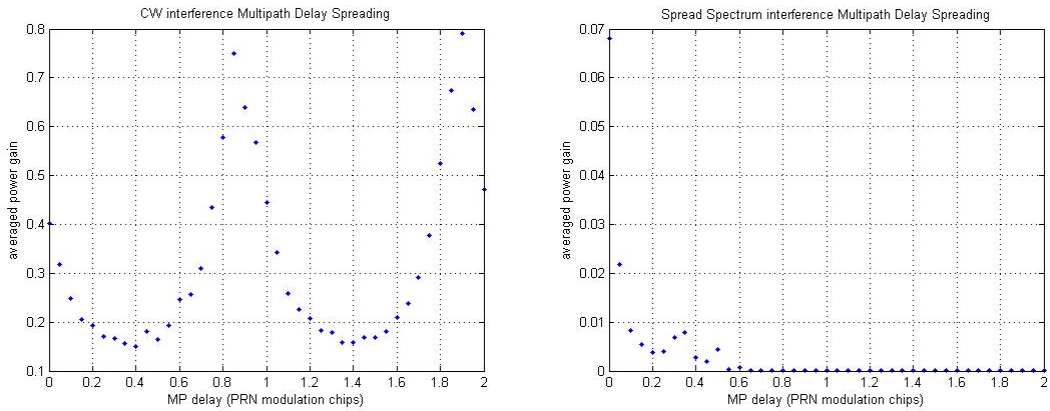
In Figure 3(a), the total power suppression for LOS and NLOS versus the angular separation in the case of CW interference is illustrated, and Figure 3(b) illustrates the same results in the case of DSSS. From Figure 3(a), we can see that the effective antenna gain for the CW interference and its multipath increases as the angular separation between LOS and multipath increases. The rate of change range from total suppression to nearly no suppression, and this depends on the relative amplitude and geometrical relationship between the two signals. From Figure 3(b), the same remark can be made about DSSS interference. However, it is seen that interference suppression is better than for CW interference. This is due to the fact that LOS and NLOS for DSSS are not as correlated as for CW. Nevertheless, DSSS interference is not completely satisfactorily suppressed because in our simulation we have chosen the delay difference to be smaller than the coherence time of the DSSS signal.



(a) (b)

Figure 3 (a) power suppression of the zenith point CW interference & its Multipath with different angular separation
(b) power suppression of the zenith point SS interference & its Multipath with different angular separation

Next, we investigate the effect of delay spread, i.e. delay difference between LOS and NLOS, on interference cancellation. Figure 4(a) and (b) depict performance of STAP versus the delay spread, which ranges from zero to 2 spread spectrum Code chip durations. It can be seen from Figure 4(b) that for the abovementioned multipath relative power conditions, significant DSSS interference suppression can be obtained when the delay spread is larger than 10% of the chip duration.



(a) (b)

Figure 4 (a) Effect of delay spread on the spatially averaged power gain for CW interference
(b) Effect of delay spread on the spatially averaged power gain for spread spectrum interference

4. Conclusions

Multipath propagation of the interference significantly degrades the performance of interference cancellation-based space-time array processing techniques. This degradation depends on the type of interference, and angular/delay separations spreads between the multipath components. Wideband interference was shown to suffer less from this degradation than narrowband interference. For a typical multipath relative power condition, an acceptable performance can be obtained in the case of wideband interference if the delay separation is larger than 10% of the inverse of the interference signal's bandwidth.

5. References

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