Differential GPS

Principle of DGPS operation

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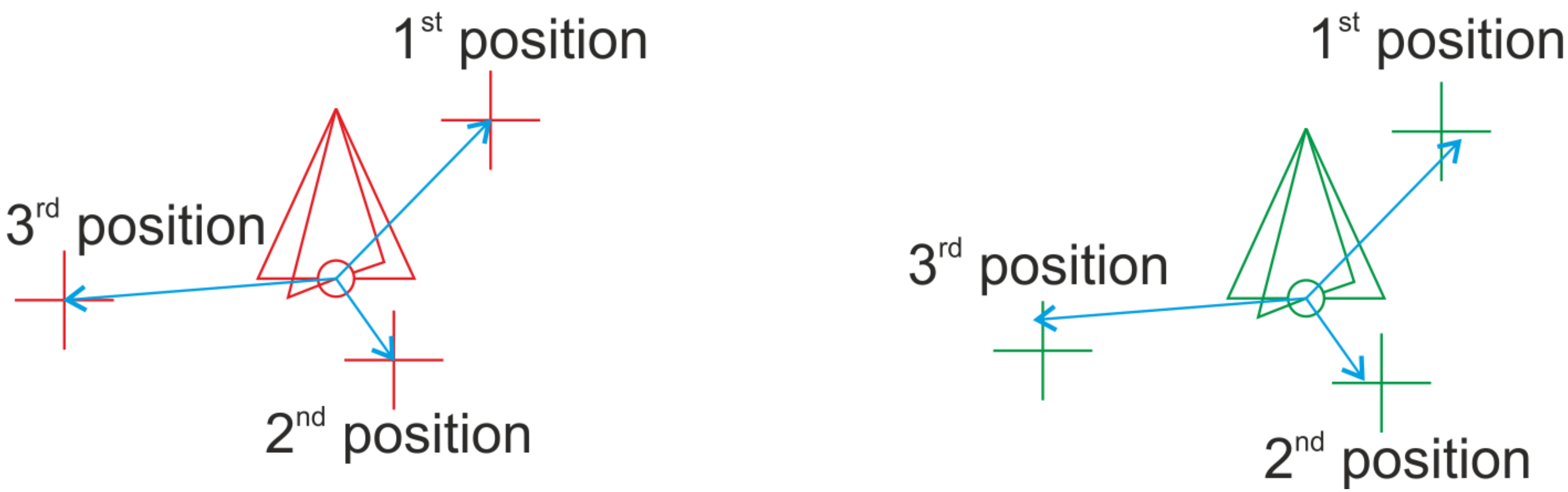
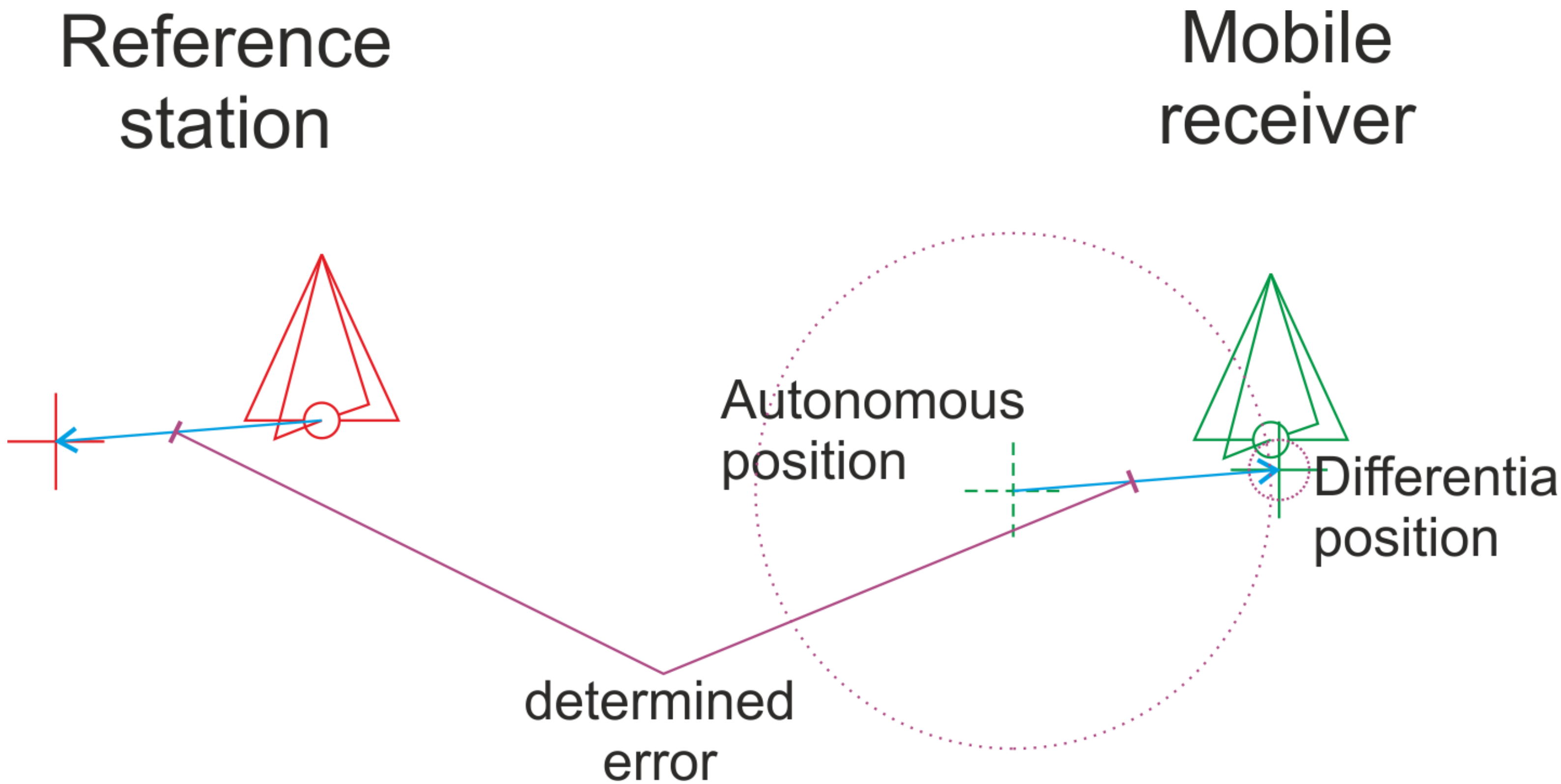
DGPS idea

During tests of GPS in early 80’s was demonstrated, that positions errors occurred into two close by receivers were correlated



DGPS idea

Therefore errors measured in one receiver which position is well known (reference station), can be used to improve accuracy another one (mobile) which position is unknown



DGPS idea

Many limitations occurring when using GPS receivers only may be removed by performing differential measurements. They can be implemented:

- introduction of corrections to the receiver in real time, provided by a parallel-working GPS receiver with known antenna coordinates, transmitted, for example, via radio,
- correction by a posteriori program developing the results of measurements made using a pair of receivers: a mobile one and a base one (with known antenna coordinates).

GPS errors

In the beginning of GPS availability for civil use it occured that accuracy of position is not good enough especially when approaching airports (landing), sailing on constrained water areas, fairways, port entries etc. Mostly because of SA (selective availability)

GPS error compensated by DGPS:

- Satellite error
  - Satellite's clock errors
    Despite of equipment the satellites with very accurate atomic clocks they are not perfect. The slight inaccuracies in their timekeeping and relativistic effects ultimately lead to inaccuracies of pseudo-range measurement.
  - Ephemeris errors
    Perturbative forces cause drift of satellites from their predicted orbits. The wrong positions of satellites, as a start points for a receiver position calculation, make an impact for position accuracy.

GPS errors

- Atmosphere errors
  radio signals traveled with constant speed of light only in vacuum. In every other medium the speed is lower and depends on its properties. The civil receivers add in a correction factors for a typical trip through Earth's atmospheric layers. Unfortunately the atmosphere varies in time and from point to point, therefore any model of atmosphere can not accurately compensates for delays, that actually occur in:
  - Troposphere
  - Ionosphere
- SA (selective availability)
  to 2000 the biggest error up to 30 m. Introduced intentionally by Department of Defense in order to ensure no hostile act using GPS accuracy against US or its allies.
  SA algorithm had been inserting some noise into satellites' clocks and slightly erroneous orbital data.

GPS errors

GPS errors uncompensated by DGPS

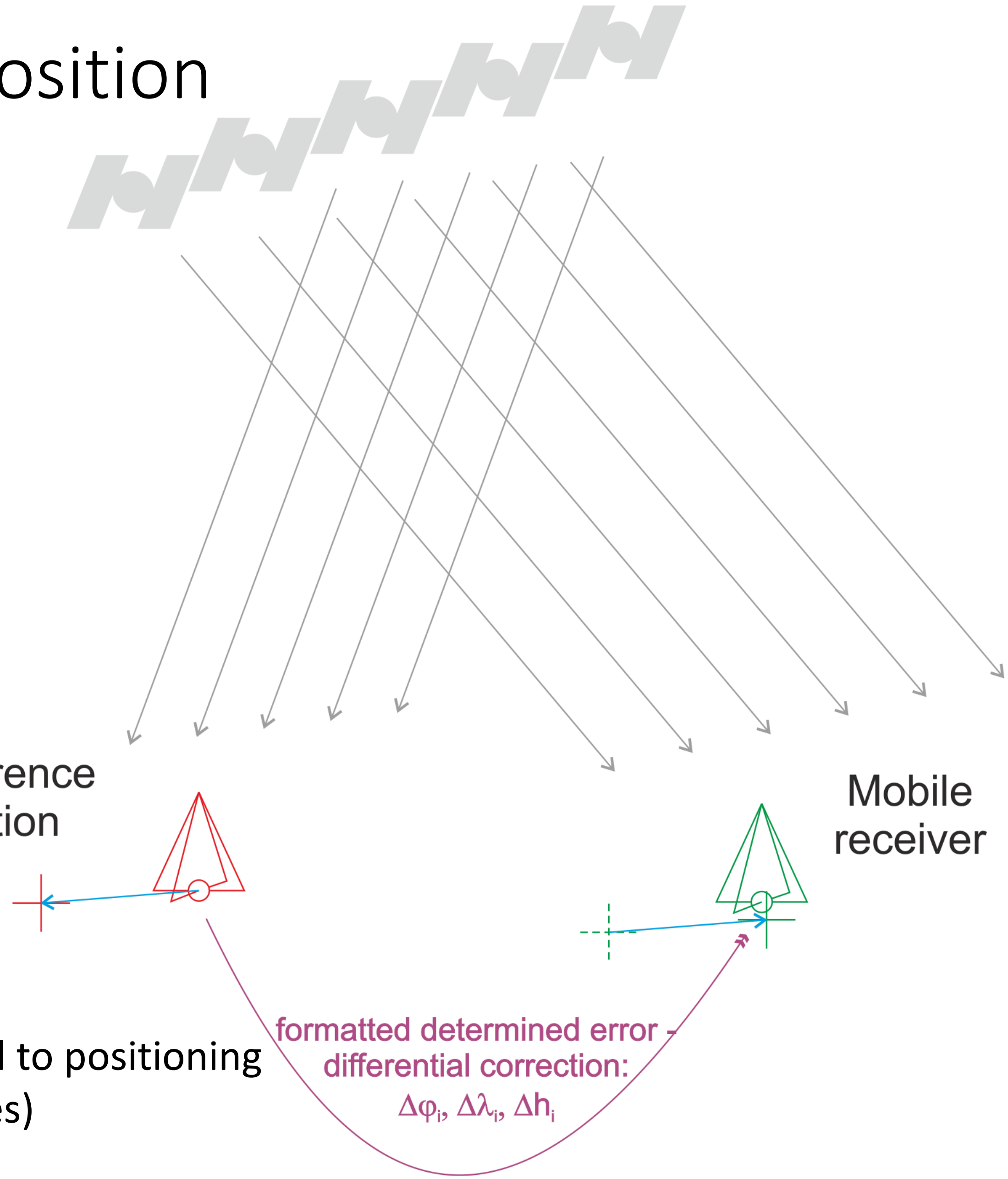
- Multipath errors
  satellite signal before arrives at receiver's antenna may reflects off local obstructions. In this case may cause a delay or interference with direct satellite signal giving noisy results.
- Receiver error
  receivers introduce their own errors which usually stem from their clocks or internal noise

The primary purpose of differential techniques (DGPS - Differential GPS) is to identify and correct errors occurring in the system. The GPS code differential technique allows to achieve accuracy from 0.5 to 5m.

Corrections to position

- An old, but sometimes offered, method is to calculate corrections as the difference between the measured and known position of the reference station.
- These corrections are then added to the position calculated by the mobile receiver.
- This approach is seemingly simpler, but the error of the determined position strongly depends on the satellites used to designate it.
- The reference receiver would therefore have to calculate and send corrections to the position calculated from each possible combination of satellites.

Corrections to position

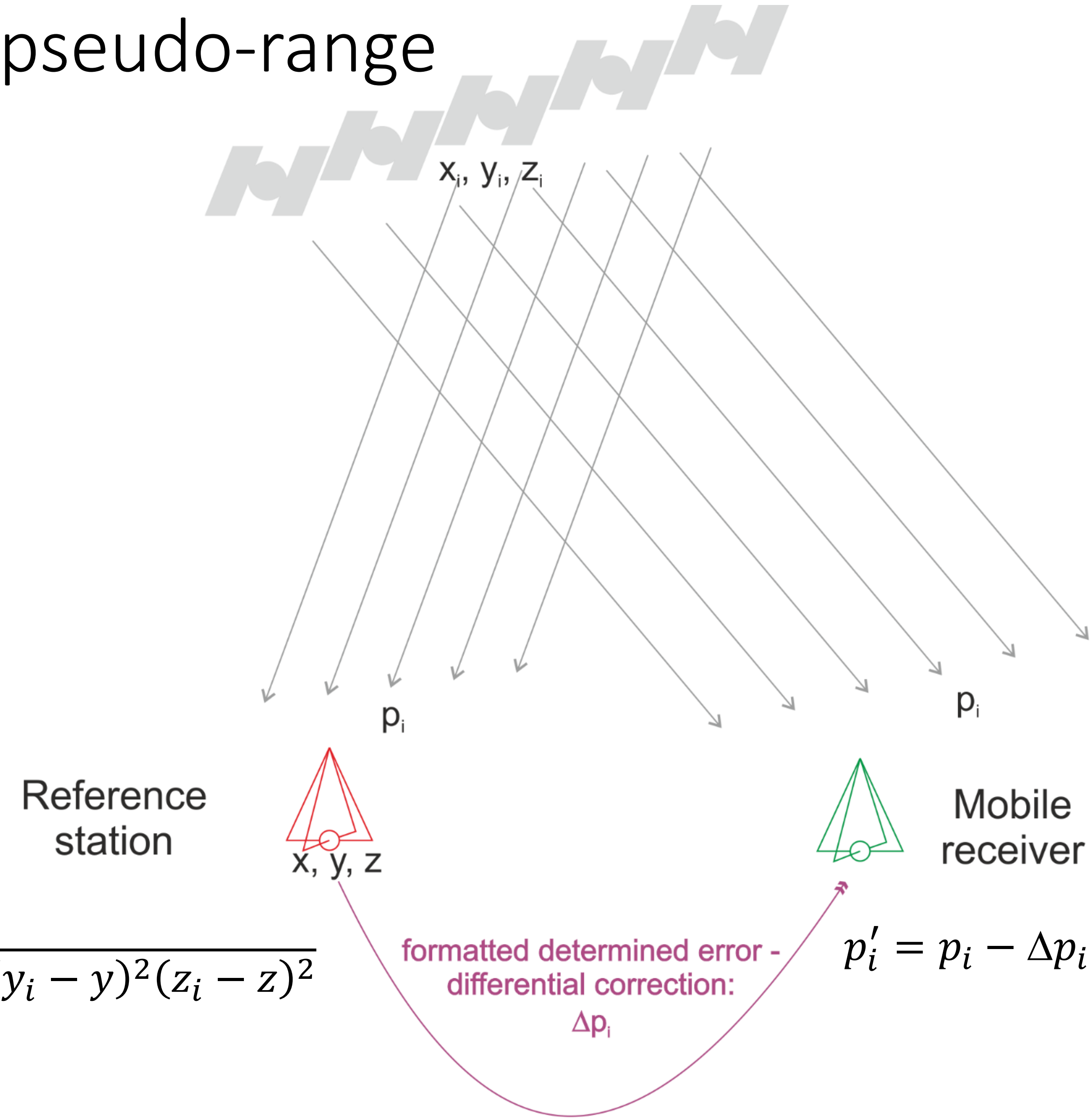


Where **i** is a given satellites' set used to positioning (from 4 to number of visible satellites)

Corrections to pseudo-range

- The most commonly used method is the calculation of pseudorange corrections.
- These corrections are the differences between the pseudoranges observed by the referance station and the distance calculated based on ephemeris and the location of the reference station.
- The mobile receiver adds corrections to its pseudoranges measurements.
- The base station should observe all visible satellites and calculate differential corrections for them. Thanks to this, there is no situation when the mobile receiver can not find a differential solution due to too few satellites with corrections

Corrections to pseudo-range



$$\Delta p_i = p_i - \sqrt{(x_i - x)^2 + (y_i - y)^2 (z_i - z)^2}$$

$$p_i' = p_i - \Delta p_i$$

Age of correction - AOC

- The corrections received by the mobile receiver are always delayed, if only because of the time needed to calculate them and the transmission time.
- AOC is a period between a time of position $\mathbf{t_0}$ obtained in a reference station for which a correction is to be determined, and implemented time $\mathbf{t_i}$ of this correction into a mobile receiver calculations:

$$AOC = t_i - t_0$$

- AOC consists of:
  - Time required for calculation and formatting a correction
  - Travel time between a reference station and a mobile receiver
  - amount of time (number of seconds) which elapsed from a time receiving of correction

Age of correction - AOC

- The main issue is the magnitude of this delay, which would not cause a significant deterioration of accuracy.
- If the dynamics of errors' changes reaches up to 0.2 m/s, after 5 seconds the corrections will be burdened with a 1 m error.
- Recognizing 1 m as the maximum permissible correction error, at least one update is required for every 5 seconds.
- This requirement can be mitigated by transmitting, apart from the pseudo-range corrections, also the rate of its change.

Coverage of DGPS

- Single station of GBAS (ground based augmentation system) – beacon – delivers valid correction within area with radius 300 km due to a variety of ionospheric and tropospheric delays
- SBAS (satellite based augmentation system) covers wide area using measurements from many of monitoring station:
  - EGNOS European Geostationary Overlay System – Europe 34 monitoring stations
  - WAAS Wide Area Augmentation System – North America 35 monitoring stations

Standard RTCM

- The most widely used standard of differential correction is the standard defined by Radio Technical Commision For Marine Services.
- The RTCM SC-104 format contains 63 types of messages.

DIFFERENTIAL GPS (DGPS)

Station name	Position	DGPS Corrections		Identification No. of		Range (in n miles)	Integrity Monitoring	Status	Transmitted Message Types
		tx fx (in kHz)	tx rate (in bps)	Reference Station	Transmit Station				
NORWAY									
Torungen Lt, Ytre Torungen	58°23′·97N 8°47′·52E	299				160		Planned	
Utsira Lt	59°18′·45N 4°52′·33E	313	100	785 815	505	160	Yes	Operational	1 2 3 5 7
Utvær Lt	61°02′·28N 4°30′·70E	314	100	787 817	507	160	Yes	Operational	1 2 3 5 7
Vardø Lt, Hornøy	70°23′·35N 31°10′·07E	305·5	100	800 830	520	160	Yes	Operational	1 2 3 5 7
If problems are encountered they should be reported to: The Coast Directorate, Post Boks 8158 Dep, 0033 Oslo 1: tel +47 22 47 62 00 or fax +47 22 42 48 35, together with the following information: date and time, approx position, brief description of the problem and possible ways to avoid the problem. A description of the radio equipment in use and a return address should also be supplied.									
POLAND									
Dziwnów	54°01′·45N 14°44′·10E	283·5	200		481	80	Yes	On trial	1 3 7 16
Jaroslaweic	54°33′N 16°33′E	295			483	80			
Rozewie	54°49′·97N 18°20′·15E	301	100		482	80	Yes	On trial	1 3 7 16

RTCM message types

Message type no.	Status according to [1]	Name
1	**Fixed**	**Differential GPS Corrections**
2	Fixed	Delta Differential GPS Corrections
3	**Fixed**	**GPS Reference Station Parameters**
4	Tentative	Reference Station Datum
5	**Fixed**	**GPS Constellation Health**
6	**Fixed**	**GPS Null Frame**
7	**Fixed**	**DGPS Radiobeacon Almanac**
8	Tentative	Pseudolite Almanac
9	**Fixed**	**GPS Partial Correction Set**
10	Reserved	P-Code Differential Corrections
11	Reserved	C/A-Code L1, L2 Delta Corrections
12	Reserved	Pseudolite (Pseudo-Satellite) Station Parameters

RTCM message types

13	Tentative	Ground Transmitter Parameters
14	Tentative	GPS Time of Week
15	Tentative	Ionospheric Delay Message
16	**Fixed**	**GPS Special Message**
17	Tentative	GPS Ephemerides
18	Fixed	RTK (Real-Time Kinematic) Uncorrected Carrier Phases
19	Fixed	RTK Uncorrected Pseudoranges
20	Tentative	RTK Carrier Phase Corrections
21	Tentative	RTK/High-Accuracy Pseudorange Corrections
22	Tentative	Extended Reference Station Parameters
23 - 30	–	Undefined

RTCM message types

23 - 30	–	Undefined
31	Tentative	Differential GLONASS Corrections
32	Tentative	Differential GLONASS Reference Station Parameters
33	Tentative	GLONASS Constellation Health
34	Tentative	GLONASS Partial Differential Correction Set or Null Frame
35	Tentative	GLONASS Radiobeacon Almanac
36	Tentative	GLONASS Special Message
37	Tentative	GNSS System Time Offset
38 - 58	–	Undefined
59	Fixed	Proprietary Message
60 - 63	Reserved	Multipurpose Usage

The end