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Statistical Analysis of Android GNSS Raw Data Measurements in an Urban Environment for Smartphone Collaborative Positioning Methods

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I) Introduction - Context

- **In May 2016**, Google announced that GNSS raw data measurements will be available on Android smartphones via their latest API Android 7.0.

  For the first time, developers and the scientific community will have access to GNSS measurements from the smartphone integrated receiver.

- A potential access to billions of GNSS smartphones data, leading to the use of advanced crowdsourcing GNSS processing techniques motivated my PhD thesis:

Precise Cooperative Positioning of Low-Cost Mobiles in an Urban Environment

Derived GNSS Measurements obtained via Android

Multiconstellation & Multifrequency

- Code measurements
- Phase measurements
- Doppler measurements
- SNR measurements
- Automatic Gain Control
- and more …

I) Introduction - Motivations

Android GNSS Raw Data Measurements Overview

Advantages

- Easy to record (GNSSLogger.apk or Geo++RinexLogger.apk)
- Support technological innovation
- Low-cost receiver
- Detailed documentation
- Analysis of the smartphone embedded GNSS algorithm

Drawbacks

- Poor quality antenna
- Duty cycle
- Variety of smartphones models and brands
- **Information on receiver architecture & tracking loop parameters are unknown**

I) Introduction - Motivations

I. Exploring the feasibility of smartphone collaborative positioning [4]

II. How does a smartphone perform compared to a low-cost GNSS receiver in an urban environment. [2][3]

III. Smartphone GNSS chipset receiver architecture & tracking loop parameters are unknown [1]

[1] Lehtola, V. V., Söderholm, S., Koivisto, M., & Montloin, L. (2019). Exploring GNSS crowdsourcing feasibility: Combinations of measurements for modeling smartphone and higher end GNSS receiver performance. *Sensors (Switzerland)*, *19*(13), 1-17. [3018]. https://doi.org/10.3390/s19133018

[2] Gioia, Ciro & Damy, Sophie & Borio, Daniele. (2019). Precise Time in your Pocket: Timing Performance of Android Phones. 137-148. 10.33012/2019.16749.

[3] Lachapelle, Gérard & Gratton, Paul & Horrelt, Jamie & Lemieux, Erica & Broumandan, Ali. (2018). Evaluation of a Low Cost Hand Held Unit with GNSS Raw Data Capability and Comparison with an Android Smartphone. Sensors. 18. 4185. 10.3390/s18124185.

[4] Garello, Roberto & Samson, Jaron & Spirito, Maurizio & Wymeersch, Henk. (2012). Peer-to-Peer Cooperative Positioning: Part II: Hybrid Devices with GNSS & Terrestrial Ranging Capability. Inside GNSS.

I) Introduction - Objectives

In order to explore the feasibility of smartphone collaborative positioning, accurate and realistic simulations must be developed. Classic error models may not apply, embedded smartphone receivers need to be treated as a black box receiver.

Existing error models will be derived from real measurements processing.

- Characterizing smartphones GNSS receiver's main parameters:
    - **Phase jitter** (σ_{PLL})
    - **Code jitter** (σ_{DLL})
    - **Doppler jitter** ($\sigma_{Doppler}$)
    - **Clock drift** ($c\dot{\delta}t$)
- Find a possible correlation between those parameters and phone brands/models or GNSS embedded chipset brands/models.

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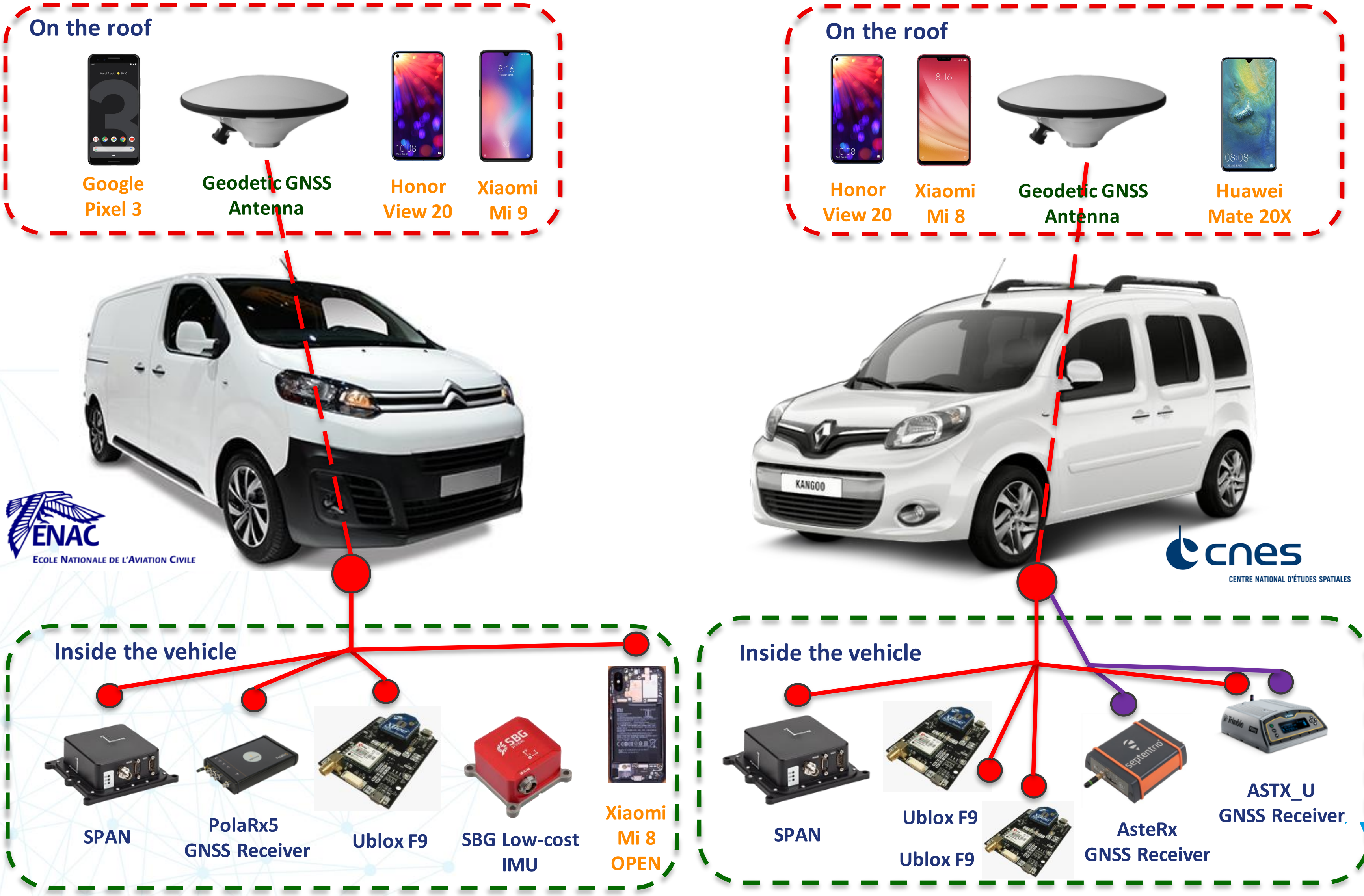
II) Methodology - Protocols

9 tested smartphones

- **Google Pixel 3** (11/2019) — **Qualcomm** Snapdragon 845 — Multi-Constellation, **Single Frequency**
- **Honor View 20** (01/2019) — x2 — **HiSilicon** Kirin 980 — Multi-Constellation, Multi-Frequency
- **Xiaomi Mi 9** (04/2019) — **Qualcomm** Snapdragon 855 — Multi-Constellation, Multi-Frequency
- **Xiaomi Mi 8** (06/2018) — x3 — Qualcomm Snapdragon 845; **Broadcom** BCM47755 — Multi-Constellation, Multi-Frequency
- **Huawei Mate 20X** (11/2018) — **HiSilicon** Kirin 980 — Multi-Constellation, Multi-Frequency
- **Samsung S10+** (03/2019) — **Qualcomm** Snapdragon 855 — Multi-Constellation, Multi-Frequency

II) Methodology - Protocols



II) Methodology - Protocols

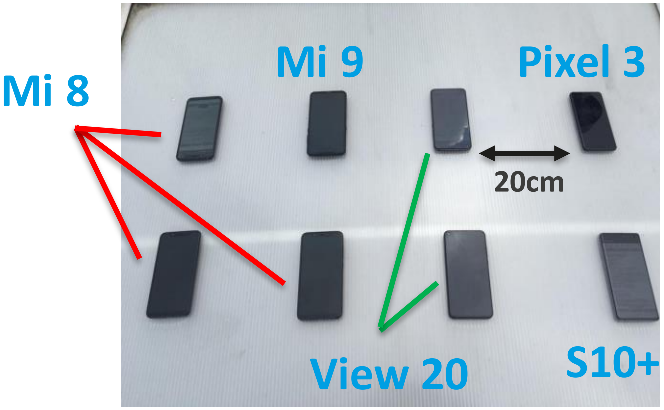
Data Collection Campaign Trajectory in Toulouse, FRANCE

Data Collection Campaign

- Various collaborative scenarios between two vehicles
- **Static scenarios for assessing nominal performance**
- Total of collection time ≈ 10 hours

Static Scenario (Open Sky Environment)

Rooftop Smartphones Configuration



II) Methodology - Clock Drift Estimation

Predicted Radial Satellite Movement : $v_i^{sv} * \overline{a_i^{sv}}$

Multiconstellation & Multifrequency

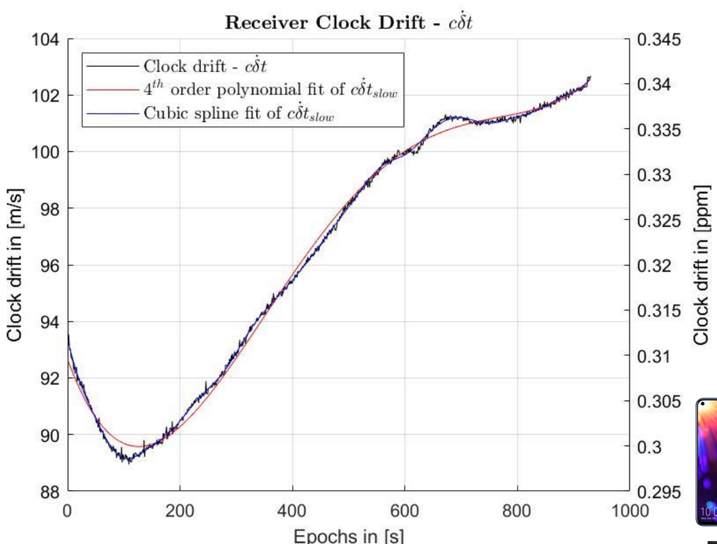
with $\overline{a}_i$ being the user-satellite line of sight vector

Doppler measurement model: $\dot{\rho}_i^{sv} = v_{x_i} \cdot a_{x_i} + v_{y_i} \cdot a_{y_i} + v_{z_i} \cdot a_{z_i} + c\dot{\delta}t + \varepsilon_{\dot{\rho}_i^s}$

Setting that:

$d_i^{sv} = \dot{\rho}_i^{sv} - v_i^{sv} * \overline{a_i^{sv}}$ *thus*

$$\begin{pmatrix} d_1 \\ d_2 \\ \vdots \\ d_i \end{pmatrix} = \begin{pmatrix} -a_{x_1} & -a_{y_1} & -a_{z_1} & 1 \\ -a_{x_2} & -a_{y_2} & -a_{z_2} & 1 \\ \vdots & \vdots & \vdots & \vdots \\ -a_{x_i} & -a_{y_i} & -a_{z_i} & 1 \end{pmatrix} \cdot \begin{pmatrix} v_{ux} \\ v_{uy} \\ v_{uz} \\ c\dot{\delta}t \end{pmatrix} + \begin{pmatrix} \varepsilon_{\dot{\rho}_1} \\ \varepsilon_{\dot{\rho}_2} \\ \vdots \\ \varepsilon_{\dot{\rho}_i} \end{pmatrix}$$



Clock Drift for a Honor View 20

Solving this equation with a WLSE, we obtain $c\dot{\delta}t$.

Hypothesis

Static scenario : *User position is computed by a reference receiver*

$c\dot{\delta}t$ *modeling :* $c\dot{\delta}t = c\dot{\delta}t^{fast} + c\dot{\delta}t^{slow}$

$c\dot{\delta}t^{slow}$ *is modeled by a curve fitting*

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II) Methodology – DLL Jitter Estimation

Best available satellite signal

***Code** model :* $\rho_i^{sv} = r + c\,(t_{rx} - t_{tx}) + \varepsilon_{Iono} + \varepsilon_{Tropo} + \varepsilon_{Code} + \varepsilon^{\rho}_{Multipath}$

***Phase** model :* $\varphi_i^{sv} = r + c\,(t_{rx} - t_{tx}) - \varepsilon_{Iono} + \varepsilon_{Tropo} + \Delta\varphi + \varepsilon_{Phase} + \varepsilon^{\varphi}_{Multipath}$

***Code minus carrier** (CMC) model :* $\rho_i^{sv} - \varphi_i^{sv} = 2\varepsilon_{Iono} + \varepsilon_{Code} - \varepsilon_{Phase} + \Delta\varepsilon_{Multipath} + \Delta\varphi$

***CMC Time differenced** model :*

$$\frac{d}{dt}(\rho_i^{sv} - \varphi_i^{sv}) = \frac{d}{dt}(2\varepsilon_{Iono} + \varepsilon_{Code})$$

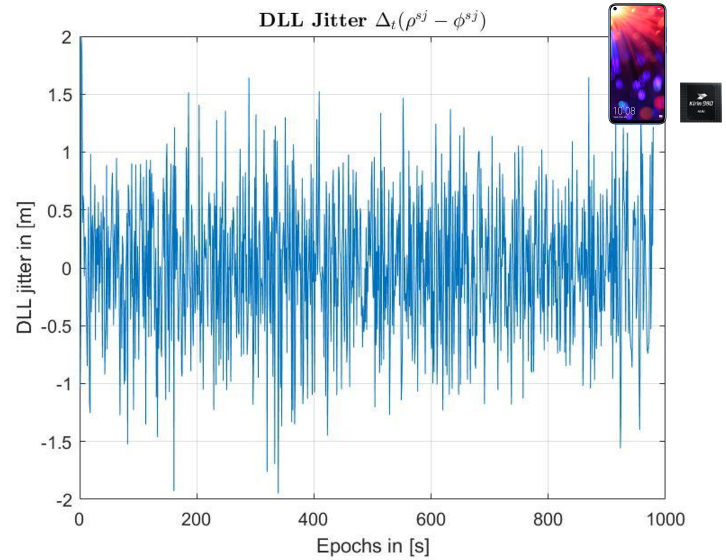
Hypothesis

Cycle slip detection: Android flag detection

Open sky scenario : $\Delta\varepsilon_{Multipath} \approx 0$

Error model : $\varepsilon_{Code} \gg \varepsilon_{Phase}$

Ionospheric variation: $\frac{d}{dt}(\varepsilon_{Iono}) \approx 0$



DLL Jitter for a Honor View 20

Galileo – PRN 21 – E1

II) Methodology – PLL/FLL Jitter Estimation

Best available satellite signal

***Phase** model :* $\varphi_i^{sv} = r + c\,(t_{rx} - t_{tx}) - \varepsilon_{Iono} + \varepsilon_{Tropo} + \Delta\varphi + \varepsilon_{Phase} + \varepsilon_{Multipath}^{\varphi}$

***Triple time differenced Phase** model [5] :*

$$\frac{d^3\varphi_i^{sv}}{dt^3} = \Delta t^3(r + c\,(t_{rx} - t_{tx})) - \Delta t^3(\varepsilon_{Iono}) + \Delta t^3(\varepsilon_{Tropo}) + \Delta\varphi + \varepsilon_{Phase} + \Delta t^3(\varepsilon_{Multipath}^{\varphi})$$

Hypothesis

Static scenario : $\Delta t^3(r + c\,(t_{rx} - t_{tx})) \approx 0$

Open sky scenario: $\Delta\varepsilon_{Multipath} \approx 0$

Tropospheric variation: $\frac{d}{dt}(\varepsilon_{Tropo}) \approx 0$

Ionospheric variation: $\frac{d}{dt}(\varepsilon_{Iono}) \approx 0$

Cycle slip detection: Android flag detection

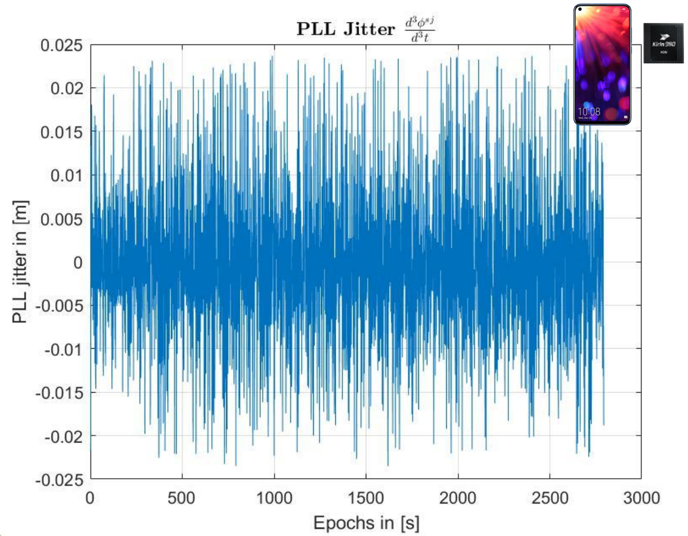


Figure: PLL Jitter for a Honor View 20

Galileo – PRN 21 – E1a

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III) Results Analysis – $c\dot{\delta}t$

Results obtained by Lethova. et al [1] | Smartphones Tested

Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
$\sigma_{c\dot{\delta}t}$ $[m/s]$	< 0.03	0.14	0.18	4.72	0.61	0.16	3.93	0.44
					0.42	0.25	2nd Phone	
						0.26	3rd Phone	

** Results obtained by Lethova. et al [1]*

III) Results Analysis – $c\dot{\delta}t$

			Qualcomm Snapdragon 835	Qualcomm Snapdragon 845	HiSilicon Kirin 980	Broadcom BCM47755	Qualcomm Snapdragon 855	Qualcomm Snapdragon 855	
Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+	
$\sigma_{c\dot{\delta}t}\ [m/s]$	< 0.03	0.14	0.18	4.72	0.61	0.16	3.93	0.44	
					0.42	0.25			2nd Phone
						0.26			3rd Phone

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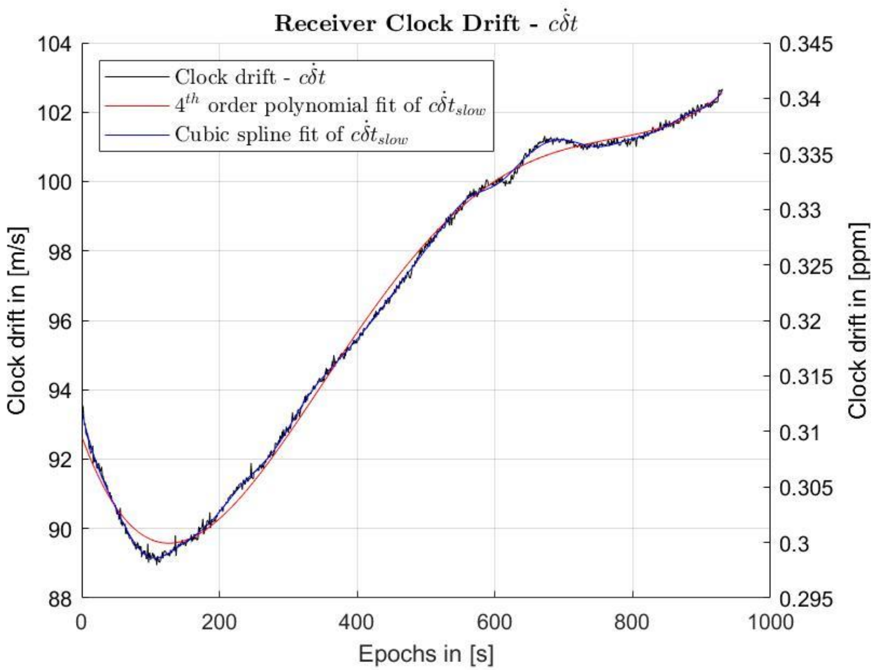
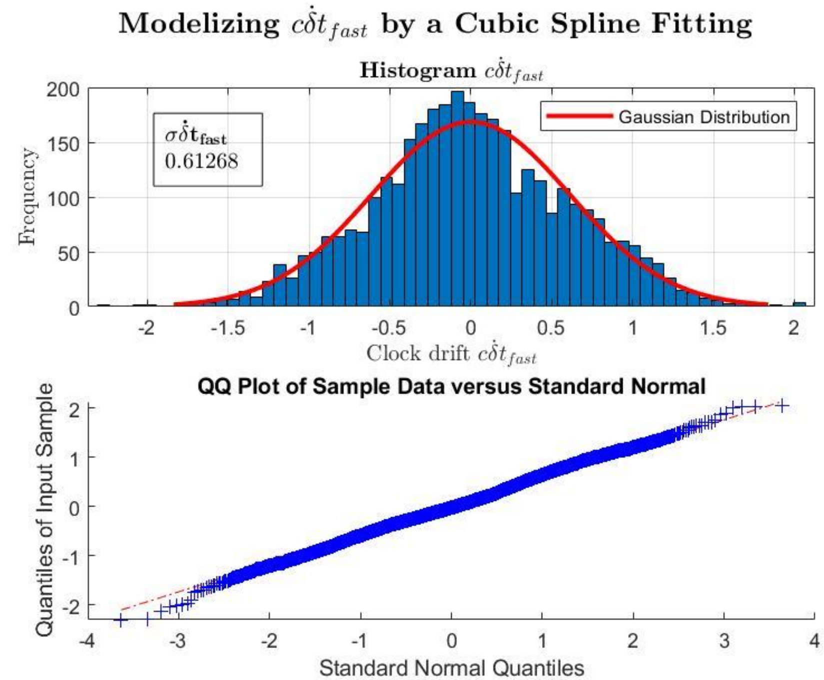
III) Results Analysis – $c\dot{\delta t}$





Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
$\sigma_{c\dot{\delta t}}\ [m/s]$	< 0.03	0.14	0.18	4.72	0.61	0.16	3.93	0.44
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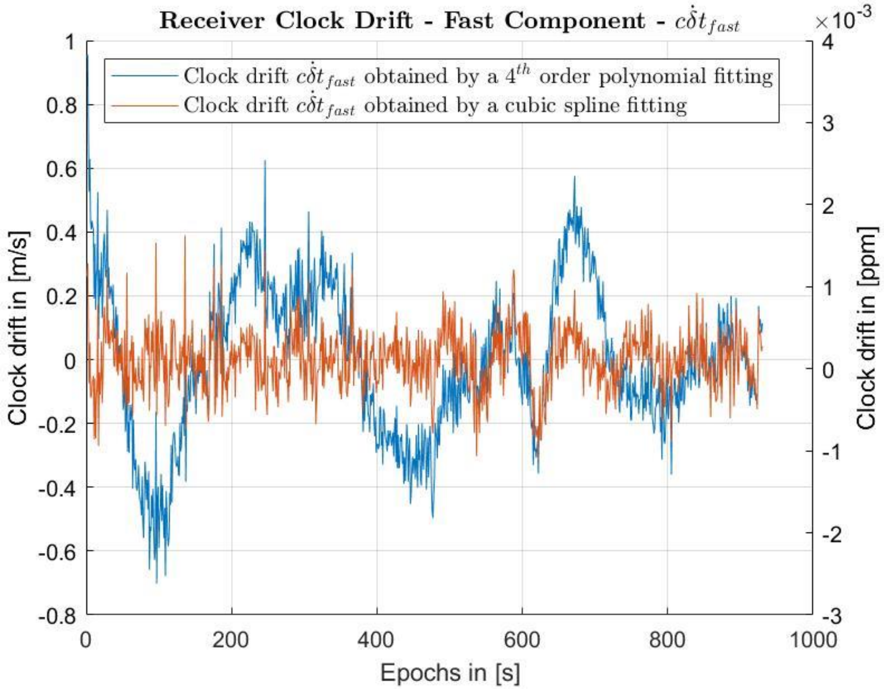

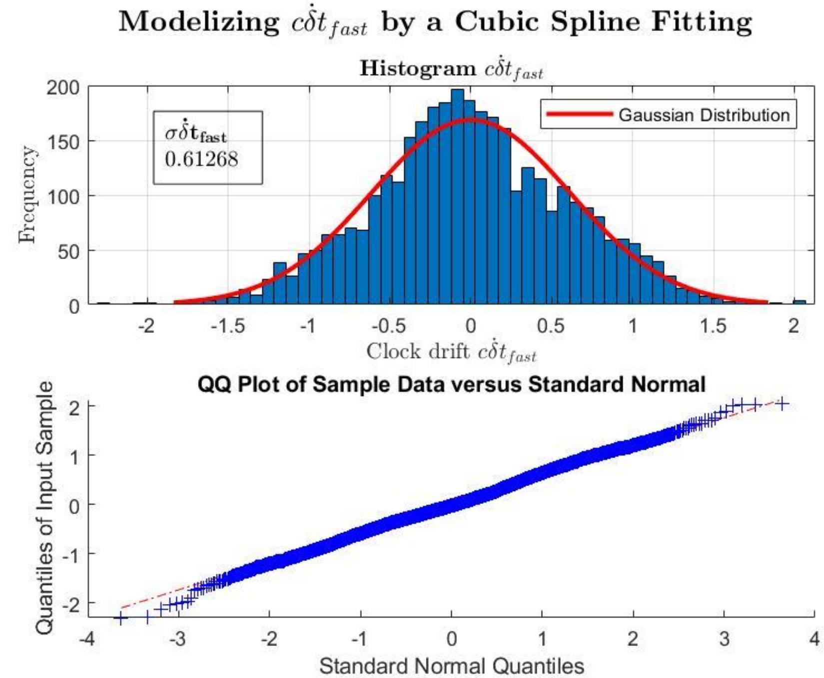

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					0.42	0.25	2nd Phone	
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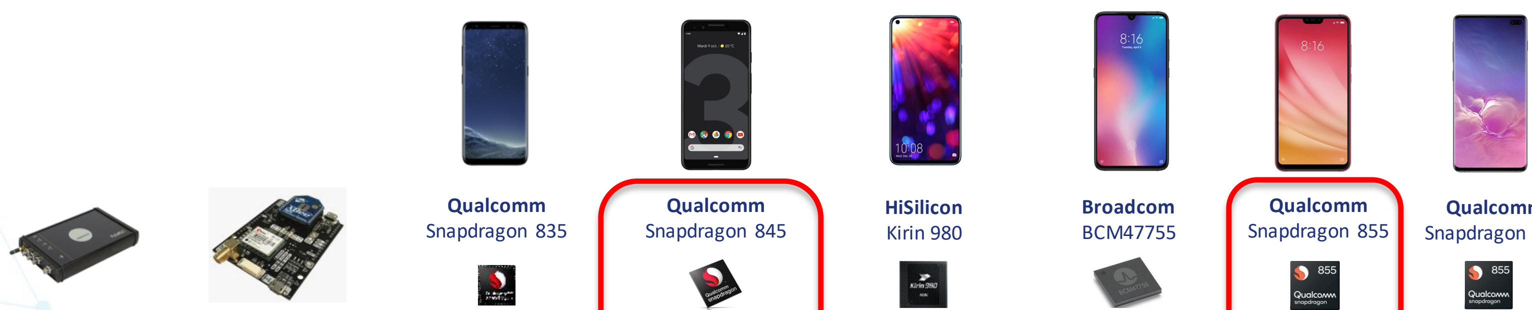
III) Results Analysis – $c\dot{\delta}t$

Comparing phones with no phase measurements



Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
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III) Results Analysis – $c\dot{\delta}t$

Comparing phones' performance to commercial GNSS receivers

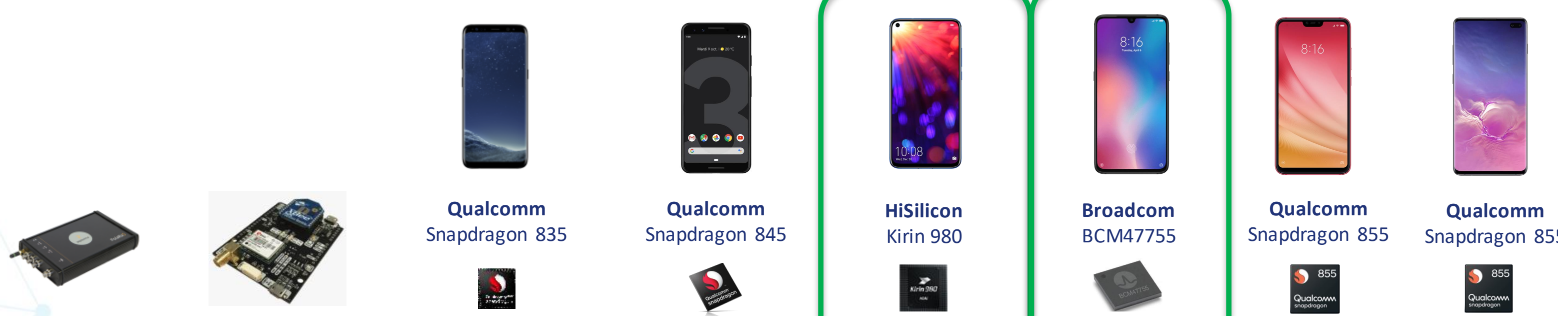


Chipset			Qualcomm Snapdragon 835	Qualcomm Snapdragon 845	HiSilicon Kirin 980	Broadcom BCM47755	Qualcomm Snapdragon 855	Qualcomm Snapdragon 855
Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
$\sigma_{c\dot{\delta}t}\ [m/s]$	< 0.03	0.14	0.18	4.72	0.61	0.16	3.93	0.44
					0.42	0.25	2nd Phone	
						0.26	3rd Phone	

** Results obtained by Lethova. et al [1]*

III) Results Analysis – $c\dot{\delta}t$

Comparing similar smartphones



Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
			Qualcomm Snapdragon 835	**Qualcomm** Snapdragon 845	**HiSilicon** Kirin 980	**Broadcom** BCM47755	**Qualcomm** Snapdragon 855	**Qualcomm** Snapdragon 855
$\sigma_{c\dot{\delta}t}\ [m/s]$	< 0.03	0.14	0.18	4.72	0.61	0.16	3.93	0.44
					0.42	0.25	2nd Phone	
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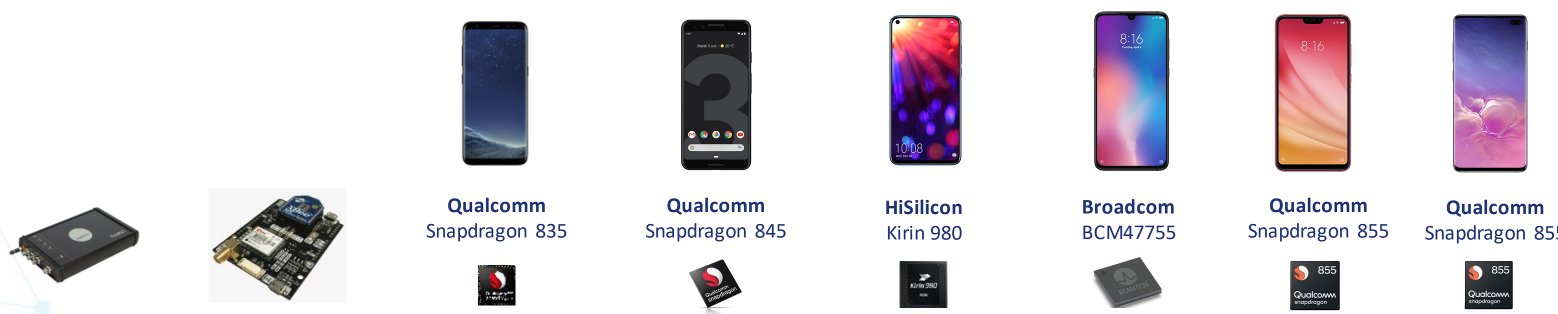
III) Results Analysis – $c\dot{\delta}t$

Comparing similar chipset manufacturer



Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
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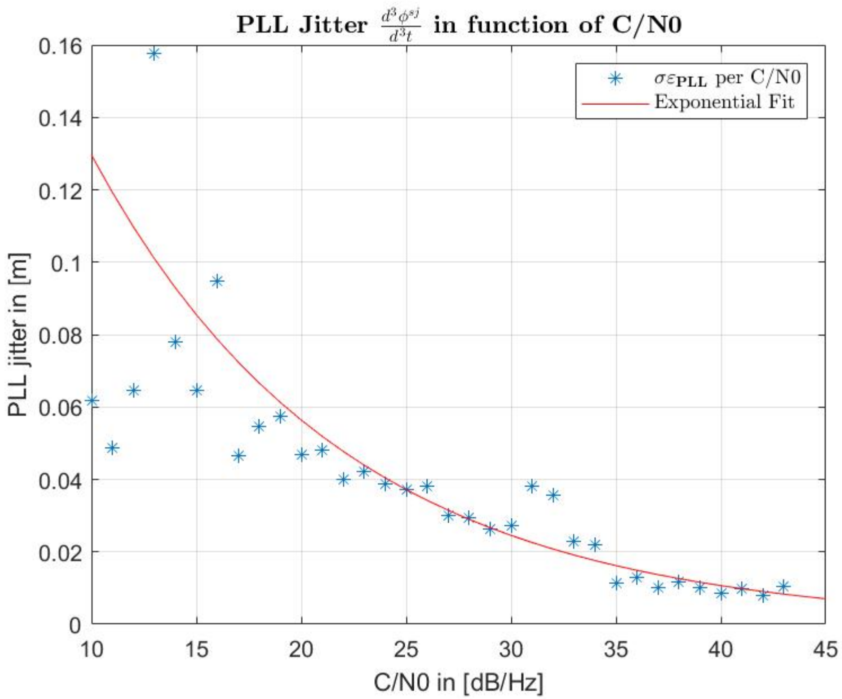
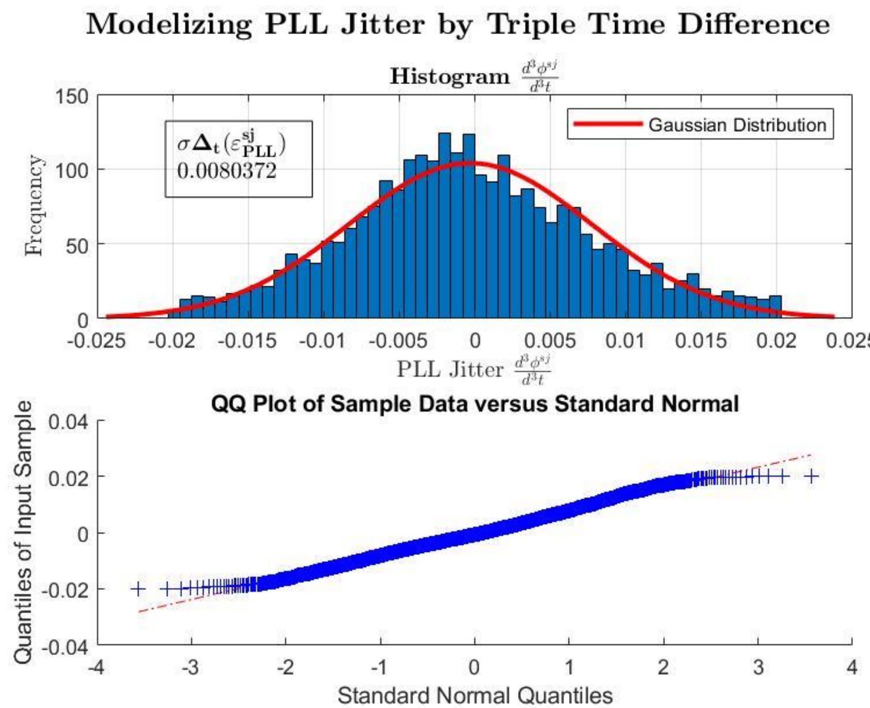
III) Results Analysis – σ_{PLL}





Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
$\sigma_{PLL}\ [m]$	0.002	0.003	0.8	NaN	0.008	0.018	NaN	0.003
					0.008	0.018	2nd Phone	
						0.014	3rd Phone	

** Results obtained by Lethova. et al [1]*

III) Results Analysis – σ_{PLL}

Comparing phones' performance to commercial GNSS receivers

Qualcomm Snapdragon 835 | Qualcomm Snapdragon 845 | HiSilicon Kirin 980 | Broadcom BCM47755 | Qualcomm Snapdragon 855 | Qualcomm Snapdragon 855

Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
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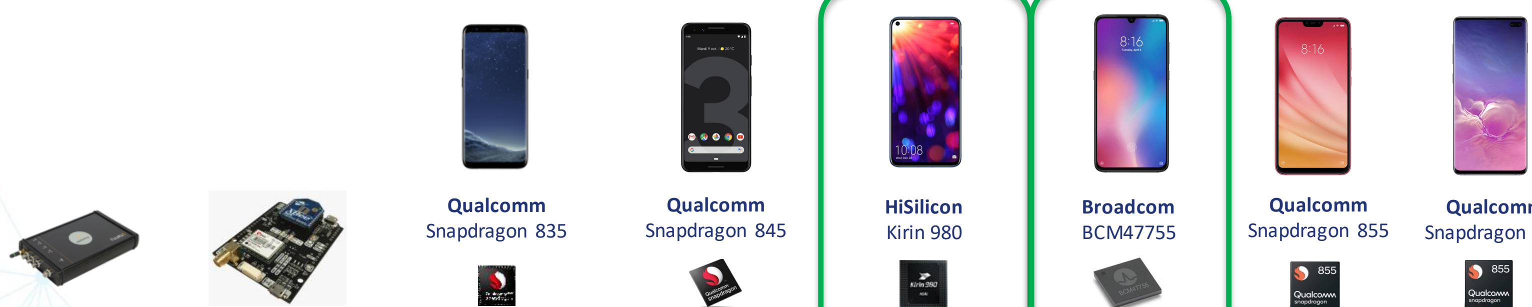
III) Results Analysis – σ_{PLL}

Comparing similar smartphones



Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
Chipset			**Qualcomm** Snapdragon 835	**Qualcomm** Snapdragon 845	**HiSilicon** Kirin 980	**Broadcom** BCM47755	**Qualcomm** Snapdragon 855	**Qualcomm** Snapdragon 855
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2nd Phone					0.008	0.018		
3rd Phone						0.014		

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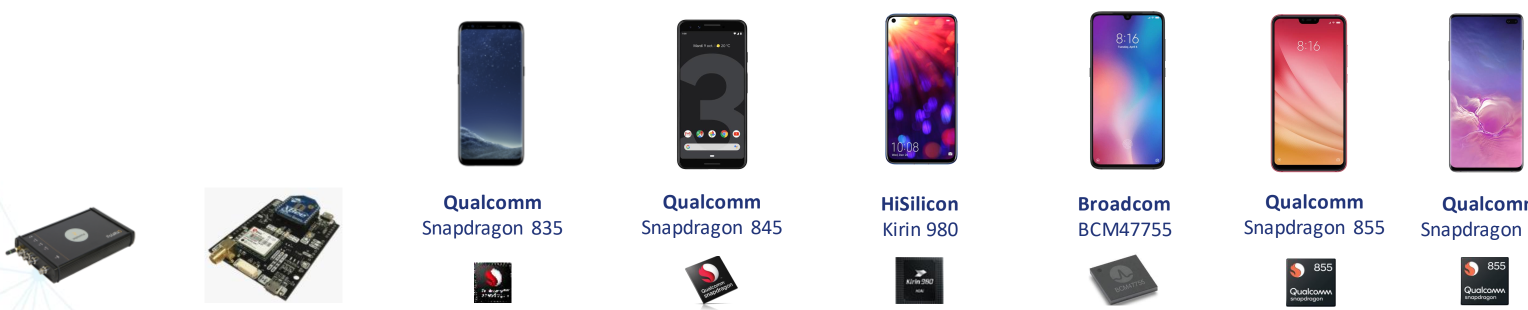
III) Results Analysis – σ_{PLL}

Comparing similar chipset manufacturer



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2nd Phone					0.008	0.018		
3rd Phone						0.014		

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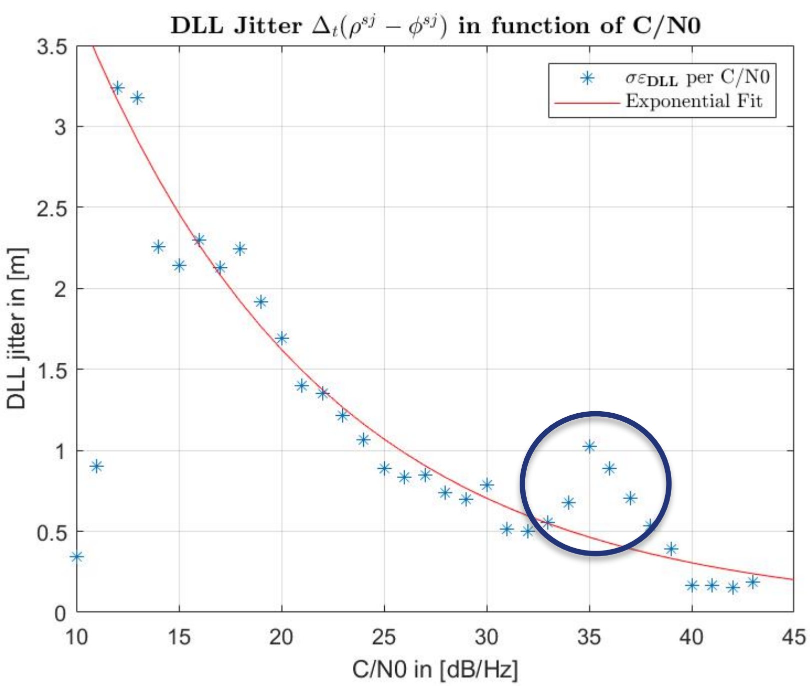
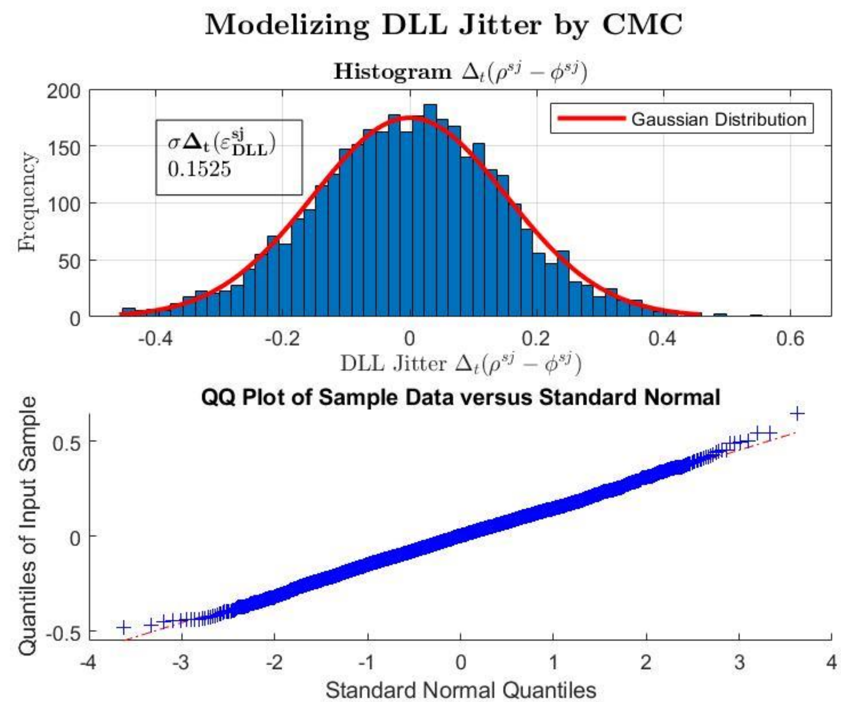
III) Results Analysis – σ_{DLL}





Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
σ_{DLL} [m]	0.049	0.22	6.42	1.88	0.152	0.68	0.24	0.97
					0.135	1.06	2nd Phone	
						0.71	3rd Phone	

** Results obtained by Lethova. et al [1]*

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III) Results Analysis – σ_{DLL}

Comparing phones' performance to commercial GNSS receivers

Qualcomm Snapdragon 835 | **Qualcomm** Snapdragon 845 | **HiSilicon** Kirin 980 | **Broadcom** BCM47755 | **Qualcomm** Snapdragon 855 | **Qualcomm** Snapdragon 855

Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
$\sigma_{DLL}\ [m]$	0.049	0.22	6.42	1.88	0.152	0.68	0.24	0.97
2nd Phone					0.135	1.06		
3rd Phone						0.71		

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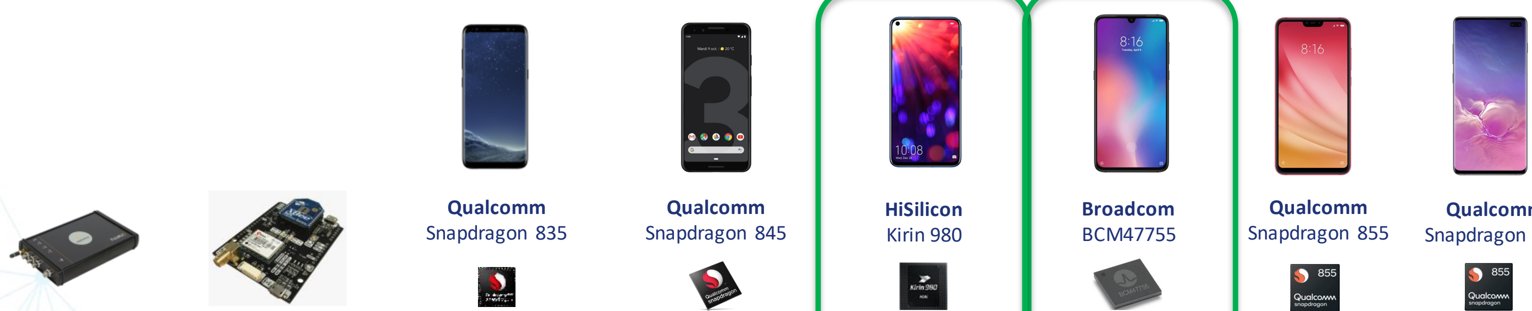
III) Results Analysis – σ_{DLL}

Comparing similar smartphones



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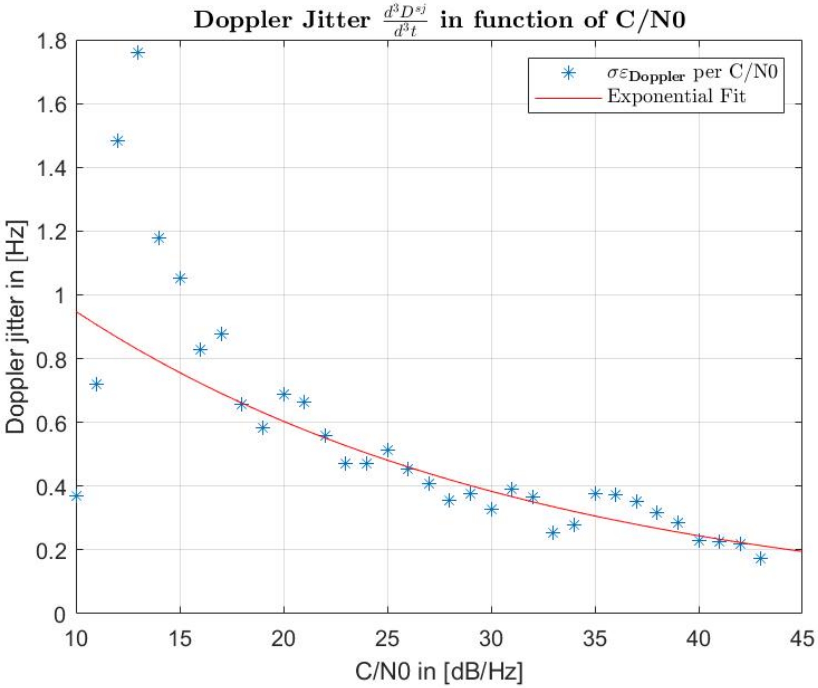
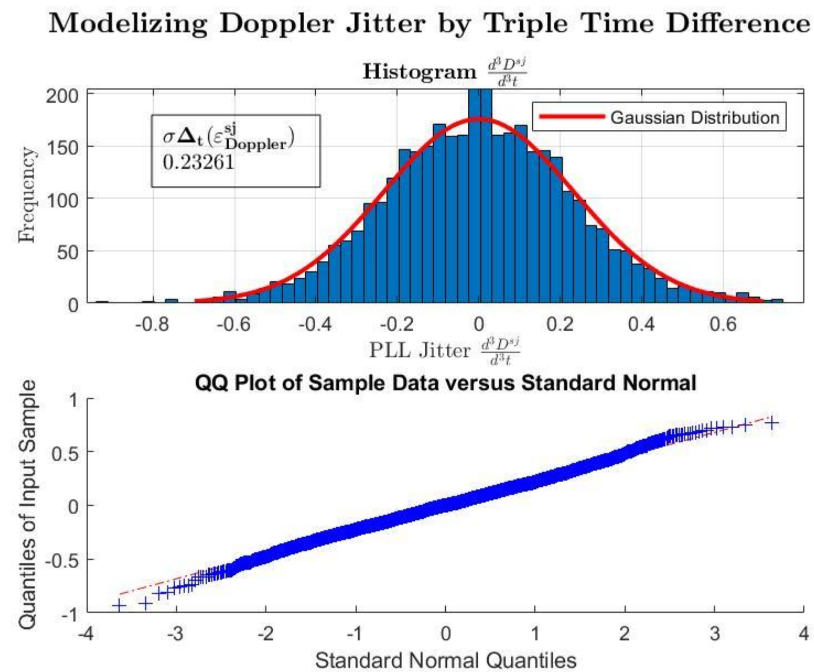
2nd Phone					0.135	1.06		
3rd Phone						0.71		

** Results obtained by Lethova. et al [1]*

III) Results Analysis – $\sigma_{Doppler}$



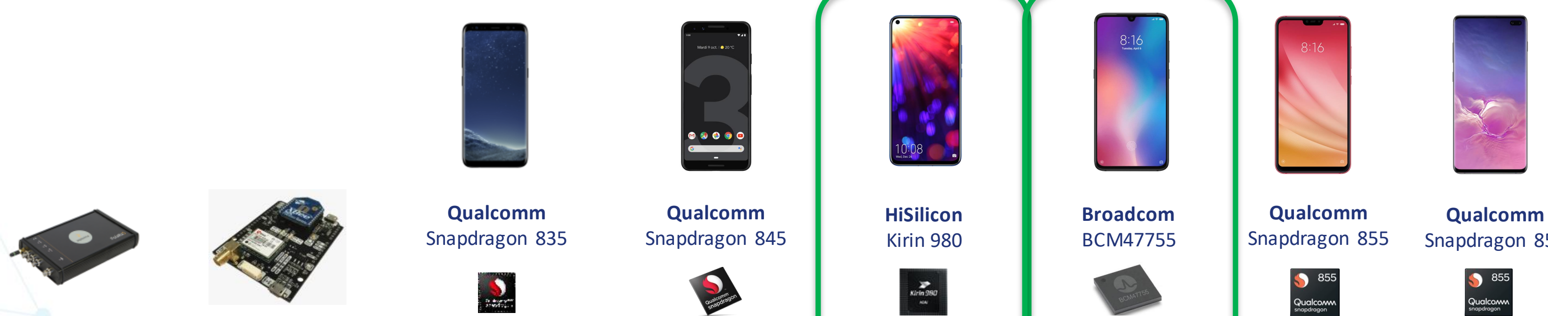


Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
σ_{Dop} $[Hz]$	N/A	N/A	N/A	4.79	0.23	0.10	1.27	0.05
					0.19	0.11	2nd Phone	
						0.14	3rd Phone	

** Results obtained by Lethova. et al [1]*

III) Results Analysis – $\sigma_{Doppler}$

Comparing similar smartphones



Receiver	*Septentrio PolaRX5S**	*u-blox M8T**	*Samsung S8**	Google Pixel 3	Honor View 20	Xiaomi Mi 8	Xiaomi Mi 9	Samsung S10+
σ_{Dop} $[Hz]$	N/A	N/A	N/A	4.79	0.23	0.10	1.27	0.05
					0.19	0.11	2nd Phone	
						0.14	3rd Phone	

** Results obtained by Lethova. et al [1]*

OUTLINE

IV) Conclusions

- Smartphone embedded GNSS receivers have been successfully characterized for a nominal performance scenario (open sky conditions).
- Estimated parameters for similar phones (same model) tend to be equals and therefore can be modeled.
- Further analysis need to be made in order to draw a clear correlation between the estimated parameters (DLL, PLL, Doppler jitters & Clock Drift) and GNSS chipset brands/models.
- A characterization method will be established for urban canyons environment
- Android Flags need a deeper investigation (cycle slip detection)

IV) Conclusions - References

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Questions ?

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