TIME TRANSFER USING GPS CARRIER PHASE METHODS

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Abstract

We have conducted several time-transfer experiments using the phase of the GPS carrier rather than the code, as is done in current GPS-based time transfer systems. We used data from geodetic quality "off-the-shelf" dual-frequency GPS receivers, where up to 8 satellites can be simultaneously observed.

We connected two GPS receivers to two different atomic clocks at NIST. The antennas connected to the receivers were separated by about 40 m. The time difference between the clocks connected to the GPS receivers was estimated using weighted least-squares methods and carrier phase data. These relative clock estimates were then compared with the NIST time-scale system. We find agreement between the two methods of 55-80 picoseconds over periods of a week.

INTRODUCTION

Soon after the Global Positioning System was developed, the geophysical community began to apply it to numerous scientific problems, including plate tectonics, post-glacial rebound, interseismic deformation, and volcano monitoring.[1] The size of signals associated with these phenomena can be as small as 1 mm/yr. In order to address their science objectives, geophysicists have long been involved in research to improve the accuracy of GPS. When it became clear that their scientific goals required greater orbit accuracy, the geophysical community and their geodetic colleagues developed a global continuously operating GPS network. Data from this networkareused to provide extremely accurate GPS ephemerides. Along with model improvements and caretui reference frame definition, the accuracy of GPS position estimates now approaches one centimeter over averaging periods of a day.[2] Sub-centimeter horizontal precisions are routinely reported for distances of several thousand kilometers.[3] These achievements were made using the GPS carrier phase observable. The objective of this paper is to investigate the resolution of GPS carrier phase methods for time transfer.

ESTIMATION

The GPS carrier phase observable $\Delta\phi_r^s$ of wavelength λ can be written as:[4]

$$-\Delta\phi_r^s\lambda = \rho + c\delta^s - c\delta_r + N\lambda + \rho_t - \rho_i + \rho_m + \epsilon \quad (1)$$

where subscript r refers to the receiver and superscript s denotes the satellite. ρ is the geometric range, or $|\vec{X}^s - \vec{X}_r|$, where $\vec{X}^s$ is the satellite position at the time of signal transmission and $\vec{X}_r$ is the receiver position at reception time. Proper determination of ρ requires precise transformation parameters between the inertial and terrestrial reference frames, i.e. models of precession, nutation, polar motion, and UT1-UTC. ρ_t and ρ_i are the propagation delays due to the troposphere and ionosphere and ρ_m is the multipath error. ϵ represents unmodelled errors and receiver noise. Since the GPS receiver only tracks the fractional phase, an integer bias, N, must be introduced to the model equation. This bias is also known as the carrier phase ambiguity. δ^s and δ_r are the satellite and receiver clock errors. An equivalent model equation can be derived for the pseudorange or "code" observable with several important distinctions. Pseudorange is not biased and so N is not estimated. The magnitude of the ionospheric delay is the same, but opposite in sign. The most significant pseudorange limitation is that the ϵ term is nearly 100 times larger than for carrier phase.

The ionospheric delay can be effectively removed by combining the two GPS frequencies. The remaining parameters, δ^s, δ_r, $\vec{X}^s$, $\vec{X}_r$, ρ_t, and N must be estimated or known *a priori*. The model equation can be linearized and solved using weighted least squares. We used the GIPSY software to solve these equations.[5] Parameter estimation in GIPSY is carried out using a Square Root Information Filter (SRIF) algorithm described in [6]. Both satellite and receiver clocks are estimated at each data epoch relative to a reference receiver clock. The clock estimates are uncorrelated from epoch to epoch. The satellite coordinates $\vec{X}^s$ are taken from the IGS service, with a radial accuracy of 5-10 cm.[7] The IGS analysis includes GPS data from 50 or more GPS receivers around the world. We estimate the wet tropospheric path delay at zenith as a time-dependent parameter with a random walk noise model.[8]

RESULTS

Over short baselines, most geodetic parameters, including clocks, are insensitive to orbit error. This is also true of atmospheric conditions, which are common to both antennas for a short baseline. The limiting error sources in this case are likely to be multipath and receiver noise.

Two geodetic quality GPS receivers were connected to NIST Clock 16 and NIST Clock 21. Clock 16 is a hydrogen maser and Clock 21 is a cesium standard. Each GPS antenna was mounted to the roof of the NIST facility. The distance between the antennas was approximately 40 meters. The receivers were operated continuously for 28 days at a data interval of 30 seconds. Parameter estimation over short distances includes the behavior of Clock 21, carrier phase ambiguities, and the coordinates of each antenna. The carrier phase ambiguity bias terms were resolved.[9] Clock 16 was treated as the reference clock and its time-varying behavior was not estimated. There was no direct connection between the GPS receivers. All GPS estimates of the clocks are based on a full analysis of the GPS carrier phase observables.

We have made independent measurements of Clock 16 and Clock 21 using a special hardware system that looks like a group of time interval counters (TIC). These data were acquired automatically every