Digital signal processing for satellite-based positioning

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Current group members: 5 PhD students and 2 MSc students (size of the group is about 9% of DCE total number of MSc/PhD students)

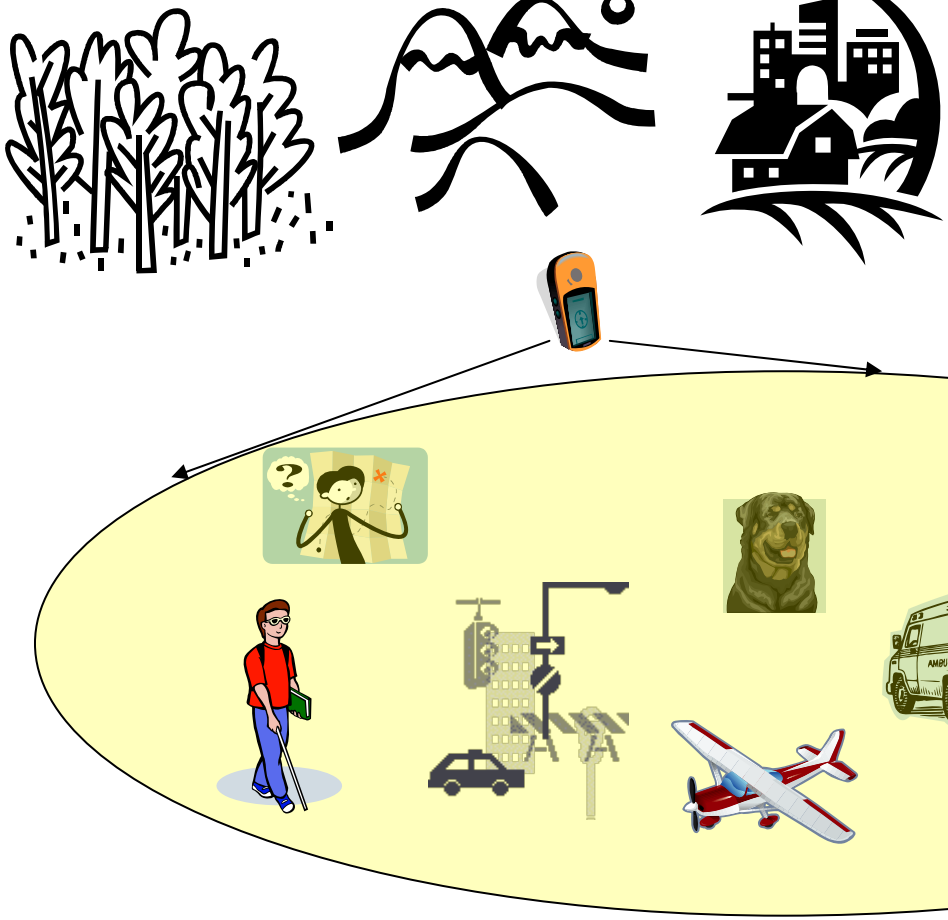
Background

- GNSS related positioning activities have started at DCE since 2003
- Previously: WCDMA/UMTS-based positioning studies (partly funded by Nokia)
- Main goals:
  - signal acquisition and tracking in multipath fading environments
  - design of low-cost low-power receiver architectures
  - indoor channel modeling (based on measurement data)
  - Pseudolite (pseudo-satellites)–based positioning
- Motivation:
  - Emergency location rules (FCC 911, E-112)
  - Development of Galileo (future European GNSS system)
  - Increasing penetration rate of 3G mobile phones -> A-GNSS
- Current funding: Tekes (Finnish funding agency for research and innovation), Academy of Finland, and TISE graduate school (another EU-FP6 GSA-funded European project just ended; pending application for its continuation within EU FP7)

Co-operation

- Local co-operation with the Department of Digital and Computer Systems, TUT and with the Department of Mathematics, TUT (positioning-related research).
- Finnish co-operation with the companies within Tekes projects (Atheros Communications, Elektrobit, Fastrax, Kalmar Industries, Patria Aviation, Space Systems Finland, and VTI Technologies)
- International co-operation with the partners in the EU GSA-funded project Galileo receivers for mass market applications ”GREAT” (Acorde Spain, DLR Germany, PA Consulting, Qualcomm Germany, and u-Blox Switzerland). Additionally: co-operation with NavSas group,Torino, Italy through exchange students.
- Summer course organized on positioning in 2006, together with Associate Professor Ridha Hamila from Etisalat University College (UAE)
- Active participation in international GNSS-related conferences

Research challenges & applications



Challenges (signal level):

-Low CNRs (especially indoors and in dense urban areas)

-Multipath propagation and fading (diffraction, reflections, refractions, scattering)

-Non-existent Line Of Sight

-Ambiguities in Galileo acquisition and tracking (due to modulation waveforms)

Applications:

-Emergency calls

-Map location, in-car navigation

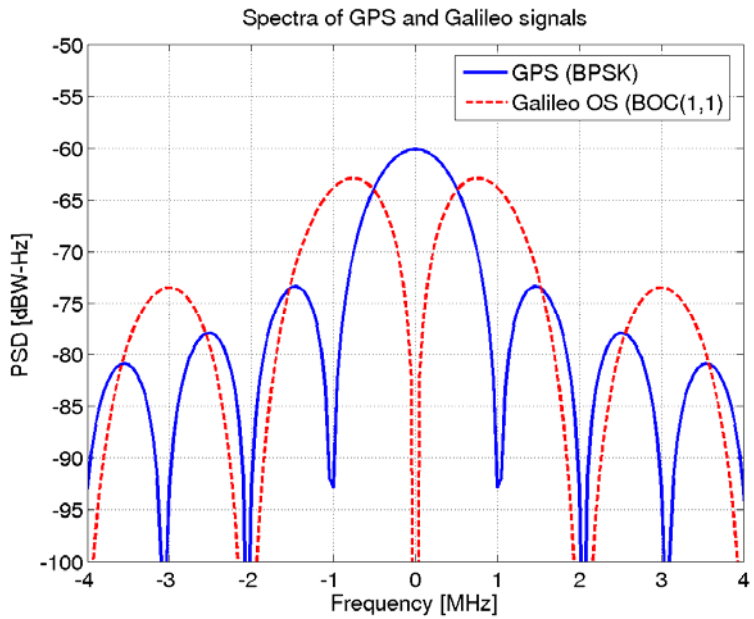
-Tag-based location (lost children, pets,…)

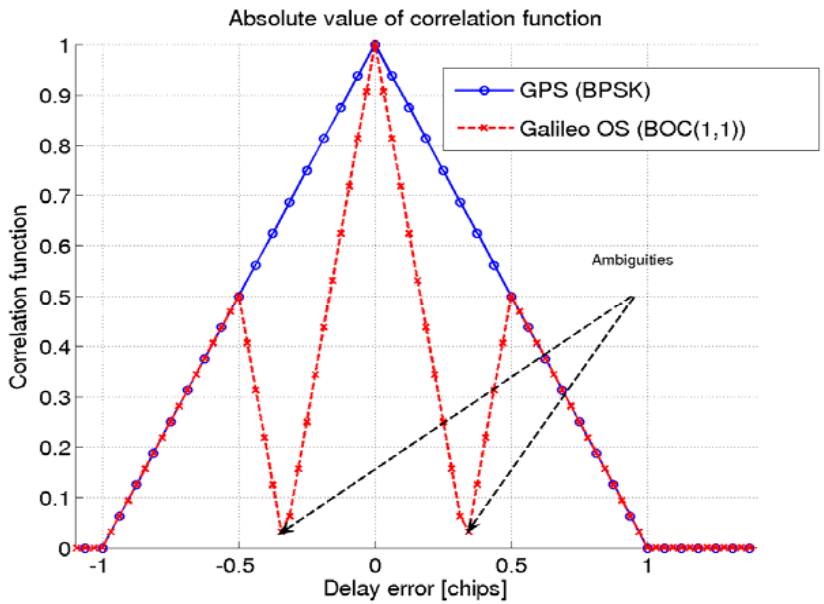
-Safety of Life applications (maritime/ air)

- Logistics, etc

Galileo signal structure

- Binary Offset Carrier (BOC) modulation – better separation with GPS signals (see the spectra in the left figure). Correlation envelopes and ambiguities are visible in the right figure:





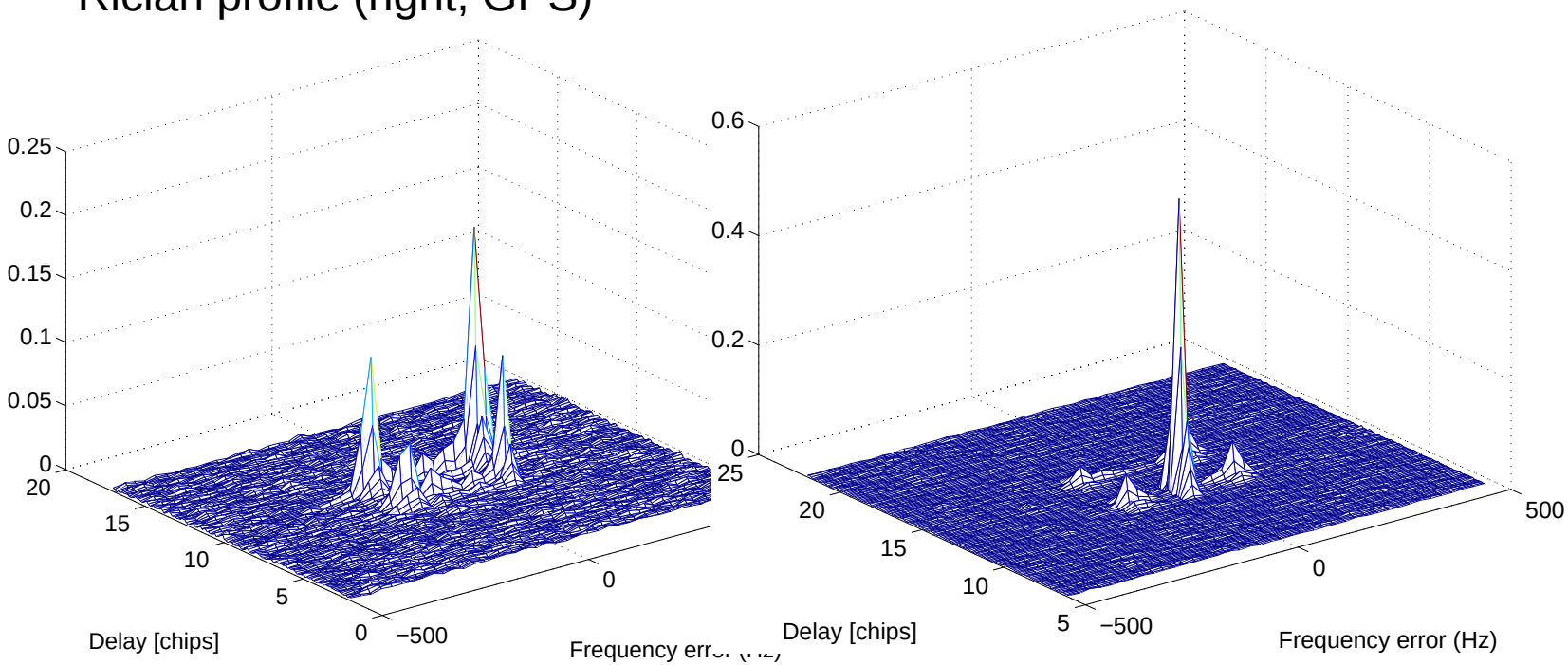
- 4092 chip lengths of Open Services (4 times higher than in GPS)
- Pilot codes available for better channel estimation/tracking

Overview of the research topics

- Theoretical studies of modulation waveforms, e.g., Binary Offset Carrier (BOC) modulation
- Delay-Doppler acquisition techniques
- Accurate delay tracking (fine delay estimation) with multipath mitigation
- Filter design and optimization for bandwidth-limited applications
- Data measurements and indoor channel modeling (based on GPS and pseudolite signals)
- CNR estimation studies
- Carrier phase estimators

Delay-Dopler acquisition techniques

- Doppler shift (due to satellite velocity) + Doppler spread (due to terminal velocity)
- Several peaks in time due to multipaths and BOC; several peaks in frequency, e.g., due to Clarke spectrum in Rayleigh fading (left, GPS) or Rician profile (right, GPS)

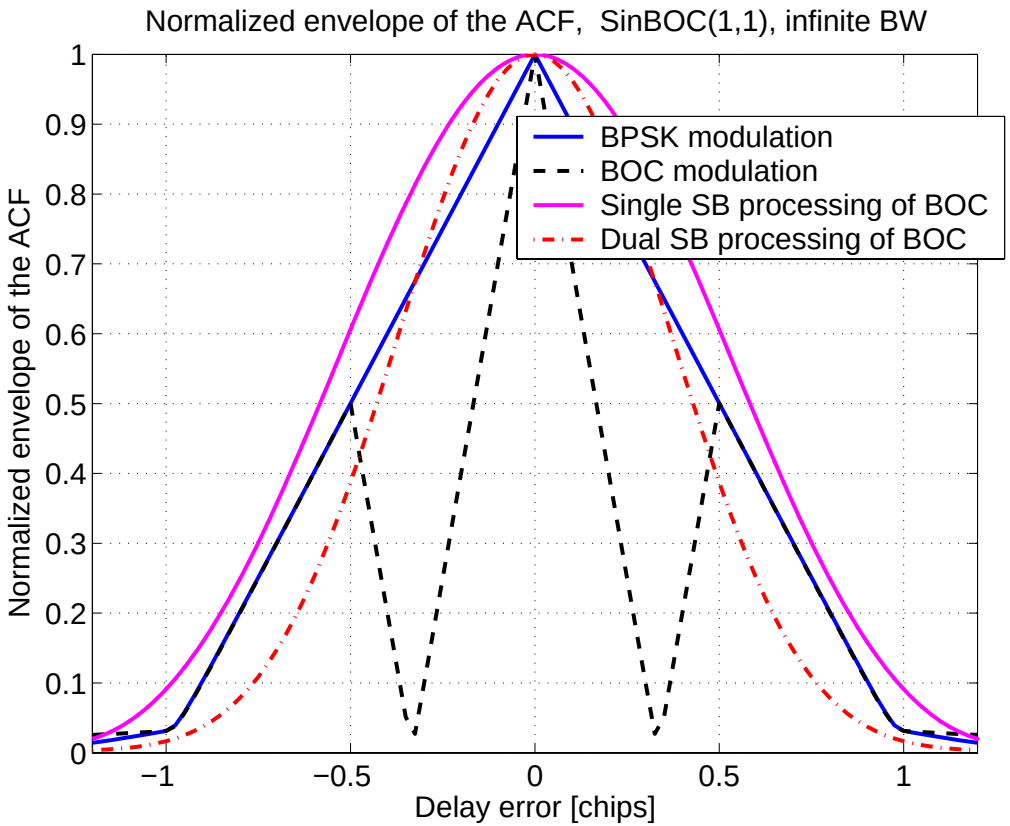


Challenges related to acquisition of GNSS signals

- Time versus frequency–based correlator structures: tradeoff between speed and complexity
- Serial/Hybrid/Parallel search strategies: tradeoff complexity/speed
- Single versus multiple dwells in the decision process
- Unambiguous BOC processing to deal with BOC ambiguities
- Theoretical models for time-to-first fix and for detection/false alarm probabilities

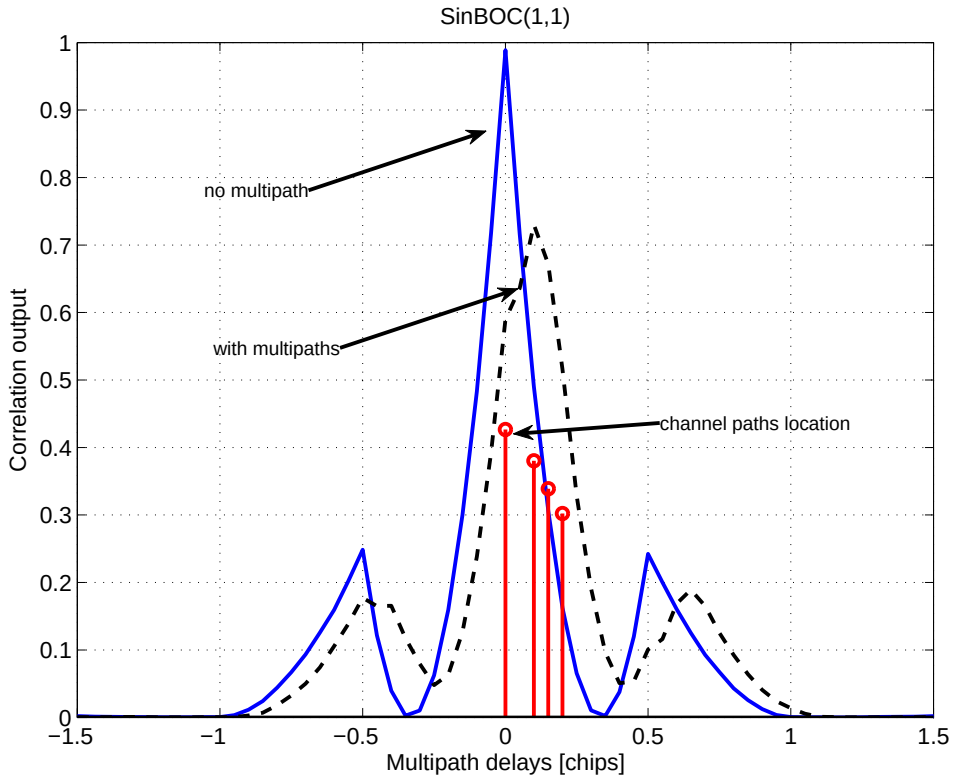
Unambiguous acquisition

- Several methods have been studied, based on single or double sideband processing or based on filter banks
- An illustrative shape of the absolute value of the correlation function (ACF) before and after unambiguous processing is shown below:



Accurate delay tracking in multipath environments – illustration of the problem

- Examples of correlation shapes in multipath presence. SinBOC(1,1) modulation (Galileo)



Accurate delay tracking in multipath environments

- Feedback versus feed-forward delay trackers (or a combination of both)?
- Several algorithms have been studied and several solutions have been proposed so far, including Sidelobe cancellation techniques, Multiple Gate Delay structures (tested also via hardware prototyping), deconvolution algorithms and various non-linear structures
- On-going studies to include carrier-aided delay tracking

Channel modeling based on measurement data

- Several campaigns based on GPS signals or pseudolite signals have been carried on, with the purpose of modeling the indoor channel for Galileo/GPS reception.
- Measurement campaigns were carried out with the help of Atheros Communications (former u-Nav Microelectronics Finland) and Space System Finland
- Estimation of signal quality and the fading characteristics: these estimates are needed both for acquisition/tracking and for different navigation algorithms.
- On-going studies

Example of measurement set-up, Tietotalo building

Other research topics

- Interference cancellation methods: one MSc thesis completed (narrowband interference);
- Carrier-To-Noise ratio estimation studies (one completed MSc thesis dealing partly with this)
- Simulink models for Galileo signal tracking, based on Multiple Gate Delay structures (one completed MSc thesis)
- Carrier phase estimators

Published results

- 2 completed PhD theses + 1 in writing phase
- 6 completed MSc theses
- 15 journal papers, about 50 conference papers
- Complete list of publications and group webpage can be found as links from:

http://www.cs.tut.fi/~simona

Conclusions

- We have been mainly focusing on signal processing aspects of satellite positioning
- No full navigation solution: we aim at giving informative models (delay error distributions, CNR variation, achievable accuracy in various scenarios, etc) for the navigation purposes (RAIM, navigation sensor integration, etc)
- Also, hardware implementation and prototyping is beyond our scope, but joint work with HW team has been done and some of the proposed multipath mitigation algorithms have been tested in FPGA and SystemC.
- **Interesting co-operation areas**:
  - Both GNSS-based positioning and cellular-based positioning; possibility to move towards other promising positioning areas (e.g., WLAN, UWB, ...)
  - Signal processing
  - Navigation layer (feeding our algorithms into navigation software)
  - Hardware (FPGA; prototyping)
  - Applications (?)