ARTICLE IN PRESS

Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research xxx (2016) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Monitoring and evaluation algorithm of GNSS signal in space availability

Ershen Wang [a,b,*], Qing Zhang [a], Gang Tong [b], Pingping Qu [a], Tao Pang [a]

[a] School of Electronic and Information Engineering, Shenyang Aerospace University, Shenyang 110136, China
[b] Liaoning General Aviation Key Laboratory, Shenyang Aerospace University, Shenyang 110136, China

Received 2 February 2016; received in revised form 9 September 2016; accepted 15 September 2016

Abstract

In civil aviation and other navigation application fields, the availability of Global Navigation Satellite System (GNSS) in Signal in Space (SIS) is a key indicator to evaluate the performance. In this paper, the SIS availability of Global Positioning System (GPS) and BeiDou Navigation Satellite System (BDS) are evaluated and analyzed. The model of satellite availability algorithm is constructed based on the Markov process, with its reliability investigated. Moreover, the evaluation algorithm of constellation availability is developed. Based on the evaluation models, the performance of GPS SIS and BDS SIS is evaluated by using the measured data, respectively. Combined with the availability standard of GPS Standard Positioning Service (SPS) performance standards and BDS Signal In Space Interface Control Document (Version 2.0), the proposed evaluation models of SIS availability are effective and the performance of GPS SIS and BDS SIS conform the availability of performance standards, respectively. Meanwhile, the results are instructive for the study of the availability performance monitoring and the evaluation of global BDS.

Keywords: GNSS; Signal-in-space; Availability; GPS; BDS

1. Introduction

With the development of Global Navigation Satellite System (GNSS), nowadays the GNSS has been widely used in navigation and positioning on Earth's surface (Jin et al., 2009, 2013, 2016a; Li et al., 2010; Hou et al., 2014). Meanwhile, the compatibility, interoperability and service performance of GNSS has become an important issue regarding to the system construction and the users' requirements (Zhao et al., 2016; Li et al., 2013; Jin, 2014). Since there is not a unified standard for satellite navigation service, e.g., GPS of the United States, Galileo of the European Union, GLONASS of Russia and BeiDou of China (Steffen et al., 2011; Jin et al., 2011, 2016b), the name of indicators, the manner and the prescribed scope of indicators also have large differences. The GPS service performance has just referred to the official documents, such as GPS Standard Positioning Service (SPS) performance standard to civil users, GPS Precise Positioning Service (PPS) performance standard to the military and particular users, and GPS Wide Area Augmentation System (WAAS) performance standard. Also since 1993, on the basis of performance standards given by GPS SPS, the Federal Aviation Administration (FAA) has monitored GPS and constructed its augmentation system, and corresponding results were shown in its quarterly performance analysis report (Federal Aviation Administration, 2015). Amongst existing standards, the GPS SPS PS released by USA is more widely used to evaluate satellite navigation systems (John and Joseph, 2011).

* Corresponding author at: School of Electronic and Information Engineering, Shenyang Aerospace University, Shenyang 110136, China.
E-mail address: wes2016@126.com (E. Wang).

http://dx.doi.org/10.1016/j.asr.2016.09.017
0273-1177/

Please cite this article in press as: Wang, E., et al. Monitoring and evaluation algorithm of GNSS signal in space availability. Adv. Space Res. (2016), http://dx.doi.org/10.1016/j.asr.2016.09.017

Accuracy, integrity, continuity and availability are the four basic service performances of satellite navigation system. Accuracy is defined as the statistical value of errors (95% probability) for any healthy satellite in normal operation. Integrity is defined to be the trust which can be placed in the correctness of the information provided by the SPS SIS. The continuity for a healthy SPS SIS is the probability that the SPS SIS will continue to be healthy without unscheduled interruption over a specified time interval. Availability is the probability that the slots in the GPS constellation will be occupied by satellites transmitting a trackable and healthy SPS SIS. As one of this four basic service performances, availability has become a key indicator in the field of civil aviation and other navigation applications, evaluating whether a navigation system is reliable or not (Zhao and Sun, 2014). So far, there are four versions of GPS SPS performance standards (U.S. Department of Defense, 1993, 1995, 2001, 2008). With the development of GPS SPS PS, the availability performance indicator is constantly improved. In the latest version, it is divided into SIS availability and service availability, respectively. SIS availability is gained more and more attention (Walter et al., 2010; Sun and Wang, 2016).

There are lots of researches of per-satellite availability and constellation availability. Ochieng et al. reported a per-satellite availability evaluation model, which calculated instantaneous availability based on failure rate and reliability, while the on-orbit restoration performance was not taken into account (Ochieng et al., 2001). In fact, most satellite failures can be restored by ground control segments or resolved by spare satellites. In addition, the previous constellation availability models (Clifford, 1999; Wu et al., 1999) were considered a specific constellation with a defined number (generally 24) of space vehicles, when more space vehicles than required for the constellation have actually been on orbit for most of the time since the declaration of Full Operational Capability (FOC). The constellation availability was based on per-satellite availability, and MTBF and MTTR of different per-satellite outages directly influenced the constellation availability in different states. U.S. Department of Defense refers that constellation availability model is based on binomial probability distribution (U.S. Department of Defense, 2008). To some extent, it reflects the constellation availability under different failure conditions, but it ignores that the satellite restoration condition and the spare satellites also have impact on constellation availability. So this model is a static analysis method of constellation availability. In order to improve the model of constellation availability, the per-satellite availability and spare satellites should be taken into account. Compared to the above model, the per-satellite availability model proposed in this paper is a combination of satellite failure and restoration. It is based on Markov process and reflects the overall availability of the satellite. To ensure more accurate evaluation, the per-satellite availability model and constellation availability model proposed in this paper are fully considered the impact of constellation status and satellite backup strategy. This paper also uses the most accurate MTBF and MTTR numbers, which measured from actual GPS experience.

The GPS SPS performance standard is more suitable to evaluate the performance of satellite navigation systems. This paper mainly aims at evaluating satellite availability and constellation availability of GPS SIS based on GPS SPS documents and other relevant data of the quarterly GPS performance analysis report released by the FAA (U.S. Department of Defense, 2008). BDS SIS is also evaluated based on BDS SIS ICD (China Satellite Navigation Office, 2013a,b). The measured data of GPS and BDS are from the quarterly GPS performance analysis report released by FAA and International GNSS Service (IGS). Furthermore, the validity of the evaluation model and the conformity to the evaluation standards of the GPS and BDS SIS availability are presented. This paper is organized as follows: in Section 2 availability evaluation model based on Markov Process is presented, Per-Satellite Availability Evaluation of GPS and BDS are investigated by the measured data in Section 3, in Section 4 constellation availability evaluation is shown, and finally the conclusion is given.

2. Availability evaluation model based on Markov process

SIS availability includes per-slot availability and constellation availability. The per-slot availability is the fraction of time that a slot in the GPS constellation occupied by a satellite transmitting the trackable and healthy SPS SIS. It mainly depends on the satellite design together with the control segment procedure for on-orbit maintenance and failure response. The constellation availability is the fraction of time that a specified number of slots in the GPS constellation occupied by satellites that are transmitting a trackable and healthy SPS SIS, mainly depending on the per-slot availability coupled with the satellite launch policies and satellite disposal criteria (U.S. Department of Defense, 2008).

Essentially, the availability evaluation needs to make statistics on per-satellite availability in both signal domain and pseudorange domain. Then it is possible to derive the constellation availability by per-satellite availability. In this way, all SIS availability of the satellite constellation can be obtained comprehensively.

2.1. Per-satellite availability model

The life distribution and the failure restoration time distribution are assumed to follow exponential distributions. As long as the satellite navigation system status is given properly, the system can always be described by the Markov process (Sonia et al., 2014). The exponential distribution model is used to describe the reliability of the satellites in many literatures (Rhonda and Karl, 1999;