GPS Solut
DOI 10.1007/s10291-013-0331-y

ORIGINAL ARTICLE

Forward modeling of GPS multipath for near-surface reflectometry and positioning applications

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Received: 9 October 2012 / Accepted: 3 June 2013

Abstract Multipath is detrimental for both GPS positioning and timing applications. However, the benefits of GPS multipath for reflectometry have become increasingly clear for soil moisture, snow depth, and vegetation growth monitoring. Most multipath forward models focus on the code modulation, adopting arbitrary values for the reflection power, phase, and delay, or they calculate the reflection delay based on a given geometry and keep reflection power empirically defined. Here, a fully polarimetric forward model is presented, accounting for right- and left-handed circularly polarized components of the GPS broadcast signal and of the antenna and surface responses as well. Starting from the fundamental direct and reflected voltages, we have defined the interferometric and error voltages, which are of more interest in reflectometry and positioning applications. We examined the effect of varying coherence on signal-to-noise ratio, carrier phase, and code pseudorange observables. The main features of the forward model are subsequently illustrated as they relate to the broadcast signal, reflector height, random surface roughness, surface material, antenna pattern, and antenna orientation. We demonstrated how the antenna orientation—upright, tipped, or upside-down—involves a number of trade-offs regarding the neglect of the antenna gain pattern, the minimization of CDMA self-interference, and the maximization of the number of satellites visible. The forward model was also used to understand the multipath signature in GPS positioning applications. For example, we have shown how geodetic GPS antennas offer little impediment for the intake of near-grazing reflections off natural surfaces, in contrast to off metal, because of the lack of diversity with respect to the direct signal—small interferometric delay and Doppler, same sense of polarization, and similar direction of arrival.

Keywords GPS · GNSS · Multipath · Reflectometry · Reflections · Interferometric · Coherent · Simulator · Simulation

Introduction

For GPS users, multipath is used to describe the combined reception of direct or line-of-sight (LOS) signals and reflections, diffractions, or scatterings thereof. Multipath is detrimental for both GPS positioning and timing applications. However, the benefits of GPS multipath for reflectometry have become increasingly clear in the last decade. Specifically, the frequencies and amplitudes of the multipath signal observed in GPS data show strong correlations with environmental characteristics such as soil moisture, snow depth, and vegetation growth (Larson et al. 2008, 2009; Rodriguez-Alvarez et al. 2011a; Small et al. 2010).

Most multipath forward models focus on the code modulation, adopting arbitrary values for the reflection power, phase, and delay, or they calculate the reflection delay based on a given geometry and keep reflection power empirically defined. Here, a fully polarimetric forward model is presented, accounting for right- and left-handed circularly polarized components of the GPS broadcast signal and of the antenna and surface responses as well. It is based on the model developed by Zavorotny et al. (2010); it has been extended to allow for variable incident power and polarization, antenna orientation, code pseudorange, and noise power. The provision of a polarimetric

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Published online: 25 June 2013