



Technology Paper

L1 RTK System with Fixed Ambiguity: What SBAS Ranging Brings

L1 RTK System with Fixed Ambiguity: What SBAS Ranging Brings

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BIOGRAPHY

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Gleb Zyryanov has been working in Magellan since 2000 as a Software Engineer. Since 2006 he is Senior Software Engineer. He received his MS in Mathematics and Mechanics from Moscow State University.

ABSTRACT

Given paper deals with centimeter level L1 RTK systems. L1 and L1&L2 RTK provide the same centimeter level accuracy for short baselines. However, unlike expensive L1/L2 RTK, with cheaper L1 RTK one cannot expect too fast (seconds) On-The-Fly (OTF) ambiguity resolution, which delivers cm accuracy.

Known disadvantages of L1 RTK system (compared to L1&L2) are baseline length restriction (typically 10 km) and noticeable performance degradation under shaded sky. Augmented GPS constellation can mitigate these disadvantages.

It is known that SBAS Satellites provide not only long/fast/ionosphere corrections. They are also a source of GPS-like signal which pseudo range and carrier phase measurements can be potentially used in positioning together with GPS measurements. Given paper proves that SBAS measurements can make a good job to augment GPS L1 RTK. We give a lot of real life collected statistic (with WAAS, EGNOS and in less degree MSAS) which demonstrate dramatic performance enhancement of L1 RTK thanks to using SBAS.

The data used for validation were collected with Magellan ProMark3 and DG14 receivers supporting L1 GPS+SBAS RTK.

INTRODUCTION

SBAS ranging signal is the same as GPS signal [1]. This means that corresponded pseudo-range and carrier phase measurements must be equivalent to GPS L1 CA measurements. The only principal difference between SBAS and GPS is different navigation data; particularly SBAS orbits and clock corrections are computed differently from GPS.

Currently there are three operating SBAS constellations:

- WAAS, which includes 2 Satellites covering North and South America and parts of the Pacific ocean.
- EGNOS, which includes 3 Satellites covering Europe and Africa and some nearby countries.
- MSAS, which includes 2 Satellites covering Japan, China and Australia.

In some areas one can see and track 2+ SBAS satellites, say in California (US) 4 WAAS could be seen at the same time until July 2007.

From the point of signal quality and maturity of orbital information, WAAS and MSAS Satellites are good. On the contrary the EGNOS signal is not yet stable, and the accuracy of the provided orbital data is currently poor. That is why usage of SBAS (especially EGNOS) measurements in position computation is a challenge.

When speaking about Fixed RTK, one is usually interested in time needed to fix carrier ambiguity and achieve cm level solution insuring at the same time preset reliability. New L1 RTK solution from Magellan allows using SBAS measurements in RTK process, thus making it a true GNSS technology. SBAS gives extra GPS-like

measurements, which improve Satellite geometry and allow achieving cm level accuracy faster compared to GPS only case.

The GPS+SBAS RTK technique is similar to GPS+GLONASS L1 RTK technique, which was also invented by Magellan (formerly Ashtech) [2], [3]. From the point of L1 RTK performance, two extra SBAS Satellites do the same job as three extra GLONASS Satellites. With the currently incomplete GLONASS constellation, the ‘power’ of L1 GPS+SBAS RTK and L1 GPS+GLONASS RTK is approximately the same.

The paper is organized as follows.

First we describe some specific details when processing SBAS ranging data along with GPS data in RTK engine.

Then we provide apple-to-apple comparison statistic showing the improvement in L1 RTK performance thanks to acquiring SBAS ranging information.

After this we overview transporting formats which allow implementing GPS+SBAS RTK process between base and rover receivers.

Finally we present open sky short baseline RTK statistic we got with different combinations of SBAS enabled base/rover RTK receivers from Magellan.

ALGORITHM

From very first glance SBAS ranging data (pseudo range and carrier phase measurements) appear to be very similar to GPS ranging data. They follow the very same observation model [4] and therefore can be absorbed into GPS positioning process as extra GPS Satellites.

However, when trying to acquire SBAS in positioning process, one realizes that it is not exactly so. Careful analysis of SBAS data from point of their usage in position has shown that the following issues must be taken into account.

1. SBAS navigation information is not always accurate. This is clearly seen with EGNOS, which often provide low quality ephemeris and no acceptable clock corrections.
2. SBAS signal is not always stable (again mainly it concerns EGNOS).
3. SBAS constellations was changed many times (e.g. re-shaping WAAS constellation in 2006 and 2007) and is still not fixed at least for EGNOS.
4. Short term SBAS clock stability is poorer than that in GPS, which does not allow to extrapolate SBAS data effectively in time.

5. There are also some receiver related issues which can lead to some SBAS measurement biases between receivers of different types/manufactures. This is simply the effect of immaturity of SBAS ranging nowadays.
6. The most of modern GPS+SBAS receivers are not SBAS-all-in-view just because the primary function of SBAS is to provide corrections rather than measurements and there is no any need to have more than 2 SBAS tracking channels.

Fortunately many existing SBAS ranging disadvantages are mitigated when SBAS measurements are used in differential processing. At the same time, some of the negative effects still exist, and when processing SBAS measurements one must take care. The new GPS+SBAS RTK processing technique from Magellan not only uses SBAS ranging and carrier data, but also takes great care that a possible SBAS failure does not spoil RTK behavior.

Instead of ‘mechanical’ usage of SBAS ranging in the RTK processing, Magellan has incorporated the following 3 principal innovations:

- Adaptive SBAS usage
- SBAS data calibration
- SBAS tracking synchronization

In many cases (especially with EGNOS), SBAS data can be bad and under no circumstances must be taken into the RTK processing engine. Adaptive SBAS usage means detecting wrong SBAS measurements and/or orbit and stopping their usage. One of the examples is poor ephemeris information. In this case transmitted URA (User Range Accuracy) is not always adequate because SBAS with very bad URA can be often effectively used in RTK process, because orbital and/or clock errors can be acceptable for RTK positioning, while cannot be acceptable for stand alone positioning.

SBAS measurements (especially when base and rover data are provided by different receiver types) can have biases which must be accounted for. A special robust procedure estimates the possible SBAS biases in real time and compensates for them in the RTK processing.

Usually a receiver is equipped with only 2 channels to track SBAS (e.g., this is the case of DGRTK and ProMark3), i.e. it is not an all-in-view SBAS receiver. In some cases 2+ SBAS satellites can be seen, so it is desirable to track in the rover those SBAS satellites for which the base transmits data. Such an algorithm has been implemented, which allows insuring matched SBAS tracking on base and rover.

PERFORMANCE

When demonstrating performance, we will focus on statistical figures rather than on presenting particular test results. All the data we used for performance evaluation were collected with static receivers. However, RTK was running w/o static assumption (i.e. in kinematics mode). All performance was evaluated with default settings which were the very same for each processed data set.

One very important note must be made. When collecting statistics we used the RTK auto-reset methodology. We always used fixed-length intervals between RTK resets regardless its current status. Some vendors provide similar auto-reset statistics using the float-length intervals, when RTK reset occurs depending on the current RTK status (e.g. few seconds after fix). This float-length interval approach usually gives a more optimistic statistic compared to fixed-length interval statistic. Moreover, the fixed-length interval statistic allows comparing in the same way two different algorithms. That is why we use the fixed-length interval statistic in all cases.

Given section demonstrates performance estimated with PC version of GPS+SBAS RTK. Given PC version is 100% adequate to what is running in a receiver. At the same time, section INTEROPERABILITY gives pure real life real time statistic.

To demonstrate Fixed RTK performance we used the following methodology. RTK rover was reset each 300 seconds and standard Time To First Fix (TTFF) performance was evaluated. In given paper we use the following particular figures of TTFF:

- ❑ Availability == the percentage of fixed trials over all the trials
- ❑ Reliability == the percentage of correctly fixed trials over all the fixed trials
- ❑ x% point of TTFF == the time within which x% of trials were fixed (e.g. x=50,90,99)

Each baseline was evaluated with and w/o using SBAS to see apple-to-apple performance. All the data were collected with 1 second interval. Preset reliability of fixed solution was set to 99%. Thanks to large data volume for each particular data set, all our estimates are statistically sufficient.

The RTK performance benefit thanks to using SBAS ranging information is demonstrated below for 3 most important cases:

- A. Open sky OTF RTK initialization
- B. Partly blocked sky OTF RTK initialization
- C. RTK initialization with geometry constrains

A. OPEN SKY OTF RTK INITIALIZATION

15 data sets (each at least 24 hours long) for open-sky baselines from a few tens of meters to 7 km were used. One or two common SBAS satellites were available to both base and rover. The most of the data were collected in Europe (EGNOS) and US (WAAS), the last data set corresponds to China (MSAS).

The diagram below shows availability for each data set with and w/o SBAS usage. In all the cases, preset reliability was met.

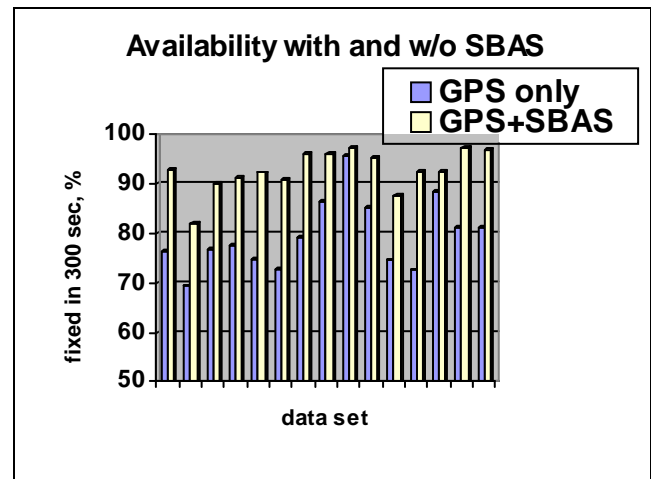


Figure 1. Improvement availability thanks to SBAS in open sky conditions

One can see that availability of fixed solution at 300 sec interval is about 15% higher due to the addition of SBAS measurements into RTK process.

B. BLOCKED SKY OTF RTK INITIALIZATION

3 data sets (each at least 24 hours long) for blocked sky baselines were used. All the data were collected with ProMark3 receivers in California, US, where 4 WAAS were seen (since July 2007 2 WAAS were disabled) and 3 of them at a good elevation. At given location even with shaded environment, at least one (and often two) common SBAS satellites were available for each baseline.

Used baseline lengths were 1 km, 3.6 km (both partly shaded) and 2 meters (most shaded). The diagram below shows the availability for each data set.

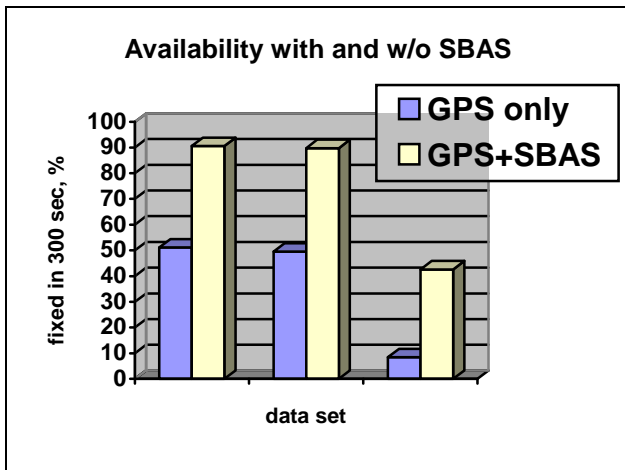


Figure 2. Improvement availability thanks to SBAS in shaded sky conditions

One can see that for partly shaded baselines SBAS makes excellent job. With heavy shading the value of SBAS is very difficult to overestimate.

It should be noted that reliability was not met for most shaded (3rd) baseline.

The primary Land Survey job is surveying points, i.e. processing static observations. In this case RTK can be commanded to work in static mode. Usually for short open sky baselines TTFF performance is quite similar when processing data in kinematics and static modes. However with problem data, static assumption can increase performance noticeably. The table below shows how TTFF can be improved when processing the most shaded 3rd baseline with static assumption. TTFF figures are given in form GPSonly/GPS+SBAS.

Table 1. Combined effect of SBAS usage and static processing option

Processing mode	Availability, Percent	Reliability, Percent	TTFF, 50%, seconds
Kinematics	8.4 / 42.6	95.4 / 96.4	>300 / >300
Static	13.7 / 56.3	97.3 / 99.7	>300 / 267

One can see that using static assumption in couple with adding SBAS, has finally allowed to increase availability and met preset reliability 99%.

C. RTK INITIALIZATION WITH GEOMETRY CONSTRAINTS

There are RTK applications when some geometric constraints can be used to speed up integer ambiguity initialization. The most known example is initialization on baseline with known length. Such an initialization can be used optionally in:

- ProMark3 RTK receiver when initializing on so called kinematics bar
- DG RTK when performing Heading determination

It is clear that additional constrain brings more information which makes ambiguity fix faster and more reliable. Here we show that for such application, the availability of SBAS in RTK process improves TTFF noticeably.

The diagram below shows 90% point of TTFF for 4 data sets corresponding to baselines of 7, 1, 9, and 20 meters collected with DG RTK receivers in Europe (EGNOS) and US (WAAS). RTK was running in so called RTK Arrow mode which used the fact that:

- Baseline length is known with sub-cm accuracy
- Baseline elevation does not exceed +/-15 degrees

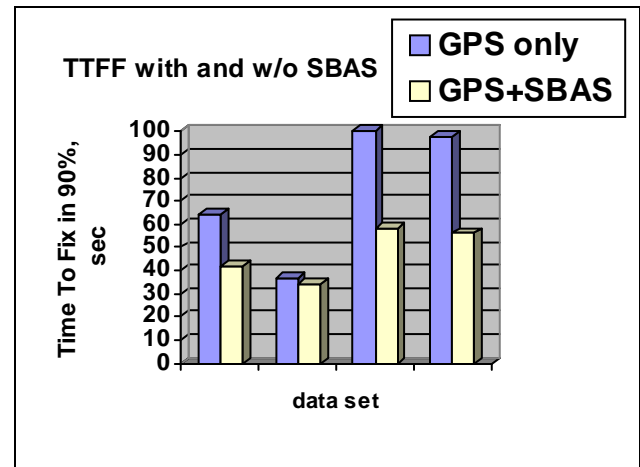


Figure 3. Improvement TTFF thanks to SBAS for RTK on short baseline with known length

In all the cases experienced reliability was higher than 99.9%. One can see again the improvement thanks to SBAS.

TRANSPORTING

Obviously, to enable GPS+SBAS RTK processing, a base station must send SBAS data. With standardized protocols, this is possible when using RTCM-3 format where a room for SBAS data is reserved [5]. Magellan ProMark3 base/rover RTK receivers support this protocol and can work effectively in GPS+SBAS RTK mode between each other. At the same time ProMark3 RTK rover can work against any other RTCM-3 enabled base. However, up to this date we do not know about commercial base receivers (e.g. in NTRIP Networks) which generate SBAS ranging data. That is why ProMark3 RTK rover shows the best performance against ProMark3 RTK base which sends SBAS.

DG RTK rover supports RTCM-3 protocol and can effectively work with ProMark3 RTK base in GPS+SBAS L1 RTK mode. At the same time, DG14 RTK base supports RTCM-2 only, which has no room for sending SBAS ranging data [6]. So it is not formally possible to broadcast SBAS corrections from a DG14 Base to a DG14 rover. However, DG RTK base can send SBAS ranging data in proprietary format. This proprietary format can be decoded by both DG RTK rover and ProMark3 RTK rover.

So ProMark3 RTK and DG RTK are 100% compatible from point of transporting used for transmission and reception of GPS+SBAS raw data. The section below proves this compatibility.

INTEROPERABILITY

GPS+SBAS RTK algorithm has been implemented into latest 2 Magellan products: DG14 OEM board and ProMark3 handheld Surveyor. While RTK source code is exactly the same, all the stuff related with deriving raw SBAS measurements, generating and decoding RTCM corrections are formally different for these receivers. That is why, compatibility between two formally different SBAS enabled RTK receivers must be checked.

As stated above, we do not know commercial RTK bases which send SBAS ranging data. So ProMark3 and DG RTK rovers cannot take advantage of GPS+SBAS RTK processing working with 3rd party RTK bases. At the same time they can effectively work with each other.

8 open sky short baseline (from meters to tens meters) RTK tests were performed in Nantes (France), Santa Clara (US) and Moscow (Russia). These tests included all possible configurations, i.e.

- ProMark3-> ProMark3
- DGRTK-> ProMark3
- DGRTK-> DGRTK
- ProMark3-> DGRTK

Receiver operated with all default settings.

Each data set includes more than 24 hours of RTK data. Since receivers can track no more than 2 SBAS simultaneously while in some cases (e.g. in Santa Clara) 4 SBAS can be potentially seen (test were performed before July 2007), we made all these tests under control of special script with forced base receiver (DGRTK or ProMark3) to switch from one 2-SBAS combination to another each 2 hours. This allowed us to validate interoperability and performance for any SBAS configurations. Please note once more that rover (DGRTK

or ProMark3) always performed synchronous (with base) SBAS tracking.

The same (as described above) RTK auto-reset methodology was used to derive TTFF performance. The diagram below gives the summary TTFF statistic.

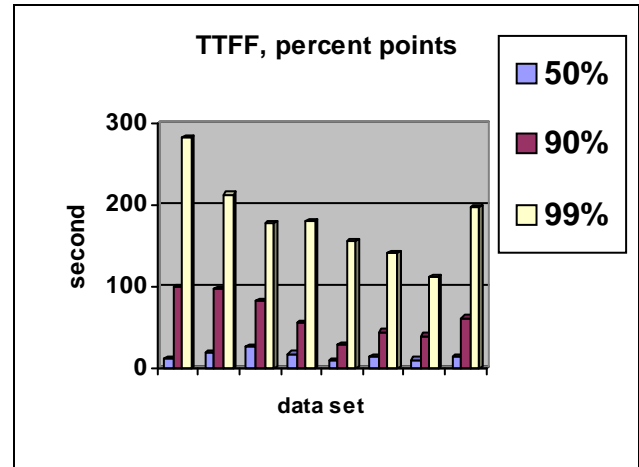


Figure 4. TTFF for different short baseline tests

One can see that all the ProMark3/DGRTK combinations are compatible and provide excellent short baseline GPS+SBAS L1 RTK performance.

CONCLUSIONS

We have demonstrated statistically that adding SBAS pseudo range and carrier phase measurement to L1 GPS RTK improves TTFF performance in very noticeable degree. This improvement is just a result of up to 2 extra GPS-like L1 measurements into RTK process.

In [7], author claimed that L1 real time solution can be very welcome for low/medium end RTK market as a reasonable competitor of expensive professional L1/L2 systems. On short open sky baselines, any extra Satellite can make L1 RTK initialization noticeably faster. SBAS is the system, which deliver such extra Satellites.

SBAS Satellites make revolution job in shaded areas where L1 GPS RTK is usually impotent to provide cm level accuracy. Only augmentation by other GNSS can make L1 RTK workable in difficult environmental conditions. Earlier it had been proven with GPS+GLONASS, now it has been proven with GPS+SBAS.

Geo-stationary Satellites are entering our life through more and more different GNSS systems. Being primary designed as a provider of corrections and other GNSS (and not GNSS) augmentation data, these geo-stationary space vehicles insure 'standard' navigation ranging signal which pseudo range and carrier phase can be measured.

These measurements appear to be usable in GNSS positioning including even such a super-accurate mode as RTK.

New L1 products from Magellan use SBAS ranging in RTK process making L1 Fixed RTK productivity much higher compared to GPS only case.

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