Introduction to
Global Navigation Satellite System (GNSS)

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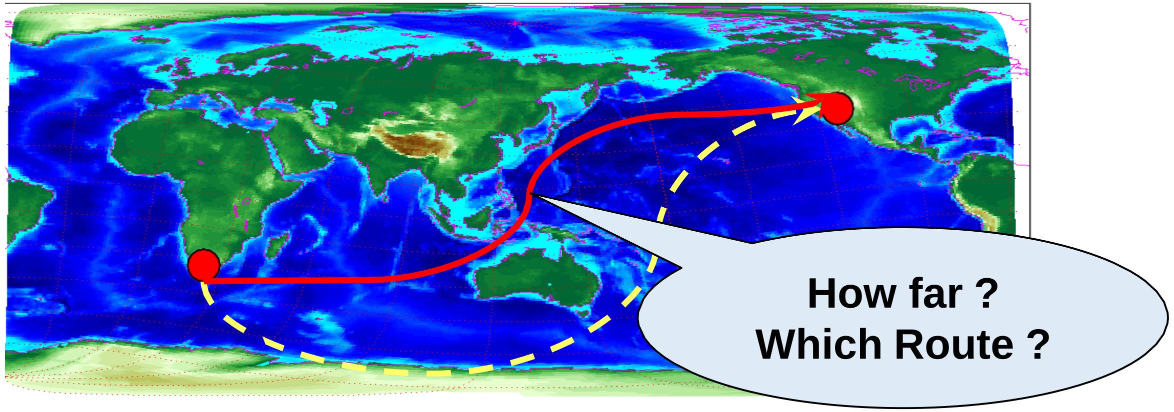
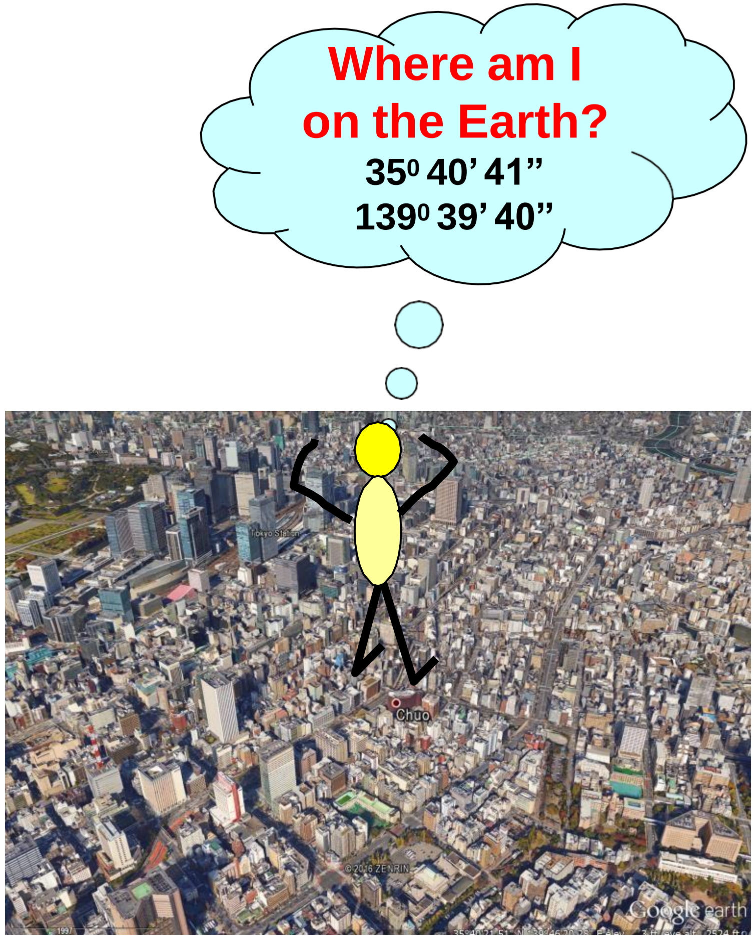
Fundamental Problem

- 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





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
    - Complicated, Errors accumulate quickly
- Radio-based Navigation
  - LORAN, OMEGA
    - Subject to Radio Interference, Jamming, Limited Coverage
- Satellite-based Navigation or GNSS
  - TRANSIT, GPS, GLONASS, GALILEO, QZSS, BEIDOU (COMPASS), IRNSS
  - Global, Difficult to Interfere or Jam, High Accuracy & Reliability

What is GNSS?

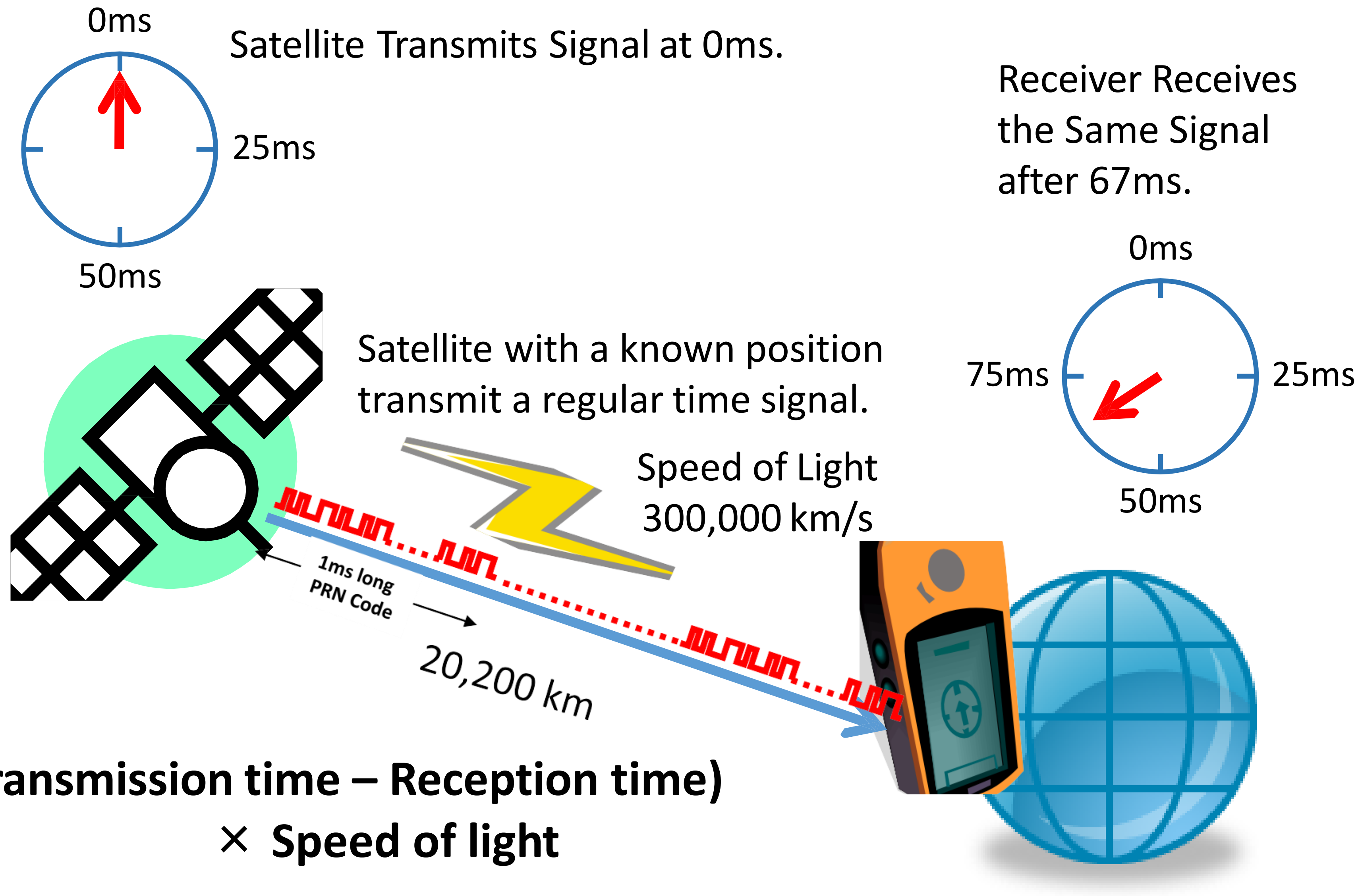
Global Navigation Satellite System (GNSS) is the standard generic term for all navigation satellites systems like GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC.

- Global Constellation
  - GPS USA
  - GLONASS, Russia
  - Galileo, Europe
  - BeiDou (COMPASS), China
- Regional Constellation
  - QZSS, Japan
  - NAVIC (IRNSS), India

Satellite Based Augmentation System (SBAS)

- Satellite Based Augmentation System (SBAS) are used to augment GNSS Data
  - Provide Higher Accuracy, Integrity, Continuity and Availability
  - Some correction data like satellite orbit, satellite clock and atmospheric data are broadcasted from communication satellites
  - Used by ICAO for Aviation
- Different Types of SBAS
  - WAAS, USA
  - MSAS, Japan
  - EGNOS, Europe
  - GAGAN, India
  - SDCM, Russia

Determine the Distance using Radio Wave



Distance = (Transmission time – Reception time)
× Speed of light

GNSS Requirements

- GNSS needs a common time system.
  - Each GNSS satellite has atomic clocks.
  - How about user receivers?
- The signal transmission time has to be measurable.
  - Each GNSS satellite transmits a unique digital signature, which consists an apparent random sequence
  - A Time Reference is transmitted using the Navigation Message
- Each signal source has to be distinguishable.
  - GNSS utilizes code division multiple access (CDMA) or frequency division multiple access (FDMA).
- The position of each signal source must be known.
  - Each satellite sends its orbit data using the Navigation Message
  - Orbit Data: Almanac and Ephemeris

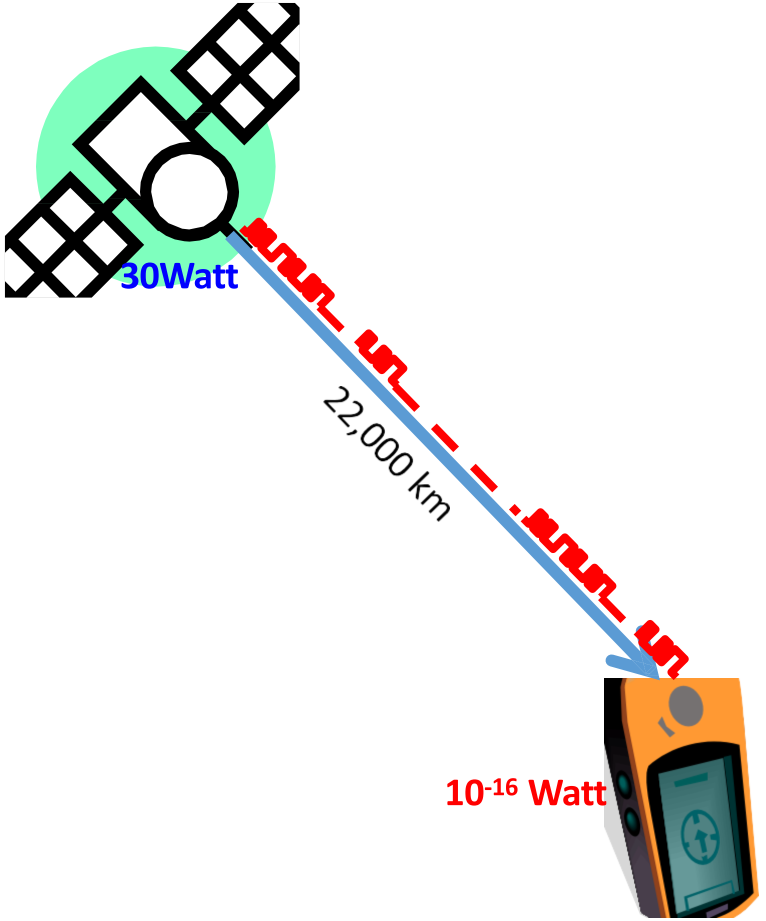
Characteristics of GNSS Signals

- GNSS Signals have basically three types of signals
  - Carrier Signal
  - PRN Code (C/A Code)
  - Navigation Data
- All GNSS Signals except GLONASS are based on CDMA
  - Only GLONASS use FDMA
  - Future Signals of GLONASS will also use CDMA
- The modulation scheme of GNSS signals are BPSK and various versions of BOC

CDMA: Code Division Multiple Access
FDMA: Frequency Division Multiple Access
BPSK : Binary Phase Shift Keying
BOC: Binary Offset Carrier

GPS Signal Power: How Strong or How Weak?

- GPS satellites are about 22,000km away
- Transmit power is about 30W
- This power when received at the receiver is reduced by 10^{16} times.
  - The power reduces by 1/distance^2
  - This is similar to seeing a 30W bulb 22,000Km far
- GPS signals in the receiver is about 10^{-16} Watt, which is below the thermal noise



GPS Signal Power: How Strong or How Weak?

- GPS Signal Power at Receiver
  - -130dBm or -160dBW
- Thermal Noise Power
  - Defined by $kT_{eff}B$, where
    - $K = 1.380658e\text{-}23JK^{-1}$, Boltzman Constant
    - $T_{eff} = 362.95$, for Room temperature in Kelvin at 290
      - Teff is effective Temperature based on Frii's formula
    - $B = 2.046MHz$, Signal bandwidth
  - Thermal Noise Power = -110dBm for 2MHz bandwidth
  - If Bandwidth is narrow, 50Hz
    - Noise Power = -156dBm

GPS
(Global Positioning System)
USA

History of GPS (1/2)

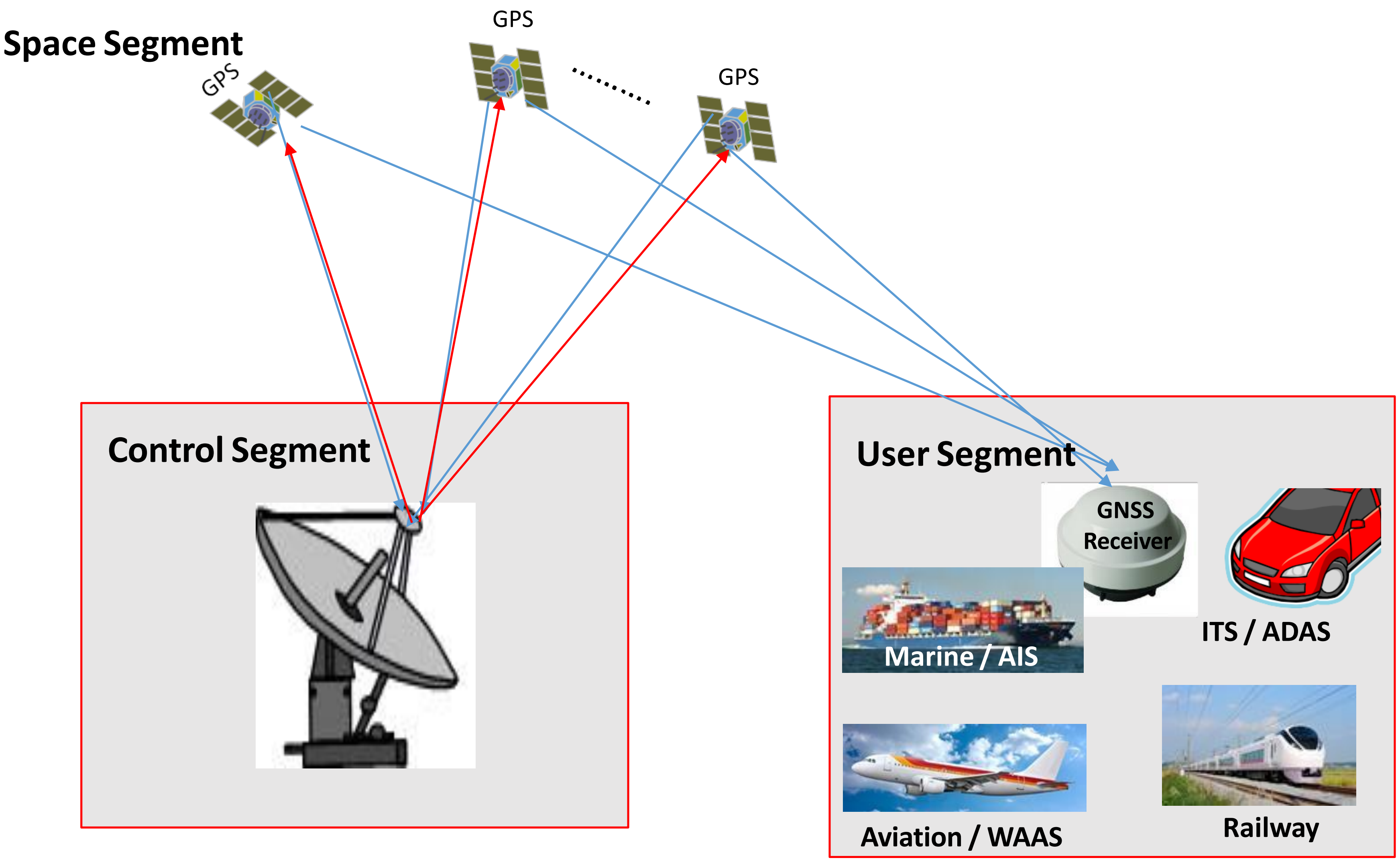
- Originally designed for military applications at the height of the Cold War in the 1960s, with inspiration coming from the launch of the Soviet spacecraft Sputnik in 1957.
- Transit was the first satellite system launched by the United States and tested by the US Navy in 1960.
  - Just five satellites orbiting the earth allowed ships to fix their position on the seas once every hour.
- GPS developed quickly for military purposes thereafter with a total of 11 “Block” satellites being launched between 1978 and 1985.
- The Reagan Administration in the us had the incentive to open up GPS for civilian applications in 1983.

How to Drop Five Bombs from Different Aircrafts into the Same Hole?
(with an accuracy of 10m)

History of GPS (2/2)

- Upgrading the GPS was delayed by NASA space shuttle Challenger disaster in 1989 and it was not until 1989 that the first Block II satellites were launched.
- By the summer of 1993, the US launched the 24th GPS satellite into orbit, which complete the modern GPS constellation of satellites.
- In 1995, it was declared fully operational.
- Today’s GPS constellation has around 30 active satellites.
- GPS is used for dozens of navigation applications.
  - Route finding for driver, map-making, earthquake research, climate studies, and many other location based services.

GPS Segments



GPS Segments

Following are the functionalities of each of these parts:

•*Satellites* act like the stars in constellations, and we know where they are because they invariably send out signals.

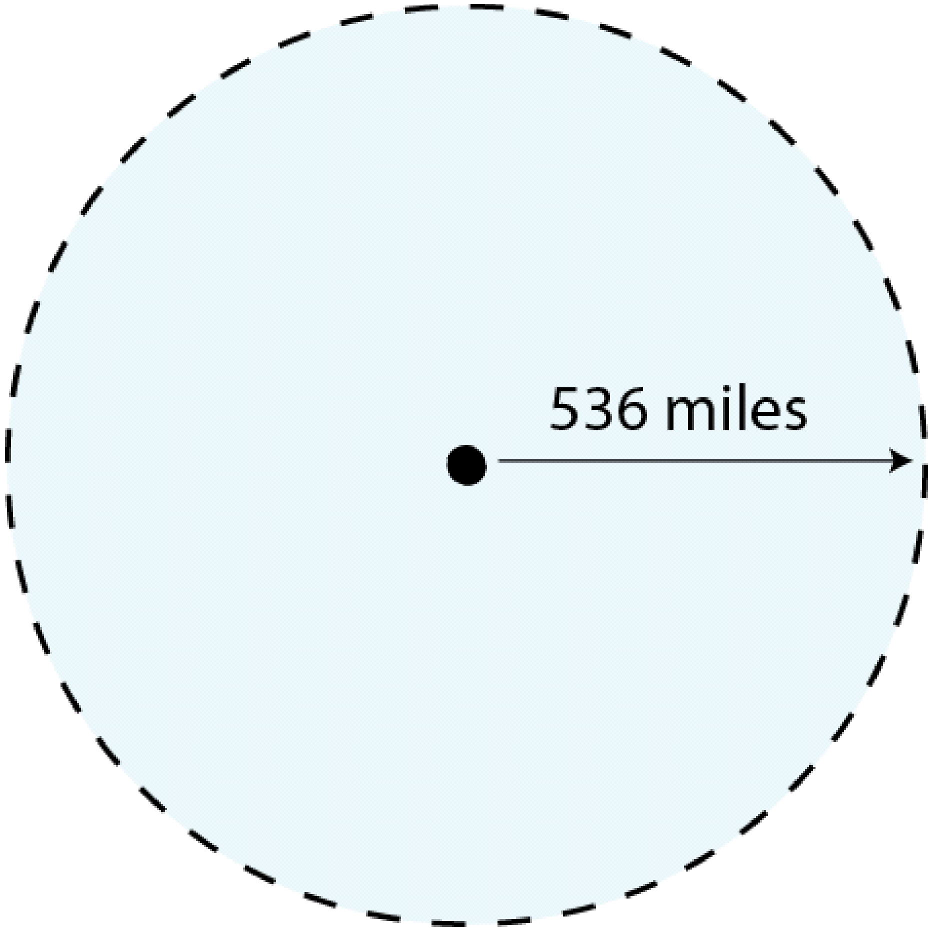
•The *ground stations* make use of the radar to make sure the satellites are actually where we think they are.

•A *receiver* is a device that you might find in your phone or in your car and it constantly seeks for the signals from the satellites. The receiver figures out how far away they are from some of them. Once the receiver calculates its distance from four or more satellites, it knows exactly where you are.

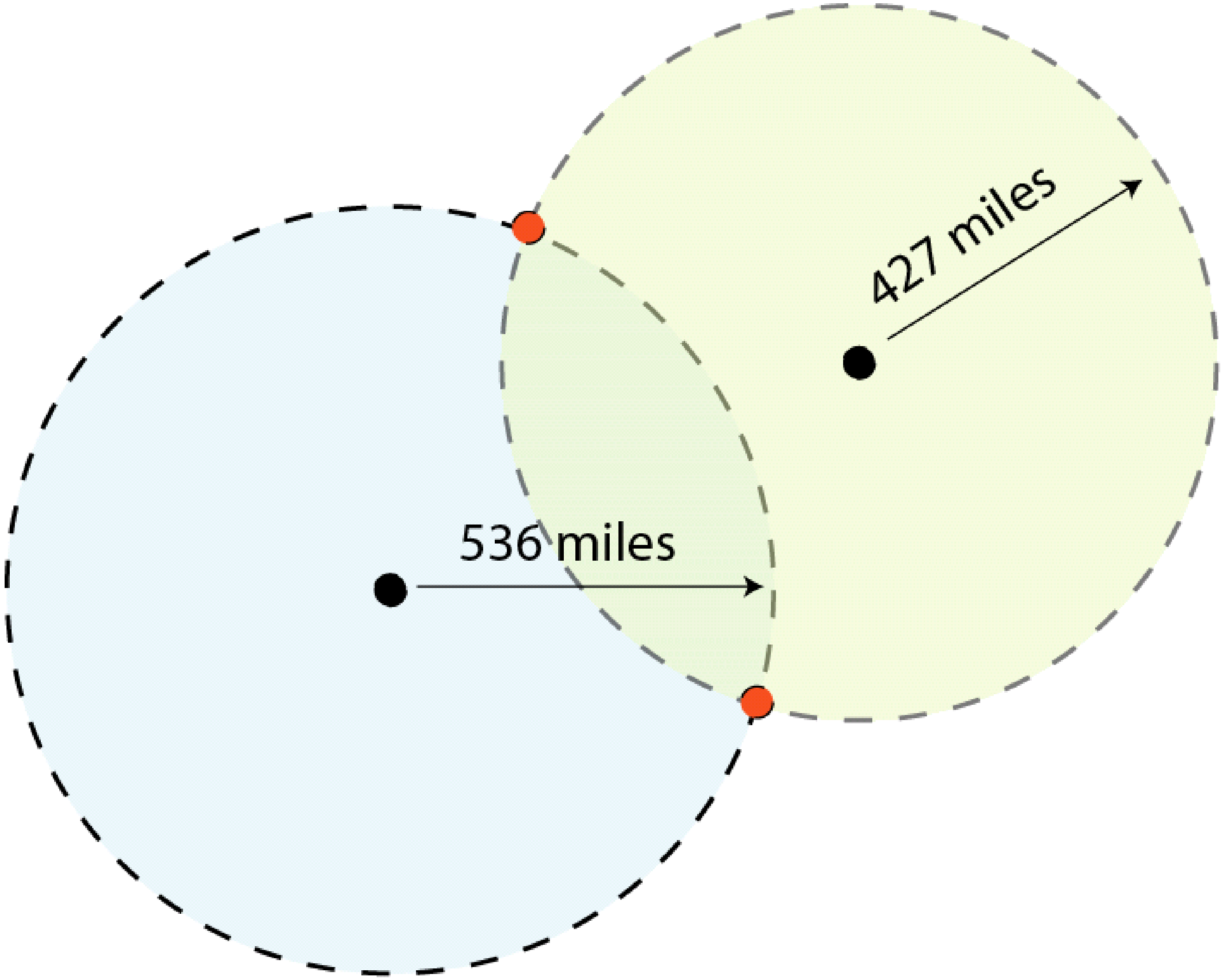
Triangulation

Geometric Principle:

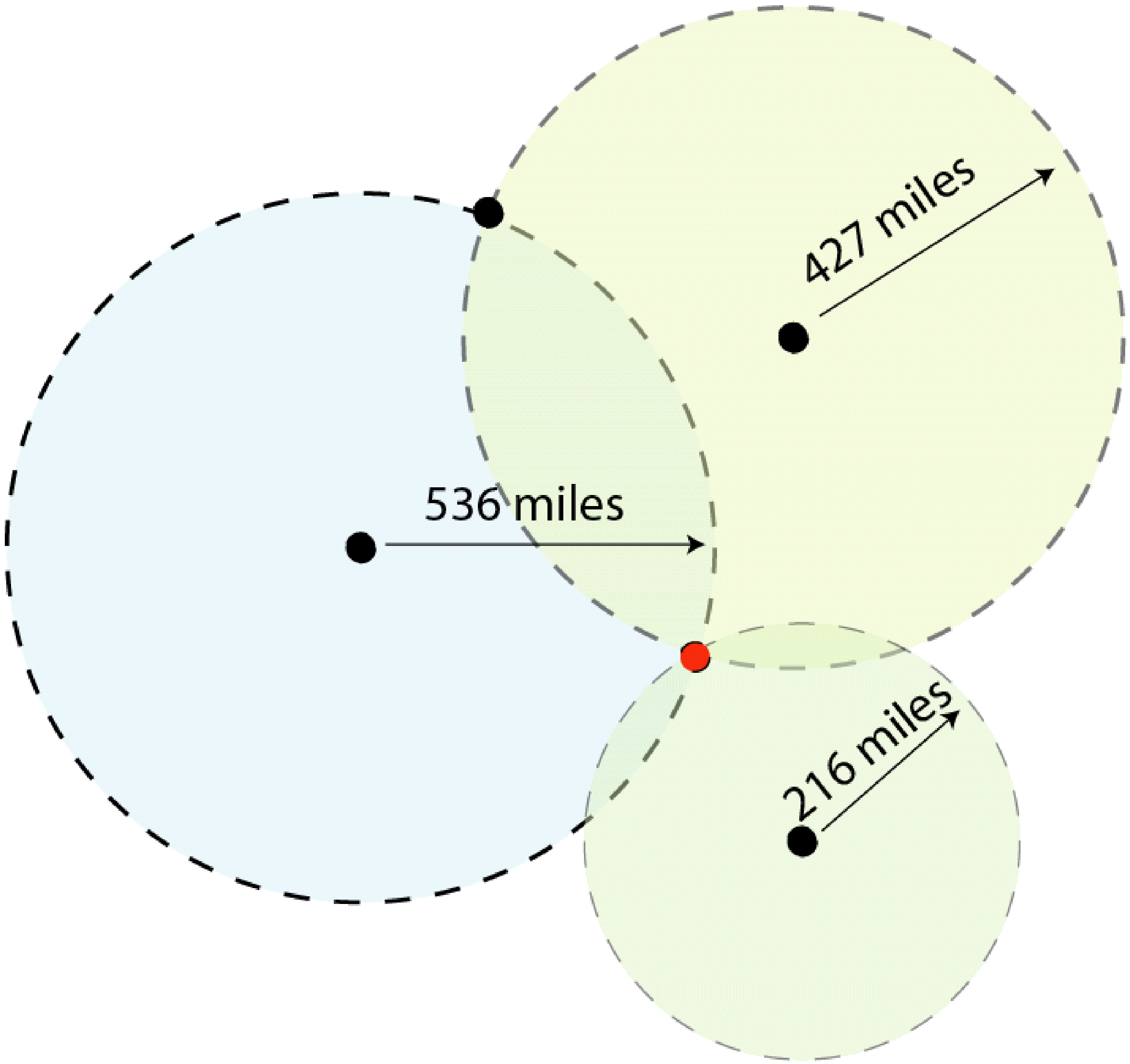
You can find one location if you know its distance from other, already-known locations.



Triangulation

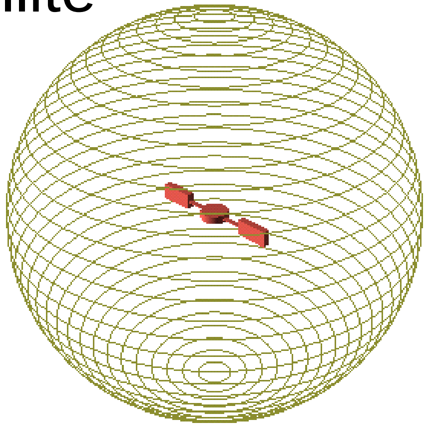


Triangulation

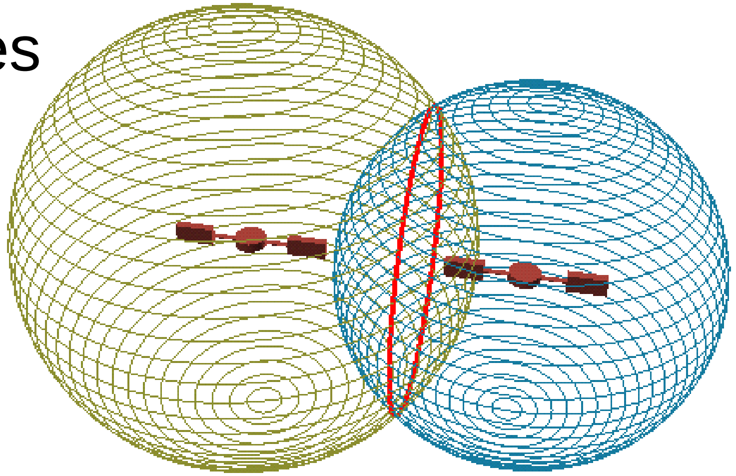


3-D Trilateration

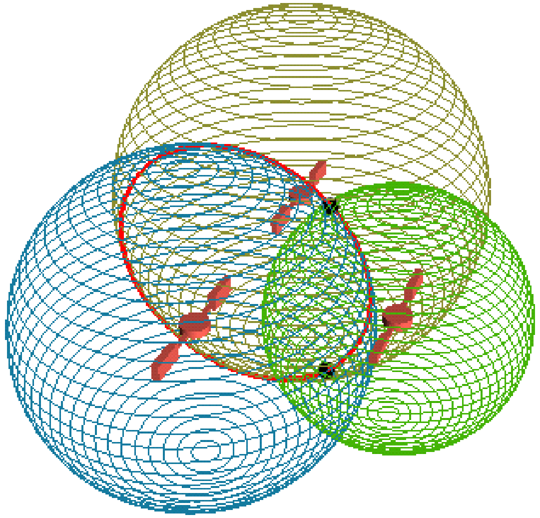
1 Satellite

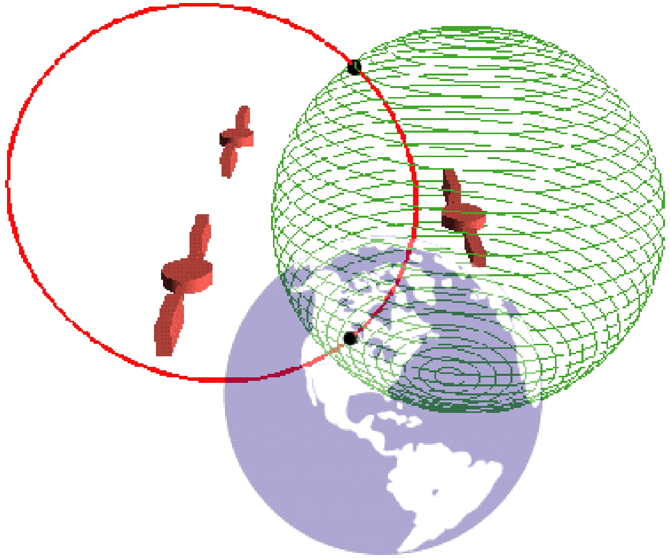


2 Satellites



3 Satellites





GLONASS
(Global Navigation Satellite System)
Russia

GLONASS Current & Future Constellation

1982 First Launch	2003	2011	Planned Launch
			
GLONASS	**GLONASS-M**	**GLONASS-K1**	**GLONASS-K2**
DECOMMISSIONED 87 Launched 0 Operational 81 Retired 6 Lost	**Under Normal Operation 45 Launched 27 Operational 12 Retired 6 Lost**	**Under Production / Operation 2 Launched 2 Operational First launch Dec 2014**	**Under Development 3 On Order First Launch Expected 2018**
•L1OF, L1SF • L2SF	•L1OF, L1SF •L2OF, L2SF •L3OC	•L1OF, L1SF •L2OF, L2SF •L3OC	•L1OF, L1SF •L2OF, L2SF •L1OC, L1SC •L2OC, L2SC •L3OC

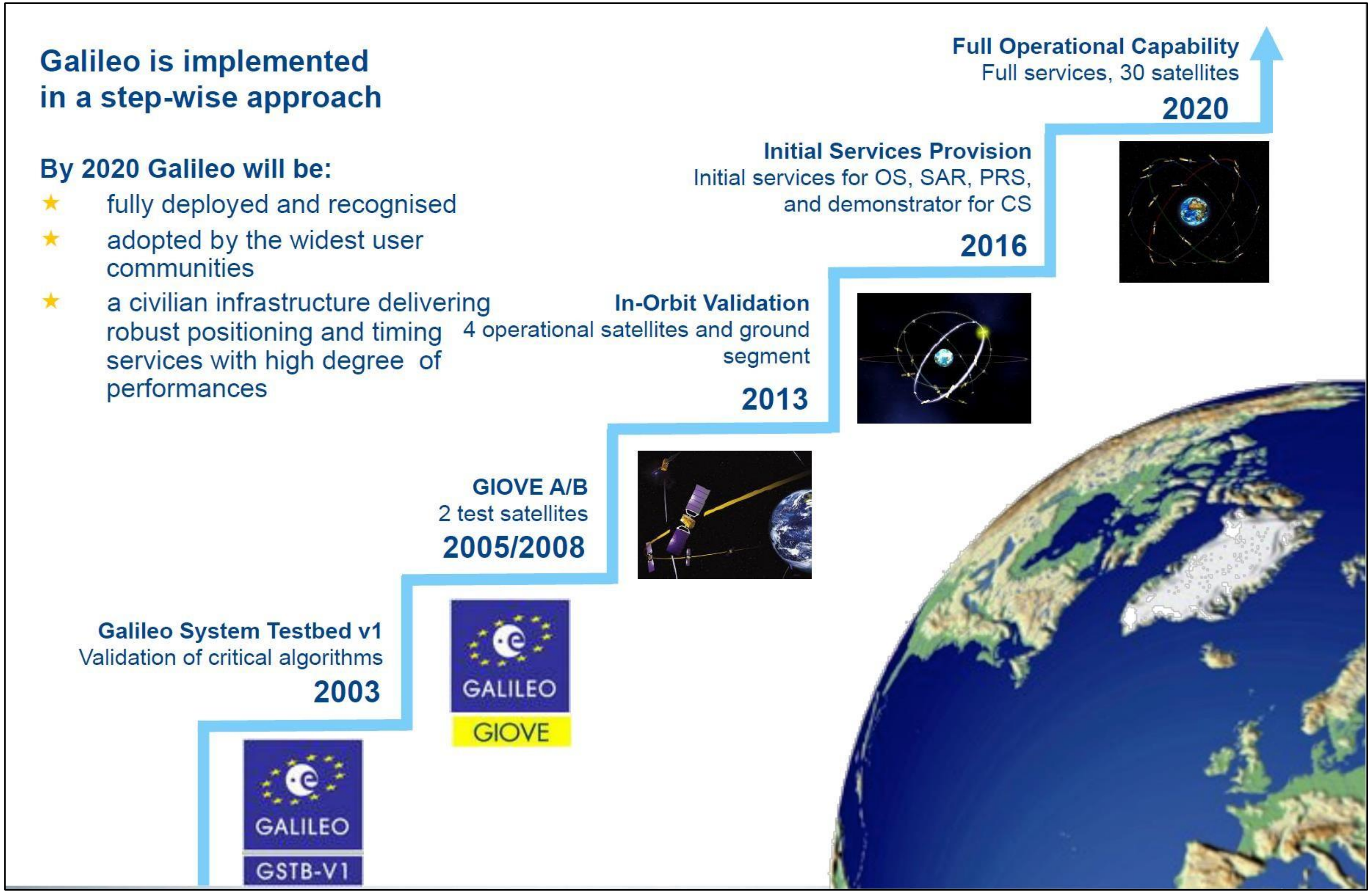
GLONASS space segment STATUS & MODERNIZATION, Joint - Stock Company «Academician M.F. Reshetnev» Information Satellite Systems» ICG-7, November 04-09, 2012 , Beijing, China, https://en.wikipedia.org/wiki/GLONASS-K2

GLONASS FDMA Signals

- L1 Band 1598.0625 - 1604.40 MHz
  - 1602 MHz + $n \times 0.5625$ MHz
    - where n is a satellite's frequency channel number ($n = -7, -6, -5, \ldots, 7$).
- L2 Band 1242.9375 - 1248.63 MHz
  - 1246 MHz + $n \times 0.4375$ MHz

Galileo, Europe

Galileo Space Segment



Galileo Signals

Band	Frequency, MHz	Signal Type	Code Length msec	Chip Rate, MHz	Modulation Type	Data / Symbol Rate, bps/sps	Notes
E1	1575.42	A	10	10.23	BOC(15,2.5)	??	Restricted
		B_{Data}	4	1.023	CBOC, Weighted combination of BOC(1,1) & BOC(6,1)	125 / 250	Data
		C_{Pilot}	100	1.023		No Data	Pilot
E6	1278.75	A	10	5.115	BOC(15,5)	??	PRS
		B	1	5.115	BPSK(5)	500 / 1000	Data
		C	100	5.115		No Data	Pilot
E5 1191.795 MHz	1176.45	A-I	20	10.23	AltBOC(15,10)	25 / 50	Data
		A-Q	100	10.23		No Data	Pilot
	1207.14	B-I	4	10.23		125 / 250	Data
		B-Q	100	10.23		No Data	Pilot

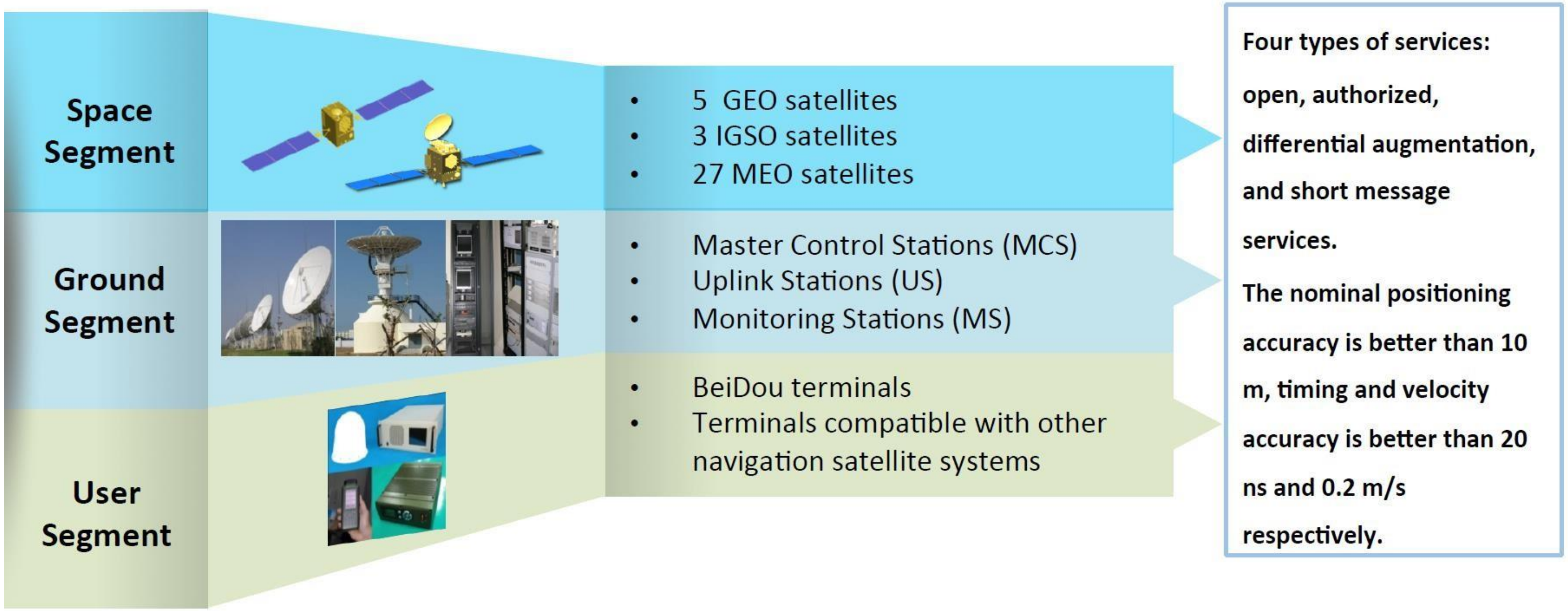
Galileo Services

Open Service (OS)	**Freely accessible service for positioning, navigation and timing for mass market**
Commercial Service (CS)	**Delivers authentication, high accuracy and guaranteed services for commercial applications**
Public Regulated Service (PRS)	**Encrypted service designed for greater robustness in challenging environments**
Search And Rescue Service (SAR)	**Locates distress beacons and confirms that message is received**
Safety of Life Service (SoL)	**The former Safety of Life service is being re-profiled**




BeiDou, China

BeiDou Space Segment



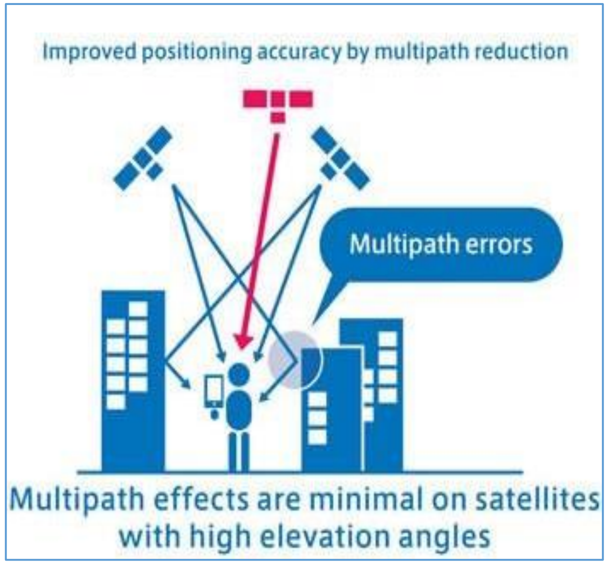
Source: Update on BeiDou Navigation Satellite System, Chengqi Ran, China Satellite Navigation Office
Tenth Meeting of ICG, NOV 2015

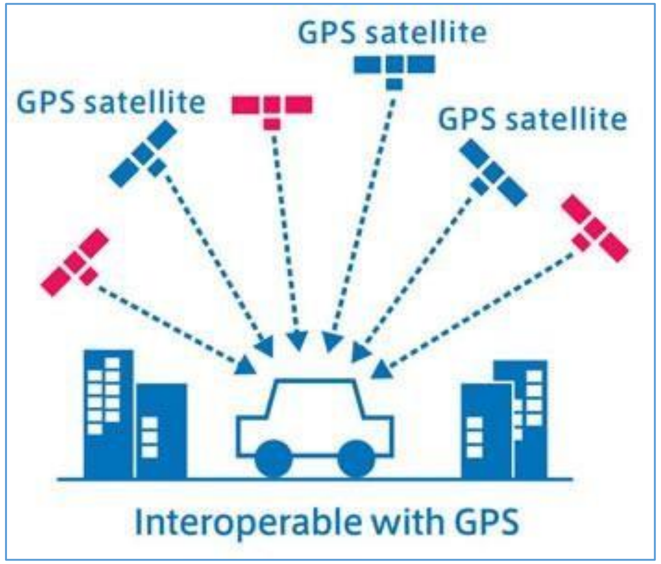
COMPASS / BEIDOU Signals: Already Transmitted

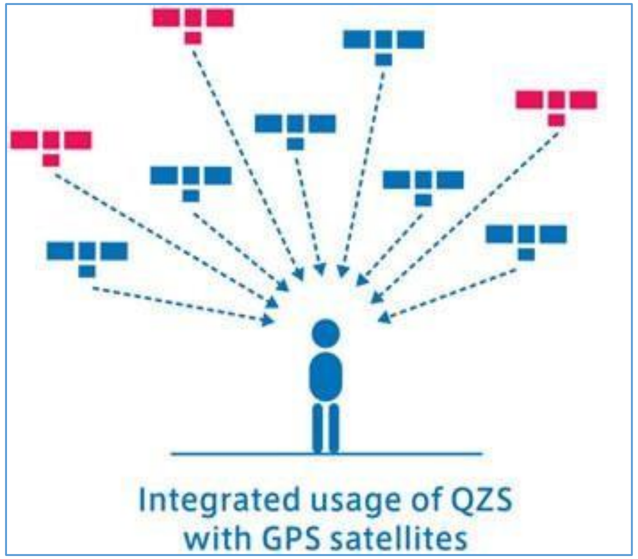
Band	Frequency MHz	Signal Type	Chip Rate (MHz)	Modulation Type	Data / Symbol rate	Notes
B1	1561.098	B1(I)	2.046	QPSK	50 / 100	Open
		B1(Q)			None	Authorized
	1589.742	B1-2(I)	2.046	QPSK	50 / 100	Open
		B1-2(Q)			25 / 50	Authorized
B2	1207.14	B2(I)	2.046	QPSK	None	Open
		B2(Q)	10.23		50 / 100	Authorized
B3	1268.52	B3	10.23	QPSK	500	Authorized

QZSS
(Quasi-Zenith Satellite System)
Japan

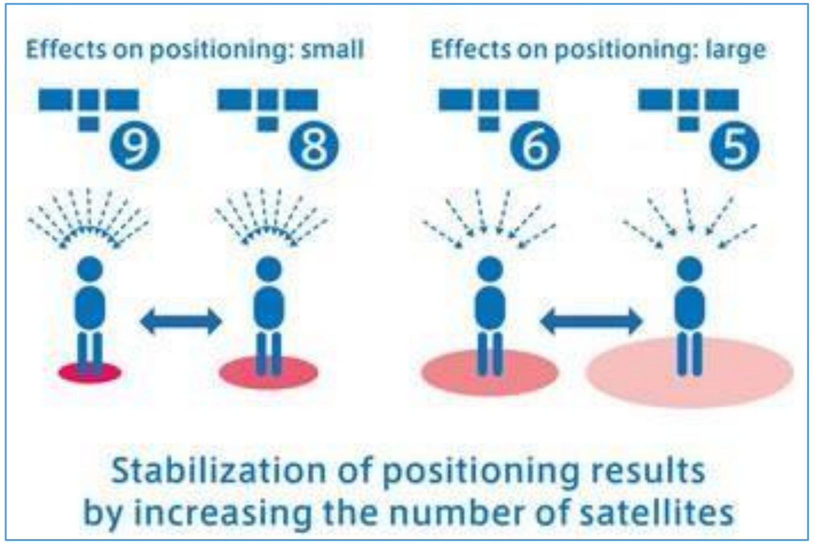
Merits of QZSS







- QZSS signal is designed in such a way that it is **interoperable with GPS**
- QZSS is visible near zenith; improves visibility & DOP in dense urban area
- Provides Orbit Data of other GNSS signals
- Provides **Augmentation Data for Sub-meter and Centimeter level position accuracy**
- Provides Messaging System during Disasters



http://qzss.go.jp/en/overview/services/sv04_pnt.html

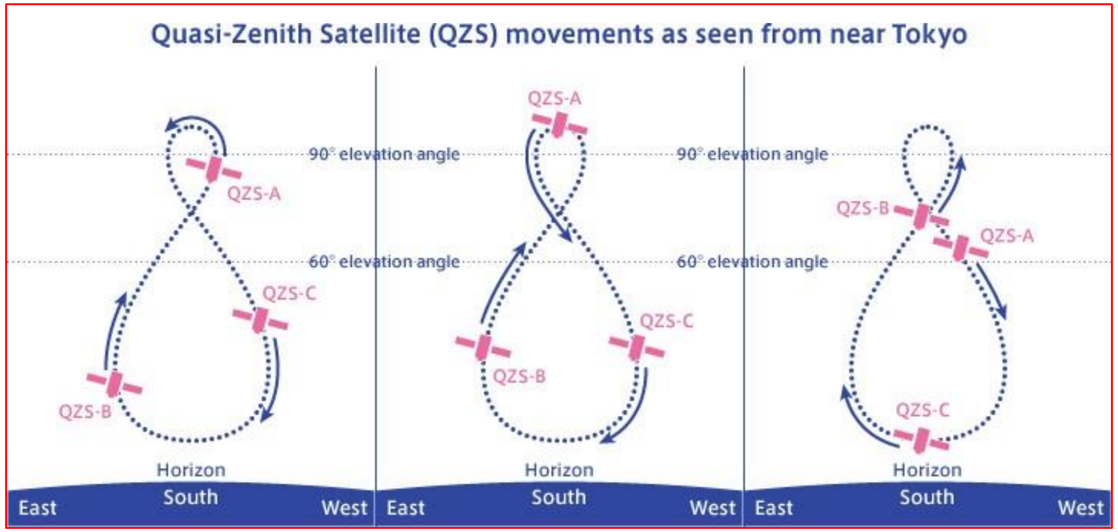
Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@iis.u-tokyo.ac.jp

QZSS Development Plan

1st Satellite launched on 11th September 2010 : QZ Orbit
2nd Satellite launched on 1st June 2017 : QZ Orbit
3rd Satellite launched on 19th August 2017 : Geostationary Orbit

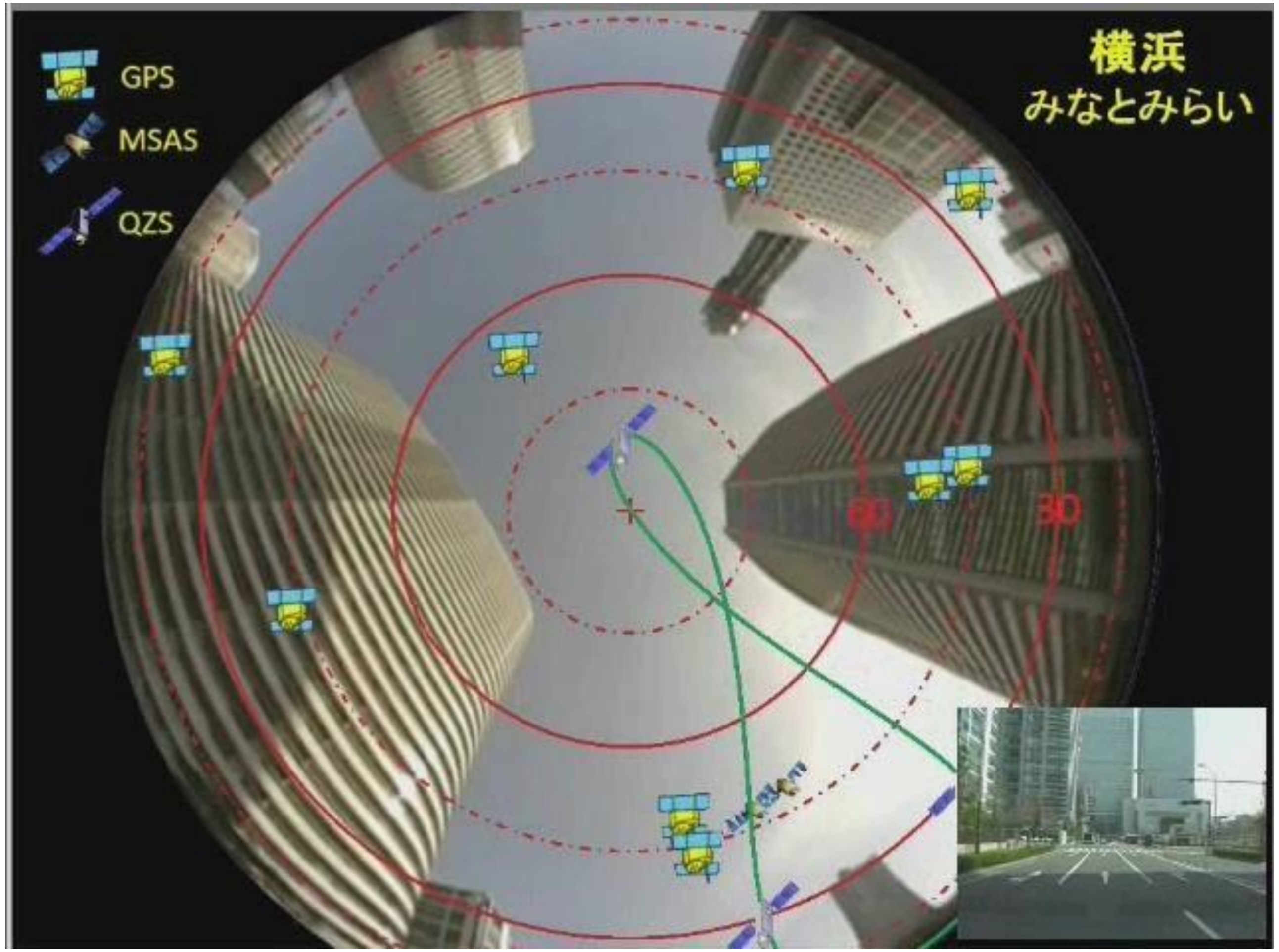
QZSS Constellation Status

- Current Status
  - One Satellite launched on 11th SEP 2010
- Total constellation of Seven Satellites
  - Three more satellites were launched by the end of 2017



Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@iis.u-tokyo.ac.jp

QZSS Satellite Visibility



Source: SPAC Animation Video

QZSS Satellites & Signal Types

Signal Name	QZS-1 Block IQ (QZO) 1	QZS-2 to QZS-4 Block IIQ (QZO) 2	Block IIG (GEO) 1	Transmission service	Center Frequency MHz
L1C/A	◎	◎	◎	Satellite positioning service	1575.42
L1C	◎	◎	◎	Satellite positioning service	
L1SAIF	◎			Sub-meter Level Augmentation Service (SLAS) / Disaster and Crisis Management	
L1S		◎	◎		
L1Sb	-	-	◎	SBAS Transmission Service from around 2020	
L2C	◎	◎	◎	Satellite positioning service	1227.60
L5	◎	◎	◎	Satellite positioning service	1176.45
L5S	-	◎	◎	Positioning Technology Verification Service	
LEX	◎			MADOCA	1278.75
L6		◎	◎	Centimeter Level Augmentation Service (CLAS)	
S-band	-	-	◎	QZSS Safety Service / SAR	2GHz

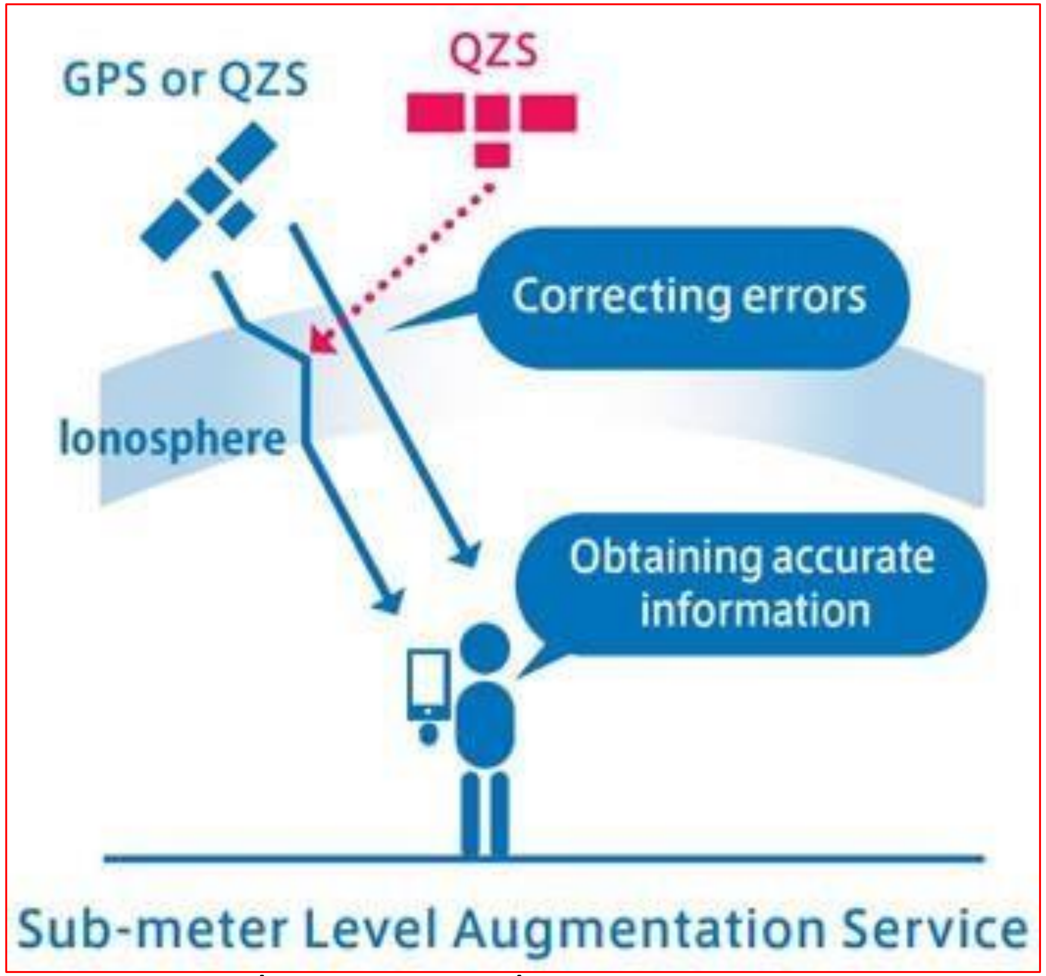
QZSS New Applications

QZSS New Applications

- Short Message Broadcast during Emergencies and Disasters
  - L1SAIF / L1S Signals
- Sub-meter Level Augmentation Service (SLAS)
  - L1SAIF / L1S / L1Sb Signals
- Centimeter Level Augmentation Service (CLAS)
  - L6 Signal
    - PPP-RTK
  - LEX Signal : MADOCA Service
    - PPP

Short Message Broadcast during Disaster

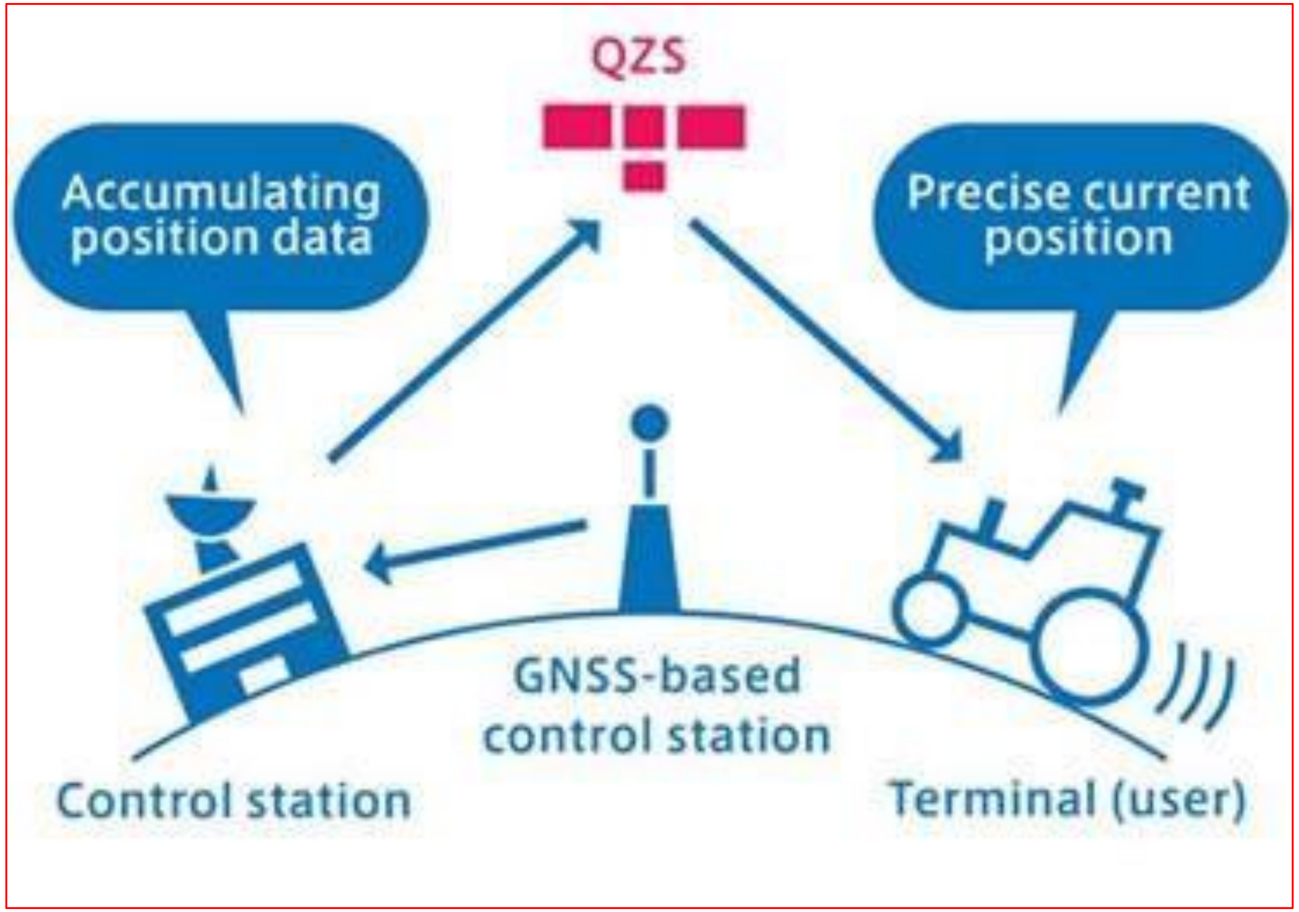
Sub-meter Level Augmentation Service (SLAS)



SLAS : Sub-meter Level Augmentation Service

Signal Used: L1SAIF / L1S

Centimeter Level Augmentation Service (CLAS)



CLAS : Centimeter Level Augmentation Service
Signal Used: LEX: MADOCA & L6

NAVIC, India
(Indian Regional Navigation Satellite System)

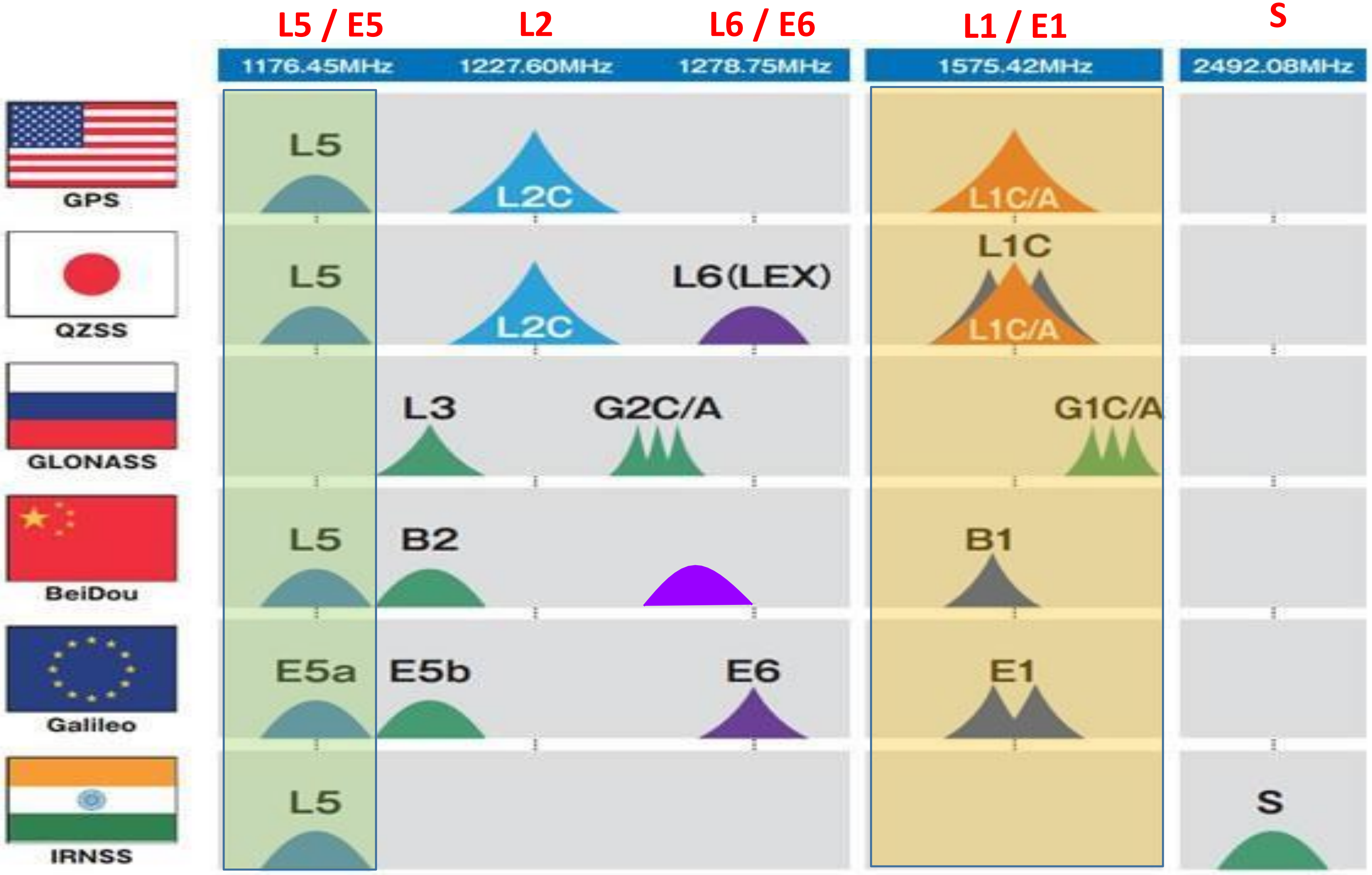
IRNSS Signal Types

Signal	Carrier Frequency	Bandwidth
L5	1176.45MHz	24MHz
S	2492.028MHz	16.5MHz

Multi GNSS Issues

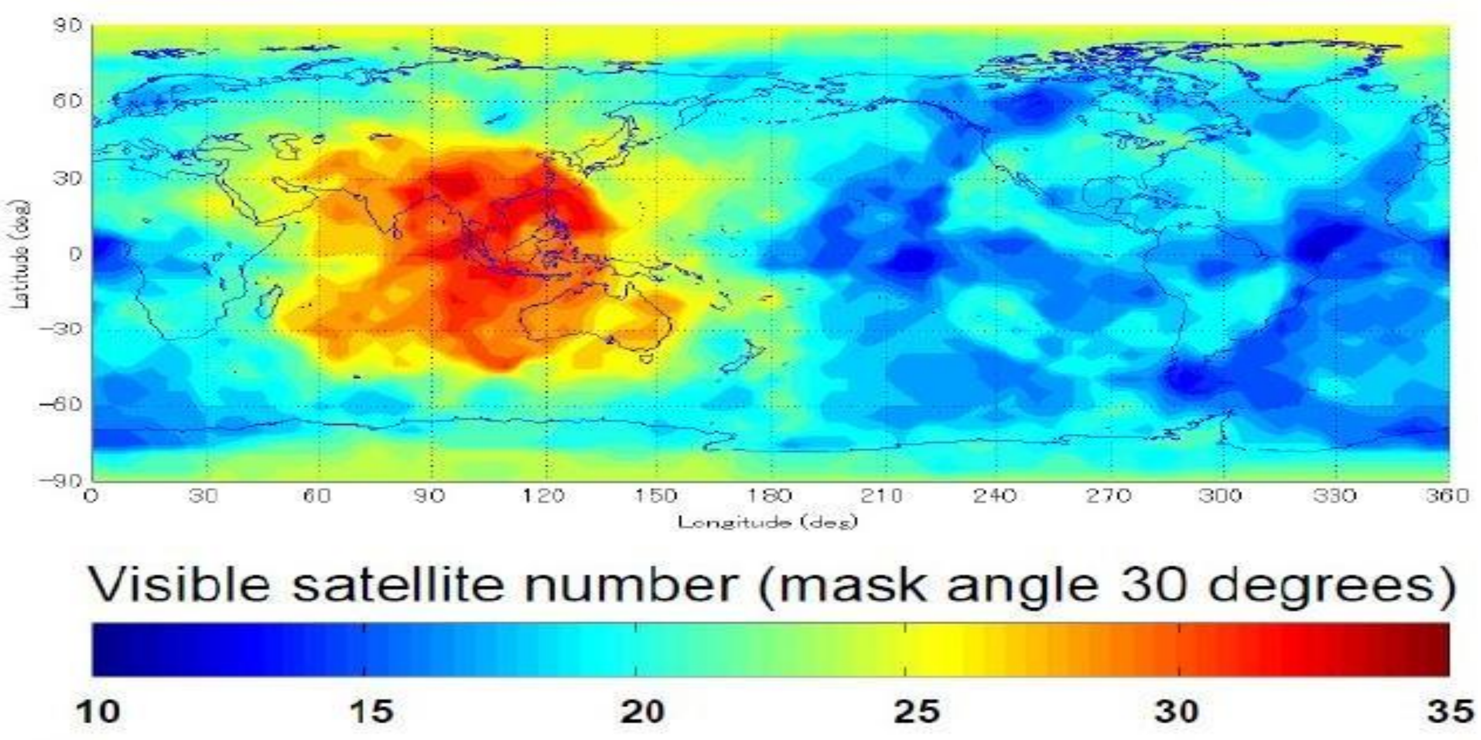
- In the past we had only GPS & GLONASS, now we have Galileo, BeiDou, QZSS, IRNSS
- Compatibility
  - Lets not hurt each other
    - Interference issues
- Interoperable
  - I'll use yours, you can use mine
    - Use of the same receiver and antenna to receive different signals
- Interchangeable
  - Any four will do
    - Can ONE GPS, ONE GLONASS, ONE Galileo and ONE COMPASS provide 3D Position?

Multi-GNSS Signals



Multi GNSS Signals: Benefits to Users

- GPS+GLONASS+Galileo+COMPASS+IRNSS+QZSS
- Asia-Oceanic region will see the maximum number of satellites



Multi GNSS Signals: Benefits to Users

- Increase in usable SVs, signals and frequencies
  - Increase in availability and coverage
  - More robust and reliable services
  - Higher accuracy in bad conditions
  - Less expensive high-end services
  - Better atmospheric correction
- Emerging new and expanding existing applications are to be expected
    - Atmosphere related applications
    - Short Message Broadcasting
    - SAR (Search And Rescue Applications)
    - Bi-static Remote Sensing
      - Compute Soil Moisture, Wind Velocity, Sea Wave Height etc…