

# Precise Point Positioning with single and dual-frequency multi-GNSS Android smartphones

Umberto Robustelli<sup>a</sup>, Valerio Baiocchi<sup>b</sup>, Laura Marconi<sup>c</sup>, Fabio Radicioni<sup>c</sup> and Giovanni Pugliano<sup>a</sup>

<sup>a</sup>Department of Engineering, Parthenope University of Naples, Naples, Italy

<sup>b</sup>Department of Civil Constructional, and Environmental Engineering DICEA, Sapienza University of Rome Rome, Italy

<sup>c</sup>Department of Engineering, University of Perugia Perugia, Italy

## Abstract

The new generation of Android smartphones is equipped with high performance Global Navigation Satellite System (GNSS) chips capable of tracking dual frequency multi-constellation data. Moreover, starting from version 9 of Android users can disable the duty cycle power saving option thus good quality pseudorange and carrier phase raw data are available thus the application of Precise Point Positioning (PPP) algorithm becomes more and more interesting. The main aim of this work is to assess the PPP performance of the first dual-frequency GNSS smartphone produced by Xiaomi equipped with a Broadcom BCM47755. The advantage of acquire dual frequency data is highlighted by comparing the performance obtained by Xiaomi with that of a single frequency smartphone the Samsung S8. The horizontal and vertical accuracy achieved by Xiaomi are of 0.51 m and 6 m respectively while those achieved by Samsung are 5.64 m for 15 m for horizontal and vertical.

## Keywords

Raw data, Android Smartphone, PPP, Xiaomi MI 8, Samsung S8, Duty Cycle

## 1. Introduction

The ability to access raw data started in May 2016 when Google announced that raw GNSS measurements would be available to apps in the Android Nougat operating system was a revolution. From that day on, it became possible to use D-GNSS algorithms with mobile phone, try to reduce errors in urban areas, to fuse GNSS data with data from the other phone sensors such as the Inertial Measurement Unit (IMU). Since that date many steps forward have been made thanks also to the appearance of new chips designed exclusively for mobile devices. Having access to smartphone raw data together with all the GNSS products made available free of charge by organizations such as International GNSS Service (IGS) [1, 2] researchers have begun to focus their studies on this area. The first studies conducted on mobile devices used the measures acquired by the Google/HTC Nexus 9 tablet because it was the only tablet/smartphone that allowed the disabling of the duty cycle guaranteeing continuous phase observations (See Realini et al., [3], Zhang et al. [4], Li and Geng [5] ). With the advent of

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EMAIL: umberto.robustelli@uniparthenope.it (.U. Robustelli); valerio.baiocchi@uniroma1.it (V. Baiocchi); laura.marconi@unipg.it (.L. Marconi); fabio.radicioni@unipg.it (.F. Radicioni); giovanni.pugliano@uniparthenope.it (.G. Pugliano)

ORCID: 0000-0002-5486-7721 (.U. Robustelli); 0000-0003-4491-7868 (V. Baiocchi); 0000-0003-3465-1525 (.L. Marconi); 0000-0002-1377-4588 (.F. Radicioni); 0000-0002-8177-1370 (.G. Pugliano)



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new generation smartphones equipped with increasingly high performance GNSS chips, the use of PPP algorithms for positioning is becoming increasingly widespread. This is due to the fact that the PPP algorithm does not need to use the measurements coming from a second receiver typically belonging to a GNSS network. Gill et al. [6] applied single-frequency PPP methodology to measurements acquired by a Nexus 9 tablet achieving an accuracy of 0.28 m, 0.25 m and 0.51 m for north, east and up component. A further step forward occurred when in May 2018 appeared the world's first dual-frequency GNSS smartphone produced by Xiaomi. It is equipped with a Broadcom BCM47755 chipset. It is a multi-constellation, dual-frequency (E1/L1+E5a/L5) GNSS chip able to record code and carrier phase measurements on GPS L1 & L5, GLONASS L1, Galileo E1 & E5a, BeiDou and QZSS L1 & L5. Until then, the GPS chipsets mounted on smartphones were single-frequency. In some cases, they were already multi-constellation, but the mono frequency extremely limited the performance because the ionospheric error could not be eliminated but only estimated using a single frequency model like Klobuchar one [7]. Thus researchers starting to apply dual frequency PPP algorithm to this data. Wu et al. in 2019 [8] analyzed the positioning performance of the Xiaomi Mi 8 in static and kinematic modes applying dual-frequency PPP algorithm to the GPS L1/L5 and Galileo E1/E5a signals processing data through an algorithm modified from RTKLIB. In the static mode, the root mean square (RMS) position errors of the dual-frequency smartphone PPP solutions in the east, north, and up directions were 0.22 m, 0.04 m, and 0.11 m respectively after about 300 minutes. Finally Wen et al. ([9] replaced the Mi 8's embedded GNSS antenna with an external survey-grade one and performed precise point positioning ambiguity resolution (PPP-AR) achieving centimeter-level accuracy after about one hour. The main aim of this work is to assess the PPP performance of Xiaomi Mi 8 (using its embedded antenna) taking advantage of all the potential offered by the Broadcom BCM47755 chip, unlike the research mentioned above, our processing strategy will be based on the use of all the constellations received by the smartphone namely GPS, GLONASS, Galileo and BeiDou.

## 2. Methods and Data

Precise Point Positioning algorithms are well known and ample literature is available (see [10] for an exhaustive description). The data collection has been carried out by using two Android smartphones and a geodetic receiver installed on the roof of a two-storey building of the Engineering Department at the University of Perugia in an open-sky area. Geo ++ RINEX Logger app was used to acquire 1 Hz data in RINEX 3.03 format over a time span of about 1 hour (13:20 - 14:20 UTC) on March 4, 2019. Figure 1 shows the setup of the two smartphones and the geodetic GNSS receiver/antenna Topcon Hiper HR. This configuration was chosen in order to simultaneously acquire measurements from the three receivers. The first smartphone used was a Xiaomi Mi 8 running Android 9 operating system, embedded with a Broadcom BCM47755 chip. This chip is the first dual frequency chip expressly developed for a smartphone [7]. It provides access both to the L1/E1 frequency for GPS, GLONASS, Galileo, BeiDou and to L5 and E5a frequencies for GPS and Galileo, respectively.

The second smartphone employed was a Samsung Galaxy S8 equipped with a Exynos 8895 Octa – EMEA, running Android 7 operating system. It support only L1/E1 frequency for GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS constellations.

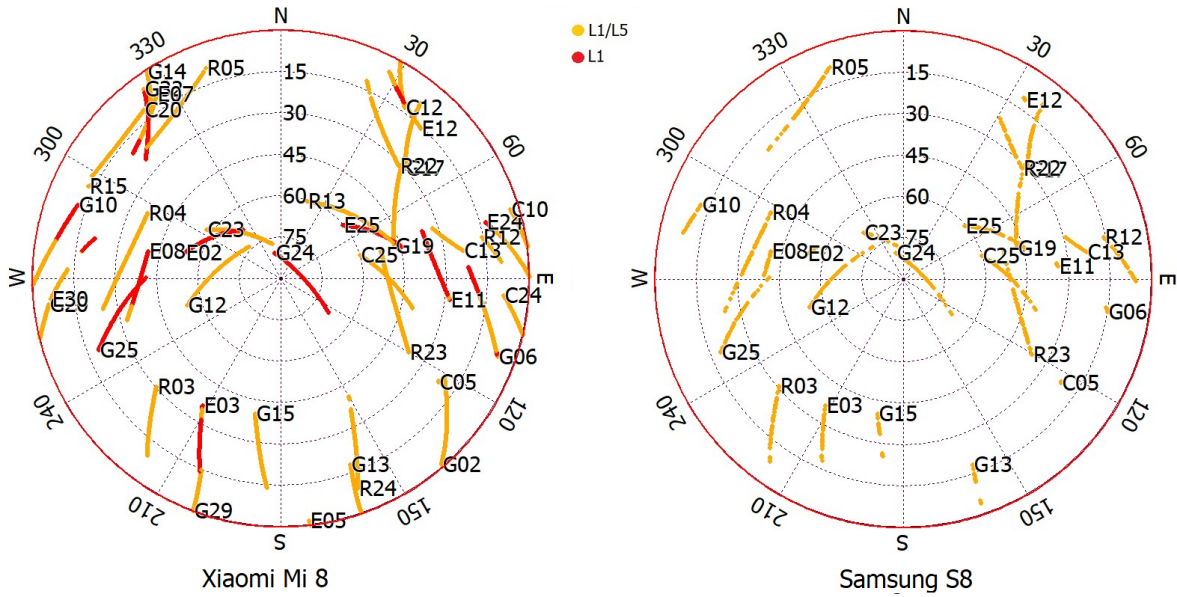
The geodetic receiver used was a Topcon HiPer HR with integrated antenna capable of receiving GPS, GLONASS, Galileo, BeiDou, QZSS, SBAS signals on all frequencies.



**Figure 1:** The location where the experimental data were collected and the equipment used in this study

The data acquired by the geodetic receiver were post processed in the static relative positioning mode. In detail, a Continuously Operating Reference Station (CORS) of the Umbria GNSS Network ([11, 12]) was used as base station. The results obtained were used as reference in order to evaluate the accuracy achieved by the two smartphones.

Starting from version 9 of Android users have the possibility to disable the duty cycle via software. This can be done by enabling the “Force full GNSS measurements” item in the developers menu. Thus for the Xiaomi Mi 8 duty cycle has been disabled while for Samsung S8 this was not possible.



**Figure 2:** Sky-plots of Perugia sites' smartphones data. Xiaomi Mi 8 and Samsung S8 data are depicted in left and right subplot respectively. The observational arcs represented in red refer to satellites whose signals are acquired both on E1/L1 and E5a/L5 frequencies. Arcs in orange refer to satellites whose signals are acquired E1/L1 signals. It can be noticed that Samsung S8 smartphone does not acquire E5a/L5 signals.

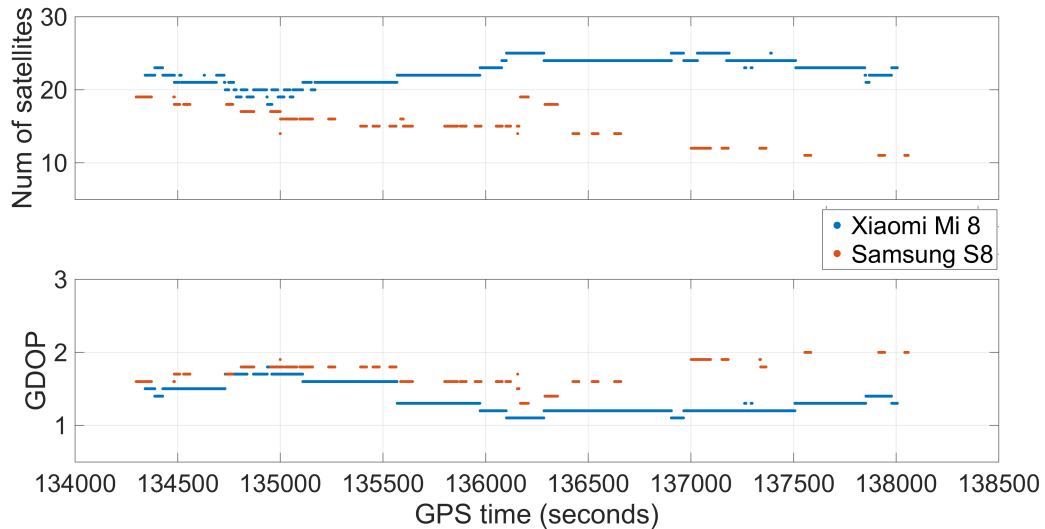
### 3. Results

As discussed in 2 section the smartphones and geodetic receiver have been installed on the roof of a building in an open-sky area. Figure 2 shows the sky-plots of Xiaomi Mi 8 and Samsung S8 in the left and right subplot respectively. The arcs depicted in red refer to satellites whose signals are acquired both on E1/L1 and E5a/L5 while arcs in orange represent satellites whose signals are acquired only on L1/E1 frequencies. From the figure it is clear that the Samsung S8 only receives the E1/L1 signals.

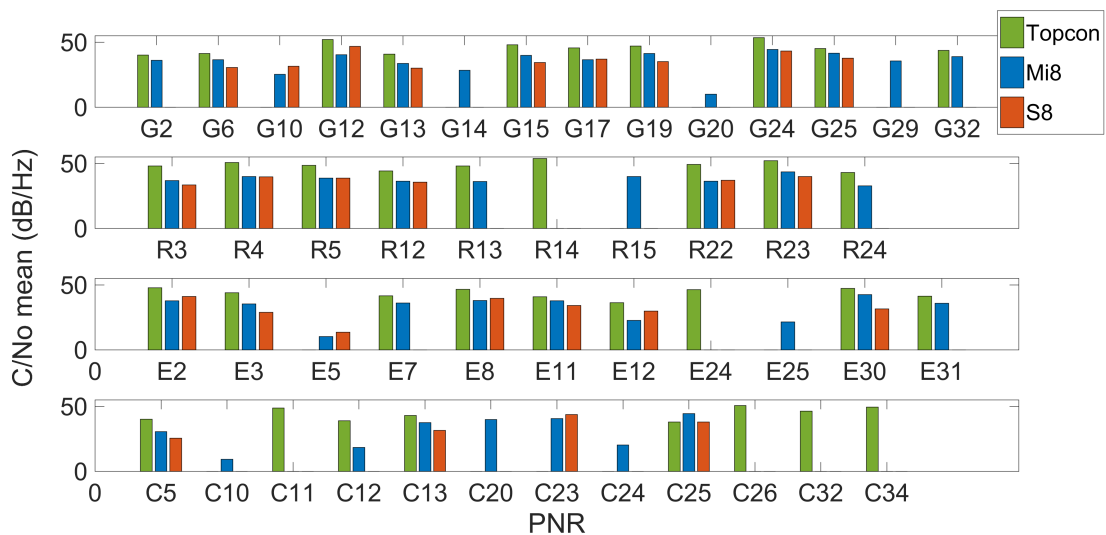
In figure 3 are shown the number of visible satellites with cut-off angle of 15 degrees and the evolution of GDOP versus time in top subplot and in bottom subplot respectively. Data relative to Xiaomi Mi 8 are depicted in blue while those relative to Samsung S8 are depicted in red. By observing the figure it can be noticed that the number of visible satellites acquired by Xiaomi Mi 8 is always higher than those acquired by Samsung S8. This is expected due to the higher tracking performance of Broadcom chip. Clearly the higher number of acquired satellites also affects the GDOP values which are always better for the Xiaomi Mi 8. Finally we want to point out the presence of some data gaps present in the data acquired by Samsung S8 (for example around 134600, 136700, 137600 seconds) caused by unwanted hardware stand-by.

Despite these differences, however, we can state that the number of acquired satellites and their geometry are good for both smartphones having an average number of visible satellites equal to 22 for the Xiaomi and 15 for the Samsung and an average of GDOP of 1.3 and 1.7 respectively.

In order to assess the quality of received signals we compared the average of signal to noise ratio of each satellites received by Xiaomi Mi 8 and Samsung S8 with those of the same satellites received by geodetic receiver on L1/E1 frequency. This comparison is showed in figure 4: green,



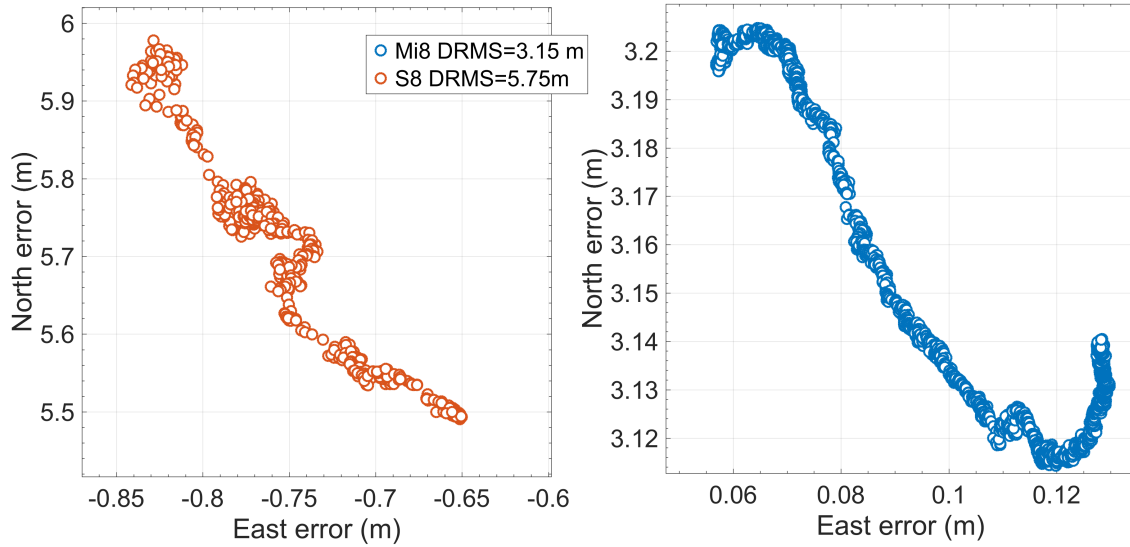
**Figure 3:** In the top subplot are shown the number of visible satellite with elevation angle cut-off of 15 degree versus epoch for Xiaomi Mi 8 and Samsung S8 plotted in blue and red respectively. The bottom subplot shows the evolution of GDOP parameter respect to GPS epoch for both the smartphones.



**Figure 4:** Mean SNR L1 comparison between Topcon, Xiaomi Mi 8 and Samsung S8 depicted in green, blue and red respectively. Figure is divided in four subplots for readability: from top to bottom are shown GPS, GLONASS, Galileo and BeiDou satellites.

blue and red bars represent Topcon, Xiaomi Mi 8 and Samsung S8 respectively. Due the high number of satellites the comparison figure has been divided in four subplots representing the four constellations used. The figure clearly highlights the better performance of Xiaomi Mi 8 with respect to Samsung S8. Moreover observing the subplot relative to BeiDou (the bottom one) it can be noticed that only the geodetic receiver tracks C11, C26, C32 and C34 satellites.

Results are obtained using the Demo5 b33a (downloadable from <http://rtkexplorer.com/download/demo5-b33a-binaries> modified version of the RTKLIB software originally developed



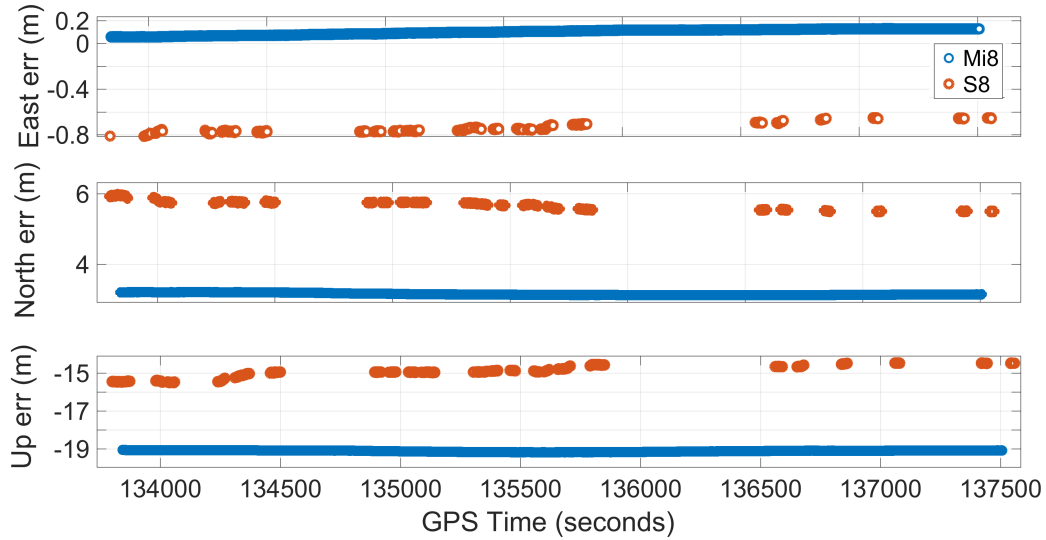
**Figure 5:** Scatter plot of L1/E1 PPP position error. Blue markers represent errors obtained by using Xiaomi Mi 8 measurements, red circles represent error for Samsung S8.

by Takasu ([13, 14]), using the PPP static algorithm, setting forward and backward option for filter solution, a cutoff angle of 15 degrees. Precise ephemeris and clocks correction used are the final CODE (Center for Orbit Determination in Europe) products. We also considered the earth rotation parameters (ERP) and satellite antenna corrections provided by IGS for PCV (phase center variations). For the ambiguity resolution we used the “continuous” method with a threshold equal to 30 to guarantee a better and more feasible estimation (See Dabove [15, 16]).

We want to emphasize that currently there are a large number of online applications that allow raw data PPP processing. In this study we also processed data by using the CSRS-PPP (Canadian Spatial Reference System) service [17]. However we will show the results obtained using RTKLIB.

Many processing cases using different combinations of GNSS systems have been investigated. However in order to facilitate the readability of the article, in this section are shown only the results obtained using signals from all the tracked constellations namely: GPS, GLONASS, Galileo and BeiDou constellation with the exception of Milena and Doresa Galileo satellites due to their elliptical orbits ([18, 19, 20, 21]). All the achieved results are summarized in tables 1 and 2. Firsts test are conducted using L1/E1 single frequency PPP algorithm in order to compare results achieved by the two different smartphones. Figure 5 shows the scatter plot of achieved results, two different scales are used in order to get better readability. Blue markers represent errors obtained by using Xiaomi Mi 8 measurements, red circles represent error for Samsung S8. The horizontal accuracy achieved is of 3.15 m and 5.75 m for Xiaomi Mi 8 and Samsung S8 respectively.

In figure 6 are depicted east, north and up solution components in subplot a, b and c respectively for Xiaomi Mi 8 (in blue) and Samsung S8 (in red). Two things are worth noting. The first is that in this test the vertical accuracy of the Xiaomi (about 20 m) is worse than that of the Samsung of about 5 m. The second is that the number of positions obtained by



**Figure 6:** Xiaomi MI 8 (in blue) and Samsung S8 point (in red) PPP solution components. Subplots a, b, c show east, north and up components respectively.

**Table 1**

Performance of single and dual-frequency PPP algorithms for Xiaomi Mi8 and Samsung S8 Android smartphones using all constellations.

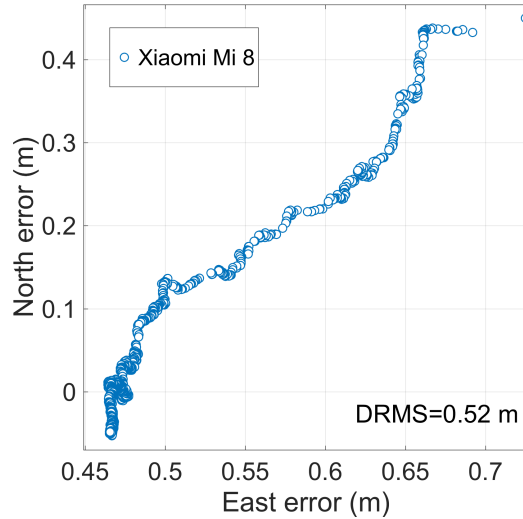
	RMS (m)				#
	East	North	Up	Horiz.	
S8 (L1/E1)	0.75	5.70	14.95	5.75	684
Mi 8 (L1/E1)	0.10	3.15	19.11	3.15	3607
Mi 8 (L1/E1+L5/E5a)	0.15	3.35	20.38	3.35	3581
Mi 8 (ionospheric-free)	0.50	0.12	6.49	0.52	1756

Samsung S8 are 684 while those obtained by Xiaomi Mi 8 are 3607. This is very evident by observing in the figure numerous gaps in the red line probably due to the activation of the duty cycle power saving mechanism.

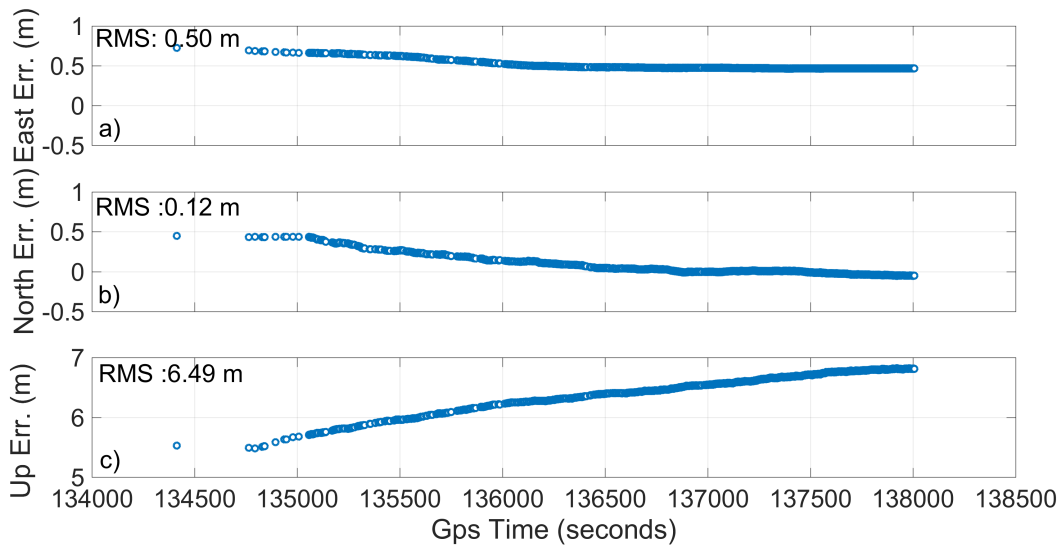
In order to take full advantage of the potential of the Broadcom chipset embedded in the Xiaomi, further processing has been carried out. By exploiting the dual frequency measurements, it was possible to use the ionospheric-free combination in order to eliminate the first-order ionospheric error.

The scatter plot of this analysis is shown in figure 7. Blue markers represent errors obtained by using Xiaomi Mi 8 measurements. The horizontal accuracy achieved expressed in terms of DRMS is 0.52 m. East, north and up solution components are depicted in the subplot a, b and c of figure 8 respectively. The vertical RMS achieved is 6.0 m and the number of positions is equal to 1756.

The statistics related to all the processing carried out with different combinations of GNSS systems are shown in table 1, and 2.



**Figure 7:** Scatter plot of ionospheric-free PPP position error. Blue markers represent errors obtained by using Xiaomi Mi 8.



**Figure 8:** Xiaomi Mi 8 PPP ionospheric-free solution components. Subplots a, b, c show east, north and up components respectively.

## 4. Discussion and Conclusion

We analyzed and assessed Xiaomi Mi 8 and Samsung S8 Android smartphone performance in open sky environment using PPP algorithms. More than twenty different elaborations have been carried out.

E1/L1 single frequency scatter plots reveals a better horizontal accuracy for Xiaomi Mi 8 with respect to Samsung S8. Vice versa the vertical accuracy achieved is better for Samsung than Xiaomi. However analyzing the east, north, up coordinate error plots in time domain we found that the number of solution achieved by Samsung S8 is about 1/6 than those achieved



**Table 2**

Performance of single and dual-frequency PPP algorithms for Xiaomi Mi 8 and Samsung S8 Android smartphones using only GPS and Galileo constellations.

	RMS (m)				# solut.
	East	North	Up	Horiz.	
S8 (L1/E1)	0.50	5.71	14.70	5.74	489
Mi 8 (L1/E1)	0.58	2.76	18.43	2.82	3595
Mi 8 (L1/E1+L5/E5a)	0.60	2.54	20.0	2.62	3556
Mi 8 (ionospheric-free)	0.93	0.37	5.80	1.00	1875

by Xiaomi Mi 8. This could be addressed to the activation of the duty cycle power saving mechanism; in particular, Samsung S8 carrier phase measurements are affected by cycle slips.

Xiaomi Mi 8 dual frequency L1/E1 & L5/E5a scatter plot shows an horizontal accuracy of 0.52 m while the vertical RMS is 6.0 m. By observing east, north, up coordinate error plots in time domain it can be noticed that the dual frequency PPP algorithm takes about 350 seconds before providing solutions with a fairly good continuity unlike the single frequency PPP algorithm.

To facilitate the readability of the article, in the previous section we have chosen to show only some graphics of the elaborations carried out. By comparing results achieved by Xiaomi in both ionospheric-free and dual frequency strategy it can be noticed that the exclusion of GLONASS and BeiDou constellations (table 2) worsens the accuracy obtained when all constellations data are used (table 1).

Results obtained show that the Xiaomi Mi 8 dual-frequency multi-constellation smartphone can be used in application with low precision requirements such as map updating and cadastral survey.

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