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Assessing the performance of raw measurement from different types of smartphones

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ABSTRACT

The objective of this paper is to assess the performance of different types of smartphones including Huawei Mate9, Huawei P10, Samsung Note8, Google Pixel2 and HTC U11+ in open sky area.

Firstly, the tracked satellites number, SNR and their NMEA results were compared with that from nearby Trimble-R10. The result shows that each types of smartphone has its advantages and disadvantages. Secondly, The analysis of double-differenced pseudorange residual indicates that the UTC 11+ performs worst and its double-differenced residual varies within ±50m, the other four phones are almost at the same level and vary within ±30m.

After a comparison of the positioning result with raw pseudorange measurements, we did not find obvious difference for the five devices, then the doppler measurements are introduced to smooth the pseudorange and it can improve the accuracy effectively.

I. Introduction

Centimeter-level position information can be obtained for high precision Global Navigation satellite system (GNSS) applications because we can access to high quality raw measurements including pseudorange and carrier phase observations. And also the characteristics of the measurements from different manufactures differ a lot for their different multipath mitigation methods. While for many low cost device, especially for smart device, users cannot obtain raw measurements even for pseudorange measurements. In recent years, the API level 24 allow the user have access to the GNSS raw measurements including pseudorange, doppler and carrier phase, which opens a new era for precise navigation on smart devices.

After the announcement of the possibility to access GNSS raw measurement from Android devices with API level 24, many efforts has been devoted to improve the possibility to use GNSS raw data effectively. In order to process the raw data conveniently, Google developed the Logger APP for retrieving raw data from smart devices and it also includes an open source software to analyze the retrieved raw measurements, but it is not stored in Receiver Independent Exchange (RINEX) format. Another APP named Geo++ RINEX Logger developed by Geo++ company, can help user acquire raw measurements form smart devices including pseudorange, doppler, SNR and carrier phase observations and preceded the progress of research on positioning based on smart devices.

Then many experiments with GNSS raw measurements from smart devices were published. Banville & van Diggelen [1] analyzed raw measurements from the Samsung Galaxy S7 smartphone running the Broadcom 4774 GNSS chip with an engineering build of the Android N OS. They concluded that current quality of carrier phase has the potential to realize centimeter-level displacement monitoring, which was also confirmed by Realini et al. [2] and Pirazzi et al. [3]. Gill et al. [4] tested the Precise Point Positioning (PPP) with the raw data retrieved from Nexus 9 BCM4752 and it can achieve decimeter accuracy, because the Nexus 9 tablet has duty cycling disabled, which can allow use access the continuous carrier phase measurements. The Airbus is also conducting the project in support of European GNSS Agency (GSA) and putting the Galileo system in the newest smartphones and they characterized the code and phase measurements and Position, Velocity and Time (PVT) solutions of different GNSS constellations especially for Galileo system[5].

But it still has many obstacles, especially the antenna and duty-cycle issues [6,7]. The geodetic grade antenna is right hand circular polarized while antenna of smart devices is usually linearly polarized, which will reduce the signal strength and increase the potential for multipath. And also most of available smart devices supporting carrier phase implement GNSS power duty cycling, which results in discontinuity of adjacent epoch phase data, which limits the positioning accuracy.

As we known, many manufactures produce smartphones that access raw GNSS measurements, such as Google, Huawei, Samsung et al. Different manufactures may use different GNSS chipset, which may result in different performance of measurements and navigation solutions. The objective of this paper is to assess the performance of different types of smartphones including Huawei Mate9, Huawei P10, Samsung Note8, Google Pixel2 and HTC U11+ in open sky area including measurements and navigation results. All of these smartphones are declared to be able to access the pseudorange, and the first-three can also output the carrier phase measurements. In following sections, the experiment design, some results and conclusions are presented.

II. Experiment design

Data description

In order to assess and compare the performance of raw measurement of different smart phones of different manufactures which can access to raw measurements, we deployed five smart phones including Huawei P10, Huawei Mate9, Samsung Note8, Google Pixel2 and HTC U11+ in open area at The Hong Kong Polytechnic University and a Trimble receiver (R10) was set up beside them at the same time. The tests were conducted on December 05, 2017 (left in figure 1) and January 02, 2018 (right in figure 1) respectively, table 1 shows the measurements available in output of these five smart-phones. As all the data were collected at the same place, we select all GNSS data collected in December 05, 2017 (left in figure 1) and data collected in January 02, 2018 (right in figure 1) with Samsung note8 to analyze. The GNSS measurements were collected with “Geo++ RINEX Logger” and Google-developed “GPS logger” app and the standard RINEX files and raw measurements files can be obtained respectively.

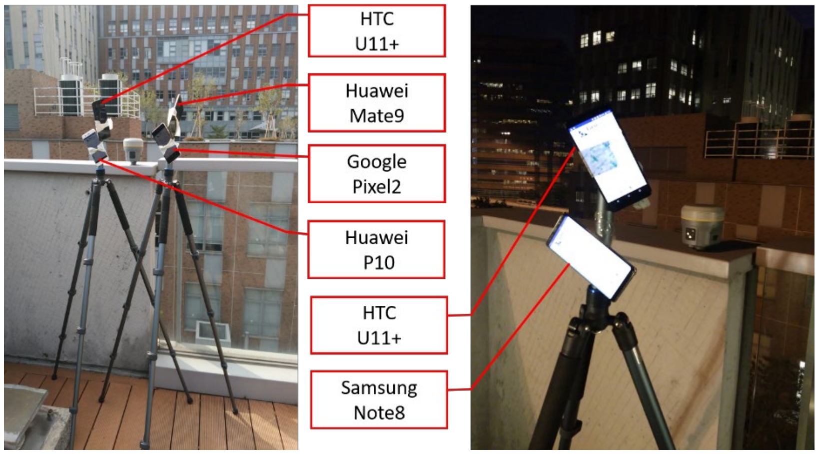

Figure 1 Smart-phones tests setup in open area at the Hong Kong Polytechnic University

Table 1 Overview of smartphones used in tests

Smart-phones	Doppler	Pseudorange	Navigation message	Carrier phase	Hardware clock
Huawei P10	Yes	Yes	Yes	Yes	Yes
Huawei Mate9	Yes	Yes	Yes	Yes	Yes
Samsung Note8	Yes	Yes	Yes	Yes	Yes
Google Pixel2	Yes	Yes	No	No	Yes
HTC U11+	Yes	Yes	No	No	Yes

As shown in table 1, all the five smartphones can access to doppler measurements or pseudorange rate, pseudorange and hardware clock value. While only the Huawei P10, Huawei Mate9 and Samsung note8 can access carrier phase measurements expressed as *AccumulatedDeltaRangeMeters*, which is actually not the truth carrier phase. Along with carrier phase, a state field named *AccumulatedDeltaRangeState* is available to validate the carrier phase.

The pseudorange cannot be obtained directly, it need to be calculated with other raw measurements from smartphone, it can be read as follow[7]:

$$\rho = \frac{t_{Rx} - t_{Tx}}{1E9} C \tag{1}$$

where t_{Tx} is the received GNSS satellite time at the measurement time, given by the variable named *ReceivedSvTimeNanos*,

t_{Rx} is the measurement time and it can be calculated from follow formula:

$$t_{Rx} = TimiNanos + TimeOffsetNanos - (FullBiasNanos + BiasNanos) \tag{2}$$

where *TimeOffsetNanos* is the time offset at the measurement time in nanoseconds. Only the first value of *FullBiasNanos* and *BiasNanos* is used to compute all the received times. This operation applies until there is a discontinuity in the internal received time. This usually only happens when the GNSS module is restarted. The italicized variables above can be obtained directly from raw measurement.

Trackable satellites

Figure 2 shows all trackable satellites of all five smartphones and Trimble R10. The obvious difference can be found for these devices. The Trimble R10 receiver can track and synchronize more than 30 satellites with quad-constellation (GPS, BDS, Galileo and GLONASS). While for the smartphones, the trackable satellites number is much less than that of R10 and varies a lot among different phones.

The Huawei P10 only tracked GPS and GLONASS satellites and the available satellite number is almost the same as that of R10 for GPS and GLONASS system. The Huawei Mate9, which is produced by the same manufacture with P10, is much similar with P10, except that the Mate9 tracked one BDS satellite C08.

For Samsung Note8, the trackable satellite number is the least and about 12 satellites, but it can track satellites from all GNSS system including GPS, BDS, Galileo, GLONASS and QZSS. And also the tracked satellites are very stable and almost did not lose lock.

Another difference is that the Google Pixel2 and HTC U11+ can track many BDS satellites even though it is just a few seconds and not stable. Both the Google Pixel2 and HTC U11+ can access many satellites from GPS and GLONASS and they did not have much difference in trackable satellite number and stability. The difference is that Google Pixel2 can track and Synchronize QZSS satellites and did not lose lock. It also received some Galileo satellites for a few seconds. The HTC U11+ did not received Galileo and QZSS satellite signals while it tracked BDS satellites for a much longer period than Google Pixel2, though it loses lock frequently and also a short period compared with Samsung Note8.

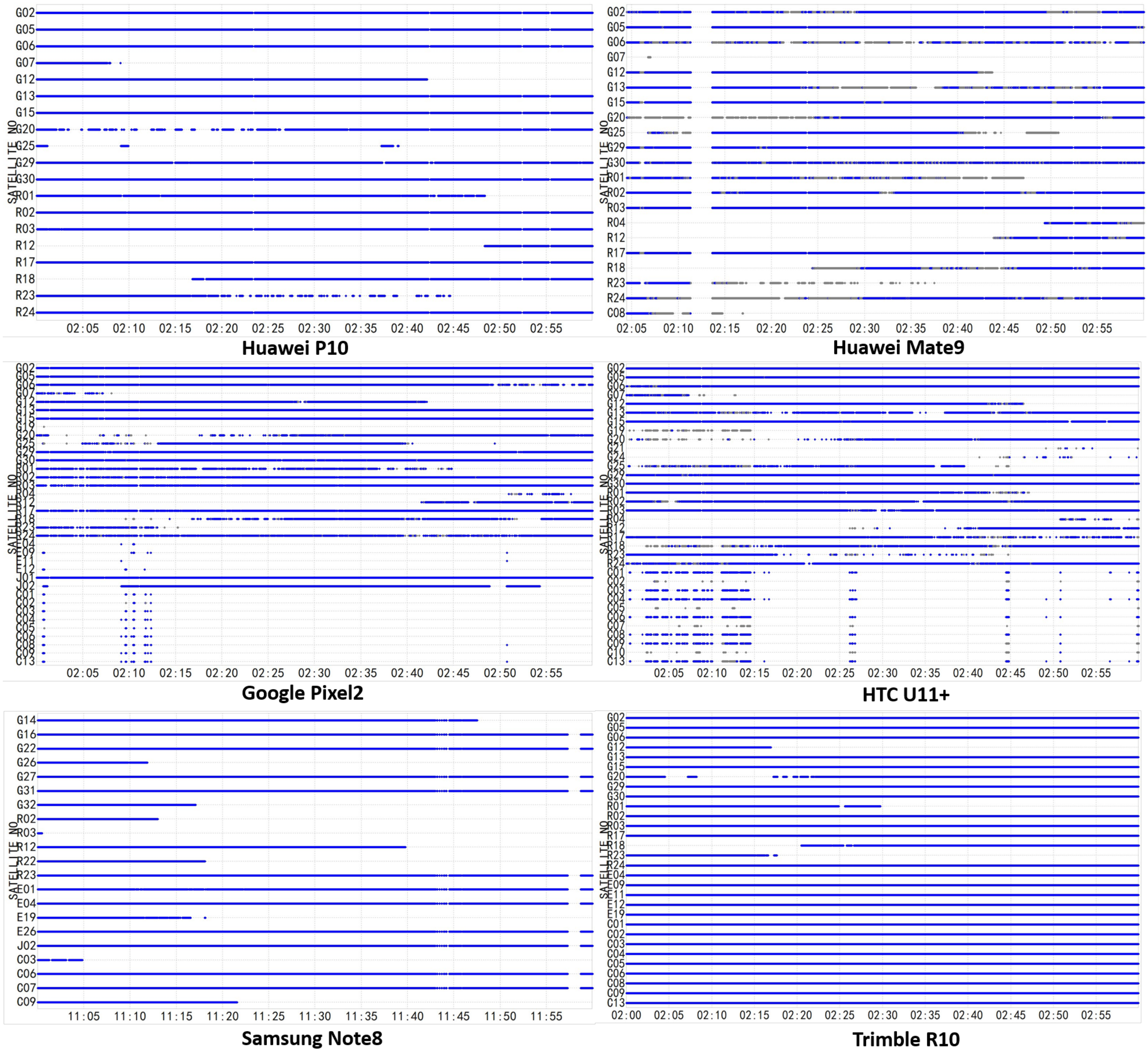

Figure 2 Trackable satellites of all smartphones and Trimble R10 receiver

Besides the tracked satellites, the SNR of all available satellites are shown in Figure 3. The similar phenomenon can be found that the lowest SNR of the tracked satellites is below 10 dB comparing the Figure 3a&3b, which may be result from that both Huawei P10&Mate9 made by same manufacture and maybe used the same chipset. The measurements SNR of other three smartphones is relative higher and the most stable is the Samsung Note8. Considering their corresponding elevation angle, we found that there is no obvious relationship between SNR and elevation, especially for the Huawei P10&Mate9. Of course, the Trimble R10 performs best as it is designed for geodetic application. Its SNR is much higher and more stable than that of smart-phones.

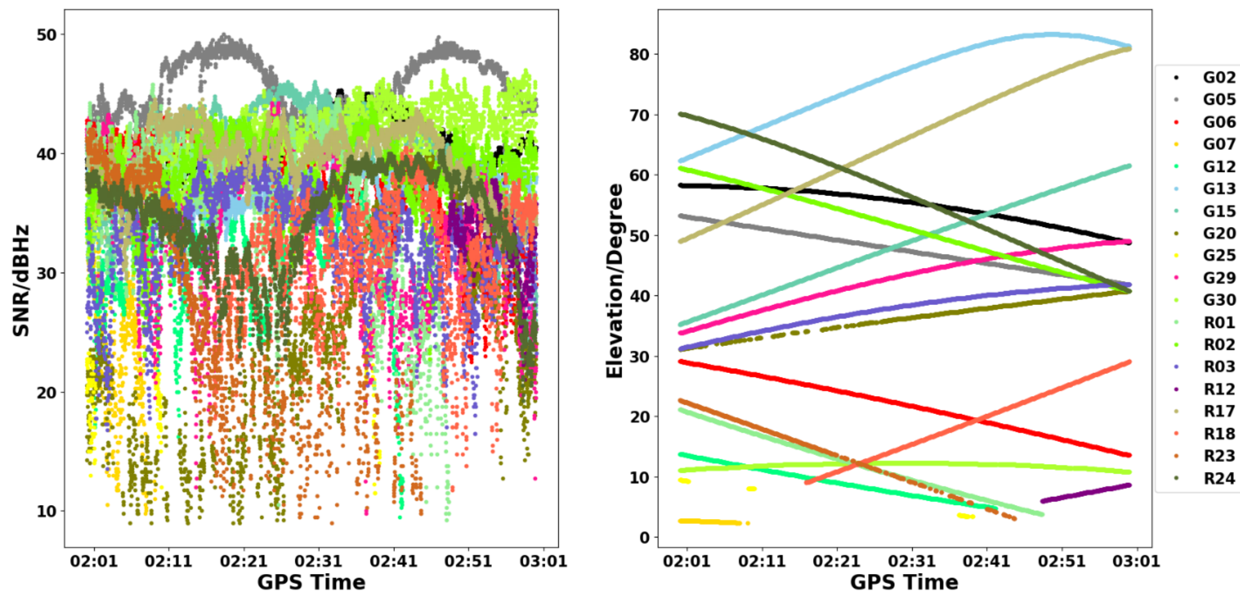

Figure 3a SNR of all tracked satellites of Huawei P10

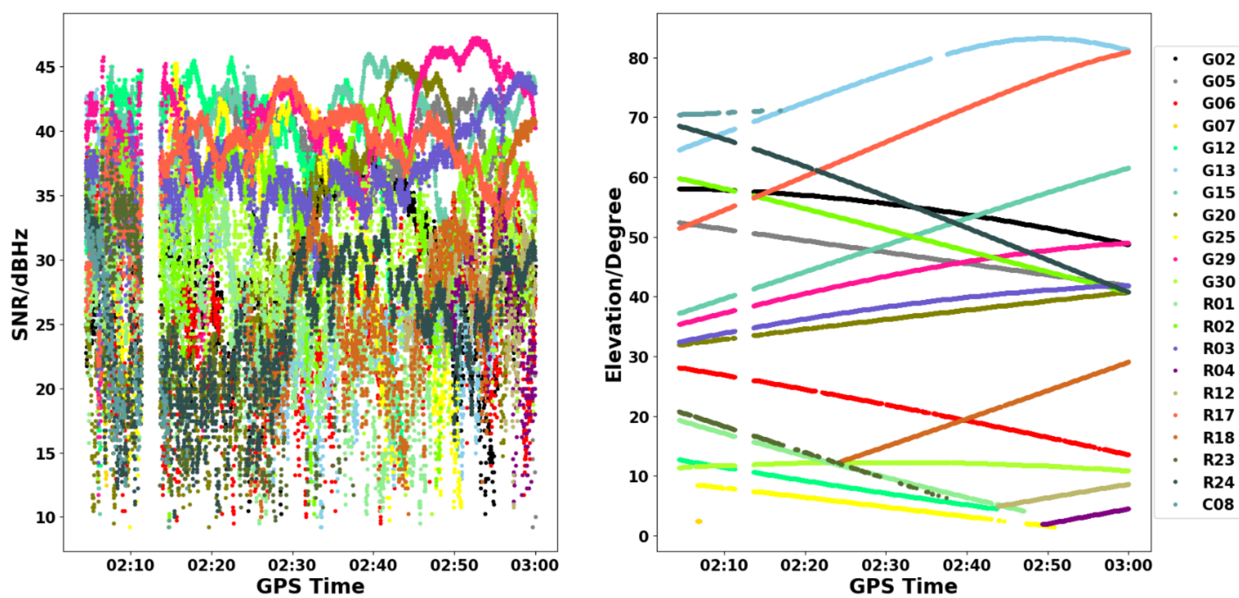

Figure 3b SNR of all tracked satellites of Huawei Mate9

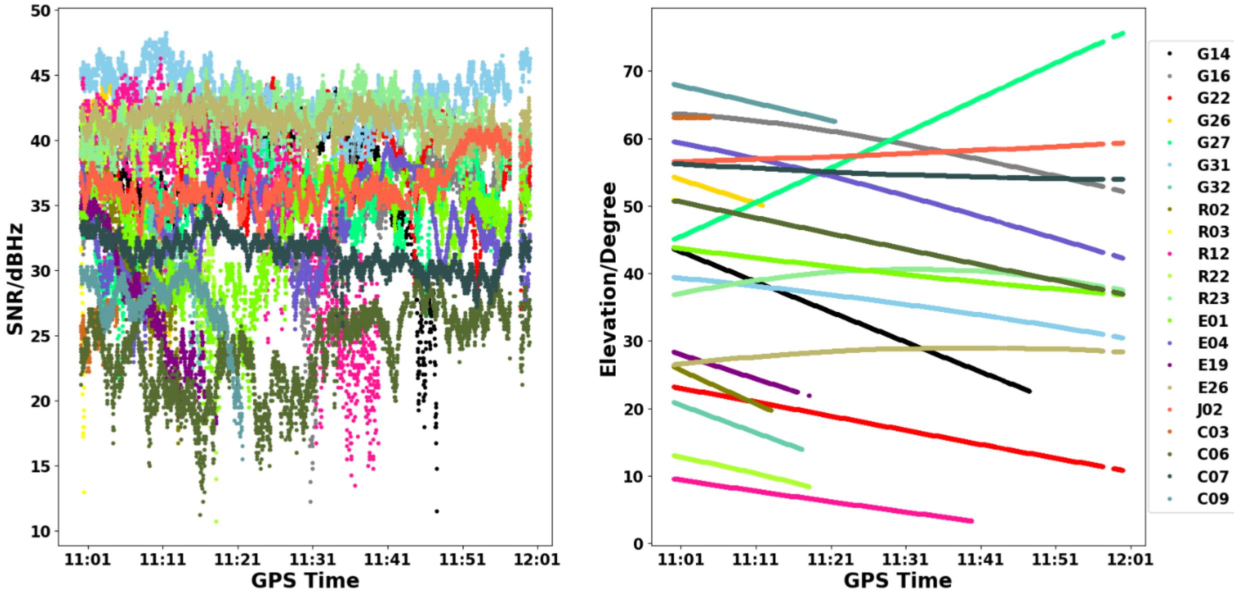

Figure 3c SNR of all tracked satellites of Samsung Note8

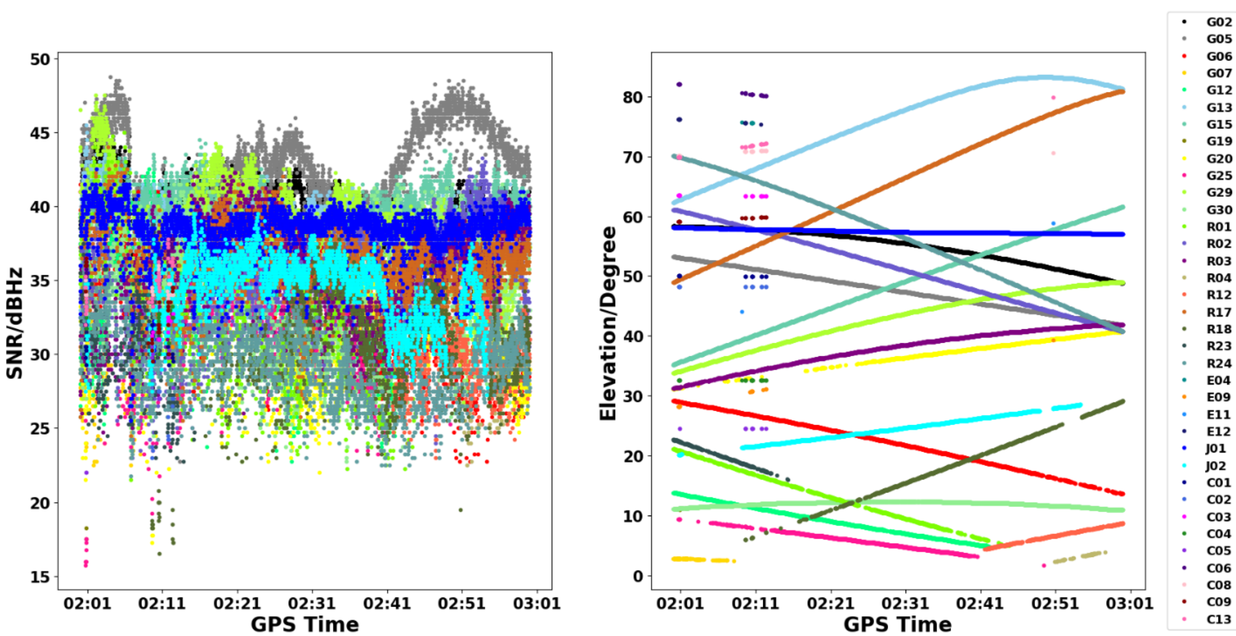

Figure 3d SNR of all tracked satellites of Google Pixel2

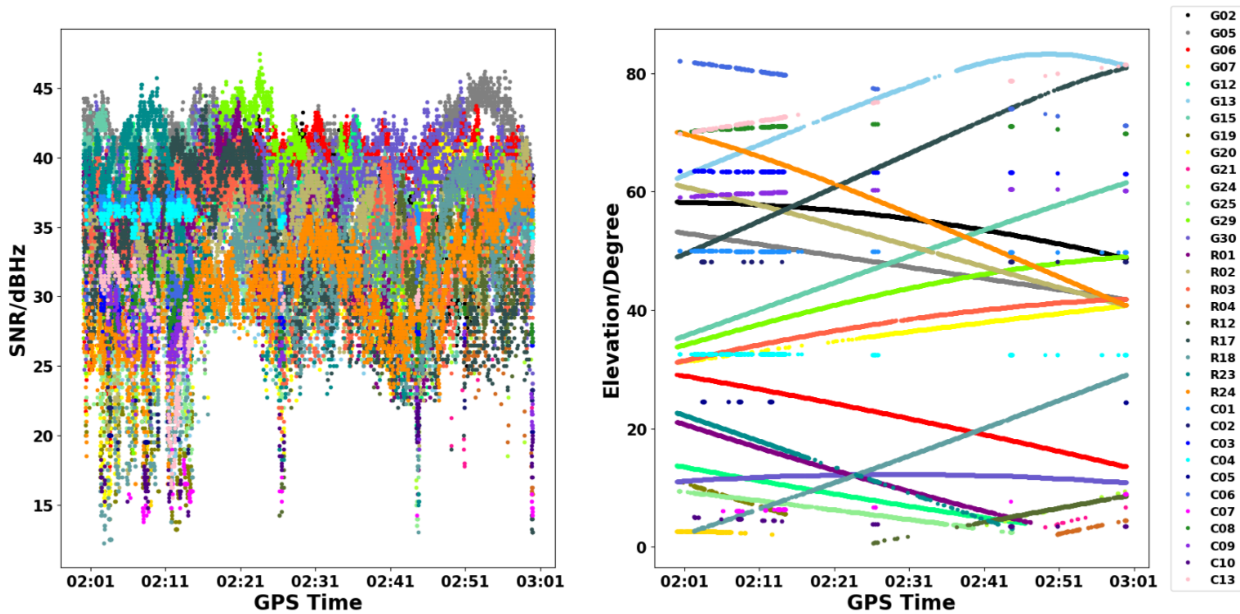

Figure 3e SNR of all tracked satellites of HTC U11+

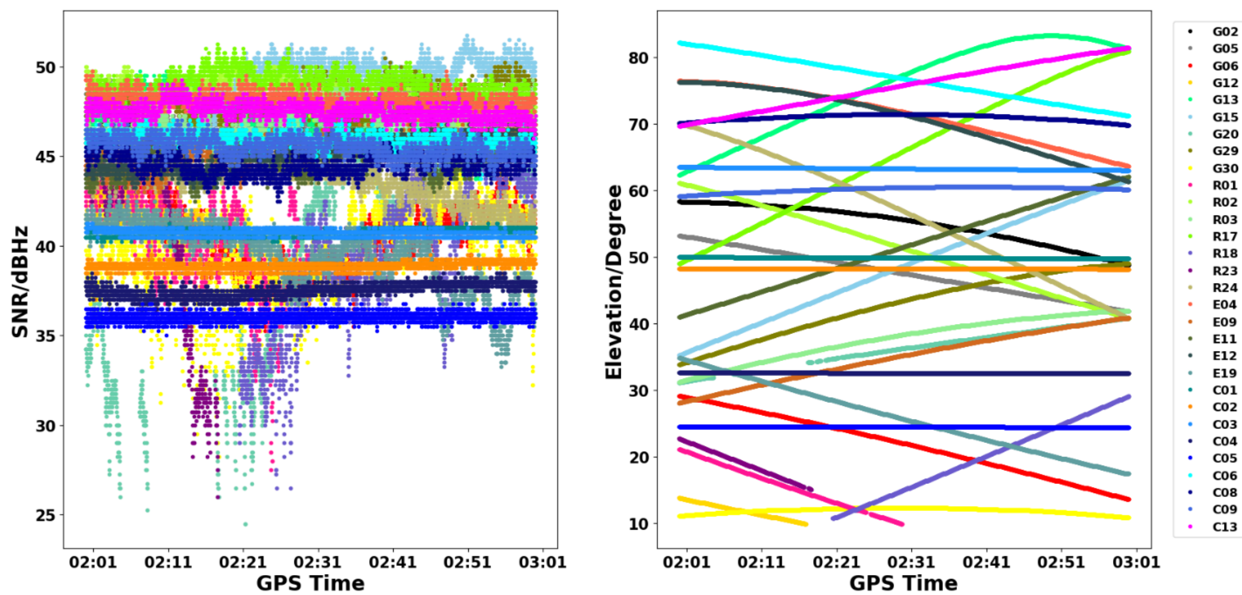

Figure 3f SNR of all tracked satellites of Trimble R10

III. Quality of pseudorange and carrier phase

The advantage of the access to raw measurement for user is that users can employ the raw measurement to calculate position and velocity with many kinds of improved algorithms. Before calculating position, the first thing we should do is to assess the performance of raw measurements. For this purpose, we employed double-differenced (DD) residual to analyze the measurement quality.

In order to compare the DD residuals of smartphone with that of Trimble R10, another GNSS reference station HKQT from Hongkong Continuously Operating Reference Stations (CORS) is selected as reference station.

DD residual of pseudorange

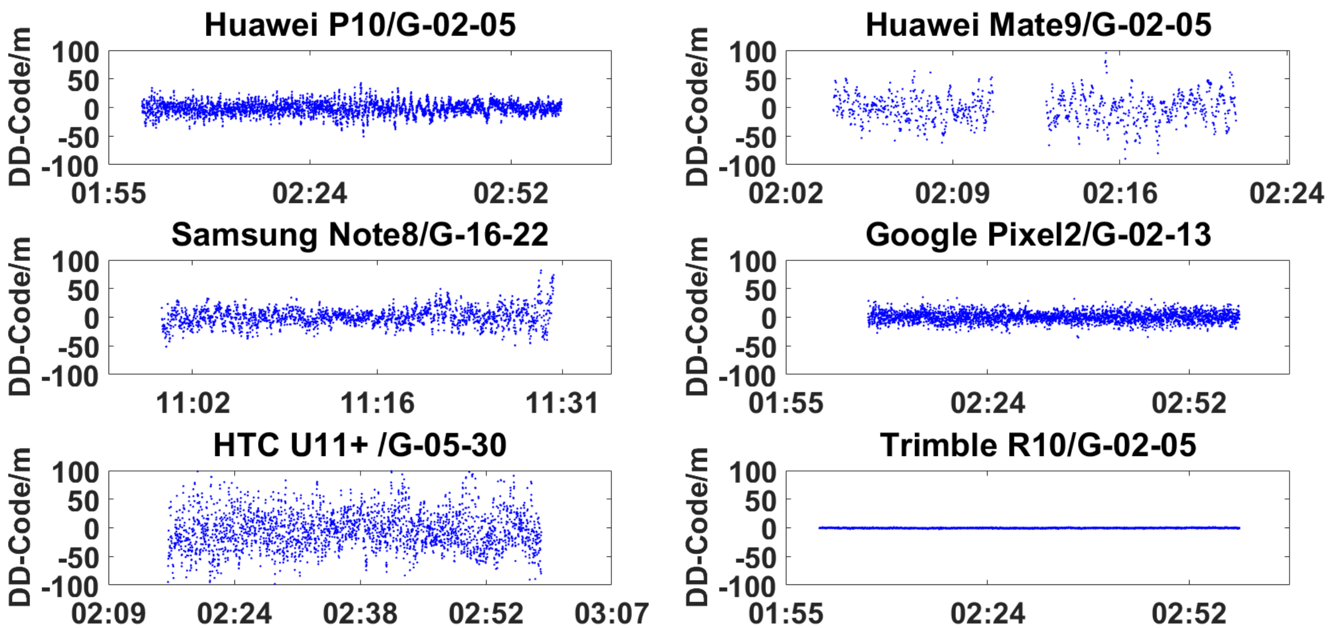

Figure 4a DD residual of pseudorange from different devices (GPS)

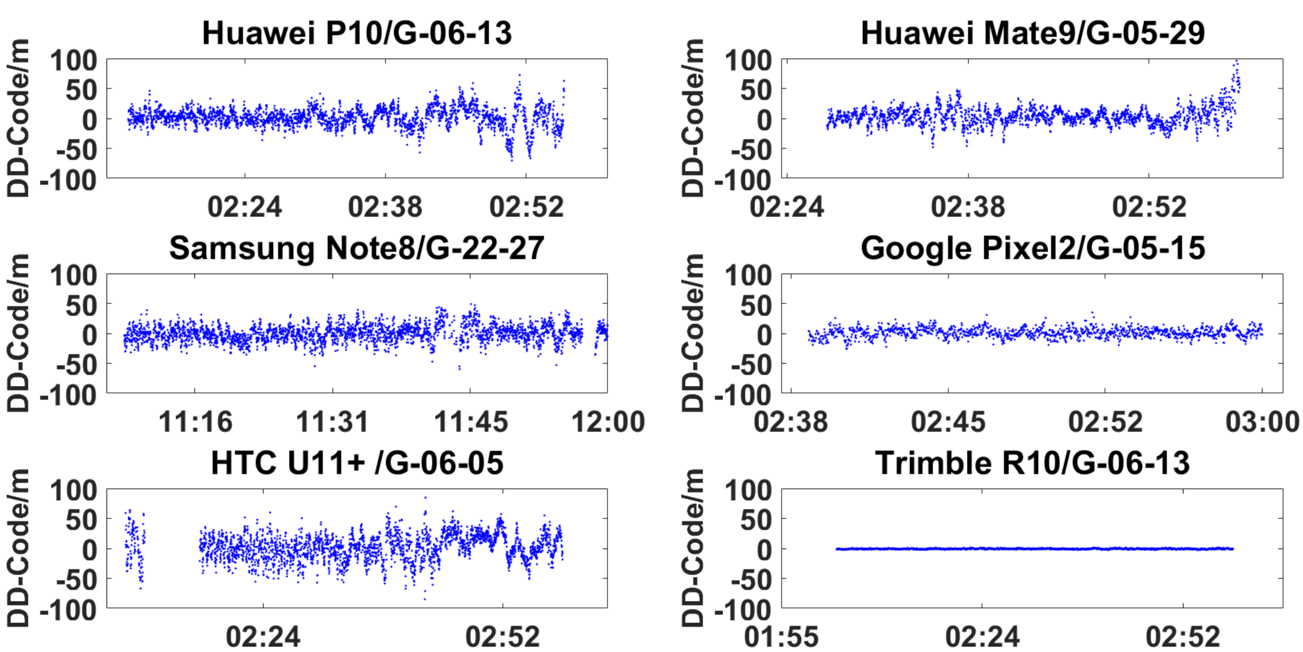

Figure 4b DD residuals of pseudorange from different devices (GPS)

As few BDS satellites available for smartphones, we just give the result of GPS and GLONASS. Figure 4 shows the DD residuals of pseudorange from different devices including five smartphones and Trimble R10. In order to demonstrate the best performance of the raw measurements, these satellites which were tracked stable were selected to be analyzed. Because the available satellites of different devices differed a lot, we cannot compare the performance with the same satellite pair strictly.

Comparing all plots in Figure 4, we found that the pseudorange DD residuals of R10 are very small, which fluctuate within several meters. While for smart devices, the DD residuals vary within tens of meters. And also, the characteristic of different system differ a lot for the smart devices, that is DD residual of GPS is much smaller than that of GLONASS.

The plots in Figure 4a&b show that the pseudorange DD residuals of GPS vary a lot with different types of mobiles. The variation of DD residuals of Huawei P10, Huawei Mate9, Samsung Note8 and Google Pixel2 is about limited within ±30 meters, while for that of HTC U11+, its fluctuation is larger than ±50 meters.

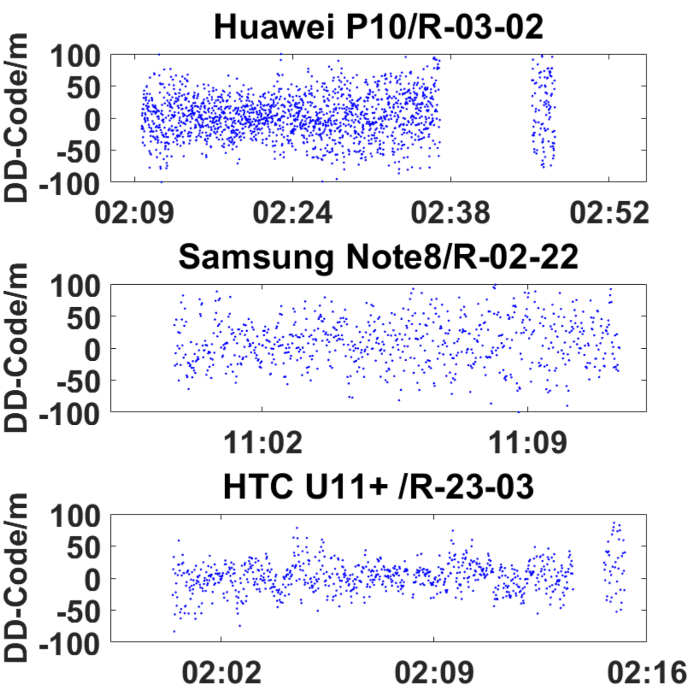

Figure 4c DD residual of pseudorange from different devices (GLONASS)

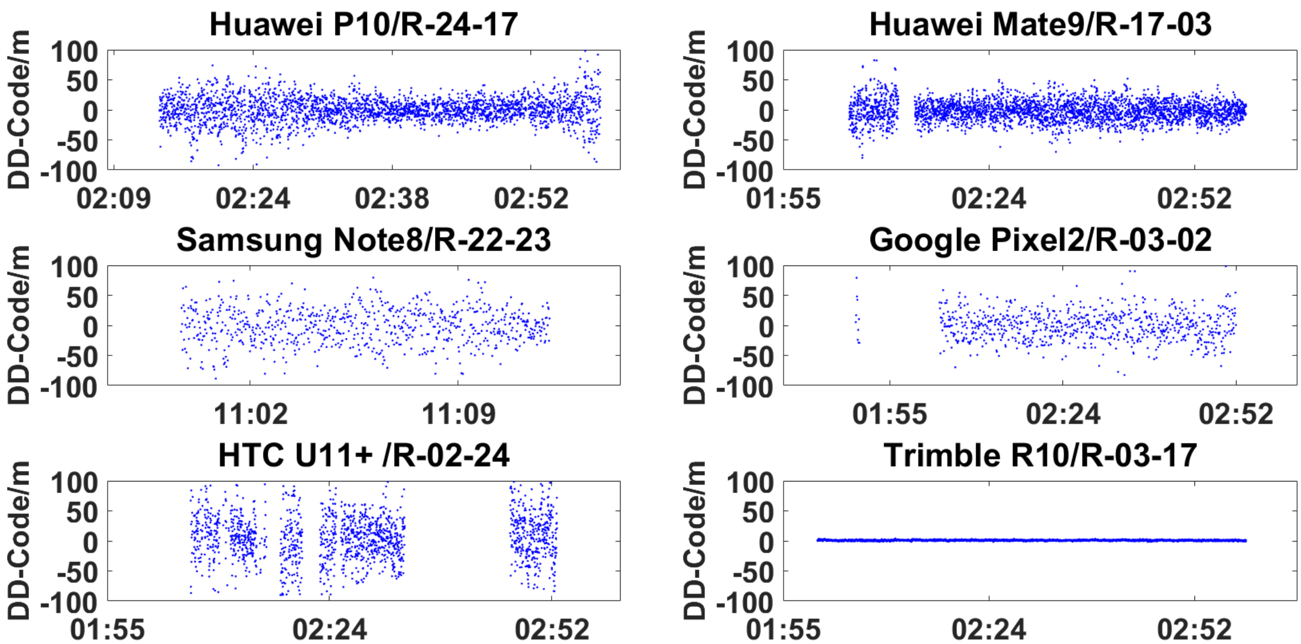

Figure 4d DD residual of pseudorange from different devices (GLONASS)

The plots in Figure 4c&d demonstrate the pseudorange DD residuals of GLONASS, which is larger than 50 meters for all five smart phones. The performance of GLONASS for different smartphones also follow the rule of GPS, that is the pseudorange accuracy of HTC U11+ is the lowest and other smartphones perform better.

Among the five smartphones, the DD residuals variation of HTC U11+ is the largest, both for GPS and GLONASS, which means the pseudorange accuracy of HTC U11+ is the lowest. The accuracy of other four smart-phones is almost the same. Of course, we only compared and analyzed some tracked stable satellites, which cannot assure all the satellites follow above rules.

DD residual of carrier phase measurements

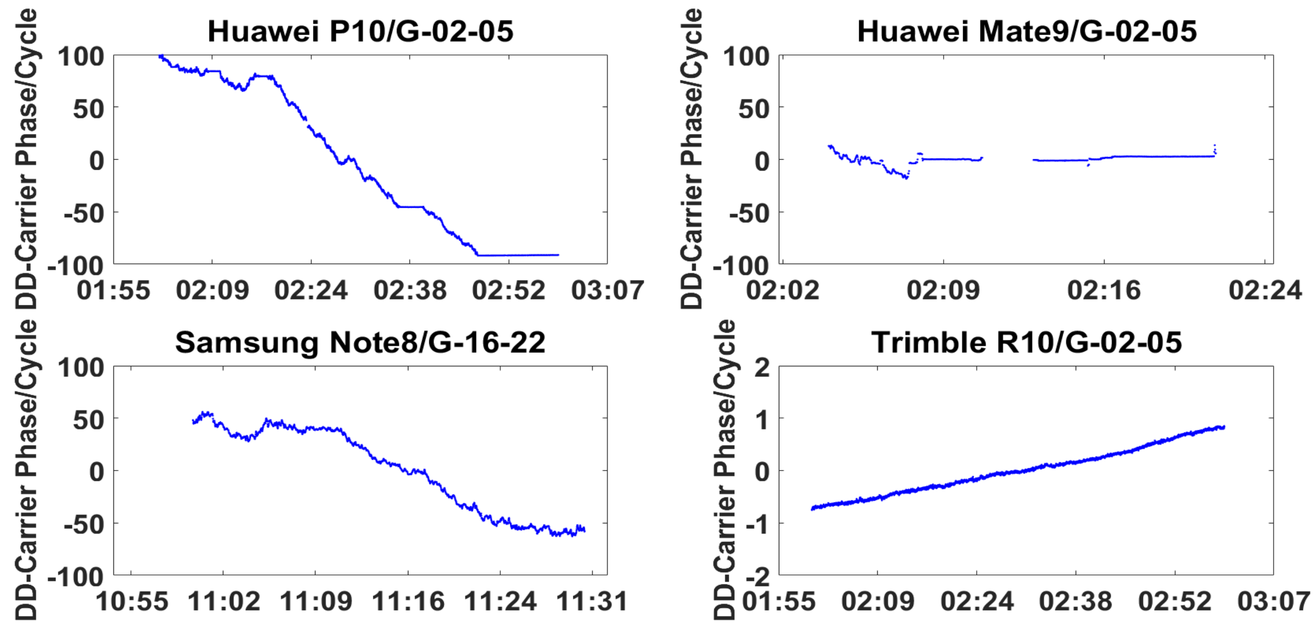

Figure 5a DD residuals of carrier phase from different devices (GPS)

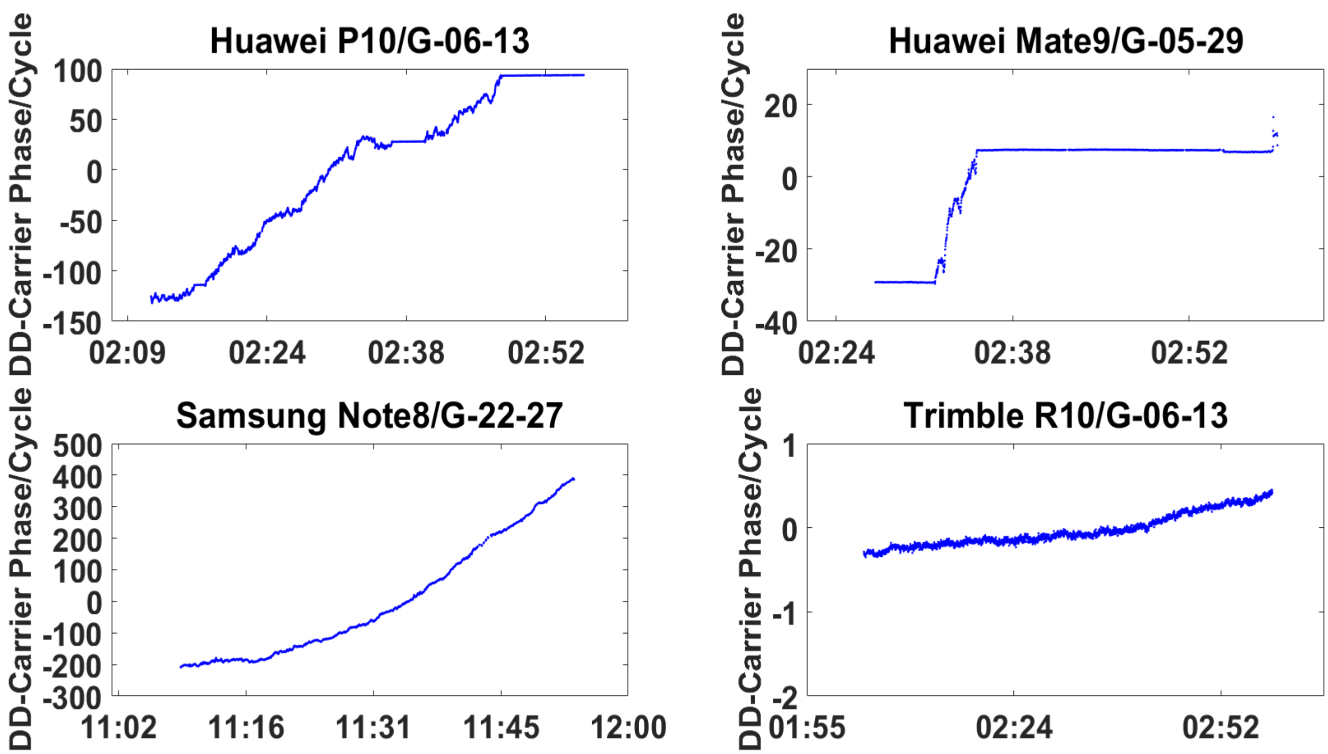

Figure 5b DD residuals of carrier phase from different devices (GPS)

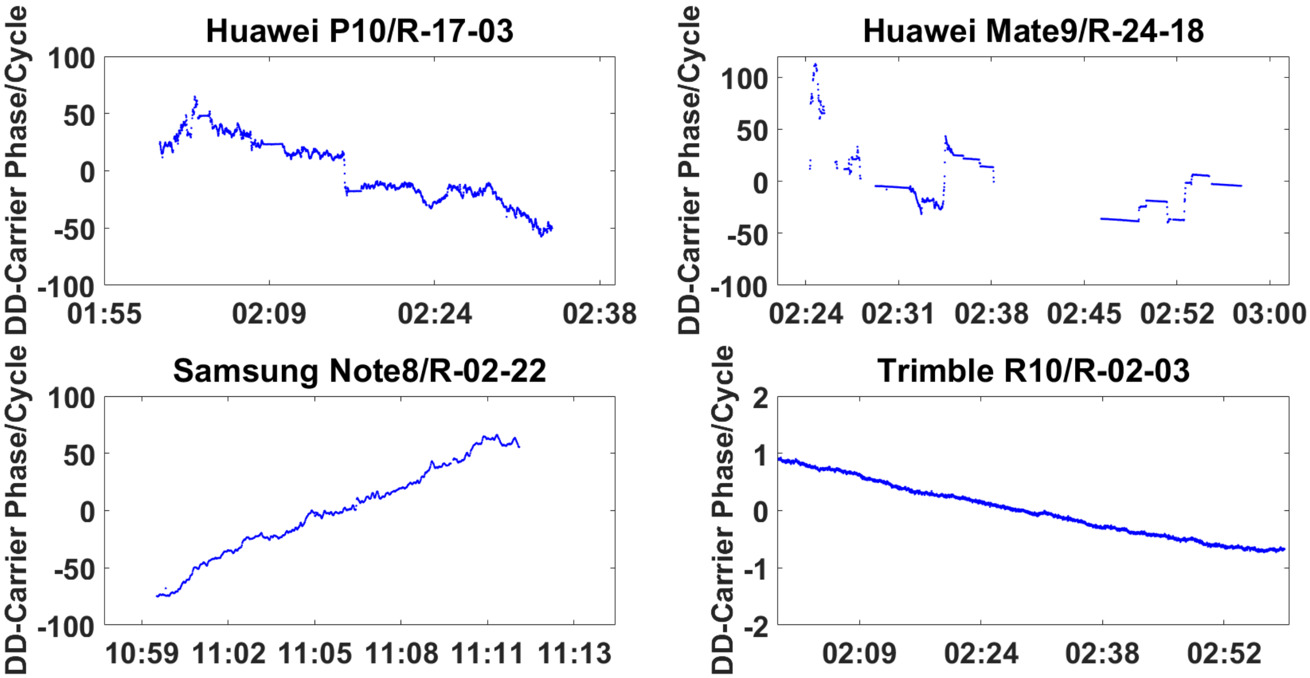

Figure 5c DD residuals of carrier phase from different devices (GLONASS)

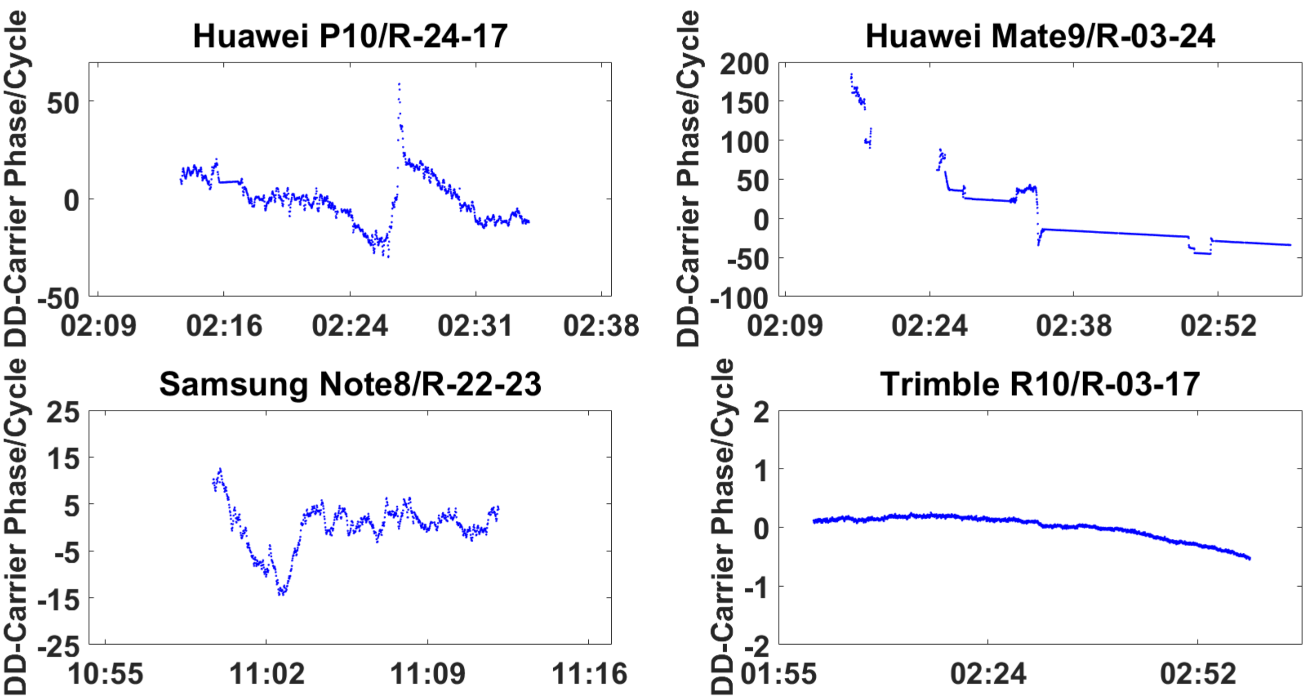

Figure 5d DD residuals of carrier phase from different devices (GLONASS)

To characterize the raw carrier phase measurement of smartphones, some satellite pairs were selected and their DD residuals of Huawei P10, Huawei Mate9, Samsung Note8 and Trimble R10 are shown in Figure 5. The series of DD residual shows a trend within several decimeters as the exist of residual of geometry error and ionospheric error. It is obvious that except the remained DD error, the DD residuals of smart phone contain unknown bias, which may be result from the duty cycle.

As we know, the implementation of different device is different, which may result in different behaviors of GNSS receiver. There are two different implementations of duty-cycle according to GNSS clock status. One is that the Temperature Compensated Crystal Oscillator (TCXO) hardware clock is continuous during non-tracking periods and another one is that the TCXO hardware clock is not continuous during non-tracking periods.

Figure 6 shows the hardware clock status of different devices, which is related to duty cycle. The Google Pixel2 and HTC U11+ show frequent discontinuity of hardware clock, while the other three phones' hardware clock keep working all the time. That is to say the Google Pixel2 and HTC U11+ has duty-cycle implementation and the TCXO hardware is turned off and the crystal oscillator (XO) clock is turned on to provide time, which will result in non-integer timestamp in measurement.

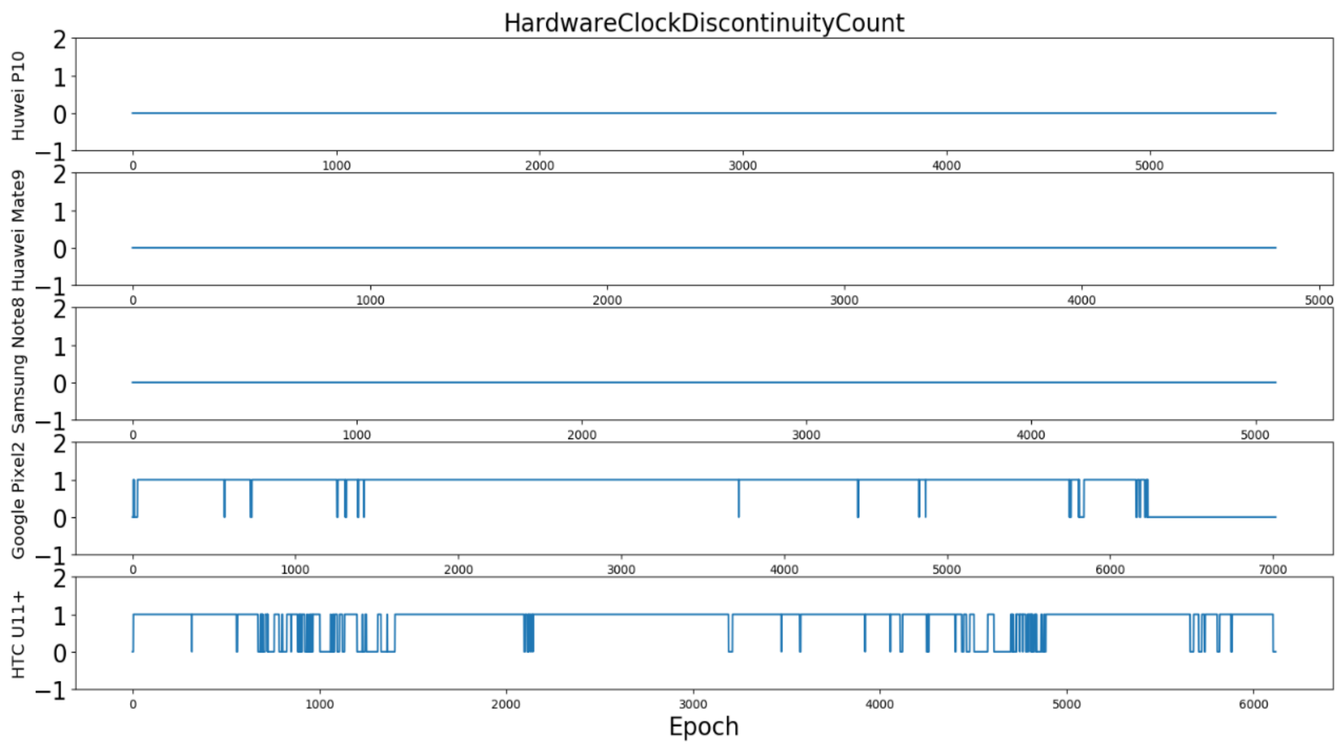

Figure 6 The behaviors of hardware clock of available smart phones (0: continuous,1: discontinuous)

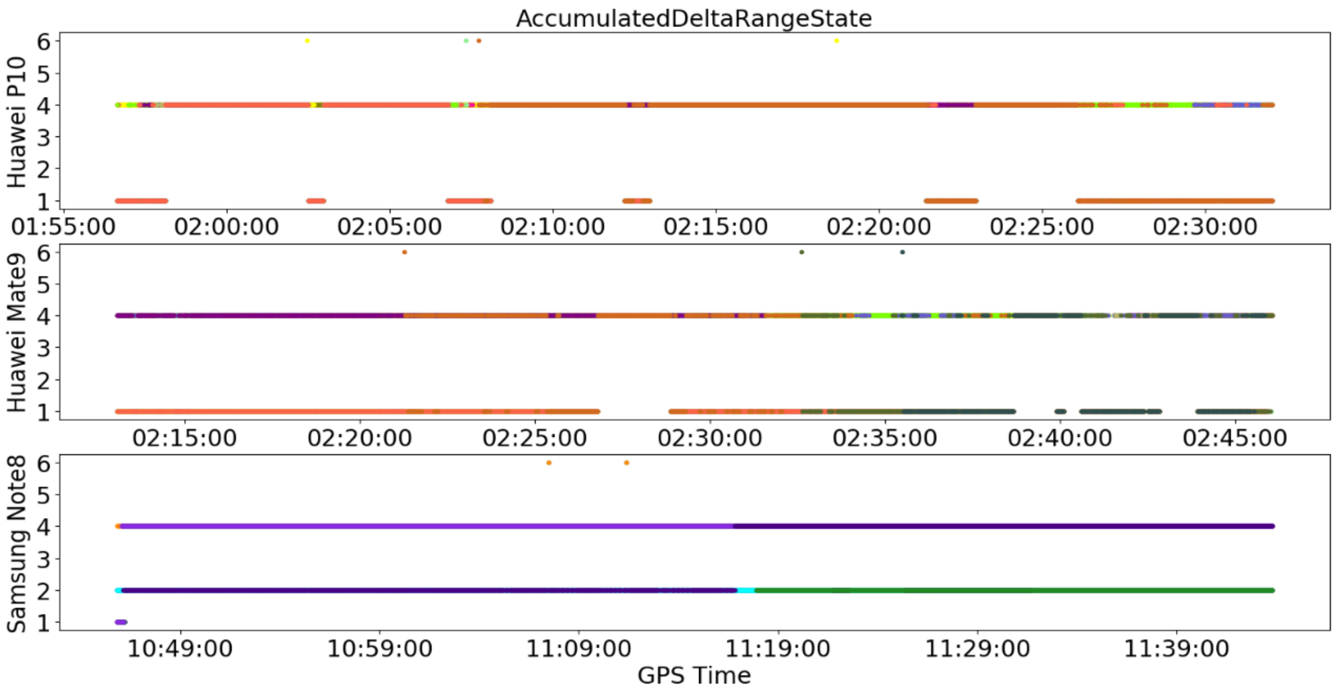

Figure 7 Accumulated deltarange state (1:valid;2: A reset has been detected;4: A cycle slip has been detected;6:unknown)

In order to confirm the duty-cycle and its implementation method of the other three smartphones, the accumulated deltarange states are shown in Figure 7, which reveal the status of carrier phase measurements. The frequent reset and cycle slip can be observed for Samsung Note9 except a short validated period, which may ne result from duty-cycle. A few short-arc validated periods are found for Huawei P10, when it comes to Huawei Mate9, a longer satellite arc is obtained, which may be due to the sync (such as code lock, bit sync, subframe sync and so on).

According to above analysis, we conclude that all the five phones enable the duty- cycle, and the TCXO hardware clock keeps running for Huawei P10, Huawei Mate9 and Samsung Note8, while for the Google Pixel2 and HTC U11+, the TCXO clock is turned off and GNSS receiver clock behaves a frequent discontinuity. No matter what implementation methods the device employed, the duty-cycle would lead to discontinuity of carrier phase, which severely limits the use of carrier phase to realize high precision positioning, such as real-time kinematic (RTK) and PPP.

IV. Performance of navigation solutions

GNSS is a basic tool for users to determine the position. In this section, the performance of National Marine Electronics Association (NMEA) results from all available devices are demonstrated and then the standard point positioning with raw pseudorange and doppler-smoothed pseudorange were compared and analyzed. For most users are only concerned about the horizonal accuracy, we show and analyze the horizonal result.

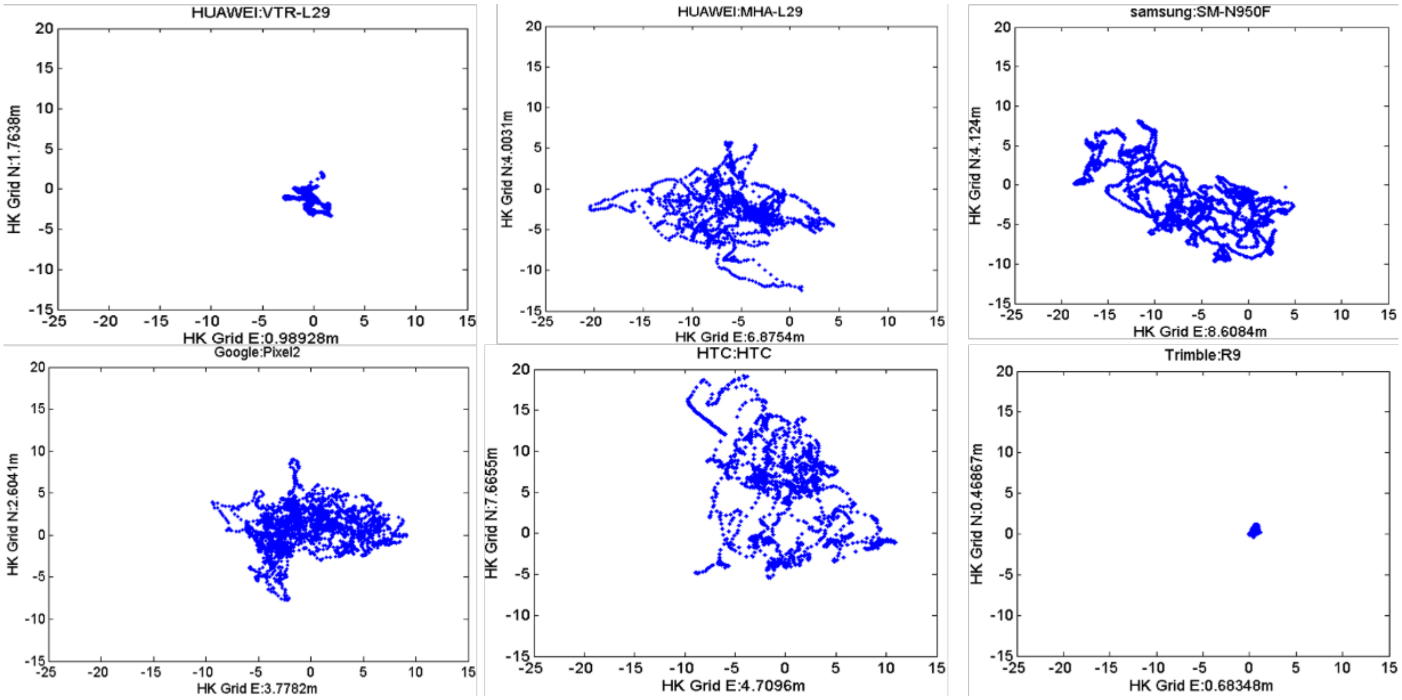

Figure 8 NMEA from different deceives

Figure 8 demonstrates the original positioning result from NMEA of those devices, and the ground truth is obtained with network RTK. There is no doubt that the result from R10 is the most accurate owing to its geodetic class GNSS receiver and antenna. Among the available smartphones, the Huawei P10 achieved the best performance and it positioning accuracies are 1.76m and 0.99m in north and east respectively. The next is Google Pixel2, whose accuracy is within 4 meters. There is no obvious difference among the others smartphones and their acracy is within 9 meters.

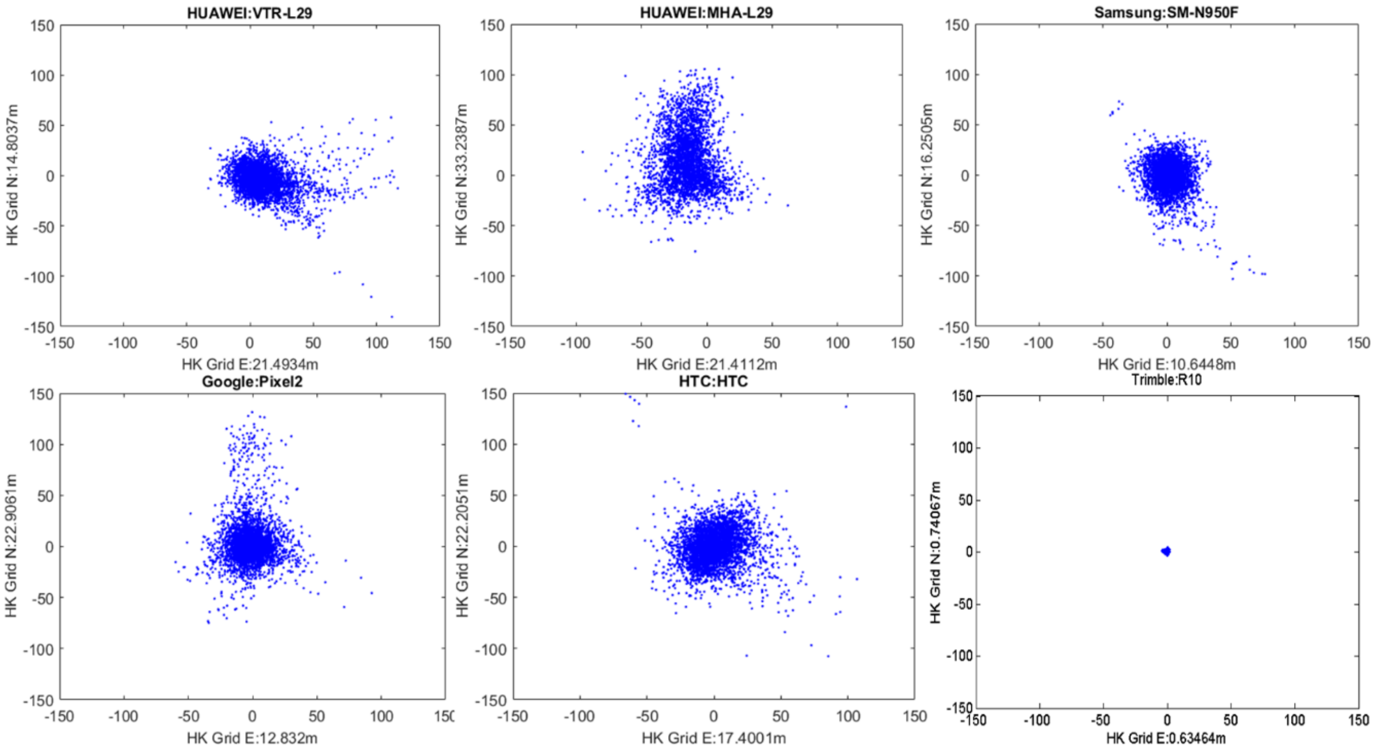

Figure 9a SPP with raw pseudorange (GPS only)

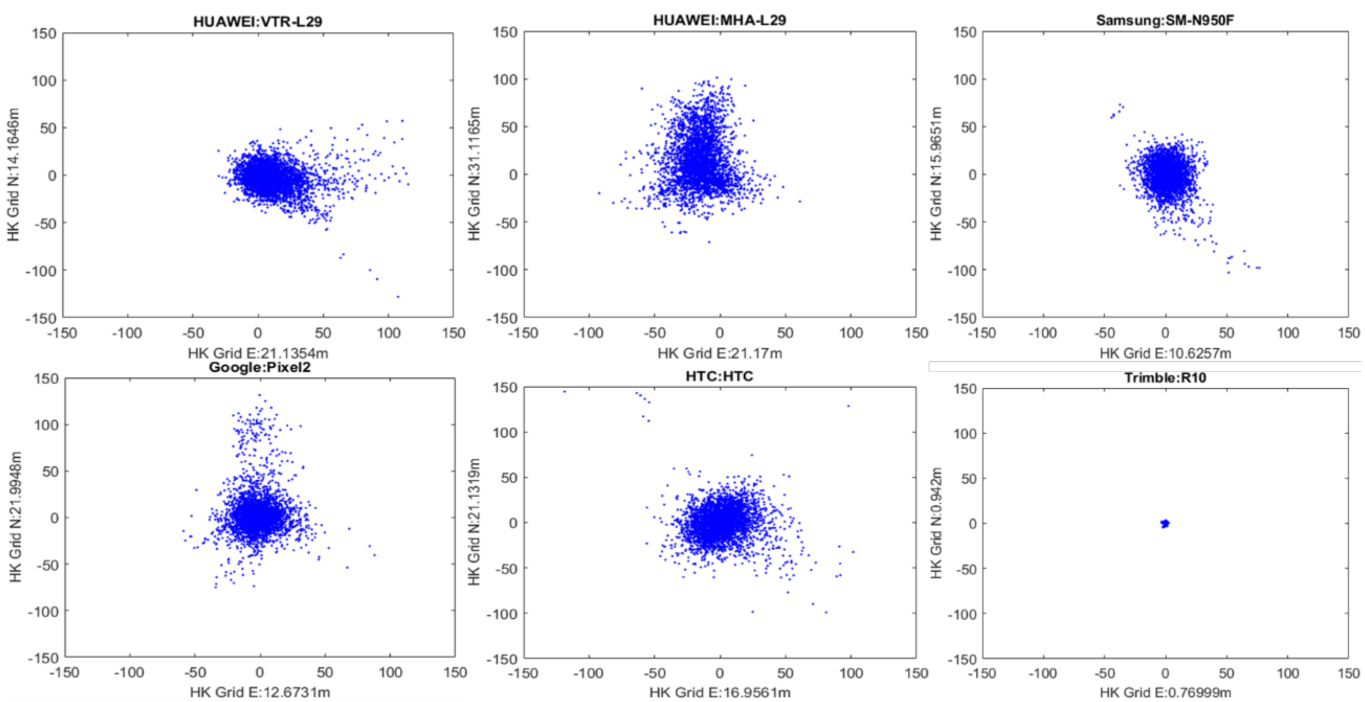

Figure 9a SPP with raw pseudorange (GPS and GLONASS)

Based on the RINEX files retrieved from the available smartphones, the raw pseudorange were employed to calculate the position with broadcast ephemeris and the result are shown in Figure 9. With the pseudorange data from Trimble R10, we obtain almost the same level of accuracy of NMEA, that is within 1 meters. While referring to the smart phones, the accuracy of single point positioning (SPP) is much lower and their accuracy is more than 15 meters, both for GPS only and combination of GPS and GLONASS. And also the combination of GPS and GLONASS improve accuracy little for all the devices for the large noise of GLONASS.

Except the pseudorange measurements, users also can access to doppler measurements for all available smartphones. We employed the doppler measurements to smooth pseudorange with hatch filter, then the smoothed SPP result can be obtained, which is shown in Figure 10. Because of the discontinuity of TCXO hardware clock of Google Pixel2 and HTC U11+, we did not use the doppler to smooth pseudorange.

The results in Figure 10a show a significant improvement for all three smartphones, especially for Samsung Note8. The accuracy are improved form 16.3m,10.6m to 8.9m,5.1m in northing and easting respectively with GPS only. The addition of GLONASS can not obtain great improvement except Huawei mate9, especially for the northing direction, the accuracy is improved from 28.3m to 20.5m.

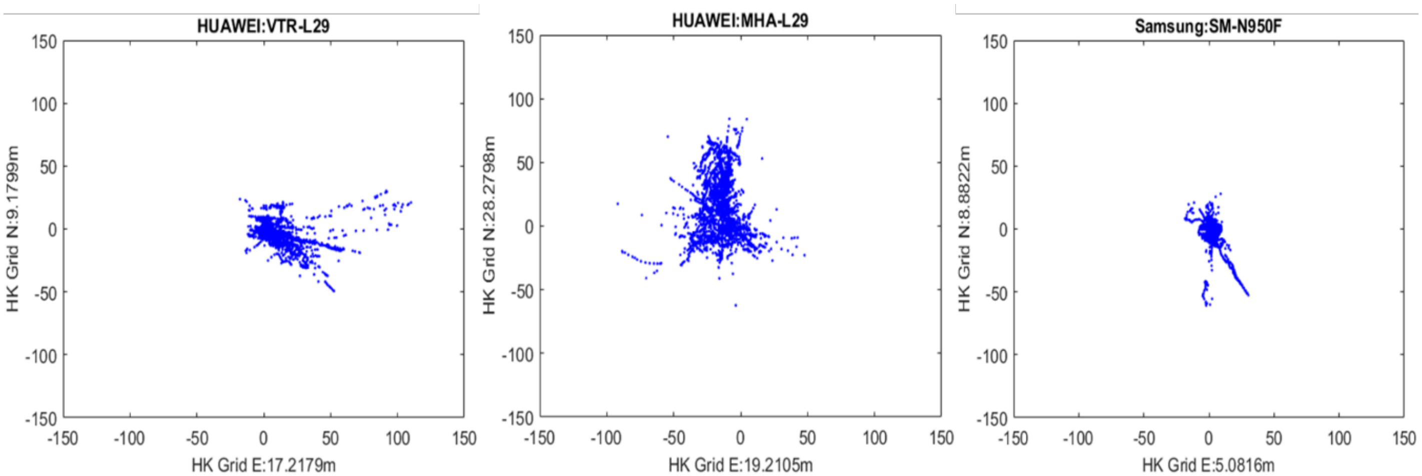

Figure 10a SPP with doppler smoothed pseudorange (GPS only)

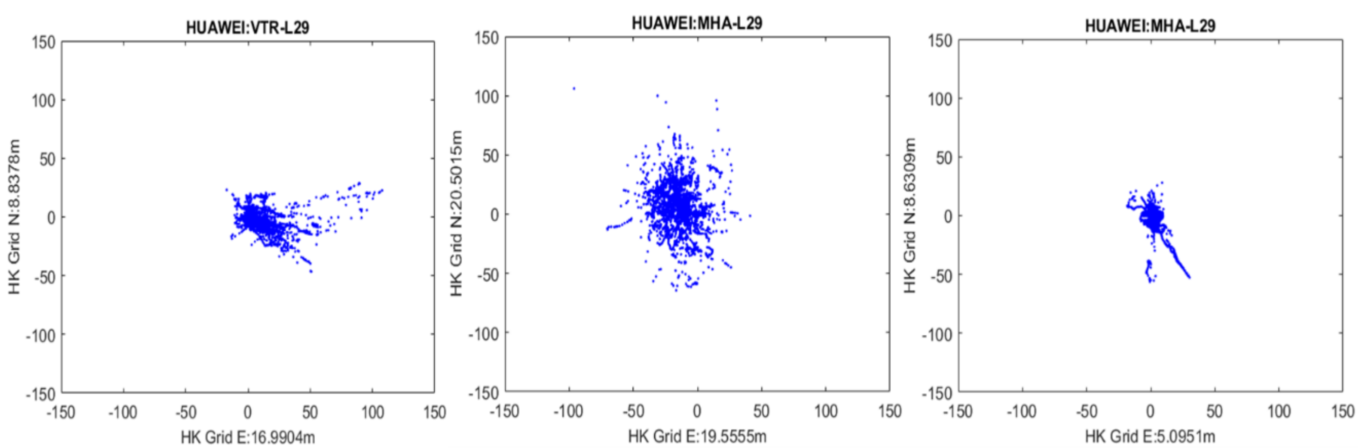

Figure 10b SPP with doppler-smoothed pseudorange (GPS and GLONASS)

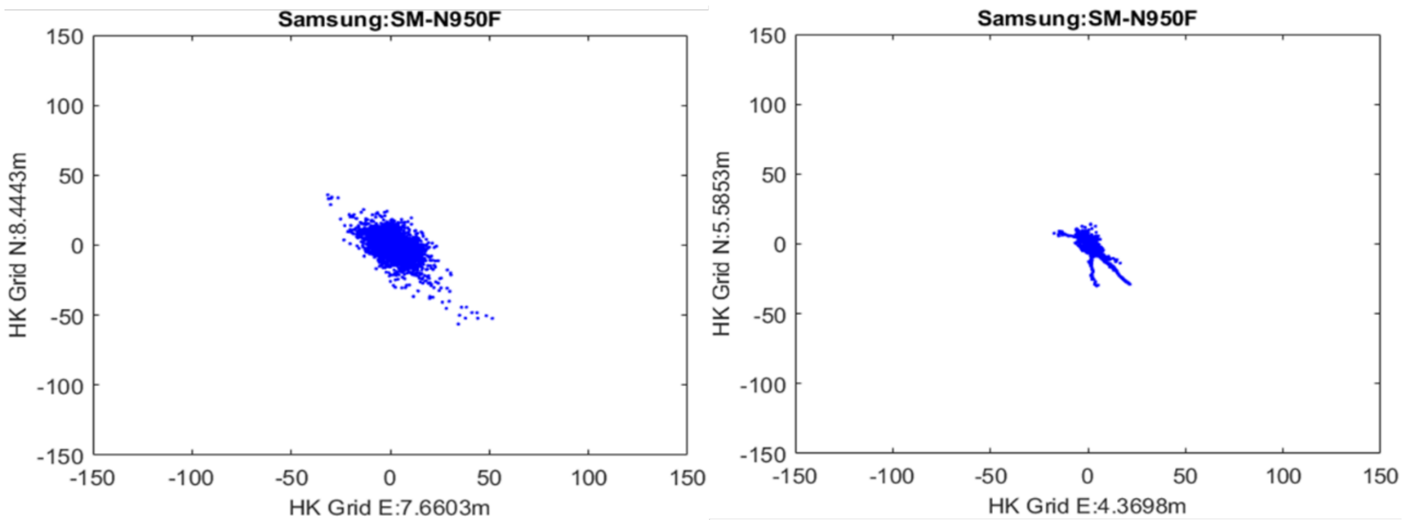

Figure 10c Samsung note8 SPP with quad-constellation (Left: raw pseudorange, right: doppler-smoothed pseudorange)

As shown in Figure3&4, many BDS and Galileo satellites are tracked very stably with Samsung Note8, then all tracked satellites except QZSS are used to calculate user position with raw pseudorange and doppler-smoothed pseudorange and the results are shown in Figure 10c. The results indicate that the combination of quad-constellation improve the accuracy greatly, when using the doppler-smoothed pseudorange of quad-constellation, the accuracy is slightly higher than that of NMEA of Samsung note8.

Of course, this is just a preliminary result, more attention will be paid to improve the positioning performance with doppler and carrier phase measurements in future research.

V. Conclusion

In this paper, a systematic comparison of performance of five smart phones including Huawei Mate9, Huawei P10, Samsung Note8, Google Pixel2 and HTC U11+ in open sky area has been conducted.

The tracking ability of available devices is comparatively analyzed including the tracked satellites number and SNR, which indicates that the performance differs a lot for different smart phones and the Samsung Note8 tracked satellites most stable and can track satellites of all GNSS system including GPS, GLONASS, Galileo, BDS and QZSS.

And then the quality of pseudorange and carrier phase is investigated with DD residual. Among the five available smart phones, the UTC 11+ performs worst and its DD residual varies within ±50m, the other four phones are almost at the same level and vary within ±30m. The DD residual of carrier phase shows that all the used smart phones have duty cycle mode, which limits the use of carrier phase in precise positioning. And different device implements the duty cycle with different method. For Google Pixel2 and HTC U11+, when they turn on duty cycle, the TCXO is discontinued and the XO is running to provide time, while referring to the Huawei Mate9, Huawei P10, Samsung Note8, the TCXO is running and then the hardware clock is continuous.

At last we compare the NMEA, SPP with raw pseudorange and smoothed the pseudorange with doppler. The result shows that the SPP with raw pseudorange cannot improve the positioning performance which is same as expectation. After smoothed with doppler observation, the result is improved significantly for Samsung Note8 comparing with SPP using raw pseudorange and is comparable with NMEA. It is just a preliminary result with raw measurement and more attention will be paid to improve the performance with raw measurement in future.

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