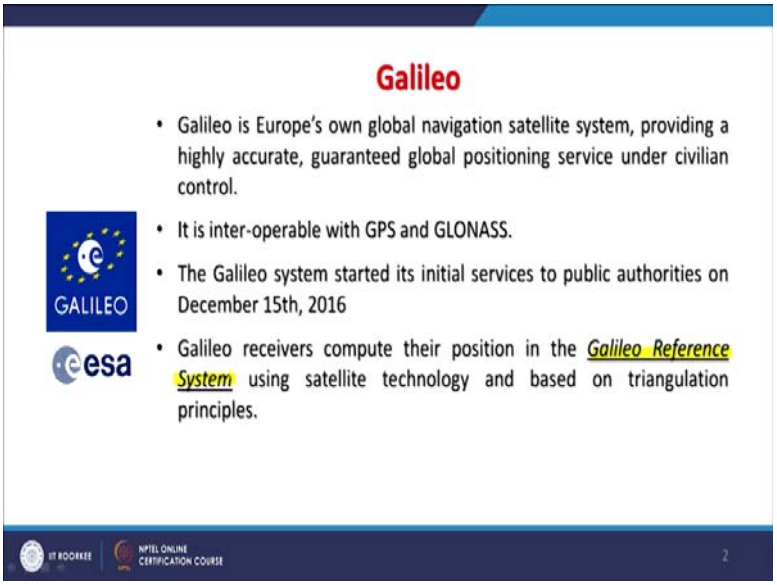
Global Navigation Satellite Systems and Applications
Prof. Arun K. Saraf
Department of Earth Sciences
Indian Institute of Technology, Roorkee

Lecture - 09
GALILEO

Hello everyone and welcome to Global Navigation Satellite System and Applications and in this lecture, we will be discussing about the GALILEO which is a European GNSS System.

(Refer Slide Time: 00:41)



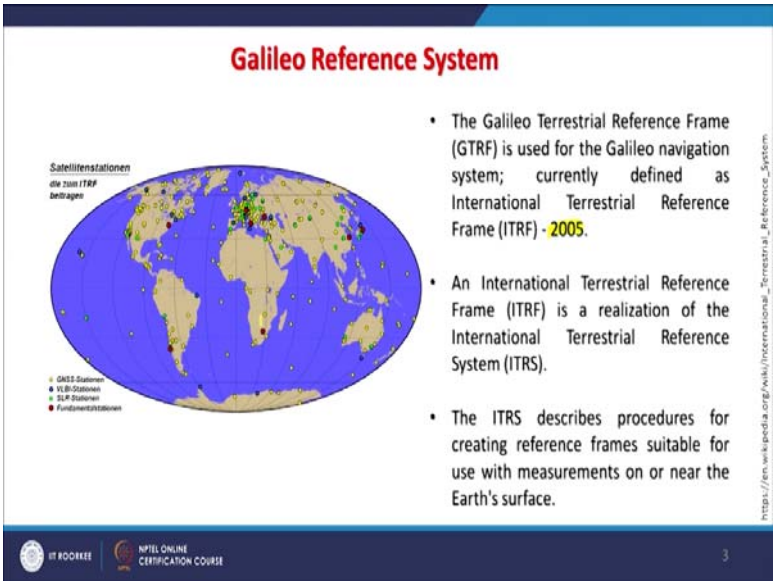
And as you know that when the Russians develop their own, American develop their own so European also thought that they should also have their own positioning system. Originally it was thought of global but currently it is working more regional, but in future it is going to be global. In that sense because now I understand very recently that in US, they have started getting signals of GALILEO. So, hopefully this too will become Global Positioning System or Global Navigation Satellite System along with GPS and BieDuo, GLONASS of course.

So, it is inter operable with GPS and GLONASS. So, there is a very good synergy which can be stabilize between these two. And the GALILEO System started its initial services to public authorities on December 15, 2016. So, very recently they have started public service. And in India, we do not get currently GALILEO signals, but once it becomes

truly global system then hopefully we will be also getting signals from GALILEO as well.

So, GALILEO receivers basically compute their position in the GALILEO Reference System. So, they do not follow the exactly the same geometric system or reference system as GLONASS or GPS or BeiDuo.

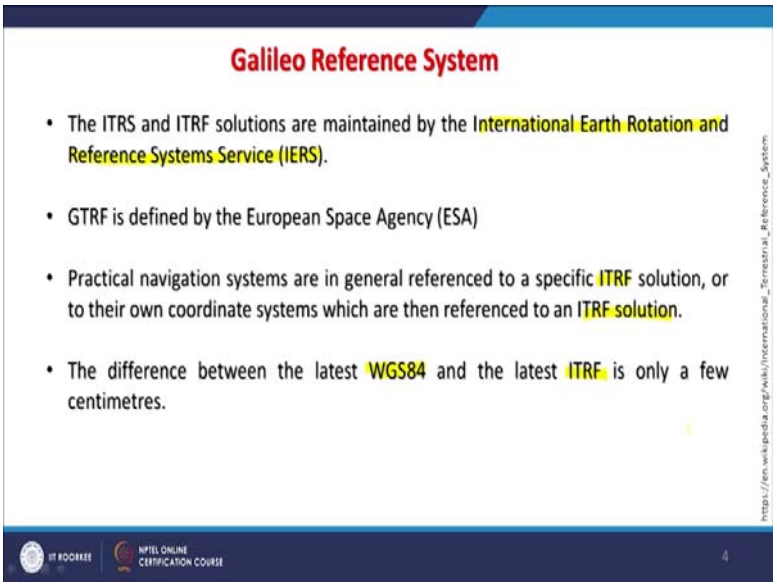
(Refer Slide Time: 02:28)



So, they are having their own that is GALILEO Reference System slight variations in the original system is there. So, GALILEO Terrestrial Reference Frame; this is called GTRF is used for the GALILEO navigation, currently defined as International Terrestrial Reference Frame or IRTF of 2005 and there are as in this figure, there are station which are soon in yellow colour, all GNSS stations are there and then some other stations are also shown.

So, these stations are used for referencing as well. An International Terrestrial Reference Frame that is ITRF is a realization of International Terrestrial Reference System which is ITRS and this ITRS describes procedure for creating reference frames suitable for use with measurements or in near the earth's surface.

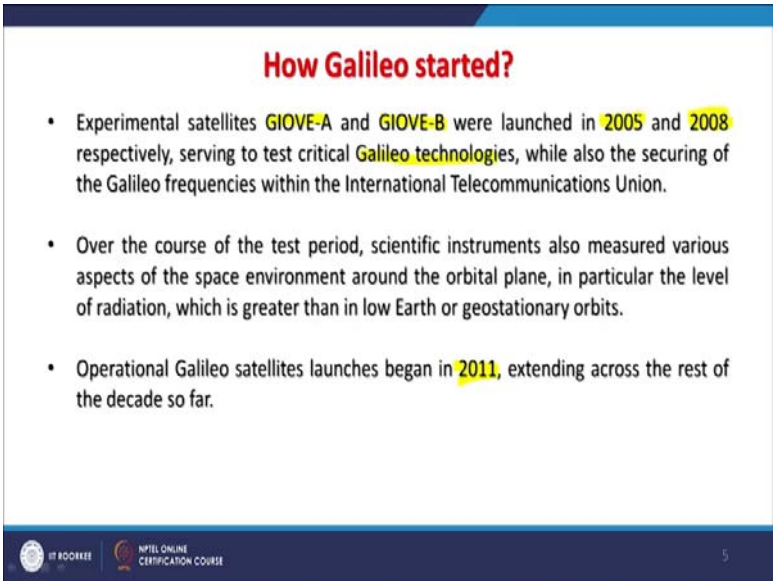
(Refer Slide Time: 03:25)



Now, this ITRS and ITRF solutions are maintained by International Earth Rotation and Reference System Services. So, IERS they maintain these two systems. And GTRF is defined by European Space Agency because this GALILEO also belongs to ESA and practical navigation systems are in general reference to the ITRF solutions or own co-ordinate system which are then reference to ITRF solutions.

So, this is how it is. So, if somebody would like to use signal suppose in future if we get the signals in our receivers then our receiver should be capable of converting these reference systems to our own system. And, the difference between as like WGS84 which is followed by GPS and the latest ITRF is only a few centimeters. So, there is not large difference, but anyway, when we go for high accuracy estimations then these things matters lots.

So, during such occasions, we have to take care about though the minor variations in different reference system, but in normal day to day, simple car navigation or other things probably we do not have to bother much about that part; minor details. (Refer Slide Time: 05:08)

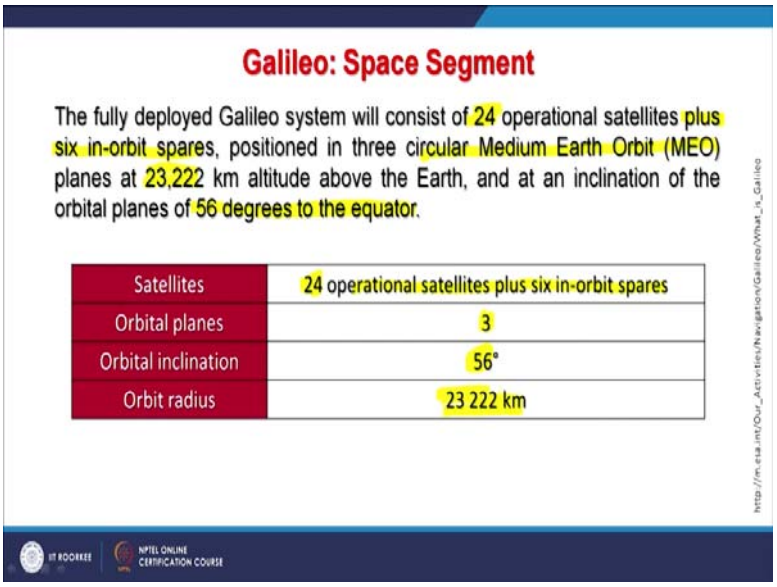


So, basically how this is GALILEO started that there were 2 satellites GIOVE-A and GIOVE-B which were launched in 2005 and 2008 respectively and where basically experimental were testing the critical GALILEO technology and while also securing the GALILEO frequencies within the International Telecommunication Union. So, from allocation point of view also, basically this experiment started in 2005 but as mention few minutes back that it was really put in service only in 2016. So, took lot of time for all this kind of preparation.

And, over the course of test period, scientific instruments also measured various aspects of space environment around these orbital parameters, in particularly the level of radiation which is greater than in low earth or geostationary satellites. So, all this radiation or frequencies which are there, which is emanating from different satellites may create some problems and this issue about the frequency encroachment, we will be discussing in the second last lecture of this course where it is now under your GPS system or other systems. Navigation systems are really under thread because of encroachment of frequencies which currently are being used by different navigation systems.

So, this is very important that the level of radiation or the frequencies which are being occupied, it is very important this should be tested before any system is developed in space. So, this operational GALILEO satellite launch begins basically in 2011, though the experimental where started in 2008 and 2005. And this extended across the rest of the decade so far. So, it is still be developed as mentioned that still it is regional though it is getting hopefully in the US and later on, may be complete global system.

(Refer Slide Time: 07:35)



In that way it is also having 24 satellites like GPS is having 24 operational or part of essential constellations and then plus 16 orbit spares. So, then that means about 30 satellites, you are having and these are position in 3 circular MEO orbit which we have discussed; what is MEO in the previous lecture. And this is the height at which the satellites are there that is 23,222 kilometer above the earth and at inclination of orbital plane at 56 degree to the equator.

Now, as you know that most of these satellites in Medium Earth Orbit and different constellations are making different layers or you can call them as envelopes within that space but if you see the distance like in GLONASS or NAVSTAR GPS, there is a difference of about 200 kilometer. So, here also more than 1,000 kilometer difference is there but they all put in the medium earth orbit.

So, in summary 24 satellites operational plus 6 in orbital spares in 3 orbital planes and this orbital inclination is 56 degree and orbit radius or the distance from the earth is 23,222 kilometer.

(Refer Slide Time: 09:13)

Galileo: Summary of satellites

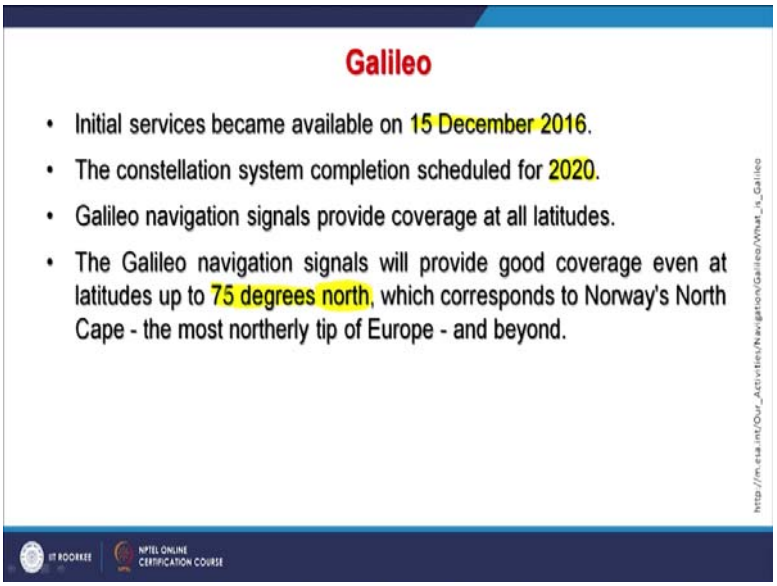
Block	Launch Period	Satellite launches			Currently in operational orbit and healthy
		Full success	Failure	Planned	
GIOVE (Galileo In-Orbit Validation Element)	2005 - 2008	2	0	0	0
IOV (In-Orbit Validation)	2011 - 2012	4	0	0	3
FOC *(Full Operational Capability)*	2014 - 2019	18	2*	12	15
Total		24	2	12	18

* One partial launch failure resulting in 2 satellites orbiting in a degraded orbit
(Last update: 13 December 2017)

Now, as you know that the GIOVE I, it was launched in 2005 and then 2008 till the experiment was done; validation were done. Then In-Orbit Validation (IOV) was done between 2011, 2012. And out of these, the two were successfully launched and there were of course, no failure and no planned nothing. But in between 2011-12, 4 satellites of GALILEO system were launched and they were full success. Now currently only 3 are in operation. FOC is Full Operational Capabilities between 2014 to 2019 it was developed; 18 satellites were launched, 2 had some problems, 12 were plant, 15 are in orbit.

So, because it was a partial launch failure resulting in 2 satellites orbiting in degraded orbit. Sometimes when missiles are sent; to launch these satellites put in their orbit something goes wrong and the missile cannot reach or the vehicle not really exactly missile, but vehicle may not reach to that height or that distance which is originally intended. So, that is why it is called the degraded orbit.

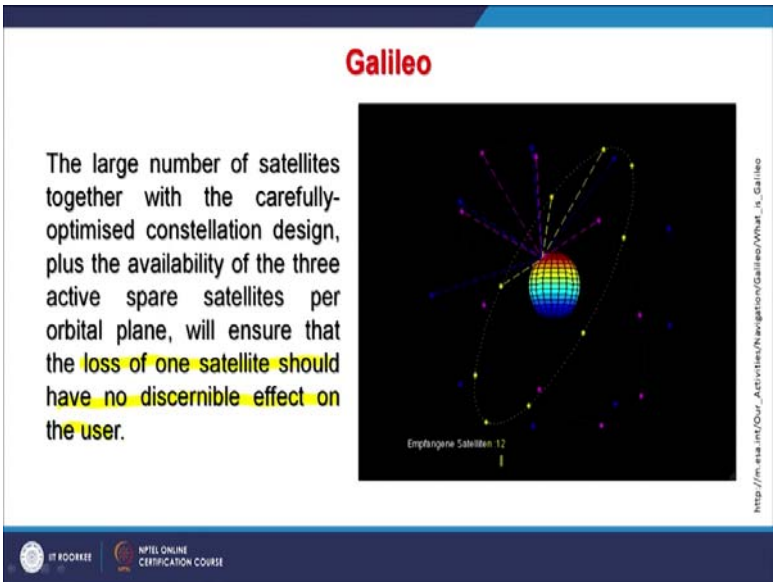
(Refer Slide Time: 10:40)



It is not in designed orbit but in the lower orbits, so then life of that satellite and utilization of such satellite become a very less. Now GALILEO, basically initial services became available on 15 December 2016 and the constellation system completion schedule next year. So, in 2020 hopefully it will have complete constellations of 24 plus 6 in a spare and GALILEO navigation signals provide coverage at all latitudes. So, it is of course, intended for completely global system.

And, GALILEO navigation signals will provide good coverage even at latitude of 75 degrees north and which correspond to Norway north and most of these northerly tips of Europe and beyond. The reason is because it is a European system developed by USA and many European countries are in higher latitude region like Norway or Denmark and Sweden and therefore, they want that it should provide full coverage to that part of the earth. So, that is why it is all designed and planned focusing mainly on Europe.

(Refer Slide Time: 11:57)

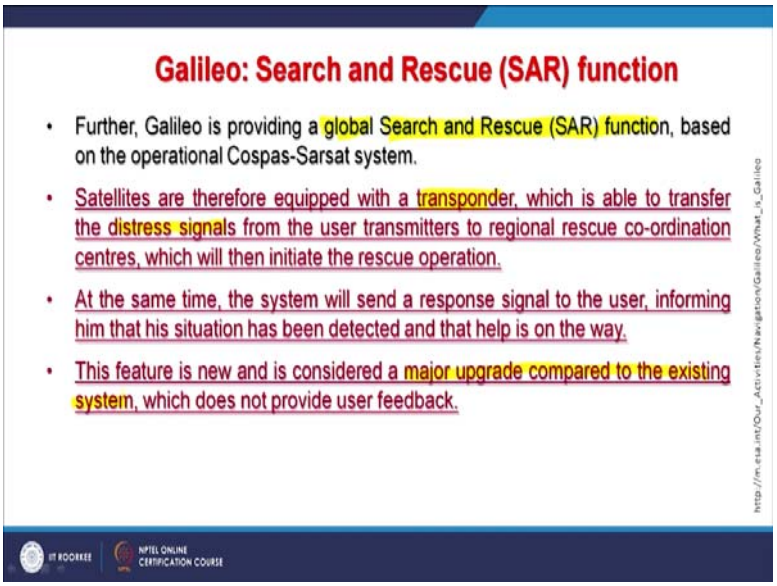


And, as you know that large number of satellites together with carefully optimize constellation design plus the availability of the 3 active spare satellites per orbital plane. So, there are 6 total spares are there, will ensure that GALILEO system even there is a loss of one satellite, should have no discernible effect on the user. So, that is why you know spares are put in the orbit. So, whenever one satellite out of say 5 or 6 is becomes non-functional then users will have signals from many-2 satellites.

As you can see in this animation that focus on this part where we are seeing that for the same location and when earth is rotating; in how many number of satellites can send signal to that location as you can see that the values are between 10 to 15 or 9 to 15 maximum. So, maximum number of satellites which will be sending signals to that particular position is 15 and minimum in certain locations in certain situations, you may get only 9, but 9 is also sufficient to get a 3D position as we know minimum 4 number of satellites are required, more the satellite better the accuracy.

So, minimum number of satellites from which you will get the signal and position can be estimated, in case of GALILEO system it is going to be 9. So, which in that way is very well designed system. Now, there is a very important part which is now being thought and implemented with the all GNSS systems about search and rescue; that means the usage of these signals in case of emergency or natural disaster and other things so GALILEO is also in that direction.

(Refer Slide Time: 14:07)



And, GALILEO provide a global search and rescue that is SAR function based on operational Cospas Sarset System. So, that is very big advantage of having such a plan for and this is also intended for global search and rescue. And satellites are therefore equipped with the transponder which is able to transfer the distress signals from the user transmitted to regional rescue coordinated centers and which then initiate a rescue operation.

So, in through this, add on instrument on such GNSS satellites will provide as this facility for global level search and rescue operation. So, as also in the previous lectures I have mention that now days, satellites are not being launched only for one single or sole purpose, they are being launched for multiple purposes.

So, if there are geostationary satellites; these geostationary satellites mainly used to be only for communication. But they are now being used like in Indian System or in Chinese System, they are now being used for navigation as well and not only for navigation or not only for communication, but they also keep graving images every half an hour or 15 minute depends on how you want and then the weather related things can be monitored. If there is a cyclone, which is developing within footprint of that satellite that can be monitored; it is being done.

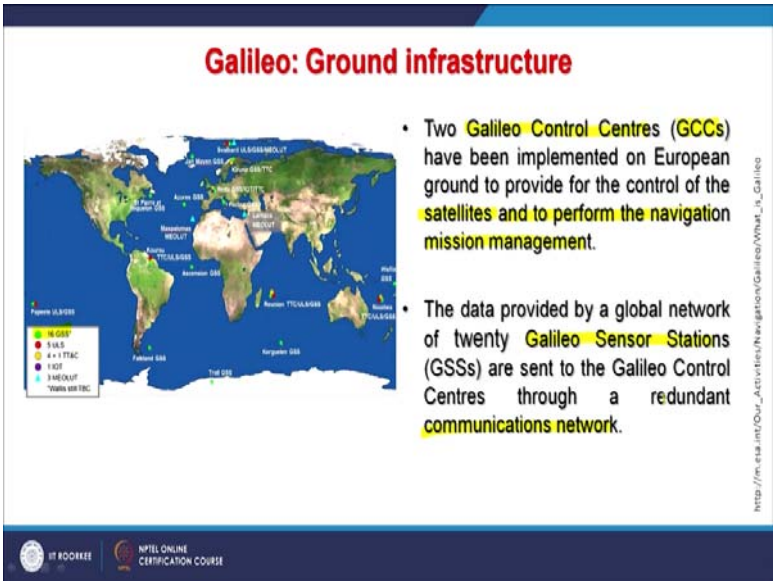
And latest thing is about this search and rescue operation. So, most of these satellites in future will have these functions available because the signals from the satellites are

available all the time, 24 hours globally and that is why these operations can be done. And, as you have seen in previous animation that minimum number of satellite which would be available to a single receiver is 9 and maximum is, of course 15.

So, if such signals are available then help and rescue can be provided in case of emergencies or natural disasters. And at the same time, the system will send a response signal to the user and then informing him that his situation has been detected and the help is on the way. So, when somebody is lost in mountain or forest or other things then these systems will also send signal. So, naturally the handheld devices or whoever is using have to have those kind of capabilities within in that so that they can translate these signals so that the correct message is reach to the person who is in trouble.

So, these things are being incorporated and of course, in near future, we will be having all these capabilities also. And this feature is new and is considered a major upgrade compared to existing systems. For example, existing systems like in GPS or GLONASS as these were not there, but now the GNSS systems are getting these search and rescue functions.

(Refer Slide Time: 17:45)

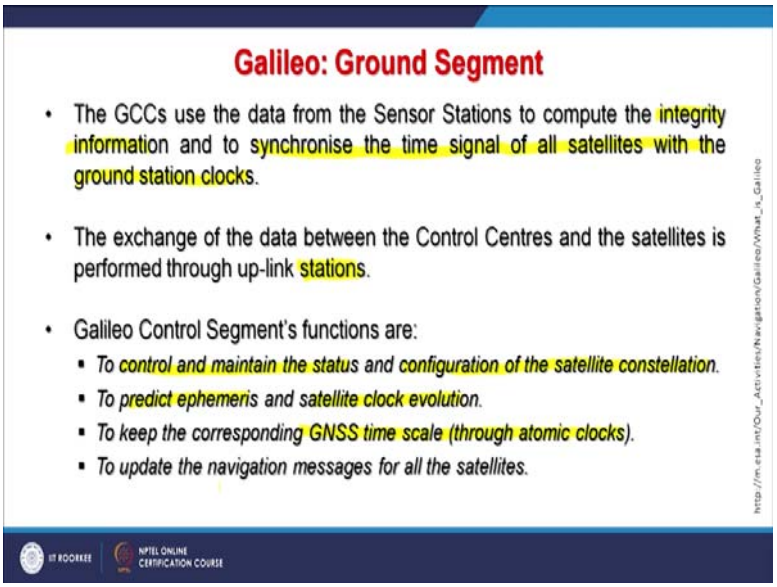


Now the ground infrastructure in case of GALILEO is; there are 2 Control Stations. We have already seen that space segment. Now in the control segment, there are 2 Control Centres and which have been implemented in the Europe. Basically, purpose of these

two is control of satellites and platforms, the navigation and to achieve the mission management or control these satellites.

And, the data provided by this global network of 20 GALILEO Sensor Stations which are spread all over the world. This is GALILEO Sensor Station; GSS in green dots which you are seeing is spread over and there are some other centres are also there; for communication network and other things which are there. whenever a country is intending for a global navigation system then they have to have at least these you know, monitoring stations all over the world in order to maintain that system.

(Refer Slide Time: 19:08)



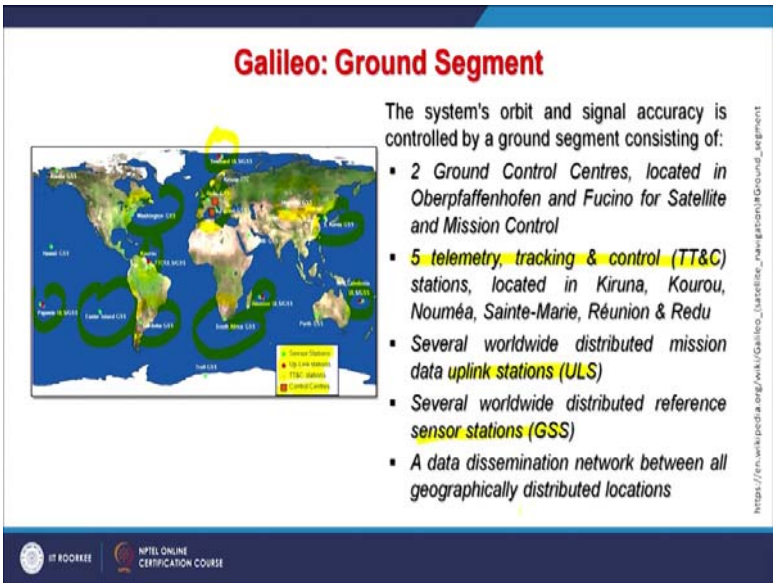
So, slowly-2 GALILEO is also going in that direction. And this Global Control Centers which are in use data from Sensors Stations, basically to compute the integrity information and to synchronize the time signals of all satellites with ground station clocks. As you know the clock, they have to synchronize within all satellites and then also with the ground stations.

So, these stations; controlled centers are doing that job and also these stations are doing the exchange of data between Control Centers and the satellites which perform through Up-Link Station. So, there are Up-Link Stations in every GNSS systems that mean, that all monitoring stations cannot uplink the data. So, for up-linking, there has to be some other facilities and Master Control Station; maybe up-linking station, but for global systems, Up-Linking Stations are required in other parts of the world as well.

So, that is why generally, they are in multiple maybe 2, 3, 4 spread world over for up-linking the data. So, because if there is only single up-linking stations and if satellite is not in reach whereas correction have to be provided in the orbit then the operators have to wait for that time when satellite will come in the reach of that Up-Linking Station then correction will be done. So, in order to minimize this time, multiple Up-Linking Stations are established.

So, GALILEO is also having multiple Up-Linking Stations and this GALILEO Control Segments functions are basically to control and maintain the status which is normally in most of these constellations which we have discussed so far. And configuration of satellite constellation to predict ephemeris and satellite clock evolution; how clock is functioning and keep the corresponding GNSS time scale through atomic clocks and then to update the navigation messages for all the satellite. So, if anything has to be done then messages are passed to all satellites of that GNSS System.

(Refer Slide Time: 21:35)

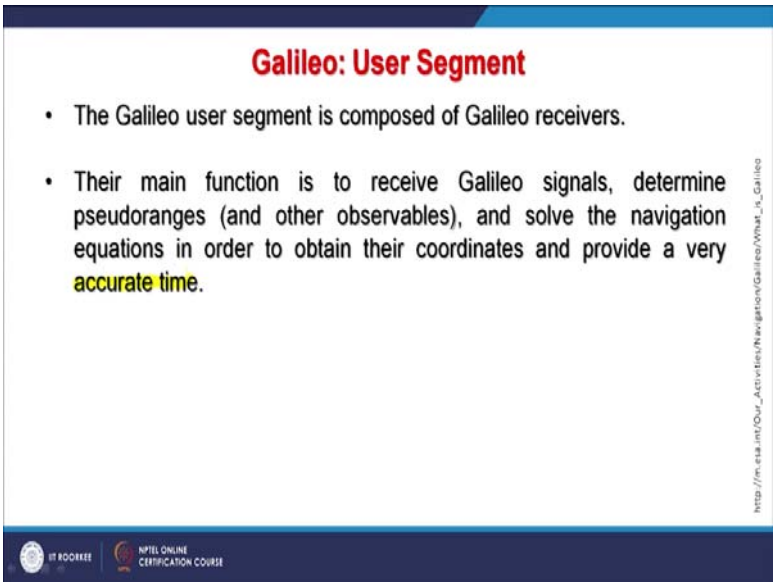


As I was mentioning that see these sensors stations are there and there are multiple Up-Linking Stations are there; here, one here, one here and one here of course, in different part. So, they are spread. So, this ground segments; the system orbit and signal accuracy is controlled by ground segment consisting of basically 2 Ground Control Centers are there. These control centers; they are mainly in the Europe and then located in Oberfaffenhofen and Fucino for Satellite and Mission Control. And, then 5 telemetry

tracking controlled stations are there which is shown in this map in yellow dots and then Kiruna, Kourou, Noumea, Sainte-Marie, Reunion and Redu.

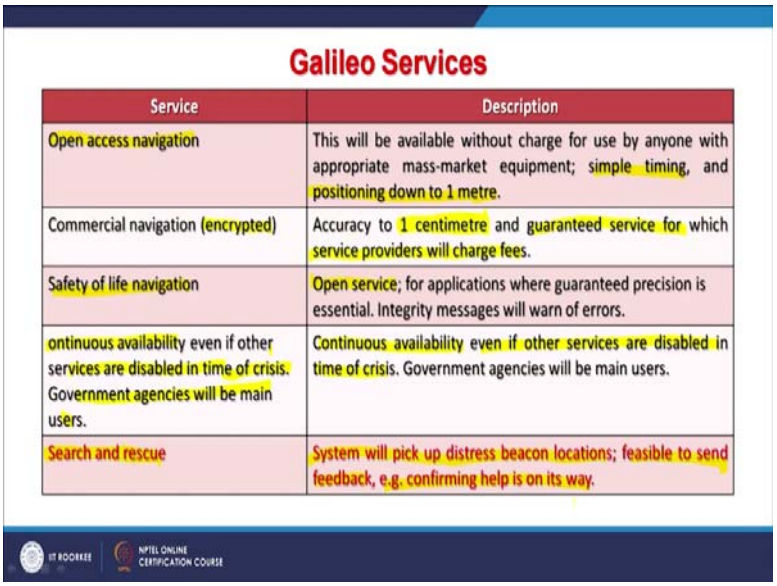
So, at these 5 telemetry or Up-Linking Stations might be there and then several worldwide distribution mission for Up-Link Stations are there which we have already touched and several worldwide distributed reference sensor stations GSS; that means, GALILEO Sensor Stations are also there because the intention is to ultimately have a global system therefore all different types of such stations have to be there as you can see in South Korea, in China and in Washington and in Colorado, Carboda and South Africa and other parts of the world, they are having this GSS stations. And Data dissemination network between all these geographically distributed locations; that is the purpose of overall ground segment.

(Refer Slide Time: 23:42)



After space segment, ground segment then we come to the user segment of the GALILEO as you know that basically its consist of GALILEO receivers and their main function is to receive signals, determine pseudo-ranges and other observables and solve navigation equations, estimate position and bring co-ordinates and provide very accurate time because time is also being used from these GNSS systems for different purposes.

(Refer Slide Time: 24:06)



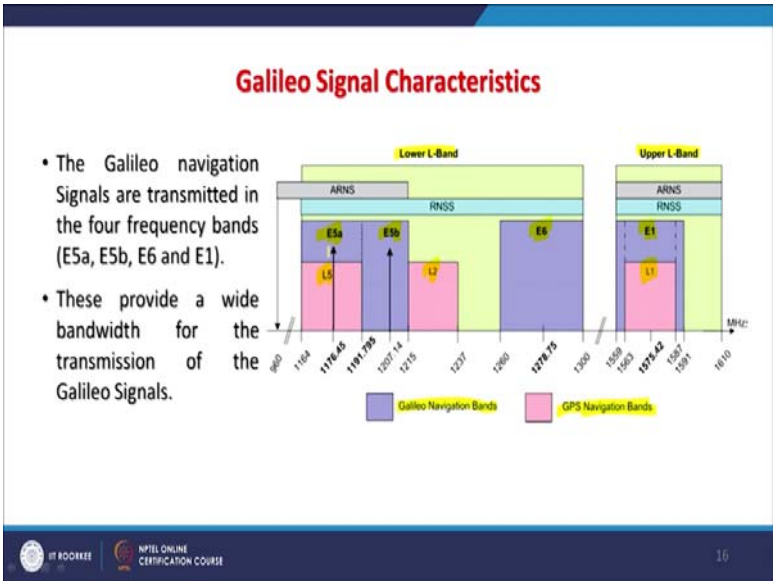
So, different types of services are there from GALILEO. Some are already there; some there some will be coming in future. So, one is the open access navigation which will be available without charge for use by anyone with appropriate mass market equipment; mass market means simple receivers and which will have simple timing and positioning down to one meter which itself is a very good accuracy with single receiver system without bringing differential or any other thing.

Whereas, this is another service which is uncorrupted; that means, someone has to pay, there will we charges, fees and this is called the commercial navigation and which will have accuracy of 1 centimeter and this is achieved through SBAS which will be discussing later because the service which is coming in order to improve the position accuracy, is coming through SBAS and the company, whoever is providing this service through SBAS that is Satellite Based Augmentation System and then your accuracy improves very significantly.

So, from 1 metre to 1 centimeter and guaranteed service, for which the service providers will of course charge money for that. Then safety of life navigation; this is again open service, for applications where guaranteed precision is essential, integrity messages will warn of errors. So, that will be also available safety of life navigation and the government agencies will be main users that are continuous availability even if other services are disabled in the time of crisis.

So, this will be mainly for European countries who have invested lot of money for this system and of course, as already we have mentioned that the search and rescue operations. So, for that this is system will pick stress beacon locations, feasible to send feedback and confirming help that it is on way. So, that kind of service will also be available, hopefully globally very soon.

(Refer Slide Time: 26:37)

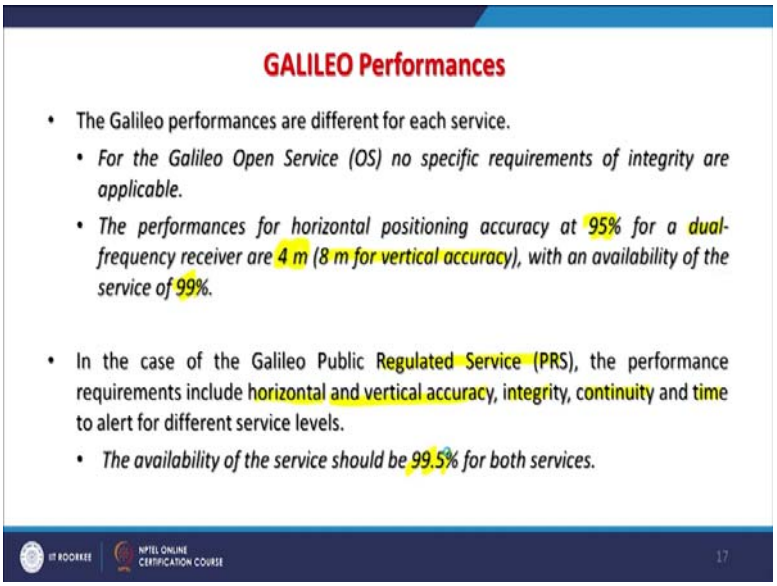


Now, the signal characteristics of a GALILEO; the bands which is it is being used. The GALILEO navigation bands as shown in this violet colour is E5a, E5b which you are saying here and of course, E6 and E1. So, these bands are being used of part of Ll band. This lower L band where E5a, E5b and E6 and upper L band which is E1. There of course, some overlap part will be there like L5; it is also there in case of GPS L1, L2, L5 are there. Indian System is going to be focusing only on L5.

So, GPS navigation bands are shown in pink colour and then there are other players in this or users of this frequencies but the danger is not yet because things are going in coordination in case GNSS but the danger will only come when we go for in mobile technology; this is say from 3G to 4G, 4G to 5G and then encroachment of these frequencies might be there.

But any way for time being, the GALILEO navigation signals are transmitted in 4 frequency bands as highlighted 5a, 5b, E5a, E5b, E6 and E1. All shown here in the violet colour and these provide a wide bandwidth for the transmission of GALILEO signals.

(Refer Slide Time: 28:15)



And, the GALILEO performances are different for each service. For GALILEO Open Service; no specific requirements of integrity are applicable which is free of cost then performances for horizontal positioning accuracy would be 95 percent for a dual frequency receiver and are 8 metre for vertical accuracy.

So, vertical accuracy is also going to improve if someone uses the dual frequency receiver. Currently most of the mobiles are using single frequency, but there are mobiles which are coming in market which will be using dual frequency. So in that case, the horizontal accuracy will improve by 4 metre and vertical accuracy by up to 8 metre with the availability of service 99 percent time so that means almost every time you are having this GALILEO Open Service available.

And in case of GALILEO Public Regulated Service that is PRS; the performance requirements include horizontal and vertical accuracy, integrity, continuity and time to alert the different service levels. So, that will be also there and availability of the service should be 99.5 percent for both services. So, this is what it is expected that almost every time you will have these services available.

So, this is what I wanted to discuss about GALILEO and as already mentioned that currently, it is working in limited manner but by 2020, it might become a completely global system. Currently like in India, we are not getting signal from GALILEO. But we expect that soon, we will be getting signals in India from GALILEO as well and this

brings to the end of this discussion on GALILEO and as usual I am leaving with the cartoon.

Thank you very much.