The BeiDou Navigation Satellite System

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The BeiDou Navigation Satellite System (BDS) is a global navigation satellite system to be developed independently by China. It will provide positioning, navigation, and timing services with a global coverage by 2020. It can be used for transport, weather forecast, fishing, forestry, telecommunications, hydrological monitoring, and mapping. The service modes are the open service (OS) and the authorized service (AS). The open service is provided free of charge with positioning accuracy of 10 meters, velocity accuracy of 0.2 m/s, and timing accuracy of 50 nanoseconds. The authorized service is provided with a more secure and higher level of integrity. Beside that AS also provides communication services.

A global navigation satellite system (GNSS) usually consists of three segments: the space segment, the ground control segment, and the user segment. The space constellation of BDS is composed of Geostationary Earth Orbit (GEO) satellites, Medium Earth Orbit (MEO) satellites, and Inclined Geosynchronous Satellite Orbit (IGSO) satellites. The BDS constellation will have 35 satellites in orbit to provide global open services according to its development schedule.

The current BDS space segment consists of 5 GEO satellites, 5 IGSO satellites, and 4 MEO satellites. The GEO satellites are operating in an orbit with an altitude of 35,786 km and positioned at 58.75°E, 80°E, 110.5°E, 140°E, and 160°E respectively. The IGSO satellites are operating in an orbit with an altitude of 35,786 km and an inclination of 55° to the equator. The right ascension difference of ascending nodes is 120°. The longitude of the intersection point for three IGSO satellites is 118°E and that for the other two is 95°E. The MEO satellites are working in an orbit with an altitude of 21,528 km and an inclination of 55° to the equator. The satellite recursion period is 13 rotations within 7 days. The phase is selected from the Walker24/3/1 constellation, and the right ascension of ascending node in the first orbital plane is 0°. The four MEO satellites are in the 7th and 8th phases of the first orbital plane, and in the 3rd and 4th phases of the second orbital plane respectively.

The ground control segment is responsible for the BDS operation and control. It consists of the Master Control Station (MCS), Time Synchronization/Upload Stations (TS/US), and Monitor Stations (MS). MCS is the operation and control center of the system and its main tasks include:

1. Maintaining the system time BDT and making time transfer to satellites and stations.
2. Generating satellite NAV messages, such as the parameters of satellite orbits, clock biases, and ionosphere time delay et al，based on the observation data from TS/US and MS.
3. Performing mission schedules for the system operation, management and control;
4. Uploading satellite NAV messages and monitoring the anomalies etc.

The Time Synchronization/Upload Stations are used to upload satellite NAV messages and to make time transfer from the ground station to the satellites. The Monitor Stations observe continuously satellite NAV signals and provide real-time observation data to the Master Control Station.

The BDS OS volume is defined as the OS SIS (signal in space) coverage of the BDS satellites, where both the horizontal and vertical position accuracy are better than 10 meters (probability of 95%). At the current stage, the BDS regional

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service capability has been achieved, which can provide continuous OS to the area including most part of the region from 55°S to 55°N, 70°E to150°E.

The coordinate reference system used in BDS is the China Geodetic Coordinate System 2000 (CGCS2000). CGCS 2000 is a terrestrial reference system. Its origin is defined to be located at the Earth's center of mass, and its Z-axis and X-axis are directed respectively to the IERS reference pole (IRP) and the intersection of IERS reference meridian (IRM) with the IRP equator plane. The Y-axis constitutes a right handed orthogonal coordinate system with Z-axis and X-axis. The semi-major axis of the CGCS2000 ellipsoid is 6378137.0m and the flattening is 1/298.257222101. The adopted geocentric gravitational constant (mass of the earth atmosphere included) is 3.986004418E14 m^3/s^2, and the rate of earth rotation is 7.2921150E-5 rad/s. In practice, the difference between CGCS2000 and ITRF is less than 1 cm on the ground.

The time reference of BDS is the BeiDou Time (BDT). It is a continuous time scale without leap seconds. The basic unit of BDT is defined to adopt the SI second. It is counted with week number (WN) and seconds of week (SOW). The zero point of BDT is the epoch January 1, 2006 UTC 00h00m00s. BDT is stirred to the UTC time scale maintained by Beijing Satellite Navigation Centre (BSNC), noted by UTC (BSNC). The time difference between BDT and UTC (BSNC) is less than 20 ns (modulo 1 second). UTC (BSNC) is related indirectly to UTC through UTC (NTSC) and UTC (NIM). The time offset of UTC (BSNC) with respect to UTC is controlled to be less than 100 nanoseconds. The leap seconds of BDT are broadcast in the navigation (NAV) message.

BDS broadcasts right-handed circularly polarized (RHCP) L-band signals, which are modulated through Quadrature Phase Shift Keying (QPSK). The signals on B1and B2 are the sum of channel I and Q which are in phase quadrature of each other. The ranging code and NAV message are modulated on the carrier. The signal is composed of the carrier frequency, ranging code and NAV message. The carrier frequencies of B1 and B2 are coherently derived from a common reference frequency standard on board. The nominal frequency of B1 signal is 1561.098 MHz， and that of B2 is 1207.140MHz.

The basic principle of satellite navigation is that the user solves his 4-coordinates (x, y, z, t) by using the observed pseudoranges. A pseudorange is usually composed of the real range, the time difference between the transmitter and the receiver, and the time delays caused by equipments and the signal propagation medium. In order to get the solution, it must be given in form of parameters or models that the message including the satellite clock offsets, the satellite positions and the time delays, such as satellite transmitter delays, ionospheric and tropospheric delays etc. Then satellite time synchronization and determinations of precise orbits and time delays are key techniques in GNSS. In BDS, two way time transfer between the ground stations and the satellites are used for satellite time synchronizations. The composed uncertainties are less than 2 ns. Rubidium clocks are used as the satellite time and frequency standards in BDS. The stabilities of satellite clocks are 1E-13 lever of Allan deviation for one day. In order to check the accuracy of the NAV data, satellite laser ranging (SLR) and two way laser time transfer are also used in BDS.

The BDS OS SIS accuracy is defined as the statistical value of errors (95% probability) for any healthy satellite in the normal operation. It is mainly described by the parameter of User Range Error (URE), which is a statistical parameter of instantaneous SIS URE data. An instantaneous SIS URE is the difference between the pseudorange measured at a given location assuming that the receiver clock is perfectly calibrated to BDT and the pseudorange derived from the NAV data and the given location. The instantaneous SIS URE includes only those pseudorange data set error budget components assigned to the BDS Space and Ground Control Segments (i.e., not including the error budget components assigned to the BDS User Segment such as the troposphere delay compensation error, multipath, and receiver noise). At present, the BDS URE is less than 2.5 m.

BDS OS SIS NAV messages are formatted in D1 and D2 based on their data rates and structures. The message D1 is broadcasted by the MEO/IGSO satellites with the data rate of 50 bps, while D2 is done by the GEO satellites with the data rate of 500 bps. The BDS OS SIS NAV message is updated once an hour. The BDS OS NAV message data mainly includes: a) satellite ephemeris parameters; b) satellite clock offset parameters; c) ionospheric delay model correction parameters; d) satellite health status; e) user range accuracy index; f) constellation status (almanac information), etc.

The BDS OS SIS NAV message D1 is broadcasted in the form of superframes. Each superframe consists of 24 frames, and each frame is composed of 5 subframes with 10 words in each. It takes 12 minutes to transmit the whole NAV message D1. More specifically, subframes 1 to 3 are used to broadcast fundamental NAV information of the broadcasting satellite; while pages 1 to 24 in subframe 4 and pages 1 to 10 in subframe 5 are used to broadcast the almanac of all satellites and time synchronization information with other navigation systems.

The BDS OS SIS NAV message D2 is broadcasted in the form of superframes. Each superframe consists of 120 frames, and each frame is composed of 5 subframes with 10 words in each. It takes 6 minutes to transmit the whole NAV message D2. More specifically, subframe 1 is used to broadcast fundamental NAV information of the broadcasting satellite, while subframe 5 is used to broadcast the almanac of all satellites and time synchronization information with other navigation systems.

Since December of 2012, BDS has been in full service to the area including most part of the Asia-Pacific region. The Interface Control Document for Open Service Signal (BDS-SIS-ICD-2.0) and the Open Service Performance Standard (Version1.0) for the current stage have been released and is available on the official BeiDou website: www.beidou.gov.cn.