Global Navigation Satellite Systems and Applications

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Lecture -02
How position is determined by the GNSS? (Part-1)

Hello everyone and welcome to the 2nd lecture of this Global Navigation Satellite Systems and Application course. And, in this one and few future lecture we will be discussing in detail, how position is determined by these navigation systems?

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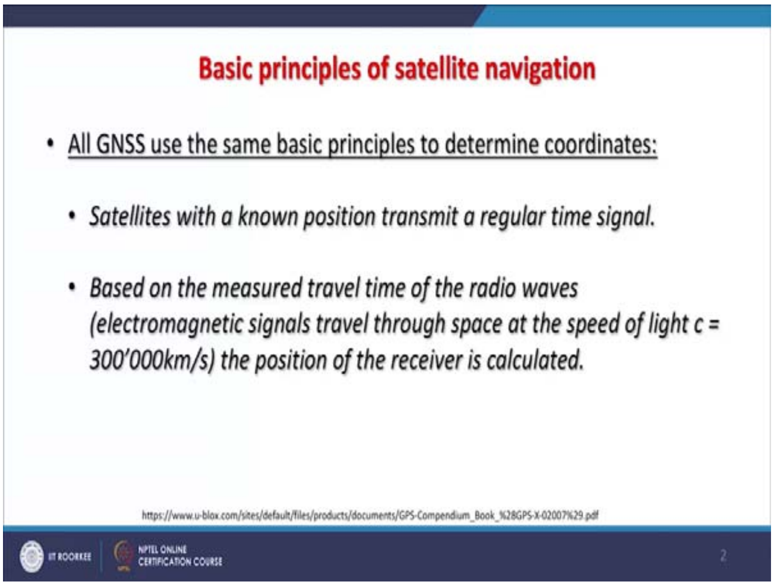

So, basic principle which is being used by all these navigation system is same that these satellites transmit the signal at a regular interval, maybe every second. And, then this signal is not just simple a signal, but it is having a set of data which are received by the receiver and then range is calculated that is the distance is calculated. So, based on the basically measured travel time of these radio waves which are used to transmit the signals from satellite towards the earth, which travels at the speed of light and position of the receiver is calculated.

Now, we will see that these signals contain some other data sets also, but before that we will take a scenario where initially first how on the ground using a transmitter tower and a car how the position is determined. And, then we will export this whole concept or idea to a space scenario.

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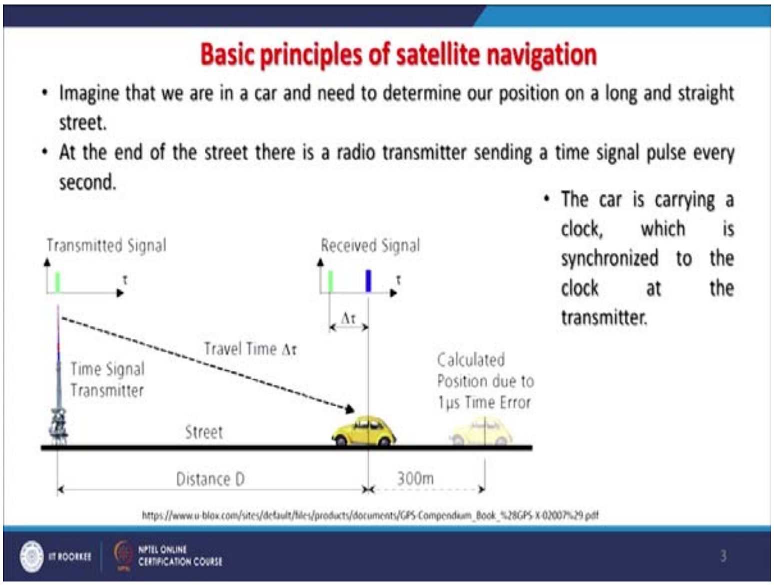

So, like if we are having a car and need to determine our position on a long and straight street. So, here the condition is long and straight, it has to be there then such systems can work. So, at the one corner of the street or end of that street there is a transmitter sending a time signal; that means, at what time the data is being transmitted in a form of a pulse and that to every second.

So, here a tower is shown here that which is transmitting the signal. This is the position of the car and when the signal is transmitted and when it is received. Then this time difference will give you this travel time or how much delay was there and then if a car is moving, then you know that how much is the velocity. So, the distance between first position and second position can also be determined.

So, likewise as you can see here that the car is a basically also will carry a clock because the time, the data has been transmitted by the tower and the time, your car has received should have a also a clock and that basically if it is having a kind of GPS receivers as today we are having that already having a clock there. So, car is carrying a clock which is synchronized to the clock at the transmitter. So, both clocks are synchronized; the clock in the car and clock in the transmitting tower.

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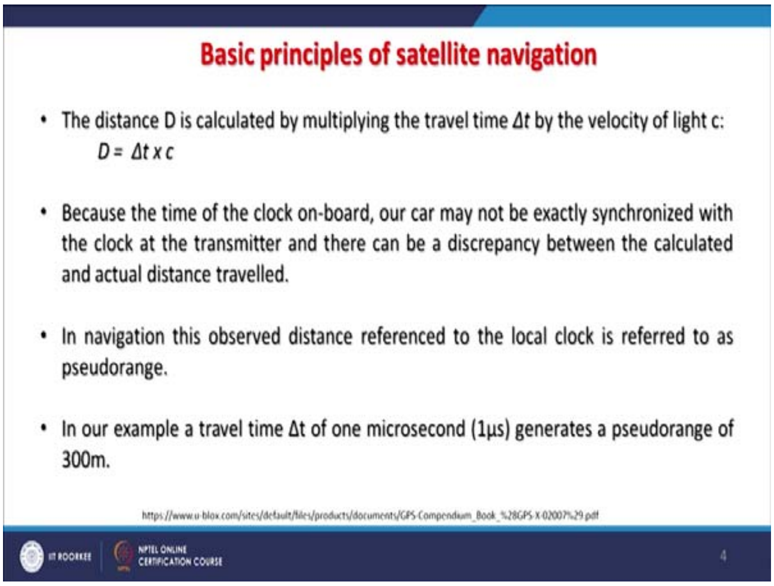

And, then by measuring the elapsed time between these two from transmission up to the receiver and when we multiply by the speed of light, then we get this distance D which is as I have said multiplying the travel time delta t by velocity of light c. So, distance is calculated by like this. It is a simple formula and because of time of clock on board that is on car, may not be fully synchronized or exactly synchronized with the clock at the transmitter. And, there can be discrepancy between calculated and actual distance traveled. That scenario might also occur and the similar situation we will also be encountering in case of satellite based navigation.

But, for time being we focus here that in this observed distance referenced to the local clock is referred as pseudo range. This is not a true range or true distance, but it will give you because these synchronization is not perfect between the two clocks. And therefore, rather than getting it true range one gets the pseudo range. But, if we bring a signals from another transmitting tower probably this issue can be resolved, this is what we will see in a few second time. So, in this example the delta t time difference of one microsecond generates a pseudo range of 300 meter that is also there.

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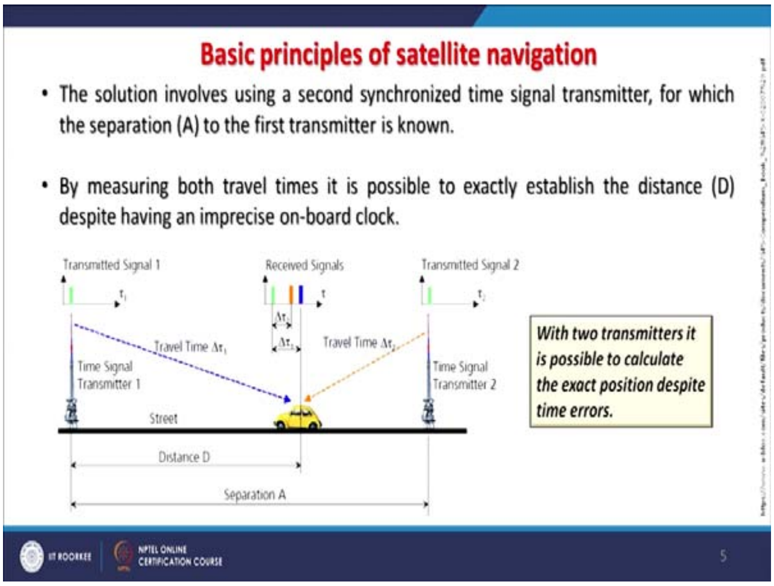

And, here now in this scenario, we have added one more transmitting tower here and then the issue of a clock which is not fully synchronized with the time signals or clocks of these transmitting towers can be resolved here. So, the two transmitters, it is possible to calculate the exact position despite time errors. And, this solution involves using a second synchronized times transmitter for which separation, here the separation from one tower to another A to the first transmitter is known, because here on the ground we know exact distances.

And, by measuring both travel time it is possible to exactly establish the distance despite having an imprecise onboard clock in the car. And, this can be calculated like the formula which is given here and this solution basically involving using a second synchronized time signal transmitter and by measuring both travel time it is possible to exactly calculate this.

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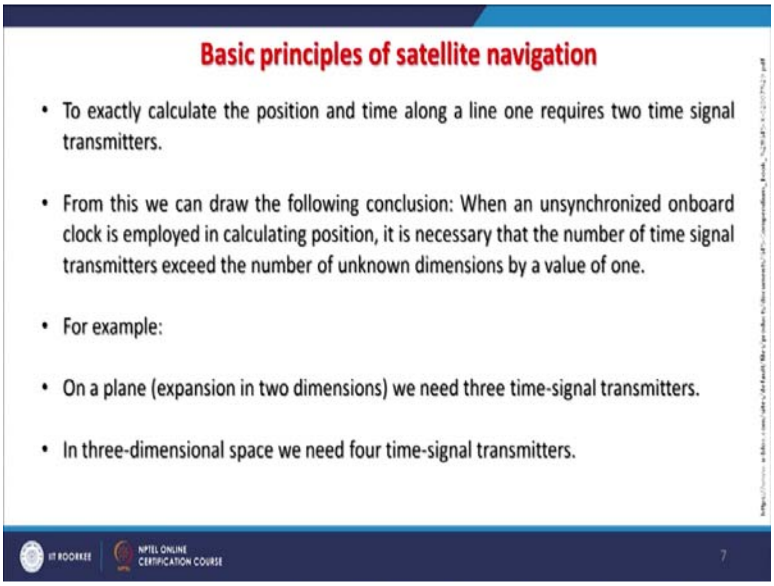

And, the position and time along a line, one requires two time signal transmitters as we have seen. And from this, we draw the following conclusions that when unsynchronized on board clock is employed in calculating position, it is necessary the number of time signal transmitters exceed the number of unknown dimensions of value of one. So, this says also the pseudo range and the problem about the time, the clock in our receiver and satellite is resolved like this in case of satellite systems (Refer Time: 08:00).

So, for example, here on a plane which is in rather going for instead of now 2D, in 3D, we need three time signals transmitters and in three dimensional space, we need four time signals transmitters. So, in a plane area on a 2D surface as mentioned earlier, three would be sufficient, but if you are going for a space you know, then at least four time signals are required. As they demonstrated here that you are getting now, signals instead of towers from satellite, satellite 1, 2, 3 and 4. And, their travel time is recorded and then position can be estimated, even the satellites clock and your car clock may have some differences, but that can be resolved by having signals from multiple satellites.

And, this is the advantage of having various signals from various navigation systems in our receivers. So, these satellites use the time transmitters, they sends the signals and contact at least four satellites is necessary in order as well as exact time.

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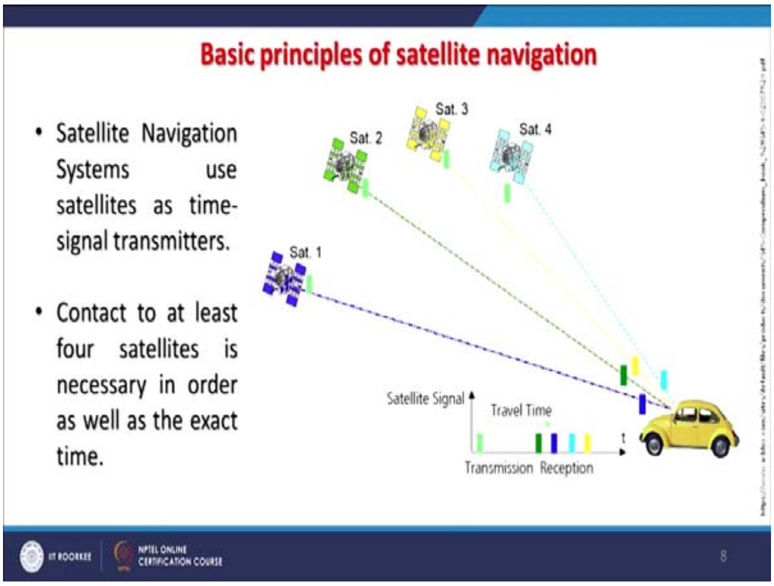

So, that is by four satellites, one should wait if you are determining your position initially maybe you may be getting signals from one or two or three satellites. Once should wait for more signals in few seconds time or few minutes time, your signals coming from number of satellites will improve. And then of course, your position estimation will also improve. So, what message or this pulse which we have been saying or the signal which are coming from the navigation satellites towards the earth, what these are carrying?

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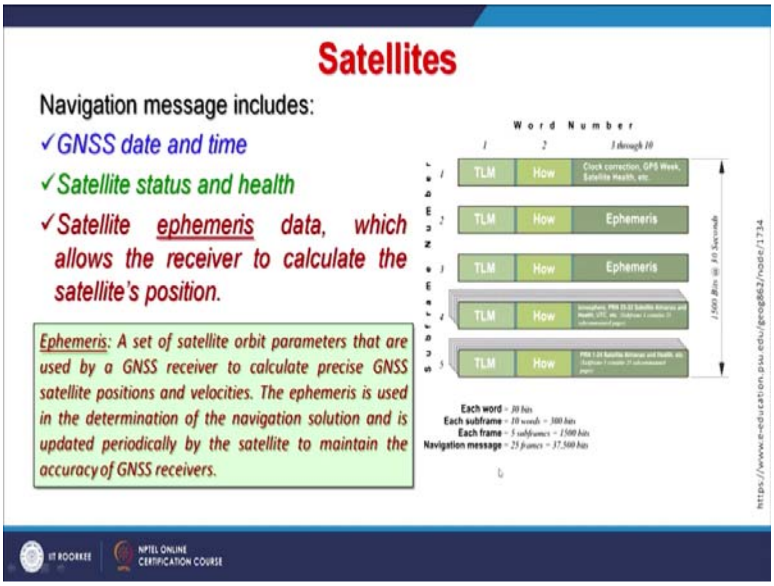

So, they are basically carrying the date and time of these satellite systems as shown here. And, then satellite status and health, whether it is functioning alright or whether there are some corrections which have been applied. And, satellite ephemeris data which allows the receiver to calculate the satellites position. So, we need to know this one also while calculating the position and basically ephemeris is a set of satellite orbital parameters that are used by a GNSS receiver to calculate precise GNSS satellite position and its velocity because these satellites are moving and we too, our receiver might also be moving.

So, that is why the ephemeris data is very important and this ephemeris is used in the determination of navigation solution and updated periodically, generally after every second by satellite to maintain the accuracy of GNSS receiver. So, they say if we see here that clock correction in the first this TLM, that clock correction GPS, whether signal weak or health that data is coming.

Then next is ephemeris, another is ephemeris and then there are some other signals are also there. And, how many bits data and which bits, like each word is 30 bits, each sub frame is 10 words; that means, 300 bits. Each frame is 5 frames that is 1500 bits and entire navigation message will have somewhere 37000 bits.

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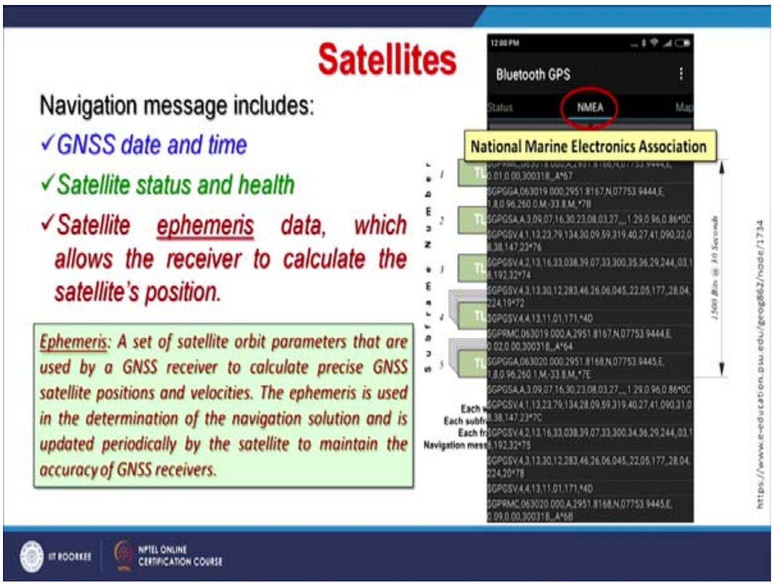

And, here a typical, when you instead of getting position if you debug and you want to see exactly how signals are coming from the satellites; as you can see such strings will come, they will have the location of the satellite, at what time it has been dispatched and ID of the satellite and so on so forth. So, like this data is getting updated every second and this is how these signals are there. Like here, you can see it is written 4D; that means, now it is providing solution for height estimation also.

So, likewise your data is being received by the receiver and this is one standard which is being followed that, this is a National Mapping Agency NMEA. So, this marine electronics association, this standard is followed in many such satellites and when you use this format, this is how you can see the signals; what they are carrying basically.

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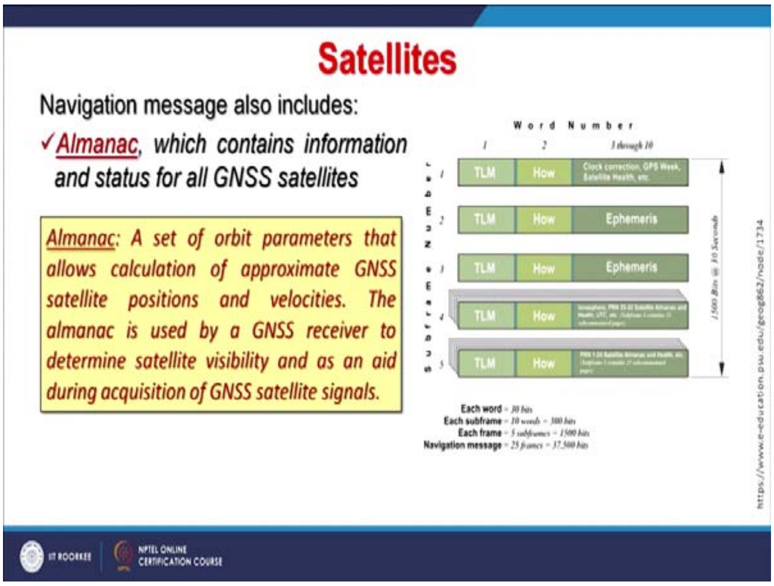

And, these navigation message also includes almanac which contains information and status of all GNSS satellites and almanac basically again set of orbital parameter that allow calculation of approximate GNSS satellite positions and velocity. The almanac is used by GNSS receiver to determine satellite visibility as an aid during acquisition of satellite signals.

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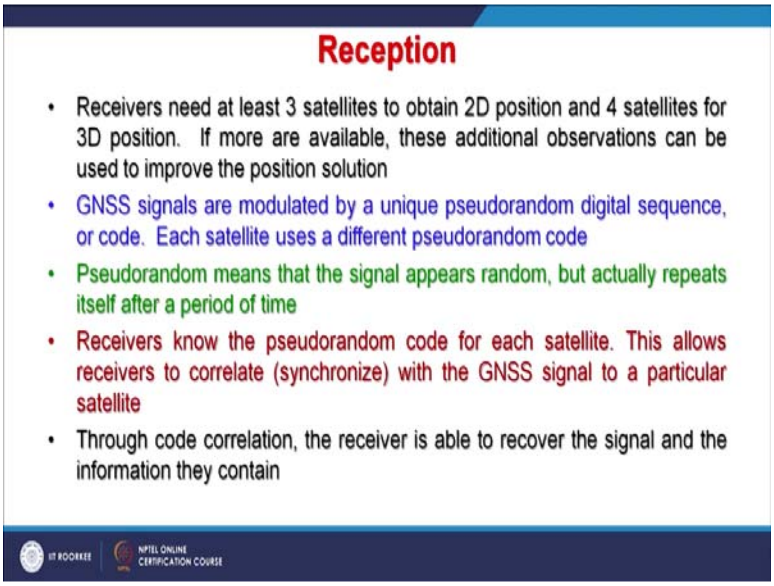

So, likewise you get. Now at the receiving when data is received, the receiver needs at least 3 satellites as mentioned to obtain a 2D position; that means, for horizontal x and y or latitude-longitude. And, you need another satellite that is the fourth one. 4 satellites together to get the 3D position that is x, y and z. If more are available, generally they are available from one single system like if your receiver is capable only of receiving signals from GPS.

then still you may get in a normal condition 6, 8 satellites signals at a time on any part of the globe, except that if you are in underground mining or inside a building or in a deep forest, then that might be different scenario, but normally you get 6 to 8 satellites from one navigation system. And, these are the minimum that does not mean that whatever will be estimated based on 4 satellite signal will be accurate, not at all.

More satellites signals are available; the additional observations can be used to improve the position solution. And, these GNSS signals are basically modulated by a unique pseudo random digital sequence or code. Each satellite uses a different pseudo random code because each satellite is carrying their ID and when the position estimations are done, these are used at the time. So, this pseudo random means that signal appears random, but actually repeats itself after a period of time generally after every second.

And, receivers know the pseudo random code for each satellite because when you switch on your receiver, first it starts getting these signals and based on that, now it has basically logged with the signals which are coming from these satellites. So, that is why after some time the receiver starts knowing that from where these signals are coming or the codes of these pseudo random code is available. And, this allows receiver to correlate or synchronize with the GNSS signal at a particular satellite.

And, then basically you can call as logged; so, then it starts getting the signal. So, if after very long time, if you switch on your GPS receiver or GNSS receiver, it takes some time to synchronize with different satellites. But, if you are using 10 times in a day then instantaneously in few second times, it will synchronize and do it. Because by the time, it has synchronized and expect that these satellite would be available within the area where you have been earlier. Through these code correlations, the receiver is able to recover the signal and the information they contain. So, if you switch on after very long time, then this correlation is not possible and that is why it take more time to, you know decode these pseudo random signals.

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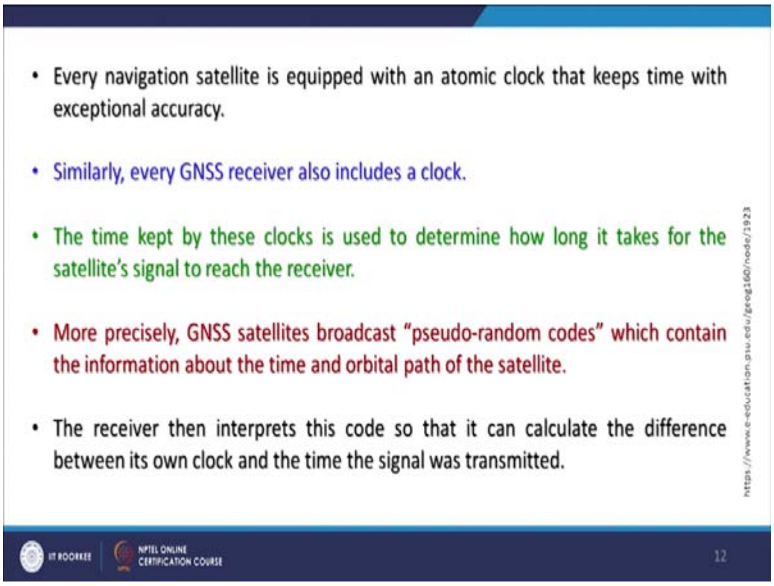

And every satellite, these navigation satellite as I mentioned also earlier that they are having synchronized atomic clock, but each system, they are having a synchronized atomic clock. And, which keeps the time and exceptional accuracy; very high accurate timings are there. Similarly, every GNSS receiver also includes a clock like your mobile receiver. So, mobile is also having a clock, we have already discussed that our clock and the satellite clock may have a difference.

But, if you get the signals from many satellites then this problem can be resolved very easily. So, time kept by these clocks is used to determine how long it takes for the satellite signal to reach the receiver because the signal which has been dispatched by the satellite, is time stamped. But, when it is received, it will depend on our clock or receiver's clock and that will give you the range or distance of the satellite which is used for the position determination.

So, if these two clocks are having different timings then position determination is going to be poor, but these issues are being resolved now to a large extent and more accurate positioning estimations that too very quickly in few second times are becoming possible. So, GNSS satellites basically broadcast pseudo random codes which contain the information about the time and orbital path of the satellite we have seen how, what and how much data is carried with each pulse of a signal, which is coming every second. And, receiver then interprets this code, so that it can calculate the difference between its own clock and the time, the signal was transmitted.

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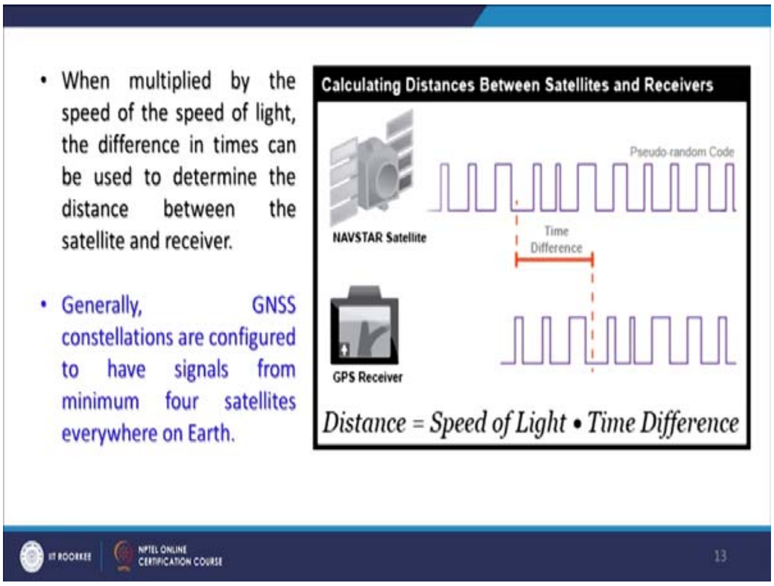

And, this is how this time difference is there. This is the pseudo random code. Suppose a satellite, this GPS example is given NAVSTAR is transmitting and this is our receiver. So, there may be some time difference, it is there and this time difference basically when multiplied by the speed of light, we get the distance. So, generally these GNSS receivers, these constellations are configured to have signals from minimum four satellites everywhere on the Earth.

If we take the example of GPS; so, there is a standard constellation, total number of satellites are basically 31 but there are, you know 6 orbits and in each orbit at equal distance, 4 satellites are there. And so, you can say that a total number of satellite plus spares that is 31, but 24 are essential for this complete constellation of GPS.

Now, theoretically if you think that on a very higher ground, on one part of the earth you may get signals from maybe from 12 satellites, 10 satellites, 8 satellites. It is getting signals from one navigation system like GPS from 8 satellites is a very common; it is not very difficult if someone is in open area. And once this pseudo code has been determined by our receiver, then that receiver starts tracking these satellites from where the pseudo code has been received.

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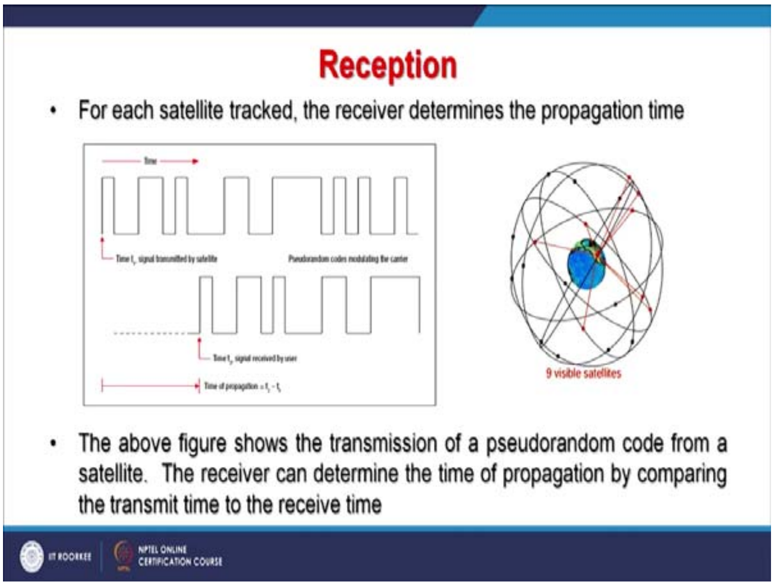

And, the propagation time is determined and as that like here this is the time which is going on, the signal is coming. So, this is t 1, then random code modulation, the carrier, then t 2 and the time of propagation that is t 2 minus t 1. So, this shows that a transmission of a pseudo random code from a satellite and the receiver can determine the time of propagation by comparing the transmitted time to receive time. Basically, that is why these systems are also called ranging systems; as in this animation, it is shown that sometimes at a one particular location which is fixed on the globe inside this like this is positioned here.

So, sometimes you are getting signals from 5 satellite, 6 satellite and this in animation or in this simulation, it is assumed that you are in a very open area. But, as mentioned earlier that if you are in a valley or inside a building or underground mine or in the dense forest, then these satellites from say GPS, the visibility or access to the signals from this satellite will reduce significantly. So, one has to be careful while estimating the position.

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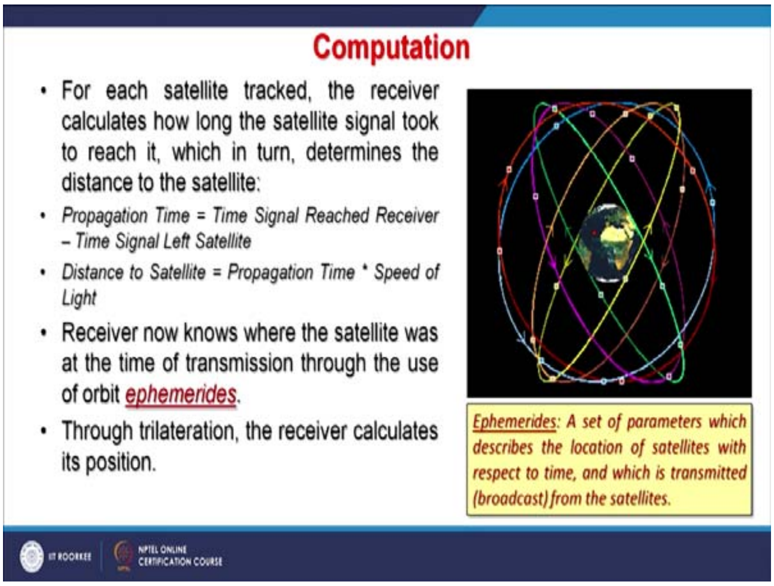

Now, basically the receiver has logged or start tracking these satellites, calculate how long the satellite signal took to reach, the time difference. And, then in turn determines the distance to the satellite as shown here that 3 satellites scenario is there, location is there and these 3 satellites scenario will give you 2D position and then this tends to satellites. And so, first the propagation time that is the time signal reach the receiver minus time signal left satellite. So, this will give you the propagation time and how to determine the distance to satellite then propagation time multiplied by the speed of light.

So, basically your receiver knows where the satellite was at the time of transmission through the use of orbit ephemerides. And, that is why it carries a lot of data not only just time signal, but also the orbital parameters of all of these satellites, where they are located in their orbit. And, this, we have already discussed that ephemerides set of parameters which describe the location of satellite with respect to time and which is transmitted broadcast from the satellite. And, through this trilateration, the receiver calculates its position as shown in this figure.

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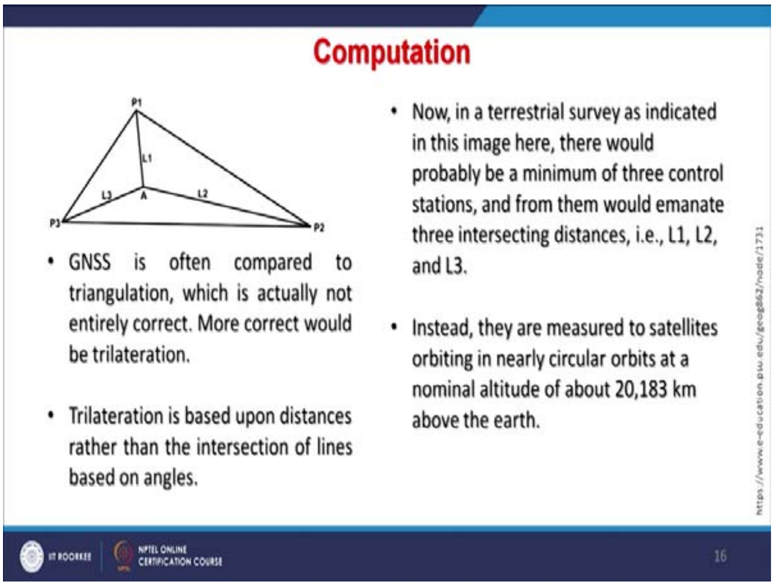

Similarly, if you are getting signals from more than 3, then of course 3D position can also be determined. So, GNSS is often compared to triangulation which is actually not entirely correct, but more correct would be trilateration because it is not in 2D, but it is in 3D. So, based upon the distance rather than intersection of lines based on angles, that is why it is trilateration.

And, now this terrestrial survey as shown in this figure that a probably the minimum of three control stations and from them would eliminate three intersecting distance is L 1, L 2 and L 3 as shown here. L 1, L 2 and L 3 are there. So, when they intersect a point A that is the position A. So, instead, they are measured satellites orbiting nearly circular orbits at a nominal altitude of 20,180 roughly 20,200 kilometer in case of GPS.

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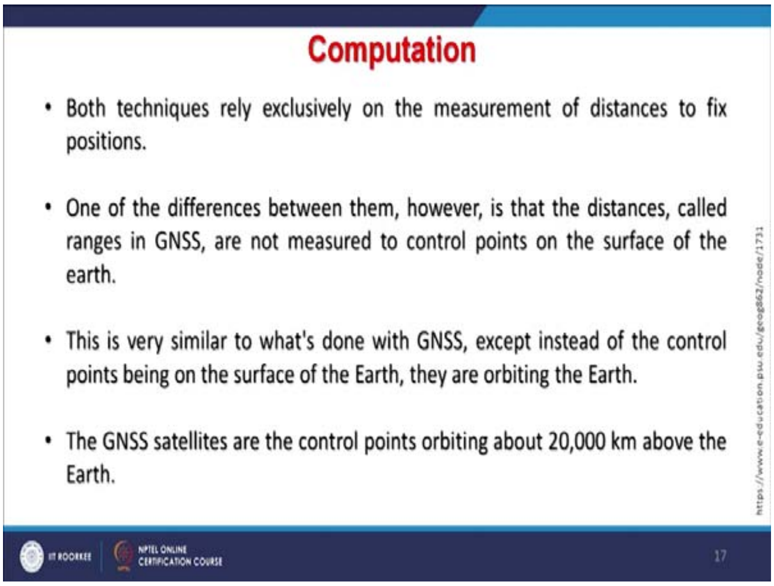

So, this example is from GPS basically and both these techniques rely exclusively on the measurement of distances to fixed position; though the position might be moving later on, but initially we assume that one location. And, then if it is moving then also because the data is getting updated every second, so you get velocity as well. So, one of the differences between them about these distances or both techniques is that the distance is called ranges in GNSS in satellite based navigation systems whereas, in other it is measured to control points on the surface of the earth.

And, this is very similar to what is done with the GNSS except instead of control points being on the surface of the other, they are orbiting the satellites. That is why I said instead of 2D, one has to imagine things in 3D. And, these control points or locations are the satellites which are moving itself, so they are orbiting at a 20,200 kilometer roughly.

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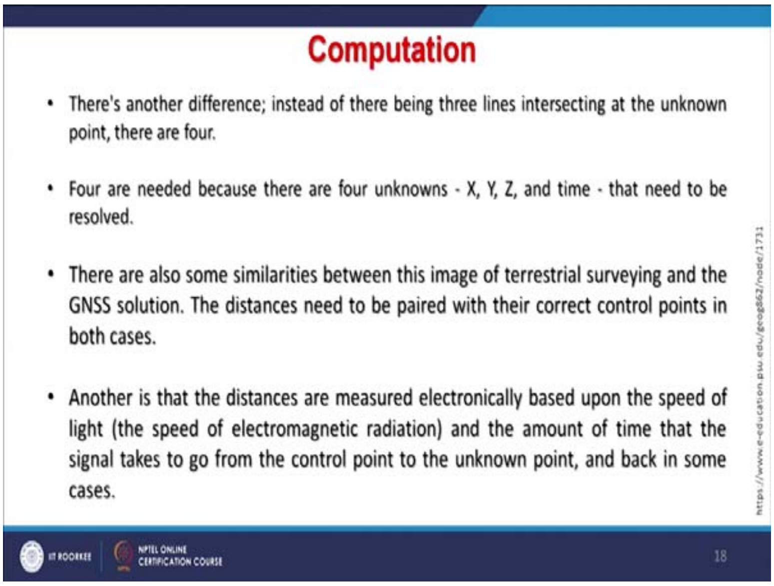

And, another difference in these techniques is, instead of there being three lines intersecting at unknown location points, there are four in case of satellite navigation. And, four are needed because there are four unknown X, Y, Z and time that need to be resolved because, as mentioned your receivers clock and satellite clock are also different.

So, that is why the time it has to also be estimated and that has to be resolved and there are some other similarities between these that this terrestrial surveying and GNSS solution. distances need to be paired with their correct control points in both the cases and another is that the distances are measured electronically based on upon the speed of light and the amount of time is taken and go, which is to receive the signal and back in some cases.

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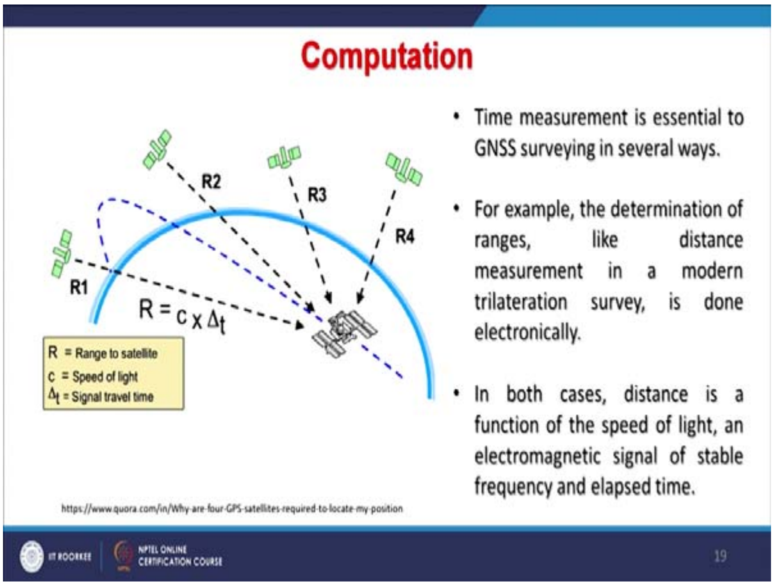

So, this is how the computation is done that range as I have been mentioning several times they basically these are the ranging systems. So, the time difference is basically giving you the range and then range is used to determine the position. So, R ranges are given here from different satellites, speed of light and time difference and the travel time is also given. So, time measurement is essential because the key part in GNSS computation or position estimation is the time because that will give you the distance to the satellite and other things as well.

So, for determination of ranges like distance measurement in a modern trilateration survey is done which is electronically in both cases whether it is done electronically or otherwise distance is a function of speed of light, an electromagnetic signal of a stable frequency and elapsed time that is there. And, in both GNSS surveys and trilateration surveys begin from control points.

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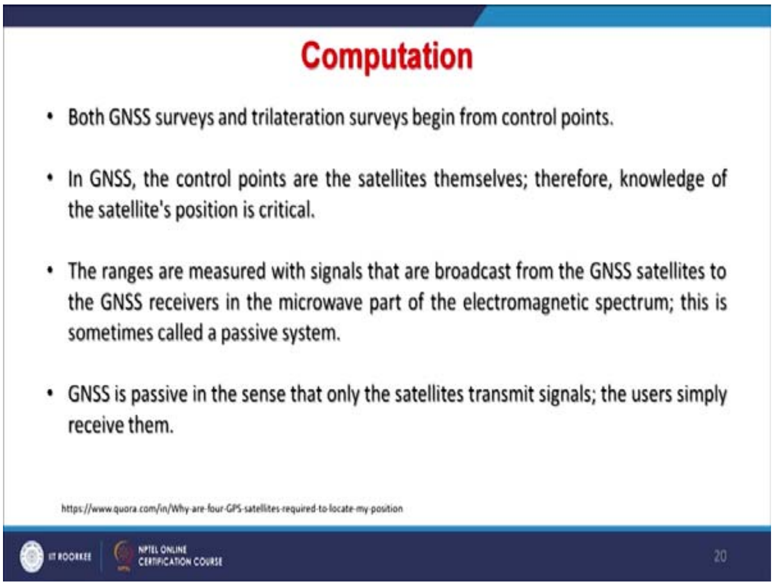

And, these in case of navigation control points are our satellites and in GNSS, control points are satellites and satellites position is critical for position determination. And, ranges are measured with signals that are broadcast from these GNSS satellites and then what the receiver receives in microwave part of EM spectrum. And, this sometimes also called passive systems because the receiver is not transmitting anything towards the satellite; they are only capable of receiving signals that is why it is called passive system. And, the GNSS passive sends that only satellite transmit signals as mentioned and user simply receives them and use them to estimate the position.

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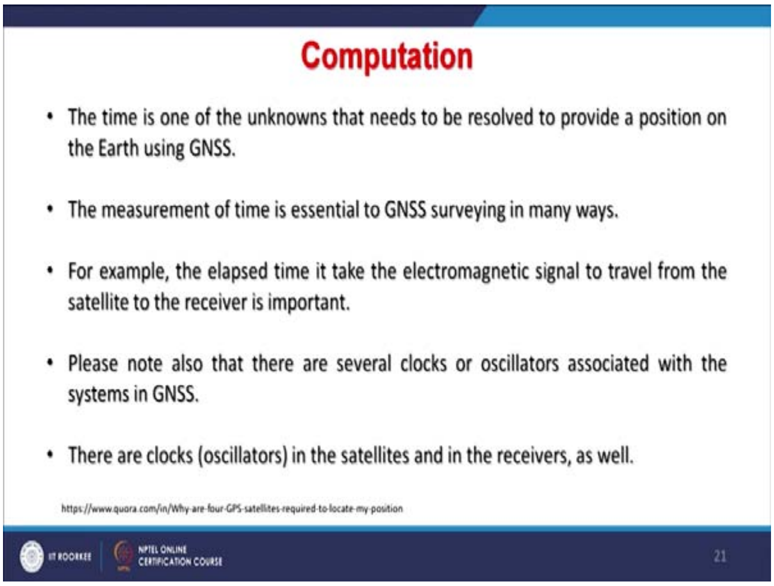

Time is one of the unknowns that need to be resolved to provide a position on the Earth using GNSS. And, first thing when computation starts, this is what first thing is attempted and then this measurement of time is essential to GNSS surveying in many ways. And, this elapsed time it takes to the electromagnetic signal to travel from the satellite to receiver is important and also there are several clocks or oscillators associated with the systems in GNSS. Several clocks that is why it is mentioned that all these clocks have to be synchronized for each these systems and there are clocks and satellites and in the receiver as well.

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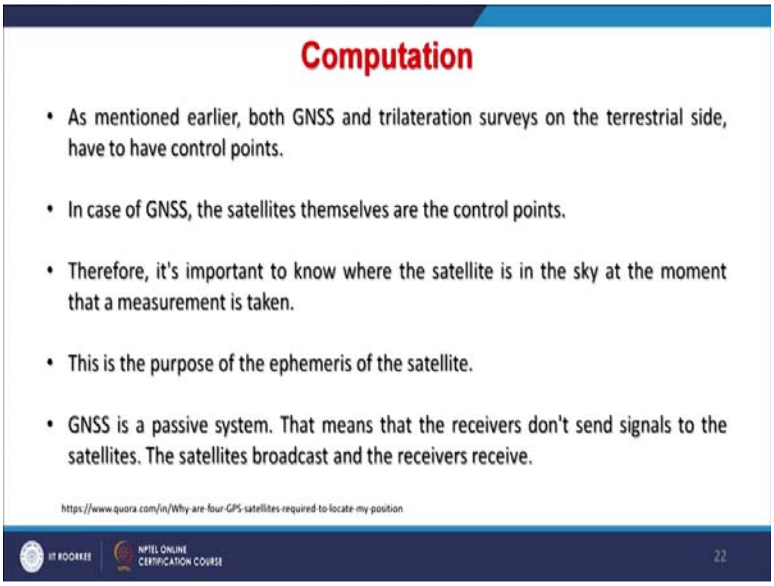

As also mentioned earlier that both these systems; the GNSS and trilateration surveys on terrestrial side have to have control points. There are control points in the satellites. And therefore, it is important to know where the satellite is in the sky at that moment of time, the measurement is taken.

So, satellite position is equally important and that is transmitted along with the signal and this is basically the purpose of a ephemeris of the satellites. GNSS is a passive system basically receiver, the controllers or those who have developed the systems, they definitely communicate with the satellite. So, for them it is not passive, but for users that is a definitely passive system.

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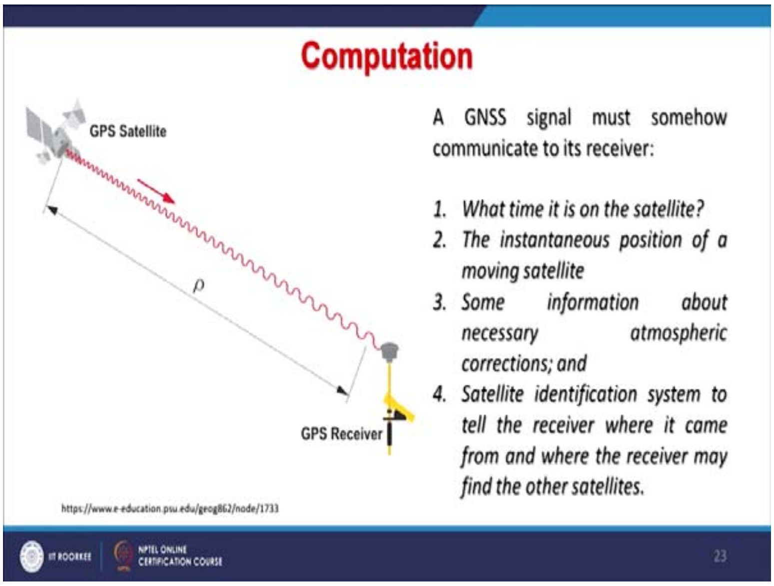

As you know, the GNSS signal must somehow communicate to the receiver. This has to come directly, if there are mountains or buildings, if you are surrounded by the buildings, then this directly signals may not be received and; that means, you are adding extra time for the signal to reach to your receiver and wrong position estimation. So, while doing or receiving signals, one has to take care when you are surrounded by mountain or buildings that whether signals are being received directly or by reflection. And, that is very important to you remember while getting values or estimations of position through the GNSS system.

So, basically these signals must communicate what is the time on the satellite, when the signal was dispatched. The instantaneous position of a moving satellite; what was the position of the satellite when the data was transmitted. And, some information about the necessary atmospheric corrections if that is available from some other sources or may be satellite itself. And, satellite ID that is also very important because each satellite will have its unique ID, so that our receiver can use that for pseudo ranger code or calculations.

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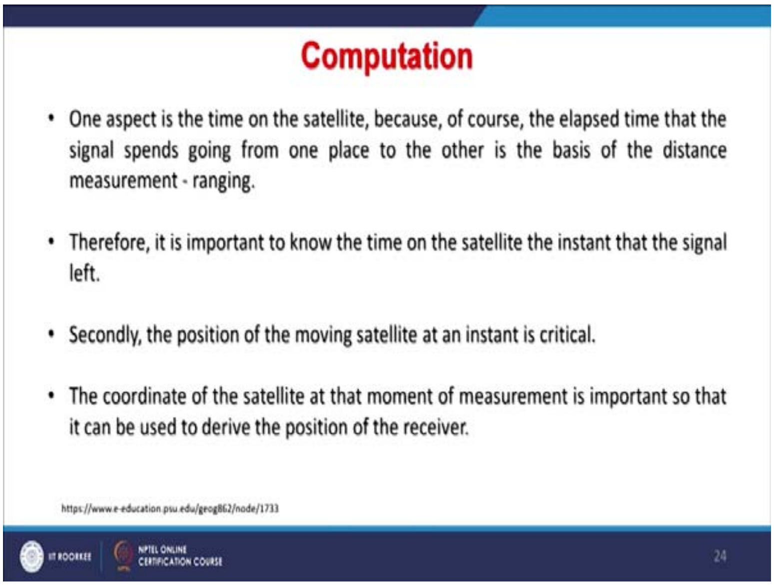

And, the aspect of time on satellite because of course, the elapsed time, the time taken between the transmission and receiver, the signal spends going from one place to another is the basis of distance measurement or ranging. And therefore, it is important to know the time on the satellite the instant that signal left. And secondly, the position of the moving satellite is that instant is critical because, these satellites are moving and if I am using this receiver inside a moving object like in a car, my object is also moving.

So therefore, this position estimation becomes much more crucial in those things because our control points are also moving which are satellites and the receiver is also moving. So, coordinate of the satellite at that moment when the measurement is done is important, so that it can be used to drive position of the receiver.

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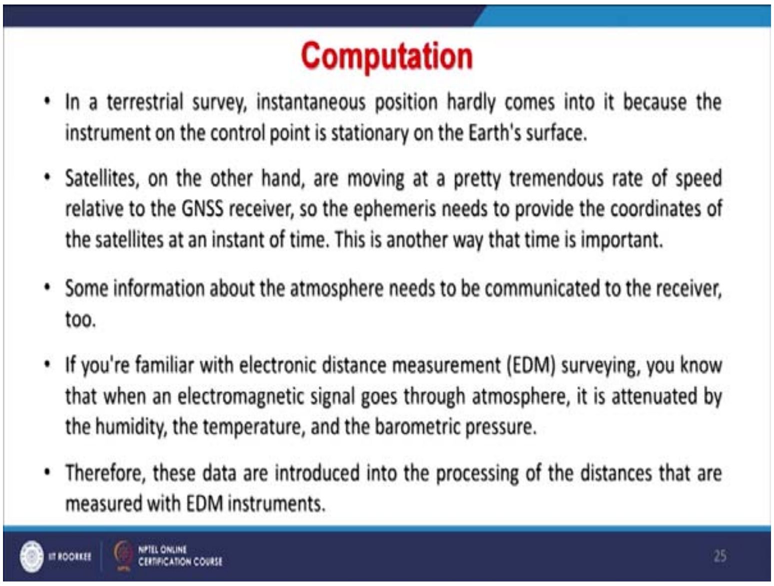

And, in a terrestrial survey when it is done on the ground, instantaneous position hardly comes into; it is because the instrument on control point is stationary on the earth's surface. And, satellites on the other hand are moving at a pretty tremendous rate of a speed relatively to the GNSS receiver. We might be inside the car and it is moving, but the speed of car is not as high as the satellites which move. You think that they are orbiting the earth at a distance of 20,200 kilometers and there, you know at least making few orbits per day. And therefore, the speed is very high there, but your receiver speed may not be that high. But, that does not matter these things can be taken care while calculation is being done; only requirement is that one should have signals from many satellite.

And, some information if at all it is available about atmosphere then our position estimation can be improved. And, if you are familiar with this Electronic Distance Measurement or EDM surveys which typically in civil engineering it is done, then you know that this electromagnetic signal goes through atmosphere. So, if someone is using these total stations or EDM they have to travel through the atmosphere. And, then if high humidity is there or some disturbances are there, then the signal will get attenuated and then there will be some delay in the signal. And, that will add some additional distance in that and in case of satellites; these signals have to pass through the atmosphere.

And therefore, there might be some delays are there which are sometimes resolved using some standard models because, live data of atmospheric conditions and using them while calculating or estimating is not that easy. Therefore, this data are introduced into processing of the distance that are measured with EDM instruments. So, if one is really looking for very high precise location, then all these things have to be taken care.

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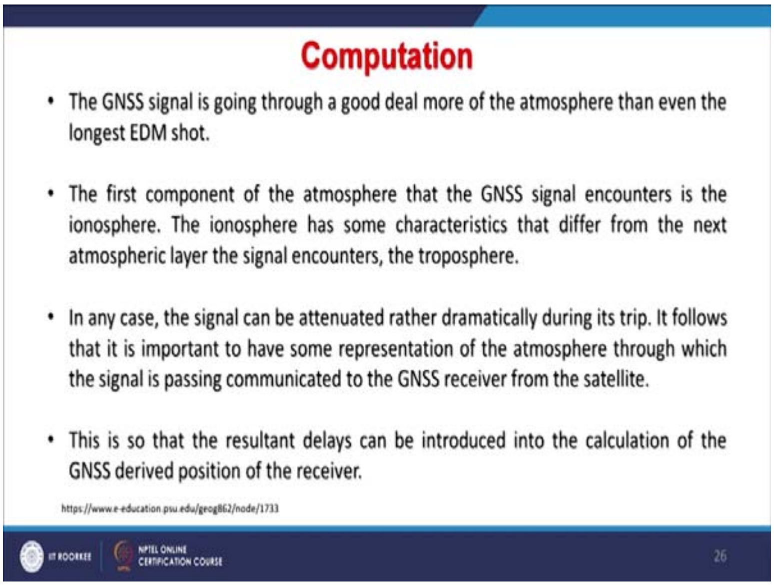

And, GNSS signal is going through a good deal of more of the atmosphere, then even the longest EDM. Because, ground-based or terrestrial survey, you are using EDM maybe for 1 kilometer or 500 meter, but here the signals are coming from very long way and the first component of atmosphere the GNSS signal encounters is the ionosphere. So, from top when it is the signals are coming first it encounters ionosphere; ionosphere delays are there with the GNSS signals.

So, this has some characteristics that differ from the other atmospheric layer and this signal will encounter that is troposphere. So, different layers of atmosphere will behave differently with these GNSS signals and therefore, they may add some delays in the signals. So, in any case the signal can get attenuated sometimes dramatically and during this journey from satellite to receiver.

And, it is important to have some representation of atmosphere through which the signal is passing communicated to GNSS receiver from the satellite. Some representation that means, some model because instantaneous or current at atmospheric conditions may not be available. And therefore, some models can be introduced here to get more better position and these delays can be introduced in the calculation as through these models as I have mentioned to get the better position. As mentioned that GNSS receivers will face more atmospheric layers as compared to EDM or these total stations and this is a big issue here.

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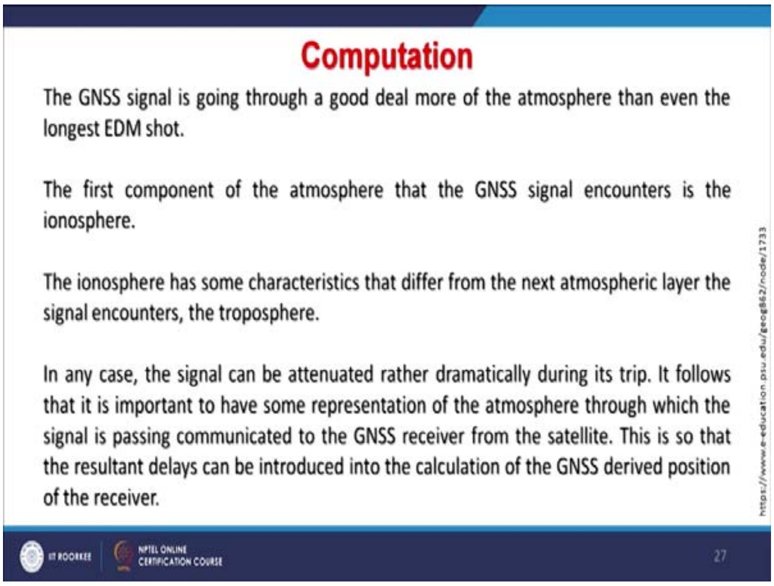

But if somebody is looking for position within 1 meter then one has need not to bother. But, if somebody is looking position estimations in millimeter accuracy, then all these things have to be taken care or have to be resolved for position estimation. And, as I have also mentioned that when set of data comes from the satellite, the satellite identification that is the ID of the satellite has to be there, each satellite has been given unique ID. And so, that the receiver can identify different satellites and can calculate the range or distances from these satellites and then can create or estimate the correct position which is there.

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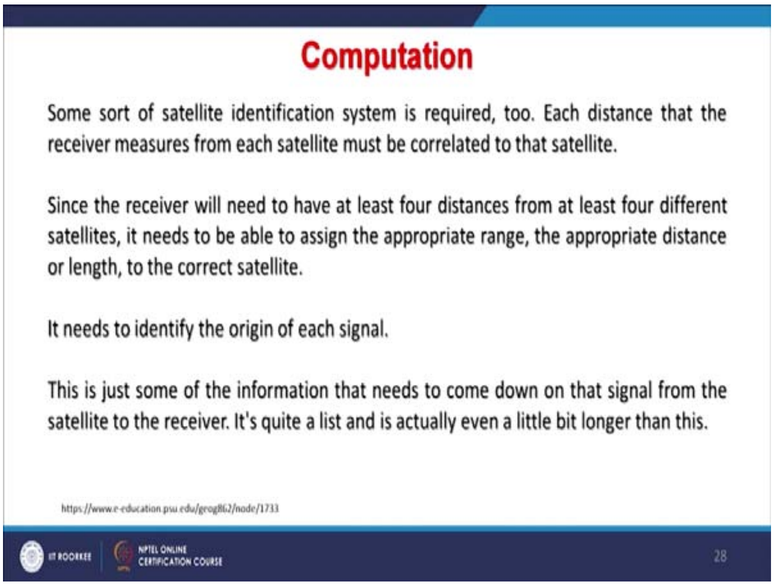

So, ID is definitely is there and because in order to identify from which satellite the signal is coming. So, when the data is transmitted by the satellite, each satellite will also transmit its ID towards the earth. So, some of the information that need to come down on the signal from the satellite to the receiver and it is a quite a list. As we have already seen that how a big data set comes and a sometimes because, the calculation may take some time here and this was the part 1 of how the position is determined by GNSS receivers.

So, in later part b, we will be seeing further details and we will make this thing more clear because, one must know how position is determined by these GNSS systems because that is the basically key. And later on of course, in later parts of this course we will be seeing other applications as well so.

Thank you very much.