Establishing a Methodology to Estimate the Time To First Fix

ICG 8 WG-B Meeting
Dubai, United Arab Emirates
12 November 2013

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TTFF Definition and Relevance

- **Time needed by the receiver to perform the first position fix, starting from the moment it is switched on**
- In the evolving GNSS scenario new signals available to the users:
  - ✓ New modulation techniques
  - ✓ New spreading codes
  - ✓ New navigation message structures
- Direct impact on the TTFF
  - ✓ Concrete feedback to the user community on the GNSS QoS
  - ✓ To be carefully understood when looking at service definition and at interoperability

TTFF Conditions

- Analytical methodology (no measurements)
- TTFF subdivided into different contributions, to be separately estimated and then combined
- Another fundamental point is to further distinguish the TTFF computation among different scenarios
  - ✓ **Cold, warm and hot start**, referring to the particular status of the receiver when it is switched on
  - ✓ The specific scenario is defined according to the availability and validity of the data required for the computation of the navigation solution
  - ✓ Typical examples are satellite almanac and ephemeris parameters, send time of the received signal, previously stored PVT solutions…

Cold Start Definition

Some preliminary definitions:

- **GST**: GNSS System Time reference (Time of week and Week number)
- **CED**: Clock and Ephemeris Data (Clock corrections and data for computation of SV position)
- **ALM**: Almanacs Data

- The **cold start** is the most straightforward to be characterized
  - ✓ No data stored in the receiver
  - ✓ The position solution has to be calculated by means of a full sky search without the use of any almanac data
  - ✓ CED and GST must be retrieved

Hot Start Definition

- The **hot start** is also quite simple
- Typical situation where after a short off-time, typically in the order of few seconds, the receiver has to fix its position
- In this case valid ephemeris and clock corrections are stored in the device and accurate position and clock error are already known
- When a hot start is performed the position solution can be computed without any information from the navigation message.

Warm Start Definition (1/3)

- Warm start is the most complicated to be defined
- It represents the intermediate situation within the cold and hot starts
- As also the name suggests, while cold and hot are two very clear conditions, warm is something that can happen under different gradations, either closer to the first or to the second
- Two main definitions can be thought, depending on the availability and validity of CED

Warm Start Definition (2/3)

- In the definition of [van Diggelen, 2009] valid ALM is stored in the device, but not valid CED.
- An a-priori PVT (with limited accuracy) and approximate information on user frequency offset are also available
- In such conditions the receiver needs to perform an acquisition (with a reduced search space with respect to the cold start) but needs to read the ephemeris and the GST information from the navigation message as in the cold start
- We can label this condition as **"long-off" warm start**

Warm Start Definition (3/3)

- Once the CED are read from the navigation message they are stored in the receiver and remain valid, even if with a gradually degrading accuracy, for some time (typically some hours)
- If the warm start is happening after that the receiver has been switched off and again on within a period of time shorter than the ephemerides validity time, the information stored can still be used for the position fix (the GST information has still to be retrieved)
- We refer to this condition as **"short-off" warm start** (receiver off for a time shorter than CED validity time but longer than typical hot start)

TTFF vs. Visible Satellite

- Beside the availability of the navigation data, the TTFF performance depends on the amount of visible satellites
  - ✓ It seems solid to assume that the number of visible satellites is always sufficient to allow the receiver to perform a first position fix within the standard accuracy requirements
  - ✓ Also, the receiver has to be able to process all the signals coming from the different satellites in parallel, as it commonly happens in nowadays receiver
- Under these conditions the TTFF equals the time needed to process one of the signals coming from the different satellites (a statistical interpretation will be given)

TTFF Analytical Definitions

- **Cold Start** → No data stored in the receiver. GST and CED to be retrieved, no a-priori PVT, full acquisition

$$\boldsymbol{TTFF_{cold}} = T_{warm-up} + T^{c}_{acq} + T_{track} + T_{CED+GST} + T^{c}_{PVT}$$

- **Long-off Warm Start** → ALM, limited accuracy PVT and approx. frequency offset available, GST and CED to be retrieved

$$\boldsymbol{TTFF_{warm_{LO}}} = T_{warm-up} + T^{w_{LO}}_{acq} + T_{track} + T_{CED+GST} + T^{w}_{PVT}$$

- **Short-off Warm Start** → ALM, CED limited accuracy PVT and approx. frequency offset available, GST to be retrieved

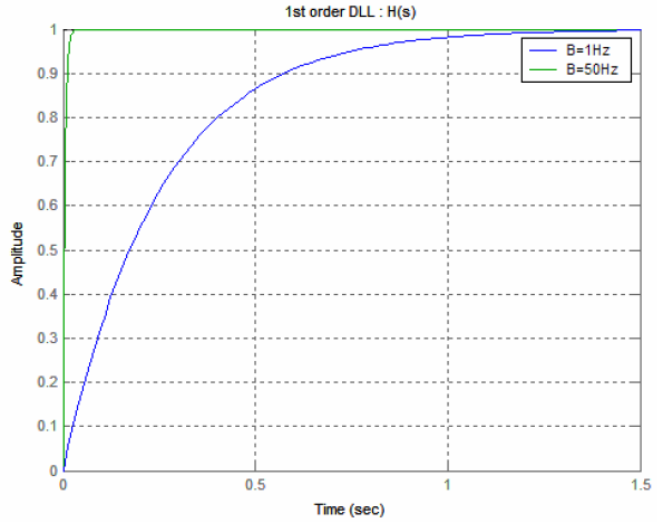
$$\boldsymbol{TTFF_{warm_{SO}}} = T_{warm-up} + T^{w_{SO}}_{acq} + T_{track} + T_{GST} + T^{w}_{PVT}$$

- Hot Start → No information to be retrieved from the navigation message, accurate position and clock error are known

$$\boldsymbol{TTFF_{hot}} = T^{h}_{acq} + T_{track}$$

Warm-Up Time and Time to Track

- The receiver warm-up time includes all software and hardware initializations that are carried out from the very first moment of switching-on and strongly depends on the technology
  - ✓ In [Holmes et al., 2006] the receiver warm-up time is fixed to 2 seconds
- T_{track} is transient time required by the receiver's tracking loops to enter into the stable region and can be estimated by studying the step response



The longest settling time is usually given by **FLL**

↓

For a loop bandwidth of 2 Hz $\boldsymbol{T_{track}}$ is in the order of 4 to 5 s (0.5 s in the case of hot start)

Time to Compute the PVT

- The time to compute the navigation solution is mainly due to the initialization of the algorithms for the positioning solution
  - ✓ In the cold start case there is no knowledge of the user position and the algorithms are initialized supposing to be in the center of the earth → longer
  - ✓ In the warm start case a very approximate positioning solution is available and the contribution becomes smaller.
  - ✓ For the hot start case, this time can be considered negligible
- Taking into account this simple assumptions and again referring to [Holmes et al., 2006] 2 seconds in the case of cold start and 1 second in the case of warm start seem could represent a reasonable assumption

Time to Acquire

- Acquisition is a two-dimensional search process
- Time to acquire depends mainly on two factors
  - ✓ Search space definition
    - Dependent on the carrier frequency, dynamics, code length, integration time
  - ✓ Search Strategy
    - Technique used to sweep the search space and detect Doppler shift and code phase
    - E.g. serial search, maximum search, FFT-based search

Acquisition Search Space

- The search space is set by fixing the total code delay uncertainty and the total frequency uncertainty
  - ✓ The code delay uncertainty depends on the length of the code to be acquired
  - ✓ The frequency uncertainty is fixed by the maximum possible Doppler shift depending on the observer dynamics, the constellation characteristics and the carrier frequency of the signal to be acquired
- The search space is system and signal specific and independent of technology

Search Strategies and Technology

- The search strategy is mainly related to technology
- Corresponding acquisition time will be function of:
  - ✓ Search Space (signal and system dependent)
  - ✓ Search Strategy and Number of Equivalent correlators (technology driven)
- Any analytical methodology aiming to assess the impact of different signals and systems into a (multi-system) TTFF should concentrate on the first aspect, taking reasonable (common) assumptions on the second and third
- A possible approach would be to consider a common standard benchmark (GPS C/A?)

Required Navigation Data

- The navigation data to be retrieved is used for the computation of satellites' position and determination of the send time reference (GST and CED)
- Methodology for the computation of $T_{CED+GST}$ and of T_{GST}:
  1. Analyze the frame structure and represent the different read times as function of the reading epochs
  2. Obtain the probability density function (PDF)
  3. Solve the following equation representing the cumulative distribution function, with respect to the data read time

$$F(T_{CED+GST}) = \int_{-\infty}^{T_{CED+GST}} f(t)\mathrm{dt} = 0.95$$

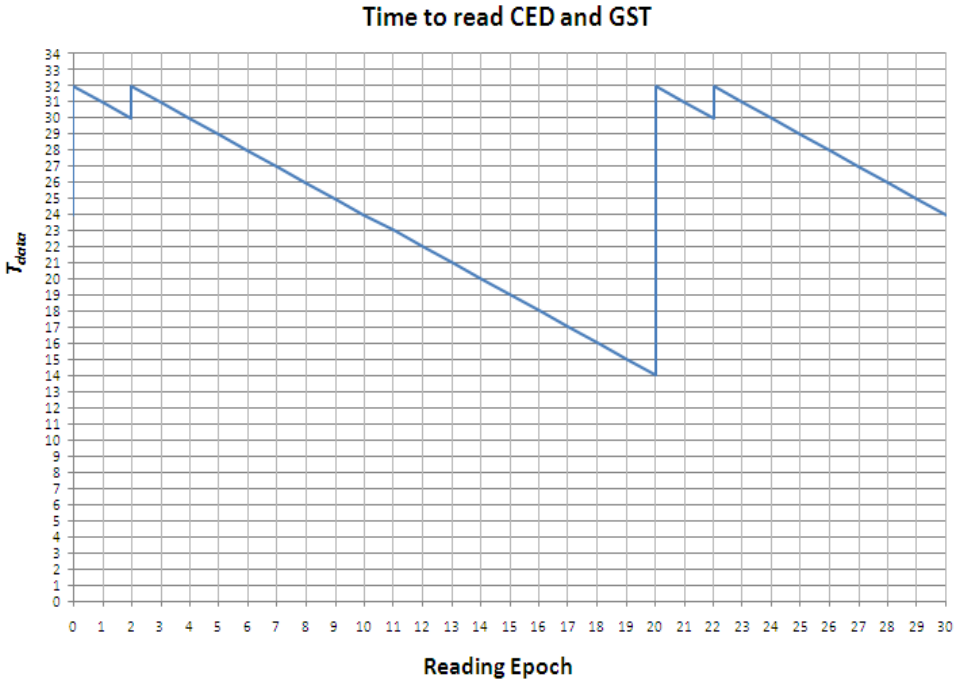
Required Navigation Data

Methodology for the computation of $T_{CED+GST}$ and of T_{GST}:

1. Analyze the frame structure and represent the different read times as function of the reading epochs time

Elapsed Time [s]	Page Type
1	Page 2 – CED (2/4)
2	
3	Page 4 – CED (4/4)
4	
5	Page 6 – GST
6	
7	Page 7/9
8	
9	Page 8/10
10	
11	Page 12
12	
13	Page 14
14	
15	Page 11
16	

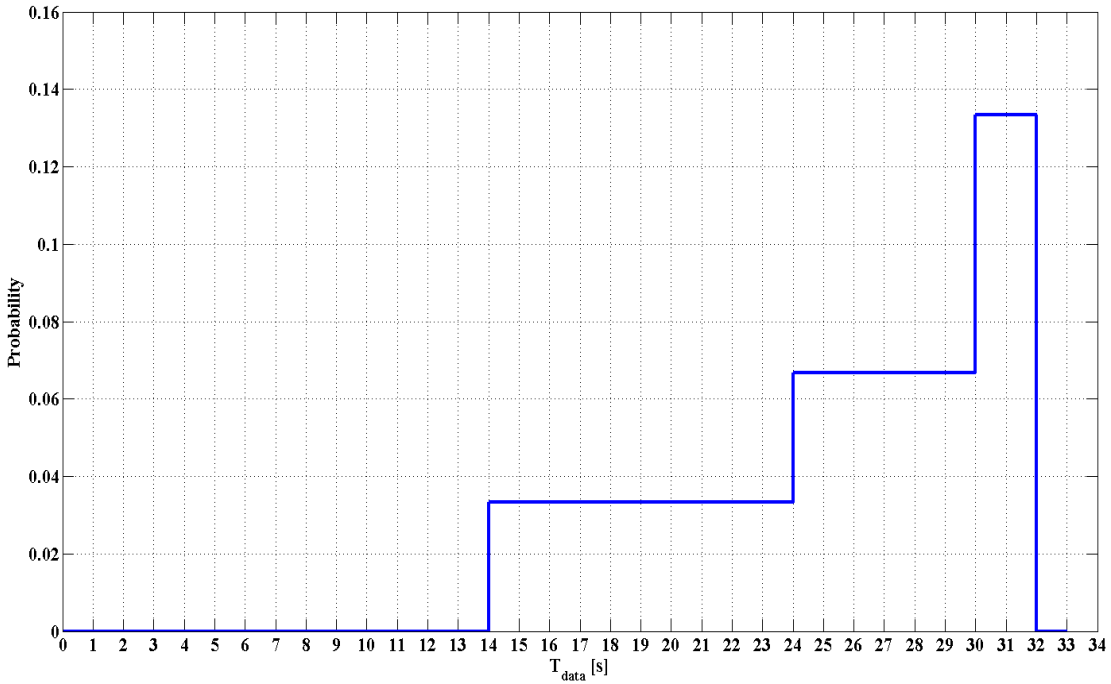
Elapsed Time [s]	Page Type
17	Page 16
18	
19	Page 15
20	
21	Page 1 – CED (1/4)
22	
23	Page 3 – CED (3/4)
24	
25	Page 5 - GST
26	
27	Spare
28	
29	Spare
30	



Required Navigation Data

Methodology for the computation of $T_{CED+GST}$ and of T_{GST}:

2. Obtain the probability density function (PDF) of the data read time



Required Navigation Data

Methodology for the computation of $T_{CED+GST}$ and of T_{GST}:

3. Solve the following equation representing the cumulative distribution function for a targeted confidence (in the specific case 95% is considered)

$$F(T_{CED+GST}) = \int_{-\infty}^{T_{CED+GST}} f(t)\mathrm{dt} = 0.95$$

Conclusions (1/2)

- The TTFF is nowadays considered by the user community an important factor on the evaluation of GNSS QoS
- Its impact needs to be carefully understood when looking at signal and service performance, also in the context of interoperability and performance of Multi-GNSS receivers
- The TTFF is impacted by a wide variety of factors and parameters, both system (mainly signal characteristics) and receiver dependent
- Regarding the receiver side, the impact of technology is a common factor in the processing of different signals from different systems

Conclusions (2/2)

- The data format is another factor impacting the TTFF
- A common evaluation of a Multi-System TTFF would be also a concrete feedback on the level of interoperability of the message structure of the various OS signals of the different systems
- Other factors should be considered in the future, as for example the impact of C/N_0 on the TTFF (research results available to the interested attendees)

Thank you very much for the attention!

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