Global Navigation Satellite Systems and Applications

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Lecture - 15
GNSS Correction Methods

Hello everyone and welcome to 15th lecture of this Global Navigation Satellite Systems and Applications course. In the previous lecture, we have discussed about some errors which are associated with GNSS. Today we will be also discussing on the same line further on this GNSS correction methods, how these can be corrected. There are some methods which we have already discussed like DGNSS that is differential GNSS is also a correction method and if you involve SBAS that is also a correction method, RTK is also one of the correction methods.

But there are also some possibilities, some we have touched in previous discussions and in some other correction methods which we will be discussing in this particular lecture. As you know that there are 2 types of services many of these GNSS providers so GNSS operators provide that you know, there is a Standard Positioning Service and another one is the Precise Positioning Service. So, SPS and PPS but here we are talking about something which is different than Precise Positioning Service.

It is Precise-point Positioning Service and how this can be achieved by providing corrections in the data and the corrections in positioning techniques basically to remove or model the GNSS system errors.

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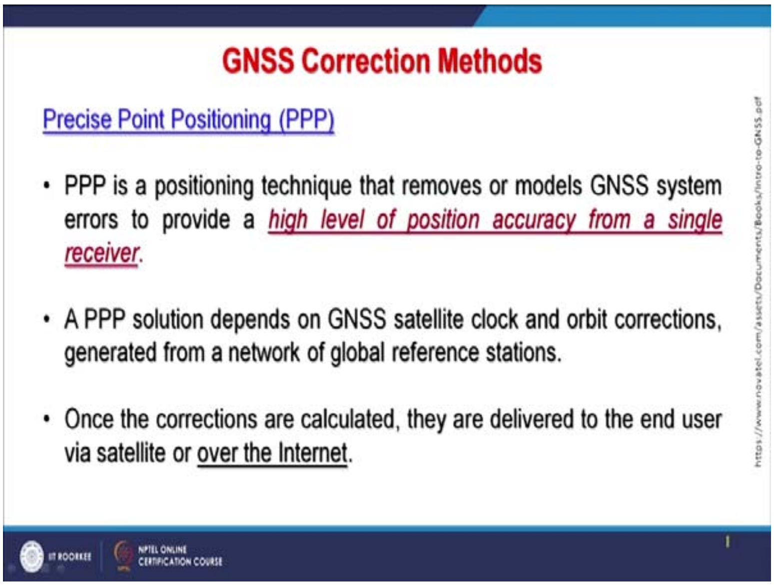

So, we can have a high level of accuracy from a single receiver. See maintaining 2 receivers; one stationary and one roving and then maintaining communication between them becomes very difficult and expensive option also.

But if we go for, this is the trend now is that people are looking a single receiver option but high level accuracy and therefore, there are some techniques or options are becoming available; one of them is like SBAS, this is also similar to the SBAS but you know, subscription based and some other ways of involving this is also here. So, this is what we are going to discuss that this PPP solution basically depends on the GNSS satellite clock and orbit corrections and these are generated from a network of global reference stations.

So, if some country or through United Nations or whatever the world community, if we install such a reference station or maybe through private companies, one of the examples which I will be showing here then these reference stations can transmit the corrections and these can reach to the end users which is having a single receiver but having capabilities of receiving these corrections either through the satellite like a geostationary satellite or maybe through internet. So, that way the corrections can be applied and high level of position accuracy can be achieved like for example here this is schematic.

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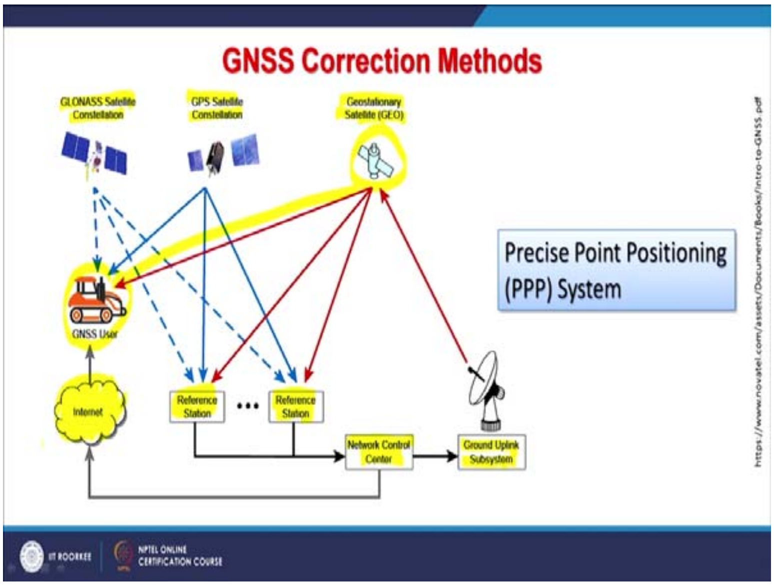

Let us discuss this that the GNSS constellations are there, various constellations now we know. One of the constellations is also highlighted here that is a GPS constellation.

But along which we are having GLONASS and BeiDou and GALILEO and IRNSS that is NAVIC and then what these GNSS constellations are doing; they are providing locations to Reference Station basically as in differential GNSS, we call them as a Base Station. Now these Base Stations through a network control center, they are collecting the data, they are making corrections in the position and those corrections; how much the position has to be corrected at that particular time when somebody is having a single receiver in the field that is uplinked through a earth station to a geostationary satellites which we see here and through that any user can get a signal directly in the field in real-time.

Now, one possibility is getting the signals directly from geostationary satellites or there is a another possibility of getting signals from internet. So, these 2 options are now being explored or available and this is what the Precise Point Positioning System is.

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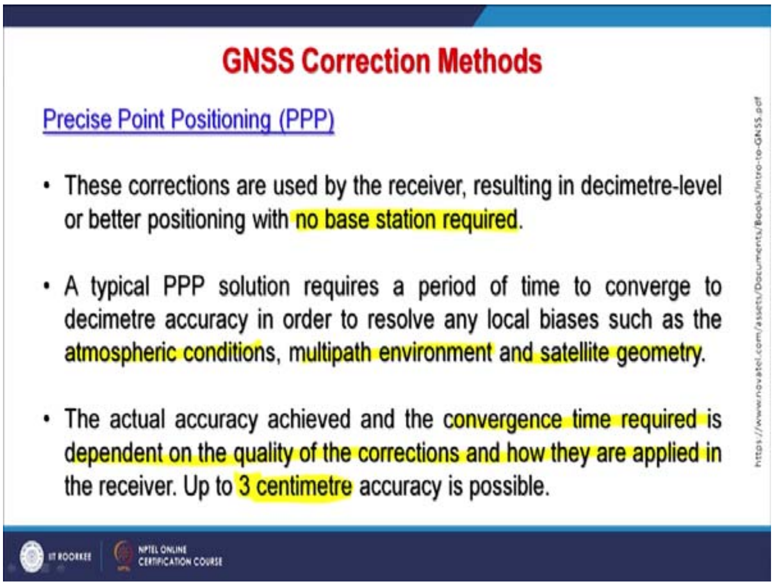

So, in this PPP these corrections are used by the receiver, resulting in decimetres level or better position with no Base Station required. This is the important point here that in this option that is PPP Precise Point Positioning System, the Base Station installed by the user is not required.

But Reference Stations by the service providers are definitely there; without that it is not possible. So, a typical PPP solution requires a period of time to coverage the decimeter accuracy in order to resolve any local biases such as atmospheric conditions, a multipath environment and satellite geometry. So, these things are definitely required and they are resolved also.

So, actual accuracy is achieved by and the convergence time required depending on the quality of corrections and how they are applied to the receiver. And by this method, we can receive of up to 3 centimetres accuracy is possible. So, with the more advancement, more options are available, we are definitely reaching to millimetre accuracy possibilities with single receiver.

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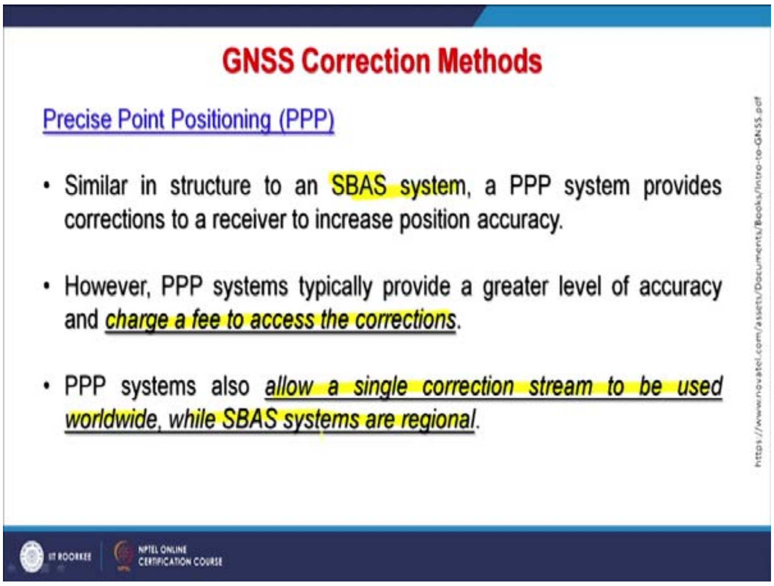

However in this PPP, which is quite similar to the structure or concept of SBAS systems which we have already discussed that the best part of PPP is that it provides corrections to a receiver to increase position accuracy. So, if I am getting signals from SBAS and using those corrections then I may not achieve that accuracy comparatively as provided through this Precise Point Positioning.

However these PPP systems typically provide a greater level of accuracy and this is important; charge a fee to access the corrections. This service is not going to be free because whoever will invest for developing Base Stations and a Central Processing Unit or center and then up-linking and finally might be having a geostationary satellite for that purpose.

So, if somebody is putting that kind of investment then definitely there will be subscription fee. And this PPP system also allow a single correction stream to be used worldwide and therefore, the same receiver can receive correction signals if it is taken in any part of the world so, that is another advantages. However, as we know that the SBAS is a regional system so, it depends whether that country is providing that service or not whereas the PPP, you can consider as a global or worldwide positioning service.

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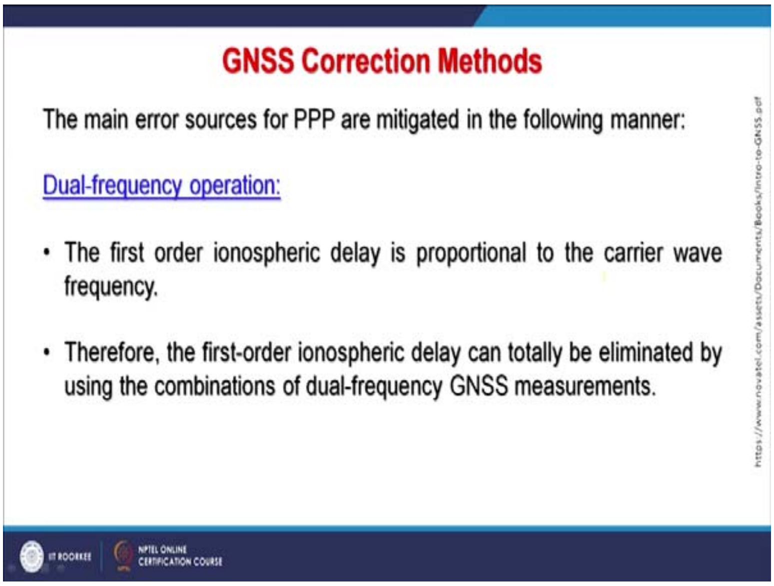

Now, the main error sources for PPP are mitigated by through these manners that the dual frequency operations because these receivers will receive signals in 2 frequencies. So, the first order ionospheric delay is basically proportional to the carrier wave frequency and those can be removed and therefore, the first order ionospheric delay can be totally eliminated by using combinations of the dual frequency GNSS measurements.

This part we have already discussed when we were discussing about that how an ionospheric delays causes the delay in the signals and then errors in the positioning and how dual frequencies can be there. Now there is another way of doing this thing is an external error correction data that includes the satellite orbit and clock corrections and also using private services or services which are available globally.

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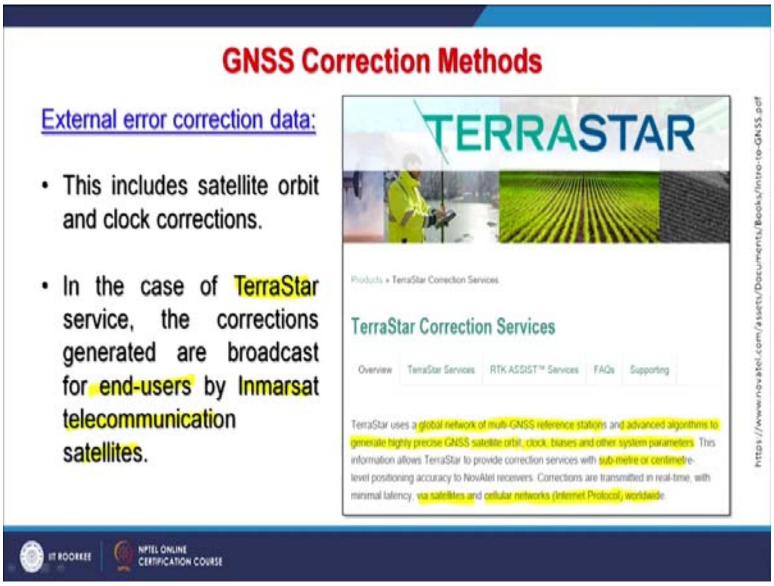

For example there is a company which provides the services which call is TerraStar service. So, these corrections are generated, broadcasted to the end users whoever subscribed to their services by Inmarsat telecommunication satellites. For example that TerraStar service and they are having a global network of multiple GNSS Reference Stations and having advanced algorithms to generate highly precise GNSS satellite orbit, clock biases and other system parameters. And this information then allowed this TerraStar service to provide correction services worldwide and a single receiver can give the position even into centimetres accuracy. Also if there is no geostationary satellite over that part of the world then these services can also be either provided through the cellular networks, through internet protocols and this service is available worldwide.

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And this is one of the examples from that same company TerraStar services. This is the coverage map, it is not complete world but let us focus over India. So, this is the geostationary satellite which is covering a large part of India and subcontinent where this service is available and it is very easy to identify which satellite is geostationary; generally they are all along the equator as you can see here.

So, there are various satellites covering various parts of the earth. Over India, we are having this IOR and which provides a services through subscription by this TerraStar coverage. So, likewise we can get a Highly Precise Point Positioning. Now of course, this tropospheric delays and ionospheric delays are there. So then modeling part is also there.

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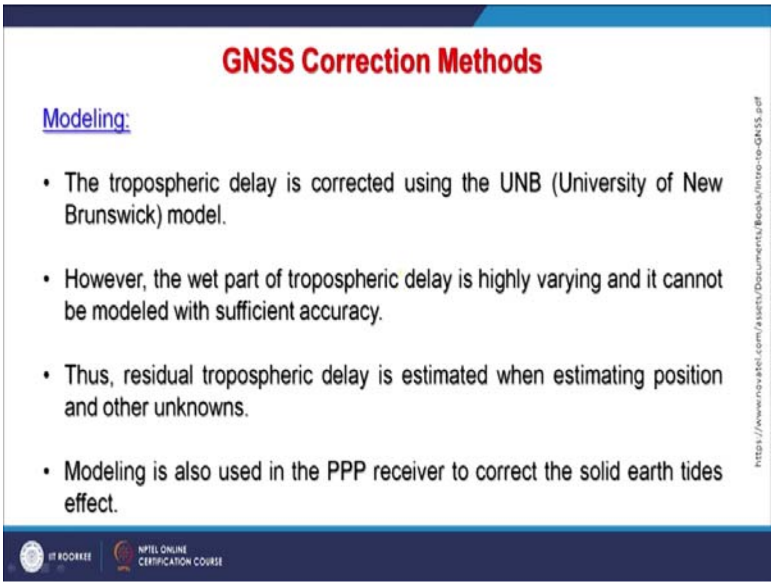

So, tropospheric delay is corrected using UNB; University of New Brunswick model. Generally this is the model people are using and however, the wet part where moisture is high of troposphere delays because of clouds and other. It is highly varying because you know the cloud keep changing and it cannot be modeled with sufficient accuracy.

So, that much inaccuracy will be there. However, this residual tropospheric delay which is caused by this wet part or clouds can be estimated when estimating position and other unknowns. And the modeling is also used in PPP receivers to correct the solid earth tides effect. So, that part is also corrected. Now there are filters which we can employ, of course they will make corrections uniformly.

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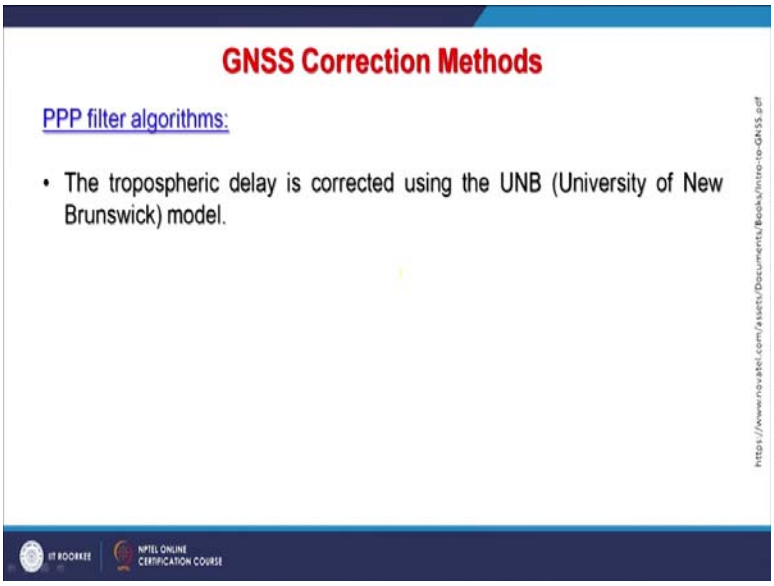

But this is how one way of doing this thing that filters are there that tropospheric delay is corrected using these filters.

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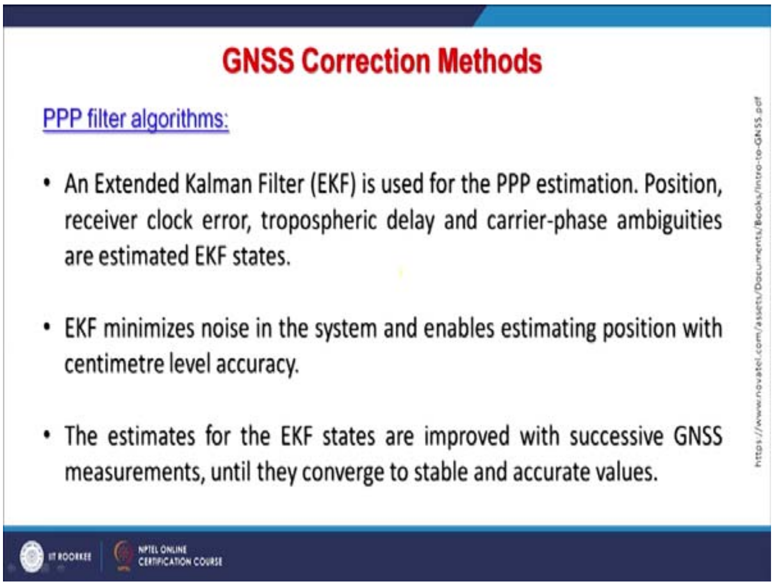

The filters are the Extended Kalman Filter which is used for PPP estimation and the position, receiver clock error, the tropospheric delay and carrier-phase ambiguities are estimated using this EKF states.

And this EKF filter minimizes noise in the system and enables estimating position with centimetre level of accuracy and these estimates of through this Extended Kalman Filter states are improved with the successive GNSS measurements until they converge to stable and accurate values.

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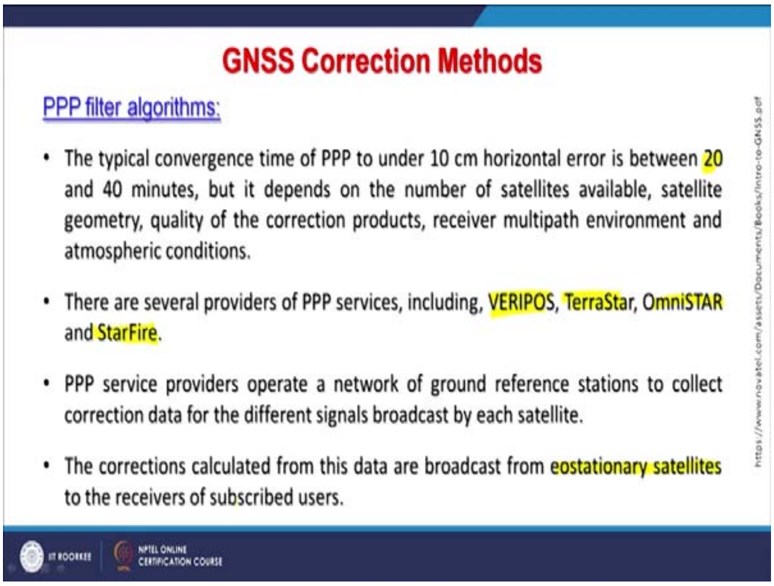

And the typical convergence time of PPP to under 10 centimetre horizontal error is between 20 to 40 minutes but it depends on the number of satellites available.

This condition is always prevailing in all scenarios that if less number of satellites are available from multiple GNSS systems then of course, it is going to affect the accuracy. So, here also it depends on the number of satellites available, how they are distributed in the space, GDOP; Geometric Dilution of Precision that is satellite geometry, quality of correction products, how the corrections are being performed, the receiver multipath environment, whether the signals are being received by the receiver directly from these GNSS satellites or through reflection; after the reflection may be through mountain or a building or any other physical object and depend also on the atmospheric conditions.

So, there are several providers of PPP services; we have already discussed that TerraStar. There are others like VERIPOS, OmniSTAR and StarFire and many more are also coming there because there is lot of demand for high precision data or Point Positioning Services. For that people are developing and of course, they are using also. And these PPP service providers operate a network of Ground Reference Stations in case of TerraStar, we have seen and to collect for the correction data, for the different signal broadcasted by these satellites and the corrections calculated from this data are broadcasted from geostationary satellite and to the receiver by subscribed users.

So, that means the service is not free. The SBAS service may be free but this PPP service is not free. Now it is also one possibility like in DGNSS or Differential Positioning Service where people go for post processing, here also the GNSS data post processing is possible.

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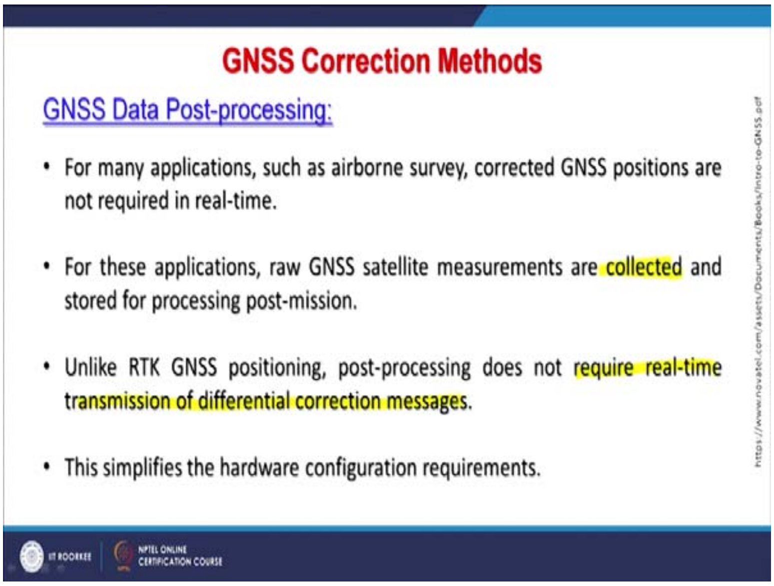

For many applications like for example, airborne survey corrected GNSS positions are not required in real-time. There can be many other services apart from this airborne service where real-time corrections are not required; means when the survey is being done either in the field or in the air then it is not necessary that at that moment I require the precise service.

However later on, through post processing methods, the same data can be collected we will be sing that scenario also. So, for such application which does not require a real-time correction, the raw GNSS satellite measurements are collected or recorded and then stored for post processing. And unlike RTK in a Real-Time Kinematic GNSS positioning, post processing does not require real-time transmission of differential correction message.

This process can be done little later and this simplifies the hardware configuration requirements because if one go for real-time or SBAS or any other thing or PPP then you have to have a dual frequency receiver or if we go for differential GNSS then again you have to have one Base, one Roving but in case of this post processing based GNSS correction, only the recording is required and later on through the software and using the data of Base Station, it can be done and therefore, it is cost effective in some cases where real-time data is not required.

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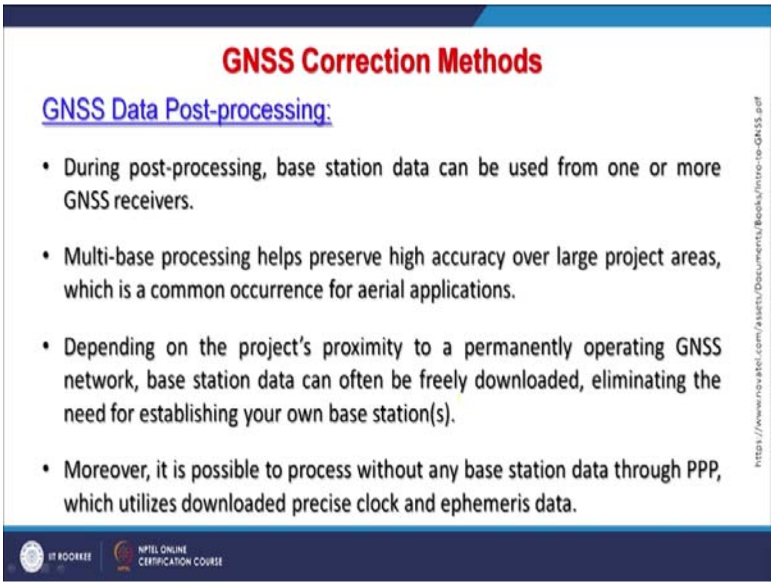

And during this post processing, the Base Station data can be used from one or more GNSS receivers. So, if there are more receivers which were involved in the surveying, all those receivers can use the Base Station data and corrections can be performed to achieve a better accuracy later on. Now multi based processing helps which preserves the high accuracy over a large project area which is a common occurrence for aerial applications.

There are various geophysical or aerial photography or LADAR where aircrafts are used and airborne instruments are used, for that this can be very useful. So, depending on the basically projects proximity to a permanently operating GNSS network, Base Station data can often be freely downloaded, eliminating the need for establishing your own Base Station or network. So, that makes this whole operation very cost effective if real-time corrections are not required.

Moreover it is possible to process without any Base Station data through PPP which utilize a downloaded precise clock and ephemeris data. So, there are other possibilities which can also be used for this one.

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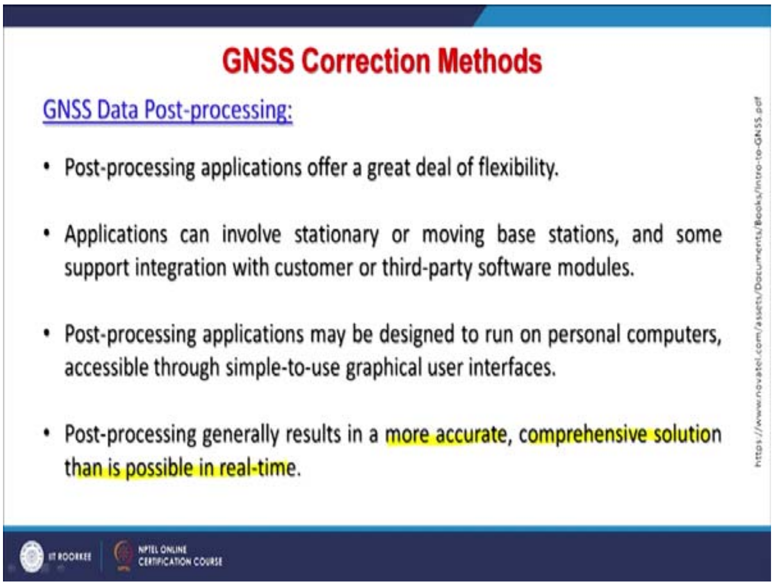

Now post-processing applications offer a great deal of flexibility because at that moment of time when survey is being done, you do not require the Highly Precise Positioning data. So, once that requirement is gone then lots of new possibilities are there and which involves the stationary or moving Base Stations and some support integration with the customer or third-party software modules. And post-processing applications may be designed to run on personal computers.

It is not necessary that a high end workstation is required all the time. If the area is not big and accessible through simple-to-use GUI; graphical user interface. And post-processing generally results in a more accurate and comprehensive solution which may not be possible sometimes in real-time.

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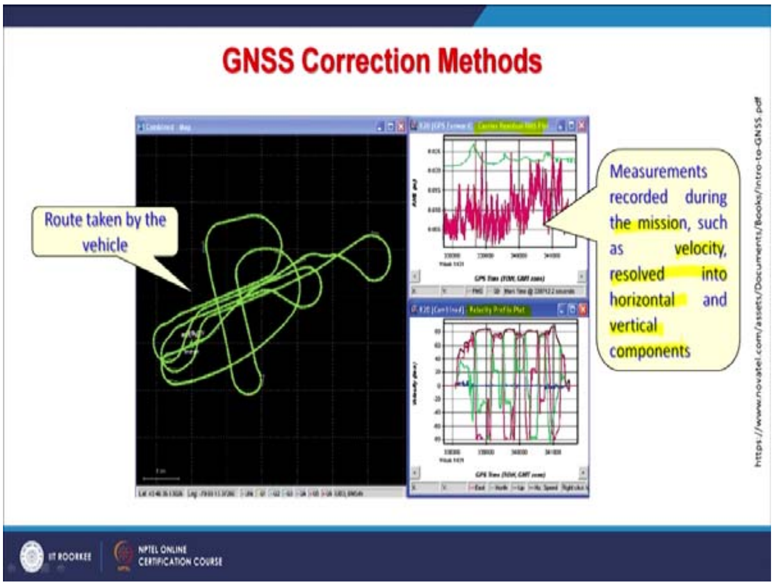

So, this is one of the examples that when survey was being done, this is how the track has been recorded and then the route taken by a vehicle or in air survey, a sortie have been recorded like this and later on through post-processing, one can make corrections and can make the data more accurate here.

So, this is a carrier residual which we see here, route mean square plot and this is velocity profile plot because when a vehicle is moving or aircraft is moving may not be all the time moving in the same speed or same velocity. So, the velocity also changes and therefore, everything is recorded and later on corrections can be performed and high accuracy can be achieved.

So, measurements recorded during the mission such as the velocity which resolves into the horizontal and vertical components because if ups and downs are there then those things are also recorded and later on connections can be performed. Now basically there can be a question that which option one should go?

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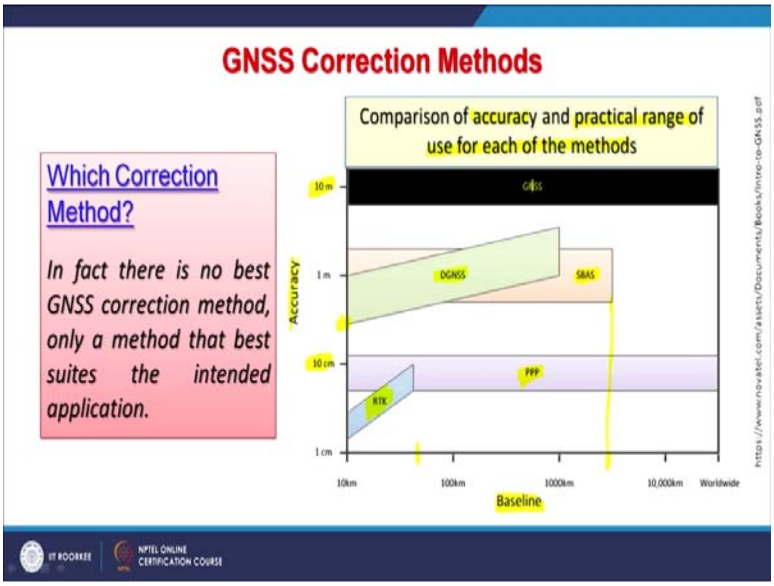

So, there is no straightforward answer to this question that which is the best GNSS correction method; various options are available. It depends basically for which application I am looking for.

So, this is basically application dependent correction methods are available. If application requires real-time corrections then few methods are available. If application does not require the real-time corrections then some methods are available. So, if we see this is the comparison between accuracy and practical range of use of each of these matters. So, if I do not use any correction method, simple GNSS system then I am having accuracy of 10 meter which in this case and then if I am using the PPP that is Point Positioning Service then I may be having accuracy of 10 centimetres.

But in real-time, sometimes I may get accuracy even less than 10 centimetres. So, that is one very good option is available but same time if you see the baseline then in RTK, the baseline has to be very small means the rover receiver and stationary receiver has to be very close by as in this example that maximum it is shown up to say 80 kilometres but in case of DGNSS that is Differential GNSS and SBAS, the scenario is almost same that SBAS may provide accuracy of about 1 to 3 metres and same with the DGNSS and may be from 50 centimetres to 1 metre but the baseline option is much more available.

That in case of SBAS, you can see that it is about say roughly 5,000 kilometres or 4,000 kilometres that baseline is available because it is basically again based on the geostationary satellite. So, basically there cannot be a direct answer that which is the best GNSS correction method. However, as mentioned earlier that depends on project application and requirements. If real-time and very highly precise positioning is required then RTK is one of the options, PPP can also be options but if that project or application does not require that accuracy as RTK can provide.

Otherwise SBAS and DGNSS because the baseline is very large there and if one can be happy with 10 metres accuracy then simple single GNSS receiver can help that one. Even sometimes in open areas, the simple single handled GNSS receivers even based on smartphone can provide accuracy of 3 metres so that is the best part. Now we will be comparing between different possibilities that DGNSS and RTK first and then later on with other options also.

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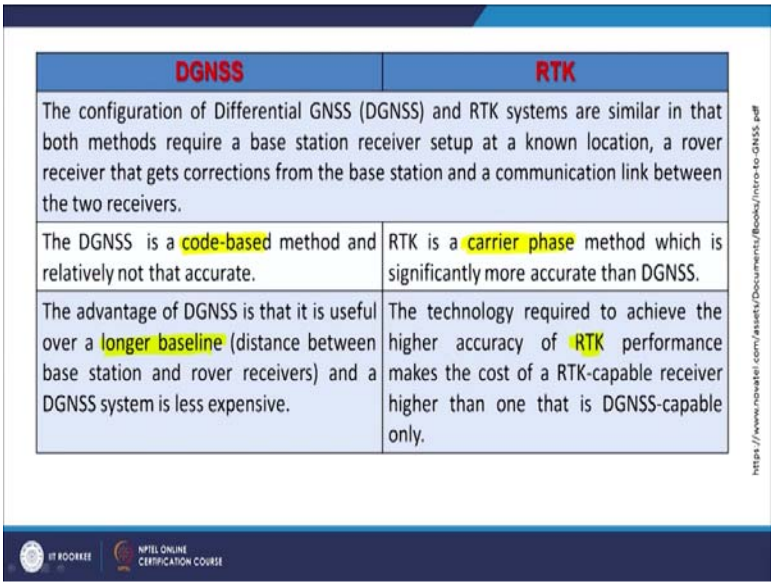

DGNSS	RTK
The configuration of Differential GNSS (DGNSS) and RTK systems are similar in that both methods require a base station receiver setup at a known location, a rover receiver that gets corrections from the base station and a communication link between the two receivers.	
The DGNSS is a code-based method and relatively not that accurate.	RTK is a carrier phase method which is significantly more accurate than DGNSS.
The advantage of DGNSS is that it is useful over a longer baseline (distance between base station and rover receivers) and a DGNSS system is less expensive.	The technology required to achieve the higher accuracy of RTK performance makes the cost of a RTK-capable receiver higher than one that is DGNSS-capable only.

So, the configuration in DGNSS and RTK is almost similar that the both methods require a Base Station receiver, setup at a known location or a location can be made known by collecting data for few weeks or a months and the rover receiver that gets corrections from base station and a communication link between the 2 receivers. So, in that case there is no difference between GNSS and RTK. However, the difference is starts because as you know that the DGNSS method is code-based whereas your RTK method is carrier-phase. So, that is the major difference between these two.

The advantage with the DGNSS; it is a useful over a longer base line as also in the previous diagram we have realized that DGNSS provides a long baseline whereas RTK provides relatively a very small base line. In all options, RTK anyway provides the minimum baseline distance between the Base Station and your roving receiver. So, this is the major difference between GNSS and RTK.

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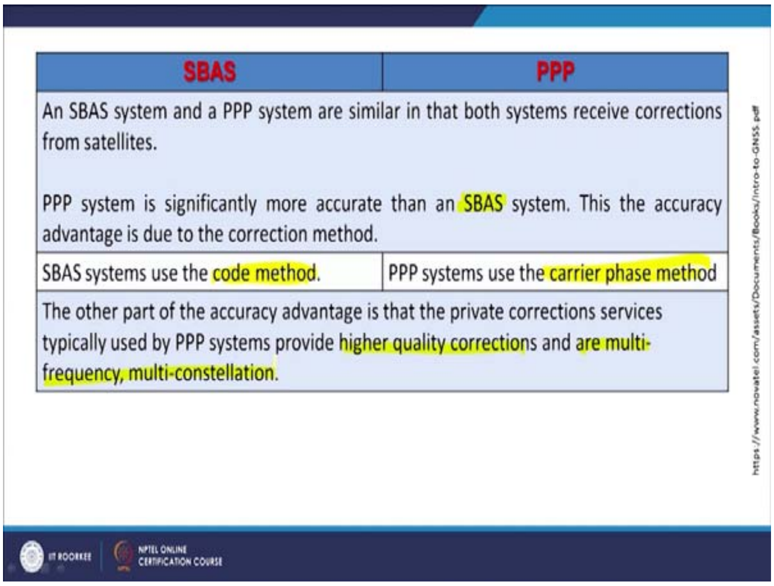

If we compare SBAS which is Satellite Based Augmentation System and this Precise Point Positioning System service then in SBAS system and a PPS system are similar; in both systems receive corrections from satellites. Maybe satellites or here we can also add through mobile network or internet and this PPP system is significantly more accurate as we have also seen when we were comparing the data through a diagram that it is definitely better than SBAS system, your PPP system and this accuracy advantage is due to the correction method.

So, though the hardware point of view is almost same but correction methods may be different and therefore, we are getting much better accuracy position estimates through PPP. SBAS systems use code method whereas your PPP use the carrier phase method. So, the same difference as in DGNSS and RTK and there are other part of accuracy advantage is that which are the common with SBAS and PPP that the private correction service is typically use PPP systems provide high quality corrections and are multi-frequency, multi-constellation.

You know that today is the trend is whoever is developing receiver or doing any survey, everyone is looking data from multi-constellations or multi GNSS systems and why not, when there is such options are available, one should definitely will use.

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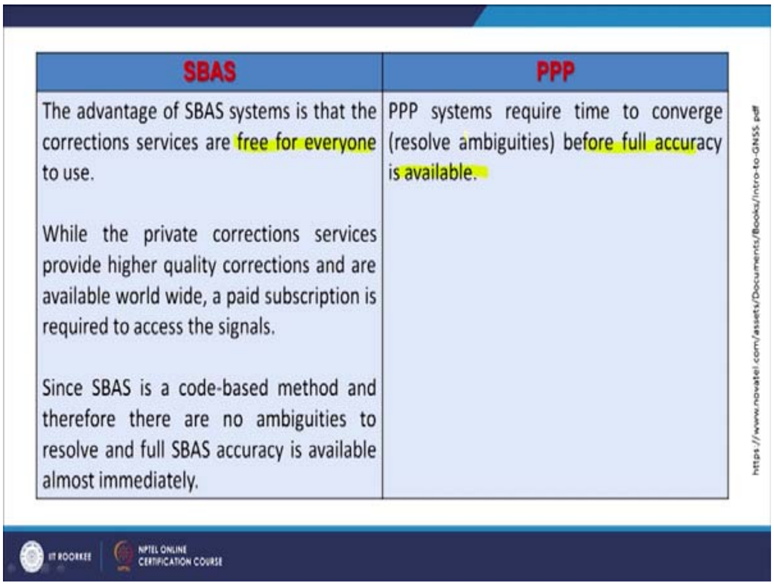

Further the advantage of SBAS system is that correction services are free for everyone whereas, PPP service; this is available only through subscription. So, one has to pay and some subscription to get this PPP service.

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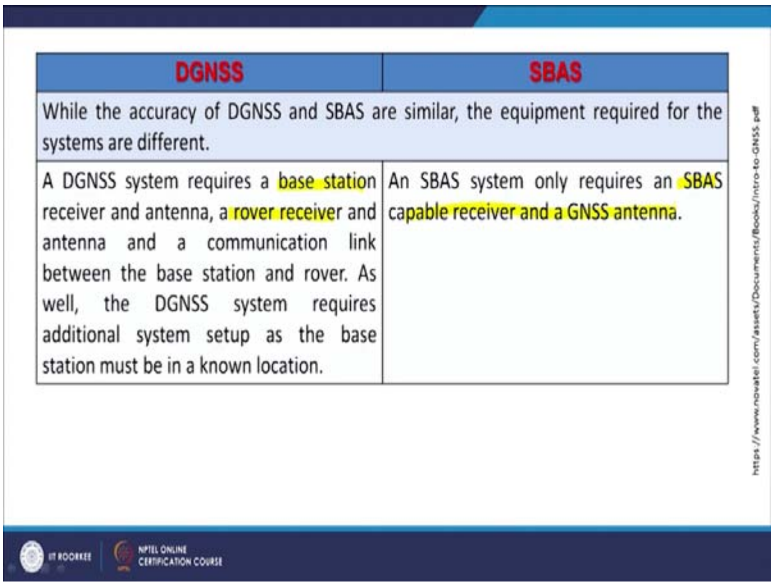

Now, DGNSS and SBAS; when we compare Differential GNSS and SBAS then while the accuracy of DGNSS are almost similar but anyway SBAS provides better than DGNSS. The equipment required for systems are different because in DGNSS requires a Base Station, antenna and rover stations and in case of SBAS only requires a SBAS capable receiver and a GNSS. So, may be a dual frequency single receiver can give you higher accuracy of a few centimetres whereas, DGNSS can also provide accuracy and to that extent.

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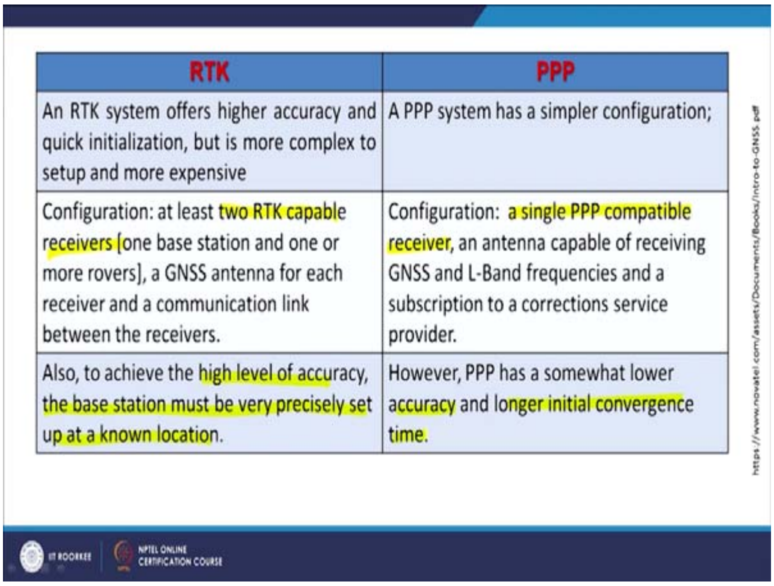

RTK	PPP
An RTK system offers higher accuracy and quick initialization, but is more complex to setup and more expensive	A PPP system has a simpler configuration;
Configuration: at least two RTK capable receivers [one base station and one or more rovers], a GNSS antenna for each receiver and a communication link between the receivers.	Configuration: a single PPP compatible receiver, an antenna capable of receiving GNSS and L-Band frequencies and a subscription to a corrections service provider.
Also, to achieve the high level of accuracy, the base station must be very precisely set up at a known location.	However, PPP has a somewhat lower accuracy and longer initial convergence time.

Now, when we compare the RTK that Real-Time Kinematic option and PPP then a Real-Time system offers again high accuracy that is the best accuracy available but it is expensive option. PPP system has a simpler configuration, single receiver system and of course dual frequency and configuration at least 2 RTK capable receivers; here only single PPP compatible receiver. So, that is makes a major difference in the cost also and also achieve high level of accuracy when the base station must be precisely set as known location.

One major difference also here between RTK and PPP is the baseline difference; here in RTK, the baseline has to be very small compared to PPP and as one example we have seen where globally this service is being provided by few companies. So, there is no limitation of basically baseline because the PPP corrections are being provided through geostationary satellites or maybe through internet.

So however, the PPP is somewhat lower accuracy, longer initial convergence time.

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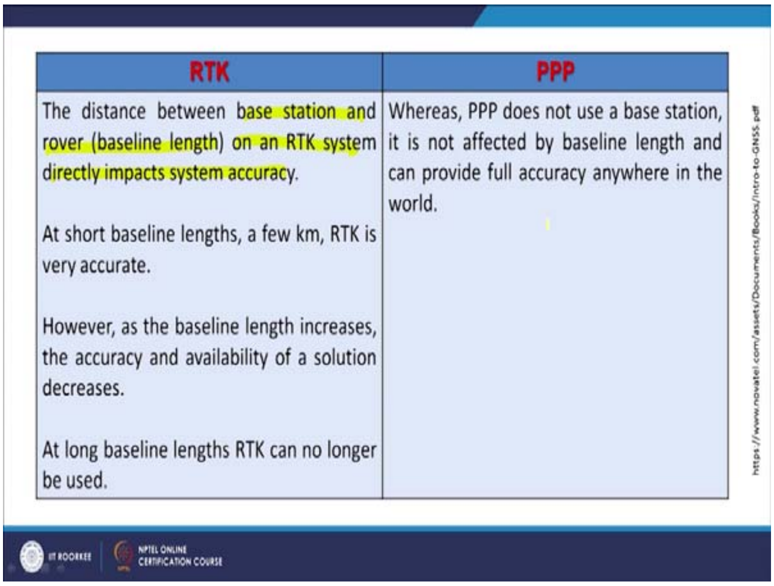

So, the RTK definitely is much better and when we go further on this that the distance between as we have already discussed that rover station; it is very limited in that compared to PPP because there is no concept of base station. The service provider or the correction provided, they might be having their own Reference Stations to provide you corrections through satellite.

So, this brings to the end of this discussion about all possible correction methods. We have discussed starting from Differential and then RTK then SBAS and then finally, we ended up with this PPP. So, basically ends this discussion on the errors part and how these errors can be corrected and how a better accuracy and position estimates can be achieved. So, this brings to the end of this discussion and as usual I am leaving with a cartoon to a smile.

Thank you very much.