Dual Frequency Smartphone Performance using SBAS

Jenni tomkinson, allison kealy, simon fuller   
RMIT University

Christopher Marshall, Eldar Rubinov  
FrontierSi

appendix A contributed by:

Lachlan Ng   
The University of Melbourne

June 2020

Table of Contents

[1 Introduction 2](#_Toc35105937)

[2 Background 3](#_Toc35105938)

[2.1 Survey Control Points 3](#_Toc35105939)

[2.2 Smartphones & Apps 3](#_Toc35105940)

[2.3 Data Collection 4](#_Toc35105941)

[2.4 Data Processing 6](#_Toc35105942)

[3 Method 7](#_Toc35105943)

[3.1 Preparation 7](#_Toc35105944)

[3.2 Processing 7](#_Toc35105945)

[3.3 Analysis 8](#_Toc35105946)

[3.4 Report 8](#_Toc35105947)

[4 Results 9](#_Toc35105948)

[4.1 Horizontal Results 9](#_Toc35105949)

[4.2 Vertical Results 12](#_Toc35105950)

[5 Analysis 16](#_Toc35105951)

[5.1 Positioning Performance 16](#_Toc35105952)

[5.2 Huawei P30 Duty Cycling 16](#_Toc35105953)

[5.3 DFMC SBAS Issues 17](#_Toc35105954)

[6 Conclusions 18](#_Toc35105955)

[References 19](#_Toc35105956)

[Appendix A Positioning Performance Evaluation of Dual-frequency GNSS Observations from a Smartphone 19](#_Toc35105957)

# Introduction

In early 2019 a team of researchers at RMIT University began investigating the positioning performance of dual frequency smartphones, with a focus on the role of the smartphone’s GNSS antenna. As part of these research efforts, RMIT collected approximately 50 hours of dual frequency multi-GNSS observations using multiple smartphones (Xiaomi 8, Huawei P30). The observations were collected over known survey control marks and stored in the RINEX 3.x format.

The data has been processed using traditional post-processing techniques (Leica Infinity, Trimble Business Centre, and RTKLib). The results have been encouraging (cm-level accuracy in some cases) but variable. In the case of the Huawei P30 the presence of the duty cycle limited the achievable performance.

The purpose of this project is to examine the performance of smartphone positioning with alternative processing methods – the services provided by the SBAS Testbed. To achieve this the existing data will be post-processed using the MagicGemini software and the following SBAS services:

* L1 Legacy
* DFMC

The post-processing results (from each service) will be analysed in terms of:

1. Accuracy, comparison of the computed coordinates to the known coordinates
2. Precision, to determine the variability/stability of the smartphone positioning
3. Comparisons to the traditional dual frequency baseline processing.
4. A subset of the analysis will focus on the performance of the Huawei P30 which is subject to duty cycling (regular power down of the carrier phase tracking loops).

# Background

This section contains summary information on the survey control points, smartphones, and data collection previously established/performed by RMIT and The University of Melbourneand provided to FrontierSI for the purposes of this project**.** For complete details please see Appendix A.

## Survey Control Points

To provide known (truth) coordinates for the smartphone data collection, five survey control marks were established in Parkville and Carlton (Figure 1). International Terrestrial Reference Frame (ITRF) 2014 coordinates for these survey control marks were determined in accordance with the Intergovernmental Committee on Survey and Mapping (ICSM) Special Publication 1 (SP1) guidelines for GNSS Control Surveys (ICSM, 2020). Complete details can be found in Appendix A.

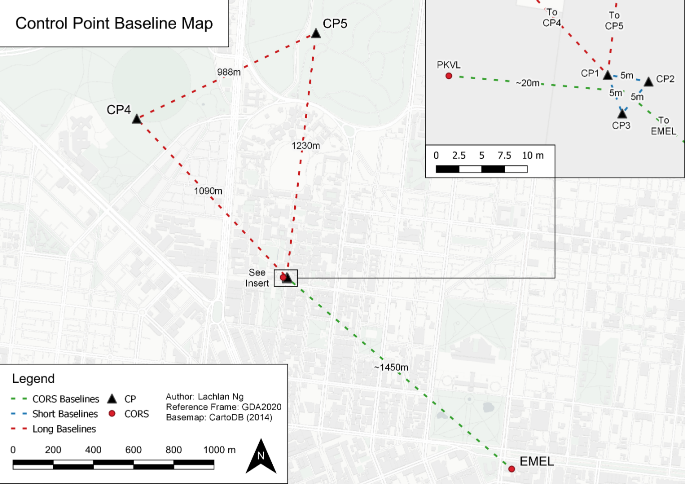


Figure 1: Location of Survey Control Points

## Smartphones & Apps

Four smartphones, from two manufacturers, were used to collect GNSS observation data on the survey control points. Details on the smartphones are provided in Table 1.

Table 1: Smartphones used in data collection

| **No.** | **Make** | **Model** | **O/S** | **GNSS Receiver** | **Serial number** |
| --- | --- | --- | --- | --- | --- |
| 1 | Xiaomi | MI8 | MIUI Global 11.0.6  Android 9.0 Pie | Broadcom -BCM4775X  GNSS Receiver with Integrated Sensor Hub | 19478/08v101290 |
| 2 | Xiaomi | MI8 | MIUI Global 11.0.6  Android 9.0 Pie | Broadcom -BCM4775X  GNSS Receiver with Integrated Sensor Hub | 19478/08V100900 |
| 3 | Xiaomi | MI8 | MIUI Global 11.0.6  Android 9.0 Pie | Broadcom -BCM4775X  GNSS Receiver with Integrated Sensor Hub | 19478/08V100971 |
| 4 | Huawei | P30 | Huawei EMUI 9.1.0.153  (Android 9.0 Pie) | Kirin 980 – Dual frequency, multi-constellation chipset | XPH5T19328013351 |

The raw GNSS observation data was collected using the Geo++ RINEX Logger Version 2.1.4. The smartphones were placed over the survey control marks using standard surveying equipment and custom manufactured smartphone brackets (Figure 2, Figure 3).

For further details on the smartphones, apps, equipment, and setup procedures see Appendix A.

|  |  |  |
| --- | --- | --- |
|  |  |  |
| Figure 2: Smartphone Setup |  | Figure 3: Smartphone Setups |

## Data Collection

Data collection occurred over three separate days, with different smartphones, different control points and varying session lengths. Summary details for each session are provided in Table 2.

Prior to commencing the data collection each smartphone was updated to the latest version of the relevant operating system and duty cycling was disabled (via Developers’ Settings). Prior to commencing each session, Bluetooth, Wi-Fi, and the cellular functions of each smartphone were disabled.

In each session the smartphone was placed flat (horizontal) with the screen facing upwards. The top of the smartphone was oriented to the North, using the default Compass App on the smartphone. The custom bracket (Section 2.2) was constructed to ensure a constant and repeatable physical relationship between a reference point on the smartphone and the survey control point. A small level bubble was used to ensure that each smartphone screen was coincident with a level surface.

Raw GNSS observation data was logged using the Geo++ RINEX Logger (see Section 2.2), in “Static” mode and the “Visible” filtering option.

Table 2: Data Collection Sessions

| **Session Number & Date** | **Control point** | **Smartphone** | **Application** | **Data Logging Frequency** | **Start Time (AEDT)** | **End Time (AEDT)** |
| --- | --- | --- | --- | --- | --- | --- |
| 1 28/07/2019 | CP2 | Phone 1 – Xiaomi Mi8 | Geo++RINEX Logger version 2.1.4 | 1Hz | 10.00 | 13.00 |
| CP3 | Phone 4 – Huawei P30 | Geo++RINEX Logger version 2.1.4 | 1Hz | 10.00 | 13.00 |
| 2 16/09/2019 | CP1 | Phone 1 – Xiaomi Mi8 | Geo++RINEX Logger version 2.1.4 | 1Hz | 10.00 | 16.00 |
| CP2 | Phone 2 – Xiaomi Mi8 | Geo++RINEX Logger version 2.1.4 | 1Hz | 10.00 | 16.00 |
| CP3 | Phone 3 – Xiaomi Mi8 | Geo++RINEX Logger version 2.1.4 | 1Hz | 10.00 | 16.00 |
| 3 30/09/2019 | CP1 | Phone 1 – Xiaomi Mi8 | Geo++RINEX Logger version 2.1.4 | 1Hz | 10.00 | 16.00 |
| CP4 | Phone 2 – Xiaomi Mi8 | Geo++RINEX Logger version 2.1.4 | 1Hz | 10.00 | 16.00 |
| CP5 | Phone 3 – Xiaomi Mi8 | Geo++RINEX Logger version 2.1.4 | 1Hz | 10.00 | 16.00 |

## Data Processing

The smartphone data collected in each session was post-processed in RTKLib using traditional differential (baseline) processing strategies. The GPSnet CORS at Parkville (PKVL) and East Melbourne (EMEL) were used as “base” receivers in the RTKLib processing, as per the baseline diagrams in Figure 1.

The baseline processing was performed using “Static” and “Epoch-By-Epoch” modes in RTKLib. The “Epoch-By-Epoch” results are used in this report (Section 4) to provide an indication of the optimum smartphone performance (cm-level, see Appendix A). The results obtained from post-processing with the SBAS services are not expected to reach this level of performance (cm-level).

Full details on the baseline processing are available in Appendix A.

# Method

To assess the positioning performance of SBAS enabled smartphones the method shown in Figure 4 was adopted. A description of each step in the method is provided below.

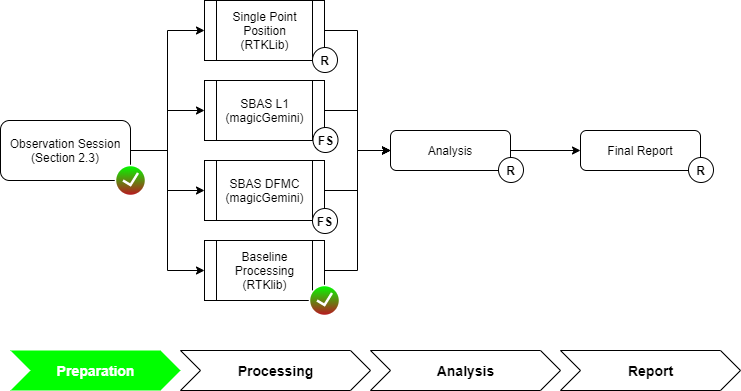


Figure 4: Method

## Preparation

RMIT provided FrontierSI with the raw GNSS observation data (in the form of RINEX files) collected in each of the observation sessions, as described in Table 2 and Section 2.

## Processing

The raw GNSS observation data was post-processed using four different techniques, which were expected to provide increasing levels of positioning performance. These processing techniques (ordered from lowest to highest performance) were:

Table 3: Processing Techniques

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Technique** | **Software** | **Observations** | **Key Parameters** | **Performance** | **Who** |
| Single Point Position | RTKLib | L1, All GNSS | Orbits – Broadcast Iono. – Broadcast Tropo. – Saastamoinen | 5-10m | RMIT |
| L1 SBAS | magicGemini | L1, GPS & Galileo | Orbits – SBAS Iono – Broadcast Tropo. - Saastamoinen | 0.5-1.0m | FrontierSI |
| DFMC SBAS | magicGemini | L1 & L5, GPS & Galileo | Orbits – SBAS Iono – IFLC Tropo. - Saastamoinen | 0.5-1.0m | FrontierSI |
| Double Difference Baseline | RTKLib | L1 & L5, GPS & Galileo | Orbits – Final Iono – IFLC Tropo. - Saastamoinen | 0.02m | Done |

Processing was on an epoch-by-epoch basis, whereby each solution was computed independently of previous solutions. The exception was the Double Difference Baseline processing, where the integer ambiguities are resolved over multiple epochs and held constant once resolved.

## Analysis

The post-processing results obtained from each of the processing techniques (Table 3) will be analysed in terms of:

1. Accuracy, comparison of the computed coordinates to the known coordinates.
2. Precision, to determine the variability/stability of the smartphone positioning solution.

In addition to these summary statistics:

1. A comparison to the traditional dual frequency processing.
2. Additional analysis of the Huawei P30 which is subject to duty cycling.

## Report

The final step is the preparation and delivery of the final report (this document).

# Results

The following tables and plots provide summary information on all post-processing results for each processing technique. All values were computed relative to known coordinates (Section 2.1). Plots are only shown for Phone #1, for brevity and because it was the only smartphone present in all experiments.

Unfortunately, there were no usable results for the DFMC SBAS processing technique. The magicGEMINI software rejected virtually all of the observations, to the extent that there were insufficient reliable results to include in the report. Further details can be found in Section 5.3.

## Horizontal Results

### Tabular Results

Table 4: Horizontal Results - Phone 1 – Xiaomi MI8 #1

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Session 1 - CP2** | | | **Session 2 - CP1** | | | **Session 3 - CP1** | | |
| **Technique** | **Count** | **Mean** | **SDev** | **Count** | **Mean** | **SDev** | **Count** | **Mean** | **SDev** |
| RTKLIB SPP | 6233 | 6.161 | 3.751 | 12488 | 4.791 | 3.313 | 18158 | 4.484 | 2.849 |
| magicGEMINI L1 enabled | 11207 | 3.215 | 2.354 | 22250 | 2.108 | 1.974 | 25709 | 2.418 | 1.773 |
| RTKLIB Baseline (PKVL) | 6233 | 0.173 | 0.354 | 19259 | 0.051 | 0.011 | 12329 | 0.054 | 0.014 |
|  |  |  |  |  |  |  |  |  |  |

Table 5: Horizontal Results - Phone 2 – Xiaomi MI8 #2

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **N/A** | | | **Session 2 – CP2** | | | | | **Session 3 – CP4** | | | |
| **Technique** | **Count** | **Mean** | **SDev** | **Count** | | **Mean** | | **SDev** | **Count** | **Mean** | | **SDev** |
| RTKLIB SPP |  |  |  | 7947 | 6.800 | | 3.783 | | 19345 | 2.943 | 1.803 | |
| magicGEMINI L1 enabled |  |  |  | 22251 | 2.522 | | 2.404 | | 21558 | 0.970 | 0.652 | |
| RTKLIB Baseline (PKVL) |  |  |  | 15666 | 0.038 | | 0.018 | | 20512 | 0.037 | 0.018 | |
|  |  |  |  |  |  | |  | |  |  |  | |

Table 6: Horizontal Results - Phone 3 – Xiaomi MI8 #3

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **N/A** | | | **Session 2 – CP3** | | | | | **Session 3 – CP5** | | | | |
| **Technique** | **Count** | **Mean** | **SDev** | **Count** | | **Mean** | | **SDev** | **Count** | | **Mean** | | **SDev** |
| RTKLIB SPP |  |  |  | 11716 | 3.881 | | 2.799 | | 16958 | 3.966 | | 2.531 | |
| magicGEMINI L1 enabled |  |  |  | 22252 | 2.157 | | 1.664 | | 22731 | 1.829 | | 1.366 | |
| RTKLIB Baseline (PKVL) |  |  |  | 17657 | 0.060 | | 0.040 | | 13380 | 0.059 | | 0.039 | |
|  |  |  |  |  |  | |  | |  |  | |  | |

Table 7: Horizontal Results - Phone 4 – Huawei P30

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Session 1 – CP3** | | | N/A | | | | | N/A | | | | |
| **Technique** | **Count** | **Mean** | **SDev** | **Count** | | **Mean** | | **SDev** | **Count** | | **Mean** | | **SDev** |
| RTKLIB SPP | 8950 | 4.244 | 2.773 |  |  | |  | |  |  | |  | |
| magicGEMINI L1 enabled | 11195 | 2.438 | 1.490 |  |  | |  | |  |  | |  | |
| RTKLIB Baseline (PKVL) | 9477 | 1.086 | 0.793 |  |  | |  | |  |  | |  | |

### Plots (Phone #1)

|  |  |  |
| --- | --- | --- |
|  |  |  |
| (a) RTKLib SPP |  | (b) magicGEMINI |

Figure 5: Horizontal Plots of Session 1

|  |  |  |
| --- | --- | --- |
|  |  |  |
| (a) RTKLib SPP |  | (b) magicGEMINI |

Figure 6: Horizontal Plots of Session 2

|  |  |  |
| --- | --- | --- |
|  |  |  |
| (a) RTKLib SPP |  | (b) magicGEMINI |

Figure 7: Horizontal Plots of Session 3

## Vertical Results

### Tabular Results

Table 8: Vertical Results - Phone 1 – Xiaomi MI8 #1

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Session 1 - CP2** | | | **Session 2 - CP1** | | | **Session 3 - CP1** | | |
| Technique | **Count** | **Mean** | **SDev** | **Count** | **Mean** | **SDev** | **Count** | **Mean** | **SDev** |
| RTKLIB SPP | 6233 | -3.574 | 12.644 | 12488 | -3.601 | 8.030 | 18158 | -2.246 | 7.783 |
| magicGEMINI L1 enabled | 11207 | 3.942 | 6.037 | 22250 | 2.054 | 4.657 | 25709 | 2.461 | 4.578 |
| RTKLIB Baseline (PKVL) | 6233 | 0.159 | 0.541 | 19259 | -0.028 | 0.016 | 12329 | -0.025 | 0.016 |

Table Vertical Results - 9: Phone 2 – Xiaomi MI8 #2

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **N/A** | | | **Session 2 – CP2** | | | **Session 3 – CP4** | | |
| Technique | **Count** | **Mean** | **SDev** | **Count** | **Mean** | **SDev** | **Count** | **Mean** | **SDev** |
| RTKLIB SPP |  |  |  | 7947 | -6.989 | 8.109 | 19345 | -2.942 | 5.727 |
| magicGEMINI L1 enabled |  |  |  | 22251 | 2.120 | 4.106 | 21558 | 1.130 | 1.942 |
| RTKLIB Baseline (PKVL) |  |  |  | 15666 | -0.036 | 0.012 | 20512 | -0.037 | 0.013 |

Table 10: Vertical Results - Phone 3 – Xiaomi MI8 #3

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **N/A** | | | **Session 2 – CP3** | | | **Session 3 – CP5** | | |
| Technique | **Count** | **Mean** | **SDev** | **Count** | **Mean** | **SDev** | **Count** | **Mean** | **SDev** |
| RTKLIB SPP |  |  |  | 11716 | -1.233 | 6.736 | 16958 | -3.015 | 7.775 |
| magicGEMINI L1 enabled |  |  |  | 22252 | 3.120 | 4.551 | 22731 | 1.318 | 3.975 |
| RTKLIB Baseline (PKVL) |  |  |  | 17657 | -0.030 | 0.020 | 13380 | -0.042 | 0.021 |

Table 11: Vertical Results - Phone 4 – Huawei P30

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Session 1 - CP3** | | | **N/A** | | | **N/A** | | |
| Technique | **Count** | **Mean** | **SDev** | **Count** | **Mean** | **SDev** | **Count** | **Mean** | **SDev** |
| RTKLIB SPP | 8950 | 2.705 | 9.755 |  |  |  |  |  |  |
| magicGEMINI L1 enabled | 11195 | 3.937 | 5.000 |  |  |  |  |  |  |
| RTKLIB Baseline (PKVL) | 9477 | 0.444 | 2.029 |  |  |  |  |  |  |

|  |
| --- |
| Plots (Session 1 – Phone #1) |

Figure 8: Session 1 – Phone #1 (RTKLib SPP)

|  |
| --- |
|  |

Figure 9: Session 1 – Phone #1 (magicGEMINI)

### Plots (Session 2 - Phone #1)

|  |
| --- |
|  |

Figure 10: Session 2 – Phone #1 (RTKLIB SPP)

|  |
| --- |
|  |

Figure 11: Session 2 – Phone #1 (magicGEMINI)

### Plots (Session 3 - Phone #1)

|  |
| --- |
|  |

Figure 12: Session 3 – Phone #1 (RTKLIB SPP)

|  |
| --- |
|  |

Figure 13: Session 3 – Phone #1 (magicGEMINI)

# Analysis

## Positioning Performance

### Horizontal Performance

The results clearly demonstrate that access to the SBAS L1 Legacy signal offers significant improvements to the positioning performance of all the smartphones tested. The mean difference to the known coordinates (accuracy) seen in Table 4 thru to Table 7 improved by a factor of 1.5-3.0 times when processed with the SBAS L1 Legacy signal. Although these improvements are significant, the absolute accuracy is still in the range of one to three meters.

The level of improvement seen in the accuracy is also evident in the precision (spread) of the results across all four smartphones. The improved precisions offered by the SBAS L1 Legacy signals is obvious in the horizontal error plots (Figure 5 to Figure 7) and is quantified by the standard deviations in Table 4 thru to Table 7. The precision improves by a factor of 1.5-3.0 times when the data is processed with the SBAS L1 Legacy signal.

Use of the SBAS signal also appears to have a positive impact on the availability of a solution. For three of the four smartphones there were significantly more solutions available than when using a basic single point position. However, the improvement in the number of solutions available should be treated cautiously. The post-processing with magicGEMINI uses downloaded, post-processed, orbit and clock data, whilst both the RTKLib techniques only make use of the orbit and clock data that was available to the device in real-time.

### Vertical Performance

The results clearly demonstrate that access to the SBAS L1 Legacy improves the precision of the vertical component (see in Figure 8 - Figure 13 for Phone #1). The improvement vertical precision is similar to that seen for the horizontal precision, a factor of 1.5-3.0 times (quantified in Table 8 - Table 11, for all devices).

With regards to the vertical accuracy (mean difference from the known coordinates) the results indicate that the vertical accuracy is significantly worse when the SBAS L1 Legacy signal is available. We believe these results to be misleading, having been informed by FrontierSI that there are known issues (with unknown and variable effects) with the vertical component when post-processing in magicGEMINI.

## Huawei P30 Duty Cycling

In the research undertaken by RMIT and The University of Melbourne the use of carrier phase data from the Huawei P30 (Phone #4) was compromised by the duty cycling (power off/on) of the GNSS receiver chip. The impact of the duty cycling can be seen in the dual frequency baseline processing results for the Huawei P30 (Table 7) compared to those for the Xiaomi Mi8s (Table 4 to Table 6).

The effect of the Huawei P30 duty cycling *should* be limited to the carrier phase data. The code data collected by the Huawei P30 *should not* be affected by the duty cycling. However, this hypothesis was not considered in the previous research. This project provided an opportunity to test this hypothesis by examining whether or not access to SBAS L1 Legacy signals improves the code-based positioning capabilities of the Huawei P30.

The results for the Huawei P30 (previously discussed above) show improvements in the horizontal accuracy, horizontal precision, and vertical precision by factors of 1.7, 1.9, and 2.0 respectively. This confirms that the Huawei P30 duty cycling is not impacting code-based positioning and that access to the SBAS L1 Legacy signal may be the only viable option for improving positioning performance in the presence of duty cycling.

## DFMC SBAS Issues

Some issues were identified with the GNSS observation data recorded by the smartphones, which significantly impacted the DFMC SBAS processing in magicGEMINI. Gaps in the observations occurred mainly on the L5 frequencies, while carrier phase observation gaps affected all frequencies in the recorded data. Furthermore, the observed signal to noise ratio values were lower than expected, and some lines in the RINEX were written with incorrect syntax. These issues have caused magicGEMINI to reject several satellites during the solution, primarily due to the data gaps. This did affect the L1 SBAS solution, though the impact on the DFMC solution was much more severe due to reliance on observations over both L1 and L5.

The Navigation data recorded during the test sessions was also insufficient to compute the DFMC SBAS solution, as Galileo satellites send both I/NAV and F/NAV messages simultaneously, and only the I/NAV was recorded by the smartphone. The SBAS Test-bed signals are configured to use the F/NAV messages for corrections, so the Galileo satellites were not initially included in results. Complete Navigation data files were sourced from GMV’s data archive to solve this issue. Additionally, there is currently an incomplete constellation of L5-transmitting GPS satellites, so only a subset of the visible GPS satellites could be used in the DFMC solution.

The magicGEMINI software is primarily designed for aviation processing, and may show a greater impact from data gaps and incorrectly formatted input files than solutions computed by other methods. In this case, the quality of the recorded measurements was the primary cause of the inconclusive results for the DFMC solution.

# Conclusions

Based on the post-processing and analysis of the provided smartphone data, described in the preceding sections of this report, we conclude that:

1. Access to the SBAS L1 Legacy signal improves the horizontal positioning performance of the tested smartphones by a factor of 1.5 to 3 times, in terms of both accuracy and precision.
2. Access to the SBAS L1 Legacy signal improves the vertical precision of the tested smartphones by a factor of 1.5 to 3 times.

We note that these improvements have been observed in a post-processing scenario and further research is needed to validate these results in a real-time scenario.

The research also discovered issues, related to the quality of the smartphone observation data that severely limits the utility of the DFMC SBAS service for smartphone positioning. Further investigation of this issue is recommended.

# References

ICSM, 2020, SP1 – Intergovernmental Committee on Surveying and Mapping, <https://www.icsm.gov.au/publications/standard-australian-survey-control-network-special-publication-1-sp1>, Accessed 01/02/20.

1. Positioning Performance Evaluation of Dual-frequency GNSS Observations from a Smartphone

See attached digital document:

Ng\_2019\_positioning\_performance\_evaluation\_dual\_frequency\_gnss\_smartphone.pdf