Workshop on GNSS for Policy and Decision Makers
21st January 2022

Basic GNSS Introduction and Applications

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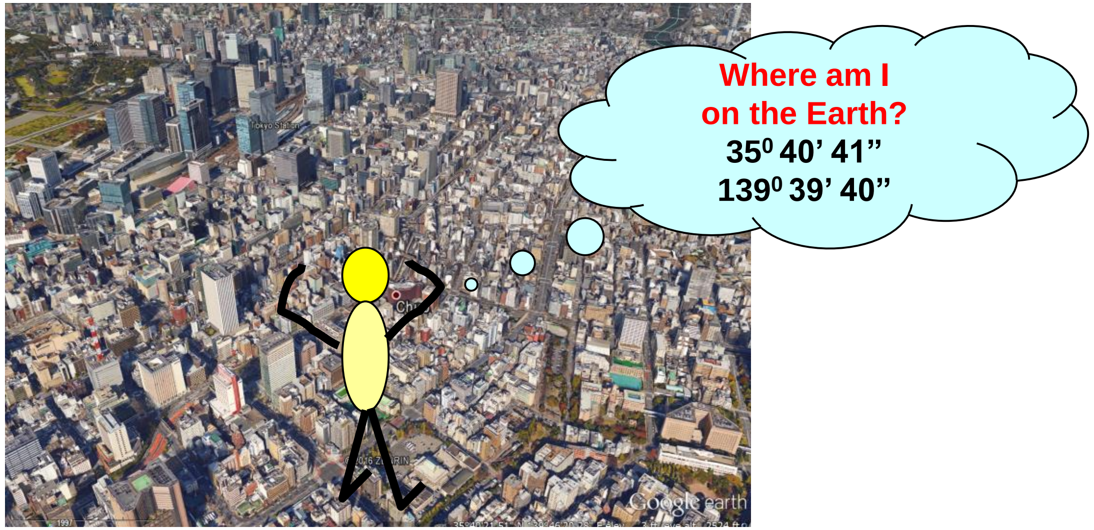
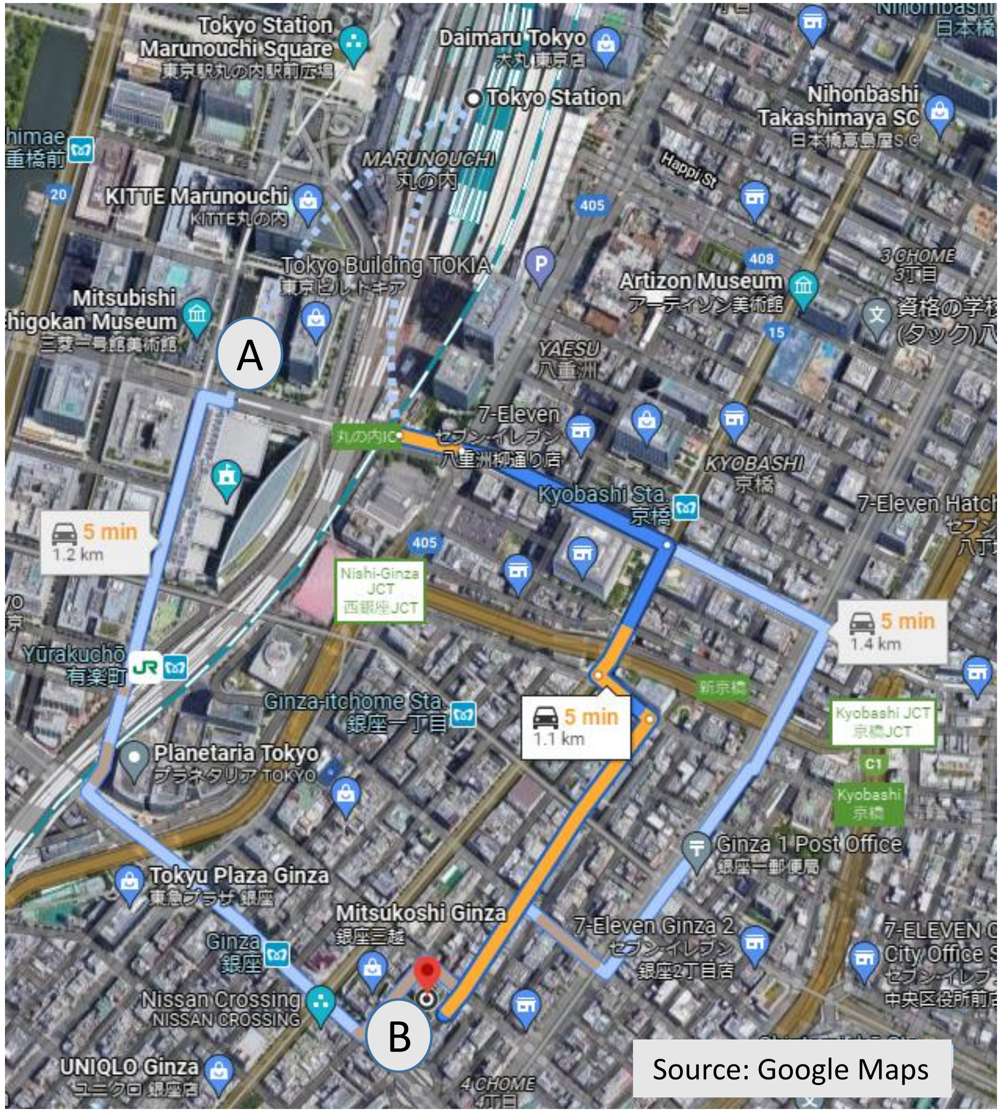
Fundamental Problem

- **How to know my location precisely ?**
  - **In any condition**
  - **At any time**
  - **Everywhere on earth (at least outdoors!)**
- **How to navigate to the destination?**
  - **Guidance or Navigation**
- **How to synchronize time globally?**
  - **Mobile phones**
  - **Financial Institutes**



How to go from A to B?



Navigation Types

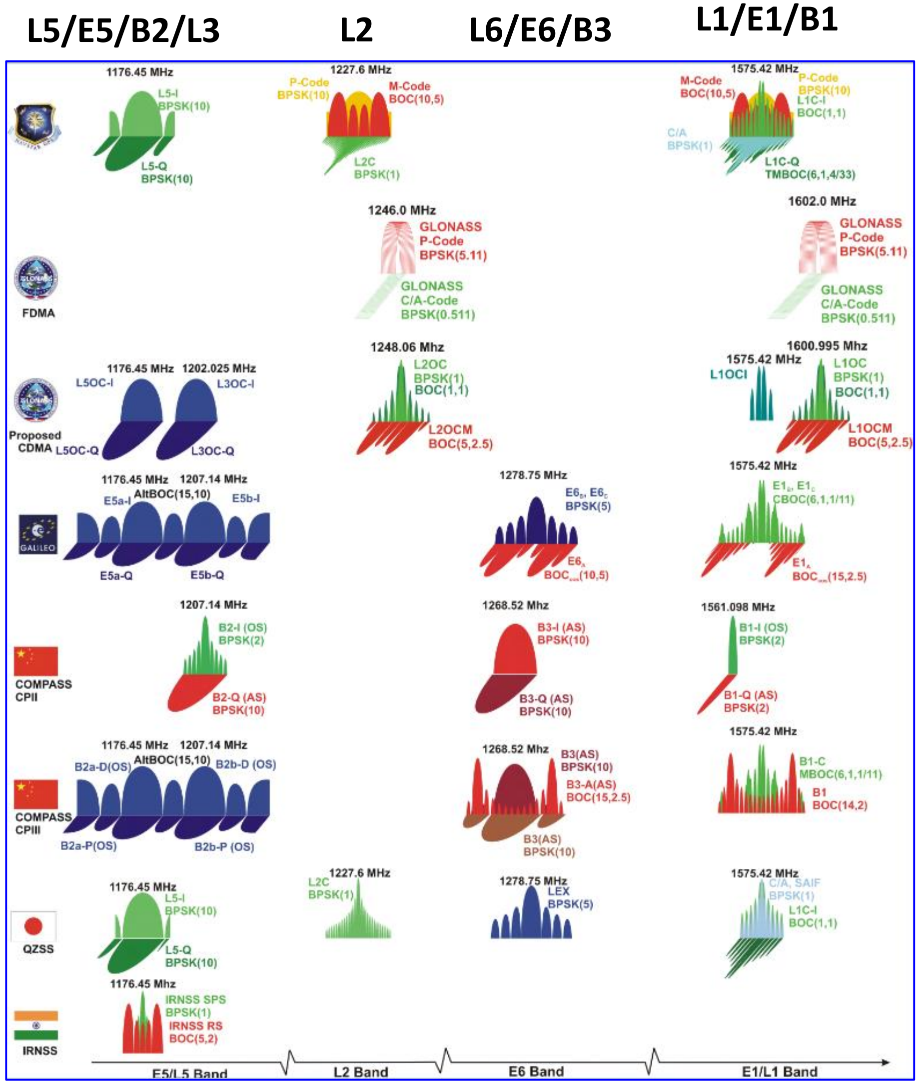
- Landmark-based Navigation
  - Stones, Trees, Monuments
    - Limited Local use
- Celestial-based Navigation
  - Stars, Moon
    - Complicated, Works only at Clear Night
- Sensors-based Navigation
  - Dead Reckoning
    - Gyroscope, Accelerometer
    - Compass, Odometer
    - Error accumulate quickly (Drift Error)
- Radio-based Navigation
  - LORAN, OMEGA
    - Subject to Radio Interference, Jamming, Limited Coverage
- Satellite-based Navigation or GNSS
  - TRANSIT (not used anymore)
  - GPS, GLONASS, GALILEO, QZSS (Michibiki), BEIDOU (COMPASS), NavIC (IRNSS)
    - Global service, QZSS and NavIC are regional
    - High Accuracy & Reliability

What is GNSS?

- GNSS or Global Navigation Satellite System is an acronym used to represent all navigation satellite systems such as

Satellite	Country	Coverage
GPS	USA	Global
GLONASS	Russia	Global
Galileo	Europe	Global
BeiDou (BDS)	China	Global
QZSS (Michibiki)	Japan	Regional
NavIC	India	Regional

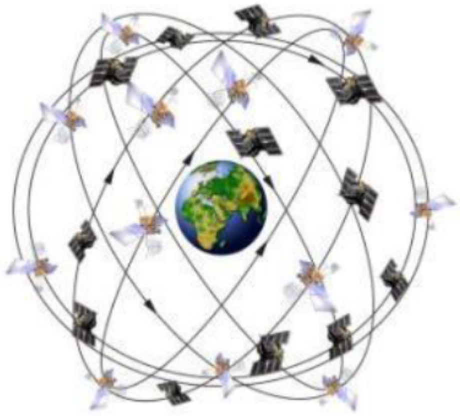
- ✓ GPS and GLONASS have signals for civilian and military usage
  - ❖ Military signals are encrypted and not available for civilian use
- ✓ Galileo and BeiDou also have Open and Restricted Signals
- ✓ All civilian signals are freely available
- ✓ Technical information for civilian signals are made public
  - ❖ Necessary to develop a receiver
  - ❖ Its called ICD (Interface Control Document) or IS (Interface Specification)



https://gssc.esa.int/navipedia/images/c/cf/GNSS_All_Signals.png

GPS (USA)

GPS Constellation Status



37 Satellites • 29 Set Healthy
Baseline Constellation: 24 Satellites

Satellite Block	Quantity	Average Age (yrs)	Oldest
GPS IIR	6 (6*)	20.0	24.4
GPS IIR-M	7 (1*)	14.2	16.3
GPS IIF	12	8.0	11.6
GPS III	4 (1*)	1.7	3.0

*Not set healthy

As of 01 Jan 2022

GPS Signal in Space (SIS) Performance

From 01 Jan 21 to 01 Jan 22

Average URE*	Best Day URE	Worst Day URE
47.3 cm	31.5 cm (20 Apr 21)	70.4 cm (13 Mar 21)

*All User Range Errors (UREs) are Root Mean Square values

Source: This slide is taken from "GPS Programme Update and International Activities to Protect GNSS Spectrum"
Link: https://www.unoosa.org/oosa/en/ourwork/icg/activities/2022/CSISTokyo/presentations.html

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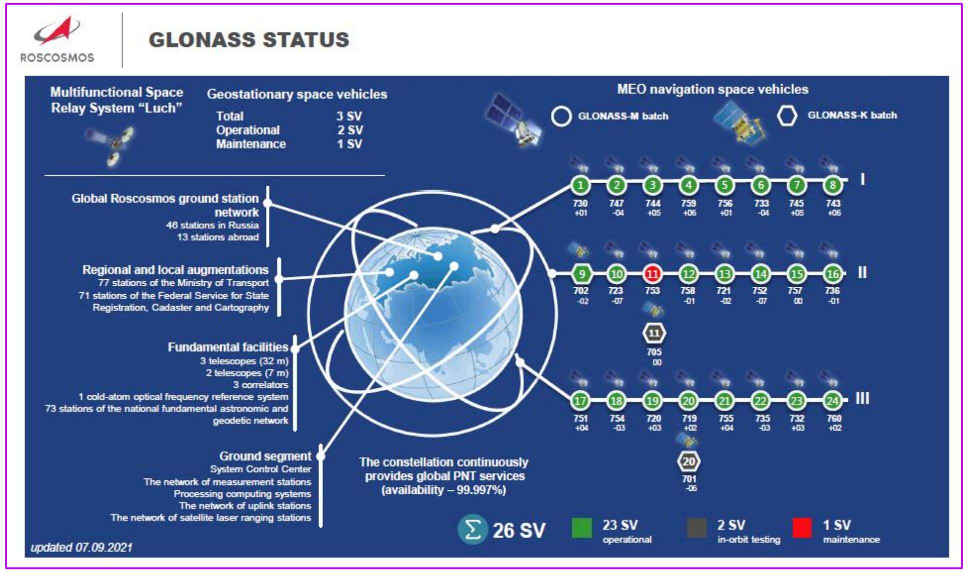
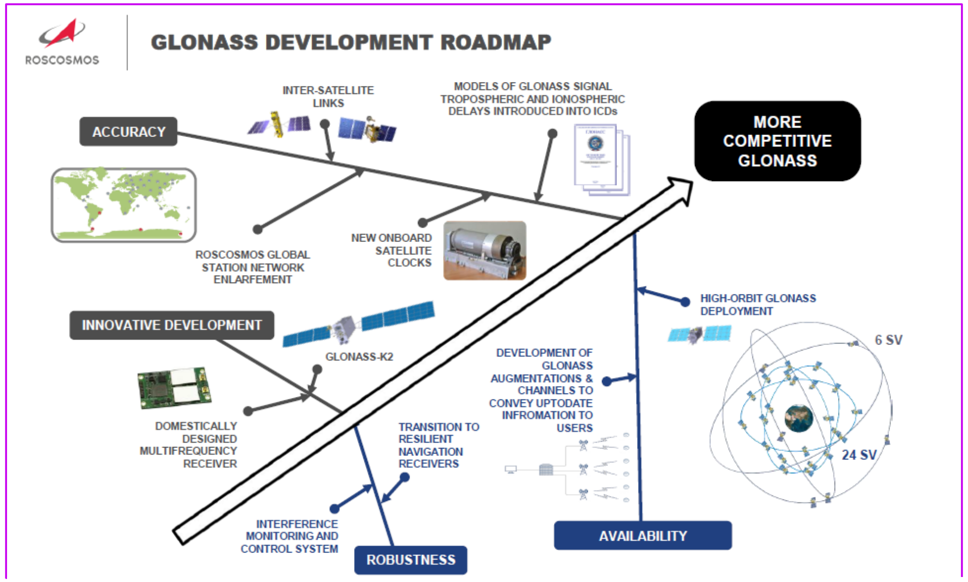
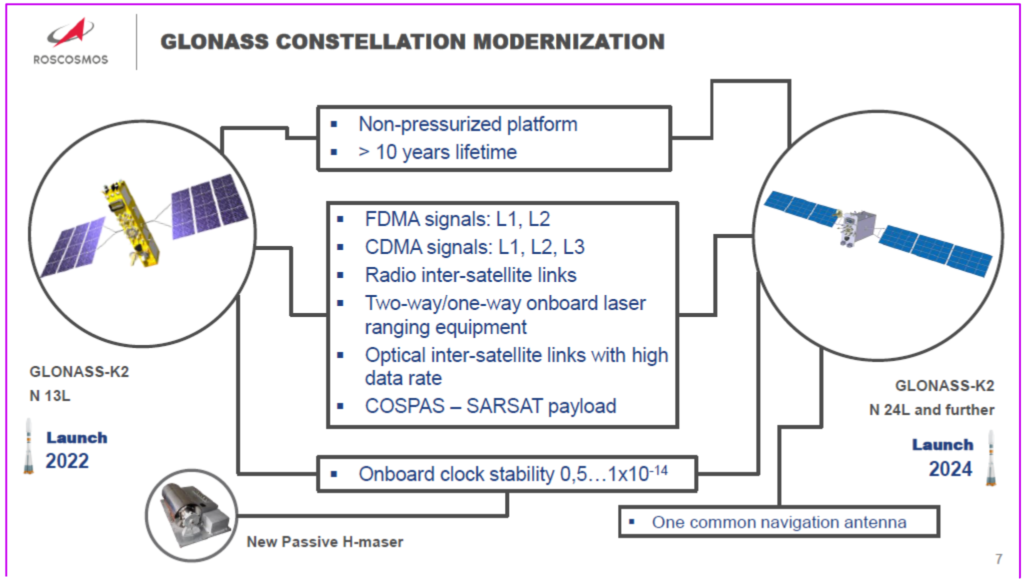
GLONASS (Russia)



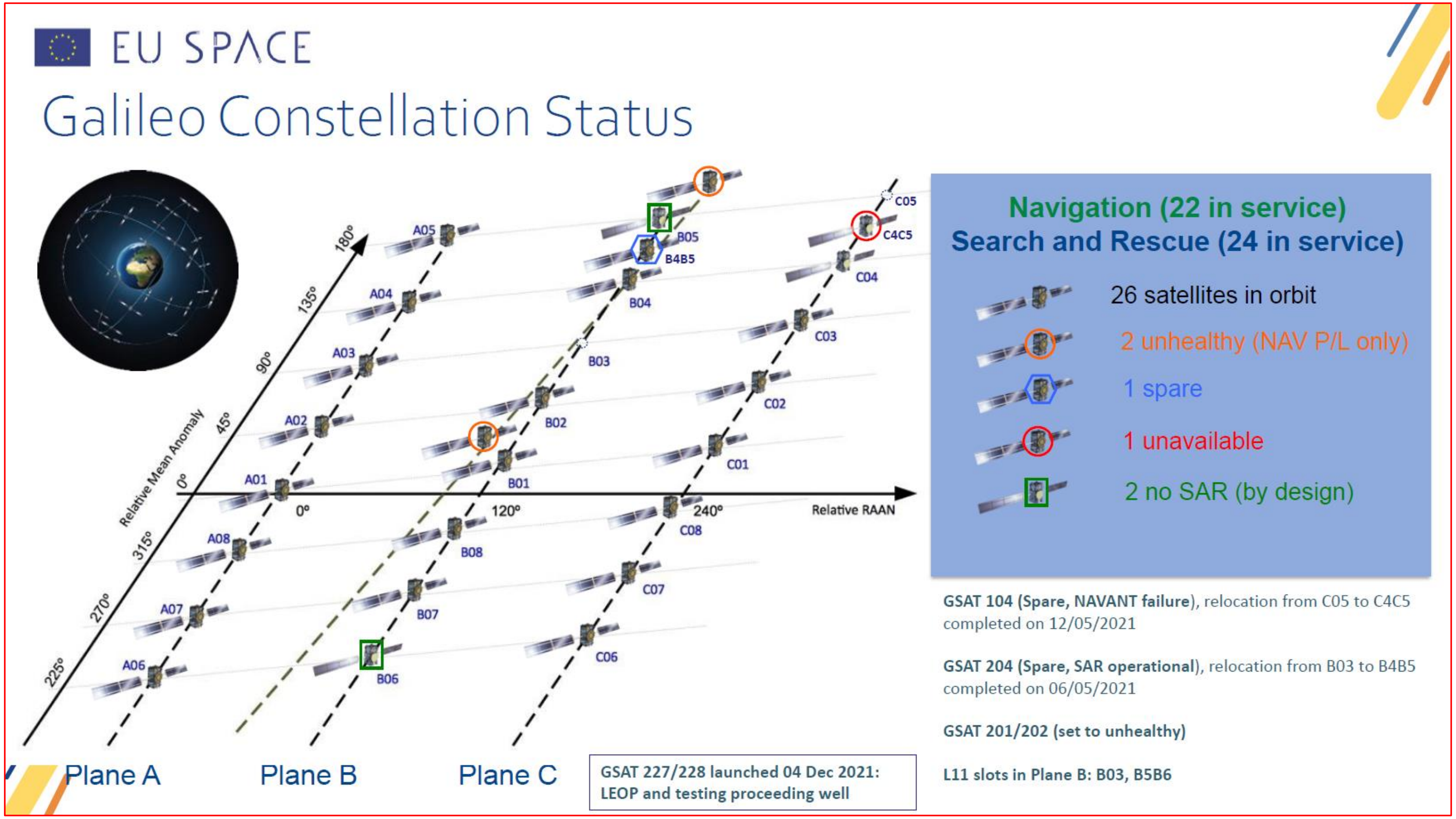




These slides were taken from ICG Website. Please refer the original presentation material at https://www.unoosa.org/documents/pdf/icg/2021/ICG15/01.pdf

Please refer original document for detail information

Galileo (Europe)



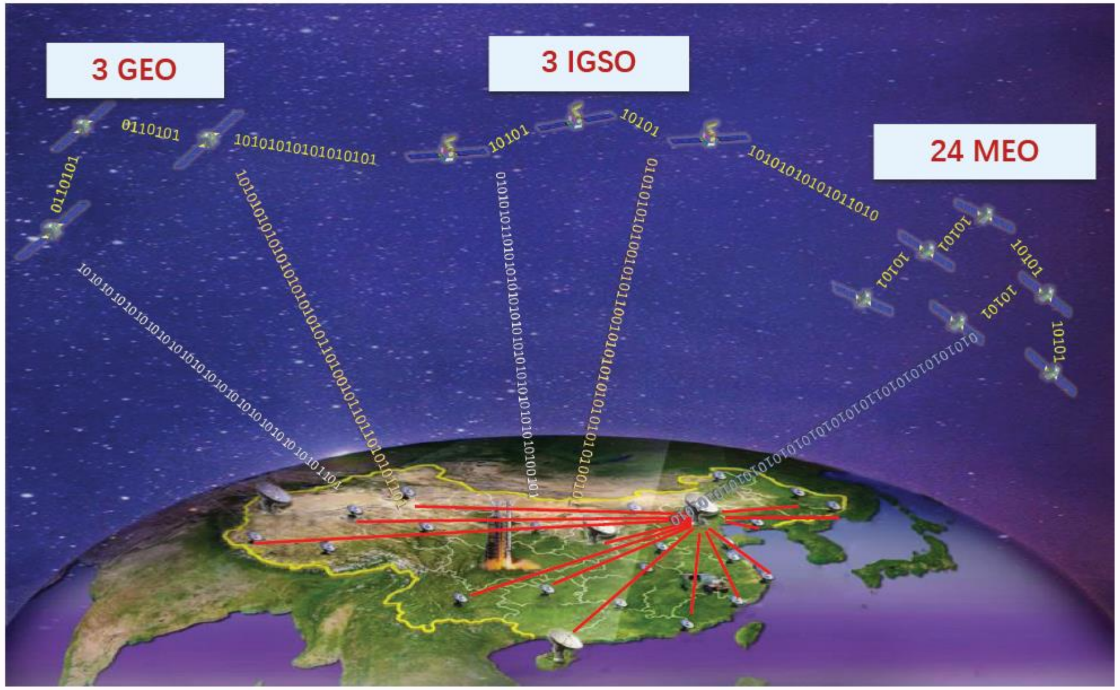
Source: This slide is taken from "Galileo Status Update"

Please refer original document for detail information

Link: https://www.unoosa.org/oosa/en/ourwork/icg/activities/2022/CSISTokyo/presentations.html

BeiDou (China)

1. System Status
——System Components



BDS is mainly comprised of three segments: a space segment, a ground segment and a user segment.

Up to now, BDS-3 constellation consists of 3 GEO satellites, 3 IGSO satellites, and 24 MEO satellites.

The BDS ground segment consists of various ground stations, including master control stations, time synchronization/uplink stations, monitoring stations, etc.

The BDS user segment consists of various kinds of the BDS terminals.

Source: This slide is taken from "BeiDou Navigation Satellite System Development and High-Accuracy Applications",
Link: Introduction to BeiDou at https://www.unoosa.org/oosa/en/ourwork/icg/activities/2022/CSISTokyo/presentations.html 5

Please refer original document for detail information

QZSS (Japan)

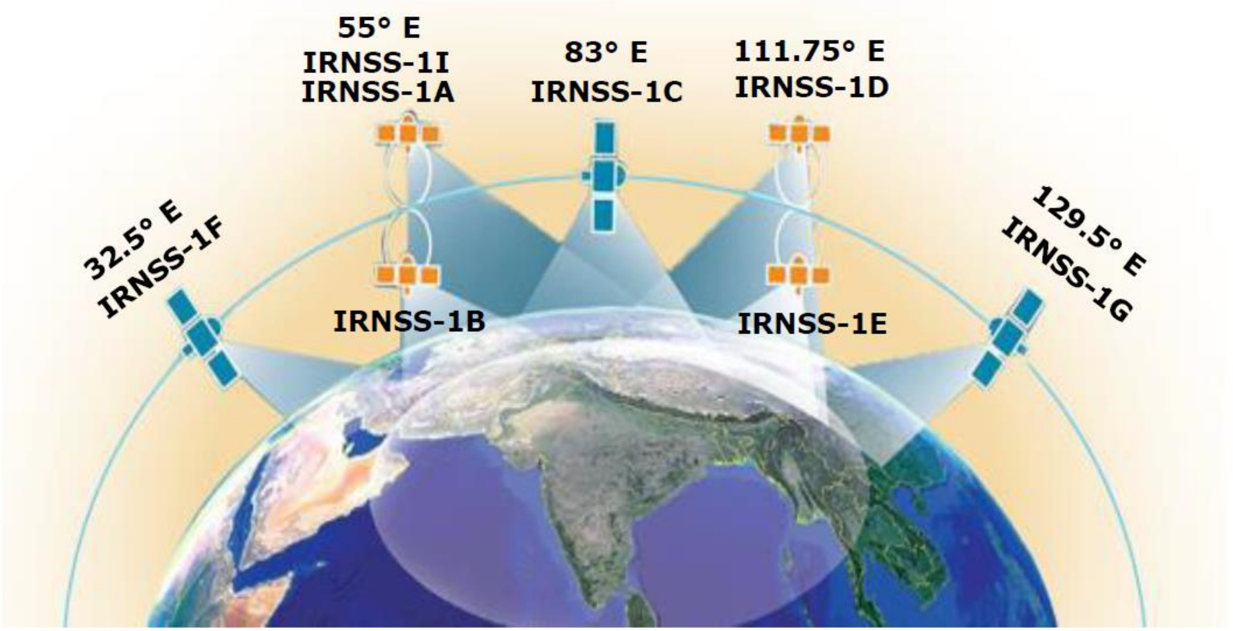
Source: This slide is taken from “Introduction to QZSS and Applications” Please refer original document for detail information

Link: https://www.unoosa.org/oosa/en/ourwork/icg/activities/2022/CSISTokyo/presentations.html

NavIC (India)

NavIC Constellation status

- **Launch dates:**
  - IRNSS 1A : 01 Jul 2013
  - IRNSS 1B : 04 Apr 2014
  - IRNSS 1C : 16 Oct 2014
  - IRNSS 1D : 28 Mar 2015
  - IRNSS 1E : 20 Jan 2016
  - IRNSS 1F : 10 Mar 2016
  - IRNSS 1G : 28 Apr 2016
  - IRNSS 1I : 12 Apr 2018



- All launches using Polar Satellite Launch Vehicle (PSLV) from Satish Dhawan Space Centre (SDSC) at Sriharikota

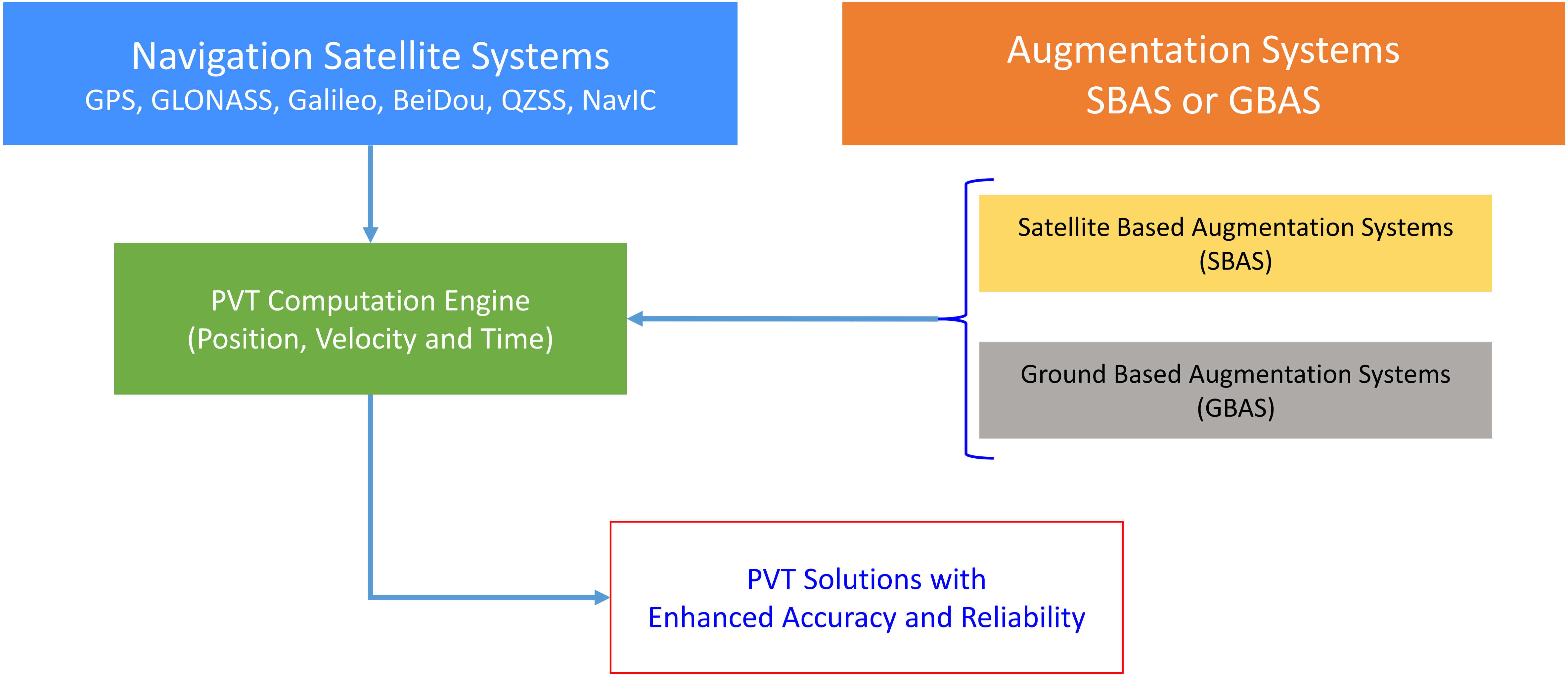
- **GSO satellites (shown in blue) are with ~4° inclination**
- **GSO satellites (shown in orange) are with 29° inclination**

IRNSS 1A and 1E are providing NavIC based safety of life alerts

Source: This slide is taken from "NavIC System and Applications: Status and Update"
Link: https://www.unoosa.org/oosa/en/ourwork/icg/activities/2022/CSISTokyo/presentations.html

Please refer original document for detail information

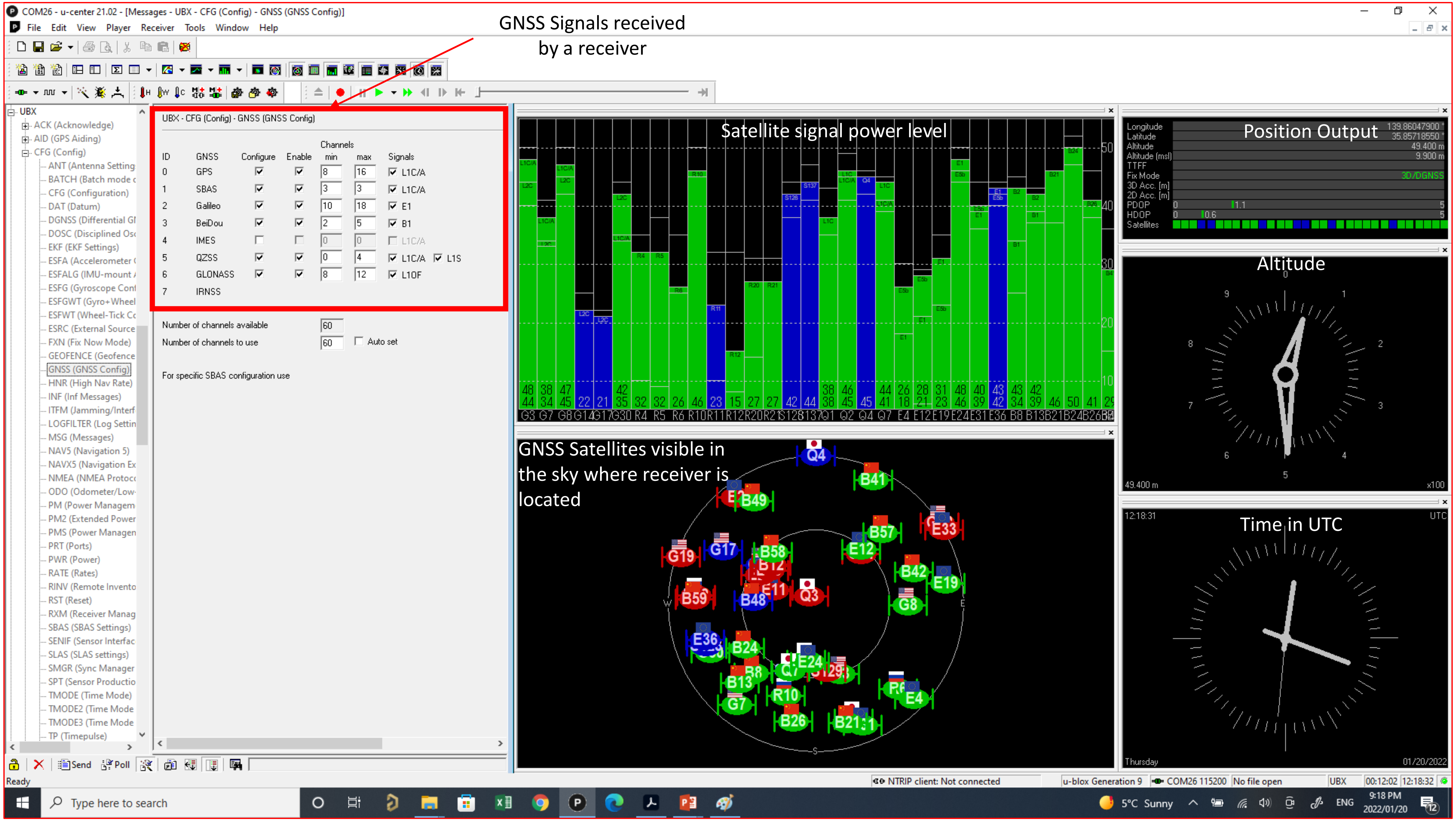
Systems Related with Navigation



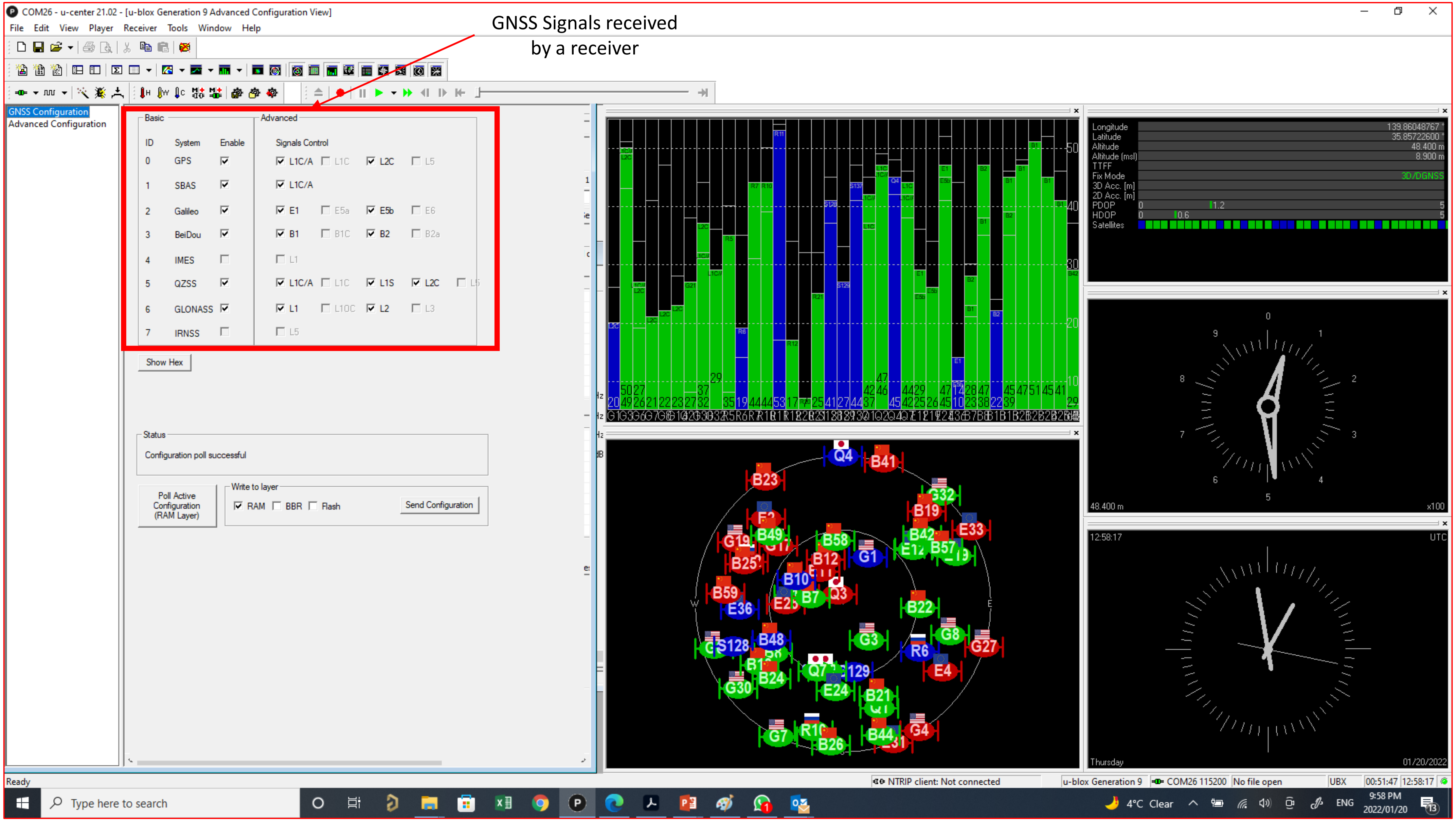
Satellite Based Augmentation System (SBAS)

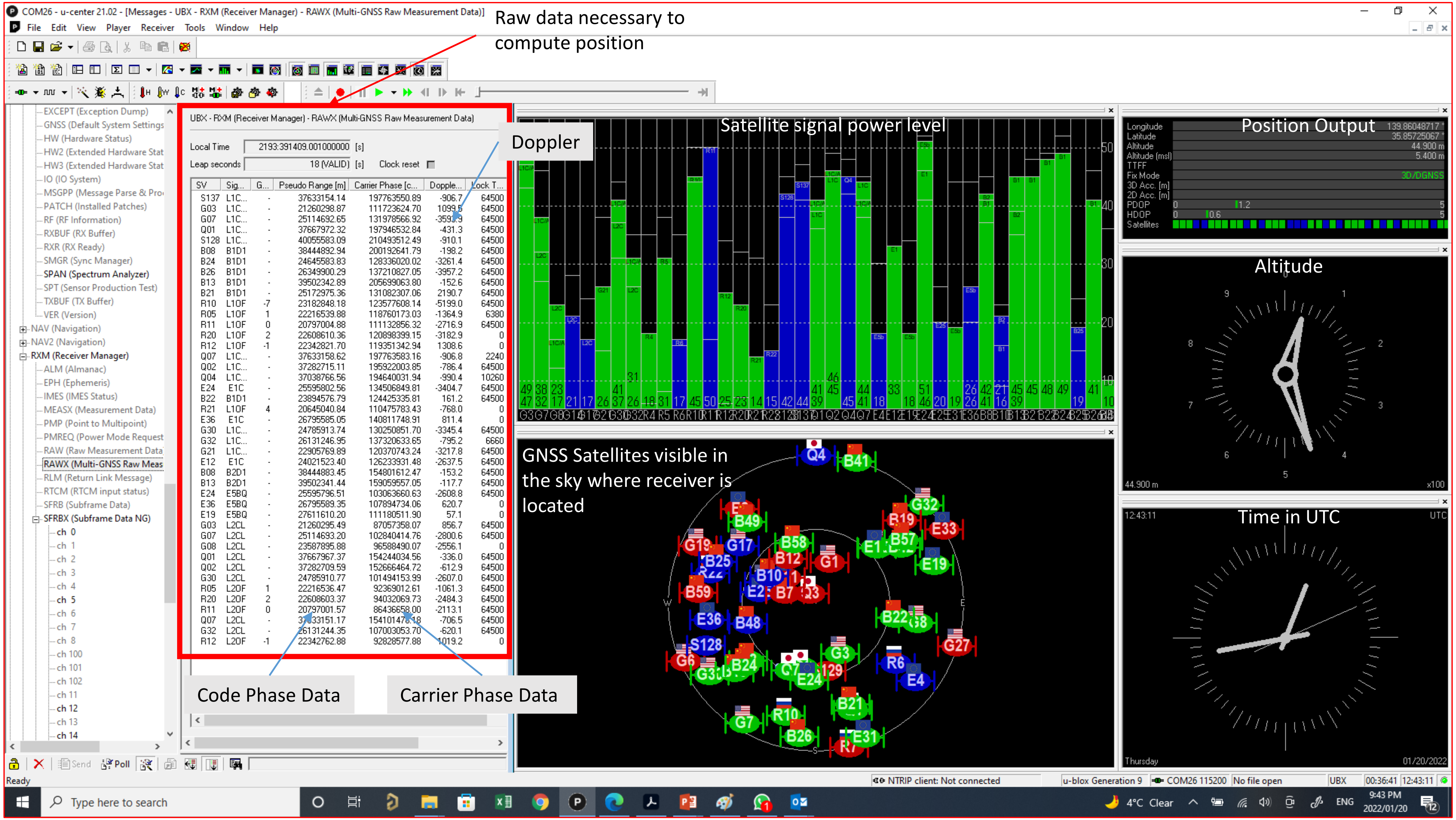
- Satellite Based Augmentation System (SBAS) are used to augment GNSS Data
  - Provide Higher Accuracy and Integrity
  - Correction data for satellite orbit errors, satellite clock errors, atmospheric correction data and satellite health status are broadcasted from satellites
- SBAS Service Providers
  - WAAS, USA (131,133,135,138)
  - MSAS, Japan (129,137)
  - EGNOS, Europe (120,121,123,124,126,136)
  - BDSBAS, China (130,143,144)
  - GAGAN, India (127,128,132)
  - SDCM, Russia (125,140,141)
  - KASS, Korea (134), Also Navigation System
  - AUS-NZ, Australia (122)
  - NSAS, Nigeria, (147)
  - ASAL, Algeria (148)

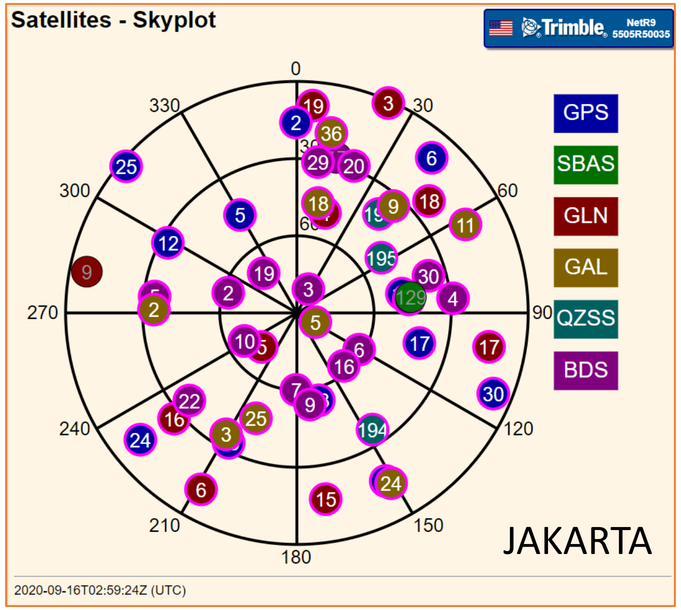
PRN code numbers are given in the bracket

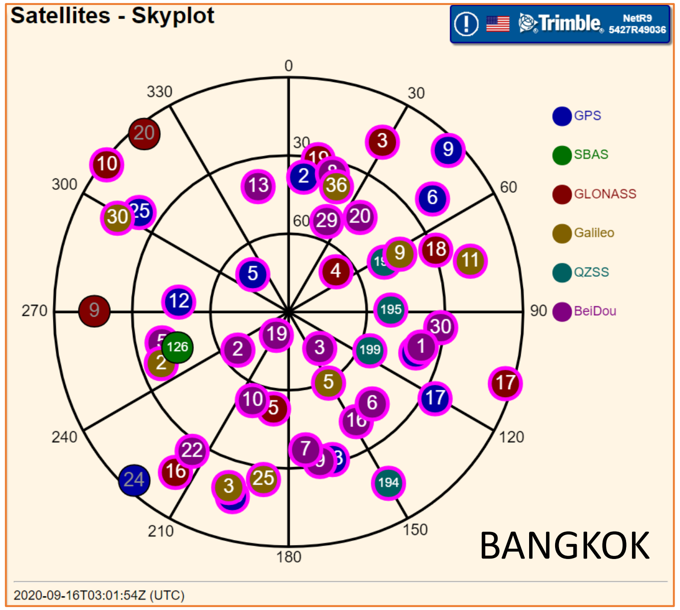

COM26 - u-center 21.02 - [Messages - UBX - CFG (Config) - GNSS (GNSS Config)]
GNSS Signals received by a receiver
UBX - CFG (Config) - GNSS (GNSS Config)
ID GNSS Configure Enable Channels min max Signals
0 GPS 8 16 L1C/A
1 SBAS 3 3 L1C/A
2 Galileo 10 18 E1
3 BeiDou 2 5 B1
4 IMES 0 0 L1C/A
5 QZSS 0 4 L1C/A L1S
6 GLONASS 8 12 L1OF
7 IRNSS
Number of channels available 60
Number of channels to use 60 Auto set
For specific SBAS configuration use
Satellite signal power level
Position Output
Altitude
GNSS Satellites visible in the sky where receiver is located
Time in UTC

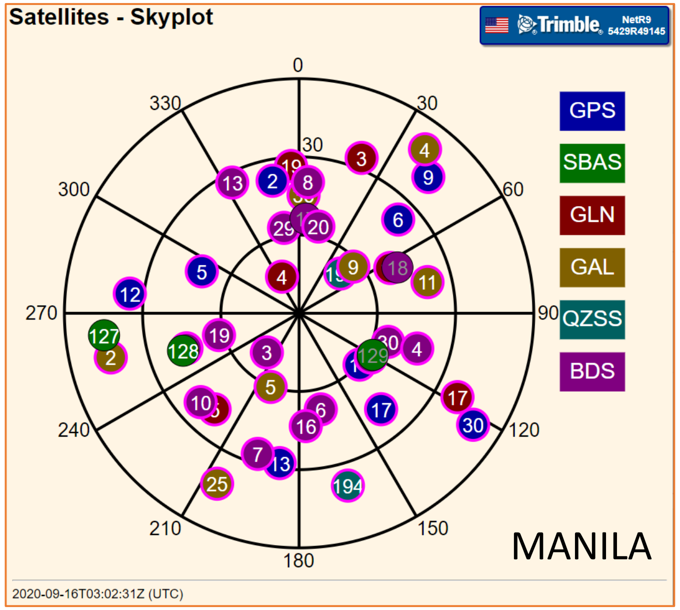
GNSS Signals received by a receiver

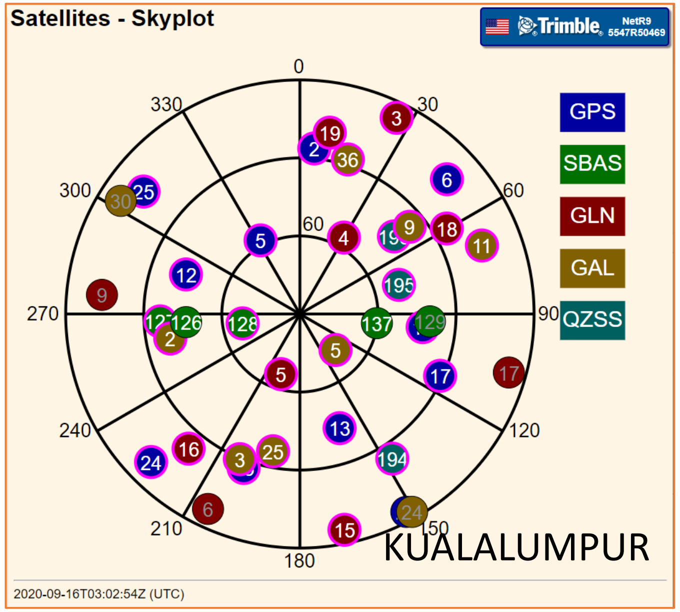


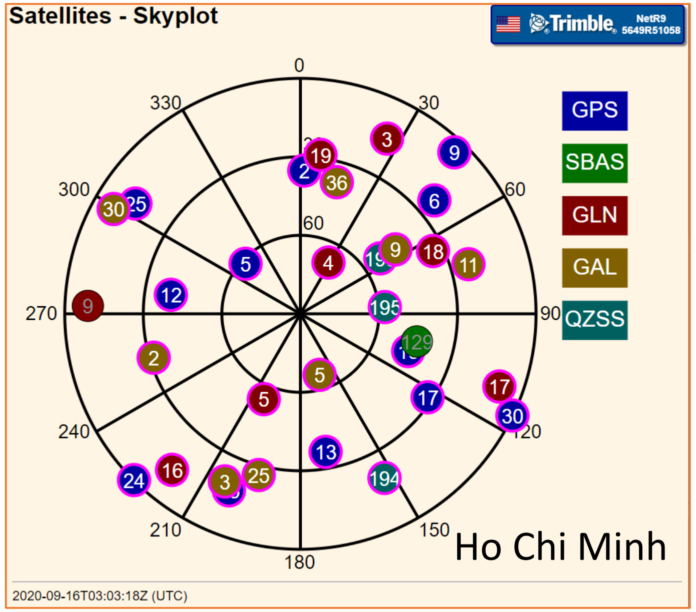

Raw data necessary to compute position
Doppler
Satellite signal power level
Position Output
Altitude
GNSS Satellites visible in the sky where receiver is located
Time in UTC
Code Phase Data
Carrier Phase Data

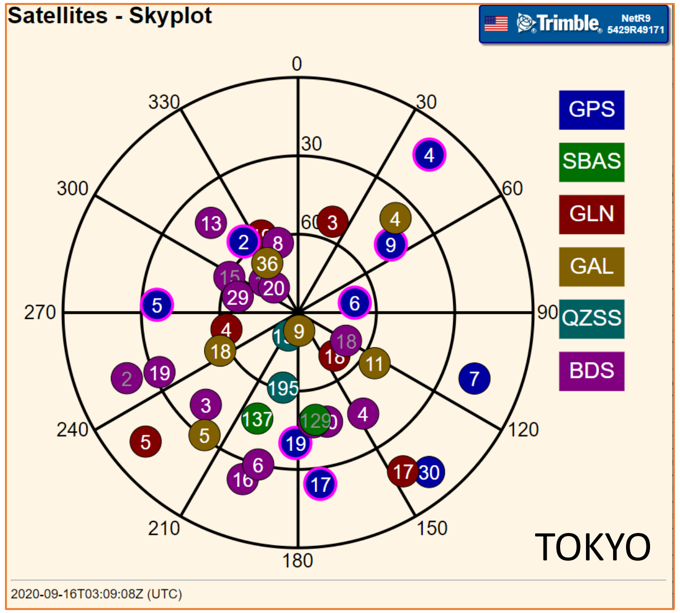








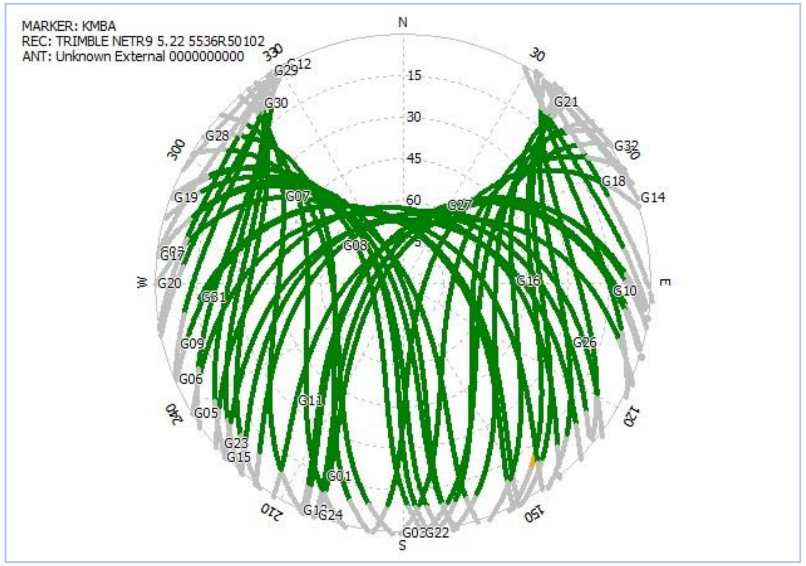


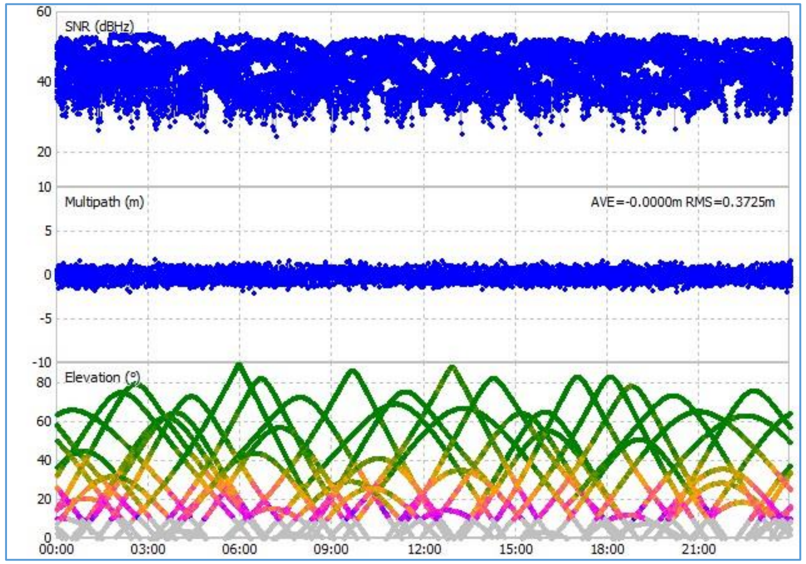


We do not have BeiDou data in Kualalumpur and Ho Chi Minh stations because of license limitation in the receiver

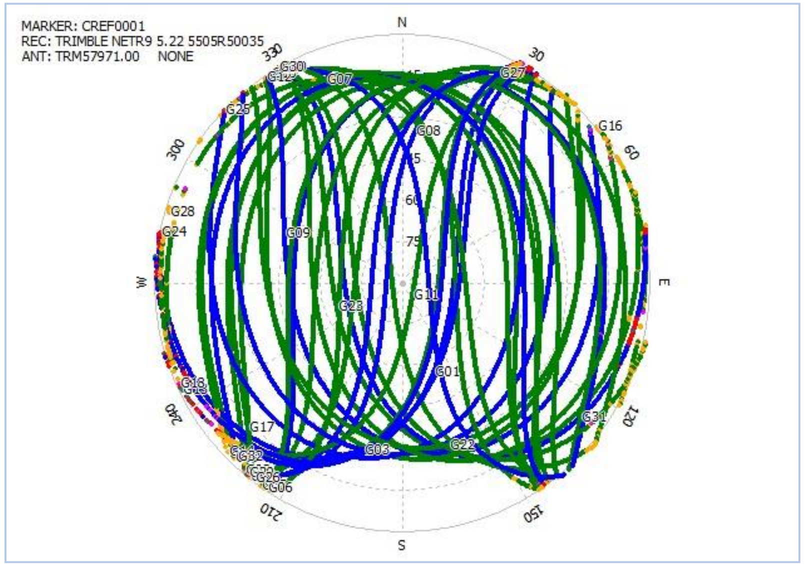
GPS Skyplots: Tokyo, Jakarta and Maputo

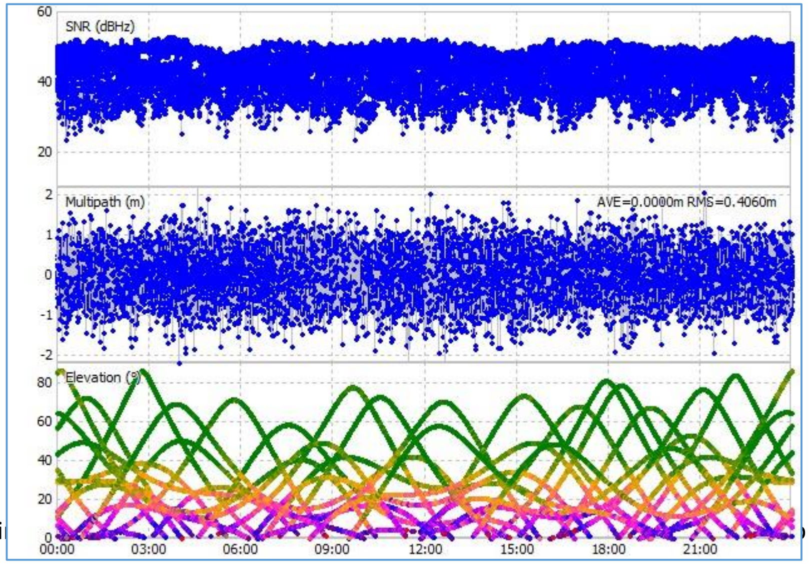
Tokyo Base-Station



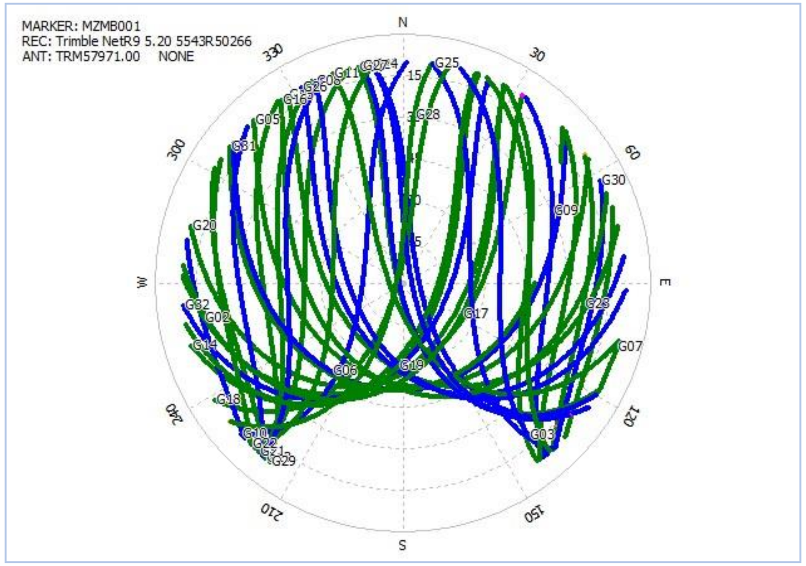


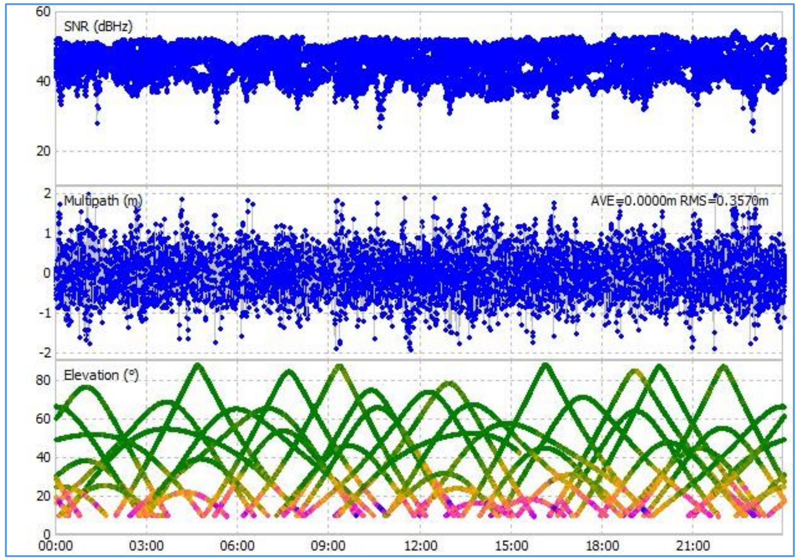
Jakarta Base-Station





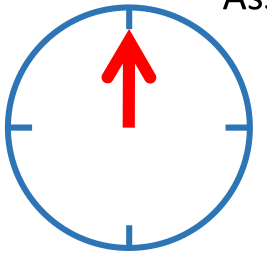
Maputo Base-Station





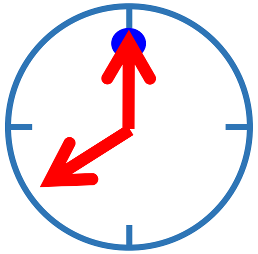
How does a GPS/GNSS Receiver Work?

GNSS: How does it work?
Determine the Distance using Radio Wave

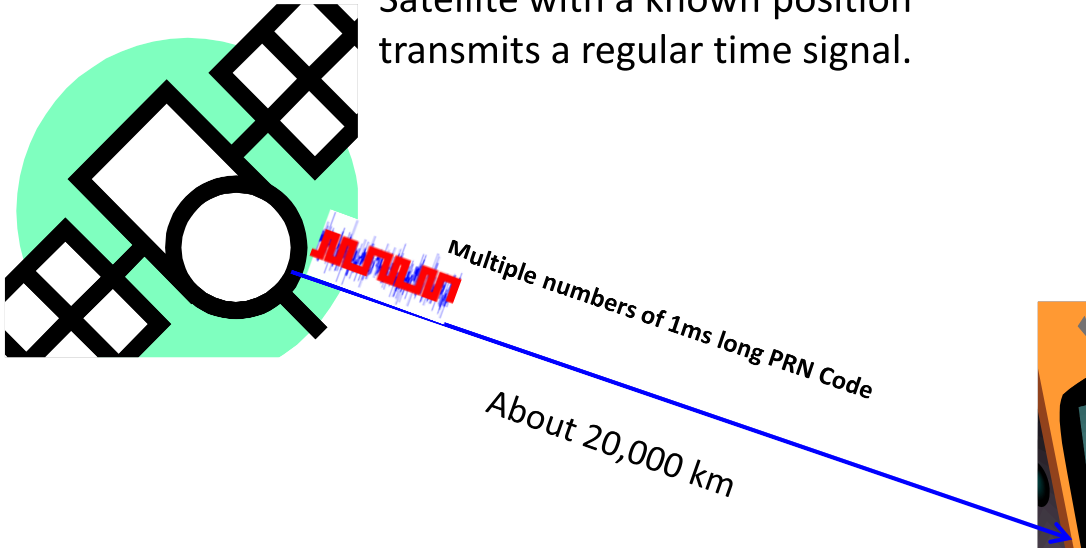


Assume that the Satellite Transmits Signal at 0ms.

If Receiver receives the same Signal after 67ms,
Distance = 67x300,000 = 20,100Km



Satellite with a known position transmits a regular time signal.



Distance = (Reception Time - Transmission time) × Speed of light

Speed of Light: 300,000 km/s

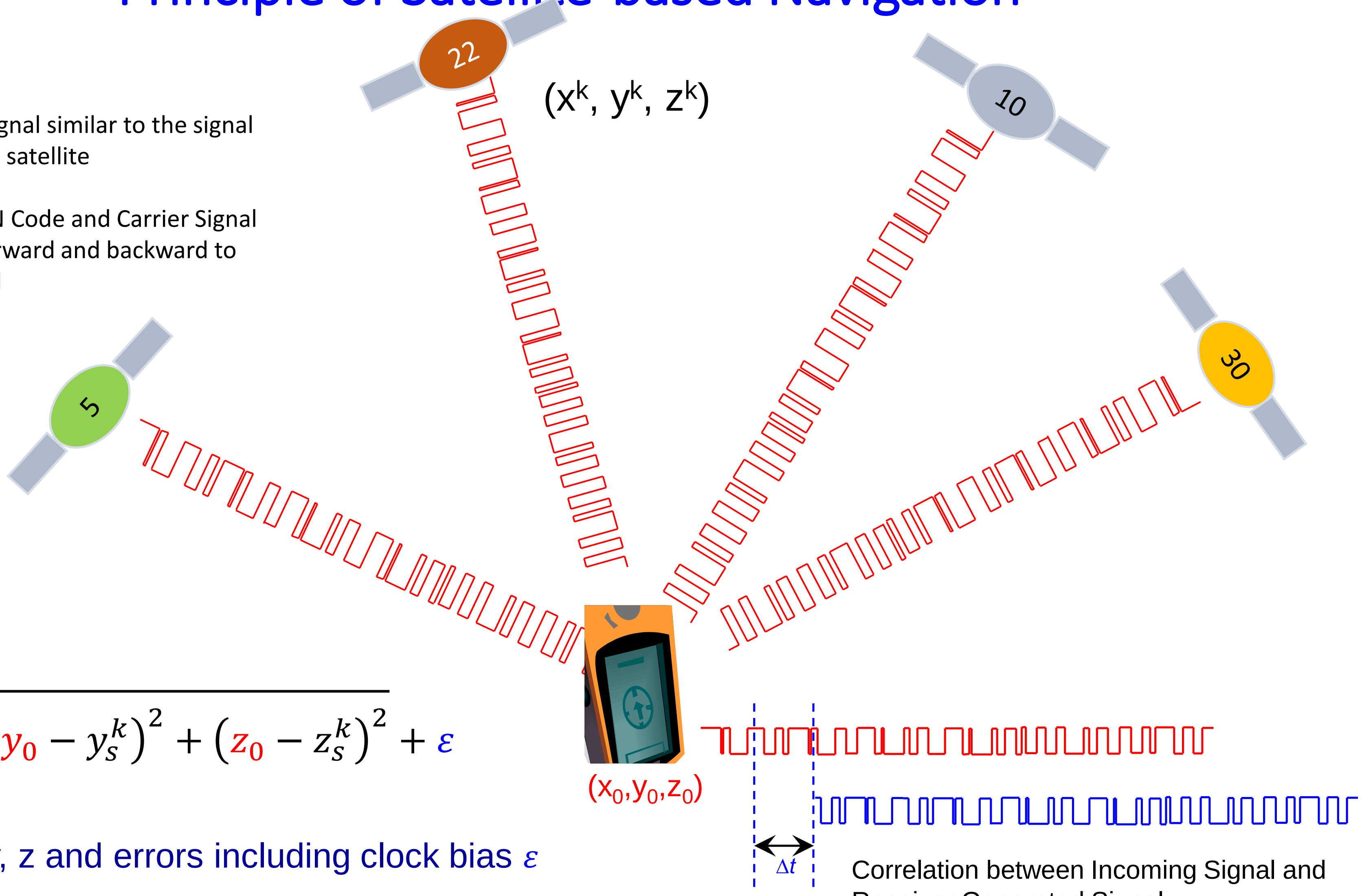
GNSS: How does it work?
Principle of Satellite-based Navigation

Receiver generates its own GPS signal similar to the signal coming from the satellite for each satellite

➔ Its called Replica Signal

➔ The Replica Signal includes PRN Code and Carrier Signal

➔ This Replica Signal is moved forward and backward to match with the incoming signal

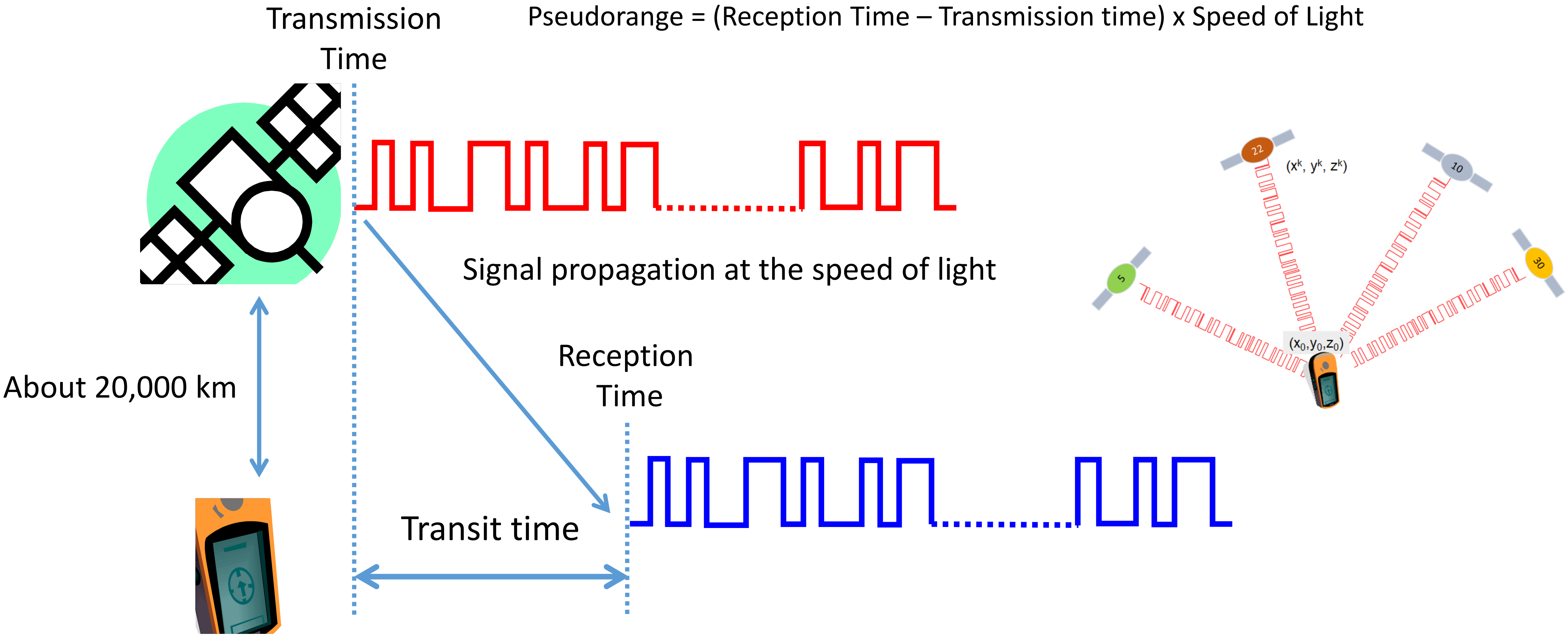


$$\rho^k = \sqrt{(x_0 - x_s^k)^2 + (y_0 - y_s^k)^2 + (z_0 - z_s^k)^2} + \varepsilon$$

If k ≥ 4, solve for x, y, z and errors including clock bias ε

Pseudorange (Code-Phase Measurement) - 1

Pseudorange = (Reception Time – Transmission time) x Speed of Light



A GPS receiver measures the signal transmission time from the code phase at signal reception time.

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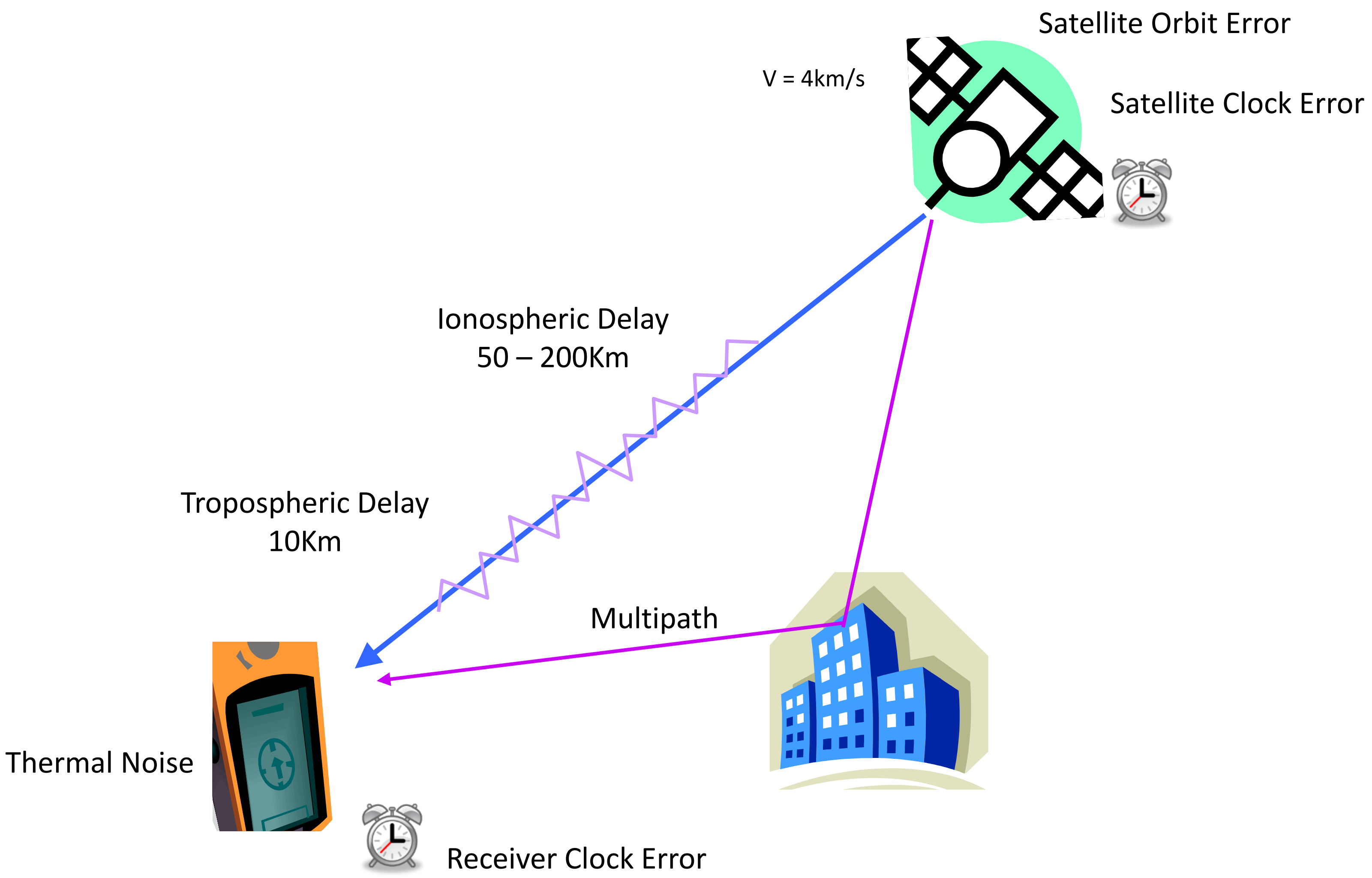
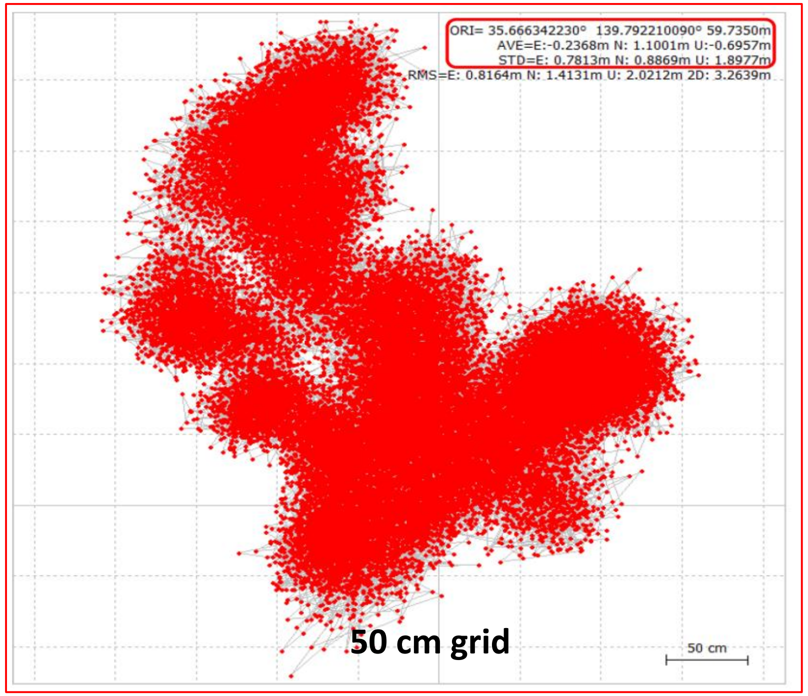
How to Improve GPS Accuracy?

Error sources

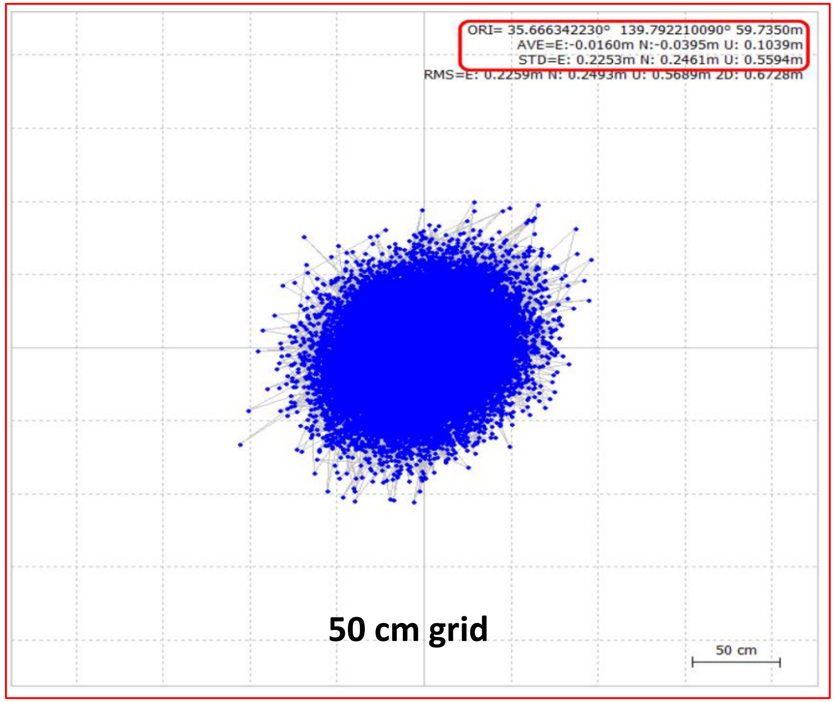


GPS Position Accuracy

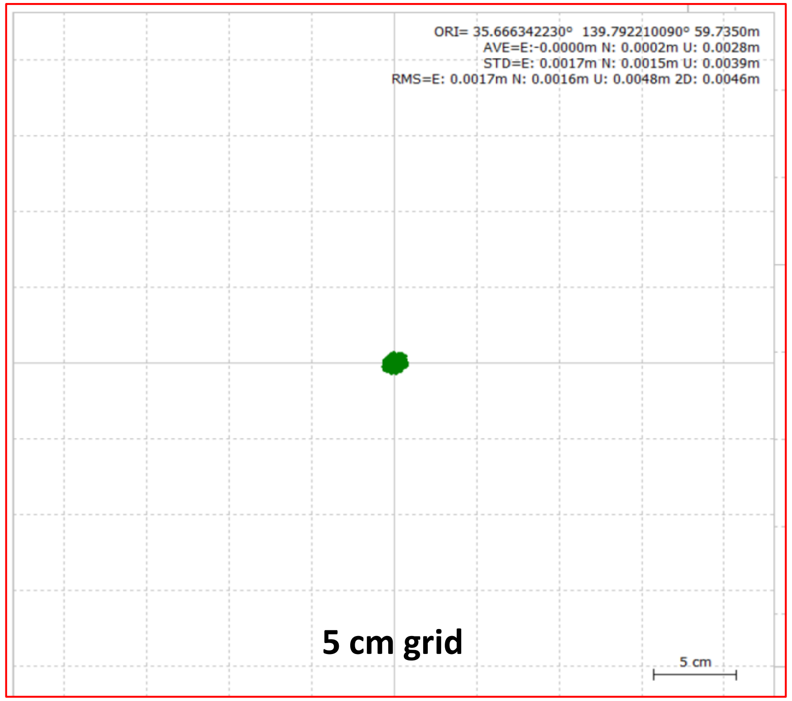
How to achieve accuracy from few meters to few centimeters?



SPP (Single Point Position)



DGPS (Differential GPS)
Code-phase observation



RTK (Real Time Kinematic)
Carrier-phase observation

Errors in GPS Observation (L1C/A Signal)

Error Sources	One-Sigma Error , m		Comments
	Total	DGPS	
Satellite Orbit	2.0	0.0	Common errors are removed
Satellite Clock	2.0	0.0	
Ionosphere Error	4.0	0.4	Common errors are reduced
Troposphere Error	0.7	0.2	
Multipath	1.4	1.4	
Receiver Circuits	0.5	0.5	

If we can remove common errors, position accuracy can be increased.

Common errors are: Satellite Orbit Errors, Satellite Clock Errors and Atmospheric Errors (within few km)

Values in the Table are just for illustrative purpose, not the exact measured values.
Table Source : http://www.edu-observatory.org/gps/gps_accuracy.html#Multipath

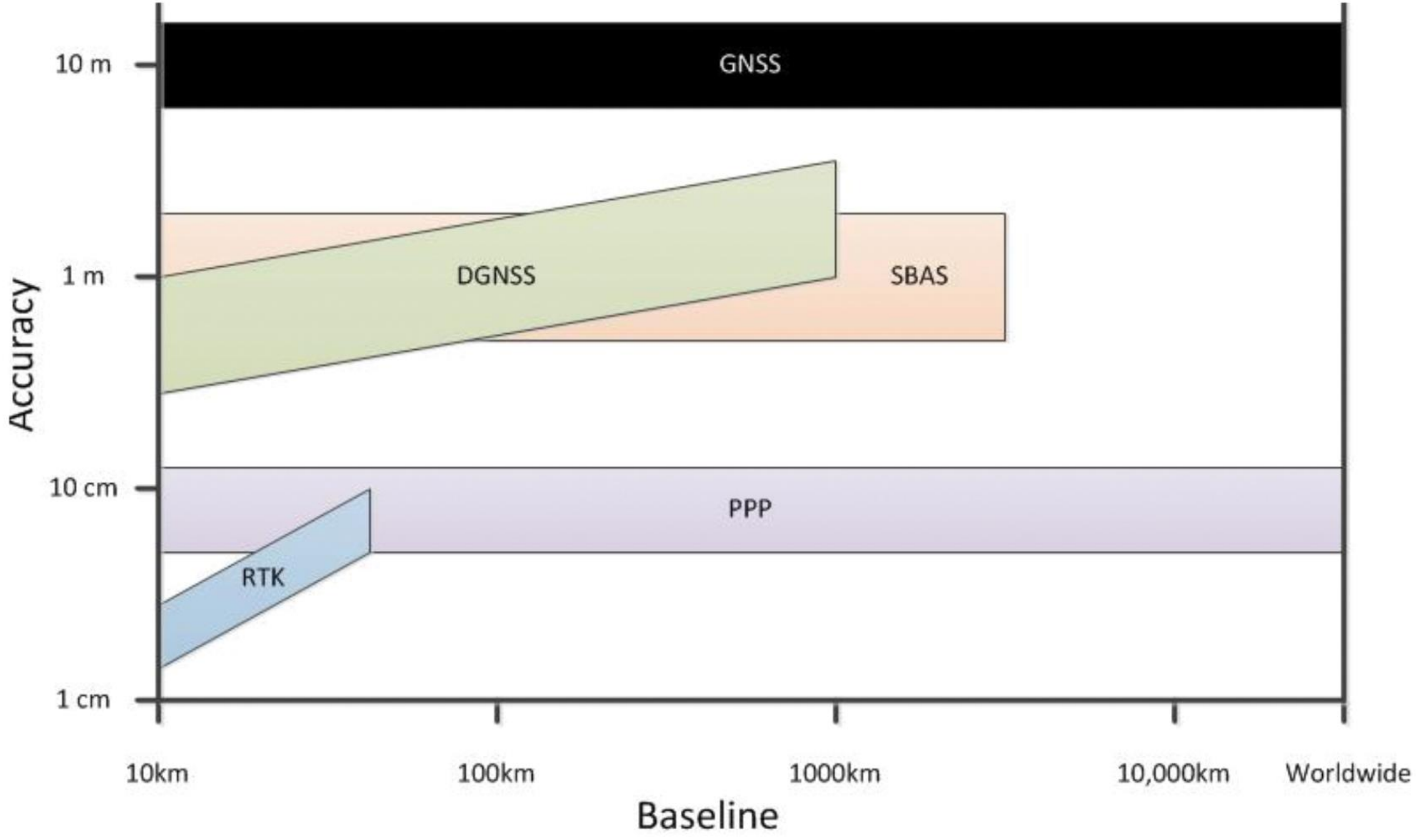
How to Improve Accuracy?

- Both Code-Phase and Carrier-Phase observations are necessary
  - Carrier-phase provides centimeter level resolution
- Need to remove or minimize the following errors:
  - Satellite Related Error
    - Satellite orbit errors
    - Satellite clock errors
  - Space Related Errors
    - Ionospheric errors
    - Tropospheric erros
  - Receiver Related Errors
    - Receiver clock error
    - Receiver circuit related

High-Accuracy Observation Methods

- Basically three types of Observation
  - DGPS (Differential GPS)
    - Code-phase observation
    - Requires Base-station (Reference Station)
  - RTK (Real Time Kinematic)
    - Code-phase and Carrier-Phase Observation
    - Requires Base-station (Reference Station)
  - PPP (Precise Point Positioning)
    - Code-phase and Carrier-phase observation
    - Does not require base-station

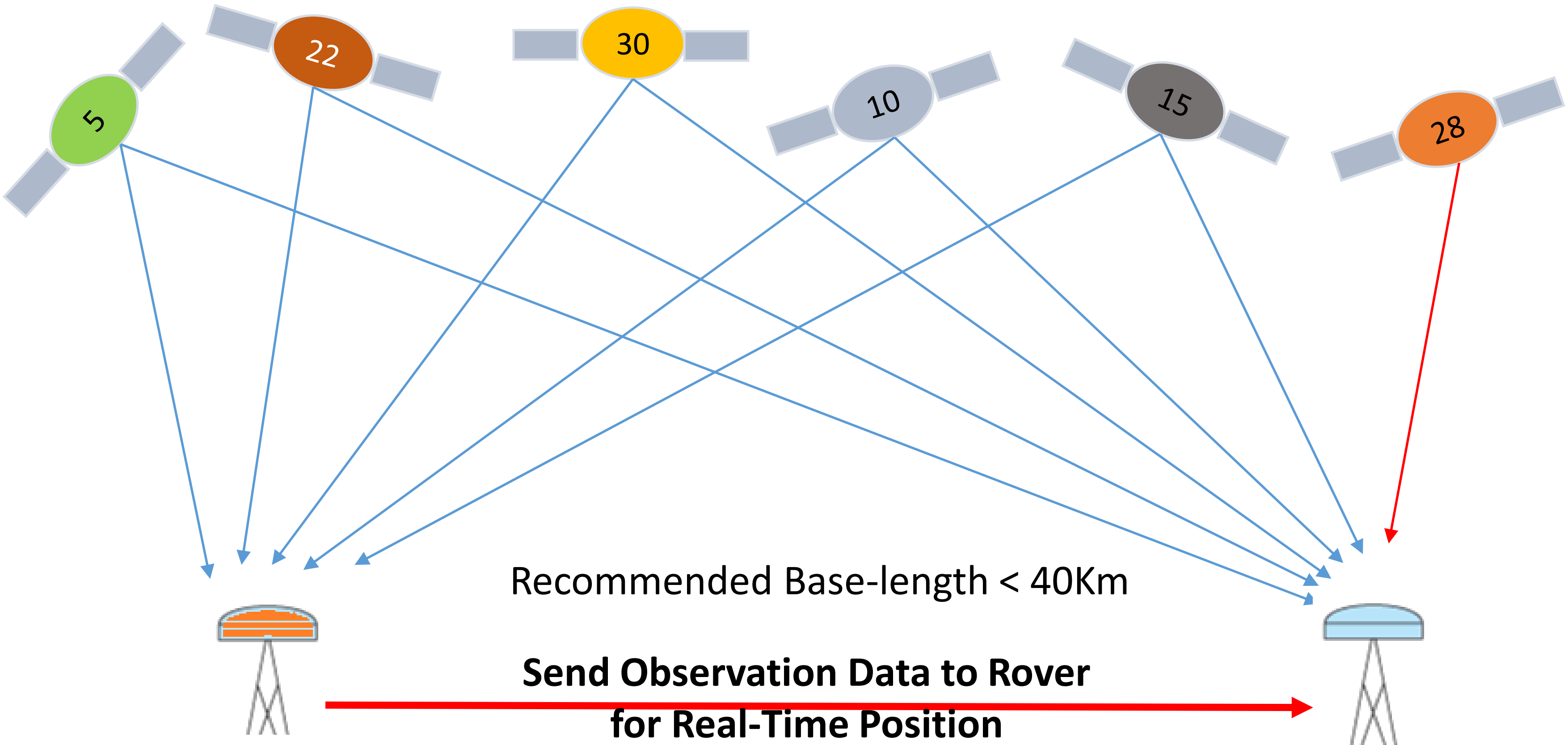
Which Method: DGPS, SBAS, RTK, PPP?



http://www.novatel.com/an-introduction-to-gnss/chapter-5-resolving-errors/

How to Remove or Minimize Common Errors?

Use Differential Correction



Base-Station

Antenna is installed at a known-position

For RTK, both base and rover receivers need to use data from the same satellites

Rover

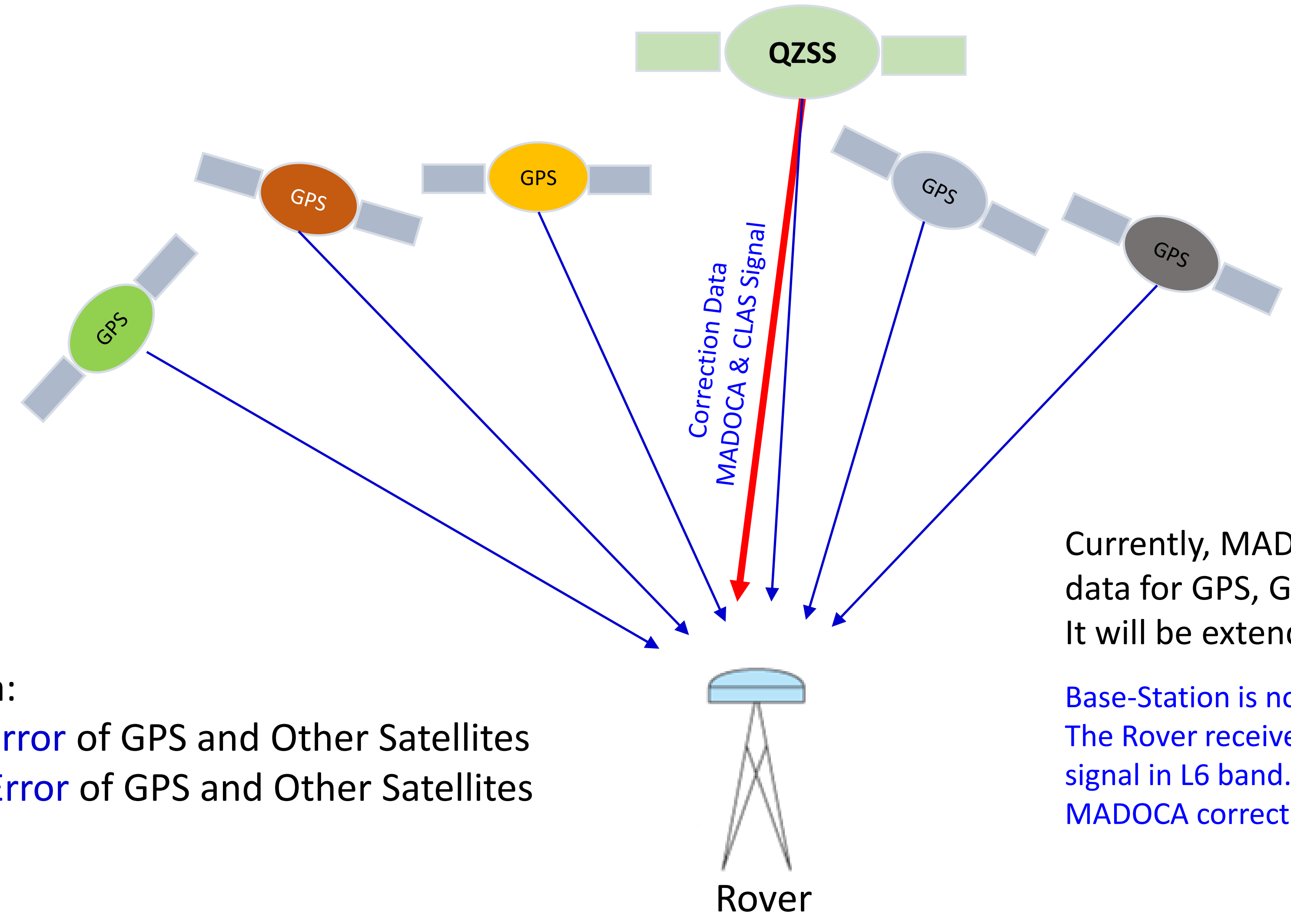
User in the Field

(Either fixed or moving)

Use RINEX data for post-processing

Base-station Antenna position shall be known in advance

How to Remove or Minimize Common Errors?
Principle of QZSS MADOCA and CLAS Services



Currently, MADOCA provides correction data for GPS, GLONASS and QZSS.
It will be extended for Galileo in future.

Base-Station is not required.
The Rover receiver should be able to receiver MADOCA signal in L6 band.
MADOCA correction data is also available online.

Correction Data:
Satellite Orbit Error of GPS and Other Satellites
Satellite Clock Error of GPS and Other Satellites

GNSS Applications

Lots of Opportunities for these GNSS Applications…..

- Legal & Law Enforcement
- Geo-Fencing
- Geo-Security
- Illegal Fishing

- Pay-As-You-Drive
- Toll Fee
- ERP

- ITS / ADAS
- Auto-Driving
- V2V / V2X

- **Surveying**
- **Mapping**
- **GIS**
- **UAV / UMV**

- Tax Collection
- Insurance
- Alternate for Fuel Tax Collection

- Secured Transport of Dangerous Goods
- Supply-Chain Management

- IoT
- M2M
- Robotics

- Emergency & Safety Services
- SoL, e-Call
- ERA-GLONASS
- Early Warning

- Agriculture
- Precision Farming

- AI
- Medical Health Services
- People Flow

- **Transport**
- **Vehicles**
- **Rail**
- **Aviation**
- **Space**

- Timing Applications
- Telecom
- Finance
- Power Grid

- LBS
- Game
- Entertainment
- Advertisement
- Marketing

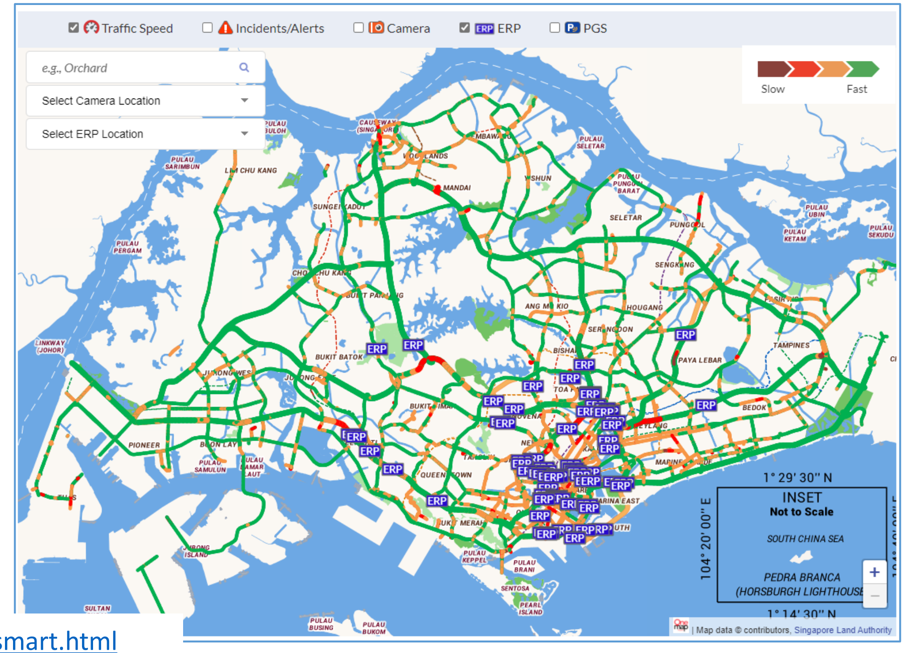
- Scientific Applications
- Space Weather
- VLBI

Road Pricing : ERP to ERP 2.0 (Singapore)

ERP ➔ ERP2.0

ERP is based on Gantry System
Requires construction of huge structures

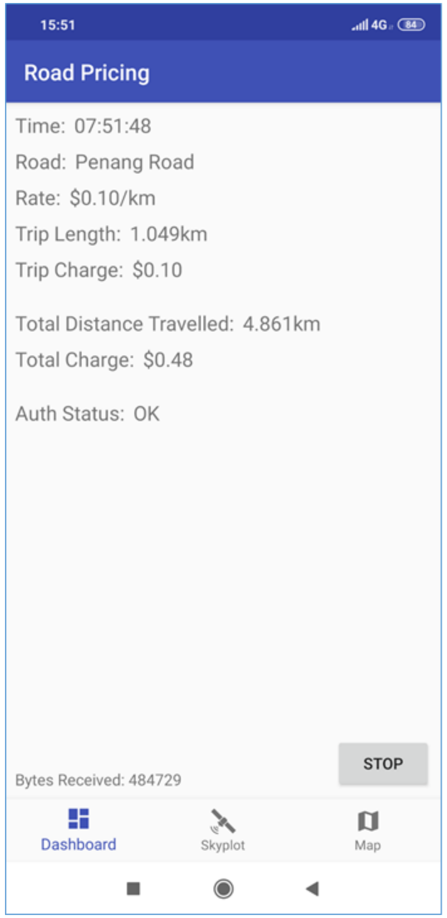
ERP 2.0 is based on Satellite System (GNSS)

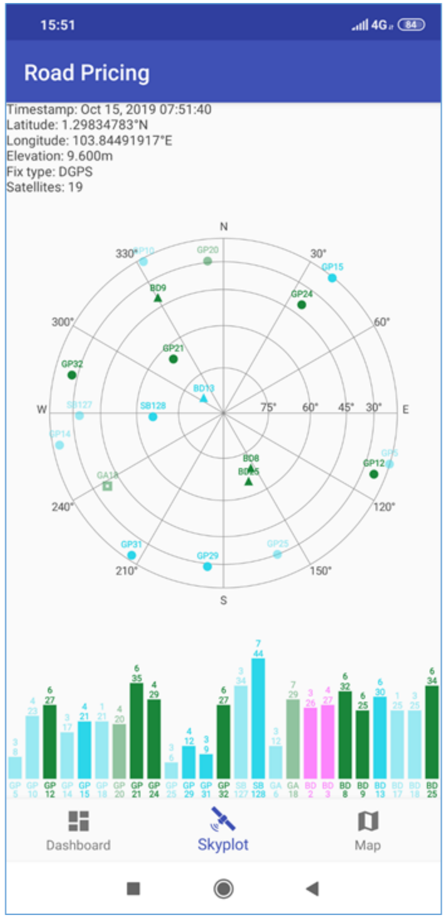


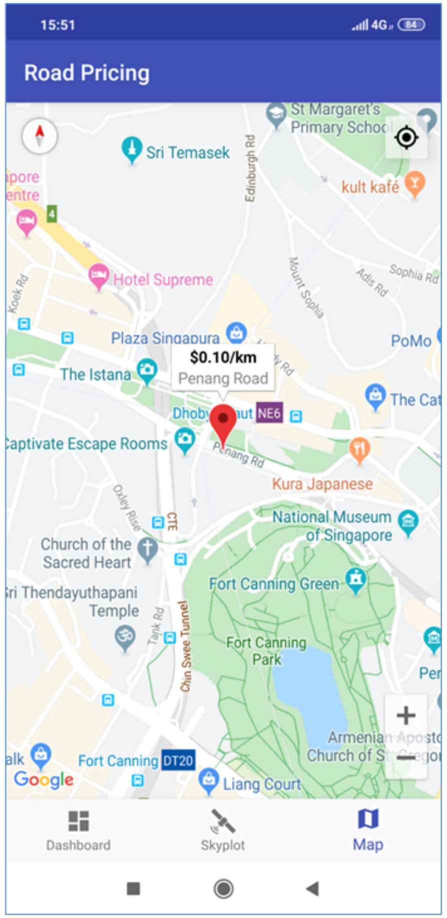
Source: https://onemotoring.lta.gov.sg/content/onemotoring/home/driving/traffic_information/traffic-smart.html

Dynamic Road Pricing (DRP) based on GNSS

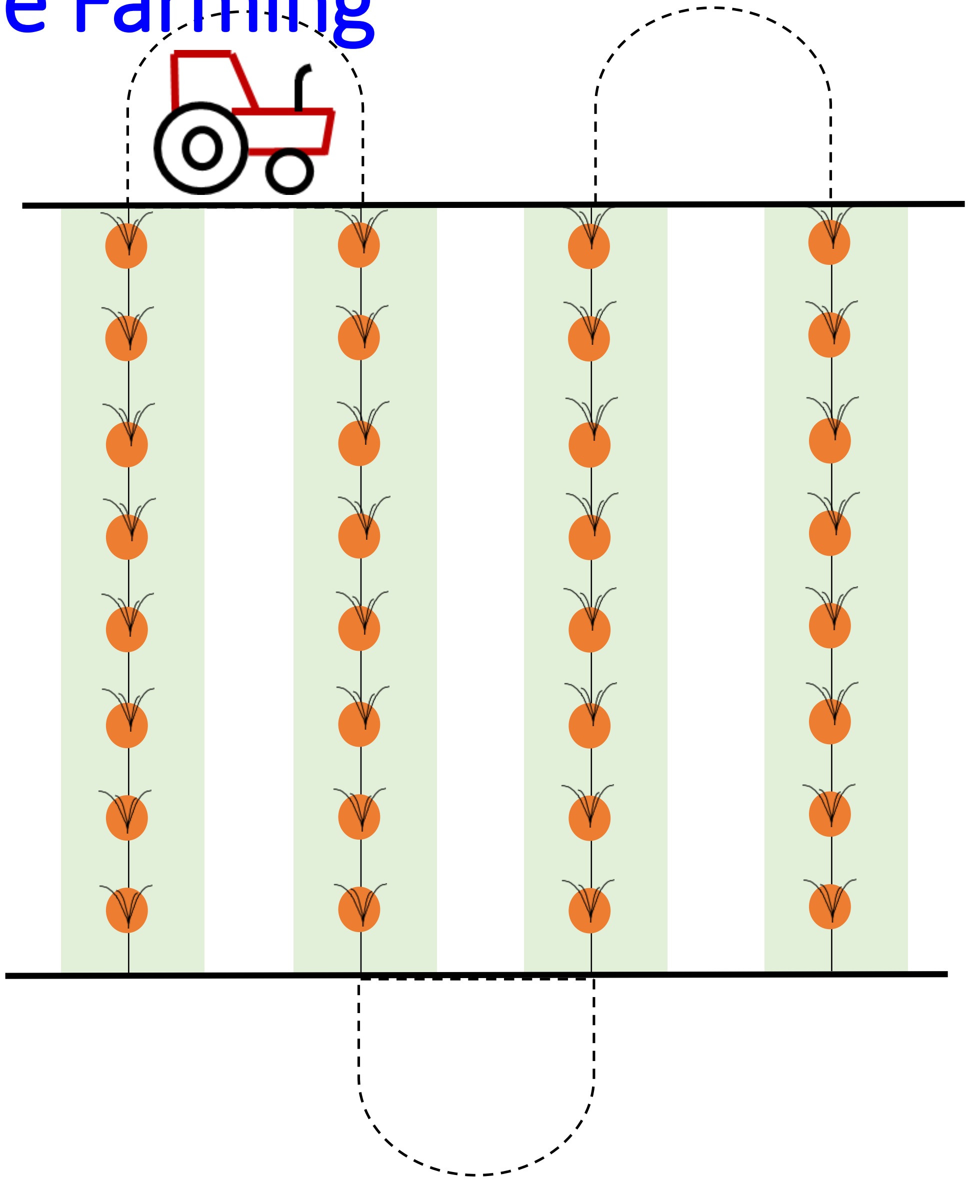
- Road Usage Charging
    - Pricing is variable and based on
        - Distance, time, location,
        - Vehicle type, lane and occupancy
        - Traffic congestion condition
- Reward road users for using alternate routes to avoid congested route
    - Payback the drivers who help to minimize traffic congestion
- No Physical Toll Gates
    - GPS-based system is used for Location, Distance and Lane occupation
    - Can be implemented on any road section
        - Not limited to only highways, express ways or toll roads
- Global Seamless Implementation
    - The same system can be implemented globally
    - The same In-vehicle device can be used globally
        - Single system for smooth cross-border operation
        - Once a border is crossed, charging or rewarding rates can be updated automatically







GNSS for Precise Farming



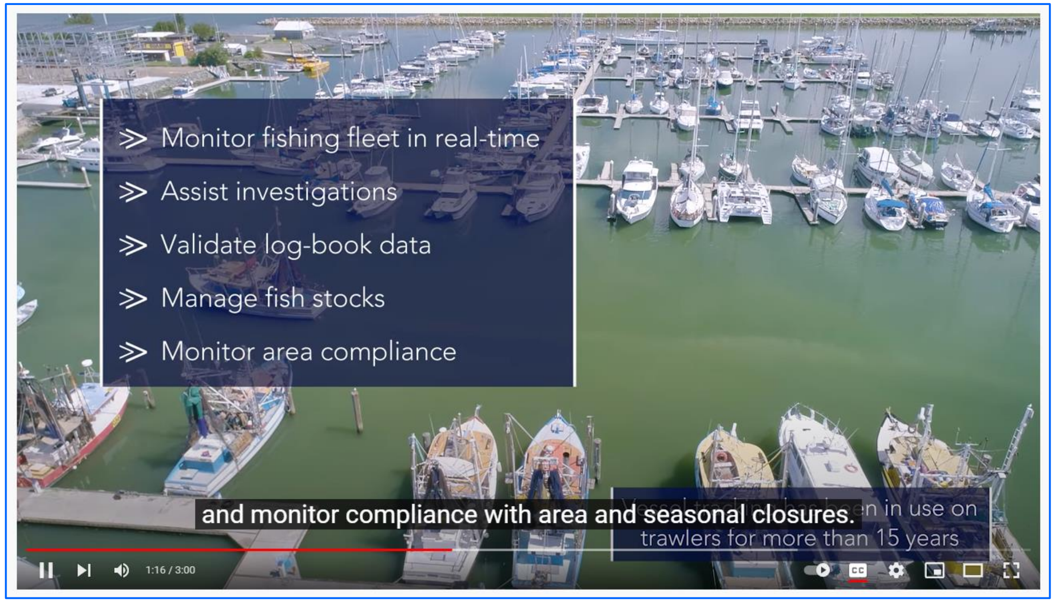
Before and after seedling, the tractor has to irrigate, put fertilizer and spray pesticides where there are plants.
If they are put far from the plant, it will affect the yield.

This requires few centimeter level of accuracy so that the tractor can automatically perform the job at different stages of plant growth and harvesting.

GNSS is a core system to provide this level of accuracy.

Fishing Boat Monitoring

Fishing boats in Bali, Indonesia



Queensland Fisheries in Australia requires every boat to have GPS tracking device
https://www.youtube.com/watch?v=2qWTAZ8hmOY&t=36s

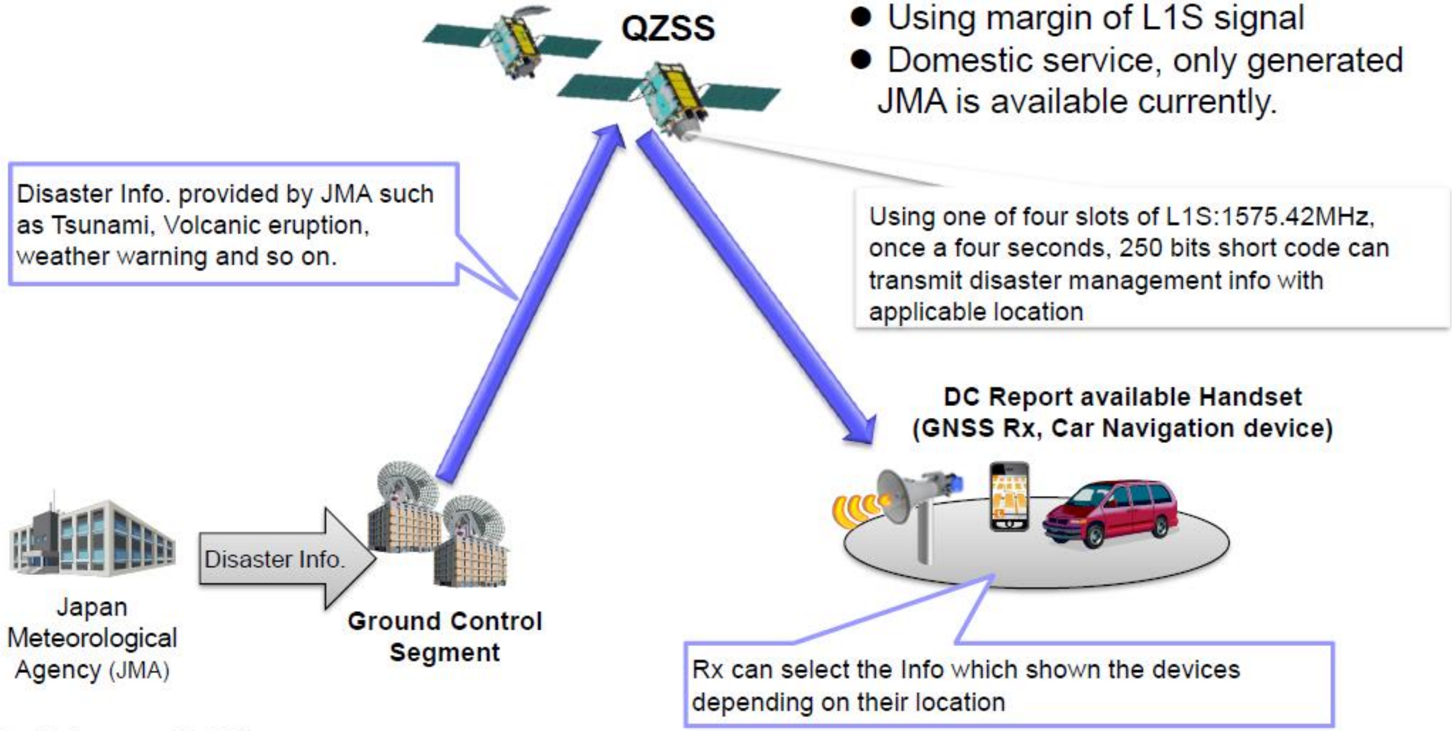
- Monitoring of Fishing Boats is necessary to fishing industry.
- This will help the fishermen to generate more income in long-term.
- Over-fishing, Illegal fishing shall be stopped to protect marine ecology and bio-diversity.

1. QZSS Overview -Current Services-

Messaging Services outline

Satellite Report for Disaster and Crisis Management (DC Report)

- Using margin of L1S signal
- Domestic service, only generated JMA is available currently.

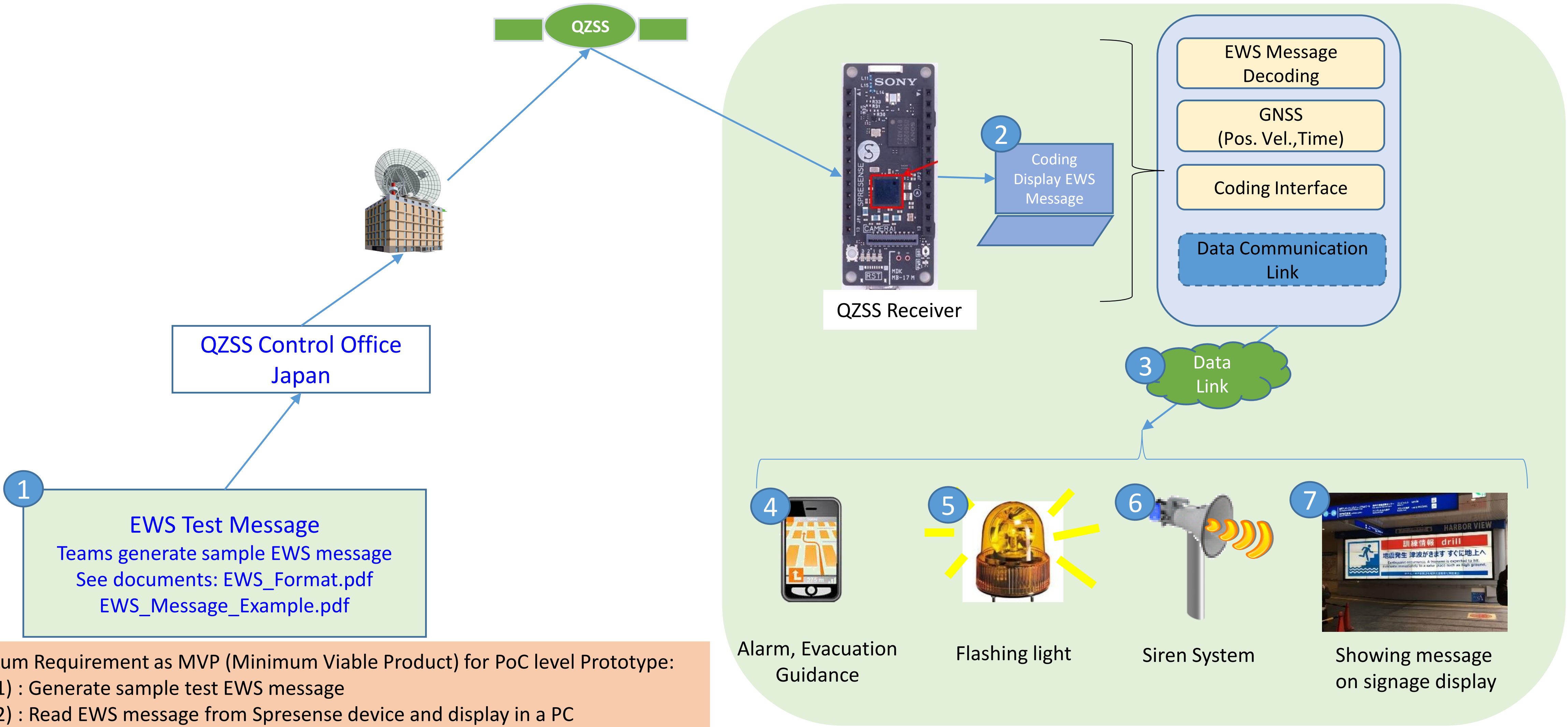


Cabinet Office
National Space Policy Secretariat

7

Slide from QZSS Presentation by S. Kogure, UTokyo/ICG GNSS Training, 11 – 14 January 2022
Link: https://www.unoosa.org/oosa/en/ourwork/icg/activities/2022/CSISTokyo/presentations.html

QZSS Early Warning System (EWS) : System to Test EWS Disaster and Crisis (DC) Management Report (in Japan)



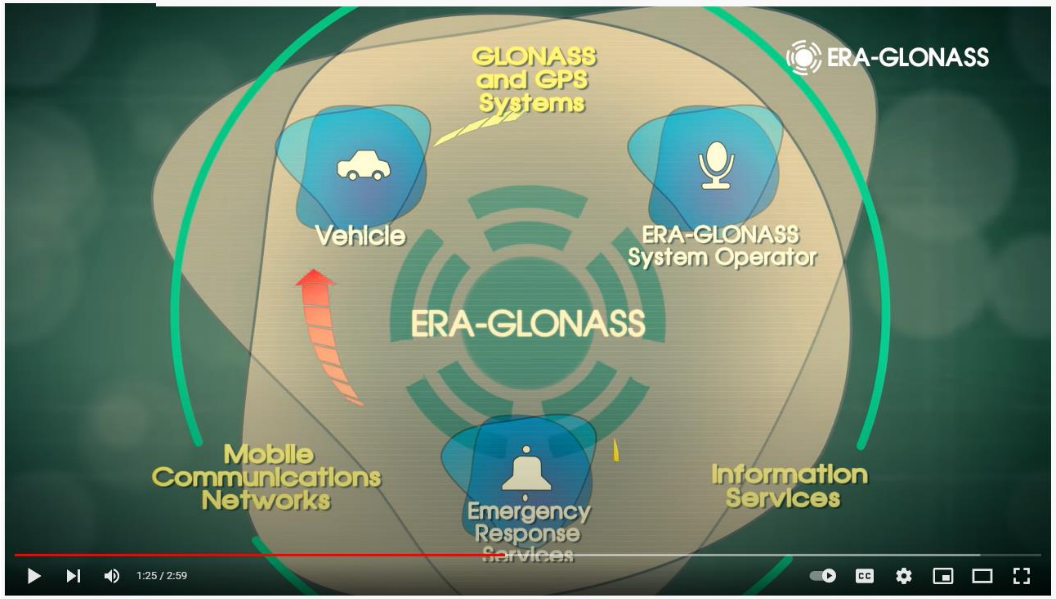
Minimum Requirement as MVP (Minimum Viable Product) for PoC level Prototype:
Item (1) : Generate sample test EWS message
Item (2) : Read EWS message from Spresense device and display in a PC

eCALL / ERA-GLONASS

eCALL (Europe)

https://www.youtube.com/watch?v=yj0j9aV7Km4

ERA-GLOANASS (Russia)



https://www.youtube.com/watch?v=pJkhBLKs2lc

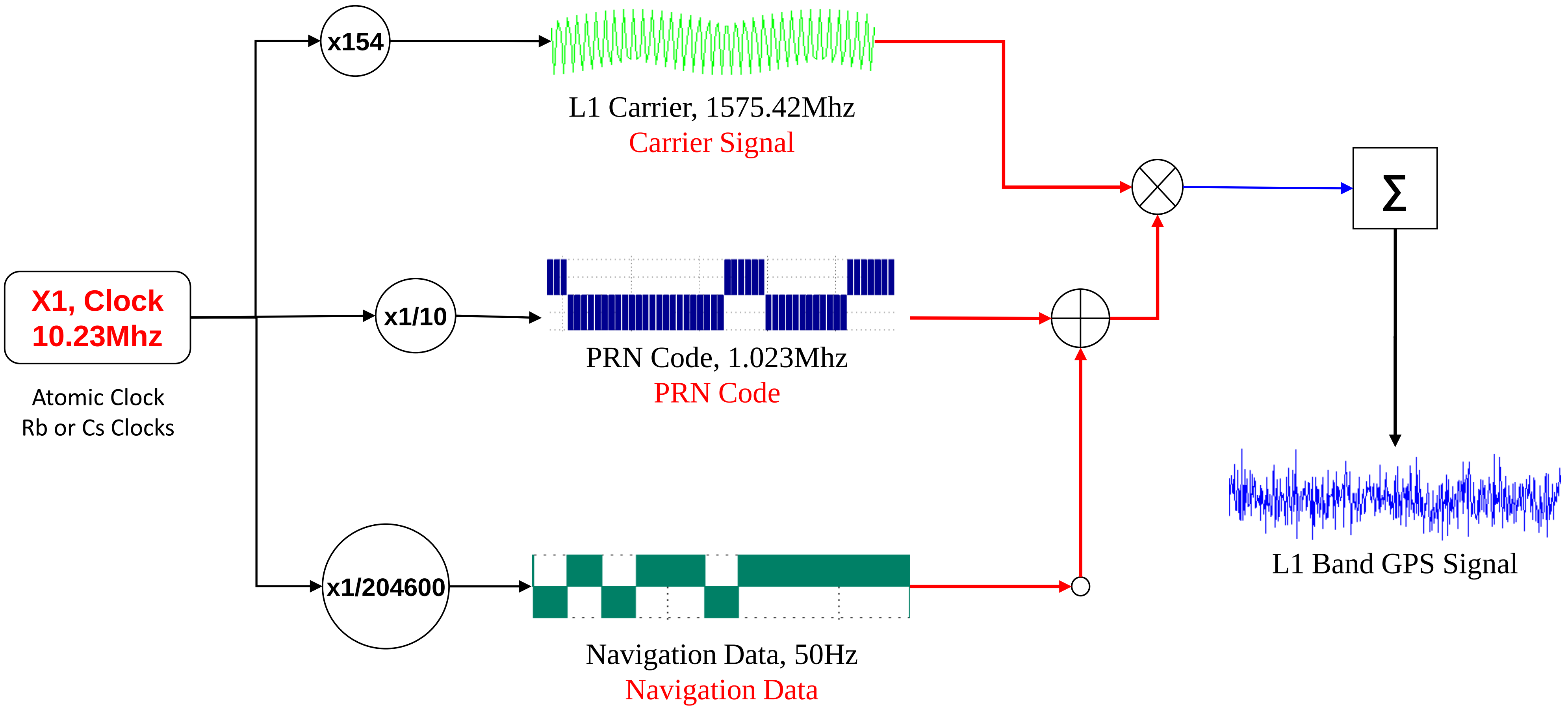
90% of accident victims survive if help is available within 9 minutes of accidents
Only 15% can be saved after 18 minutes – ERA-GLONASS

Reference Slides

GPS L1C/A Signal Structure

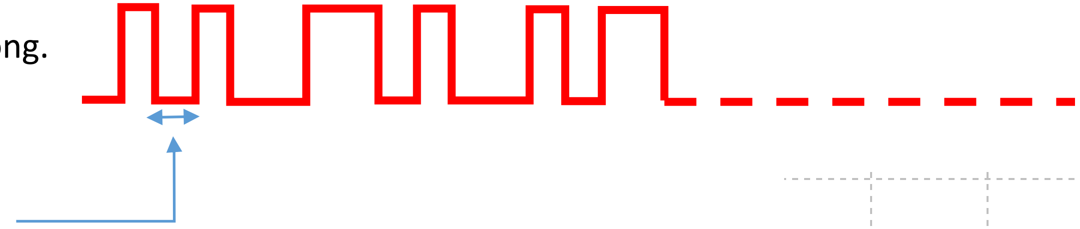
- Carrier Signal
  - It defines the frequency of the signal
  - For example:
    - GPS L1 is 1575.42MHz, L2 is 1227.60MHz and L5 is 1176.45MHz
- PRN Code
  - Necessary to modulate carrier signal
  - Used to identify satellite ID in the signal
  - Should have good auto-correlation and cross-correlation properties
- Navigation Data
  - Includes satellite orbit related data (ephemeris and almanac data)
  - Includes satellite clock related information (clock errors etc.)
  - Includes satellite health information

GPS L1C/A Signal Structure (Satellite Side)

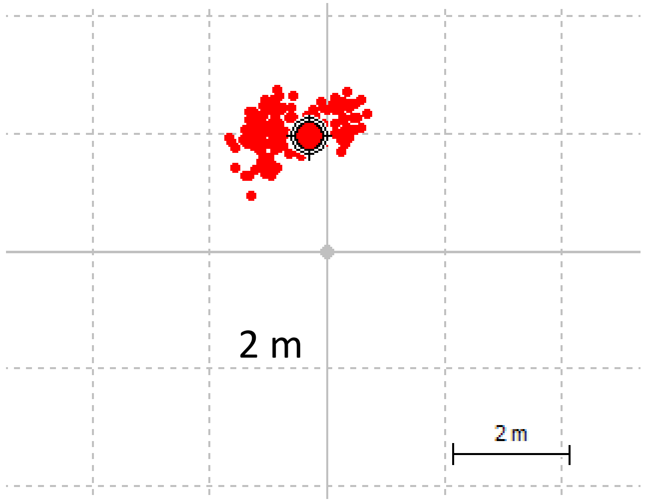


Pseudorange (Code-Phase Measurement) - 2

1-sequence of PRN Code is 1023 bits, 1ms long.
This corresponds to 300Km



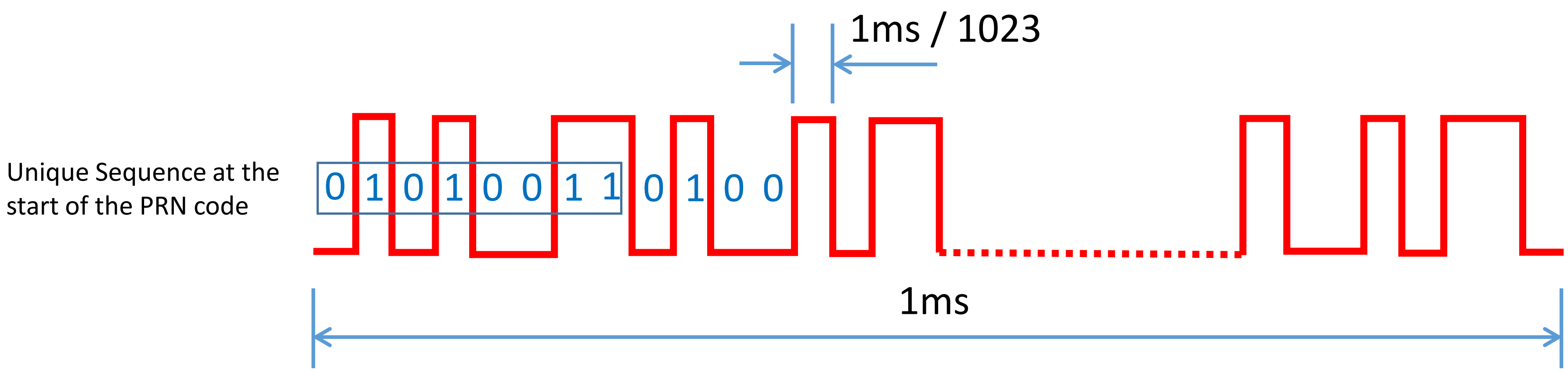
1-bit or chip corresponds to 1/1023 ms.
This is about 293m (say 300m) in distance.



In the receiver, signals are resampled at certain frequency, say 10MHz.
This means every chip will be further divided into 10 smaller chips.
If it is possible to detect code phase at 1/10 of this sampled chip, then range measurement accuracy would be about 300/10/10 = 3m.
However, there are various types of noises and this accuracy may not be possible.
Normally, GPS L1C/A guarantees an accuracy within 10m.
Thus, using Code-Phase (PRN code) measurement, the accuracy will be limited to few meters level.

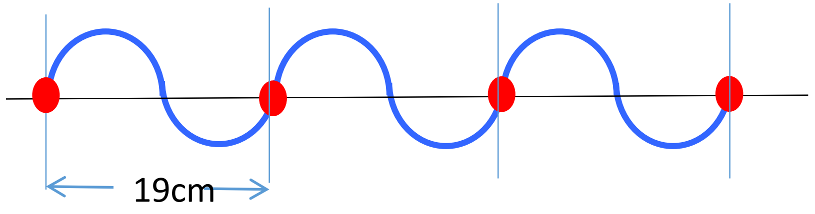
PRN (Pseudo Random Noise) Code

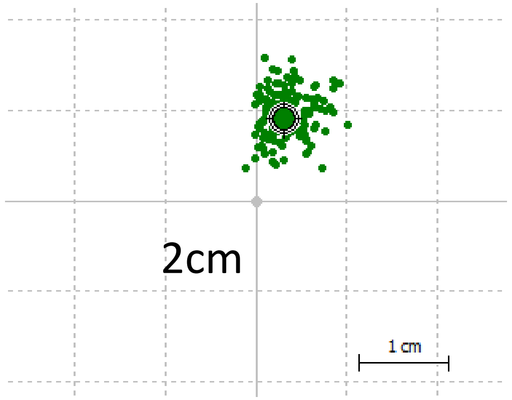
- PRN Code is a sequence of randomly distributed zeros and ones that is one millisecond long.
  - This random distribution follows a specific code generation pattern called Gold Code.
  - There are 1023 zeros and ones in one millisecond.
- Each GPS satellite transmits a unique PRN Code.
  - GPS receiver identifies satellites by its unique PRN code or ID.
- It continually repeats every millisecond
  - The receiver can detect where the PRN code terminated or repeated.
  - A unique sequence of bits indicates start of a PRN code.
- It helps to measure signal transit time and compute pseudorange between the receiver and the satellite
- Its also called C/A (Coarse Acquisition) code in GPS



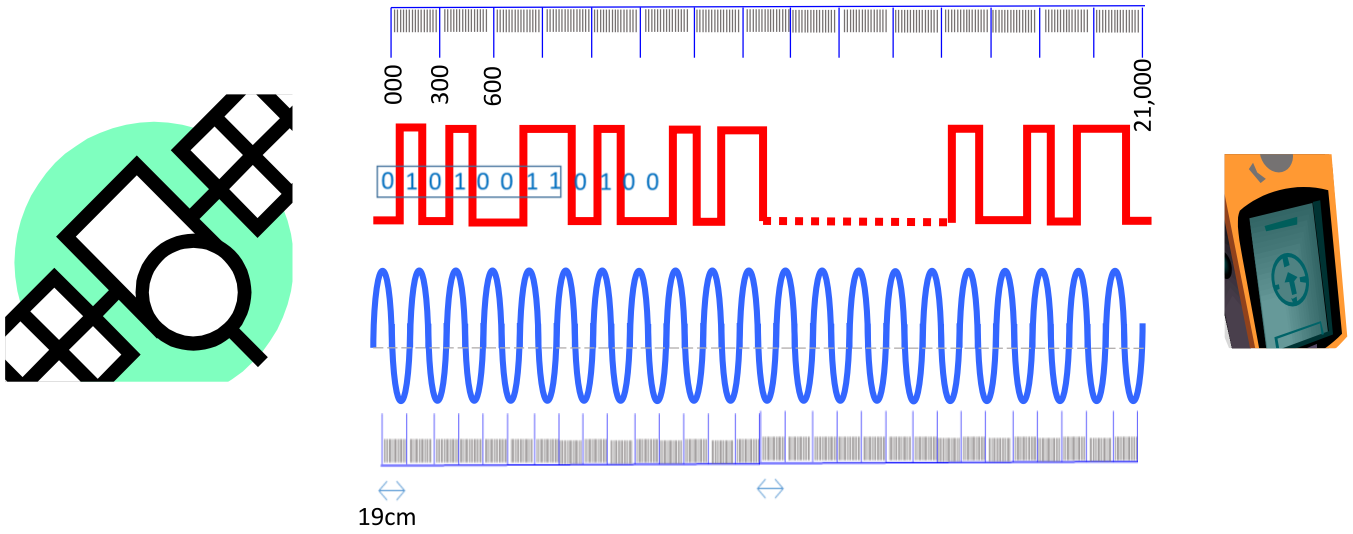
Carrier-Phase Measurement – 1

- Carrier-Phase measurement is done by counting the number of cycles coming from the satellite to the receiver.
- However, there are many complexities in measuring total number of cycles (N) from the satellite to the receiver.
  - This is called integer ambiguity
  - This is due to the fact that all cycles are the same and there are no headers to tell the receiver when a new cycle has arrived after number of cycles as in PRN code.
    - A PRN code has a header to tell the receiver that this is the beginning of the PRN code that is 1023 chips long.
    - There are algorithms to solve this problem of ambiguity resolution.
- One complete cycle for GPS L1 band is 19cm long.
  - Thus, if we can measure one wavelength, we can get 19cm accuracy
  - If we can measure 1/10th of a cycle, we get about 2cm accuracy.
  - Thus, Carrier-Phase measurement can provide centimeter level accuracy.





Code-Phase (PRN Code) vs. Carrier-Phase Measurement



Code-Phase Measurement	Carrier-Phase Measurement
Measuring distance between the satellite and the receiver with a tape that has distance markings as well as distance values written. So that we can measure correct distance.	Measuring distance between the satellite and the receiver with a tape that has distance markings but distance values are not written. We only know that each distance marker is 19cm apart. So, we need to count at certain point the number of cycles separately that's coming to the receiver. This is called integer ambiguity solving.
Only provide meter level accuracy	Provides centimeter level accuracy
Simple and required measurement. It's part of signal demodulation process. So this can't be avoided.	Counting of number of cycles (solving integer ambiguity) is not required if carrier-phase based measurement such as RTK or PPP is not required.

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