Satellite Navigation Systems

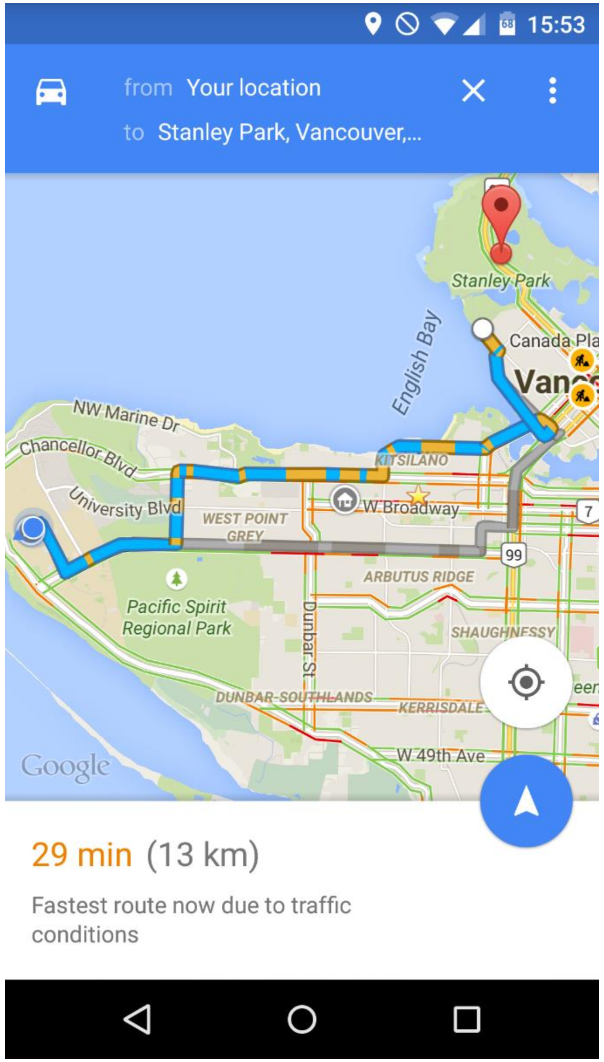
Learning Objectives

- Global Navigation Satellite Systems and satellite navigation
- What information is needed to define location from space
- How Global Navigation Satellite System works
- Differential and kinematic GNSS
- Different applications of GNSS

Have you used GPS today?

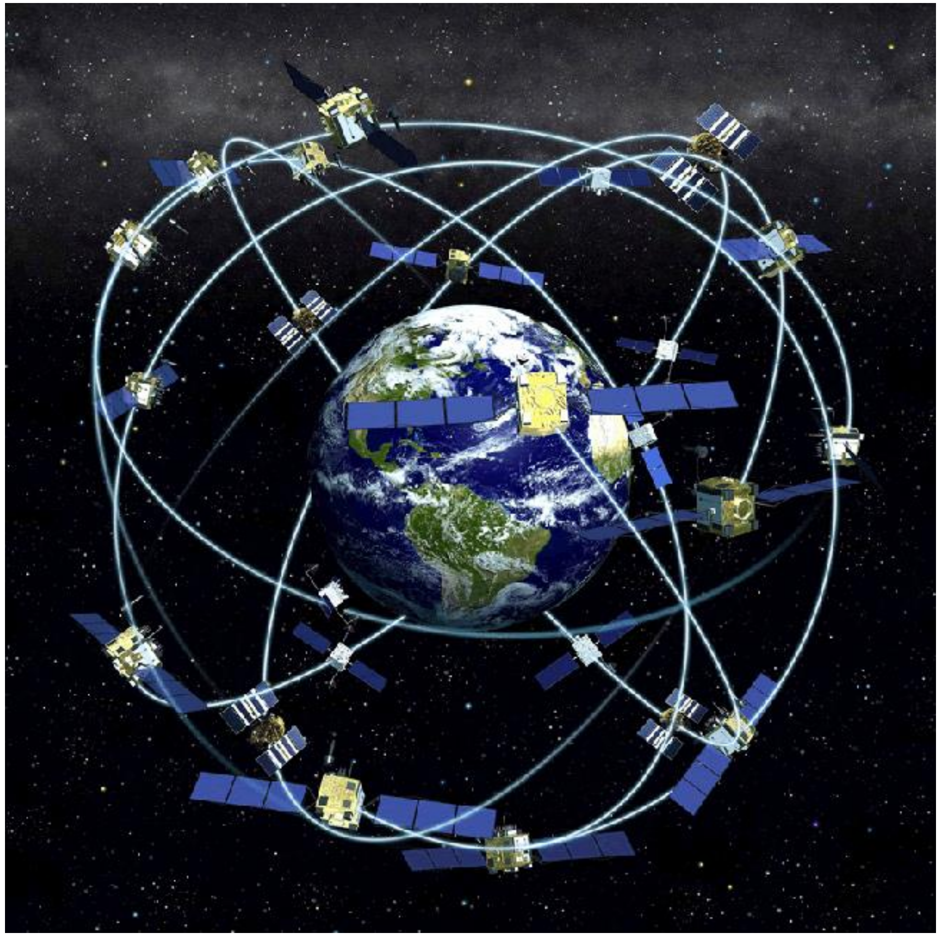
Ndrive GPS (Source: Wikimedia Commons)

Cockpit of Air France A380 F-HPJC (4943144092)



Satellite Navigation

- As we learnt, navigators have looked to the sky for direction for thousands of years
- Since 1957, celestial navigation has simply switched from natural objects to artificial satellites
- Navigation satellites are like orbiting landmarks
- If the satellite orbit is known, measurements can be used to find a location on the Earth with at least 4 satellites

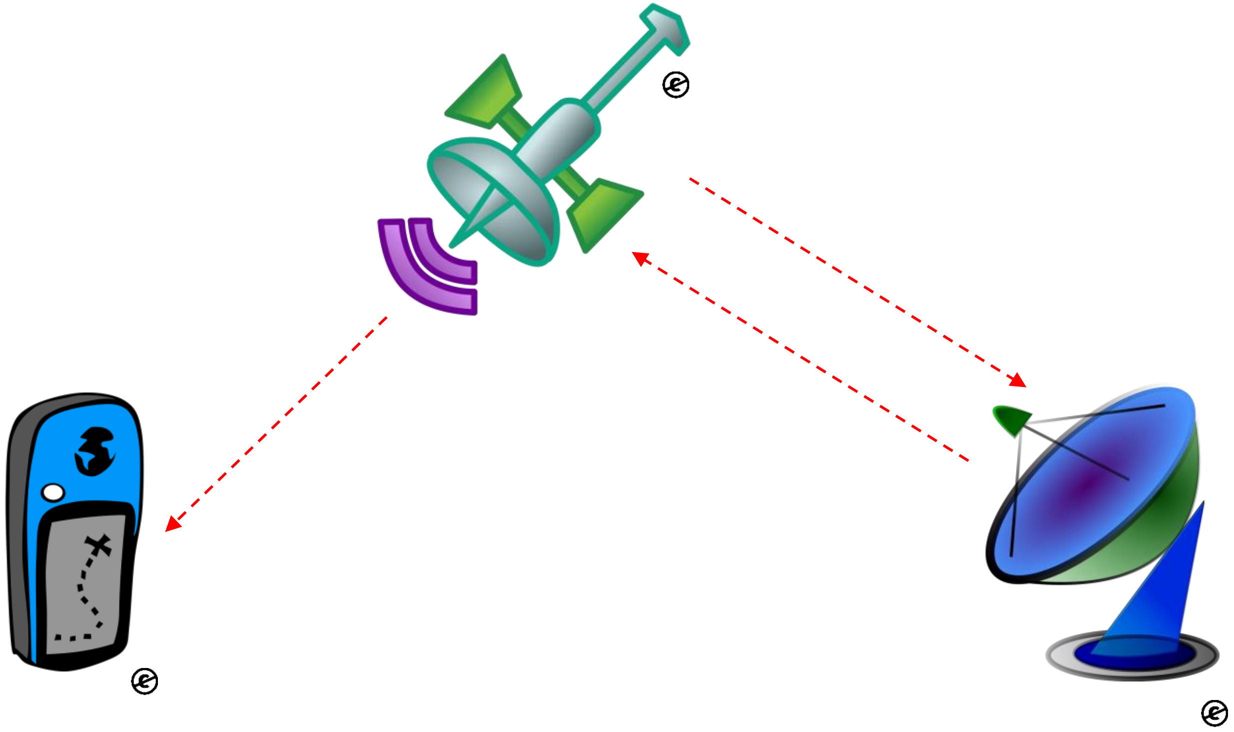


History of GPS

- Developed by the US military from 1973
- Became operational in 1995 with 24 satellites
- Many people starting using it from 1996 and it became a civilian asset from 2000

How do GNSS systems work?

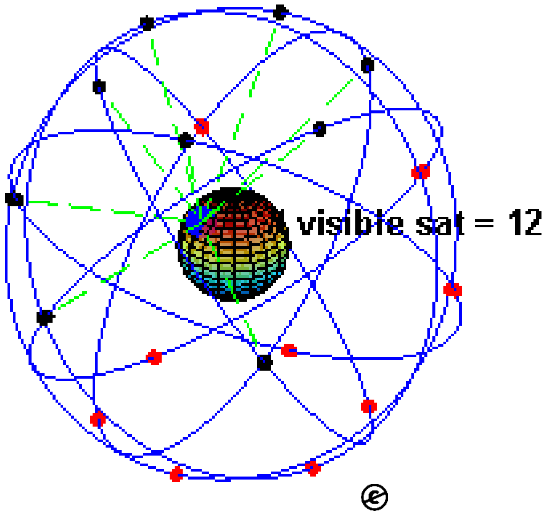
- Three system segments:
  1. Space segment
  2. Control segment
  3. User segment



- Satellites are communicating with control stations (two way signal)
- Satellites send one way signal to receivers

Space Segment (GPS-NAVSTAR)

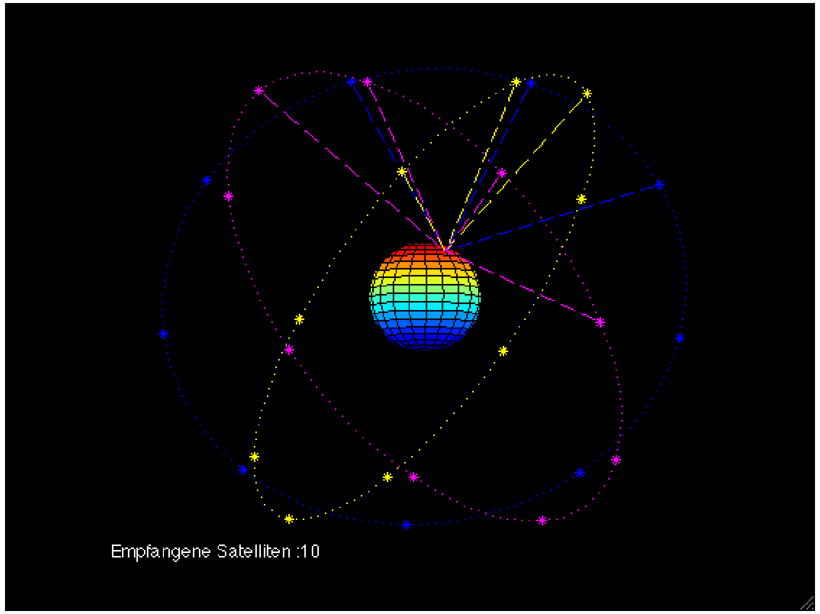
- Minimum of 24 satellites on 6 orbits (20,200 km)
- From any point on Earth, at least 4 satellites are visible for the receiver



Space Segment

	GLONASS	GPS	GALILEO	BeiDou
Number of satellites	24	24	22 of 30	35
Number of orbital planes	3	6	3	NA
Orbital Inclination	64°8'	55°	56°	Geostationary
Orbital altitude	19.140 km	20.180 km	23.222 km	NA
Period of revolution	11h 15m	11h 58m	14h 22m	NA
Date of first launch	1982	1978	2005	2000

2018 numbers



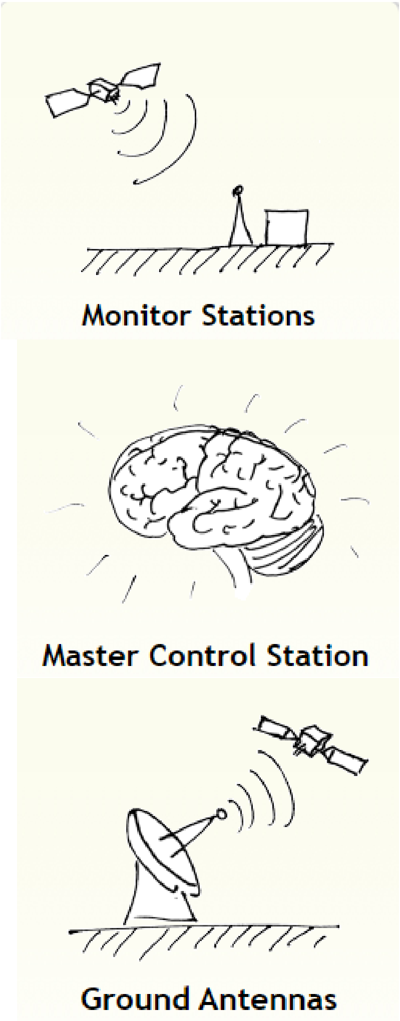
Galileo sat constellation (Source: Wikimedia Commons)

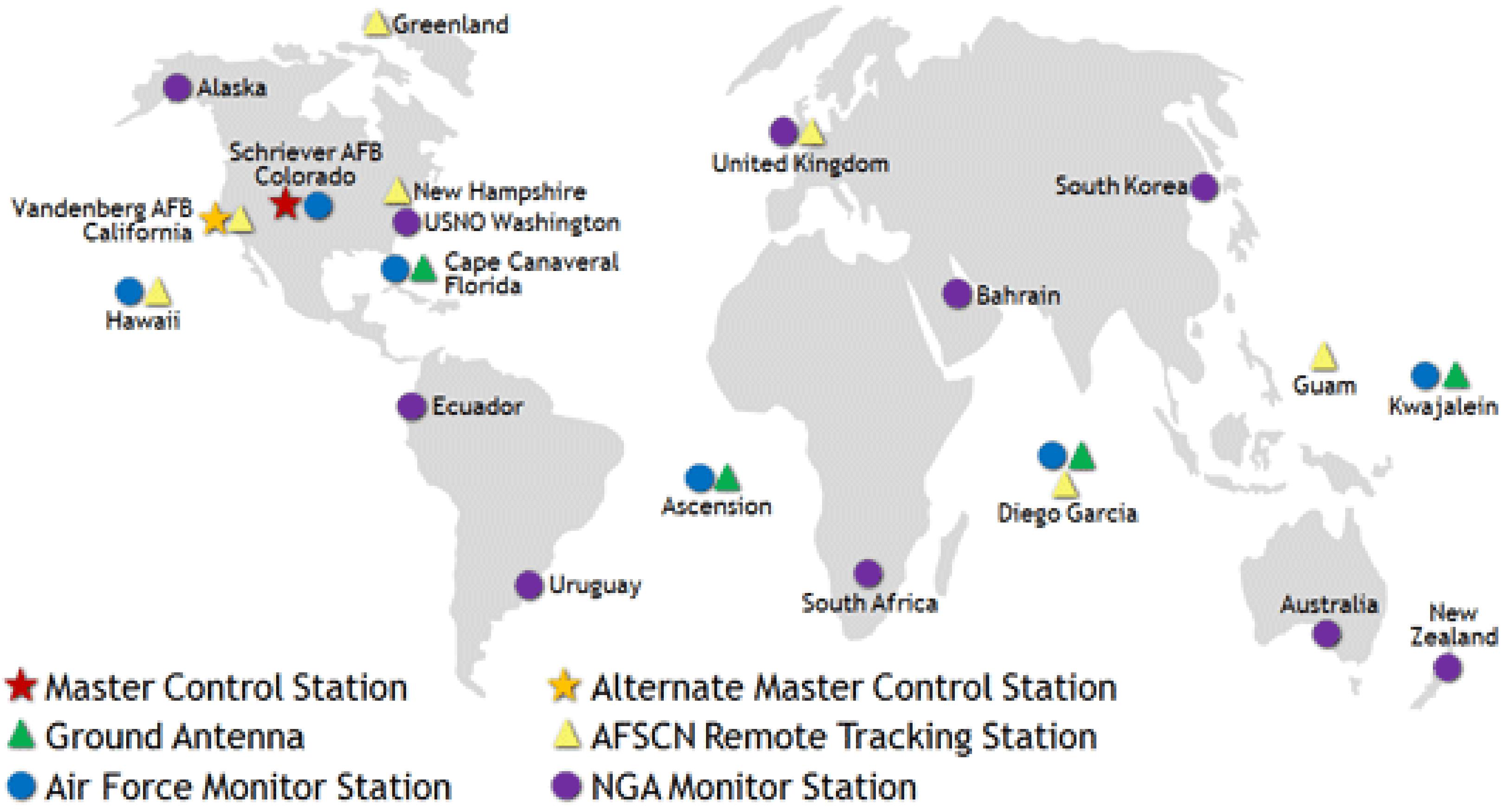
Space Segment

User Segment

- That's you!

Control Segment





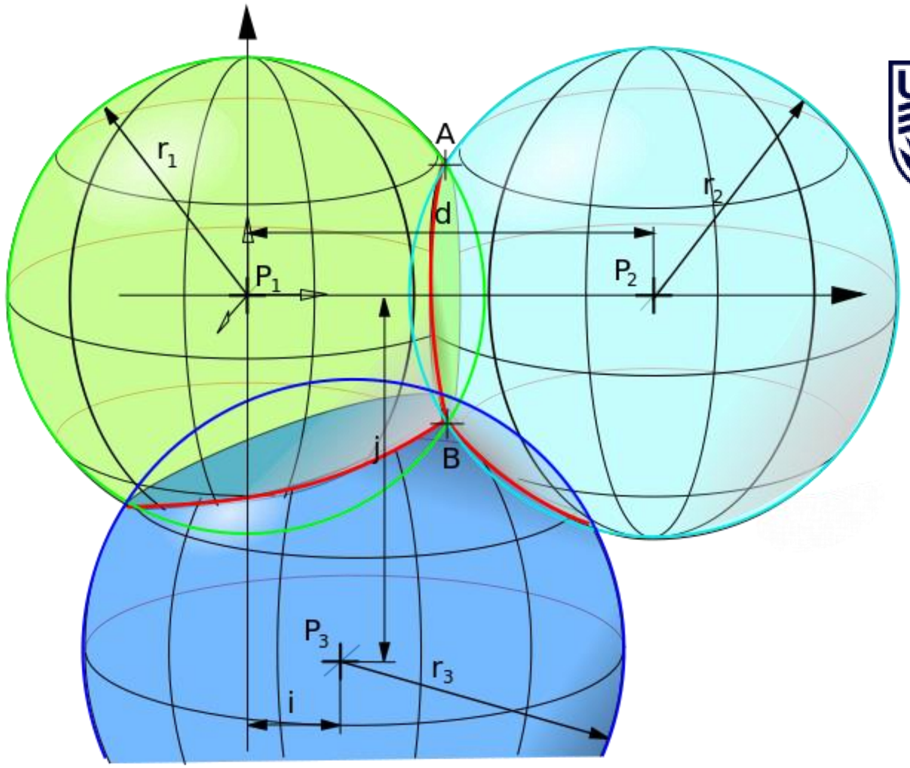
How to determine a location of an object?

- Example - which city is:
  - 175 km from Amsterdam
  - 320 km from London
  - 185 km from Luxemburg


175 km
320 km
185 km
Hamburg
Schwerin
Bremerhaven
Wilhelmshaven
Lüneburg
Leer
Groningen
Leeuwarden
Oldenburg
Bremen
Celle
Wolfsburg
Hanover
Brunswick
Magdeburg
Osnabrück
Bielefeld
Münster
Paderborn
Göttingen
Halle
Dortmund
Essen
Kassel
Germany
Jena
Cologne
Bonn
Aachen
Fulda
Koblenz
Frankfurt
Mainz
Würzburg
Bamberg
Bayreuth
Mannheim
Nuremberg
Trier
Luxembourg City
Liège
Belgium
Charleroi
Brussels
Antwerp
Ghent
Bruges
Dunkirk
Calais
Lille
Arras
Amiens
Rouen
Le Havre
Caen
Eindhoven
Rotterdam
The Hague
Amsterdam
Alkmaar
Netherlands
Arnhem
Nottingham
Leicester
Peterborough
Norwich
ENGLAND
Cambridge
Ipswich
Colchester
Oxford
London
Reading
Southend-on-Sea
Canterbury
Brighton
Satellite
Google
Map data ©2019 GeoBasis-DE/BKG (©2009), Google
Canada
Terms
Send feedback
50 km

Satellite Navigation

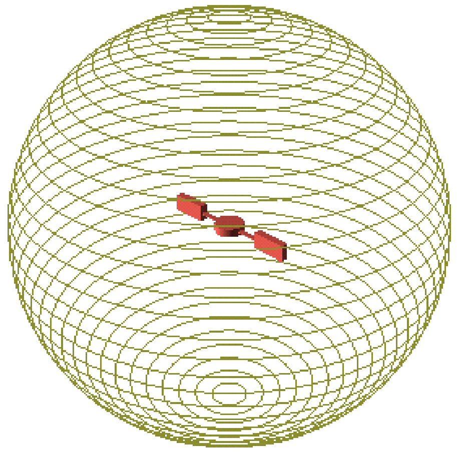
- Trilateration rather than triangulation.
  - In the case of GNSS, uses the speed of light to calculate distances
- Ranging (distance) measurements are calculated by determining differences in time
- Combining the distances and satellite locations, the receiver can find its latitude, longitude, and height.



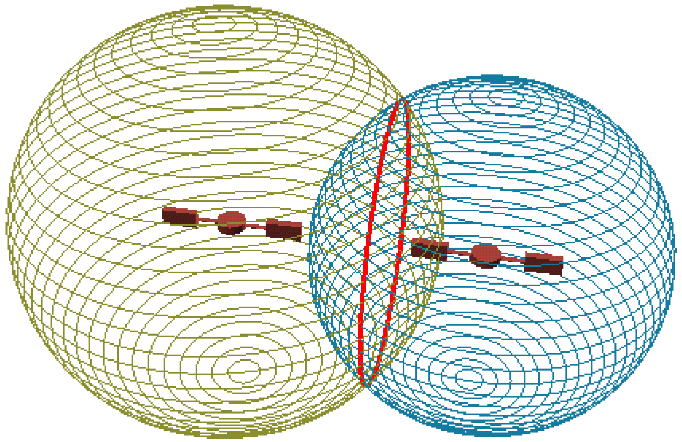
Trilateration (Source: Wikimedia Commons)

Calculating Location

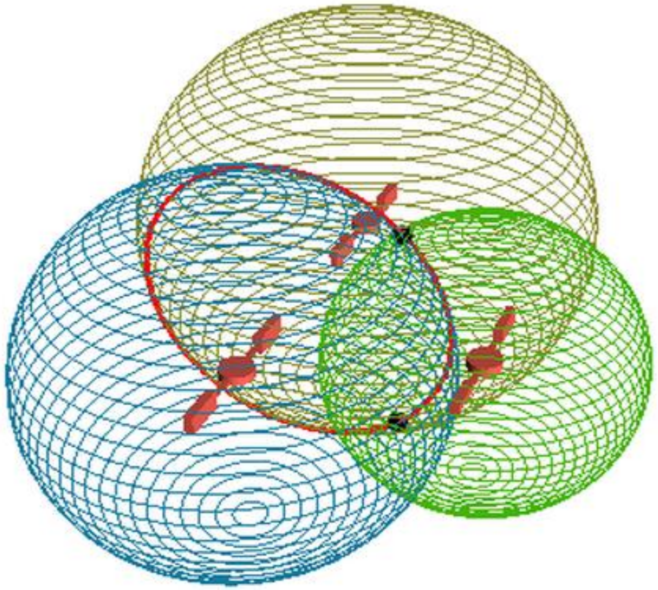
- General rule: the more signals received (from different satellites), the more accurate the calculated position



One satellite signal (Source: Keep Environment Nature's Blog)



Two satellite signals (Source: Keep Environment Nature's Blog)



Three satellite signals (Source: Keep Environment Nature's Blog)

Position is determined in steps:

- Download almanac (information on satellites, their status, health etc.)
- Download ephemeris (predicted location of each satellite)
- Download GPS date and time
- Measure ΔT to at least 4 satellites
- Determine range
- Calculate X, Y, Z

GNSS Ephemeris and Almanac

Ephemeris:

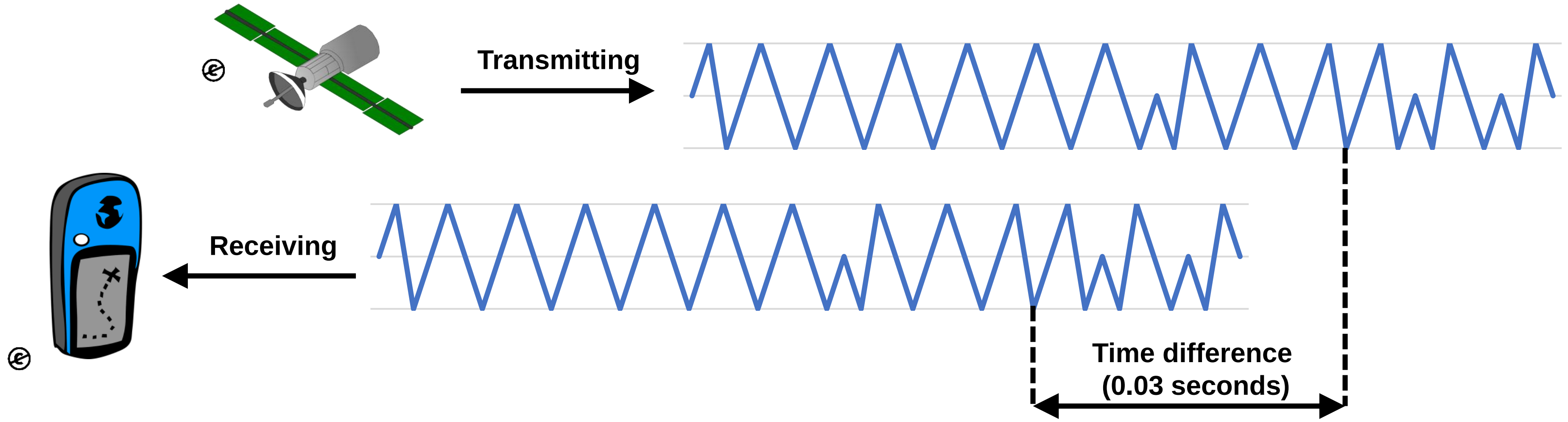
- Detailed information on the day and time, satellite accuracy and health, age of data, satellite clock correction coefficients, and orbital parameters. It is valid for 2 hours and is different for each satellite.

Almanac:

- Contains less accurate orbital information than ephemerides and is valid for 90 days. It can speed up the time to the receiver takes to find the first few satellites. It is the same system wide.

Therefore a receiver can work without the almanac but ephemerides data is always needed.

How is ΔT measured?



- Comparing the time that the transmitted PRN code is received with the known time the PRN code was generated provides the time difference
- The time difference (t) is multiplied by the speed of light (c) to estimate the distance to the satellite (P)
- P = c(t) = 299,792,458(0.03) = 8,994 kilometers
- These calculations happen instantaneously by the GPS receiver

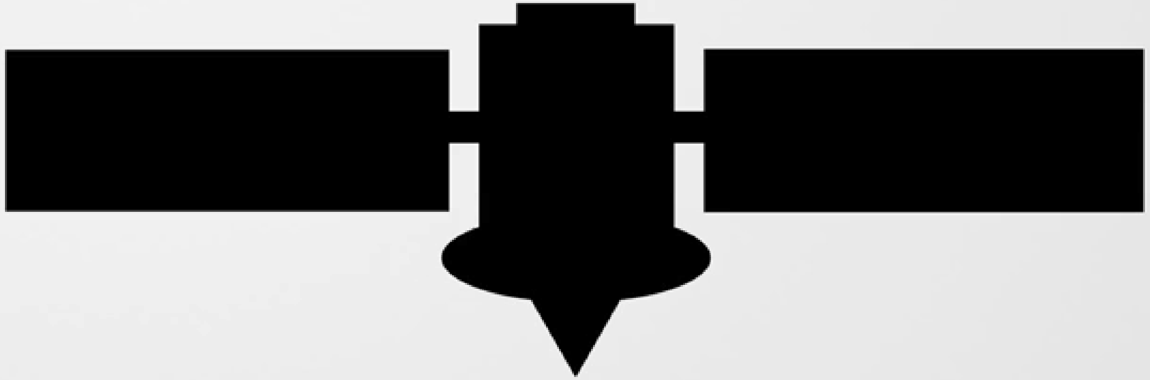
Measuring Travel Time

Why the fuss over the clocks?

- Signals travel a meter in about 3 billionths of a second (i.e., speed of light).

- So if satellite clocks were off by just 1 millionth of a second, our position would be off by 3000 meters!

GALILEO

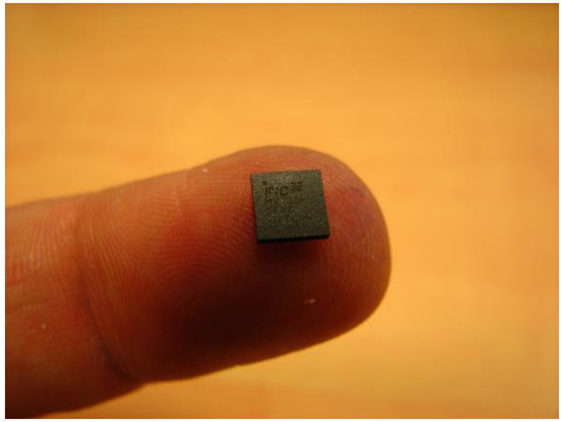


Receivers

The first GPS receiver from 1977 (Source: The Smithsonian Institute)

GPS Receiver Science Instrument (Source: Pixabay)

GPS Receiver CompactFlash (Source: Wikimedia Commons)

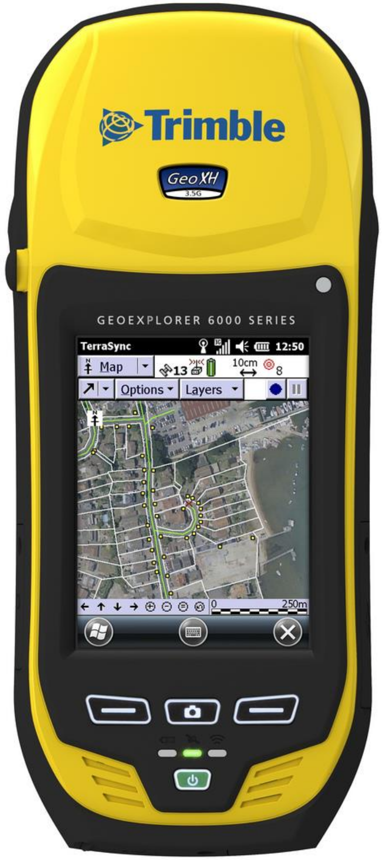


Microchips (Source: fdecomite)

Receivers

Map of the United Kingdom on Apple maps, pictured on an iPhone 8 plus (Source: Holiday Gems)

<700CAD



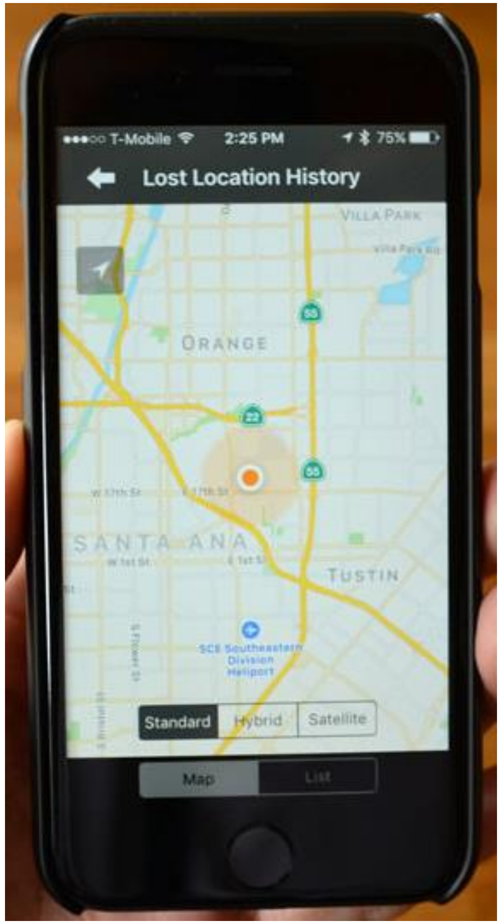
~3000CAD

TerraSync Trimble GIS Data Collection Software (Source: @gletham)

Station GPS receiver (Source: Wikimedia Commons)

Accuracy & cost

How accurate is this?



iPhone showing VSF finder on Google Maps
(Source: Your Best Digs)

- 3 – 15 m, 95% of the time (clear view of the sky)
- Accuracy is influenced by:
    - Number and position of satellites
    - Atmospheric effects
    - Obstructions (trees, buildings etc.)
    - Receiver quality
    - Corrections / post-processing

Maximum Accuracy?

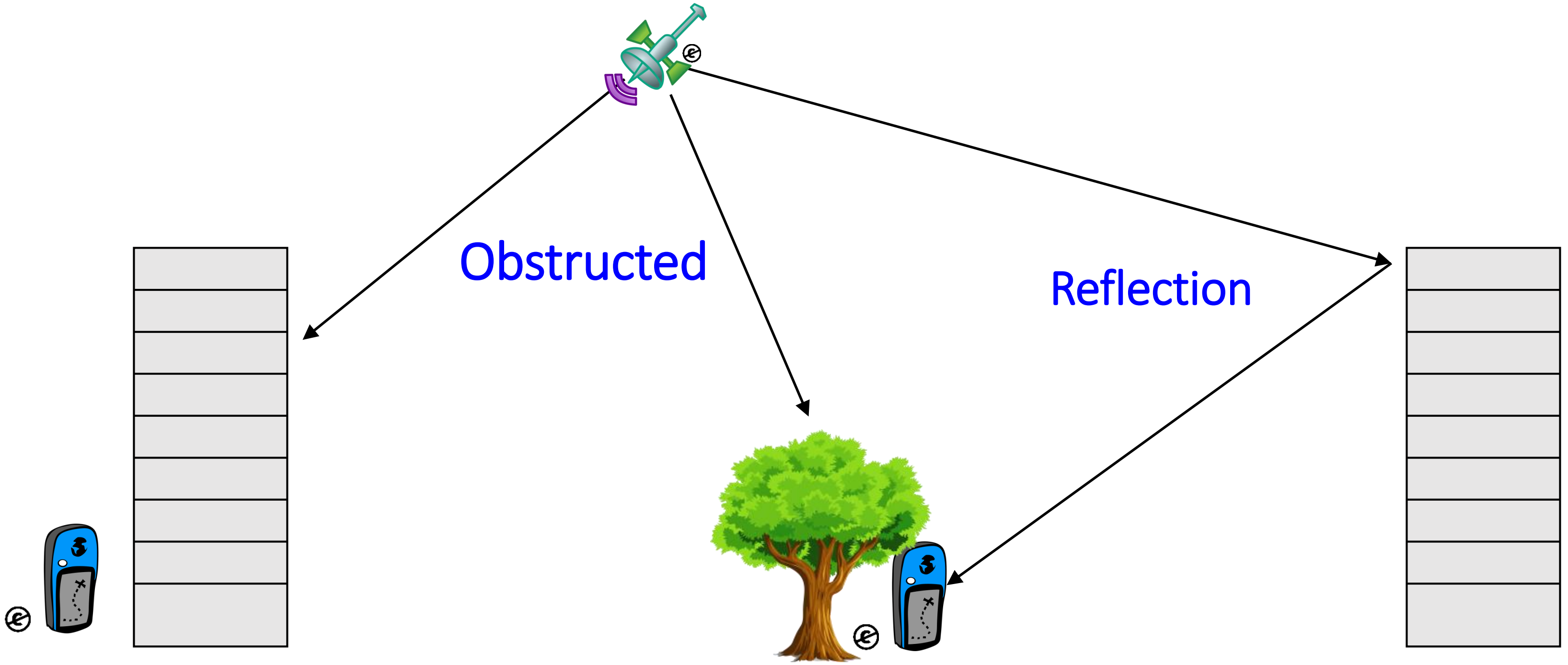
- GNSS receivers designed for precise surveying, using Differential GPS*:
  - Horizontal: 10 mm
  - Vertical: 20 mm

Station GPS receiver (Source: Wikimedia Commons)

Vermessung mit Trimble GPS System in Sofia 2012
PD 3 (Source: Wikimedia Commons)

Sources of GPS Error

- Radio waves cannot pass through some objects: buildings, some trees, mountains.
- Radio waves can bounce or be reflected off of certain objects: water, large metal objects, buildings. Signal will not be accurate.
- These can result in an inaccurate measurements due to multi path errors



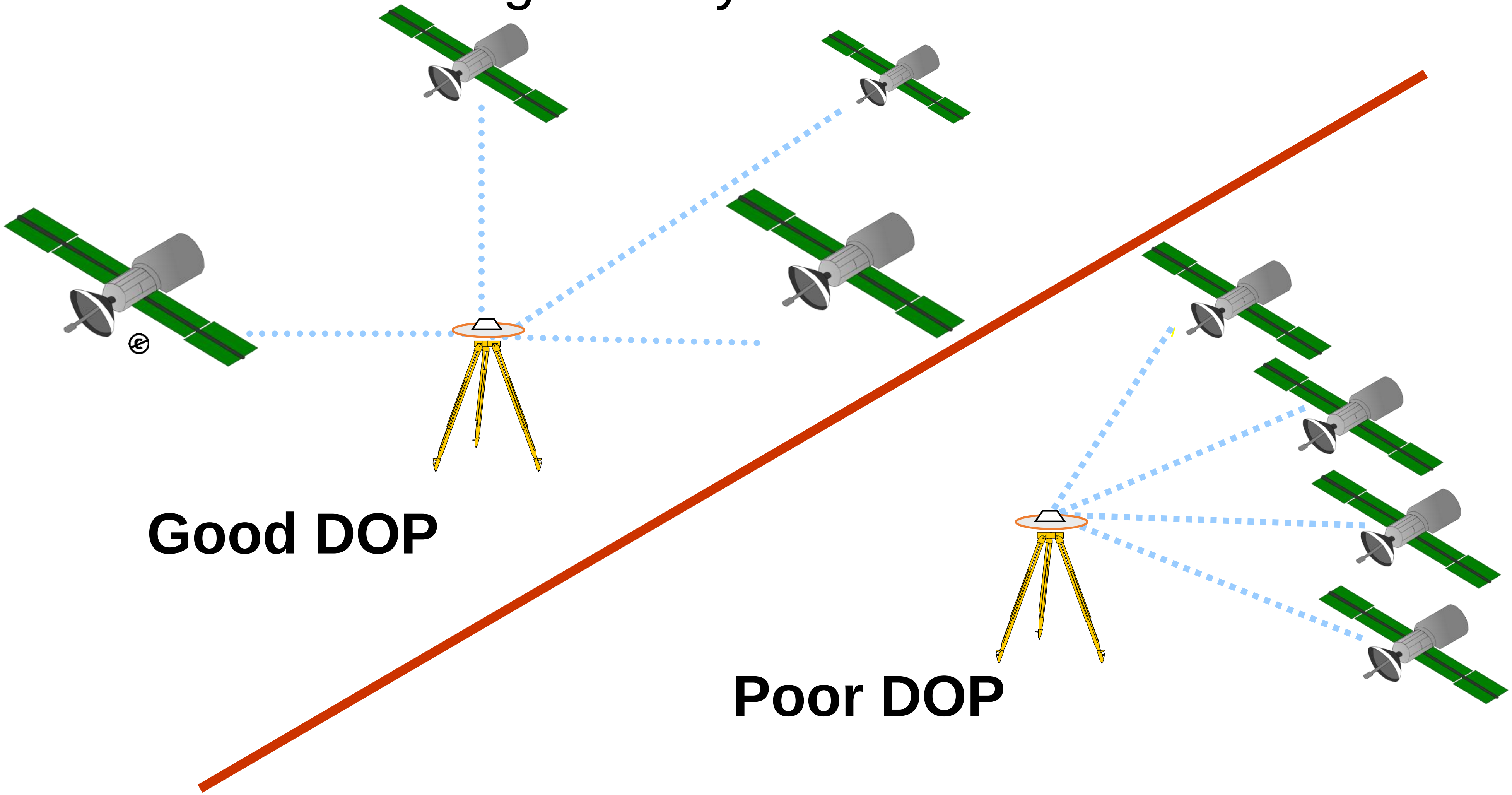
To Get the Best Measurement

- Remain in the open
- Avoid buildings and tall trees
- Take several measurements and average them
- Be patient

Remember the satellites are orbiting, and a satellite that was not visible earlier may come into view of the receiver and give you a more accurate measurement.

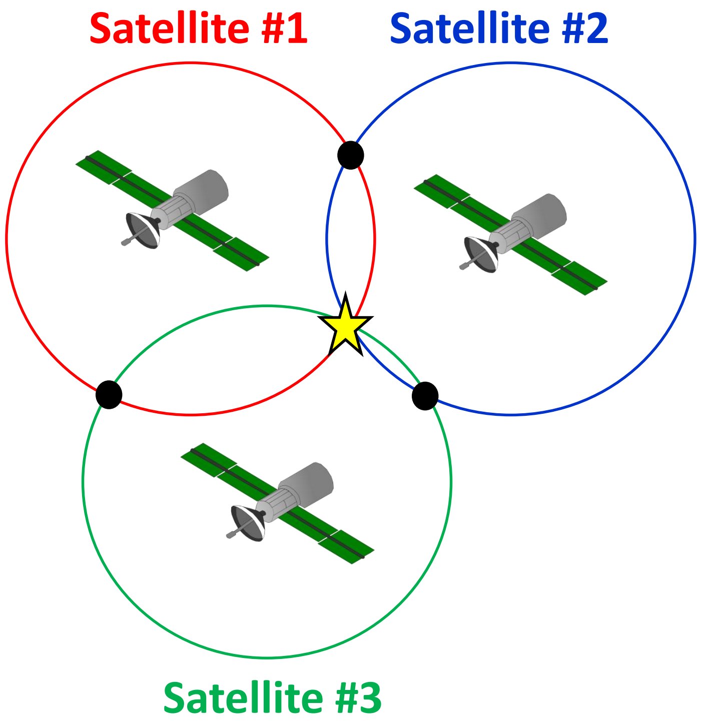
Dilution of Precision (DOP)

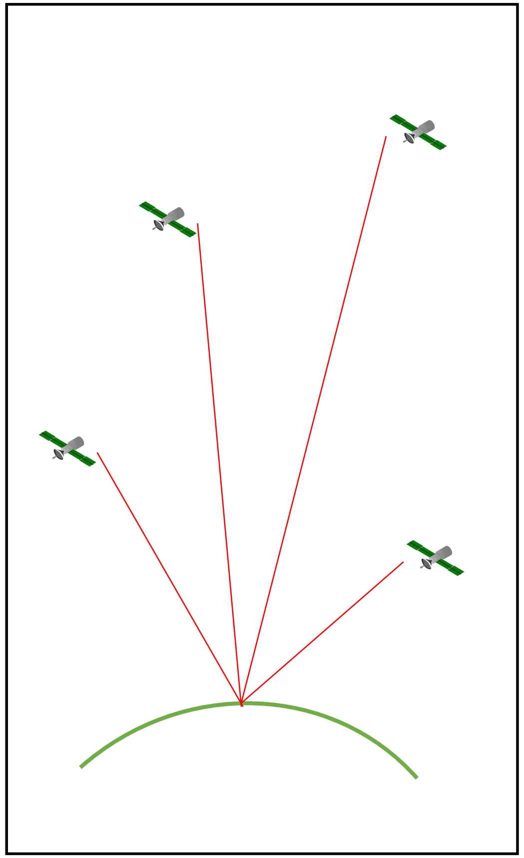
- A measure of the geometry of the visible GPS constellation



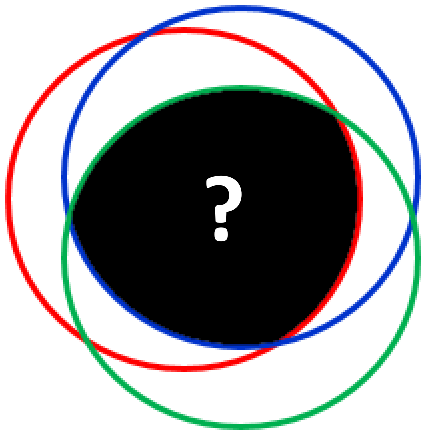
Dilution of Precision (DOP)

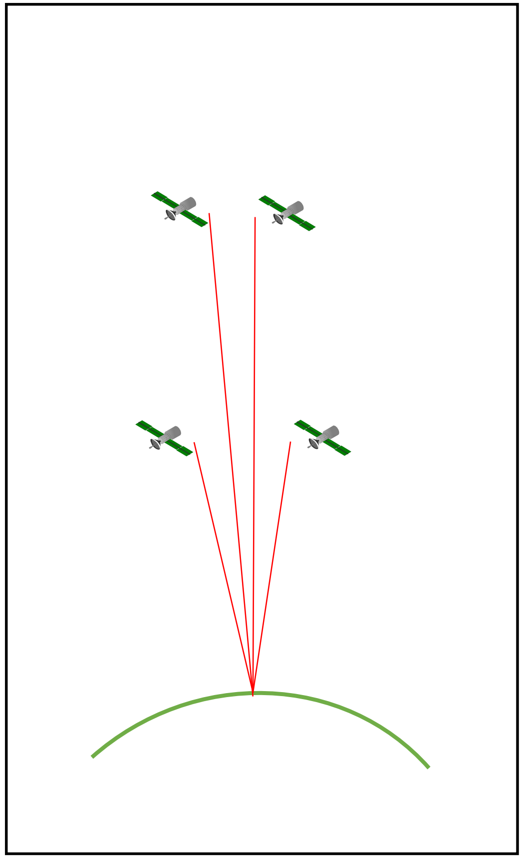
Good DOP





Bad DOP





Dilution of Precision

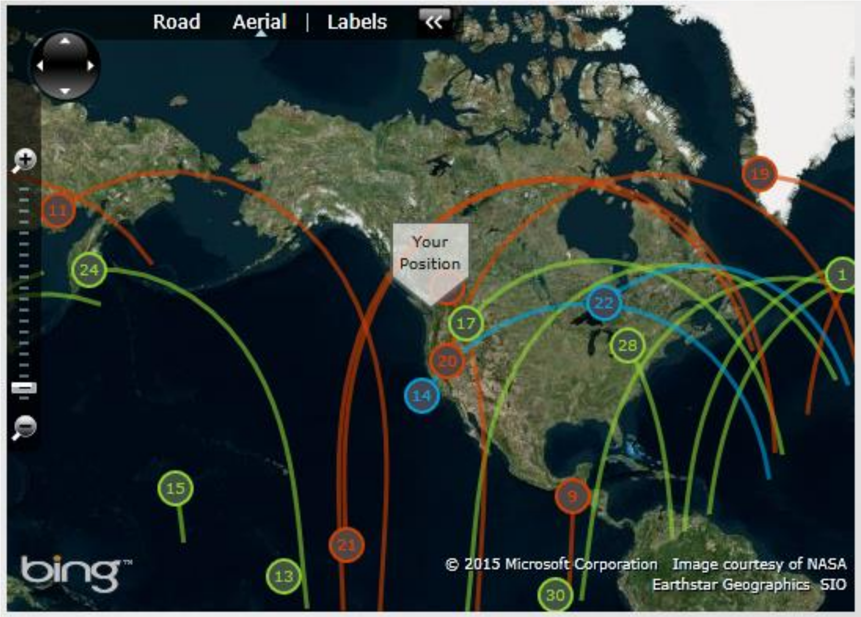
- PDOP = Position Dilution Of Precision (Most Commonly Used)
- VDOP = Vertical Dilution Of Precision
- HDOP = Horizontal Dilution Of Precision
- TDOP = Time Dilution Of Precision

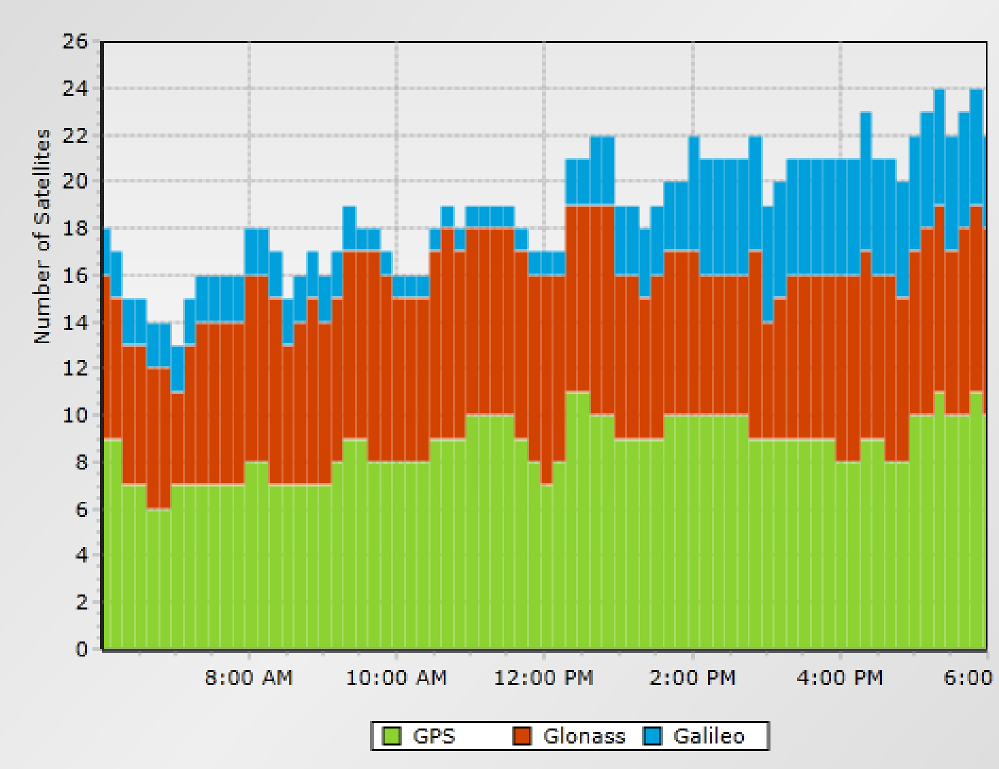
QUALITY	DOP
Very Good	*1-3*
Good	*4-5*
Fair	*6*
Suspect	*>6*

Mission Planning Is Critical to Obtain Good DOP

Mission Planning

- http://www.trimble.com/gnssplanningonline
- For given date and location provides information on satellite visibility and expected accuracies (PDOP)



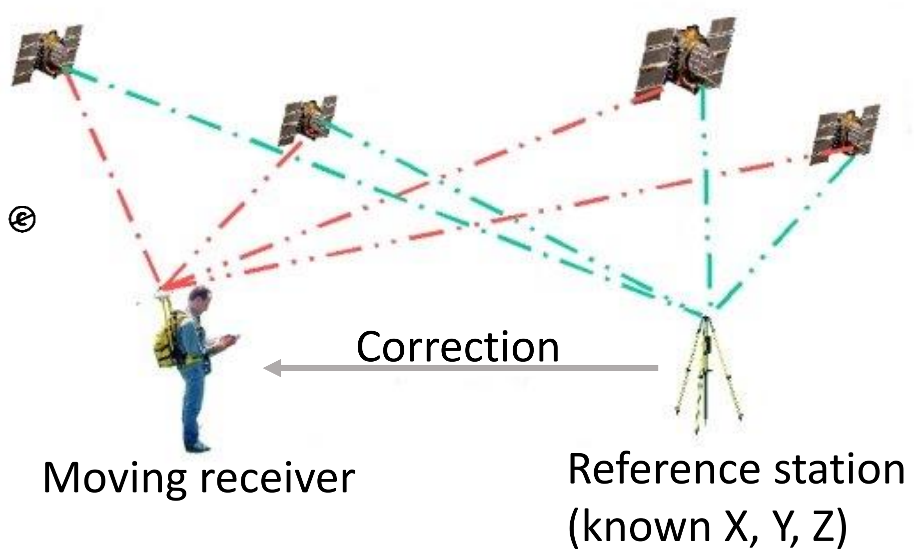


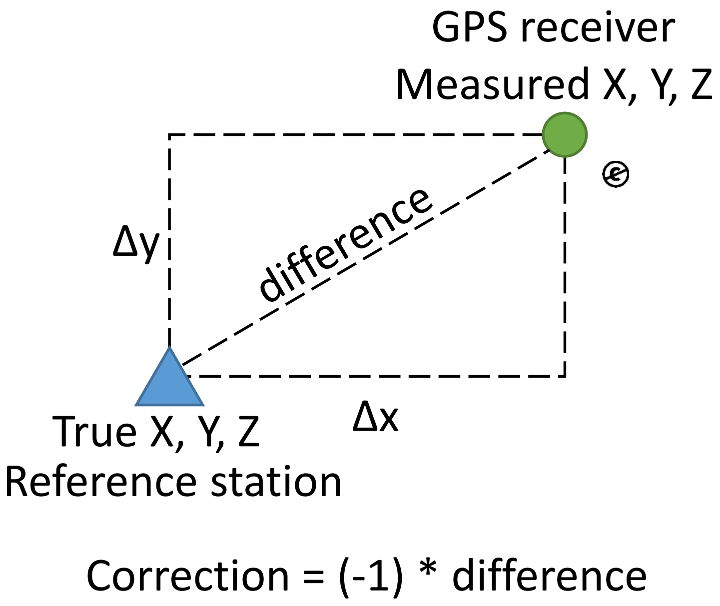
Costs of Errors

GPS Receiver	1-2
Clock Errors	1
Ephemeris Errors	1
Tropospheric Delays	1
Ionospheric Delays	10
Multipath Errors	0.5
Total	10 - 20

Differential GNSS

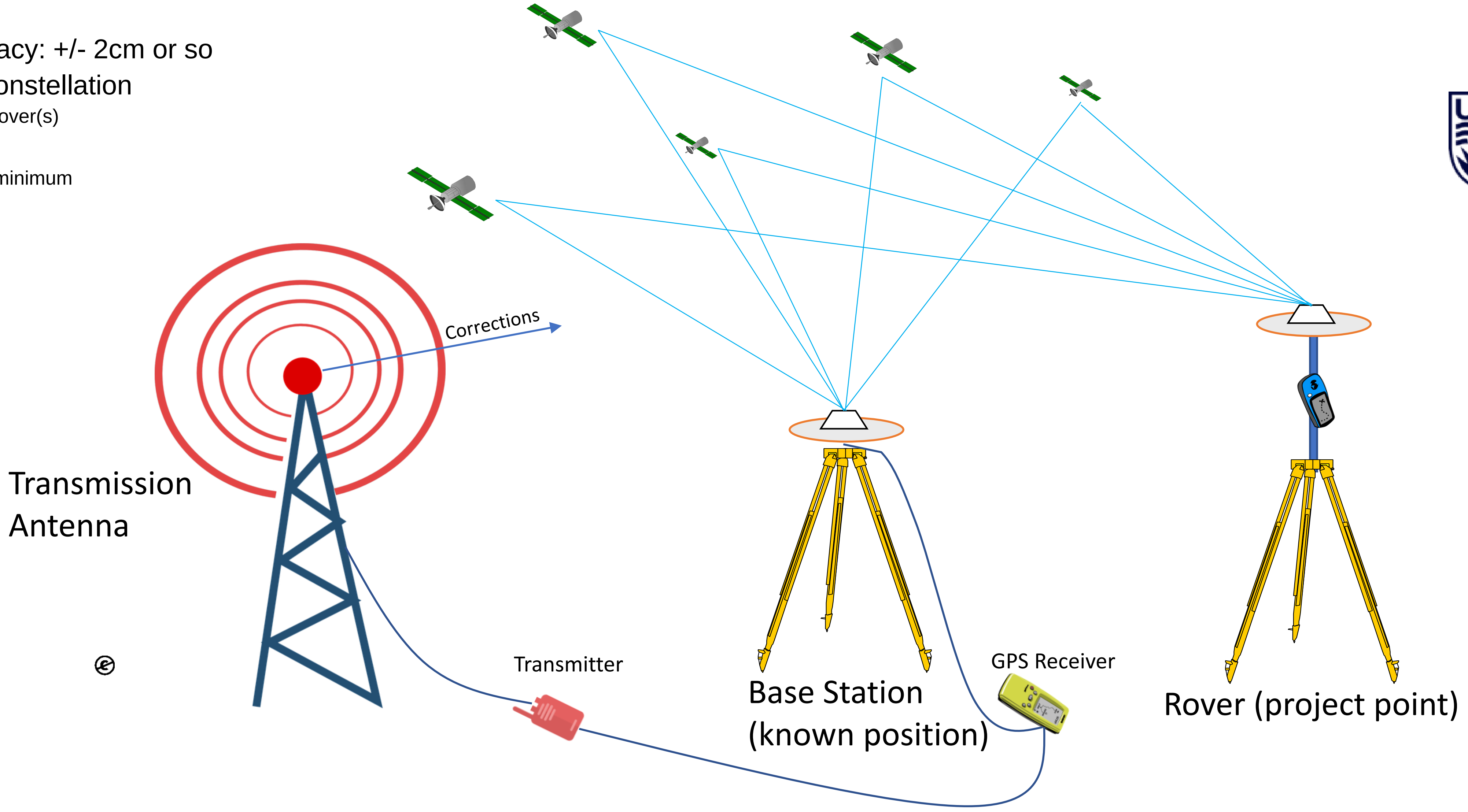
Differential correction is used to increase the accuracy of GPS location. A base station with known location can compute corrections for remote receivers. Corrections can be made in real time or by post-processing.





Real-Time-Kinematic GPS (RTK)

- Positional Accuracy: +/- 2cm or so
- Same satellite constellation
  - Base station and rover(s)
- Carrier Phase
  - Track 5 satellites minimum
- Radio link
  - More information
  - Fast transmission
  - Real-time results



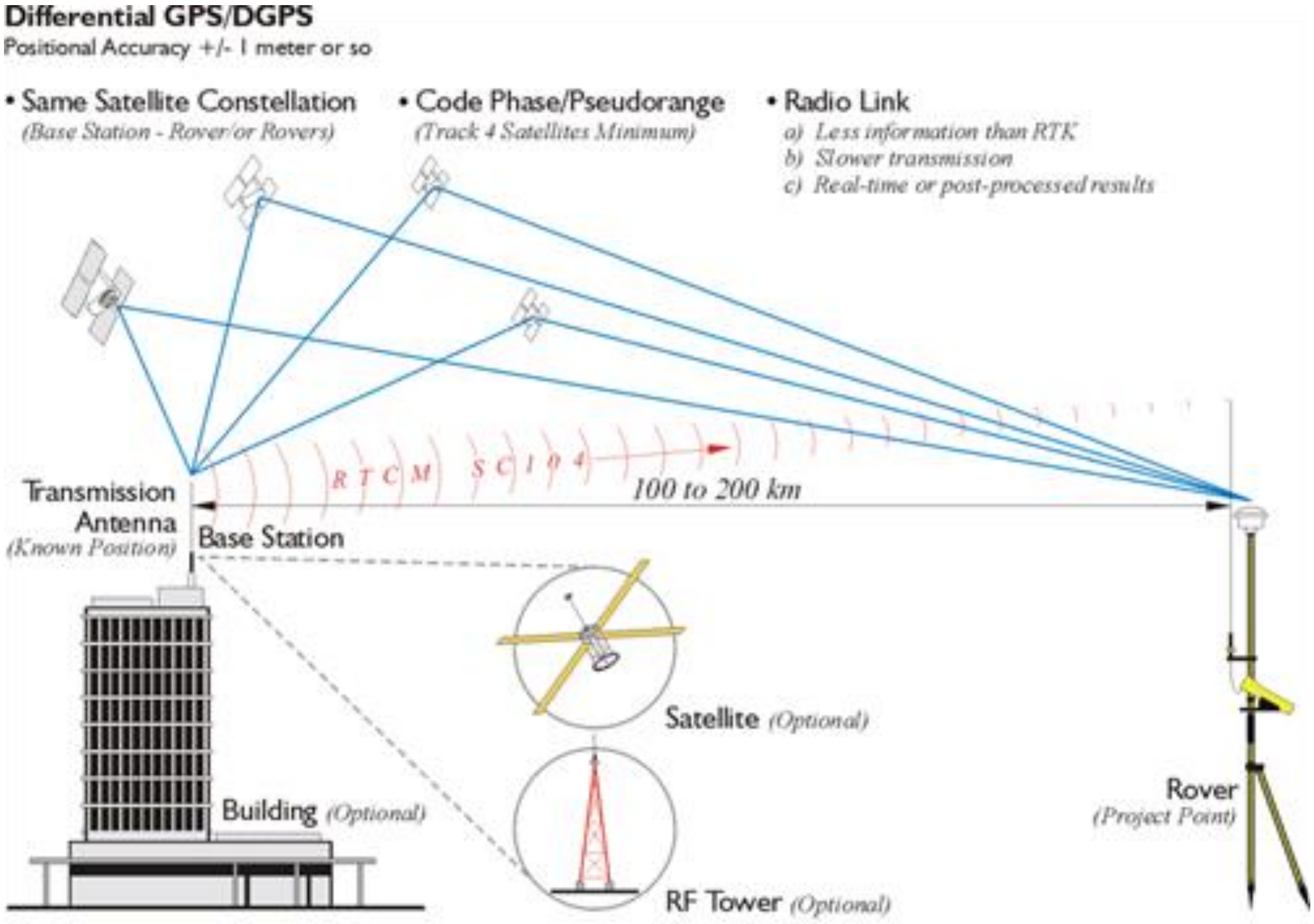
What’s the difference?

DGPS

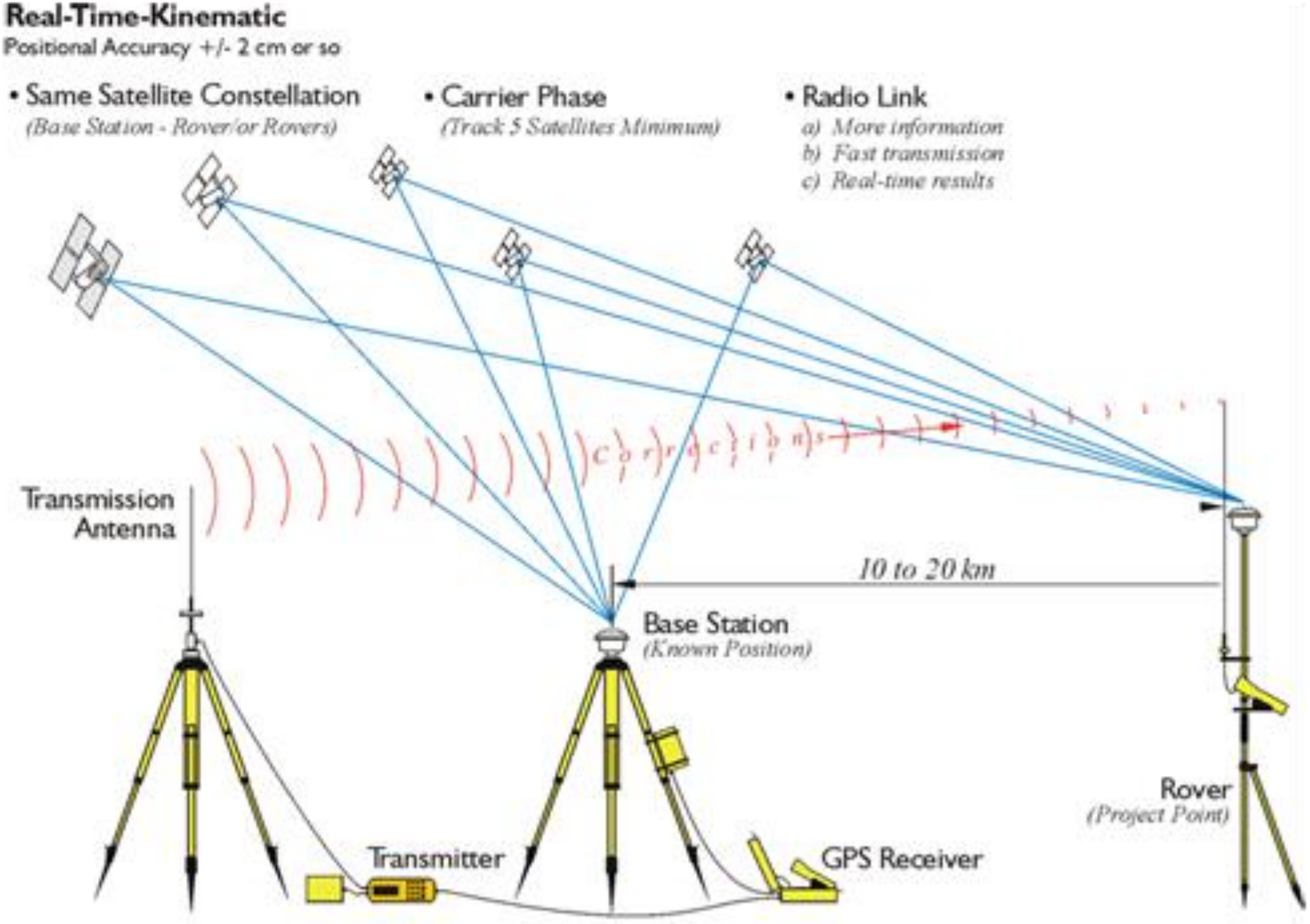
- Satellites
- Base station with known location
    - Often a permanent station
- Less correctional information transmitted than RTK
- Transmitted slower
    - Could be in real time
- Post processing

RTK GPS

- Satellites
- Base station with known location
    - Base station is mobile
    - Bring your base station to your site
- More information transmitted than DGPS
    - Newer algorithm
- Transmitted faster
- Real time correction



https://www.e-education.psu.edu/geog862/node/1828



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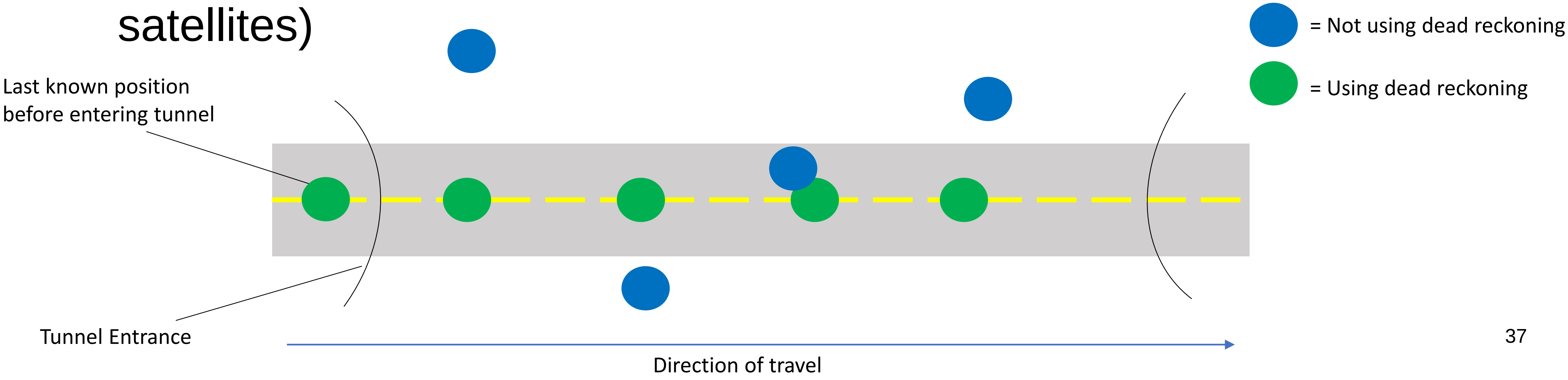
A-GPS

- A-GPS = Assisted GPS
- When a receiver is turned on, it needs to find orbit and clock data of relevant satellites. This can take up to several minutes in some cases.
- A-GPS improves start-up performance of a GNSS receiver by using the cellular network towers that pass information about location and relevant satellites to the receiver.

Dead Reckoning

- Calculating position by using previously determined position, speed, and course
- Can be used to overcome some limitation of GNSS technology (e.g. in tunnels, blocked lines of sight to the satellites)

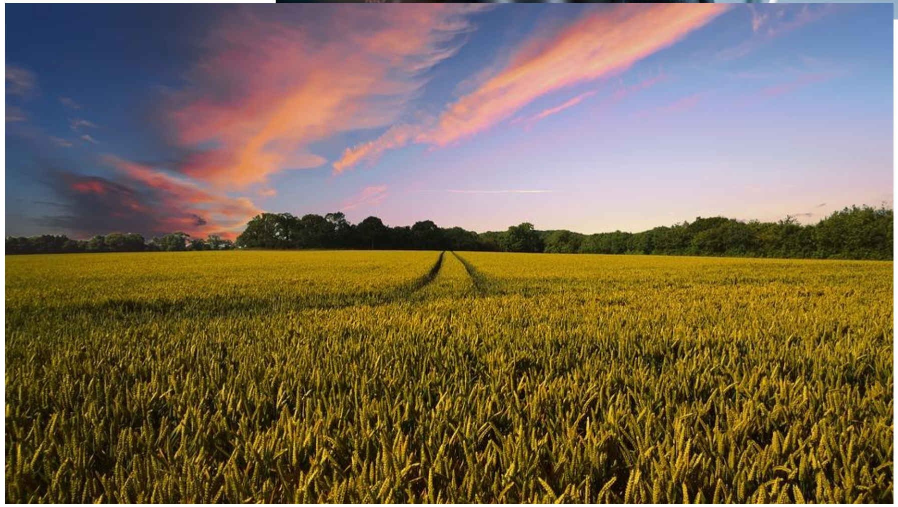


Going Further – Positioning in Closed Environments

- IPS = Indoor positioning systems
- Using Wi-Fi
- Bluetooth

Applications of GPS

- Transportation (navigation)
- Mapping and surveying
- Agriculture
- Aviation
- Environment
- Public safety & disaster relief
- Recreation
- Wildlife



Important Topics

- How does a receiver find your position?
    - What is the method/principle used?
    - What are the steps required?
- What is the accuracy of GNSS positioning?
- What does DOP stand for and what does it measure?
- What is RTK GPS?

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Thank you!

Additional Resources

- http://www.gps.gov/
- http://www.insidegnss.com/
- TED talk - Todd Humphreys: How to fool a GPS