Ensuring GPS Availability in an Interference Environment

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ABSTRACT

We have studied a number of space-time processing algorithms that can be used to ensure availability of at least four GPS satellites in the presence of multiple strong interferers.

INTRODUCTION

We have previously shown [1] that although a space-only adaptive array is inadequate the adaptive space-time processor in Figure 1 can cancel broadband and narrowband interferers plus multipath, while preserving the integrity of GPS signals. However, there are multiple cancellation algorithms that can be used. In this paper, we will perform tradeoffs among these algorithms, using GPS satellite availability as a metric.

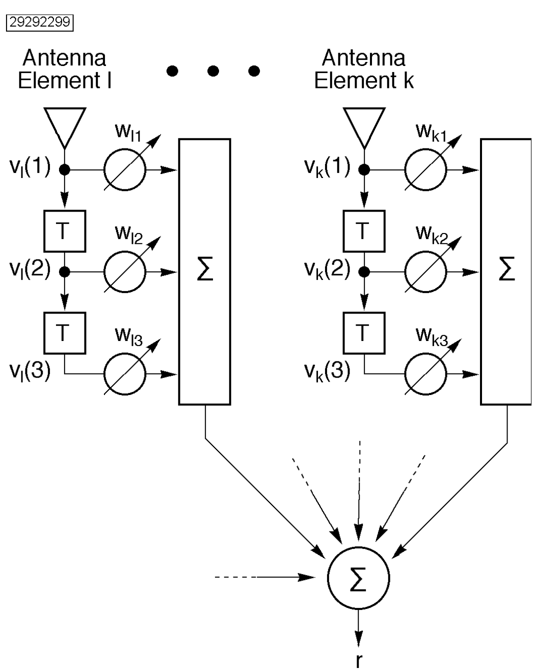

Figure 1. Adaptive Space-Time Array

ADAPTIVE PROCESSING ALGORITHMS

We desire to determine the set of weights that allow the processor shown in Figure 1 to cancel interference plus multipath while simultaneously permitting availability of GPS signals from as much of the upper hemisphere as possible. The most promising solutions are based on integrated approaches that require broad changes to a conventional GPS receiver. Solutions in this class include:

a) <u>Satellite Tracking (ST)</u>. Here, the processor uses navigation data to maintain a constraint on the antenna gain in the direction of each GPS satellite in view so that each channel in a multi-channel GPS receiver has a dedicated STAP processor. Of course, much of the weight computation is common among the channels. The data from each satellite is then processed independently to cancel interference, with the results from each satellite combined to obtain a navigation solution.

b) <u>Fixed, Independent Constraints (IC).</u> Rather than track each satellite, we place Q fixed constraints at predetermined locations in the upper hemisphere. Each of the Q data streams is processed independently (i.e., a different weight vector is applied to each of the Q beams) to cancel interference, and then processed with independent all-in-view processors. Pseudorange measurements from each of the Q all-in-view processors are combined to obtain the navigation solution.

Next, let us consider some algorithms that lead to solutions that are appropriate as appliques to existing antenna arrays. These could be implemented as an antenna electronics module inserted between an antenna array and a standard GPS receiver. These approaches do not require information on satellite positions. Some candidates are:

a) <u>Fixed, Simultaneous Constraints (SC)</u>. Apply constraints in P directions in the upper hemisphere, and then calculate a single weight vector that minimizes the output interference while simultaneously satisfying the *P* constraints. This weight vector is then applied to a single data stream. This method requires information only on platform attitude.

b) Maximum Average S/I (MA). Choose the weight vector that maximizes the signal-to-noise ratio averaged over the upper hemisphere. This algorithm requires information on platform attitude in order to determine the upward direction.

c) Minimum Mean Square Error Over Hemisphere (MM). Obtain the weight vector that minimizes the mean square error between the desired signal from a GPS satellite and the output of the processor in Figure 1, averaged over the upper hemisphere. This algorithm requires attitude information, but nothing else.

d) Power Minimization (PM). Because the received GPS satellite signals are well below the noise floor, this algorithm simply chooses the weight vector that minimizes the power out of the processor in Figure 1. This approach requires no navigational data.

PERFORMANCE TRADEOFFS

The aforementioned algorithms are compared based on their ability to provide a navigation solution in the presence of multiple interferers. We perform this comparison for a seven-element, planar, circular array with each element having a 3-dB gain at broadside (normal to the plane of the array and decreasing to –10 dB in the plane of the array. The array is oriented such that the broadside direction is normal to the surface of the earth. The antenna is assumed to be illuminated by M strong broadband interferers that are randomly located in azimuth within 6^o elevation band above the horizon. Also present are S multipath scatterers located randomly near the horizon at an average distance $R = 14\ m$ from the center of the array. The operating bandwidth B is 20 MHz (P-Code) and the K time taps shown in Figure 1 are separated by $T = 0.833/B$ (oversampled by 20%). All calculations to follow assume that the receive channels are perfectly matched, mutual coupling is ignored, and that the ideal interference covariance matrix is available. Thus, the results presented represent an upper bound on performance.

The results for GPS satellite availability are presented in terms of the margin in carrier-to-noise ratio (C/N_o) at zenith for a single antenna element. Margin at zenith is defined as

$$M_z = (C/N_o) - (C/N_o)_{th} \qquad (1)$$

where $(C/N_o)_{th}$ is the value at which carrier or code lock on a GPS satellite is lost. Typical margins range from about 15 dB-Hz for stressing State 5 conditions to about 28 dB-Hz for benign State 3.

By performing multiple Monte Carlo trials on interferer locations, we have been able to calculate the fraction of the upper hemisphere (minus a 10^o elevation mask at the horizon) where a GPS satellite is above the loss-of-lock threshold. In the limit of very many trials, this leads to the probability of single GPS satellite availability. This quantity can then be used to calculate the probability that N_s or more GPS satellites are available, where $N_s = 4$ represents the minimum number required to maintain a navigation solution.

A comparison of the performance of all the algorithms for the case of three $(M = 3)$ broadband interferers and four $(S = 4)$ multipath scatterers, each of strength –30 dB, is shown in Figure 2 for the case when there are $K = 5$ time taps per antenna. Each interferer is assumed to be so strong that it produces an interference-to-noise ratio of 60 dB on each antenna element. Note that if the time taps are not present $(K = 1)$ the performance was unacceptable. The shorthand notation used to describe each algorithm is shown in Table 1, where the notation $(\pi/4, 0)$ means that the constraint is placed at polar angle $\theta = \pi/4$ and azimuthal angle $\phi = 0$, with $\theta = 0$ corresponding to zenith.

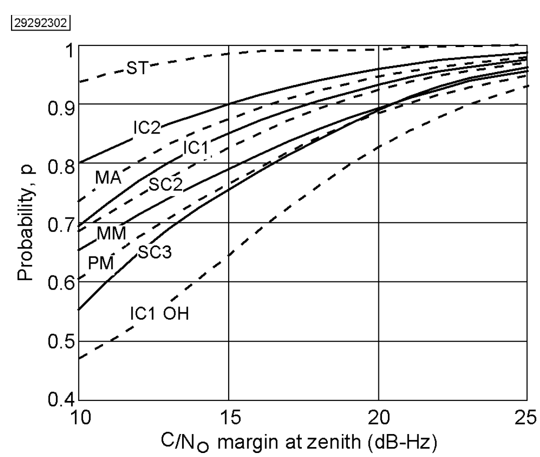

Figure 2. Probability of Single Satellite Availability in the Presence of Three Broadband

Interferers and Multipath

Table 1. Definitions of Acronyms Used in Figures

ST	=	satellite tracking
IC1	=	one independent constraint at *(π/4,0)*
IC2	=	two independent constraints at *(π/4, 0), (π/4, π)*
IC1 OH	=	one independent constraint at *(0, 0)*
PM	=	power minimization
SC2	=	two simultaneous constraints at *(π/4, 0), (π/4, π)*
SC3	=	three simultaneous constraints at *(π/4, 0), (π/4, 2π/3), (π/4, 4π/3)*
MA	=	maximum S/I averaged over hemisphere
MM	=	minimum mean square error averaged over hemisphere

From Figure 2 we see that, as expected, satellite tracking (ST) gives the best performance, followed by two fixed independent constraints at $(\pi/4, 0), (\pi/4, \pi)$. Using a single overhead constraint (IC1 OH) always gave the poorest performance. We can use the results in Figure 2, along with the results for differing number of interferers, to compute the probability of acquiring 4 or more satellites, 5 or more satellites, etc. The probability that N_s satellites will exceed the threshold is

$$P(N_s) = \int d\phi P_\phi(\phi) \sum_{N_I=0}^{\infty} P(N_s/\phi, N_I) P_I(N_I) \qquad (2)$$

where $P(N_s/\phi, N_I)$ is the probability that N_s satellites exceed the threshold given that the receiver is located at latitude ϕ and N_I interferers are present, $P_\phi(\phi)d\phi$ is the probability that the receiver lies within $d\phi$ about latitude ϕ and $P_I(N_I)$ is the probability that N_I interferers are present.

Consider a typical scenario where the probability $P_I(0)$ of no interferers present is $3/7$, the probability $P_I(1)$ of one interferer present = $2/7$, $P_I(2) = 1/7$, $P_I(3) = 1/28$, $P_I(4) = 1/28$, $P_I(5) = 1/28$, $P_I(6) = 1/28$ and $P_I(7) = 0$. Also, the receive array is assumed to have a uniform probability density of being located anywhere in longitude within the -65^o to $+65^o$ latitude band. The acquisition probabilities for this case are shown in Figures 3 and 4. The results for satellite tracking (ST) are not shown because that probability is essentially unity.

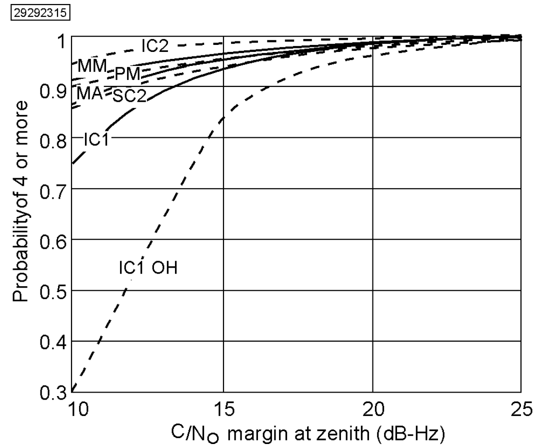

Figure 3. Average Probability That Four or More Satellites Are Available

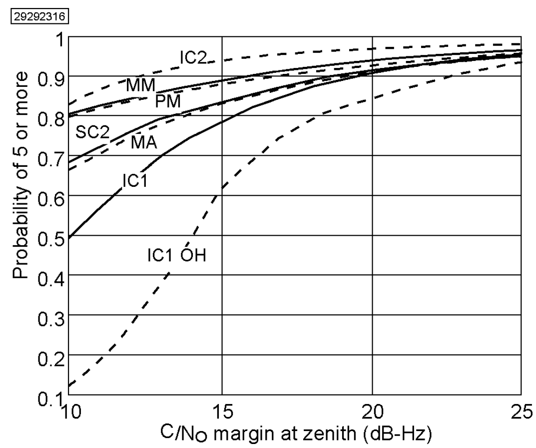

Figure 4. Average Probability That Five or More Satellites Are Available

These figures demonstrate that some of the appliques such as power minimization (PM) and minimum mean square error averaged over the upper hemisphere (MM) give performance that is nearly as good as the methods (e.g., IC2) that require processing multiple data streams. We have employed a severe threat with a J/N of 60 dB on each antenna element. Though not shown, absolute and relative performance did not appreciably change when J/N was reduced to 40 dB.

SUMMARY

Because space-only adaptive arrays give unacceptable performance for P(Y) code, we have considered space-time adaptive arrays. We studied two general types of adaptive algorithms: those that use NAV data and process multiple data streams independently and those that require little or no NAV information, and processes a single data stream. This latter class can be used as a next generation antenna electronics module (applique'). The best performance is always obtained by using an algorithm (ST) that tracks and places a separate constraint on each satellite vehicle. The next best performance is always obtained by using an algorithm (IC) that places two or more independent constraints in the upper hemisphere, and processes each beam independently. Neither of these approaches can be used as an applique'. We considered four algorithms (SC, MA, MM, PM) that have potential for use as an applique'. Of these, we found that the best combination of good performance and low computational complexity was achieved by minimizing the mean square error (MM) and power minimization (PM). These conclusions will be verified in a future study where we will synthesize constellations of GPS satellites, and then use the geometric dilution of precision (DOP) transformation along with the adapted C/N_o for each satellite vehicle to compute the east, north and vertical DOPs. These more detailed (and lengthy) simulations will confirm the first-order approach presented in this report. Included in our study will be the robustness of each algorithm when the receiver is banking (so that jammers may no longer be near the antenna-array horizon).

References

[1] R. L. Fante and J. J. Vaccaro, "Cancellation of Jammers and Jammer Multipath in a GPS Receiver", IEEE AES Systems Magazine, vol. 13, pp. 25-28, November 1998.