COMP0130 Robot Vision and Navigation

1C: Introduction to GNSS Positioning

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Session Objectives

- Introduce the language of satellite positioning
- Explain how ‘basic’ satellite positioning works
- Present some details of GPS and other satellite positioning systems
- Show some applications

Contents

1. Introduction
2. Components of GNSS
3. How GNSS Positioning Works
4. General Applications

1. Introduction

What is GPS? (1)

- GPS = **G**lobal **P**ositioning **S**ystem
- Developed by the United States government as a military navigation system, originally for precision bombing

The First GPS Receiver from 1977

Image: Rockwell Collins

- GPS Development programme started in **1973** following the merger of separate Air Force, Navy and Army projects
- First operational satellite: **1978**
- Initial operational capability: **1993**
- Full operational capability: **1994**
- GPS is now undergoing a modernization programme

1. Introduction

What is GPS? (2)

The term “Global Positioning System” (GPS) refers to the whole system

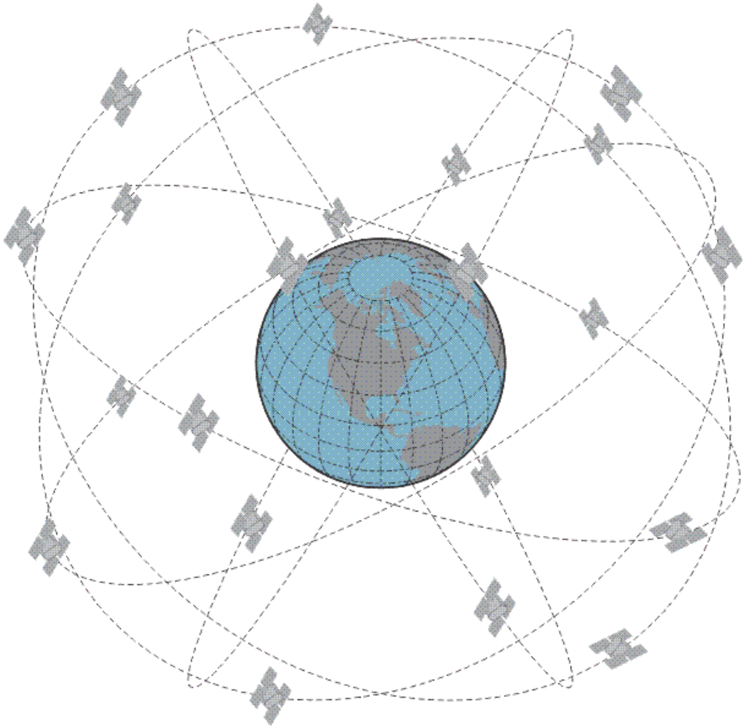


Image: GPS for Land Surveyors

The device that determines your position is a “GPS receiver” or “GPS user equipment”

NOT “a GPS”

Unless it is very old, it is probably actually a **GNSS** receiver

Image: Garmin

1. Introduction

What is GNSS?

GNSS = **G**lobal **N**avigation **S**atellite **S**ystem(s)

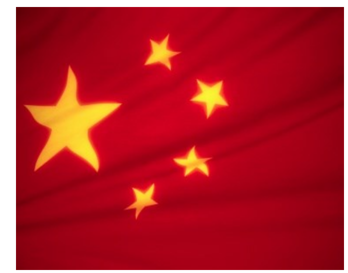
A generic term covering GPS and similar satellite navigation systems

Four global systems:

GPS
(United States)

GLONASS
(Russia)

Galileo
(European Union)



Beidou
(China)

And various regional augmentation systems

Most modern receivers use two or more of these systems

1. Introduction

GLONASS, Galileo and Beidou

GLONASS (Russia)

Developed in parallel with GPS from the 1970s

Fully operational in 1995, but not maintained

Fully operational again in 2011 and modernization

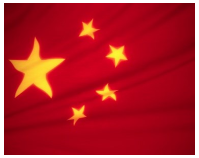
Galileo (European Union)

Development started in 1999

First main satellite launch in 2012

Initial operational capability in 2016

Beidou (China)



Development started in the 2000s

Regional system fully operational from 2012

Global system fully operational from 2020

1. Introduction

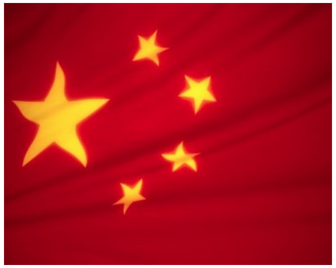
Terminology

In this session:

- “**GNSS**” is used for anything applicable to GPS, GLONASS, Galileo *and* Beidou
- “**GPS**” is used only for things that apply specifically to GPS

BUT lots and lots of people say “**GPS**” when they mean “**GNSS**”, including many receiver manufacturers – Ignorance Rules!



1. Introduction

How does GNSS work? (1)

Contrary to what you may have read in the newspapers:

- GNSS is NOT a "Spy in the Sky"
- It does NOT track users
- User equipment **only receives** GNSS signals
- The satellites **only transmit** to users
- Satellites only receive signals from the control segment
- Where equipment does report user position, this is **completely independent** of GNSS itself

1. Introduction

How does GNSS work? (2)

- Each satellite continuously transmits ranging signals
- GNSS user equipment measures signal arrival time, t_{sa}, from 4 (or more) satellites

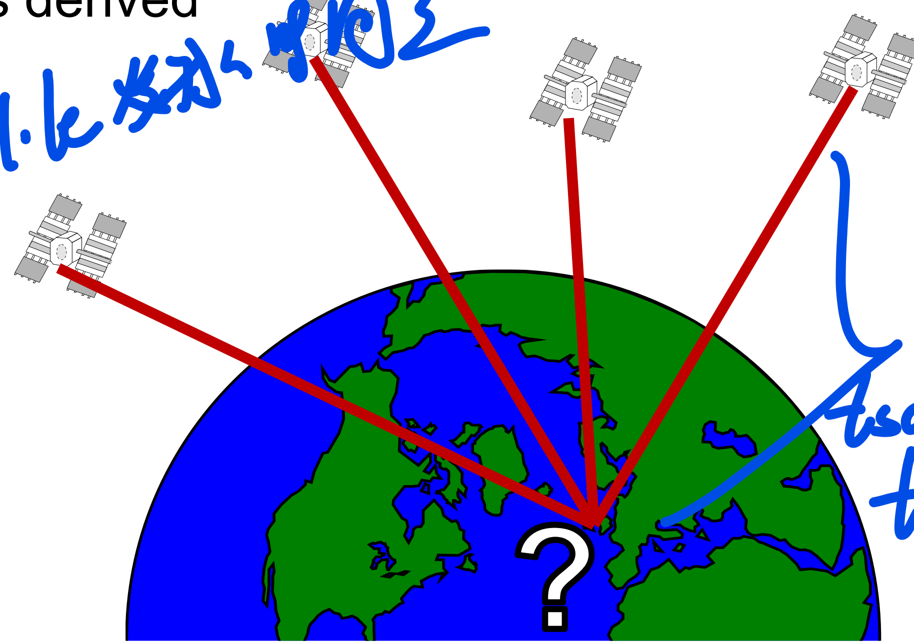
用户接收到信号的时间点

- Each transmission time, t_{st}, is derived from the signal modulation

$$\rho = c(t_{sa} - t_{st})$$

satellite发射的时间点

- This is pseudo-range, not range, because of unknown receiver clock offset
- With four pseudo-range measurements, the 3D user position and clock offset may be determined



$t_{sa} - t_{st}$

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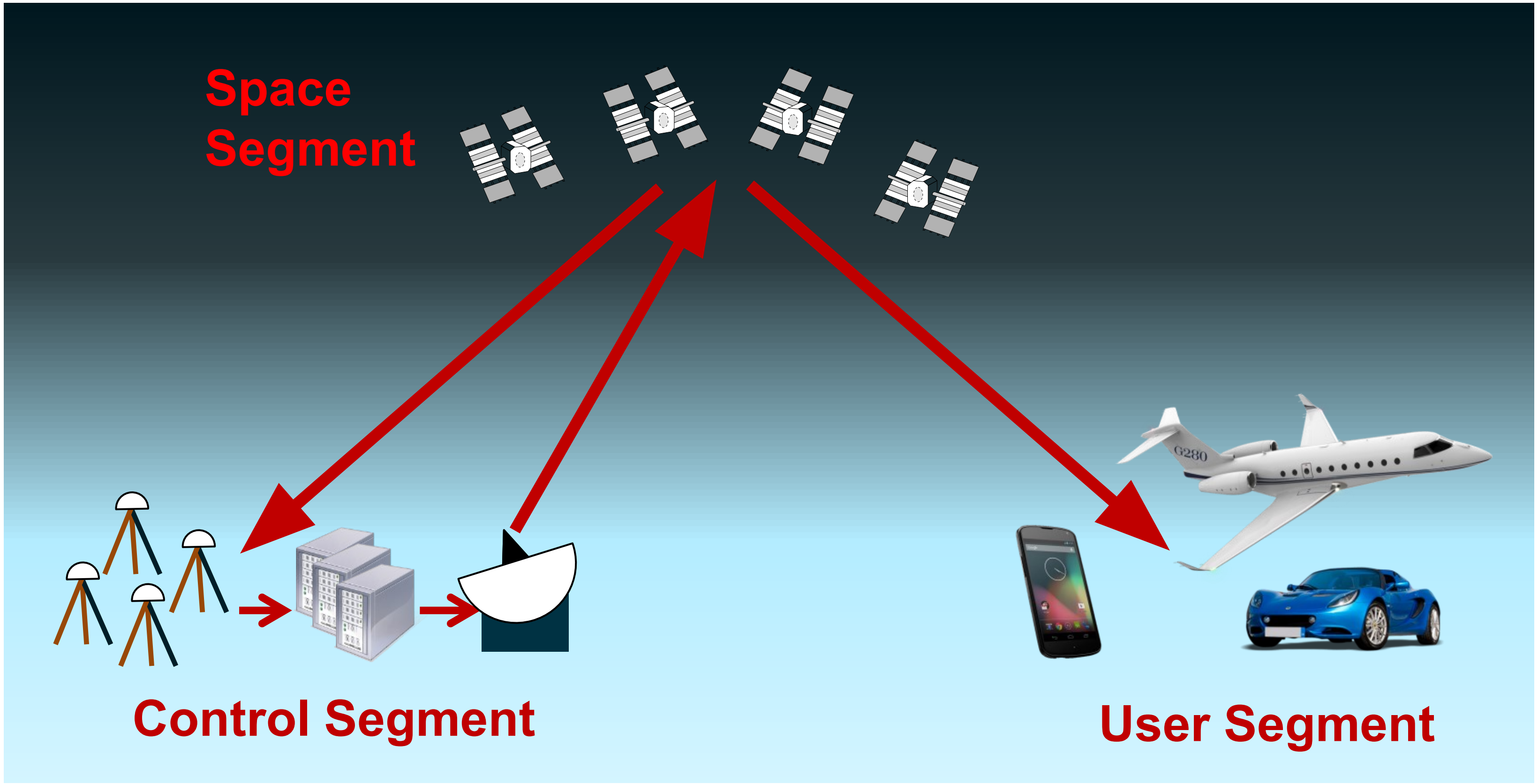
2. Components of GNSS

The Segments

Each GNSS comprises three segments



2. Components of GNSS

Space Segment: GPS

- Designed with at least **24** satellites
- Currently **31** active satellites
- Mid Earth orbit (MEO):
  - **26 600** km orbital radius
  - **20 100** km height
- **6** orbit planes at **55**° inclination separated by **60**° longitude

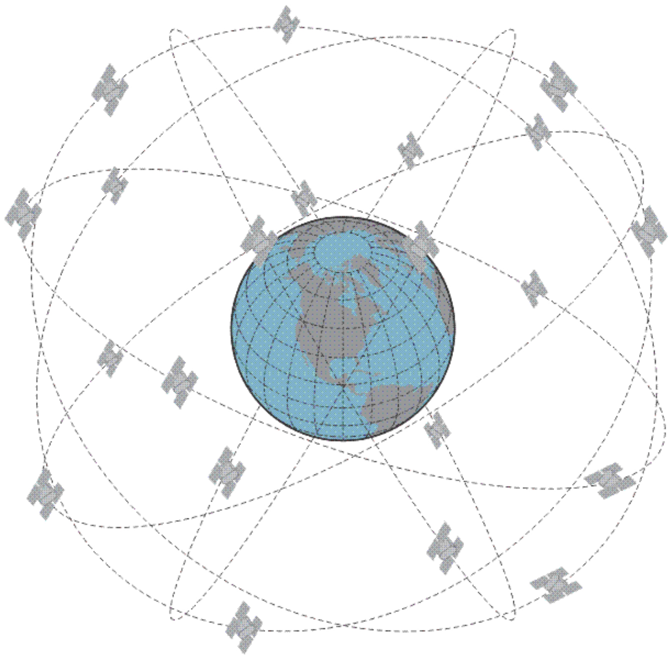


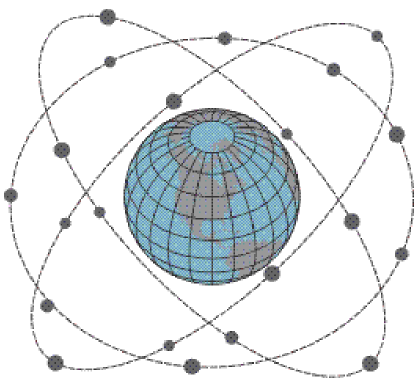
Image: GPS for Land Surveyors

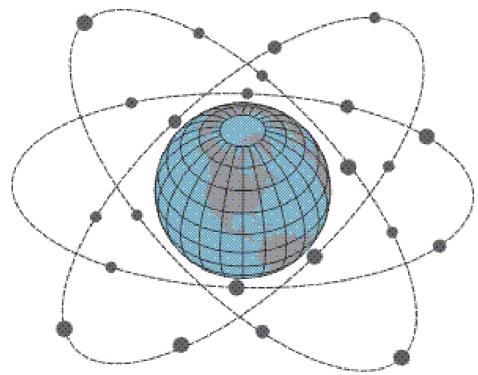
Multiple non-parallel planes are needed for:

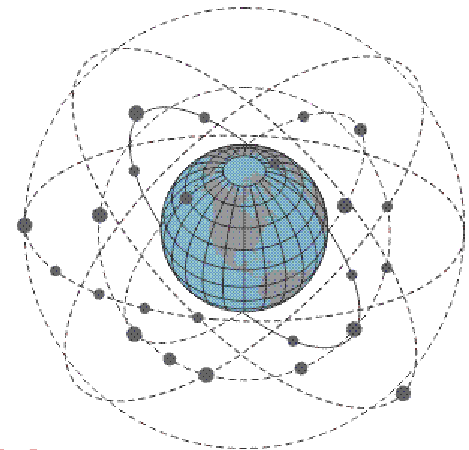
- Good coverage of the Earth
- Adequate signal geometry

2. Components of GNSS

Space Segment: GLONASS, Galileo, Beidou







GLONASS

- **24** satellites
- Radius **25 600** km
- **3** orbit planes at **64.8°** inclination separated by **120°** longitude

Galileo

- Nominally **30** satellites
- **24** currently working
- Radius **29 720** km
- **3** orbit planes at **56°** inclination separated by **120°** longitude

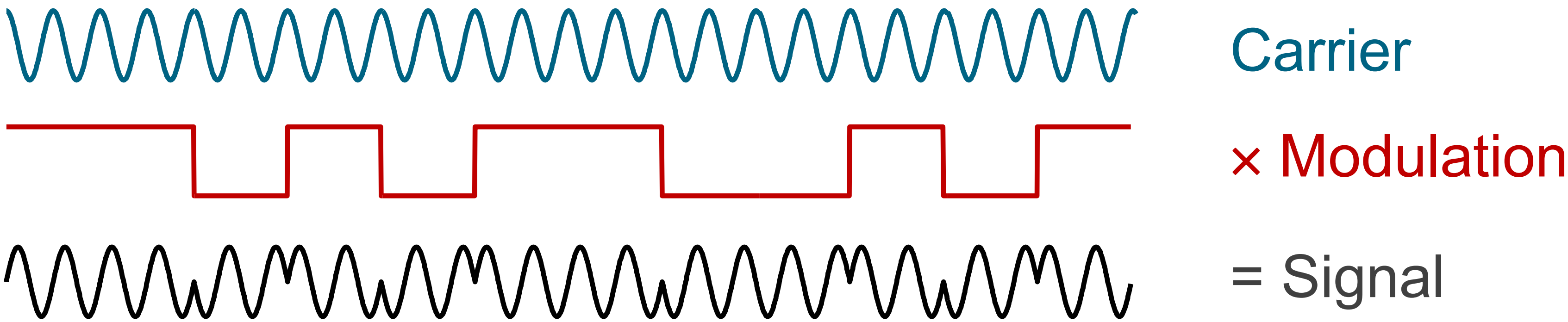
Beidou

- **27** MEO satellites
- Radius **28 000** km
- **3** orbit planes at **55°** inclination
- **+8** geosynchronous satellites

Images: GPS for Land Surveyors

2. Components of GNSS

GNSS Signal Structure



Modulation comprises

- **Pseudo-random noise** (**PRN**) ranging code, known to the receiver
  - Used to measure pseudo-range
  - Between 1,000,000 and 10,000,000 symbols per second
- On many signals, an unknown **Navigation Data Message**,
  - Contains satellite position, velocity, clock and other information
  - Between 50 and 1000 symbols per second

These are multiplied together

2. Components of GNSS

GNSS Signal Types

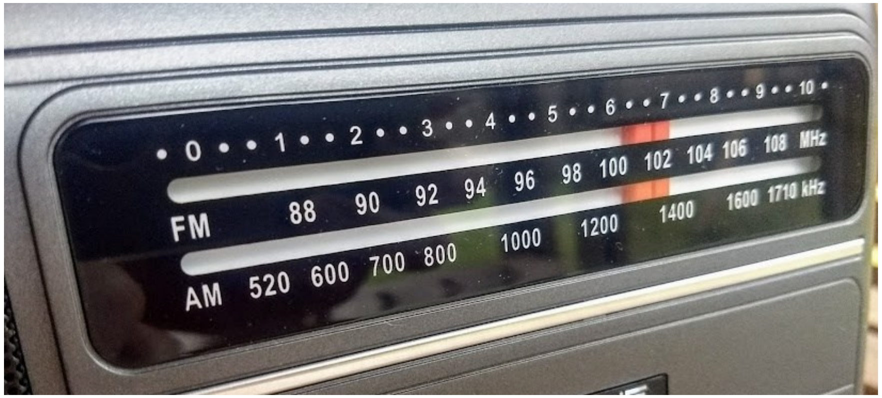
Each satellite transmits multiple signals

Three main types:

- Low-cost Open Access
- High-precision Open Access
- Encrypted

Multiple Frequencies are used for enhanced resilience

- **L1** (1575 MHz) for GPS, Galileo & Beidou low-cost signals
- **L5** (1176 MHz) for GPS, Galileo & Beidou high-precision signals
- Further frequencies are unique to each system



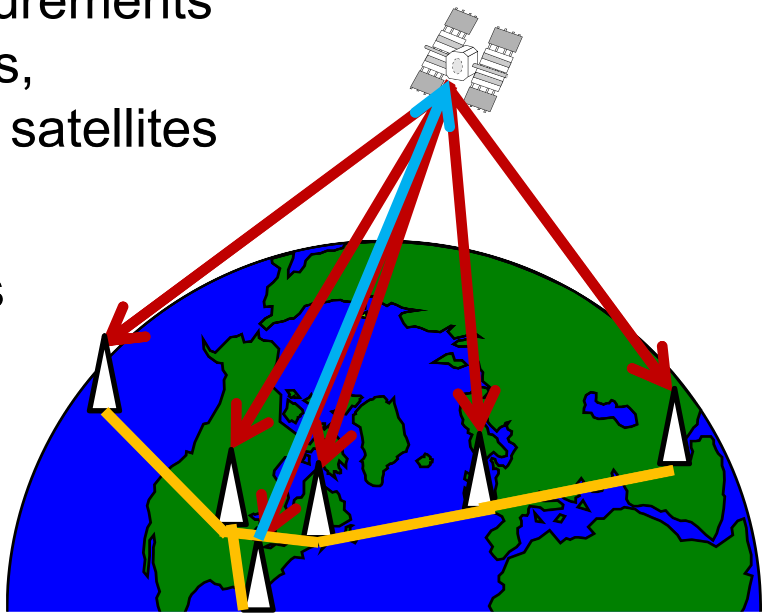
GPS, Galileo and Beidou use **Code division multiple access (CDMA)**

Satellites use the same frequencies with different ranging codes

2. Components of GNSS

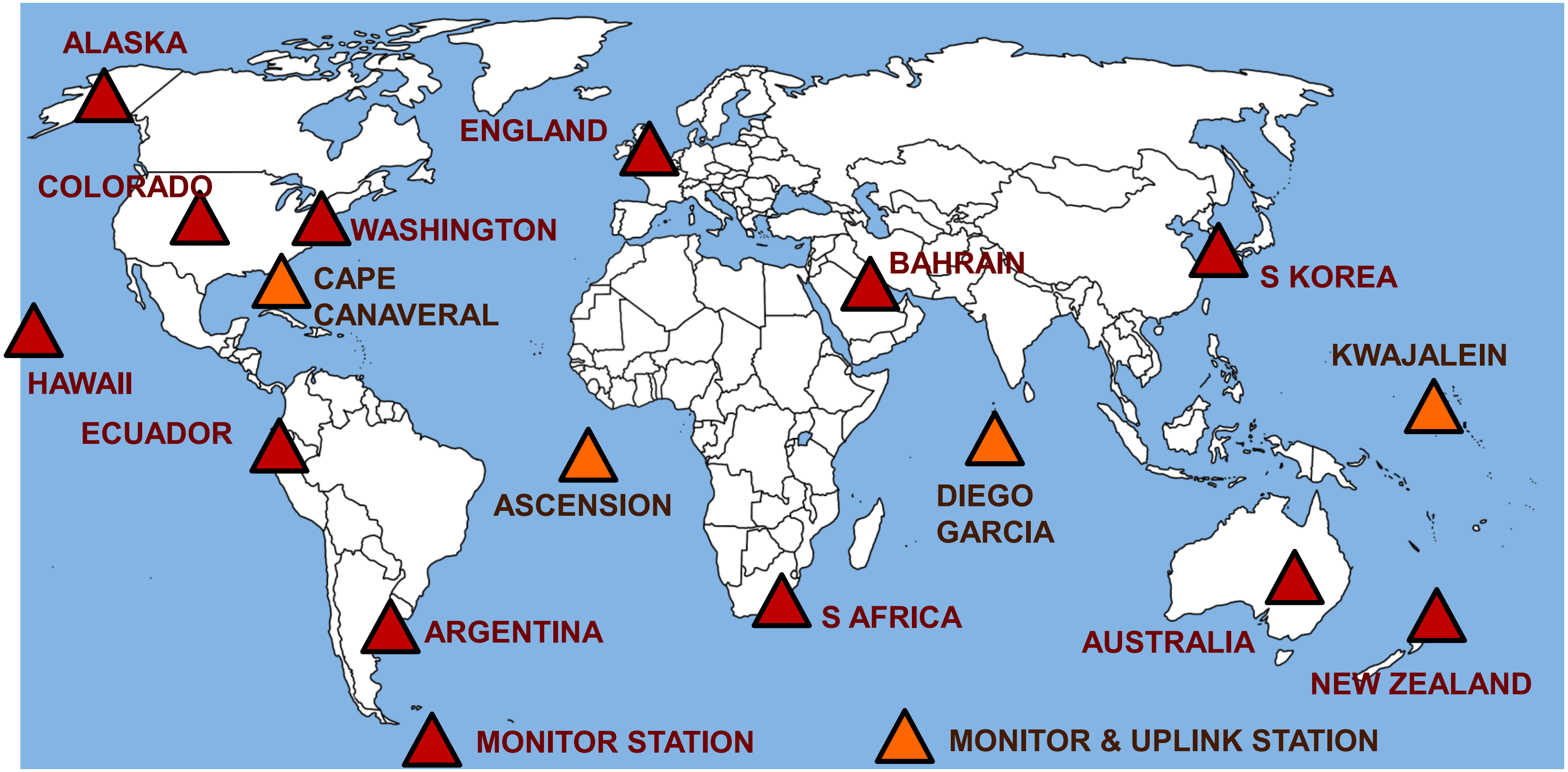
The Control Segment

- GPS, GLONASS, Galileo and Beidou have separate control segments
- Monitor stations around the world receive signals from the satellites
- As these stations are at known locations and have synchronised clocks, their measurements can be used to determine the positions, velocities and clock parameters of the satellites
- The measurements are sent to the master control station, which performs these calculations and generates commands for the satellites
- These are transmitted to the satellites using uplink stations near the equator



2. Components of GNSS

Example: GPS Operational Control Segment



2. Components of GNSS

GNSS User Equipment

User Antenna
Converts GNSS signals from radio to electrical

Receiver Hardware
Downconverts, Samples & Correlates Signals

Ranging Processor
Acquires and tracks the signals

Navigation Processor
Computes position solution

Images from the manufacturers

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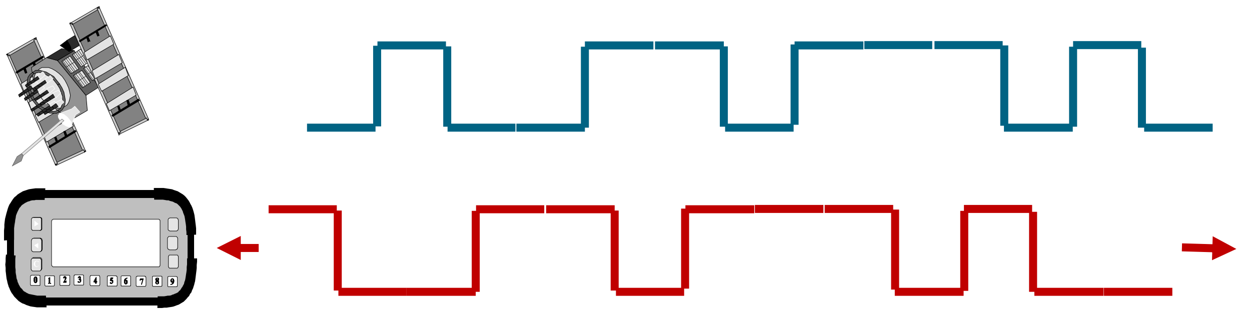
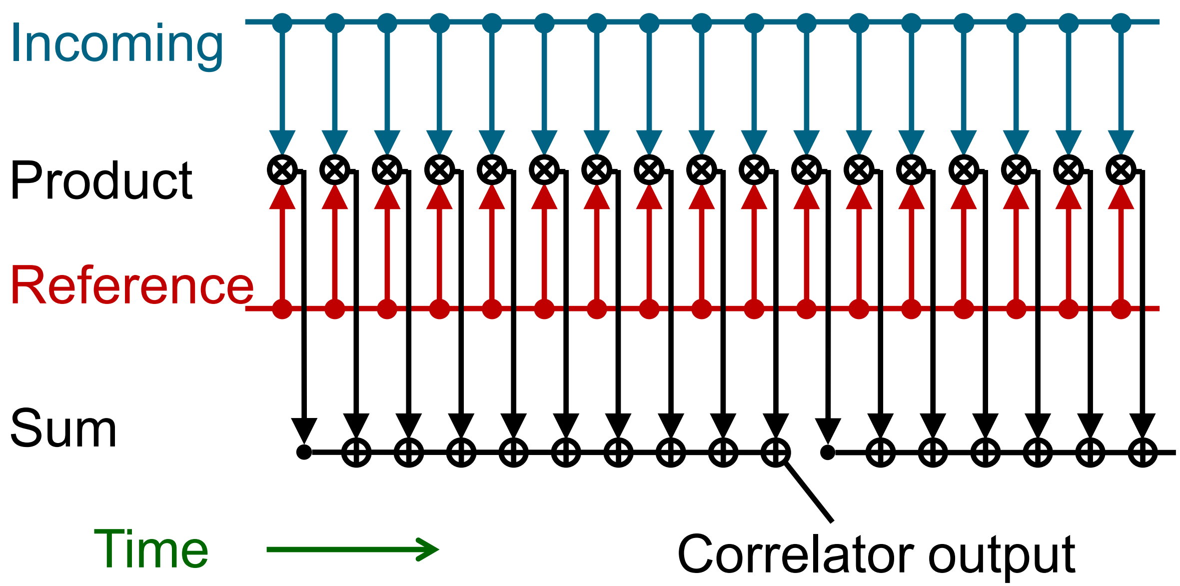
3. How GNSS Positioning Works

Code Correlation of GNSS Signals

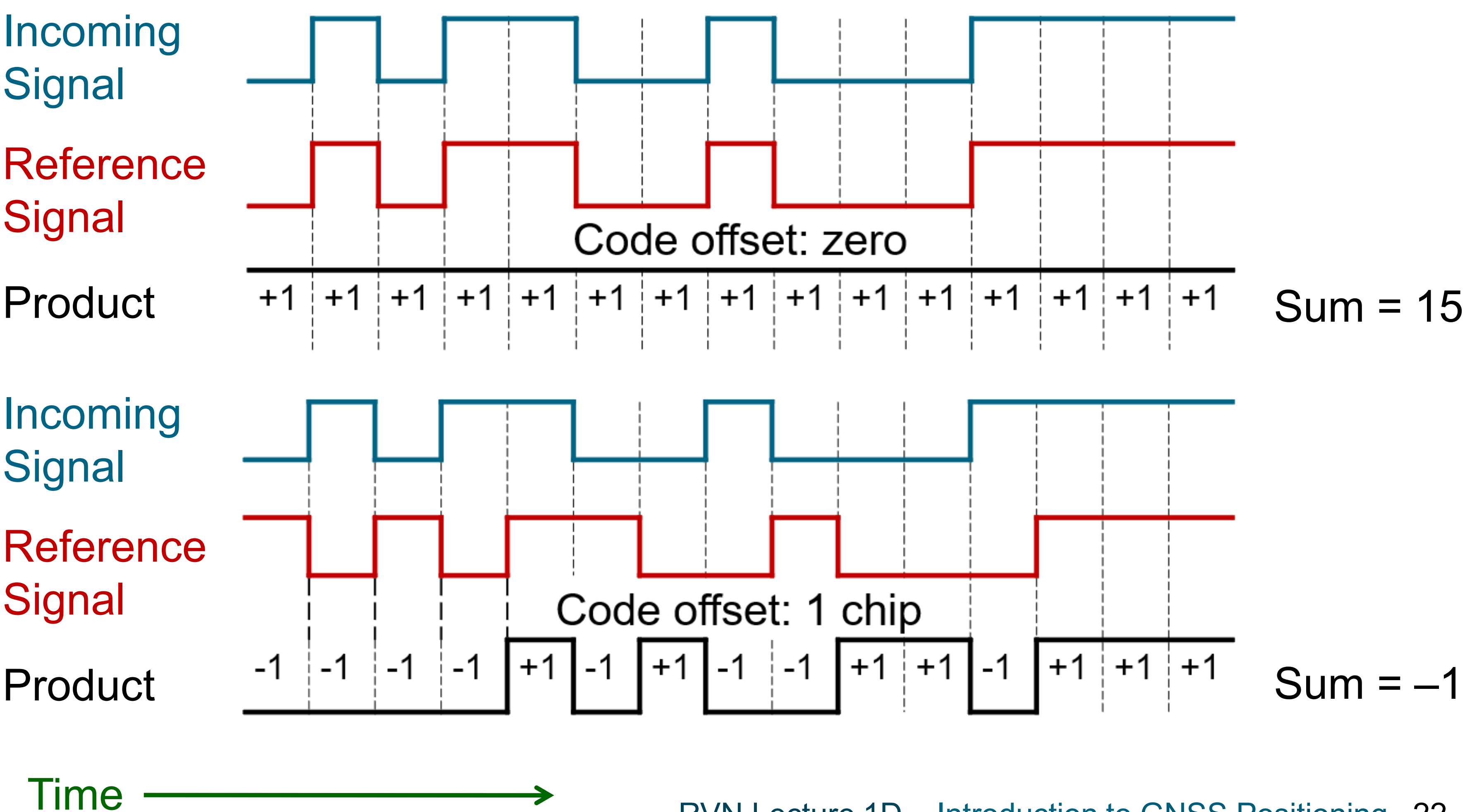


GNSS signals are modulated with a known pseudo-random noise (PRN) code

This is correlated with a receiver-generated replica to determine pseudo-range

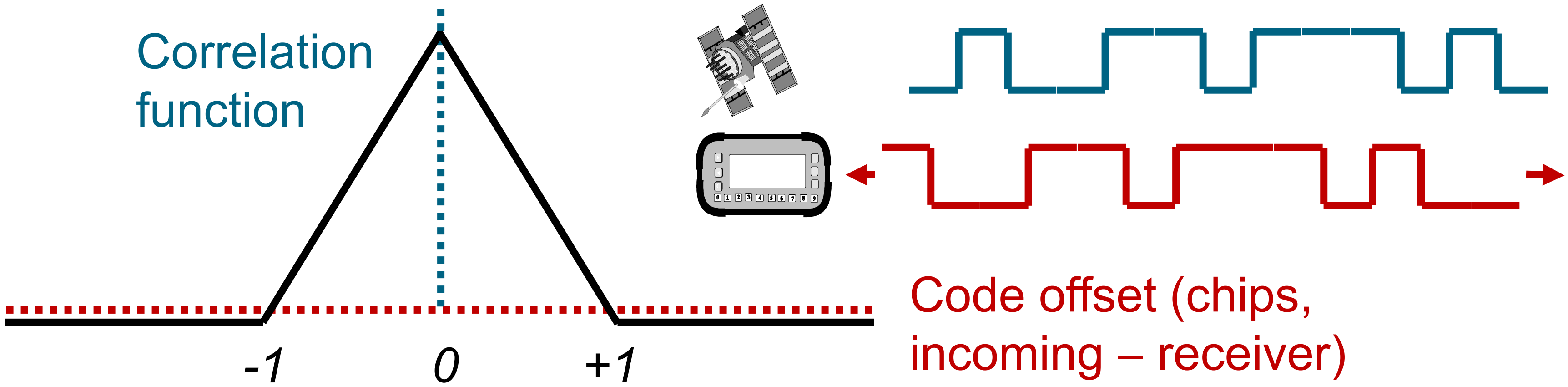


Correlation of Aligned and Misaligned Codes



3. How GNSS Positioning Works

Pseudo-range measurement



- Reference signal timing is adjusted to find the correlation maximum
- Pseudo-range is proportional to this time shift

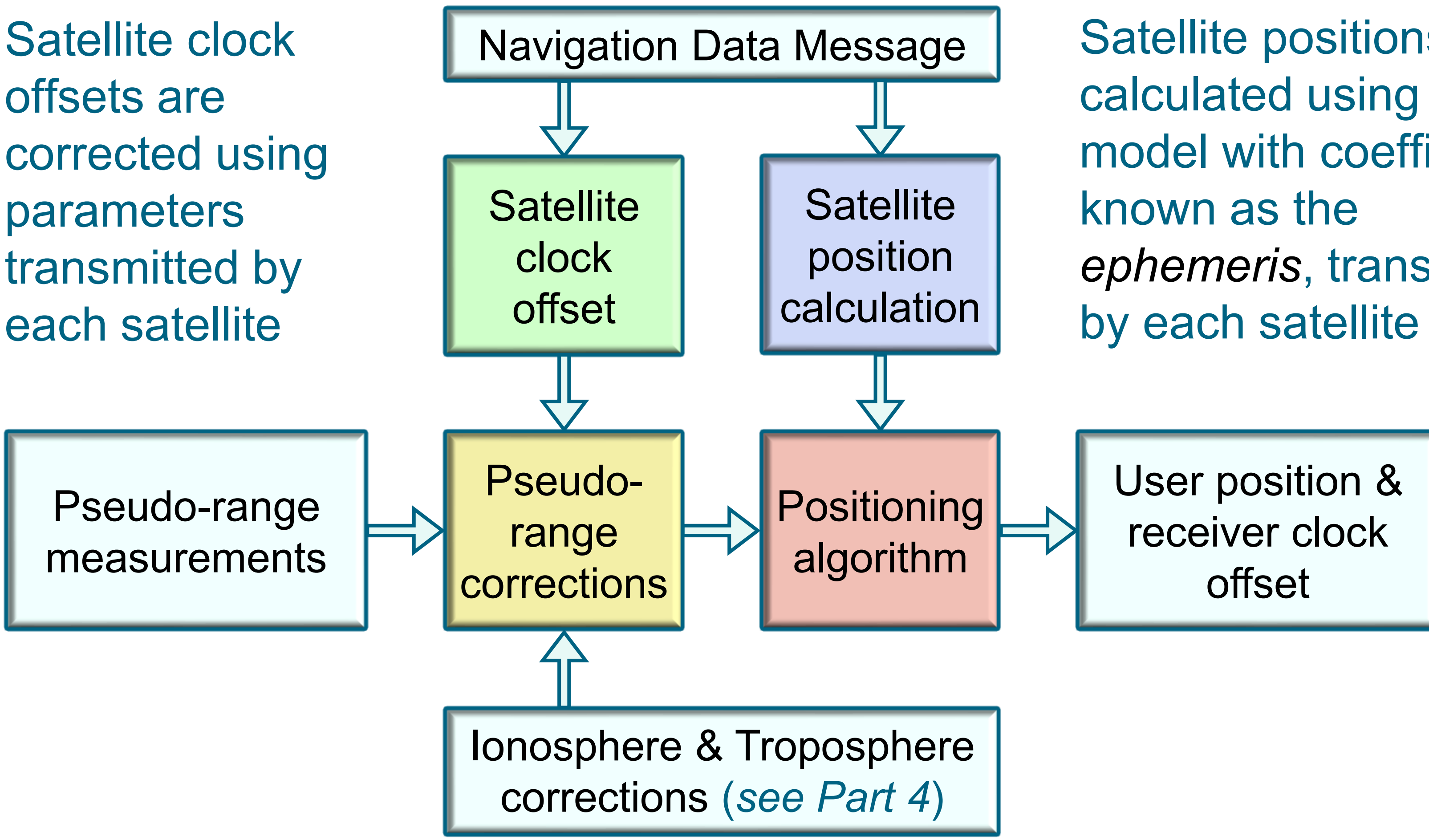
The reference is actually correlated with the sum of *all* incoming signals on a given frequency, BUT…

- Each satellite transmits a different PRN code
- The correlator output with non-matching codes is always very low
- Thus interference is minimised, so code division multiple access (CDMA) works

3. How GNSS Positioning Works

The Positioning Process

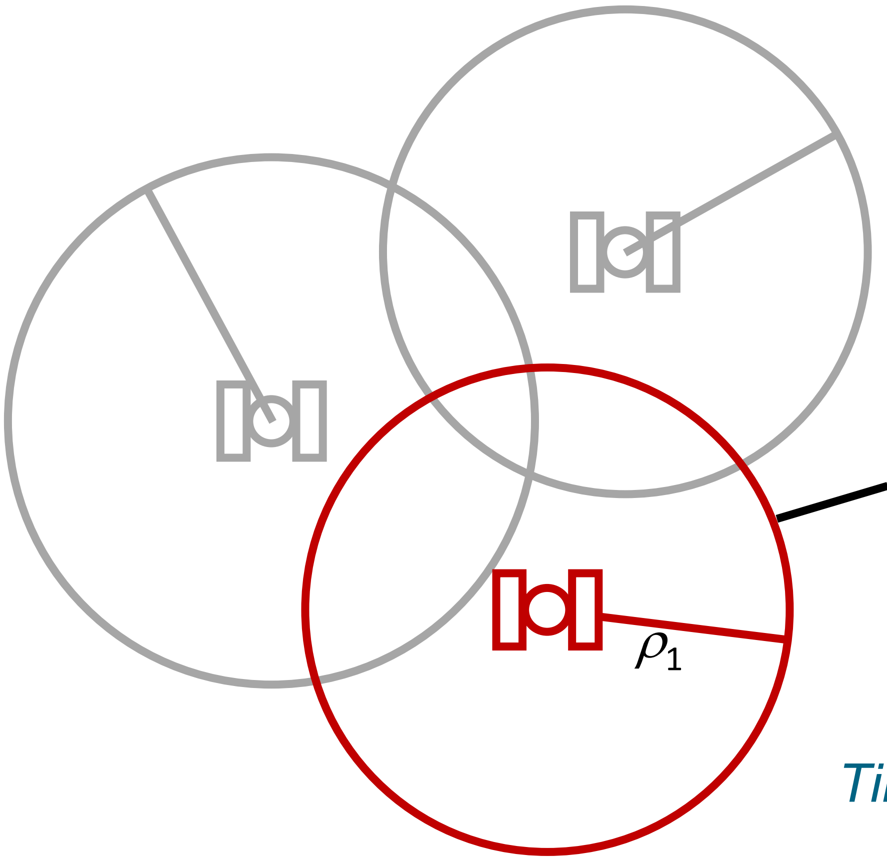
Satellite clock offsets are corrected using parameters transmitted by each satellite



Satellite positions are calculated using a model with coefficients, known as the *ephemeris*, transmitted by each satellite

3. How GNSS Positioning Works

Positioning geometry in 3 dimensions (1)

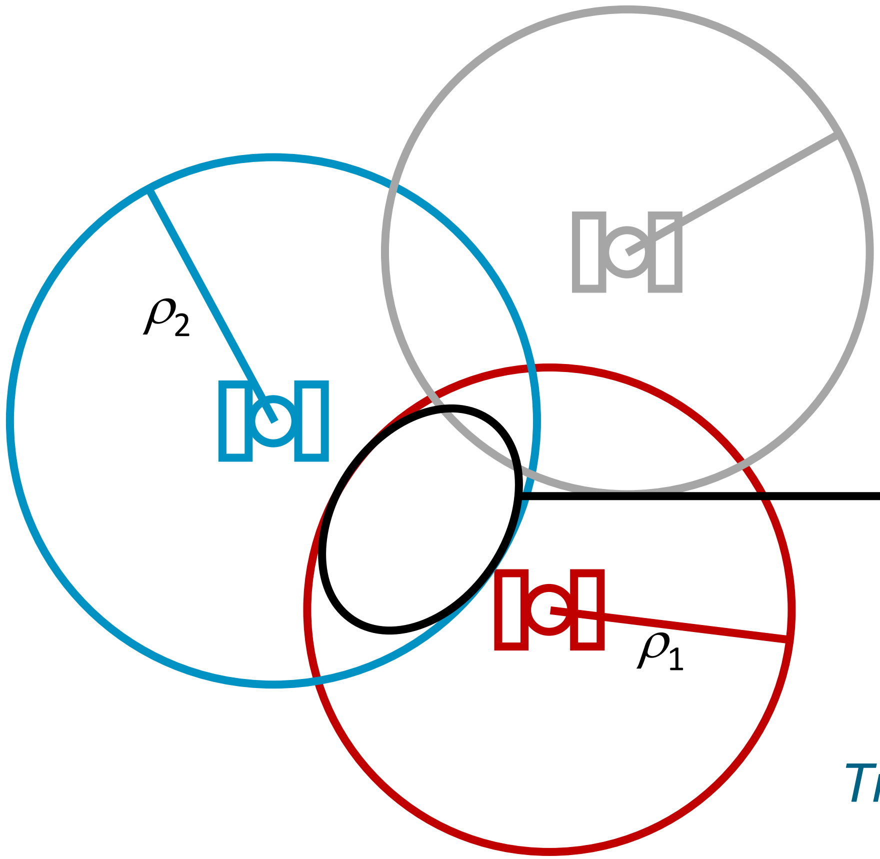


Single range position locus (surface of sphere)

Timing errors are neglected

3. How GNSS Positioning Works

Positioning geometry in 3 dimensions (2)

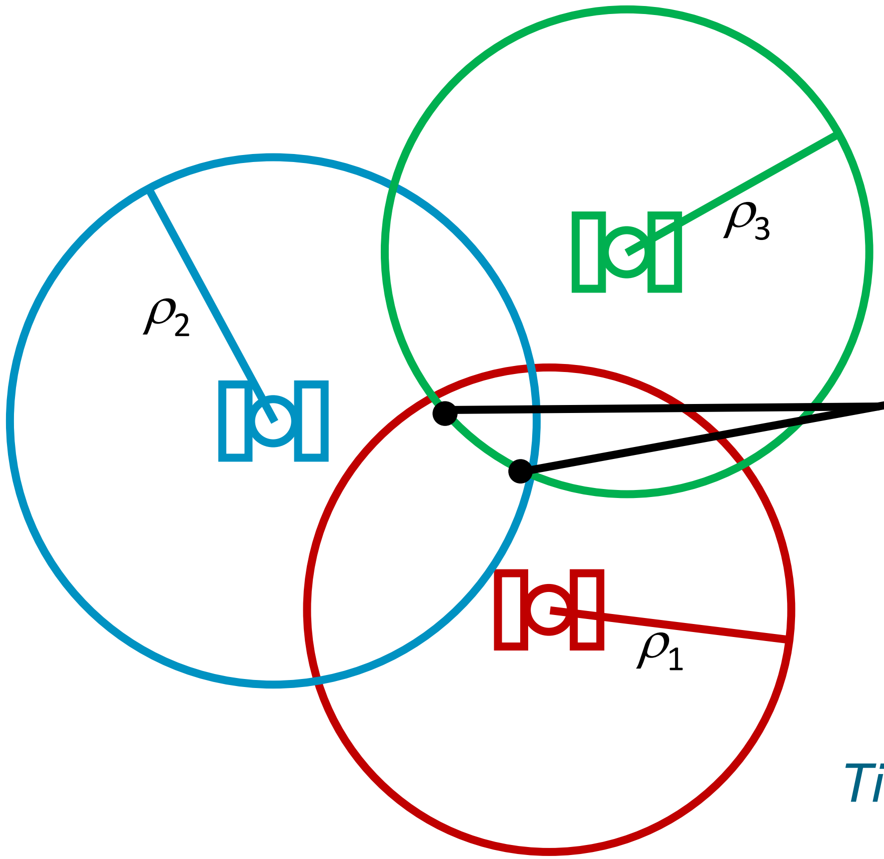


Dual range position locus (circle of intersection)

Timing errors are neglected

3. How GNSS Positioning Works

Positioning geometry in 3 dimensions (3)



Three-range position solutions

Usually one solution is infeasible:

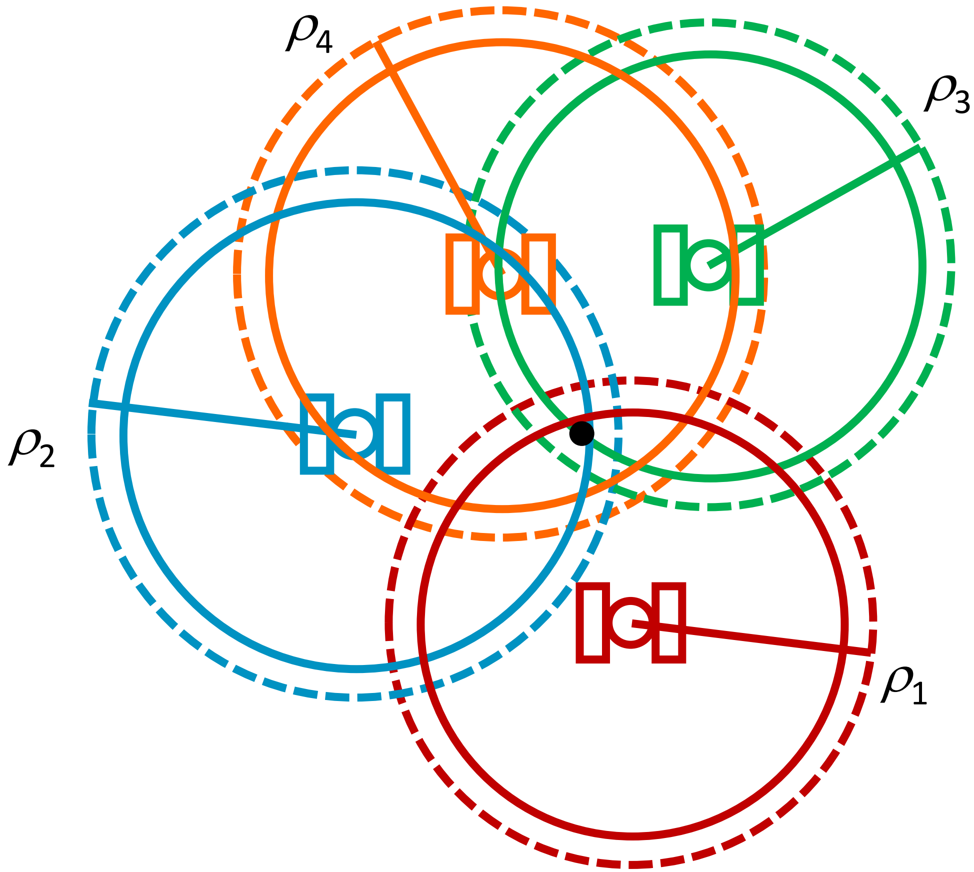
In space or

Inside the Earth

Timing errors are neglected

3. How GNSS Positioning Works

Positioning geometry in 3 dimensions (4)



The position solution is determined by the *ranges*

With GNSS, we have *pseudo*-ranges, due to the receiver clock error

A 4th satellite is needed to determine this

An unknown correction must be applied to the pseudo-ranges to obtain spheres that intersect

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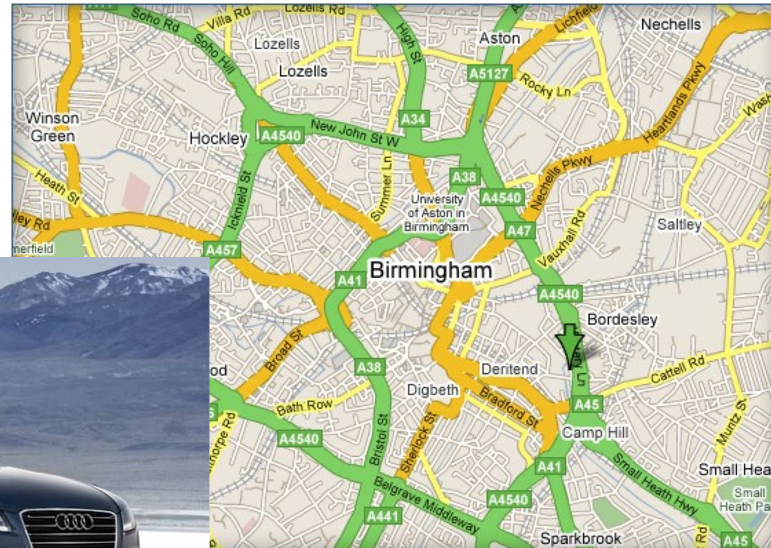
4. General Applications

“Satnav” for cars



Integrated with mapping and route guidance

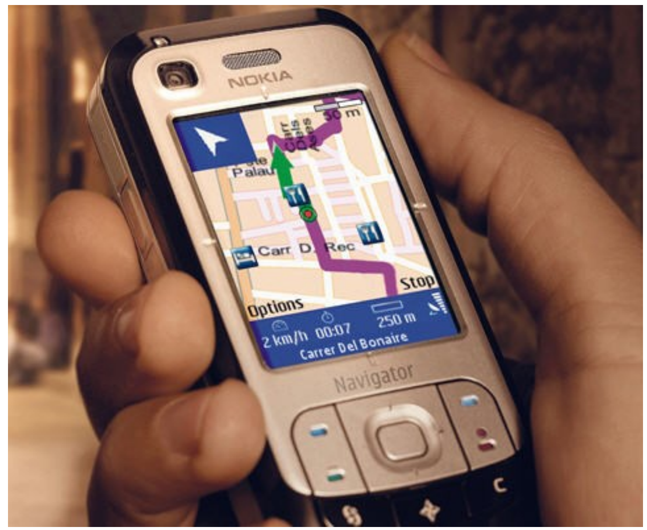
4. General Applications

Public Transport

Safety critical

4. General Applications

Mobile Phones



- Emergency caller location (E911/E112)
- Location-based services
- Mobile gaming