**Global Navigation Satellite Systems and Applications**
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**Lecture – 04**
**How position is determined by the GNSS? (Part-III)**

Hello everyone and welcome to this fourth lecture of Global Navigation Satellite System and Application course. And, this is a third part on how position is determined by the GNSS receivers and mainly in this one; we will be discussing error parts also.

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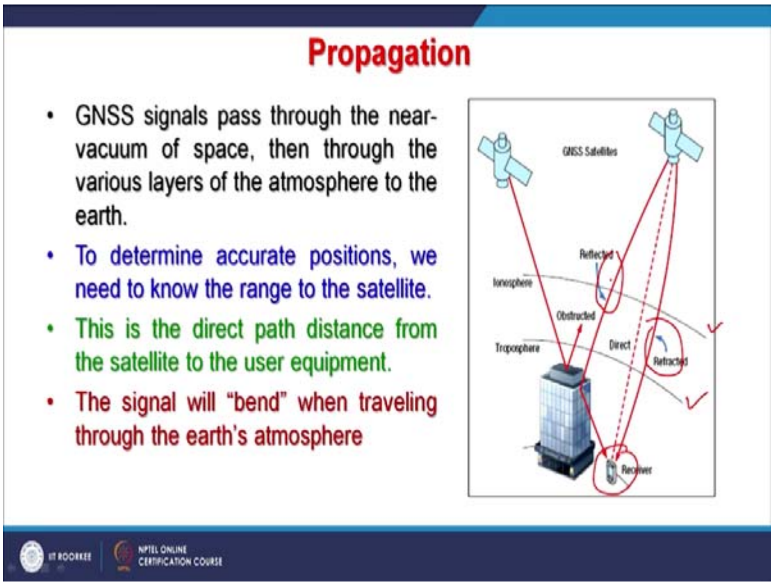


So, that comes here and this is basically, how the signals are propagated from these satellites. GNSS signals from satellites towards the earth and they have to pass through the various layers of atmosphere. So, this propagation part, we will be mainly focusing and also the error part as well.

So, basically it starts from near vacuum of space, the signals because these satellites are especially like GPS satellites are 20200 kilometre away from us and then later when signal starts coming towards the earth then the signal has to encounter with various layers of atmosphere which is in between the earth.

As you can see that when satellites are sending signals in a ideal situation, the signal should come straight to the receiver, if receiver is installed on you say in this one, receiver is here, but it does not receive sometimes or many times it does not receive directly. So, when it passes through these two layers; ionospheric layer and tropospheric layer so, that there is a reflected signals are also there and there are refractions are also there through these atmospheric layers.

And, that means, the additional time, the delay in the signals and that means, more the overestimation or the time is taken more; that means, the distance will be calculated more, may not be the real one. And therefore, as you recall that in previous lecture, we have discussed that this time delay through this atmospheric layers which is also corrected through these already available models because real time data may not be available and these are the dynamic layers and therefore time delay is also estimated through these models.

And, sometimes these signals may get reflected from some building also or some mountains or may be a forest and these obstructions will also add the additional path to the signal which received by the receiver. And that means, again recall that when the range is larger, the time difference is large, a larger sphere will be constructed imaginary one and then you can understand that how, then it will give you the wrong position basically.

So, in order to determine the accurate positions we need to know the range to the satellites and this range is coming basically from time difference and this is direct path distance from the satellite to the user equipment. But, as I have just mentioned that many times it is not really direct path, may be reflected part, may be refracted part and so. And, therefore, the signal will bend when travelling through the earth’s atmosphere.

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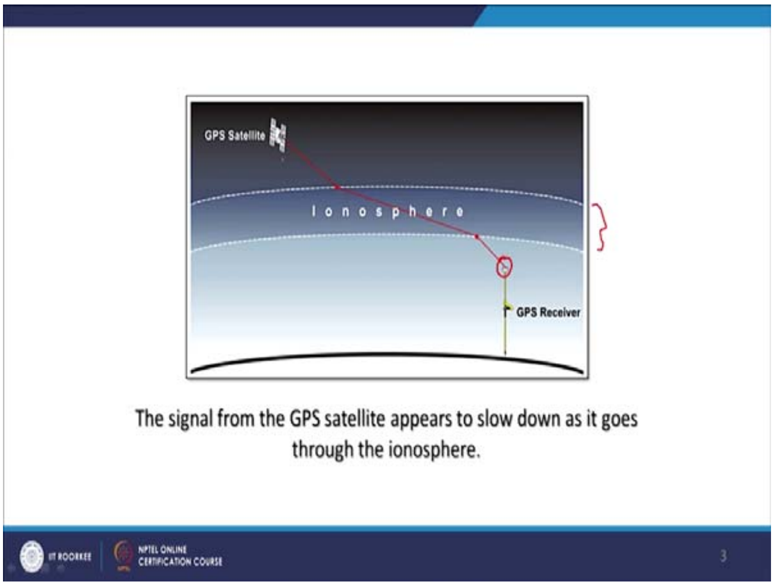


And, as you can also see here that it is more exaggerated from bending point of view that there is a ionospheric layer is shown here and then GPS receiver is here. And, when the signal is coming through these refraction, there will be change in the path as well as extra time or the pseudo range is increased and more distance will be calculated that means less accurate position.

So, those bending increase the amount of time, the signal takes to travel from satellite to receiver. In the previous discussion, we have also discussed this mask angle. So, if we take a low mask angle; that means, this refraction will be more and therefore, that a very small mask angle may not be good for such purposes. So, this also should be kept in mind.

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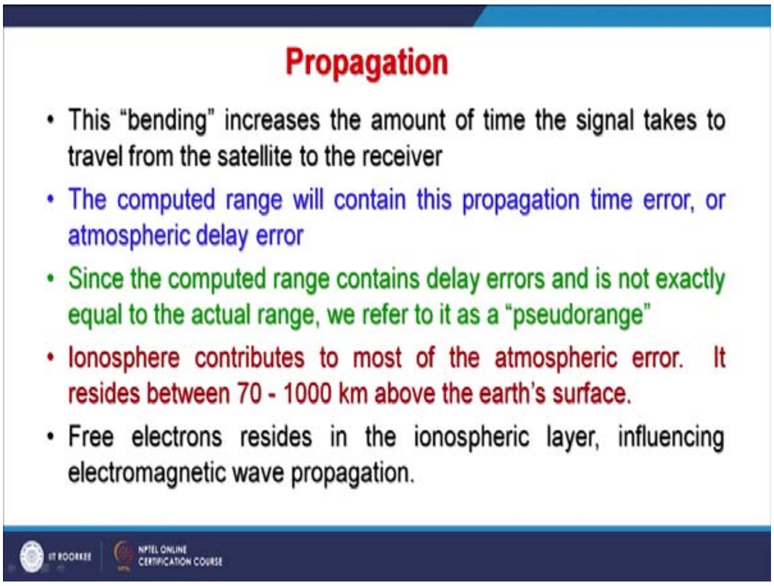


And, this computed range will contain this propagation time error or atmospheric delay error. This atmospheric total delay will be there and sometimes it is very difficult to identify that whatever the delays are there, the sources of these delays whether it is because of these ionospheric and tropospheric layers or because of some you know, extra path which has been added because of these obstructions.

So, since the computed range contains delay errors and it is not exactly equal to the equal range so, we refer as instead of true range, we refer as a pseudo range and these ionospheric contributions especially from ionospheric layers of atmosphere to the most of the atmospheric error. So, this says the maximum errors are introduced during this ionospheric layer propagation and the size between from earth's surface towards the space 70 to 1000 kilometres above the earth's surface.

So, it is quite long distance; that means, a quite thick ionospheric layer is there, for bending of these signals and free electrons basically, resides in this ionospheric layer which influences the electromagnetic wave propagation. So, these free electrons basically creates problem in the atmospheric layer. But, interesting part here I will touch very briefly that these delays in ionospheric layer in the pseudo ranges of these satellites are also being exploited nowadays by the scientists for they are using these delays and to model the ionospheric layer because different locations the delays are different.

So, through these delays, ionospheric layer can also be model or thickness of these layers can be estimated and basically in near real time and that can give some advantages. And, some people are also using these electron perturbances which are happening during an earthquake event and they might be influenced by an earthquake event rather than a simple ionospheric delay.

So, people are also going in this total electron counts and they have identified that when earthquake occurs, there are changes in total electron counts within this ionospheric layer and which can be estimated through permanent GPS or GNSS stations. So, a blessing in disguise, though for position estimations, this is a problem, this is an error, but that error can be exploited for some other purposes. So, each and every part of the GNSS signal is being used for different purposes.

Time example I have given, this ionospheric delay example I have given; of course, position and simple timing, also one interesting thing is about the frequency. Or anybody who is developing some equipment or would like to calibrate their equipment which are based on some frequency then for frequency calibrations also because standard frequency available throughout the globe, round the clock and therefore, those calibrations with those standard frequency can be done about different equipment. So, that information or that part of that signal can also be used for calibrations. So, there are various applications of these signals coming from these navigation satellite systems.

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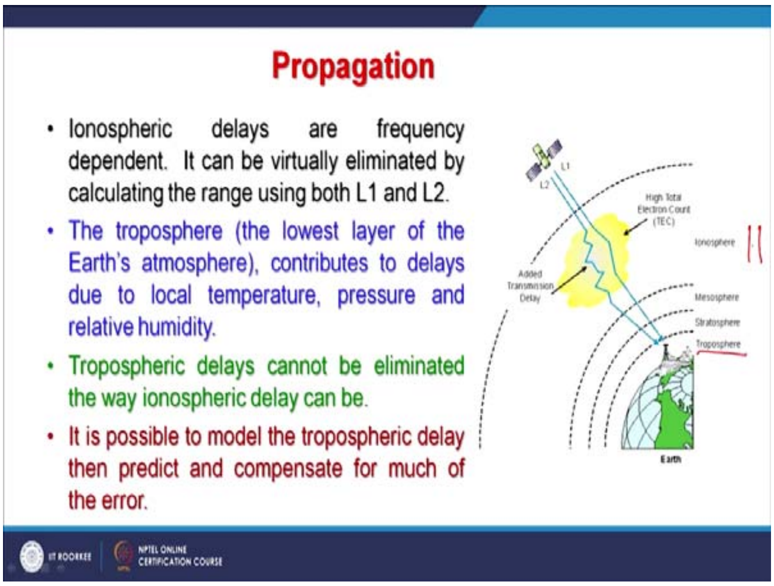

Ionospheric delays as you can understand are frequency dependent and it can be virtually eliminated by calculating the range using both L 1 and L 2. So, if your signals are available as indicated here that there is a high total electron count TEC I have just mentioned related with the earthquake also and added transmission delay which in L 2 and by using these two; L 1 and L 2, this can be virtually eliminated or minimized this delay factor.

So, lowest layer here that is the tropospheric layer of the earth atmosphere contributes the delay due to local temperature, pressure and relative humidity and these things keep changing. In cloudy conditions, the temperature or pressure may be different, relative humidity may be different and they may also bring some additional delays in the time signals to be received by a receiver.

So, tropospheric delays cannot be eliminated the way ionospheric will, because this L 1 and L 2 frequencies, they behave differently because these delays are frequency dependent. So, they behave differently through these ionospheric layers and therefore, using these two we can eliminate, but tropospheric delays errors cannot be corrected, but while employing some model, these delays can be minimized based on certain prediction.

So, it is possible to model the tropospheric delay then predict and compensate for much of this error. So, as time is passing, people are developing new and new ways to remove these errors because data may not be very perfect, but how best we can exploit, how best we can estimate the position by employing whether some model or some other concepts and so on so forth.

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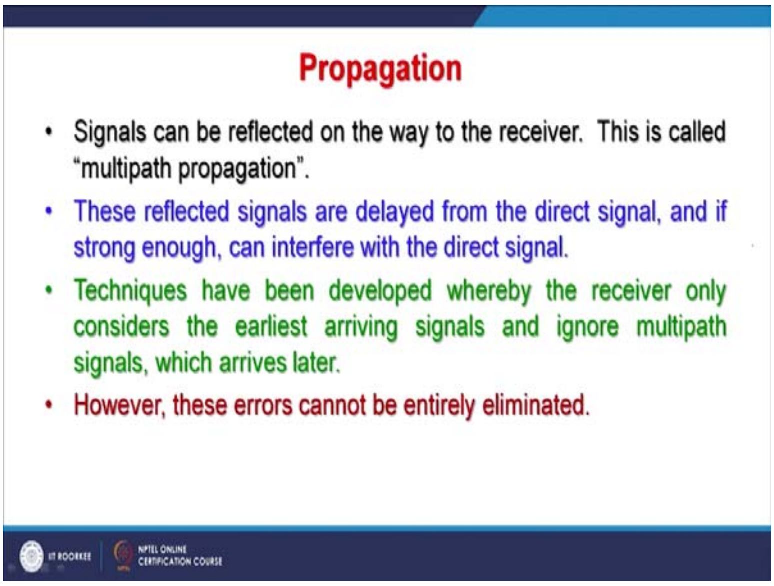


So, signals can be reflected on the way to the receiver and this is called multipath propagation; multipath propagation is there. And, these reflected signals are delayed from the direct signal as we have seen already that strong enough can interfere with the direct signal. And, these techniques have been developed whereby the receiver only consider the earliest arriving signals and ignore multipath signals which arrives later.

So, to some extent, this multipath propagation can be avoided by this technique by which that the earliest arriving signals are only considered for position estimation then signals which are received later. However, these cannot be entirely eliminated; a perfect positioning, ideal positioning may not be there because some error component, some delays component will always be there like troposphere delay though through models we can minimize, but not completely remove.

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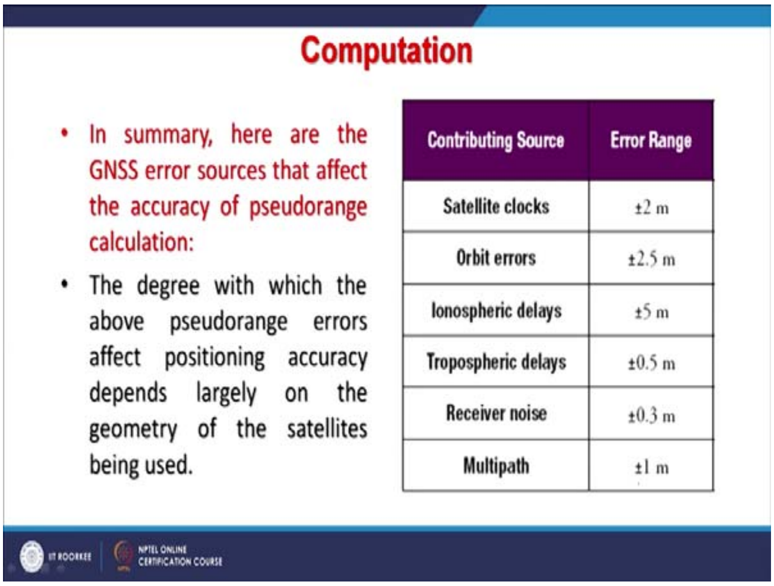


So, in summary here we are GNSS error sources that affect the accuracy of pseudo range calculations. So, if there is some problem with the satellite clocks then in position estimations, we may get error of plus minus 2 meter. But, if there are orbit errors because after all these satellites are moving objects in a space and sometimes they drift from their position because of many reasons and therefore the error range may be plus minus 2.5 meter.

Ionospheric delays can also introduce errors of about plus minus 5 meter. Tropospheric delay not big as compared to ionospheric delays errors, but anyway plus minus 0.5 meter. And, these are very generalized average estimates of error ranges. Receiver noise because after all receivers is also having antenna. There may be signal to noise ratios and other electronic component may bring some errors, some noise. So, this receiver noise can also bring some error component in position estimation of roughly plus minus 0.3 meter.

Multipath error can add the error of 1 point. It is not necessarily that all the errors will occur at every time. Sometimes some error may become bigger. These are the sort of average value and, but all errors may not occur at the same time. So, the degree with which these pseudo ranges errors affect positioning accuracy basically depends largely on the geometry of the satellite being used. As we have discussed in the GDOP; the Geometric Dilution Of Precision that these errors as I was mentioning in the sky plot if positions of these satellites are well distributed throughout that circle, then these errors can be minimized to some extent. It is a good practice to wait for some time, get the good Dilution Of Precision and then record the position.

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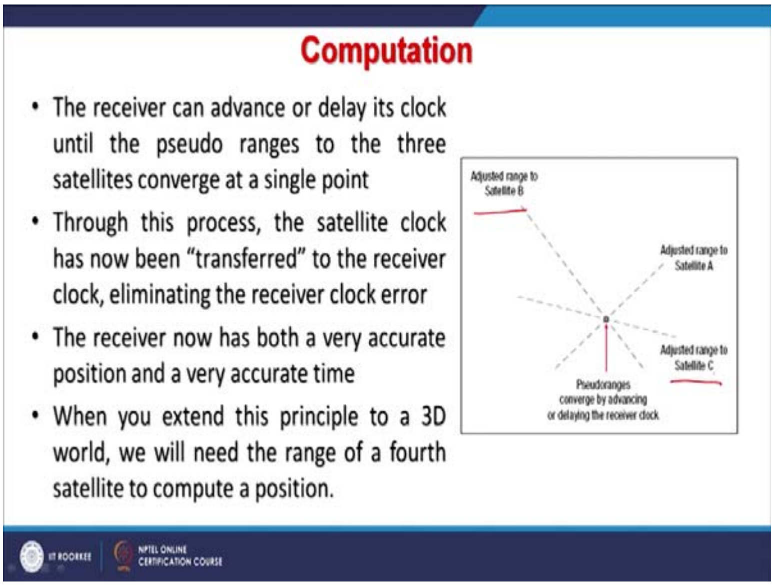


So, receiver can advance or delay its clock until the pseudo ranges to three satellites converge at a single point. As here that first adjusted range to satellite A the first one, then adjusted to the satellite B and then finally, adjusted to in satellite C and if keep adjusting and keep calculating more accurate and accurate position as you get signals from more and more satellites.

So, through this process, the satellite clock has now been transferred to the receiver clock, eliminating the receiver clock error. So, in very first few seconds, all the error which is in the receiver clock can be removed and then you get the receiver now has both very accurate position and very accurate time with minimum three or four satellites. And, when you extend this principle to a 3D world, we will need to range a fourth satellite to compute a position. So, x-y position can be determined initially while first three satellites, fourth one will also give you elevation and also improve your x-y position.

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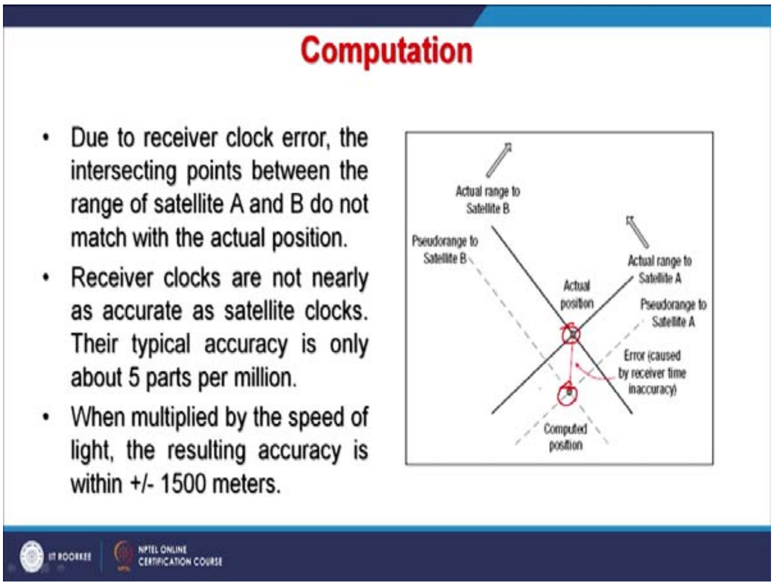


Now, due to receiver clock error if there is, the intersecting points between the ranges of satellites A and B do not match with the actual position. So, if this error is large then the actual position is here whereas a computed position would be here and that means, wrong estimations about the position.

So, the receiver clocks are not really, nearly as accurate as satellite clock. Of course, they are having atomic clocks, these are having simple electronics clock our receivers so, but their typical accuracy is only about 5 parts per million. So, atomic clocks on space vehicles are more accurate, but in few second times, our clocks are synchronized with those clocks and then we start getting good signals.

So, when multiplied by the speed of light as we know the resulting accuracy is within plus minus 1500 meters.

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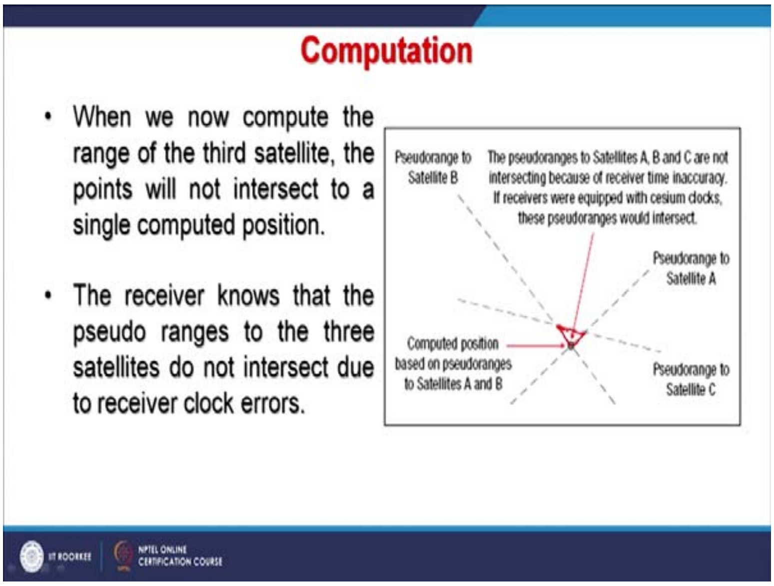


Now, compute the range of third satellite, the point will not intersect to a single computed position. So, it is almost now the same scenario as we have been discussing in back bearing concept. So, that instead of all three these lines, pseudo ranges cutting at one location, now you are having a triangle here; that means, I am somewhere or receiver is somewhere within this triangle. So, therefore that means at least from one satellite, the signals are not as accurate as it should have been, that the pseudo range is having large error.

So, the receiver knows that the pseudo ranges to the three satellites do not intersect due to receiver clocks and if this is the situation, the receiver though might be receiving signals from three satellites, but it will not give you a 2D position that is x-y location. So, it will wait for another satellite and if the fourth one cuts it earlier two ranges then it will start giving you 2D position, then 3D position and so on.

As already, briefly discuss about selective availability which was introduced intentional errors of up to a hundred of meters into publicly available navigation signals initially up to May 2000 and this disabled as already mentioned on first May, 2000.

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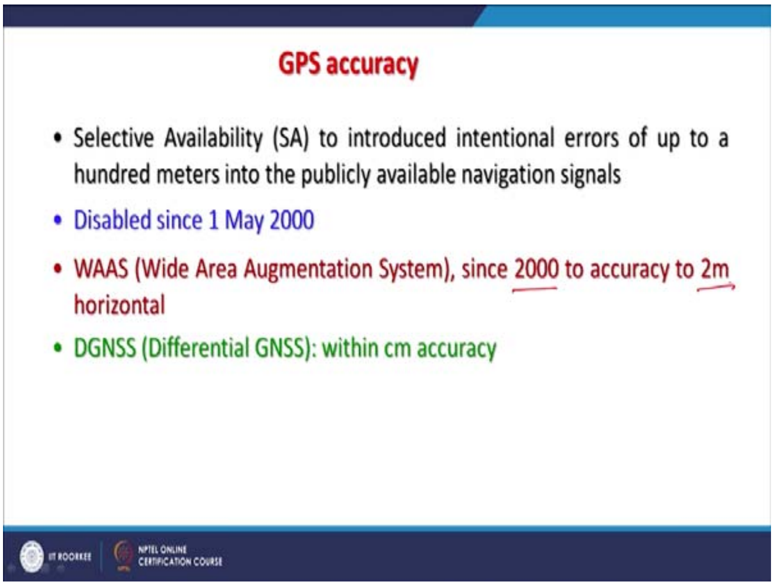


There is another system was introduced for land areas as well as for coastal areas through augmentation system. So, first time it was introduced in since year 2000 and through a WAAS. WAAS that it stands for Wide Area Augmentation System and that provided accuracy of 2 metre that is horizontal means x and y, 2D position.

And, now this concept of augmentation of signals, ground based augmentation system like in India, we are having for coastal regions we are having GAGAN. Now, Satellite Based Augmentation Systems are also coming SBAS which we call them satellite based augmentation system SBAS which are also coming and these signals are transmitted live all the time.

And, basically these signals, these are sort of like permanent stations and these satellite base signals are coming from geostationary satellite. So, they are synchronized with the position of the earth. So, all the time, round the clock, they are providing signals in order to improve the accuracy. So, if I am not using these augmentation signals then I may get accuracy say within 10 meters, but if I start using this augmentation accuracy maybe from SBAS which is ground based is a little cumbersome.

But, using these satellite based and using those same frequencies; L 1, L 2 or L 5 then my accuracy improves to few centimetre. As initially with wide area that is ground based augmentation system are there, now satellite based and all these, we will be discussing further. If we imply this differential GNSS then our accuracy can also improve to centimetre. Now, even implying these SBAS that is Satellite Based Augmentation System, a simple GNSS receiver can give you a differential accuracy that is within centimetres.

So, there are now lot of improvements are happening. SBAS satellites which are available under this SBAS system, they are also providing signals.

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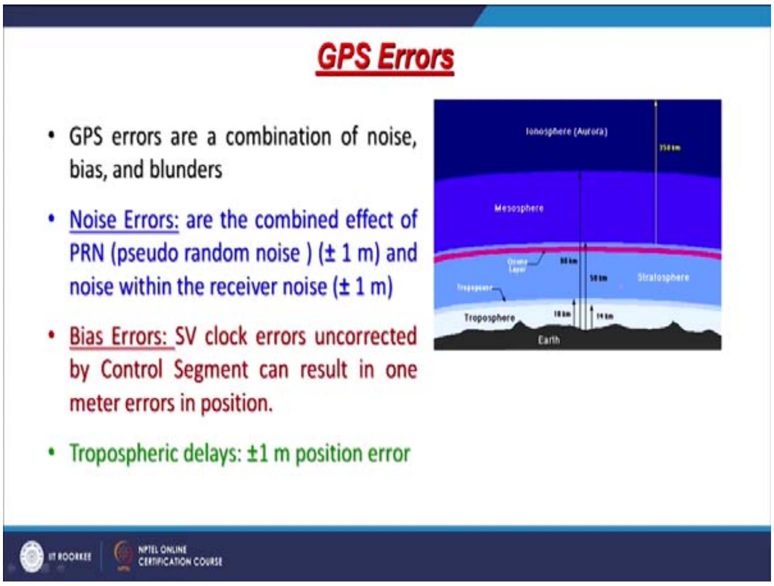


Now, the last part of this discussion is the GPS errors or GNSS errors. So, GPS errors are a combination of noise, bias and blunders. Noise errors are the combined effect of pseudo random noise, may be plus minus 1 meter; noise within the receiver plus minus 1 meter and they these errors might be there because of noise in the system.

Bias errors are the satellite vehicle or these s navigation satellite clock errors uncorrected by control segment. If control segment has not taken care for some time then that error may erupt and can reduce your accuracy part as well. So, this bias error and that is why these control segments have to keep complete track on the clock part or clock of all these satellites. So, then the errors can be minimized and if there is a bias error because of uncorrected by control segment, this can result to 1 meter errors in position, plus minus 1 meter.

As also discussed this tropospheric delays that is plus minus 1 meter position error might be there. So, as we have already seen that different layers are there and because of bending in the signals, extra time is taken and that can add one more meter in the error part as well.

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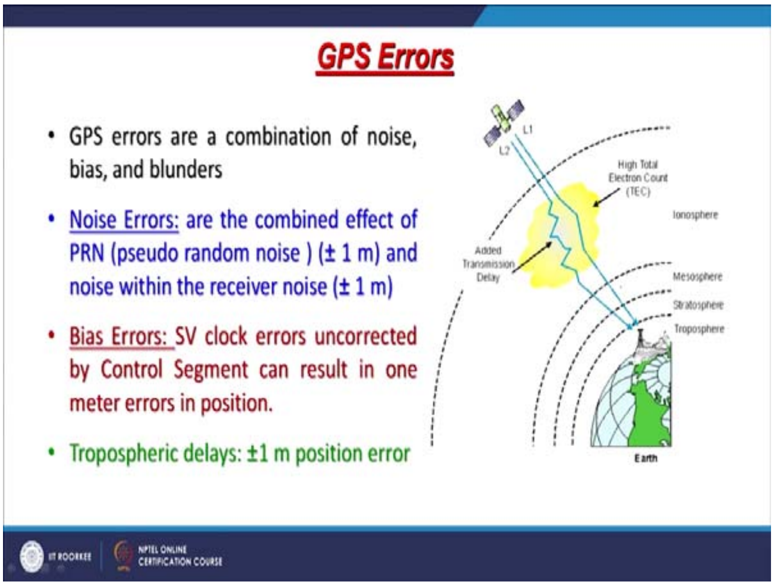


And, we have also discussed that L 1, L 2 can be used to minimize the errors of ionospheric layer, but it is difficult to reduce errors in the troposphere so, some models are used. Now, position estimations if only noise error is there because earlier when I was showing a table, I said all errors may not occur at the same time.

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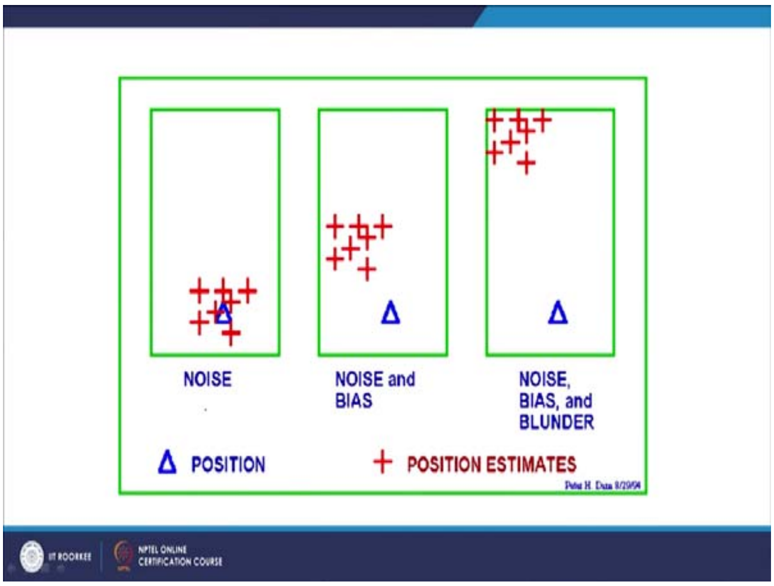

But, suppose all errors occurs, these three noise, bias and blunders. if these three occurs together; blunders means I am using a wrong spheroid, I am setting all together a wrong system and then start using, then we called as blunders which we will see later. So, when if there is a noise only then this is the triangle which is showing my supposed to be position and I am getting position here and there, but not very far. But, when noise and bias, bias through the SB clock errors then this triangle is here and my position estimations are somewhere else.

But, if noise, bias and blunders; all three are there. I have chosen wrong as spheroid, I have chosen wrong coordinate system and other things; projection systems, I may get a completely very bad position estimations. my position is supposed to be here but I am getting position here. So, it is not necessary as already I have mentioned that all errors will occur together sometimes may be, sometimes may not.

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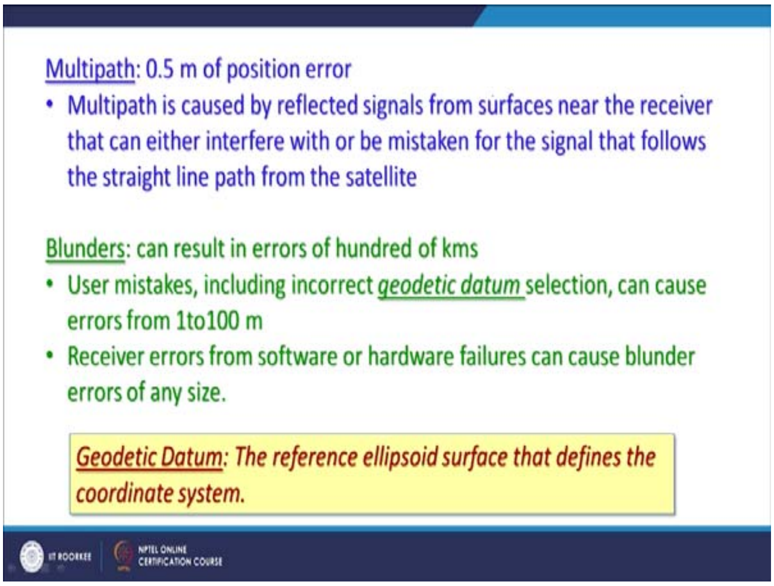


Now, multipath errors because the reflection from some buildings or mountains can also add 0.5 meter position error. Multipath can be because it is very difficult to identify whether signals are coming directly or indirectly through this reflection, but if it is there, there are techniques which we have just discussed that the error the signals which reaches first are considered and signals which reaches later are not considered of different satellites.

Blunders can result in errors of hundreds of kilometres as just shown in the previous figure and these might be user mistakes including incorrect geodetic datum selection, can cause errors of 1 to 100 meters. And, geodetic datum basically, the reference ellipsoid surface, that defines the coordinate system. So, like you know that if I take the example of GPS then it is uses the WGS 84 system and in default settings, the UTM coordinate system is there and you know world geodetic spheroid is used.

But, like if I compare my position with t survey of India, older toposheets then the spheroid which survey of India toposheets have used is the Everest spheroid. So, Everest spheroid and world geodetic spheroid 84, they are having different parameters and therefore, my position estimation compared to my toposheets position may be different.

So, I need to set or convert my position which has been determined using this world geodetic spheroid into my Everest spheroid and also in the coordinate system, the default might be coming in UTM whereas as, I might be using in latitude longitude and that too through the projection. Then the projection which survey of India, older toposheets used that is marketer polyconic projection so, that projection I have to set before I note down or record the position, then only I can compare.

So, if I am using a different system for position determination and I am comparing that determined position with the toposheet which is based on different system of course, then I will get lot of mismatch. So, that we consider as under blunders. So, these things have to be taken care in order to avoid blunders and get better position. Sometimes may be something wrong with the hardware or the software or app which we are using, maybe have some bugs or maybe some failure which can also cause errors of any size basically.

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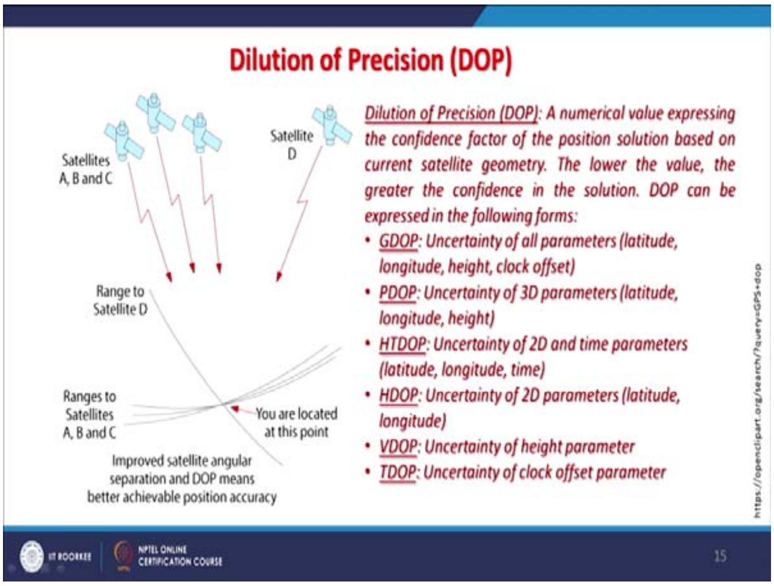


Now, this Dilution Of Precision, we have already discussed. So, very briefly I will go through this one that Dilution Of Precision is a numeric value expressing the confidence factor of position solution based on current satellite geometry; lower the value the greater the confidence in the solution. And, it can be expressed in the following forms that GDOP which is uncertainty, PDOP and then HTDOP or Horizontal Dilution Of Precision and other Dilution Of Positions. So, the time is there so, HTDOP, when only latitude longitude means only horizontal we are talking then HDOP.

The main point here when these receivers also estimate the DOP, the minimum the value, lesser the value, smaller the value, it is better. This thing has to be remembered and their time set also so, TDOP can also be their uncertainty of clock offset parameters. So, those things are also there.

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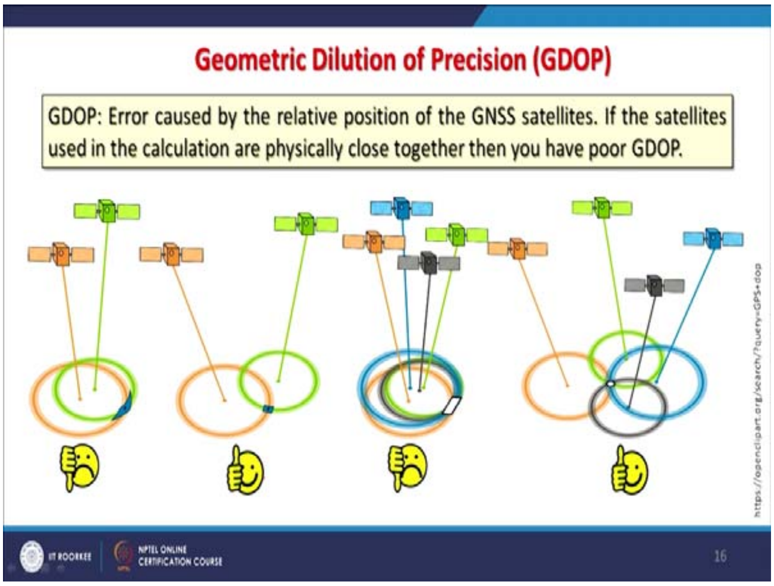


So, this GDOP which is error caused by the relative position of the satellites in a space and how they are shown in a sky plot and as one can see here that this is not a good GDOP, but satellites are located far apart as in same concept as in back bearing then I am having little better GDOP. And, again they are located in a very small space, very close by then not good GDOP; and if they are spread over in a sky plot they are distributed throughout these circles then I get good GDOP.

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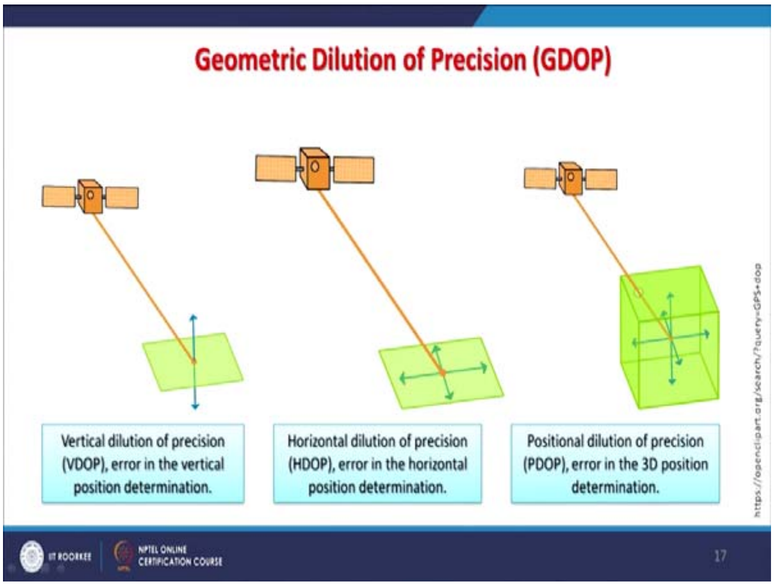

Now, geometric dilution of precision, this is a vertical dilution of precision. The error is vertical position determination is here; horizontal is here and then when you go for 3D position, this is how it is determined. So, these things matters about the spread of the satellite, you can think in terms of a sky plot and spread of satellites.

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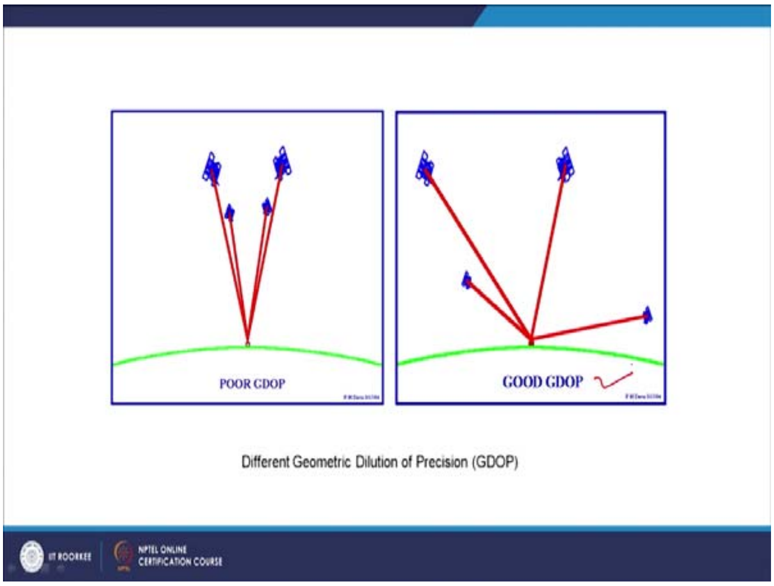


Another example the same way that though you are accessing signals from four satellite, your receiver is getting signals from four satellite, but they are very close by and therefore, poor GDOP, wrong estimations or inaccurate estimations of position. But, the satellites, though they are still four, but they are spread and in a sky plot, there will be a quite good distribution of these satellites so, I am getting good GDOP.

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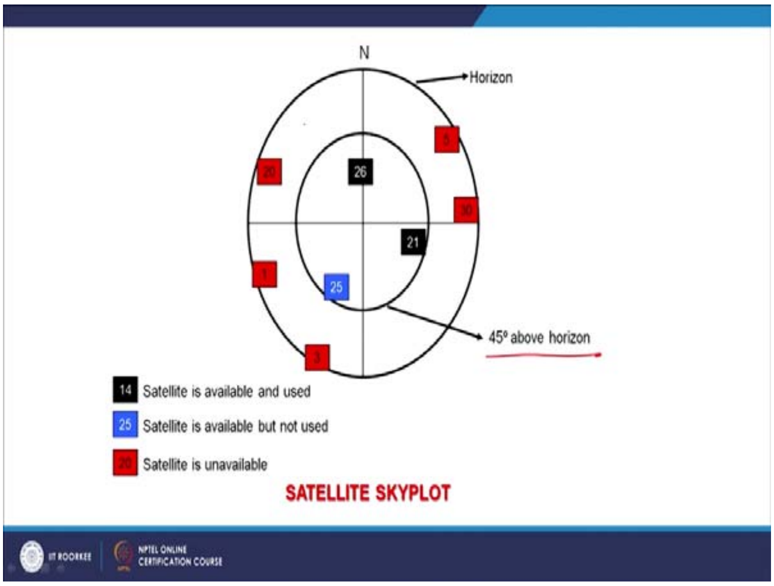


This is typically sky plot which I have grabbed through a receiver and this is how generally you see that ID of these satellites are also written there and sometimes they are also coloured. So, if you see that like here black one; these satellites are available and being used. So, this is what a sky plot is showing. Second is that the blue coloured one are available, but not used because the signal quality is not good.

So, when you go for a sky plotting in through that interface or whatever the software you are using, most of these software's will support this sky plot. So, if you see that then colours are also given and that can indicate whether those satellites are available. Like in this case; red colour one, these satellites are unavailable; that means as per almanac, the prediction of the satellite that these satellites should have been here in the sky within where I am located or receiver is located, but they are not there.

That means that I have shifted my position. I have to wait for some time and also they are in the edges of these circles and this outer circle is near horizon, maybe you know 5 or 15 degree this mask from horizontal is there and. So, this is near horizon and this is 45 degree above the horizon. So, the target should be through sky plot that these satellites should be distributed and most of these satellites if this is the interface then should show in black background and, that means, my position estimations is going to be very accurate.

If it is not there, suppose this is the exact scenario then wait for some time because these are on the periphery of or near the horizon, these satellites will come somewhere in these circles and close to inner circles and then we may get good signals. So, waiting is the good solution for getting good position estimations.

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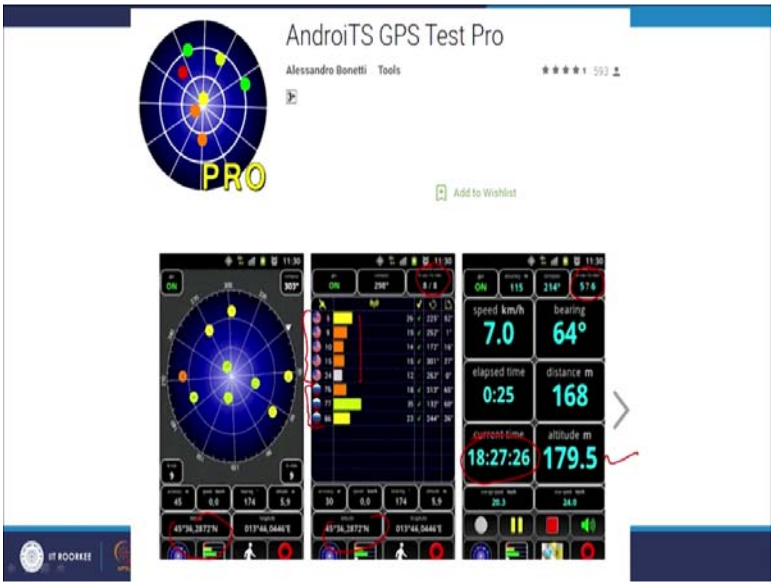


This is one interface through a smart mobile which you can see the sky plots are here and their colours and other things are there. Since this particular receiver was is capable of receiving signals from this GPS receivers which you are seeing through a flag here of US then you are having GLONASS of Russian satellites. And, these bars are showing the strength of the satellite; the numbers are showing the ID of the satellite and these are showing whether they are being used or not or should have been available, these colours are indicating. And, the same time in third screen you get the position and other things as well.

So, these interfaces are there in most of these satellites. You get the position very easily and all those parameters, data, current time is important. More than four satellites are being used as he says that all eight satellites are available. In this case eight we are used here, six satellites are available, five are being used and good position estimations are there.

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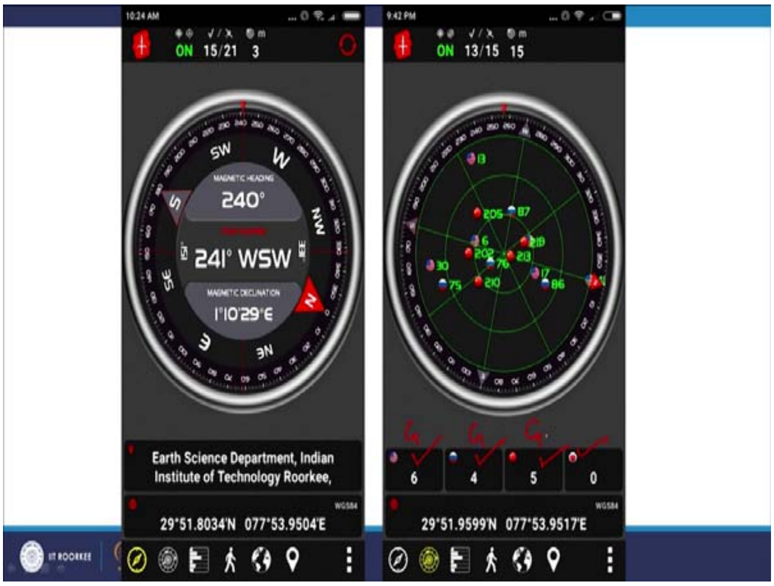


Another interface through this sky plot; so, you are having now signals from 5 GPS satellite, NAVSTAR satellites; you are having signals from 4 GLONASS satellite and 5 from BEIDOU satellites and one supposed to be there and this is flag representation of Japan. So, that is there but currently no satellite is available from that. Sometimes we may get, sometimes you may not get because this QZSS which is Japanese system is a regional system whereas, GPS is a global system, this is also global system and this is also global system.

So, these signals from these satellites if receiver is capable of receiving signals from this L 1, L 2 and L 5 then you may get signals from various satellites. Simultaneously their signals are used for calculation like in this scenario, 15 satellites are being used out of 21. In this one, 13 satellites are being used for position estimation out of 15. As you can see that this GDOP is shown 3 meter and when only 13 are being used, it is shown as 15 meter because the spread of satellite is not throughout this sky plot. They are mainly close to the inner circle. So, if that improves then you get this thing. This is how the signals and other things are there.

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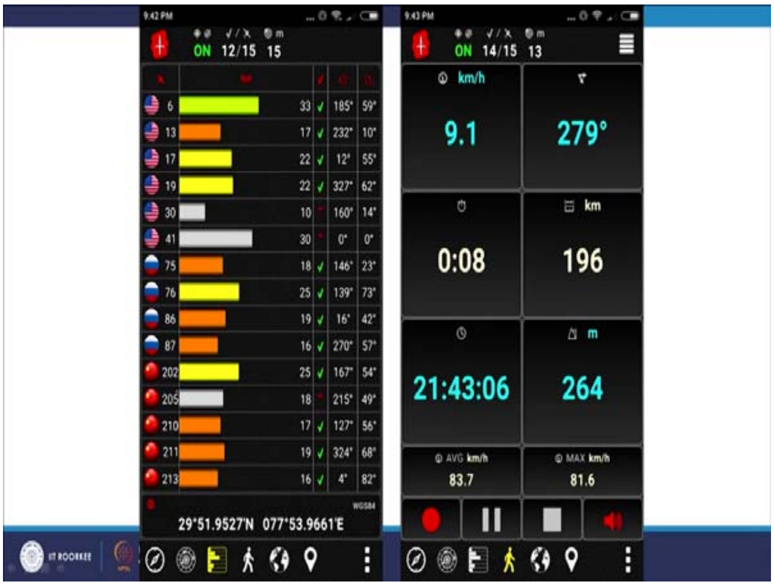


You can identify most of the things of these satellites.

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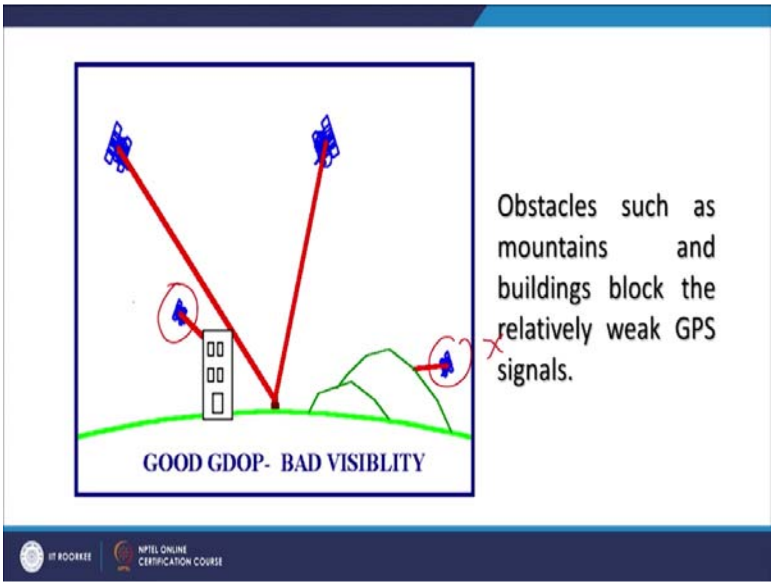
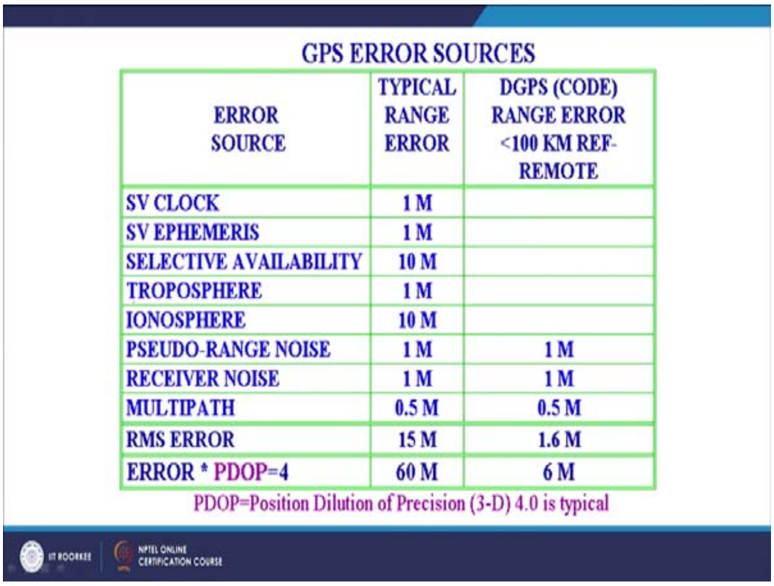



And, multipath or hindrances, we have already discussed bad visibility. Suppose the satellite we expected as per almanac is here, but it is behind the mountain so, no signals are coming; it is behind the building again no signals are coming. So, obstacles such as mountains and buildings block the relatively weakness signals.

(Refer Slide Time: 36:07)



GPS ERROR SOURCES

| ERROR SOURCE | TYPICAL RANGE ERROR | DGPS (CODE) RANGE ERROR <100 KM REF-REMOTE |
|---|---|---|
| SV CLOCK | 1 M | |
| SV EPHEMERIS | 1 M | |
| SELECTIVE AVAILABILITY | 10 M | |
| TROPOSPHERE | 1 M | |
| IONOSPHERE | 10 M | |
| PSEUDO-RANGE NOISE | 1 M | 1 M |
| RECEIVER NOISE | 1 M | 1 M |
| MULTIPATH | 0.5 M | 0.5 M |
| RMS ERROR | 15 M | 1.6 M |
| ERROR * PDOP=4 | 60 M | 6 M |

PDOP=Position Dilution of Precision (3-D) 4.0 is typical

Different errors ranges are there. 1 meter SV clock, 1 meter SV ephemeris, Selective Availability which is currently is not there so, 10 meter error is completely gone and, errors maybe with the calculations, multipath and so on so forth.

So, this brings to the end of this how position is determined through GNSS receivers and thank you very much.