GNSS, How it Works and Applications
Historic Navigation

• Reference points in the sky used for navigation
  – The Sun
  – The Pole Star / North Star
  – Southern Cross

• Gives Direction, but not position

• Add a sextant to give latitude

• And a clock to give longitude
GNSS Principles

- GNSS satellites in the sky are the new reference points.
- If my GNSS receiver "sees" 4 or more satellites, it can compute my position.
  - "see" means track and process navigation signals.
Satellites as Accurate Reference Points

- GNSS signals contain information about the satellites' positions
  - very accurate reference points
- Measure the distance from the satellites to the receiver
- Knowing at least three distances from three reference points gives position
How do you measure distance?

\[ \text{speed} = \frac{\text{distance}}{\text{time}} \]

\[ \Rightarrow \text{distance} = \text{speed} \times \text{time} \]

Satellite signals contain 'time stamps':
\[ \text{time} = t_{\text{sent}} - t_{\text{received}} \]

Radio waves travel at light speed "c":
- 300,000km in 1 second
- 300km in 1ms (1/1000th)
- 300m in 1µs (1/millionth)
- 300mm in 1ns
Compute position

distance = speed \times time

- speed = 3 \times 10^8 \text{ m/s}
- time = t_{sent} - t_{received}

- but, receiver time not accurately known
- so the time stamp from a fourth satellite is measured
- compensates for the missing receiver time
Example GNSS Signal

- radio frequency at "L-band"
  - typically 1575MHz
- at satellite: signal energy spread by a code
- at receiver: spread signal energy is unlocked and refocused
  - "code gain"
- allows simple antennas to receive low power signals
- and to share the frequency with other satellites/systems
Position relative to?

- A position is pointless without having a ground reference.
- A world reference is used, e.g., WGS84 - World Geodetic System 1984.
- Allows position fix to be placed on a World grid.
- Maps can be referenced to the same grid.
- You can determine where you are on a map.
What is GNSS used for?

PNT

• Positioning… surveying and mapping
  – location based services
  – air traffic management
  – search and rescue

• Navigation… a given. cars, ships, cranes
  – remember GNSS gives position, you still need reliable/up-to-date maps and routing software

• Timing?… most large networks synchronised
  – telecoms
  – electricity distribution
  – banking… microseconds matter for transactions!
What about?

• Monitoring sea/lake/snow levels
  – uses GNSS reflections seen into a fixed receiver

• Atmospheric measurements
  – GNSS signals change as they pass through atmosphere: air quality, gaseous content, etc

• Space weather monitoring
  – measuring changes in the ionosphere

• Soil and vegetation moisture measurements

• Volcanic plume density measurements
  – atmospheric ash uncertainty after eruptions

• Sea surface roughness, wind direction and more

• Earthquake/tsunami monitoring….

 etc, etc……
GNSS compared to terrestrial signals (why GNSS is vulnerable)
GNSS signal power

- radio waves disperse energy as they propagate
- satellites are 23,000km away
- signal emitted at about 30W
- signal strength proportional to: $\frac{1}{\text{distance}^2}$
- at 23,000 km, GNSS signal reduced by a factor of about $10^{18}$!
- Imagine trying to see a lightbulb 23,000km away
- signal levels are below the natural background radiation
Terrestrial signal powers

- mobile phone base station
  - typical transmit power, 10-100W
  - signal power reduction depends on range
  - at 10km, signal power reduced by factor of $10^{11}$
  - at 1km, reduced by $10^9$
  compared to the GNSS signal ($10^{18}$ reduction) it is over billion times stronger

- mobile phone, typical transmit power, 0.1-1W
  connected to a cell tower at 1km
  - typical signal reduction $10^9$
  still over a million times stronger than the GNSS signal!
Expected receiver signal power levels

- GNSS receivers expect to receive and can operate at signal levels even below the natural background radiation level, the "noise floor"

- **GNSS receivers** need a minimum power level "$-130\text{dBm}"
  - GNSS receivers designed to work at these low levels
  - provided they are not overloaded by other signals
  - modern GNSS receivers can use even lower levels!

- **Mobile phones** (eg GSM) expect a minimum "$-104\text{dBm}"
  - around a thousand times higher than GNSS
Consequences of the different levels

- The large difference between GNSS and mobile signal levels make GNSS receivers comparatively more susceptible to interference.
  - Mobile network devices also have the luxury of being able to raise their power levels in steps to cope with obstructions and poor radio environments - GNSS cannot, the low power level is fixed.
- If GNSS signals shared frequencies with mobile systems, they would be swamped by interference.
- GNSS reception would not be possible.
How do you avoid interference?

• To avoid such interference, the **Radio Regulations** separate different types of services (eg terrestrial mobile, satcoms, TV) into different frequency bands
  – eg mobile at 900MHz
  – TV at 600MHz
  – satcoms at 1650MHz
  – GNSS at 1575MHz

• However, when high power services operate in nearby frequencies, interference to GNSS is still possible (covered later)

* the Radio Regulations is treaty text agreed between the 195 member states of the International Telecommunication Union