

Performance Analysis and Simulation

- Analysis of existing and new navigation systems, services and related technologies through
 - Evaluation of the system performance
 - Assessment of user requirements
 - Evolution of existing concepts
- Work focused on Galileo but is applicable to other systems and applications
- Provide expertise and consulting covering a large range of PNT topics



System and Service Volume Simulation Environment

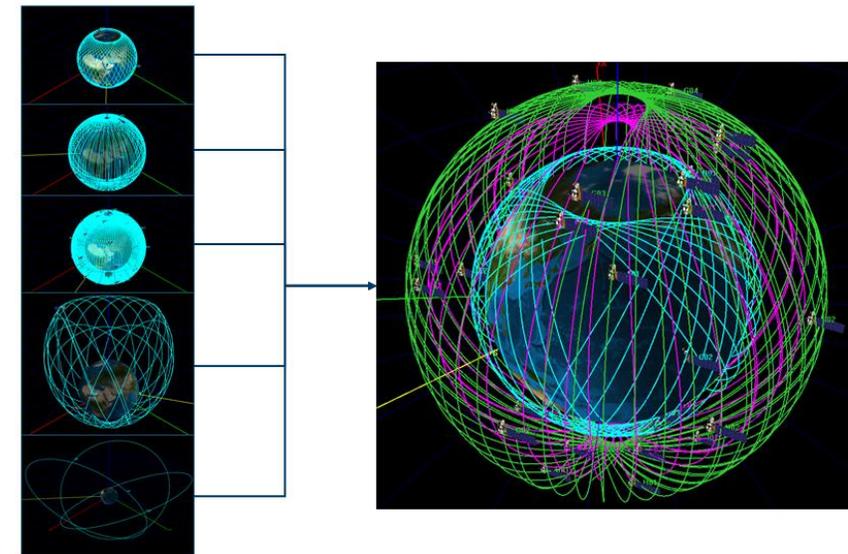
- Modular and flexible simulation and performance analysis tool for the space, ground and user segment
- Reproduction, analysis and study of current and future GNSS structures and operational scenarios
- Evaluation of the system performance under different conditions and influencing factors (constellations, propagation effects, technologies, ...)



Constellation Generation & Analysis

- A continuously increasing number of satellites as well as existing and planned constellations creates the demand for analysis of constellations
- Current work concentrates on the evaluation of planned LEO PNT constellations
 - As standalone system
 - As augmentation of existing GNSS
- S²VSE has the capability to rapidly generate single- or multi-layer constellations
- Analysis encompasses the performance of the system as well as the resulting impact on the user

Constellation Frameworks
Walker Delta
Walker Star
Street of Coverage
Flower
Drain



Constellation Design Search Space



- A LEO satellites position can be described by using six Kepler elements
- This would create 11.56 trillion (1.16×10^{13}) possible positions for one satellite
- The search space could be limited by further constraints to the minimum and maximum values or a reduction of granularity for the steps
- For a constellation of 400 satellites this would mean a total search space of 10^{5200} possible combinations

Parameter	Min	Max	Steps
Altitude	400	2000	17
Eccentricity	0	0.8	81
Inclination	0	179	180
RAAN	0	359	360
Argument of Perigee	0	359	360
True Anomaly	0	359	360

Constellation Design Search Space Reduction

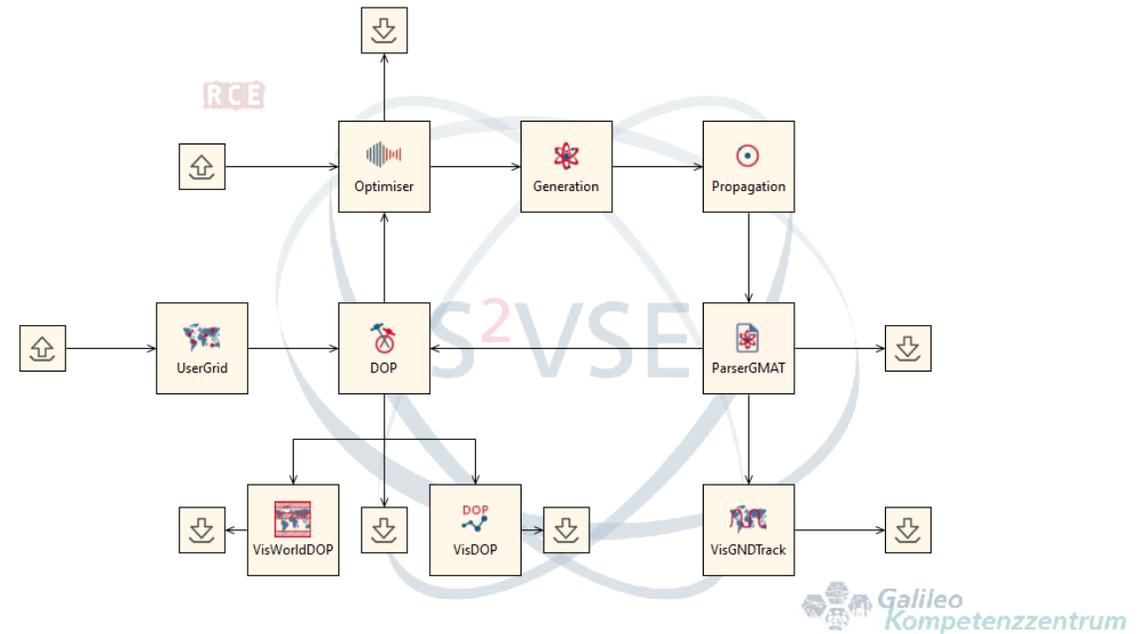


- To reduce the search space to a reasonable number constellation frameworks like Walker Delta can be used
- Instead of describing each satellite individually they describe the relations between them
- Steps for the number of planes are defined by possible divisors leading to whole numbers
- This will lead to 4.59 million (4.59×10^6) possible combinations in case of 400 satellites
- If the number of satellites is not fixed the search space again becomes much larger going into the hundreds of millions (906.4×10^6)

Parameter	Min	Max	Steps
Number of Satellites	400	400	1
Number of Planes	1	400	15
Altitude	400	2000	17
Inclination	0	179	180
Phasing	0	P-1	100

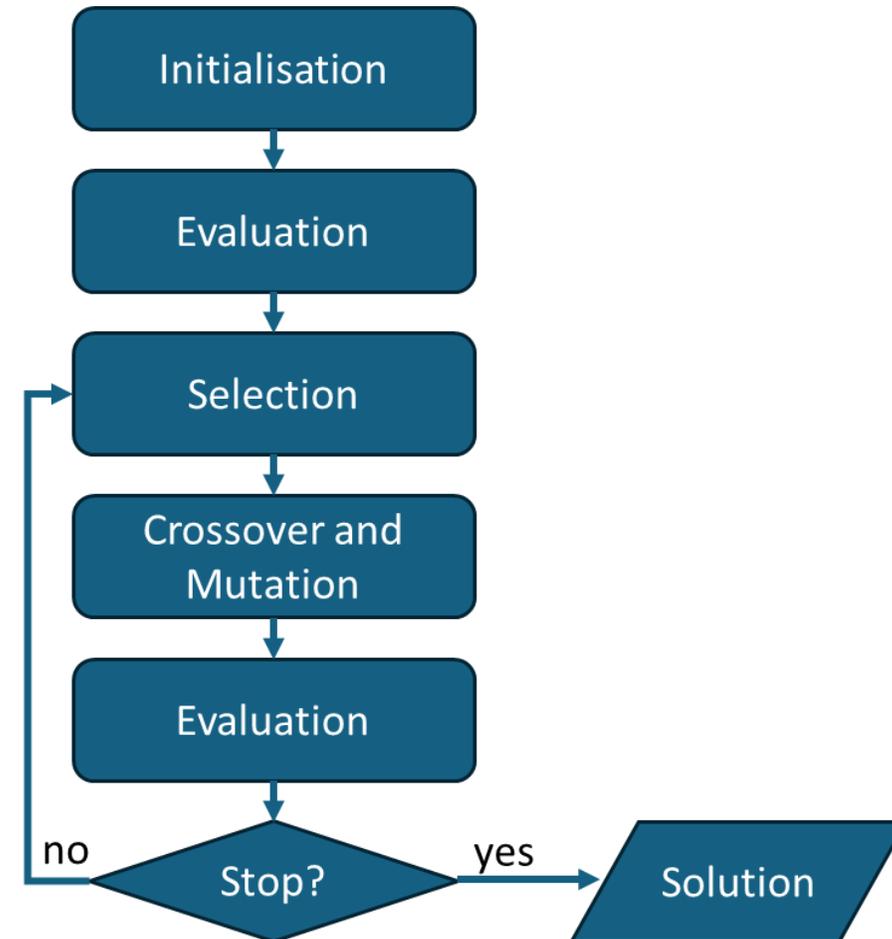
Constellation Optimisation

- Optimisation of constellations via the use of genetic algorithms:
 - non-dominated sorting genetic algorithm 2/3 (NSGA-II/III)
 - strength pareto evolutionary algorithm 2 (SPEA-II)
- Objectives for optimisation:
 - Dilution of precision (DOP)
 - Global or regional depth of coverage (DOC)
 - Visibility
 - Revisit-time
 - Reduction of number of satellites
 - Constellation cost



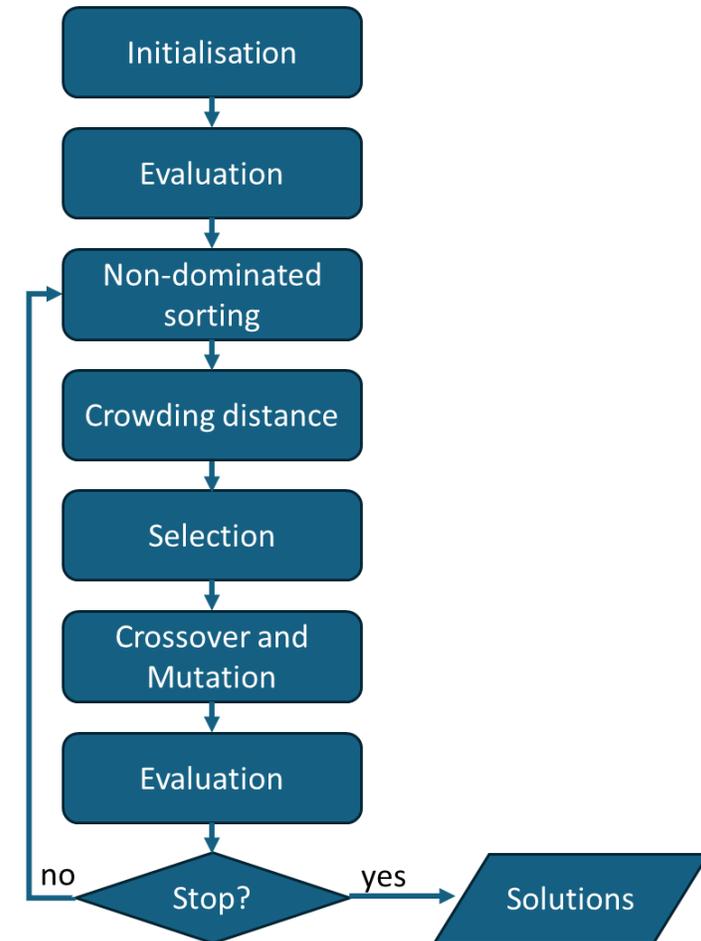
Evolutionary Optimisation

- Generalised heuristic techniques to approximate solutions for non-differentiable and/or expensive optimisation problems
- A category of optimisation methods inspired by the process of natural evolution
- Require the definition of:
 - A method to generate initial solution(s)
 - Transition or generation function(s) to build new solutions based on previous ones
 - An objective function to evaluate solutions
 - A stopping criterion, e.g. reaching a quality threshold or a time limit
- Stochastic methods, so results vary between executions



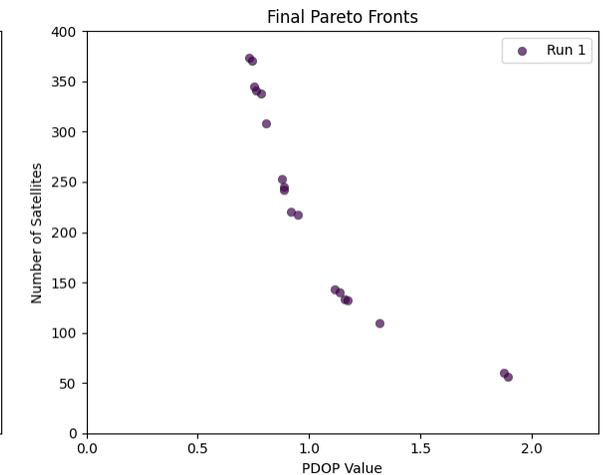
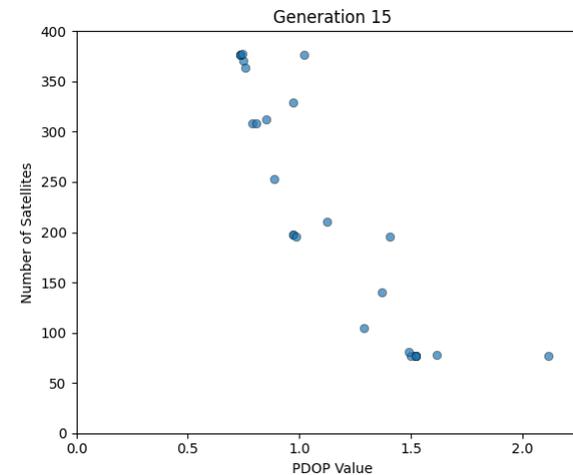
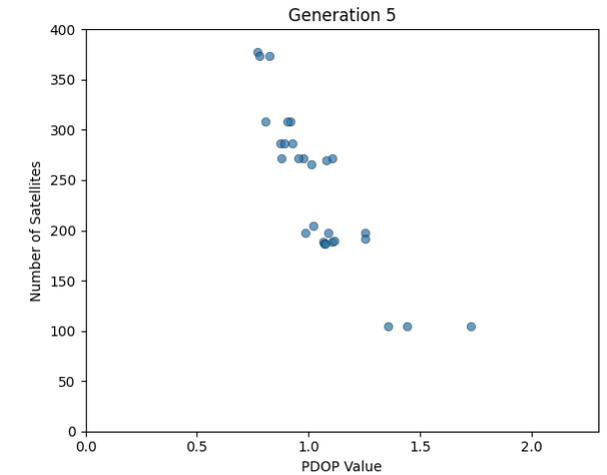
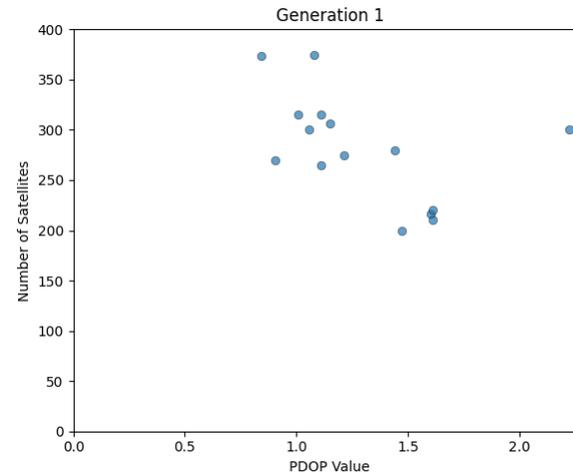
NSGA-II Algorithm Overview

- Non-dominated Sorting Genetic Algorithm II (Deb et al. 2002)
 - Fast non-dominated sorting to rank solutions
 - Crowding distance to maintain diversity
 - Best solutions are usually preserved across generations (elitism)
- Can be adapted to various different optimisation problems by choosing appropriate operators for crossover and mutation
- Many different improvement strategies available for complex problems



Evolutionary Multiobjective Optimisation

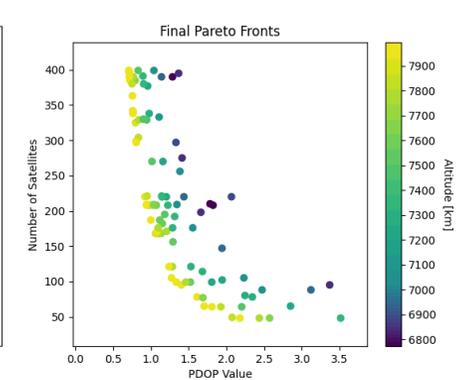
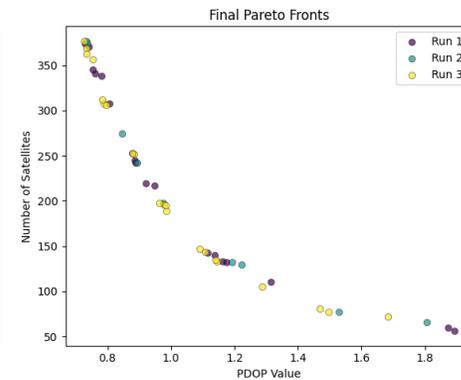
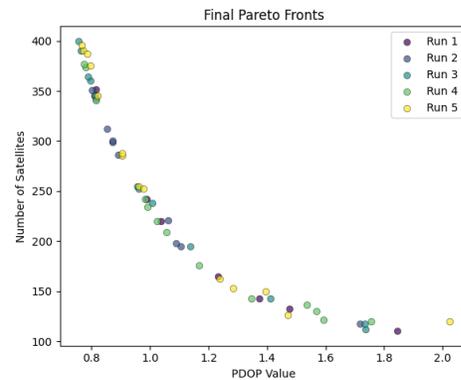
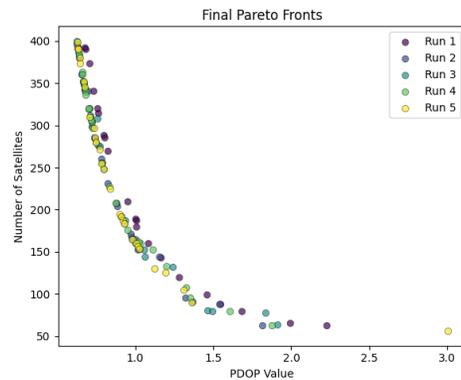
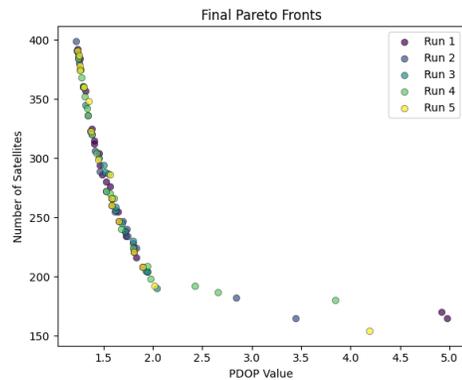
- Simultaneous optimisation of different, potentially conflicting goals:
 - Combine different objectives into a weighted sum
 - Search for a set of solutions with different trade-offs compared by Pareto dominance
- Pareto dominance:
 - Pareto dominance: solution is better in at least one objective and not worse in any other
 - Pareto optimal solution: no objective can be improved without degradation of another
 - Pareto front: objective values of set non-dominated solutions that present optimal trade-offs
- Decisions regarding trade-offs and preferred solutions can be made after optimisation



Initial Optimisation Results

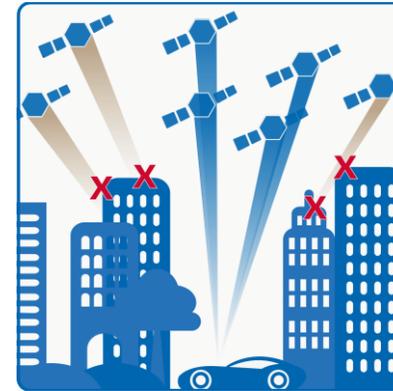


One station	One station	Five stations	Five stations	Five stations
Europe	Europe	Globally distributed at 0 and +90° on the Equator and at +-70° Latitude	Globally distributed at 0 and +90° on the Equator and at +-70° Latitude	Globally distributed at 0 and +90° on the Equator and at +-70° Latitude
<ul style="list-style-type: none"> Fixed altitude at 400km 	<ul style="list-style-type: none"> Variable altitudes 400km – 2000km 	<ul style="list-style-type: none"> Variable altitudes 	<ul style="list-style-type: none"> Variable altitudes Galileo like constellation at MEO 	<ul style="list-style-type: none"> Variable altitudes Galileo like constellation Optimisation prioritising lower altitudes



Impact of User Environments on Satellite Systems

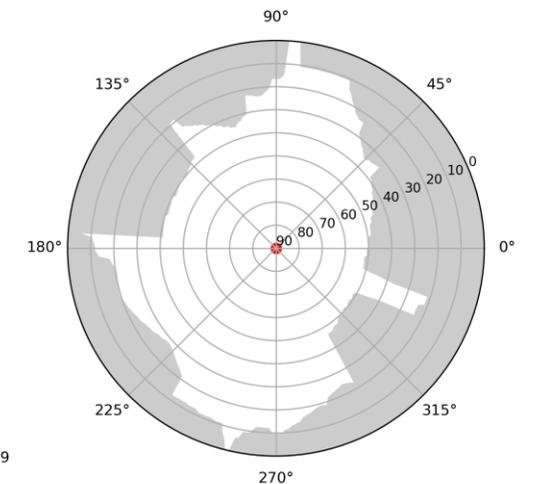
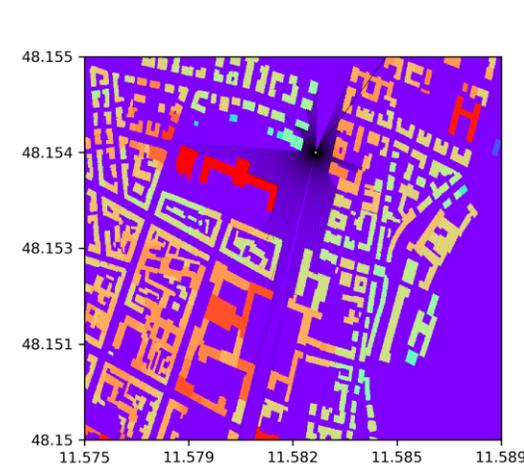
- Satellite systems experience reduced functionality in obstructed environments
- Obstructions can be natural like trees and canyons or man made in the form of buildings and so called urban canyons
- S²VSE includes a Digital Surface Module which can extract data from different open data sources to create virtual user environments for evaluation
- The module combines natural environments (e.g. trees) with street layouts and buildings heights and then calculates possible signal obstructions due to Non Line of Sight (NLOS)



Spatial Location of Receiver and LOS Obstructions



Skyplot - Elevation angle [°]



Next Steps & Publication



- Next Steps:
 - Expansion to different genetic algorithm implementations
 - Further tuning of parameters and operator selection
 - Different representations and optimisation approaches for multi layer systems
 - Incorporation and evaluation of additional objectives
 - Expansion of study use cases regarding suburban to deep urban user environments
- Publications:
 - Satellite Navigation Constellation Optimisation Problem Definition for the Application of Genetic Algorithms (ICINCO 25)

Satellite Navigation Constellation Optimisation Problem Definition for the Application of Genetic Algorithms

Paula Piñeiro Ramos¹, Sebastian Bernhardt¹, Helena Stegherr² and Jörg Hähner²

¹DLR Galileo Competence Center, Oberpfaffenhofen, Germany

²Universität Augsburg, Augsburg, Germany

{paula.pineiroramos, sebastian.bernhardt}@dlr.de, {helena.stegherr, joerg.haehner}@uni-a.de

Keywords: Constellation Optimisation, Evolutionary Algorithms, GNSS, LEO-PNT, Multi-Objective Optimisation, Navigation, Problem Characterisation

Abstract: Global Navigation Satellite Systems (GNSS) are used on a daily basis, providing Positioning, Navigation and Timing (PNT) services for various applications ranging from smartphones over the financial sector up to areas such as aviation and space. Classical GNSS constellations positioned in Medium Earth Orbit (MEO) often experience reduced performance in areas of low visibility like forests and cities. To rectify this, augmentation constellations are deployed, improving the provided positioning accuracy. Recent proposals for augmentation systems have often been based in Low Earth Orbit (LEO), which, for global coverage, require a large number of satellites and are incredibly complex to design due to dependencies, coverage requirements and the large search space. This makes the constellation design problem well-suited for applying Genetic Algorithms (GA) to find an optimal solution. However, previous research has only addressed highly constrained versions of the problem. This paper presents an approach for applying GAs to constellation design with a large search space. In particular, the focus is on the description of the multi-objective fitness function and the simulation necessary for its evaluation, options for the solution encoding, and a discussion of algorithmic features applicable in this scenario.

