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ORIGINAL ARTICLE

Satellite clock bias estimation for iGPS

John Pratt · Penina Axelrad · Kristine M. Larson · Bruno Lesage · Richard Gerren · Nicholas DiOrio

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Abstract The High Integrity GPS program seeks to provide enhanced navigation performance by combining conventional GPS with a communications and ranging broadcast from the Iridium® Communications System. Through clock and message aiding, it would enable existing GPS receivers to acquire and track in more challenging environments. As is the case for standard GPS, accurate and precise timing is key to performance. An approach is presented for estimating the bias of each Iridium satellite clock using satellite-to-ground and satellite-to-satellite measurements. The satellite clock bias estimates are based on a Kalman filter that incorporates code-type observations from the measurements at 10 s intervals. Filter parameters are set based on the expected behavior of the clocks, allowing for discontinuous bias and frequency adjustments due to ground commands. Typical results show the current filter to be accurate to within 200 ns while always meeting the initial system specification of half a microsecond.

Keywords iGPS · Clock estimation · Kalman filtering · Clock ensemble

Introduction

The Office of Naval Research sponsored High Integrity GPS (iGPS) Technology Concept Demonstration Program is designed to improve the position, navigation, and timing performance for military GPS users by integrating the communications capability of the satellite network from Iridium Satellite LLC, hereafter referred to as Iridium. The Iridium constellation consists of 66 satellites. These satellites communicate with each other and the Iridium ground stations, or earth terminals, as well as users. With its network of satellites supplying coverage of the entire planet, Iridium provides global voice and data telecommunication services to both military and commercial customers with equipment and services targeting numerous markets such as maritime, aviation, defense/government, machine-to-machine communications, disaster response, and exploration/adventure (Foosa et al. 1998; Schuss et al. 1999).

The iGPS concept uses the Iridium communications capability to precisely transfer GPS time to properly equipped users in challenging environments such as natural and urban canyons, heavily wooded areas, and in the presence of intentional or unintentional interference. By establishing a robust means to provide this time to within 0.5 μs, the system will facilitate the acquisition of GPS and accelerate the time to first fix for properly authorized users in degraded environments. More information on using Iridium to augment GPS can be found in Joerger et al. (2009, 2010).

The Iridium satellites are in six orbital planes located in a low-Earth orbit altitude of $\sim$780 km with a high inclination of $\sim$86°. This leads to relatively short contact times with the ground, for 10 min or less, but higher received power signals than GPS. Each of the satellites is assigned a satellite vehicle (SV) number. The SV numbers are used to identify results shown in later sections.

The Iridium satellites use oven-controlled crystal oscillators onboard to generate the communications signals and maintain system time. Over short time intervals, these clocks are very stable, but over time spans larger than 100 s, the bias and drift of these clocks are less stable than

J. Pratt · P. Axelrad (✉) · K. M. Larson · B. Lesage · R. Gerren · N. DiOrio
Department of Aerospace Engineering Sciences, University of Colorado Boulder, 429 UCB, Boulder, CO 80309-0429, USA
e-mail: penina.axelrad@colorado.edu