A COMPASS for Asia: First Experience with the BeiDou-2 Regional Navigation System

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Abstract

Following GPS and GLONASS, COMPASS/BeiDou-2 is the first new navigation system enabling stand-alone positioning in at least a regional context. Even though the contents of the broadcast navigation message has not been publicly disclosed so far, a pre-operational status has been reached and the COMPASS/BeiDou-2 navigation signals can already be tracked by various commercial multi-GNSS receivers. This enables the determination of COMPASS/BeiDou-2 orbit and clock products independent of the control segment and paves the way for initial experimentation. The poster provides an overview of the current status of the regional component of the COMPASS/BeiDou-2 system, which is based on a total of nine satellites in geostationary or inclined geosynchronous orbits. The signal quality and tracking performance is described based on a small network of receivers in the Asia-Pacific region. Special attention is given to the availability of three frequencies, which enables advanced ambiguity resolution concepts. First results of COMPASS/BeiDou-2 based positioning are presented.

The COMPASS/BeiDou-2 Constellation

As of June 2012, a total of 13 COMPASS/BeiDou-2 satellites have been launched, out of which 11 satellites are in active service. These include two satellites in medium altitude Earth orbits (MEO), as well as four satellites in geostationary orbits (GEO) and five satellites in inclined geosynchronous orbits (IGSOs). With a total of nine satellites permanently visible in the Asia-Pacific region, COMPASS is the third constellation that can offer an independent navigation service in this area.

Table 1 COMPASS/BeiDou-2 Constellation

Sat	PRN	COSPAR ID	NORAD ID	Type	Notes
G1	C01	2010-001A	36287	GEO	
G2	C02	2009-018A	34779	GEO	Uncontrolled
G3	C03	2010-024A	36590	GEO	
G4	C04	2010-057A	37210	GEO	
G5	C05	2012-008A	38091	GEO	
I1	C06	2010-036A	36828	IGSO	
I2	C07	2010-068A	37256	IGSO	
I3	C08	2011-013A	37384	IGSO	
I4	C09	2011-038A	37763	IGSO	
I5	C10	2011-073A	37948	IGSO	
M1	C30	2007-011A	31115	MEO	Clock failure
M3	C11	2012-018A	38250	MEO	
M4	C12	2012-018B	38251	MEO	

The COMPASS/BeiDou-2 spacecraft (Fig. 1) are based on the DFH-3A bus (for GEO satellites) and the DFH3 bus (for MEO and IGSO satellites) and differ slightly in their respective payloads. Aside from the common navigation payload, the GEO satellites are equipped with a C-Band telecommunications antenna and a two-way satellite time and frequency transfer (TWSTFT) equipment. All COMPASS/BeoDou-2 spacecraft are equipped with laser retroreflector arrays and satellite laser ranging is presently conducted by the ILRS for a total three satellites (M1, I3, G1).

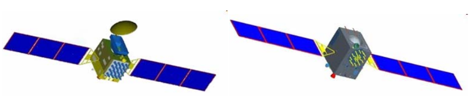

Fig. 1 Artist's impression of COMPASS/Beidou-2 GEO satellites (*left*) and MEO/IGSO satellites (*right*).

The COMPASS/BeiDou-2 spacecraft transmit open service and encrypted navigation signals in a total of three frequency bands overlaying the Galileo E5b, E6, and E2 bands (Fig 2.).

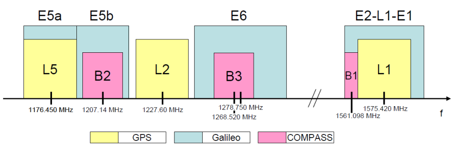

Fig. 2 COMPASS/BeiDou-2 frequency bands

Monitoring Station Network

COMPASS/BeiDou-2 tracking data are routinely collected by five monitoring stations in Singapore, Sydney, Perth, Tanegashima, and Chennai owned by DLR, Curtin University of Technology, the Japan Aerospace Exploration Agency (JAXA) and Trimble. In addition, multi-GNSS observations from a reference station in Kazan are made available as part of the IGS MGEX project. The stations are mostly equipped with Trimble NetR9 receivers offering COMPASS/BeiDou-2 tracking in all three frequency bands. A Septentrio AsteRx3 receiver offering B1/B2 dual-band tracking is employed at Sydney (Fig.3).

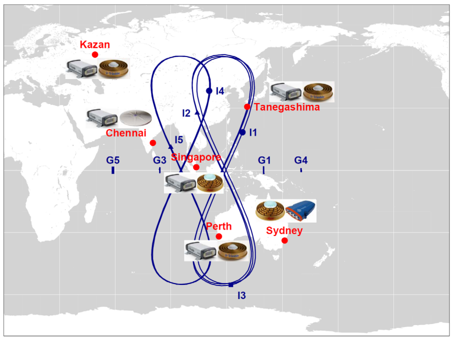

Fig. 3 COMPASS/BeiDou-2 monitoring stations and ground tracks of GEO/IGSO satellites (June 2012)

Signal and Tracking Performance

Carrier-to-noise-density ratios (C/N_0) measured by the employed receivers indicate a lower power of the COMPASS/BeiDou-2 open service signals as compared to the civil GPS signals. For the three MEO satellites, peak C/N_0 values of 50-52 dB-Hz are achieved (Fig. 4), which is roughly 4 dB lower than for GPS. In accord with their larger distance, the GEO and IGSO satellites of the COMPASS/BeidDou-2 constellation are tracked with a 2-4 dB lower signal strength than the MEO satellites. Independent signal strength measurements have earlier been reported by Shi et al. [1] based on data from a Chinese Unicore UB240-CORS dual-frequency GPS/COMPASS receiver. Their results for the IGSO satellites are in good accord with Fig. 4, whereas the C/N_0 of the GEO satellites appear to be systematically biased by roughly 5 dB.

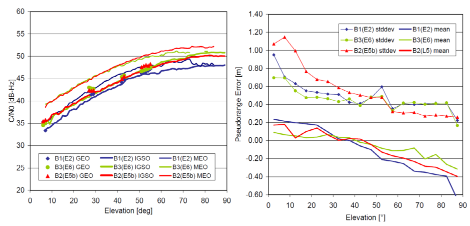

Fig. 4 Carrier-to-noise-density ratio (C/N_0) (Tanegashima station, *left*) and pseudorange errors (Chennai station, *right*) for COMPASS/BeiDou-2 tracking in week 1692 (10-16 June 2012). Both stations employ Trimble NetR9 receivers.

Pseudorange errors of the NetR9 receiver as deduced from the "multipath-combination" exhibit a typical standard deviation of 0.4 m at high elevation and 1 m at low elevation for all three COMPASS/BeiDou-2 signals (Fig. 4). Aside from the stochastic code errors, a systematic bias can be observed that varies by 0.4-0.6 m from horizon to zenith. It is most pronounced for the B1 signal and smallest for B3. The elevation-dependent code bias, which has earlier been identified in COMPASS-M1 [2], is consistently observed with other receivers and antennas and must thus be attributed to the transmitting satellites. In analogy with GPS SVN49 [3], slightly inconsistent code phases of signals transmitted by individual antenna segments may be suspected.

As shown in [4], the three carrier signals exhibit a good consistency and inter-frequency biases vary by less than ±2 cm (for the difference of ionosphere-free B1/B2 and B1/B3 combinations) across the orbit even during eclipse periods. Based on the noise level of a geometry- and ionosphere-free triple-carrier combination, an elevation-dependent carrier phase accuracy of 1 to 3 mm has, furthermore, been inferred for COMPASS/BeiDou-2 GEO/IGSO tracking with the NetR9 receiver.

Orbit and Clock Determination

Even though the definition of the COMPASS/BeiDou-2 navigation message has not been published so far, the constellation can still be used for stand-alone or multi-GNSS positioning with post-processed precise ephemeris products. Orbits and clock offsets of the regional COMPASS/BeiDou-2 constellation are routinely determined at TUM/IAPG from measurements of the regional monitoring network described above. For the IGSO satellites a representative position accuracy of 0.2 m (3D rms) is achieved, using 5-day arcs whereas the GEO orbit determination accuracy is limited to approximately 1 m due to the static viewing geometry. Further details are provided in [4] and [5].

Positioning

The unique availability of three carriers on all COMPASS-BeiDou-2 satellites enables novel strategies for differenced and undifferenced positioning. Based on B2 and B3 measurements, an extra-widelane (EWL) combination with a wavelength of 4.9 m can be formed. This enables an almost instantaneous EWL ambiguity resolution and greatly facilitates a subsequent widelane ambiguity fixing.

Results of a short baseline relative positioning using measurements from all operational COMPASS/BeiDou-2 satellites is shown in Fig. 5. Compared to GPS, a consistency of about 1 cm is achieved, which reflects a notable improvement over initial results obtained with a six satellite constellation in [1].

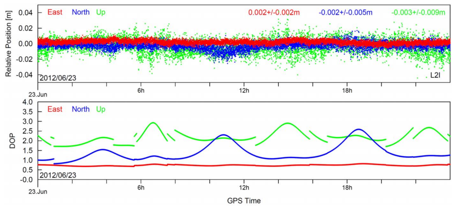

Fig. 5 Short-baseline COMPASS/BeiDou-2-based relative positioning of two receivers at Curtin University (see [4]). *Top*: baseline accuracy relative to GPS-only solution. *Bottom*: Dilution-of- Precision (DOP) using GEO, IGSO, and MEO satellites. Between 6 and 9 double-difference observations can be formed at all times.

References

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