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Performance assessment of GNSS single point positioning with recent smartphones

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***Abstract* – The new generation of Android smartphones are equipped with high performance Global Navigation Satellite System (GNSS) chips. These new chips are 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 it is feasible to acquire good quality raw carrier-phase measurements. Nevertheless, there is still a need to evaluate the accuracy, which may be reached with current smart devices in a standard navigational solution. In this work we assessed the performance of GPS + Galileo single point positioning of three recent smartphones, namely Xiaomi Mi 8, Xiaomi Mi 9 and Huawei P30. The best positioning accuracy, in terms of horizontal root mean square error (DRMS), was obtained by Huawei P30 with a DRMS of 4.46 m. Xiaomi MI8 shows very similar performance (4.56 m of DRMS) but these results were subject to outliers. Finally Xiaomi Mi9 shows a DRMS of 7.26 m, and therefore demonstrates the poorest accuracy among tested smart devices.**

I. INTRODUCTION

As reported by GSA [1], smartphones are nowadays dominating the installed base of devices equipped with GNSS (Global Navigation Satellite System) chipsets. The ubiquity and current positioning performance of recent smartphones have expanded their initial applications such as personal navigation and social networking and therefore opened the door to novel areas of market, industry and science [7], [14], [15]. Recently a great deal of effort has been made in the development of the processing algorithms which address the specific limitations of smartphone GNSS observations. As a result, several researchers have proved the feasibility of precise positioning with such observations under the specific conditions ([10], [16], [17]). Nevertheless, there is still a need to evaluate the accuracy which may be reached with current smart devices in a standard positioning service based on code pseudoranges, since even now there are few smartphones, which support continuous phase observations. In a view of these expectations, this paper aims at the characterisation of the positioning performance level which may be reached with the selected recent smartphones. This evaluation was preceded by the analysis of the GNSS observation quality in terms of signal power.

II. EXPERIMENT DESIGN AND RESULTS

A. Data collection

The smartphone GNSS observation analysis as well as single point positioning performance assessment take advantage of GNSS data collected by selected recent Android smartphones, namely Huawei P30, Xiaomi Mi 8 and Xiaomi Mi 9. These smartphones are capable of collecting dual frequency multi constellation (GPS + Galileo + GLONASS + BDS) signals. The last smartphone collects only code pseudoranges, whereas Huawei P30, Xiaomi Mi 8 allow the acquisition of both phase and code measurements. Since phase observables are not employed in a standard navigational solution with the single point positioning (SPP) mode, we neither assess nor use them in positioning experiment. The observations were collected on December 11, 2019 over a time span of about 5 hours (approximately 8-13 UTC) using Geo++ RINEX Logger ver. 2.1.6 application running on Android system. The applied smartphones were collocated and centred over the temporal sites using tribrachs, tripods and dedicated wooden beam as showed in figure 1. The ground truth coordinates of the temporal geodetic sites were determined be the means of static relative positioning using data collected by geodetic receivers and processed with house-developed GNSS processing software [8].

B. Observation analysis

The performance assessment of the single point positioning is preceded by a quality evaluation of GNSS observations acquired by the employed smart devices. As recent studies show, smartphone GNSS observations are not only subject to several unwanted effects but also suffer from significant observation noise and low suppression to multipath effect ([4], [6], [9]). Such results may be, to some extent, related to low strength of the GNSS signals acquired by smartphones. Hence this subsection examines

Fig. 1. Huawei P30, Xiaomi Mi 8 and Xiaomi Mi 9 during GNSS data collection.

selected characteristics of GNSS observations and verifies, with regard to recent smartphones, the common presumption that smartphone GNSS signals are of poorer quality with respect to these collected by geodetic grade receivers.

Our investigations in this study are limited to the Carrier-to-Noise density ratio (C/N0), which characterises the GNSS signal power ([3]). Figure 2 shows the skyplots of the C/N0 of the GPS signals collected by the applied smartphones. Taking advantage of the presentation of C/N0 as a function of signal azimuth and elevation, we may easily verify the presumption of high dependency of C/N0 on satellite elevation, which was already proved for geodetic and other high grade receivers. Looking at the plots in figure 2, we may learn that this statement does not hold true with regard to GNSS observations collected by the smartphones. Such results may suggest the application of C/N0-dependant rather than commonly used elevation dependant weighting functions in data processing ([5], [9]).

In figure 3 we present the time series of C/N0 of GNSS signals collected by applied smart devices. The values corresponding to different satellites are distinguished by different colours. As we may read from the plots, the maximal power of acquired signals does not exceed 50 dB-Hz. This is a significantly lower value with respect to geodetic grade receivers which allow acquisition of signals with power reaching up to 60 dB-Hz ([2], [18]). In general the applied smartphones show similar performance in this

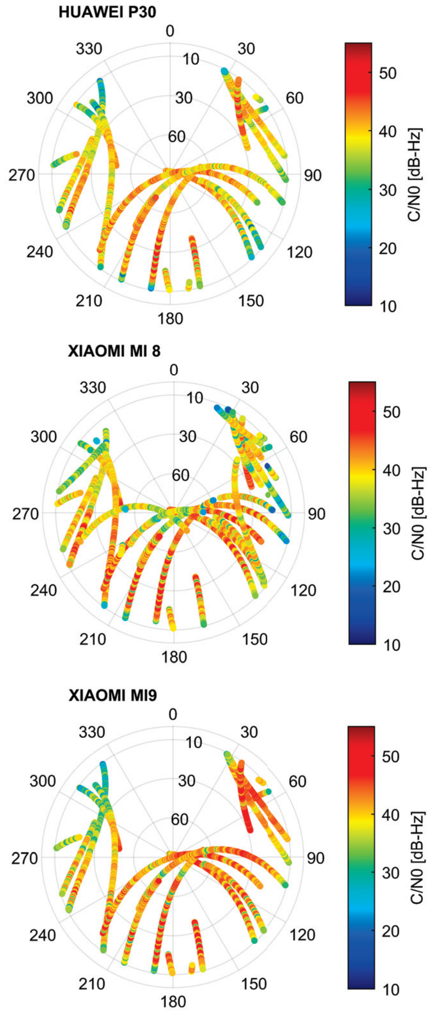

Fig. 2. Skyplots of GPS L1 C/N0: Huawei P30, versus Xiaomi Mi 8 and Xiaomi Mi 9.

term, however we can easily detect a higher number of outliers characterised by ultra-low values of C/N0 for Xiaomi Mi 9. This may be connected with higher susceptibility to multipath effect or worse elimination of outlying observations by Xiaomi Mi 9 with respect to other, analysed in this case study, smartphones.

C. Assessment of Single Point Positioning

Three selected post processing scenarios were applied for each smartphone; in the first one we used only GPS constellation, the second one took advantage of Galileo system and in the last both constellations were used. Tables 1, 2 and 3 demonstrate detailed results of single point positioning performance assessment achieved with the application of Xiaomi MI 9, Xiaomi MI 8 and Huawei P30 smartphones, respectively. As expected, the results clearly proved the benefit from multi-constellation signals over

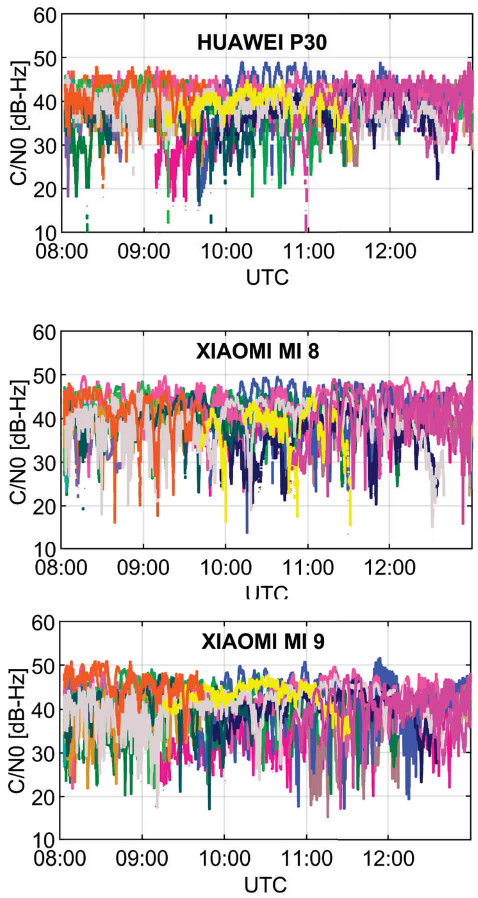

Fig. 3. Time series of C/N0 collected by smartphones. The values corresponding to different satellites are distinguished by different colours.

single system solution. Here, for the sake of brevity, only the most interesting results will be described in detail.

Figure 4 shows the scatter plot of single point positioning with three selected smartphones. Blue, red and yellow markers represent errors obtained using Xiaomi Mi 9, Xiaomi Mi 8 and Huawei P30 multi constellation measurements (both GPS and Galileo) respectively. In this figure the outliers detected in Mi 8 dataset (described in previous section) have been eliminated. The horizontal accuracy expressed in terms of DRMS (horizontal root mean square error) is of 7.26 m, 4.56 m and 4.46 m for Xiaomi Mi 9, Xiaomi Mi 8 and Huawei P30, respectively. With regard to vertical accuracy, the results confirmed the best performance of the Huawei P30 with a RMS of the vertical component of 7.46 meters compared to the 8.56 m and 11.49 m of the Xiaomi Mi 8 and Mi 9, respectively.

Figure 5 depicts the time series of East (top panel), North (middle panel) and Up (bottom panel) error components obtained with Xiaomi Mi 9 (in blue), Xiaomi Mi 8 (in red) and Huawei P30 (in yellow) in multi constellation scenario. We can read from the figure that the best performances are provided by the Huawei P30 in the GPS + Galileo configuration. In reality, the performance of the Xiaomi MI 8 is also very similar after the elimination of the outliers.

Table 1. Xiaomi Mi 9 coordinate statistics.

	GAL	GPS	GPS+GAL
DRMS [m]	9.64	11.77	7.26
RMS East [m]	5.31	5.63	4.02
RMS North [m]	8.05	10.33	6.05
RMS Up [m]	15.86	16.98	11.49
#Pos	18196	18196	18196

Table 2. Xiaomi Mi 8 coordinate statistics.

	GAL	GPS	GPS+GAL
DRMS [m]	12.45	6.01	4.56
RMS East [m]	3.93	2.95	2.38
RMS North [m]	11.81	5.24	3.89
RMS Up [m]	19.42	10.63	8.56
#Pos	9284	17300	17300

Table 3. Huawei P30 coordinate statistics.

	GAL	GPS	GPS+GAL
DRMS [m]	-	5.49	4.46
RMS East [m]	-	2.59	2.33
RMS North [m]	-	4.83	3.81
RMS Up [m]	-	7.90	7.46
#Pos	0	18218	18221

In figure 6 are presented the time series of East (top panel), North (middle panel) and Up (bottom panel) error components obtained with Xiaomi Mi 9 (in blue) and Xiaomi Mi 8 (in red) using only the signals of Galileo constellation. The positioning analysis was carried out excluding the Doresa and Milena satellites due to their eccentric orbits (for more information, please refer to [11, 12, 13]). It should be emphasized that the three smartphones had a fairly different behavior in relation to the reception of signals from the satellites of the Galileo constellation. In particular, the Huawei P30 smartphone was able to receive only 5 Galileo satellites (E05, E21, E25, E27, E31) but not simultaneously. The Xiaomi Mi8 and the Xiaomi Mi9 instead tracked more than four Galileo satellites simultaneously. Figure 7 shows Galileo satellites tracked by the Xiaomi Mi 8 and Mi 9 in the upper and lower panels respectively. As it can be seen, the Mi 9 was able to track more satellites than the Mi 8. In this analysis Huawei P30 is not represented since no solution can be obtained using

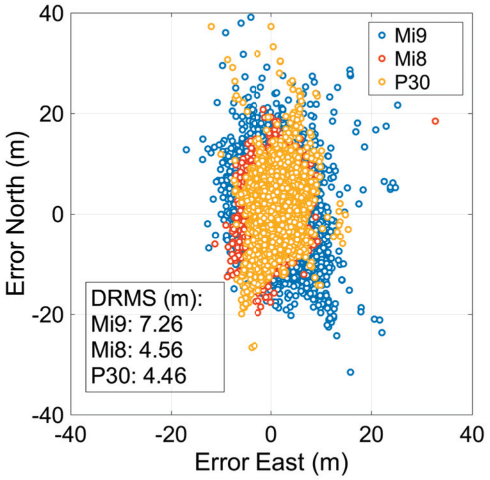

Fig. 4. Horizontal error scatter plot: blue, red and yellow circles correspond to MI9, Mi8 and P30 solution, respectively.

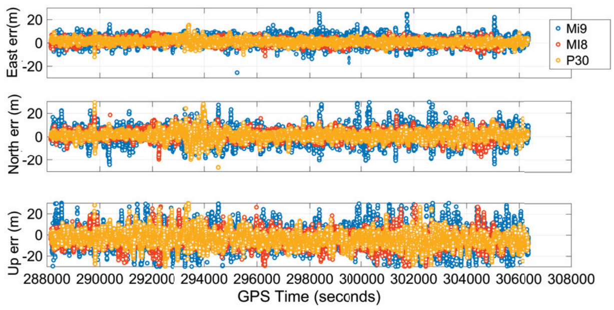

Fig. 5. Time series of coordinate error for Xiaomi MI 9 (in blue), Xiaomi MI 8 (in red) and Huawei P30 point (in yellow) SPP solution obtained using both GPS and Galileo observables. Top, middle and bottom subplots show East, North and Up components, respectively.

only the Galileo measurements. Figure 6 clearly shows that with GNSS measurements of Xiaomi Mi 8 it was feasible to obtain about a half of the expected epoch solutions. This was not the case for Xiaomi Mi 9 which provided the position during entire time span. A poor availability of Xiaomi Mi 8 positioning was caused by a low number of tracked Galileo satellites during the experiment.

III. CONCLUSIONS

In this work we assessed the performance of single point positioning with recent Android smartphones, namely Xiaomi Mi 8, Xiaomi Mi 9 and Huawei P30. Detailed results revealed a better horizontal accuracy for Huawei P30 and Xiaomi Mi 8 (4.46 m and 4.56 m of DRMS, respectively) with respect to Xiaomi Mi 9 with a DRMS of 7.26 m. With regard to vertical accuracy, the results confirmed the best performance of Huawei P30 with a RMS of the vertical

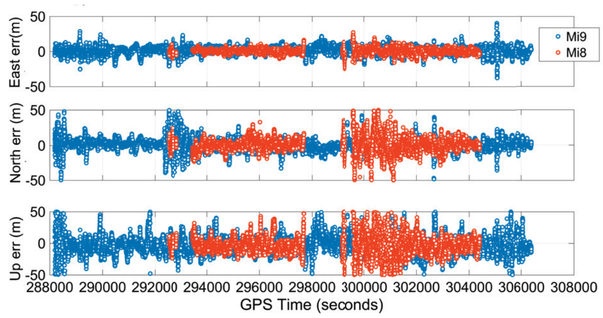

Fig. 6. Time series of coordinate error for Xiaomi MI 9 (in blue), Xiaomi MI 8 (in red) SPP solution obtained using only Galileo observables. Top, middle and bottom subplots show East, North and Up components, respectively.

component of 7.46 meters compared to the 8.56 m and 11.49 m of Xiaomi Mi 8 and Mi 9 smartphones, respectively. The results proved a high impact of the outliers on SPP positioning with smartphones, hence this issue should be further investigated.

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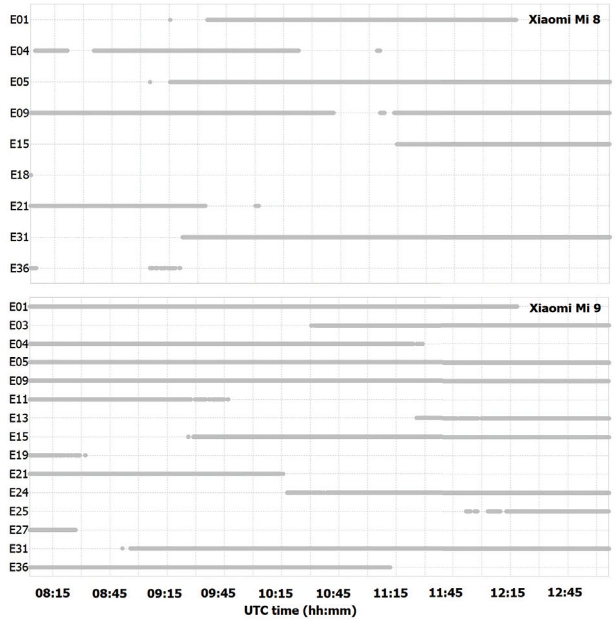

Fig. 7. Galileo satellites tracked by Xiaomi Mi 8 (top panel) and Xiaomi Mi 9 (bottom panel).

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