High-Sensitivity Adaptive GNSS Acquisition Schemes

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Prof. Marie-Laure BOUCHERET

Toulouse, May 27th 2014
I. Introduction to GNSS and Signal Acquisition

II. Thesis Contributions
   A. Analysis and Compensation of Doppler Effect
   B. Characterization of Differential Detectors
   C. Multi-Constellation Collective Acquisition

III. Conclusions and Future Work

GNSS – Global Navigation Satellite System
Presentation Outline

I. Introduction to GNSS and Signal Acquisition

II. Thesis Contributions
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GNSS – Global Navigation Satellite System
The underlying principle of GNSS systems is *trilateration*:

*An unknown position can be inferred from distances to points with known positions*

- Satellites position can be established accurately
- User pseudorange to satellites can be estimated
- User position and clock bias (with respect to GNSS system time) can be determined

Number of unknowns = 4 ➔ A *minimum of 4 satellites* is required to determine user *navigation solution*
Part I: Introduction

**Goal:** Trilateration

**Requires** Distance

**GNSS** Time

\[
\text{Distance} = \frac{\text{Time}}{\text{Speed-of-Light}}
\]

How to estimate the signals time of travel accurately? **Correlation!**

- Besides *code phase* also *Doppler offset* needs to be estimated
- First phase of (coarse) estimation of both parameters is **ACQUISITION**
Part I: Introduction

Acquisition Role

- Acquisition output example for GPS L1 C/A signal:

  Outdoor
  ✓ Line-of-sight visibility

  Standard Acquisition
  ✓ 1 code period

  Comput. Complexity
  ✓ Search Points: 1E3
  ✓ Number of Operations Required ~ 1E5

Acquisition is a combined estimation and detection problem

Why a PhD thesis in acquisition?
Acquisition Challenges

Part I: Introduction

- Acquisition output example for **GPS L1 C/A** signal:

**Outdoor**  **Indoor**
- Non line-of-sight

**Standard Acquisition**
- 1 code period

**Comput. Complexity**
- Search Points: $1 \times 10^3$
- Number of Operations Required ~ $1 \times 10^5$

---

Standard GNSS Acquisition is not capable of satisfying current user expectations!
Acquisition Challenges

Part I: Introduction

Acquisition output example for GPS L1 C/A signal:

Outdoor vs Indoor
- Non line-of-sight

Standard Acquisition vs High-Sensitivity Acquisition
- 100 code periods

Comput. Complexity
- Search Points: $1 \times 10^5$
- Number of Operations Required ~ $1 \times 10^9$

10,000 times higher than standard acquisition!

High-sensitivity acquisition involves a sensitivity vs complexity trade-off
Thesis Objectives

- Propose innovative solutions to the current challenges of acquisition
  - Current challenges and innovation opportunities: identified through state-of-the-art review

  - Analysis carried always considering the sensitivity vs complexity trade-off of High-Sensitivity GNSS acquisition
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Part II: Thesis Contributions

Part IIA: Analysis and Compensation of Doppler Effect in GNSS Acquisition

Contents:

1. Introduction
2. Compensation of Doppler Effect in Low-Dynamics
3. Analysis of Doppler Effect in Medium-Dynamics
4. Compensation of Doppler Effect in High-Dynamics
5. Conclusion
Part II: Thesis Contributions

Part IIA: Analysis and Compensation of Doppler Effect in GNSS Acquisition

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5. Conclusion
Doppler shift is unavoidable in GNSS given the significant (relative) user-satellite motion.

The Doppler shift experienced by a land-based user is mainly due to 3 sources:

1. **Satellite Motion**
2. **User Motion**
3. **User Receiver Oscillator**

*High-sensitivity* signal processing techniques require *long observation times*

Doppler *variation* throughout signal observation time is also important!
Introduction

Three Doppler-related scenarios can then be defined:

1. **Low-Dynamics**
   Doppler offset remains approximately *constant* during acquisition time

2. **Medium-Dynamics**
   Doppler offset *changes slightly* and does not impact the acquisition process

3. **High-Dynamics**
   Doppler offset *changes significantly* and impacts the acquisition process

✓ Conclusion and Possible scenarios of application
Part II: Thesis Contributions

Part IIA: Analysis and Compensation of Doppler Effect in GNSS Acquisition

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1. Introduction
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3. Analysis of Doppler Effect in Medium-Dynamics
4. Compensation of Doppler Effect in High-Dynamics
5. Conclusion
I. Motivation

 Acquisition involves a search over a finite number of candidate frequencies (Doppler offsets) and code phases.

 Residual code and frequency estimation offsets are inevitable.

 What is the impact on acquisition of a residual frequency estimation error?
Part IIA: Analysis and Compensation of Doppler Effect in GNSS Acquisition

Coarse vs Fine Search Grid comparison (worst-case scenario)

- **Coarse Acquisition Grid**
  - « Low » computational cost
  - Potentially « high » frequency-derived losses

- **Fine Acquisition Grid**
  - « High » computational cost
  - « Limited » frequency-derived losses
Part IIA: Analysis and Compensation of Doppler Effect in GNSS Acquisition

I. Motivation

- Most computationally efficient GNSS acquisition methods employ Fast Frequency Transform (FFT) for computation optimization.

**FFT imposes coarse frequency grid**

**Objective**: Adapt the most computationally efficient methods in order to reduce the maximum frequency attenuation losses!
Part IIA: Analysis and Compensation of Doppler Effect in GNSS Acquisition

Low-Dynamics

2. Proposed Approach

- How to counteract the coarse FFT frequency resolution?

Spectral Peak Location algorithms (from Digital Signal Processing literature)

\[ \delta = f(\text{correlation outputs}) \]

\[ f_{\text{delta corrected}} = f_{\text{simple}} + \delta \]

Interpolate the FFT outputs to calculate \( \delta \)

FFT output profile known (sinc function)
2. Proposed Approach

- New *delta-corrected* acquisition methodology

**Flowchart**

- Input Signal
  - Perform Acquisition
  - Detection?
    - Yes: Refine frequency estimation
      - Use fine frequency in acquisition
        - Detection? (Output)
          - Yes: Tracking or Navigation Module
          - No: Refine frequency estimation (Input)
    - No: Refine frequency estimation (Input)
      - Delta (Spectral Peak Location) algorithm
      - Candidate code phase: most likely code phase

Low-Dynamics

**Notes**

- 2. Proposed Approach
- New *delta-corrected* acquisition methodology
- Flowchart
Low-Dynamics

2. Proposed Approach

- New **delta-corrected** acquisition methodology

![Graph showing detection threshold and metric for delta-corrected acquisition.](image)
3. Results

- Analysis of real data collected with test and reference receivers (1ms GPS L1 C/A signal)

**Doppler offset estimation:** simple vs *delta-corrected* frequency estimator

- Simple FFT Doppler estimation
- Delta-corrected Doppler estimation
- Reference Doppler value
3. Results

- Analysis of real data collected with test and reference receivers (1ms GPS L1 C/A signal)

**Satellites Detection:** simple vs delta-corrected acquisition scheme

### Results

<table>
<thead>
<tr>
<th>SV PRN</th>
<th>Mean Doppler Offset (Hz)</th>
<th>Mean C/N₀ (dB-Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1450</td>
<td>48.1</td>
</tr>
<tr>
<td>4</td>
<td>-1570</td>
<td>48.1</td>
</tr>
<tr>
<td>5</td>
<td>4480</td>
<td>46.7</td>
</tr>
<tr>
<td>7</td>
<td>1930</td>
<td>48.1</td>
</tr>
<tr>
<td>8</td>
<td>4080</td>
<td>48.9</td>
</tr>
<tr>
<td>10</td>
<td>1550</td>
<td>47.1</td>
</tr>
<tr>
<td>13</td>
<td>-1020</td>
<td>48.6</td>
</tr>
<tr>
<td>23</td>
<td>-1550</td>
<td>46.4</td>
</tr>
</tbody>
</table>
Part II: Thesis Contributions

Part IIA: Analysis and Compensation of Doppler Effect in GNSS Acquisition

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1. Introduction
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4. Compensation of Doppler Effect in High-Dynamics
5. Conclusion
Medium-Dynamics

1. Motivation

For detection of weak signals (very) long signal observation times are required

Assumption of a constant Doppler offset is no longer valid!

\[ f_{\text{received}} = f(t) \]

<table>
<thead>
<tr>
<th>Source</th>
<th>Maximum Expected Variation (Hz/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Motion</td>
<td>± 10</td>
</tr>
<tr>
<td>User Motion</td>
<td>± 50</td>
</tr>
<tr>
<td>Receiver Oscillator</td>
<td>Variable</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>± 60 Hz/s</td>
</tr>
</tbody>
</table>

How does a changing Doppler offset impact the acquisition process?
2. Proposed Approach

**Chosen model:** frequency ramp (linear variation)

\[ f_d = f_{d0} + \alpha t, \quad \alpha \equiv \text{Doppler change rate (Hz/s)} \]

- **2 different analysis conducted:**
  1. **Detector employing exclusively coherent integration:**

     ![Diagram of coherent integration process]

     Correlation Output \( \sum_{N \text{ Code Periods}} \) \( \rightarrow \) Phase Removal \( \rightarrow \) Detection Metric

  2. **Detectors employing coherent and postcoherent integration:**

     ![Diagram of coherent and postcoherent integration process]

     Correlation Output \( \sum_{N \text{ Code Periods}} \) \( \rightarrow \) Postcoherent Integration \( \rightarrow \) Detection Metric
3. Results

1. Detector employing exclusively coherent integration

- Percentage of Doppler bin «swept» by the Doppler frequency during coherent integration - **Sweep factor** $(\gamma)$

$$\gamma = \alpha \cdot T_{coh}^2$$

- Simulation analysis of effect of $\gamma$ in coherent integration

**Conclusions:**

- For $\gamma < 100\%$ worst-case detection metric attenuation equal to FFT coarse grid loss
- Coherent integration time adjusted according to expected dynamics $(\alpha)$
Part II: Thesis Contributions

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Part IIA: Analysis and Compensation of Doppler Effect in GNSS Acquisition

2. Proposed Approach

- **For Medium-Dynamics:** proposed formulas adapt integration times only, implying no design changes.

- **For High-Dynamics:** application scenarios and involved dynamics require new design!

**Proposed approach:** Frequency Offset Correction Loop
3. Results

- Two different frequency compensation approaches analyzed:
  - Staircase compensation
  - Chirp compensation

Chirp compensation **more efficient** than staircase approach

Chirp-compensated acquisition **limited by \( \alpha \) estimation** at low input signal powers
Part II: Thesis Contributions

Part IIA: Analysis and Compensation of Doppler Effect in GNSS Acquisition

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5. Conclusion
Three different Doppler scenarios were defined and evaluated:

1. **Low-Dynamics**
   - Improve sensitivity/complexity trade-off of GNSS Acquisition
   - Proposed for mass-market applications

2. **Medium-Dynamics**
   - Adapt acquisition schemes parameters according to expected level of dynamics
   - Proposed for urban receivers and LEO and GEO satellite receiver

3. **High-Dynamics**
   - Inclusion of a dynamic Frequency Offset Correction loop for enhanced robustness
   - Proposed for receivers targeting indoor acquisition
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Part IIB: Sensitivity Characterization of Differential GNSS Detectors

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Introduction

GNSS signal integration techniques

- Code Period 1
- Code Period 2
- Code Period 3

Correlation Outputs

Coherent Integration

Coherent Integration Output

1. Coherent Integration


**Introduction**

**GNSS signal integration techniques**

1. **Coherent Integration**

2. **Noncoherent Integration**
Part IIB: Sensitivity Characterization of Differential GNSS Detectors

Introduction

- GNSS signal integration techniques

**Correlation Outputs**

1. **Coherent Integration**
2. **Noncoherent Integration**
3. **Differential Integration**

**Differential Operation**

\[ S_2 S_1^* \]

**Differential Integration**

\[ S_3 S_2^* \]

* - Complex conjugate
GNSS signal integration techniques: coherent and postcoherent

1. Coherent Integration
2. Noncoherent Integration
3. Differential Integration

Postcoherent Integration

Correlation Outputs

Code Period 1 \( S_1 \)
Code Period 2 \( S_2 \)
Code Period 3 \( S_3 \)
Coherent and Postcoherent integration techniques comparison

<table>
<thead>
<tr>
<th></th>
<th>Coherent</th>
<th>Postcoherent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity Improvement</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Robustness to Signal Phase (Doppler and data bit)</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Impact on Computational Complexity</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

Given limitations of coherent integration, transition to postcoherent integration is usually required.

What is preferable: transition to noncoherent or differential?
**Introduction**

Noncoherent integration

- Most commonly employed approach (standard technique since radar)
- The *sensitivity loss* of performing \( N \) noncoherent integrations instead of \( N \) coherent integrations has been expressed as:

\[
L_{NCD} = f(N, P_d, P_{fa})
\]

- \( P_d \) – Probability of Detection
- \( P_{fa} \) – Probability of False Alarm

**Objective:** Propose a similar formula for most suitable differential detector
Part II: Thesis Contributions

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**Sensitivity Characterization of Nonoptimal Detectors**

### Optimal Detector: Coherent Integration exclusively

Through its statistical characterization it is possible to express the required input Signal-to-Noise Ratio (SNR) to achieve a given working point \((P_d, P_{fa})\):

\[
SNR_{in} = f(P_d, P_{fa}, N) = SNR_{in, min}
\]

Theoretical minimum SNR required to achieve target working point.
Nonoptimal Detector: Coherent Integration + Nonoptimal Operation(s)

Given its nonoptimality, the SNR required to achieve the same working point as the optimal detector is higher than $SNR_{in,min}$:

$$SNR_{in,req} (P_d, P_{fa}) > SNR_{in,min} (P_d, P_{fa})$$

The sensitivity loss of the nonoptimal detector can then simply expressed as:

$$L_{detector} = \frac{SNR_{in,req} (P_d, P_{fa})}{SNR_{in,min} (P_d, P_{fa})}$$

From statistical characterization of nonoptimal detector!

From statistical characterization of optimal detector
Part II: Thesis Contributions

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Noncoherent Differential Detector Sensitivity

Noncoherent Differential Detector (NCDD)
- Most appropriate differential detector for GNSS applications

NCDD sensitivity loss: combination of differential and squaring losses!
- Squaring loss is known from noncoherent integration

How to find the sensitivity loss of differential integration?
- Statistical characterization of differential operation!

Part IIB: Sensitivity Characterization of Differential GNSS Detectors
Noncoherent Differential Detector Sensitivity

Part IIB: Sensitivity Characterization of Differential GNSS Detectors

- Sensitivity Loss of Differential Operation
  - Statistical characterization of differential operation:
    - Apparently « good » fit between theory and simulation results
    - Not good enough to propose a model for the sensitivity loss given the significantly different profile
  - Model proposed based on simulation results exclusively

- Fixed Probability of False Alarm
  - Gaussian Approx. Loss
  - Simulation Loss
  - Polynomial Approximation

  - Theoretical Loss
  - Simulation Loss
  - Proposed Approximation
Noncoherent Differential Detector Sensitivity

Part IIB: Sensitivity Characterization of Differential GNSS Detectors

- **Sensitivity Loss of NCDD Detector**

  - Mathematical « subtility » to extend proposed model from \( I \) to \( N \) differential integrations

  - Proposed formula includes all targeted parameters:
    \[
    L_{NCDD} = f(N, P_d, P_{fa})
    \]
    \[
    \approx 1 + \frac{0.2 \cdot (N + 1)}{SNR_{diff}} + \frac{0.45 \cdot \sqrt[3]{(N + 1)}}{\sqrt[3]{SNR_{diff}}}
    \]
    \[
    SNR_{diff} = f(P_d, P_{fa})
    \]

  - Simulation analyses show **very good fit** of proposed formula in predicting NCDD sensitivity

![Graph showing sensitivity loss with number of differential integrations]
Part II: Thesis Contributions

Part IIB: Sensitivity Characterization of Differential GNSS Detectors

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The proposed formula allows the objective of comparison of the NCDD with the Noncoherent Detector (NCD)

**Example:** Sensitivity loss of NCDD and NCD detectors for \((P_d, P_{fa}) = (0.9, 1E-5)\)

- Examples of application of proposed formula described in the thesis
- Theoretical conclusions validated by acquisition of real GPS data
- In case of medium- or high-dynamics, NCD shown to be more robust than NCDD
Part II: Thesis Contributions

**Part IIB:** Sensitivity Characterization of Differential GNSS Detectors

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5. Conclusion
Given **limitations of coherent integration**, transition to **postcoherent integration** is typical for acquiring weak signals

- **Noncoherent integration** - standard and well-characterized technique
- **Differential integration** - still required full characterization

Theoretical and simulation results enabled proposal of a formula for the **sensitivity characterization of the NCDD detector**

The objective of formal comparison between the **NCDD** and the **NCD detectors** can now be conducted
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GNSS – Global Navigation Satellite System
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Part IIC: Systematic and Efficient Collective Acquisition of Multi-Constellation GNSS Signals

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3. Hybridization with Sequential Acquisition
4. Multi-Constellation Collective Acquisition
5. Conclusions
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5. Conclusions
GNSS signals are usually acquired independently from one another.

New acquisition techniques (**combined acquisition**) recently developed in which signals are **combined to improve overall acquisition sensitivity**.

**New Approach: Collective Detection / Collective Acquisition**

| Individual satellites (2D) code phase and Doppler search | User (4D) position and clock bias domain |

**Objective:** Acquire all visible satellites at the same time (collectively)
**Introduction**

- **Collective Detection principle:** estimate signal code phases based on candidate position and clock bias

- Doppler offset can be removed to a great extent through Assistance information

\[ SV \text{ code phase} = f(\text{position, bias}) \]
**Introduction**

- Biggest drawback in Collective Detection → **Complexity**

**Example search grid found in literature [Axelrad 2011]**

<table>
<thead>
<tr>
<th>Item</th>
<th>Rough (m)</th>
<th>Medium (m)</th>
<th>Fine (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North/East</td>
<td>±10.000</td>
<td>±2.000</td>
<td>±900</td>
</tr>
<tr>
<td>North/East Step</td>
<td>1.000</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>Clock Bias</td>
<td>±150.000</td>
<td>±1.200</td>
<td>±300</td>
</tr>
<tr>
<td>Clock Bias Step</td>
<td>1.000</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td>Number of Points</td>
<td>132.741</td>
<td>42.025</td>
<td>182.329</td>
</tr>
</tbody>
</table>

- Search grid impacts not only **complexity** but also **sensitivity**!

**First Objective:** Propose a methodology for the **systematic and efficient application of Collective Detection**

- **Systematic** – Search steps are determined by a set of input parameters
- **Efficient** – Avoid excessively fine and computationally heavy search grids
Part II: Thesis Contributions

Part IIC: Systematic and Efficient Collective Acquisition of Multi-Constellation GNSS Signals

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Systematic and Efficient Collective Acquisition

How to ensure a Systematic and Efficient Collective Detection search process?

Satellite code phase is function of:
1. User position  
2. User clock bias

Satellite code phase search resolution is function of:
1. User position search resolution  
2. User clock bias search resolution

The inverse is also applicable!

Maximum allowable code phase estimation error

Position search step  
Clock bias search step
Proposed Approach: redefinition of horizontal search from North-East to Rho-Theta coordinates

Maximum allowable code phase estimation error, $\beta$

Radius search step $\delta R = f(\beta, w_{position})$

Angular search step $\delta \theta = f(\beta, w_{position})$

Clock bias search step $\delta B = f(\beta, w_{bias})$

More intuitive
Simplifies mathematics involved
The lower the maximum allowable code phase estimation error is…

… the higher the number of search points to consider!

1. Iterative search process
2. Code phases considered are a range around the central code phase

First Iteration

$\beta_0$ – initial maximum tolerable code phase estimation error

Candidate code phase

Total Uncertainty: 2046 code phases
The **lower** the maximum allowable code phase estimation error is…

… the **higher** the number of search points to consider!

1. Iterative search process
2. Code phases considered are a range around the central code phase

Second Iteration

\[ \beta_1 = \beta_0 / \text{division factor} \]
Systematic and Efficient Collective Acquisition

Part IIC: Systematic and Efficient Collective Acquisition of Multi-GNSS

- The **lower** the maximum allowable code phase estimation error is…
  
  … the **higher** the number of search points to consider!

1. Iterative search process
2. Code phases considered are a range around the central code phase

Third Iteration

\[ \beta_2 = \beta_1 / \text{division factor} \]

![Graph showing Code phases](image)

**Candidate code phase**

Total Uncertainty: 40 code phases

400 380 420

\[ \beta_2 \]

\[ x \times 10^{-9} \]
Example of application

- 6 nominal power satellites
- True user position: \((\Delta N, \Delta E) = (-4000, 7000)\)
- Radial uncertainty: 10 km
- \(\beta_0 = 5\) chips, \(\beta_i = \beta_{i-1} / 10\)
- 3 iterations

<table>
<thead>
<tr>
<th>Iteration</th>
<th>Number of search points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>44330</td>
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Example of application

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<td>44330</td>
</tr>
<tr>
<td>2</td>
<td>3500</td>
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<td>44330</td>
</tr>
<tr>
<td>2</td>
<td>3500</td>
</tr>
<tr>
<td>3</td>
<td>3500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>52030</strong></td>
</tr>
</tbody>
</table>

1+ orders of magnitude more efficient than fixed step search grids found in literature
Part II: Thesis Contributions

Part IIC: Systematic and Efficient Collective Acquisition of Multi-Constellation GNSS Signals

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Hybridization with Sequential Acquisition

**Part IIC: Systematic and Efficient Collective Acquisition of Multi-GNSS**

Collective Detection is intended for acquisition of weak signals

> In the visible satellite set both strong and weak signals may exist!

**How to profit from strong signals presence in Collective Detection?**

1. **Reduce search dimensions** (in particular clock bias)
2. **Establish dependency between search dimensions**

<table>
<thead>
<tr>
<th>No strong satellites</th>
<th>1 strong satellite</th>
<th>2 strong satellites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clock bias (full)</td>
<td>Clock bias (reduced)</td>
<td>Clock bias</td>
</tr>
<tr>
<td>Azimuth</td>
<td>Azimuth</td>
<td>Azimuth</td>
</tr>
<tr>
<td>Radius</td>
<td>Radius</td>
<td>Radius</td>
</tr>
<tr>
<td></td>
<td>f(x)</td>
<td>f(x)</td>
</tr>
</tbody>
</table>

Enhanced sensitivity and complexity (depending on algorithm parameters)
Part II: Thesis Contributions

Part IIC: Systematic and Efficient Collective Acquisition of Multi-Constellation GNSS Signals

Contents:

1. Introduction
2. Systematic and Efficient Collective Acquisition
3. Hybridization with Sequential Acquisition
4. Multi-Constellation Collective Acquisition
5. Conclusions
Multi-Constellation Collective Acquisition

- GNSS systems are not limited to GPS!

**How to adapt Collective Detection for multi-constellation GNSS signals?**

- Multi-Constellation Collective Detection considerations
  - Time offset between constellations
  - Difference in code lengths
  - Difference in clock bias magnitude

- Development of proposals to handle these issues in a combined GPS and Galileo context

- Preliminary results *not very promising* but further assessments are required
Preliminary assessments carried on Indoor data collection

- Combined GPS+Galileo (1)
- Combined GPS+Galileo (2)
- GPS-Only
Part II: Thesis Contributions

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Conclusions

- Collective Detection is an innovative approach capable of improving GNSS signal acquisition sensitivity

- **Biggest drawback** in Collective Detection is the **computational complexity** of approaches found in literature

- A methodology for the **Systematic and Efficient** application of Collective Detection has been proposed

- **Hybridization with sequential acquisition** has also been addressed and shown as capable of **improving sensitivity and complexity** of Collective Detection

- The application of Collective Detection in a **multi-constellation GNSS receiver** has also been addressed with the acquisition of both real **GPS** and **Galileo** signals
I. Introduction to GNSS and Signal Acquisition

II. Thesis Contributions
   A. Analysis and Compensation of Doppler Effect
   B. Characterization of Differential Detectors
   C. Multi-Constellation Collective Acquisition

III. Conclusions and Future Work

GNSS – Global Navigation Satellite System
**Conclusions**

- **High-sensitivity GNSS acquisition** is necessary to fulfill current user expectations.
- A thorough **state-of-the-art review** allowed identifying possible axes of research.
- In this thesis **three different aspects** of high-sensitivity GNSS acquisition were considered for improvement:
  1. **Analysis and Compensation of Doppler effect**
     - Low, Medium, and High-dynamics
  2. **Sensitivity Characterization of Differential Detectors**
  3. **Systematic and Efficient multi-constellation Collective Detection**
- Solutions were proposed for enhancing the overall acquisition process keeping in mind the key **sensitivity-complexity trade-off**.
Future Work Recommendations

**Doppler**
- Dynamic scenarios analysis carried only with linearly changing Doppler and not validated with real data
- More complete research of Doppler change rate estimators is required for high-dynamics scenario

**Differential**
- Analysis carried assumes that data bit effect is aptly mitigated which is not necessarily the case

**Collective Detection**
- Complementary study required for assessing best parameters for tuning the proposed methodology
- More analysis required to assess true potential of Collective Detection for Indoor scenarios in a multi-constellation receiver context
Published Works

5 conference articles:

✓ Sahmoudi, M., Esteves, P. et al. – ION GNSS 2011
✓ Esteves, P., Sahmoudi, M. et al. – ENC 2013  Best student presentation award
✓ Esteves, P. – ION GNSS 2013  Best student paper award
✓ Esteves, P., Sahmoudi, M. et al. – SIGNALS 2013

1 journal article (accepted, under second revision):


1 magazine article (to be published in next issue):

Thank you!

Questions?