Advanced 3G and 4G Wireless Communication

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Lecture - 37
Hata Model and Log Normal Shadowing

Hello, welcome to another lecture in the course on 3G, 4G wireless communication systems. In the last lecture, we had completed our discussion on the ground model ground reflection model for wireless signal propagation.

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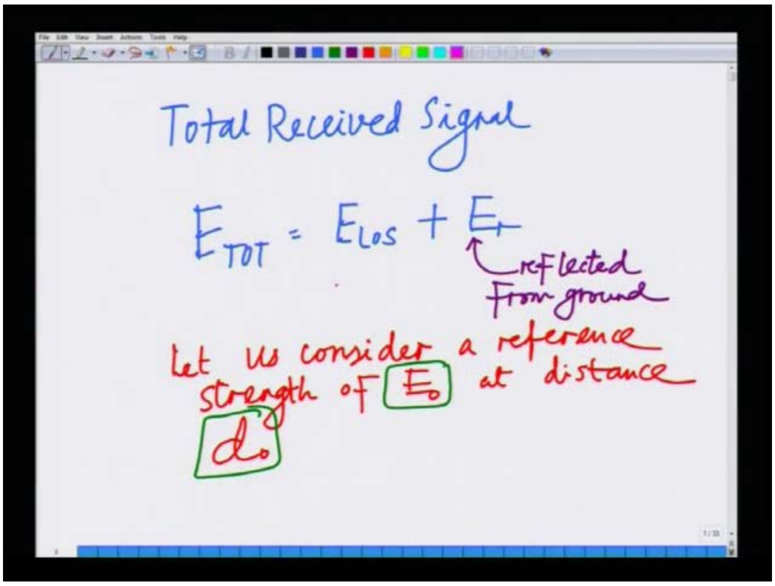

We said in the ground reflection model, I have a total received signal field strength which is given as some of the line of sight or the direct component plus the reflected component E r.

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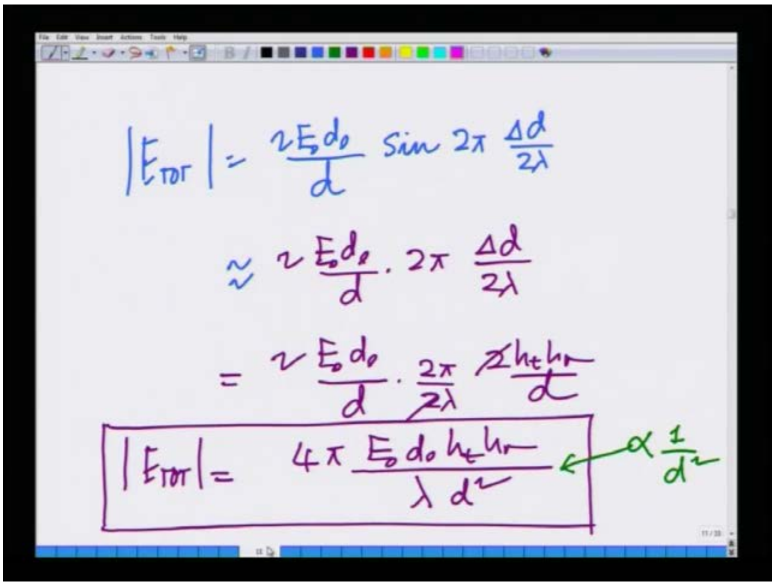

Further, we said that in this ground reflection component, the received field strength is proportional to 1 over d square hence the total received power is proportional to 1 over d to the power of 4. That means the power decays as the fourth power of distance hence the path loss exponent is nothing but 4.

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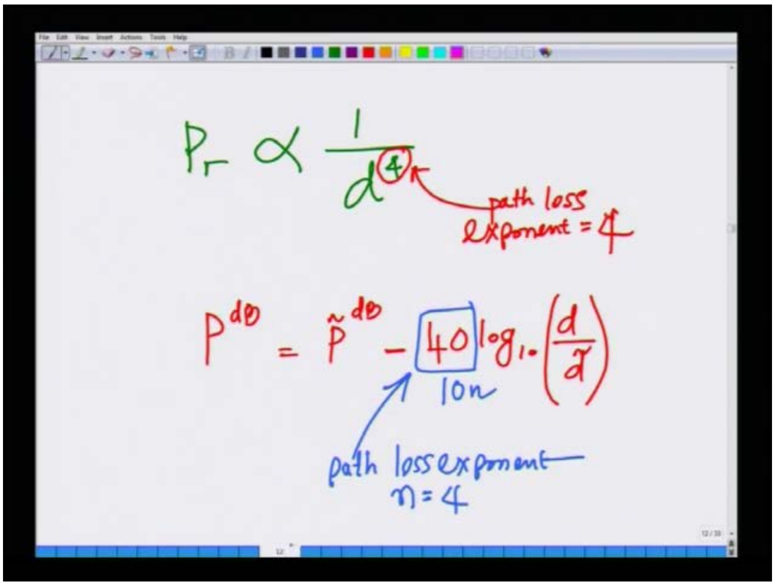

Hence, the received power in dB is p tilda the reference minus forty log d over d tilde that is a path loss exponent of 4. Hence, there is a path loss of 40 dB per 40 d tilda, hence there is a loss of this thing, it decays as 40.

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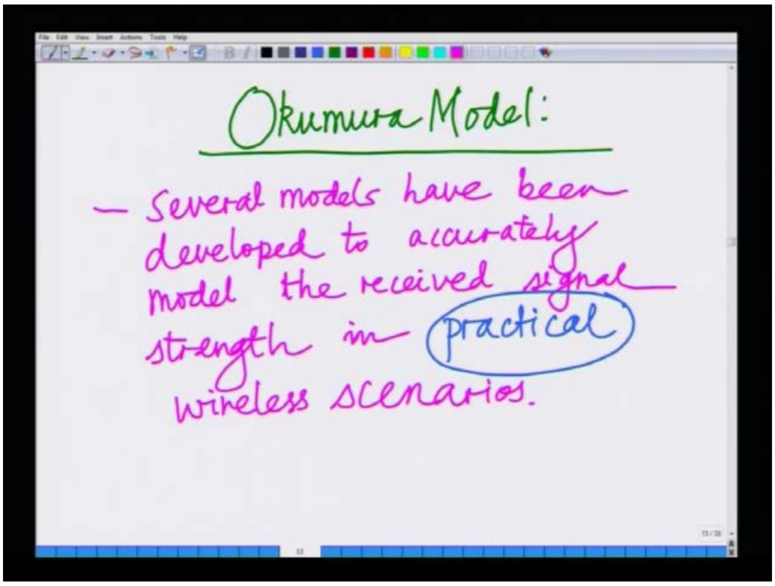

Essentially, the other thing that we started looking at is we started looking at the Okumura model for wireless communication we said that in a practical scenario. In a practical wireless channel propagation scenario, we want to consider a model which gives you a signal strength as a function of distance. This Okumura model is one such practical model which is applicable in practical scenarios that is with to accurately model the received signal strength as a function of the distance.

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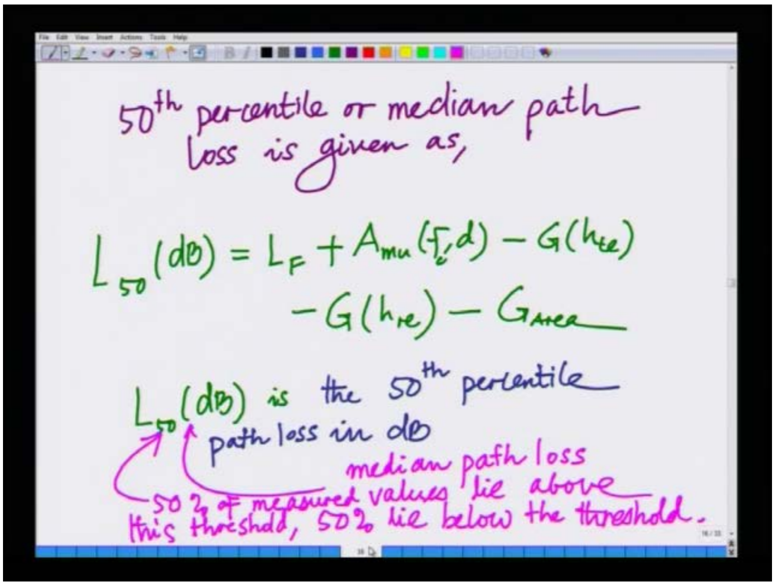

We said that in the Okumura model the fiftieth percentile path loss that is L 50 in dB is given as L f the free space path loss plus a mu which is a correction factor which is a function of the carrier frequency. The distance minus g h which is a gain factor that is you are you are subtracting from the loss this gain is arising because of the height of the transmit antenna another gain which is arising. The height of the receive antenna minus g area which is essentially the area gain factor. As you move from an urban to a sub urban to open area there is less clutter which means there is a net reduction in the loss hence there is a gain factor which subtracts from the from the fiftieth percentile path loss.

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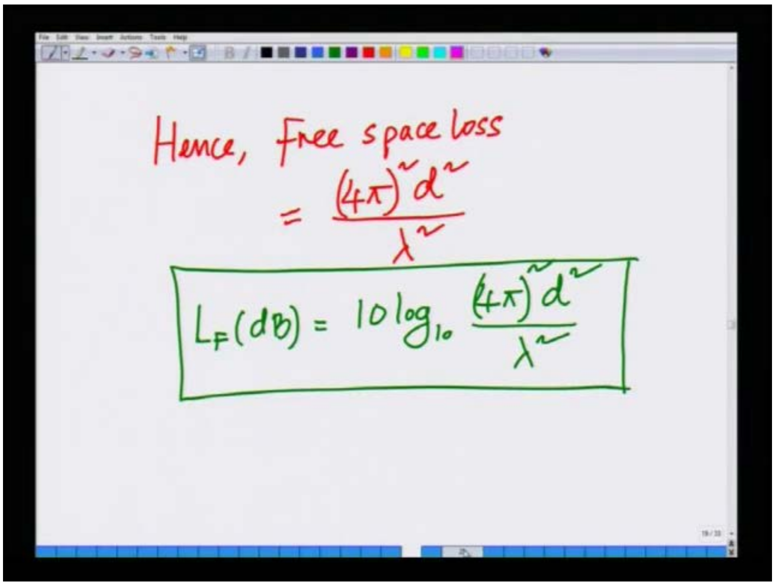

We said we looked at the different expressions; we looked at the expressions for the free space path loss we looked at the expressions for transmit and receive antenna height gain factors. Then, we have also looked at the charts which give us this a mu correction factor and then we also looked at this G chart which gives us the G area factor and then we started looking at a comprehensive example.

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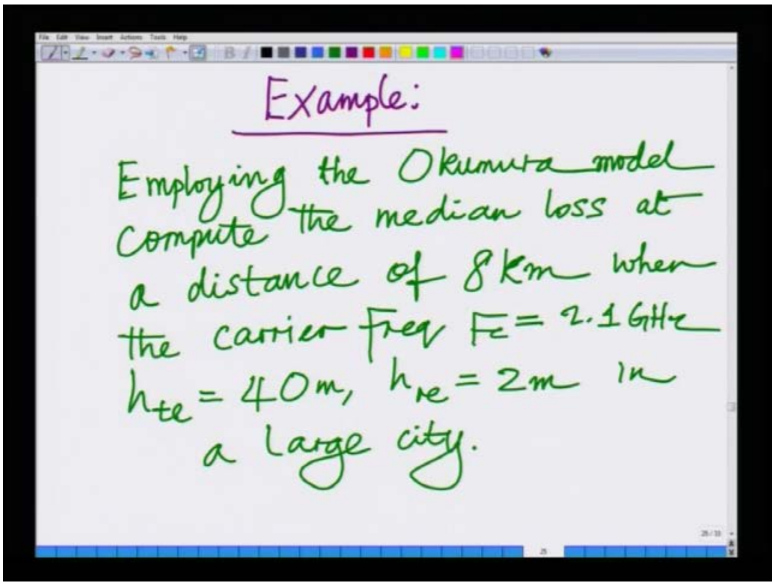

We wanted to use the Okumura model to characterize the median path loss at a distance of eight kilometers when the carrier frequency F c is 2.1 Giga Hertz h t is 40 meters h r e receive antenna height is 10 meters. We are considering a large city environment that is we want look at this example in a large city environment to essentially consider what the received signal strength as a function of the distance is.

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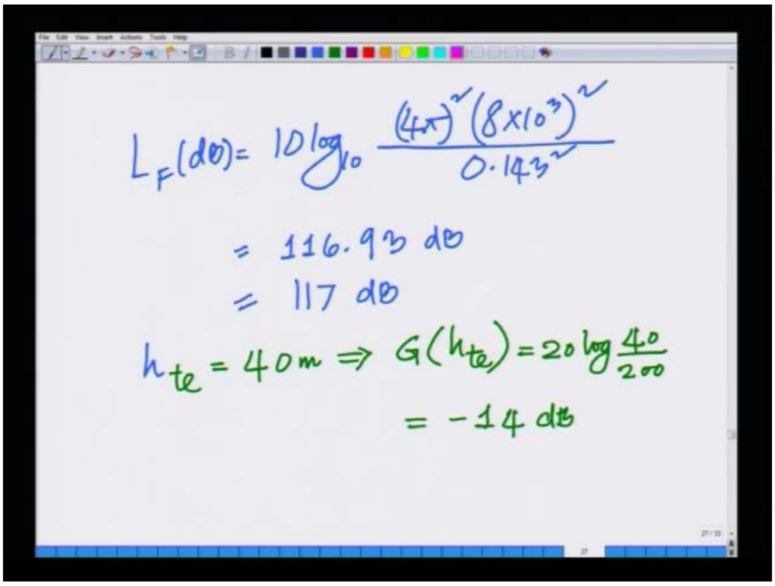

As part of it we had looked at the free space loss we said the free space loss is 117 dB. The transmit antenna height is minus the transmit antenna height gain factor because of its height 40 meters is minus 14 dB and let us start from this point and continue with this lecture.

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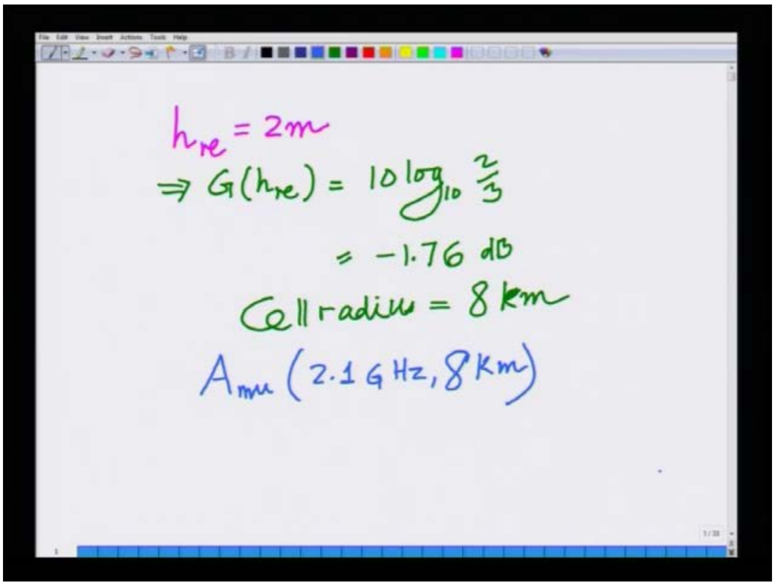

So, we want to next thing we want to compute is the receive antenna gain factor we have the receive antenna gain height equals 2 meters hence the receive antenna gain factor g h r e equals n log 10 2 by 3 equals minus 1.76 dB. So, the receive antenna gain factor that is minus 1.76 dB corresponding to a height of at receive antenna height of 2 meters. So, let us now look at the next factor which is essentially wanted to compute the mu factor that is the correction factor. Let us look at a we said that the cell radius equals 8 kilometers, hence we want to compute the a mu factor at 2.1 Giga Hertz and 8 kilometers, for that purpose we have to look at the chart related to the Okumura model.

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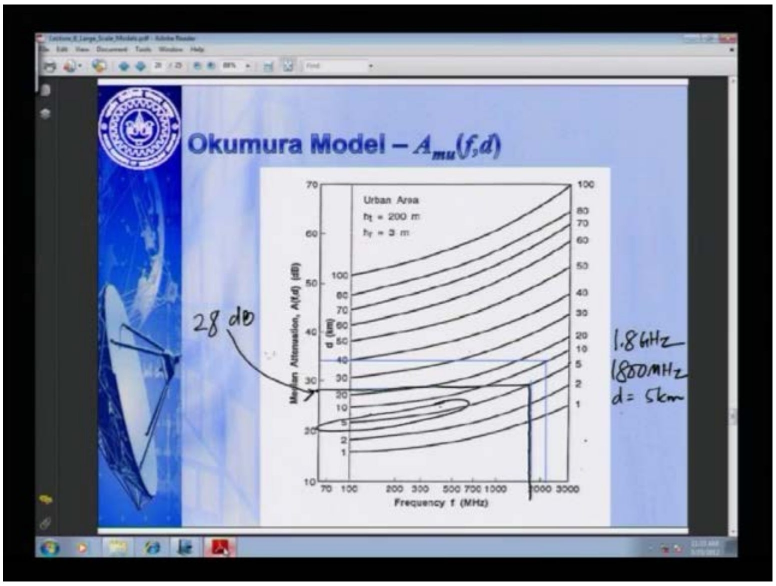

Let us go and look at the chart that is related to the Okumura model at 2.1 Giga Hertz, if you look at 2.1 Giga Hertz and I approximate the distance of 8 kilometers, I am approximating this. So, I go to this chart for the mu correction factor and I look at the carrier frequency corresponding to 2.1 Giga Hertz. I am approximating since I do not have any curve for 8 kilometers, I am approximately using the curve for 10 kilometers. Hence, I look at of the 10 kilometer curve, I look at approximately 2.1 Giga Hertz and I see that that factor a mu f d is essentially 34 instead of free, approximately 34 dB.

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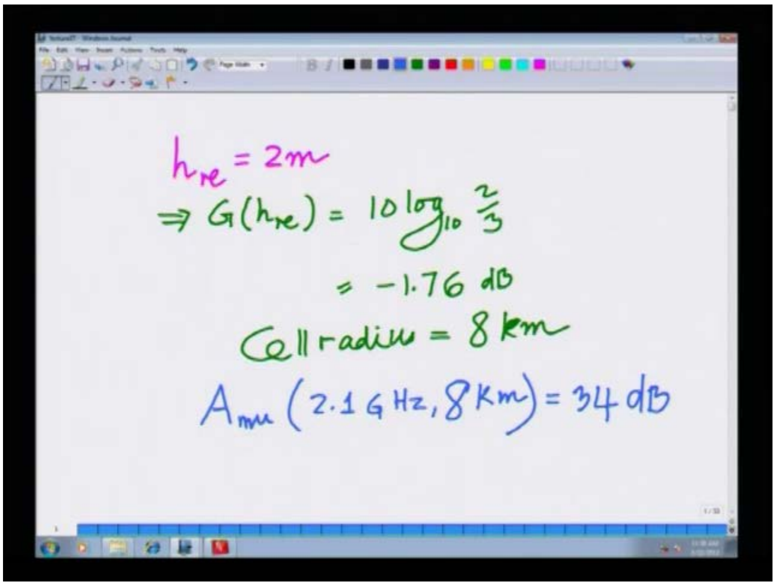

Hence, what we can say is if you look at this, if you go back to this, this a mu factor corresponding to 2.1 Giga Hertz and 8 kilometers from the Okumura model that is approximately equal to 34 dB. So, this mu factor from to corresponding to 2.1 Giga Hertz and eight kilometers that is equal to 34 dB. Hence, essentially one can put all these things together hence putting all these things together further since the environment is urban. Remember, we are considering an urban environment that is a large city environment hence the g area factor that is 0 because the g area factor is only positive only for sub urban or quasi open areas.

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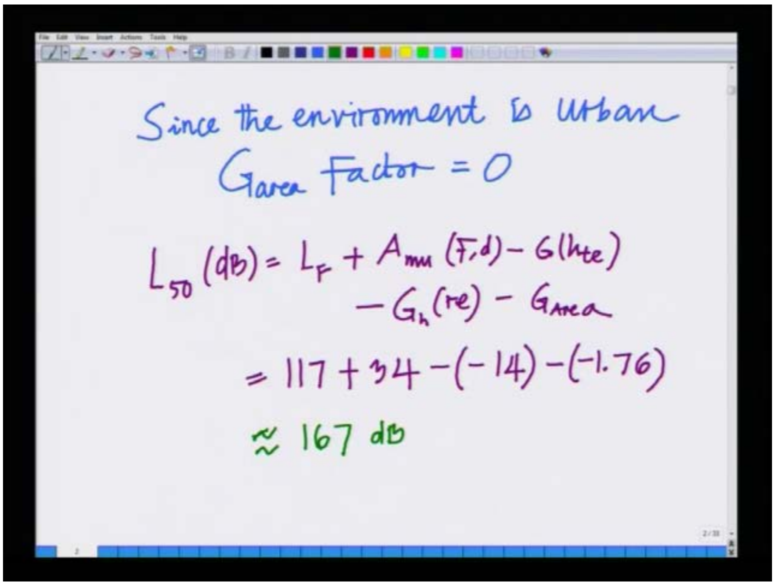

That is since that is since, we are considering an urban environment the g area factor is 0. Since the environment is urban the G area factor is 0, since the environment is urban the g area factor is 0. Hence, we have now all the components that we need to put together to compute the path loss the fiftieth percentile path loss. If the fiftieth percentile path loss in the Okumura model l fifty in dB is nothing but the free space path loss plus a mu factor f of d minus g h t e minus g h r e plus g minus g area.

This is nothing but the free space path loss which is 117 dB minus plus a mu which is essentially 34 dB minus the transmit antenna gain factor which is minus of 14 dB minus 1.76 dB and that you can put together that is approximately equal to 167 dB. Hence, we have computed the Okumura path loss for the for the Okumura model corresponding to the model in 2.1 carrier frequency 2.1 Giga Hertz and 8 kilometers in a large city for a transmit antenna at 40 meters and receive antenna at 2 meters. We found out that the path loss in practical scenario is given by 167 dB that is what the path loss that we get from the Okumura model.

Hence, this shows us in practical scenarios to essentially reach the receiver or the mobile user at a distance of 8 kilometers you have to essentially account for this path loss. So, the transmit power has to transmit higher of power, so that after the path loss is removed you have enough power remaining for the decoding at the receiver.

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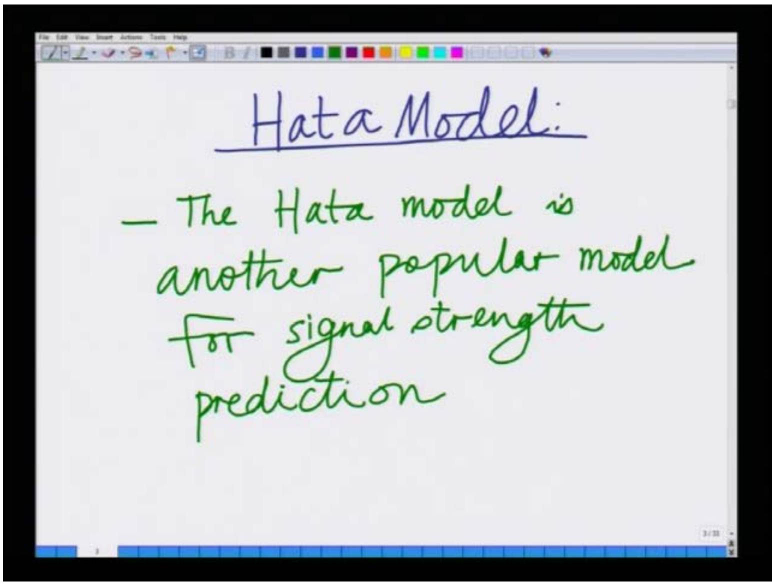

So, this path loss has to be accounted, so the transmit power has to be essentially increased to compensate for this path loss that is the help or that is essentially the purpose of all these path loss model. There is another popular path loss model which we will also discussed, and which is also again relevant for practical scenarios and this model is known as the Hata model. This is the Hata model for propagation and this so the Hata model is another popular model for signal strength prediction, so this is the Hata model the Hata model is another popular model for signal strength prediction especially in cellular scenarios.

So, this Hata model similar to the Okumura model, this Hata model can also be employed for essentially signal strength prediction in cellular scenarios and the advent the essential reason or the essential motivation for the Hata model. It presents an analytical formulation for the graphical models or for the plots and so on the graphical information that is embodied in the Hata model. Remember, in the Hata in the Okumura model we look at a lot of these plots to derive the a mu factor and the g area factor and so on those have now been essentially simplified in to analytical expressions.

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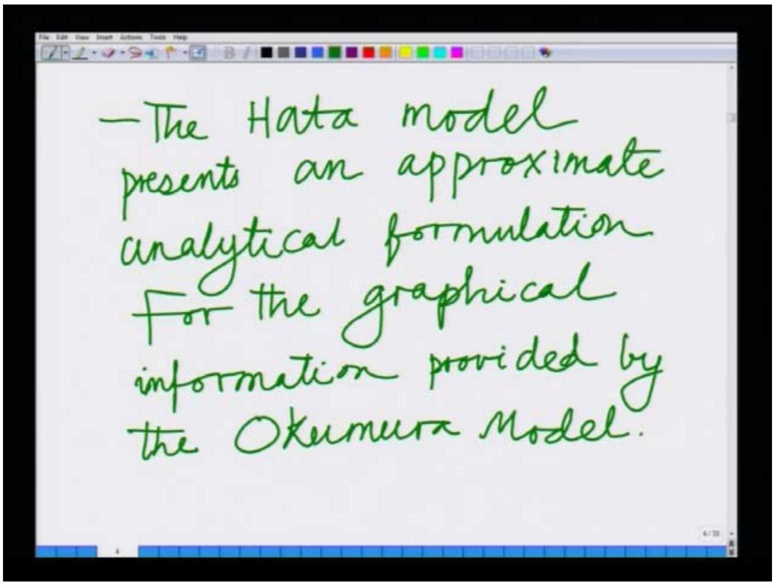

So, you can one can compute the received path loss without the received path the loss at a certain distance without the aid of some of those plots and that is essentially the advantage of the Hata model. So, the Hata model essentially it provides an analytical formulation for the graphical information that is given by the Okumura model. So, the Hata model presents an approximate it presents an approximate analytical it presents an approximate analytical formulation.

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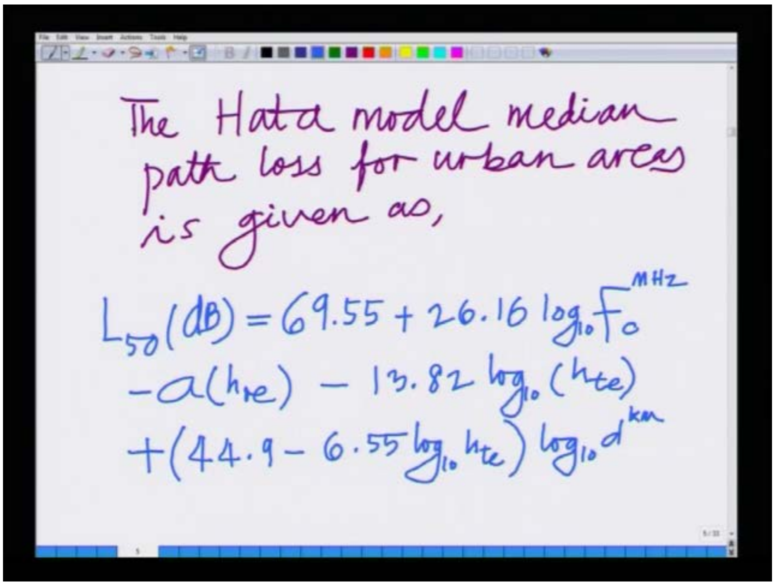

For the graphical information for the graphical information provided by the Okumura model, so what is the Hata model, Hata model essentially is an analytical approximation of the Okumura model. That is what the Hata model is and employing the Hata model the median path loss the expression for median path loss for urban areas in the Hata model is given as follows the Hata model median path loss for urban areas is given as the median path loss.

Again, similar to what we had in the Okumura model the median path loss l 50 dB is 69.55 plus 26.16 log 10 carrier frequencies in mega Hertz minus h r e. I am going to describe these terms shortly plus 44 plus another factor which is essentially minus 13.82 log 10 h t e plus another factor which is essentially 44.9 minus 6.55 log 10 h t e. Here, h t e is the transmit antenna height in to log 10 distance in kilometers, so this is the expression for the Okumura model. So, the Okumura model gives the fiftieth percentile path loss using this expression, let me define the different quantities.

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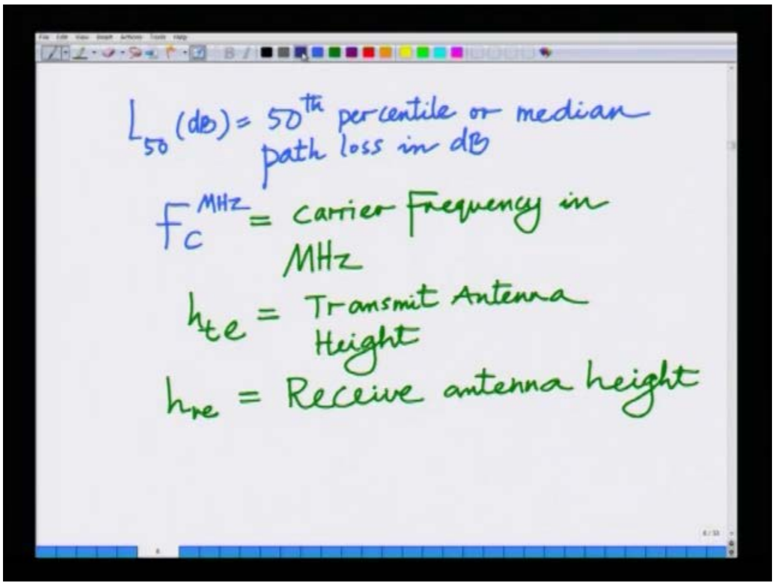

Here, L 50 dB equals the fiftieth percentile or the median, so L 50 similar to what we had seen earlier is a fiftieth percentile path loss or the median path loss in dB. So, this is a fiftieth percentile or median path loss in dB f c mega Hertz is nothing but the carrier frequency. It has to be given in mega Hertz this is equal to the carrier frequency in mega Hertz f c equals the carrier frequency in mega Hertz h t e equals the transmit antenna h t e equals the transmit antenna height h r e equals the h r e equals the receive antenna height.

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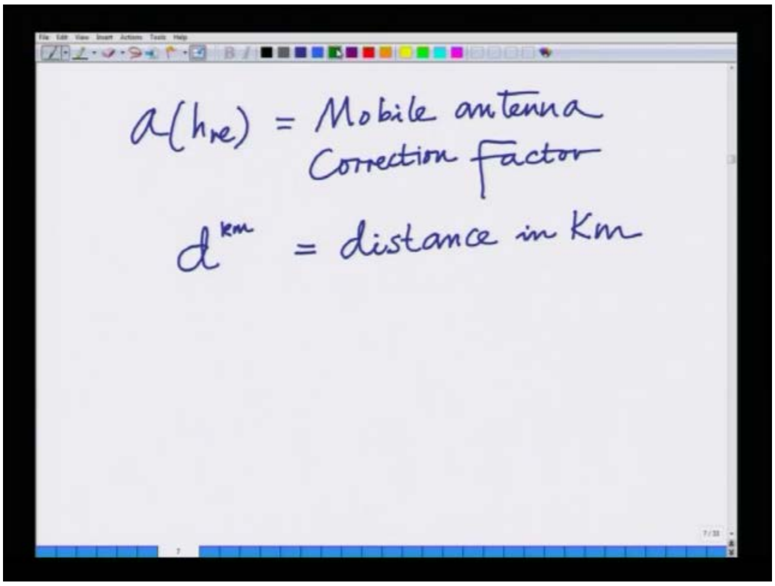

Here, a h r e is the mobile antenna correction factor the factor a h r e the factor a h r e is nothing but the mobile antenna correction factor d kilometers.

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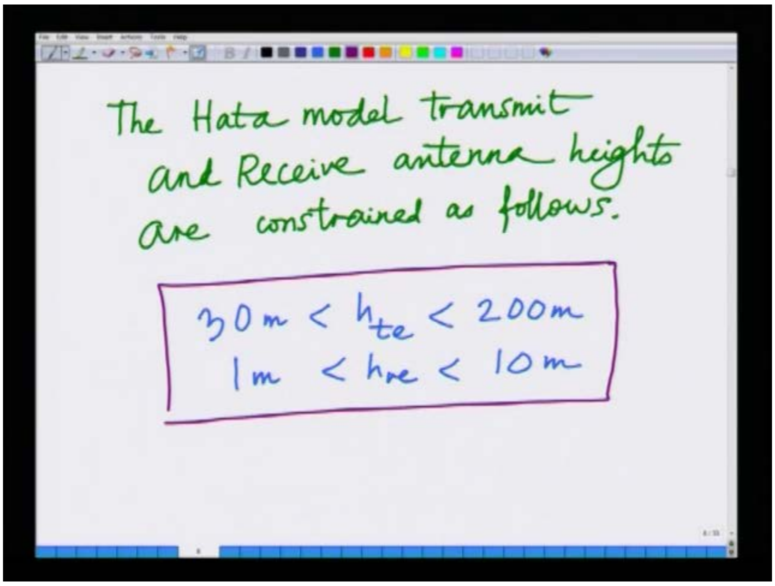

It is nothing but the that is the distance in kilometers the distance d is the distance however d kilometers is the distance it has to be given in kilometers. So, this distance has to be given in kilometers and transmit and receive antenna heights are constrained as follows the transmit the Hata model h t e h r e the transmit and receive antenna heights are constrained as follows the Hata model transmit. Receive antenna heights are the higher transmit and receive antenna heights in the Hata model are constrained as follows.

We have 30 meters less than h t e less than 200 meters and 1 meter less than h r e less than 10 meters. So, transmit and receive antenna heights are constrained to lie between 30 and 200 meters the transmit antenna height is constrained to lie between 30 and 200 meters. The receive antenna height is constrained to lie between 1 and 10 meters, these are the range of the different heights in the Hata model.

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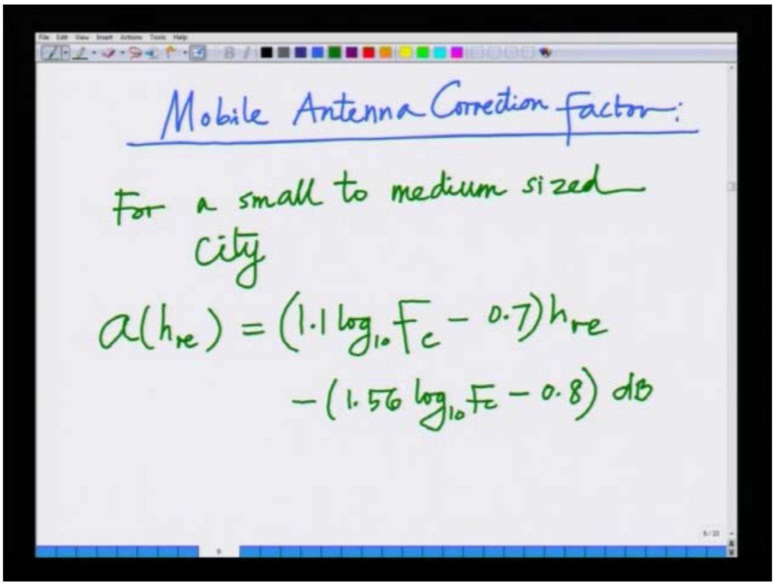

So, let us again now look at the correction factors remember we talked about this a h r e which is the mobile correction factor and that is given as follows. So, let us look at the mobile antenna the mobile antenna the mobile antenna correction factor that is nothing but, a h r e and that is two different expressions for a small to medium city. Then, for a large city so for a smalls for a small to medium size city for a small to medium sized city a h r e is given as 1.1 log 10 f c minus 0.7 into h r e minus 1.56 log 10 f c minus 0.8 dB.

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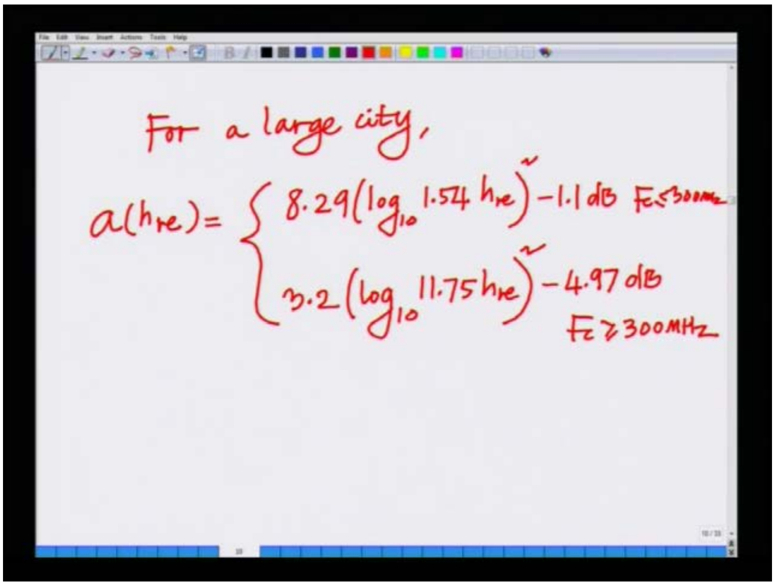

This is the expression for the mobile antenna correction factor for a small to medium size city that is 1.1 log 10 f c minus 0.7 whole in to a h r e minus 1.56 log 10 f c minus 0.8 dB and for a large city this correction factors are given as follows that is a h r e. Again, here we have two expressions for a large city 1 is 8.29 into log 10 1.54 h r e whole square minus 1.1 dB if f c less than or equal to 300 mega Hertz.

It can be 3.2 it is 3.2 log 10 11.75 h r e whole square minus 4.97 dB if f c is greater than equal to 300 mega Hertz. So, this antenna correction factor for a large city is equal to 8.29 log 10 to the base 10 1.5 for h r e whole square minus 1.1 dB if f c is than or equal to 300 mega Hertz it is equal to three 0.2 log 10 11.75 h r e whole square minus 4.97 b d if f c is greater than or equal to 300 mega Hertz.

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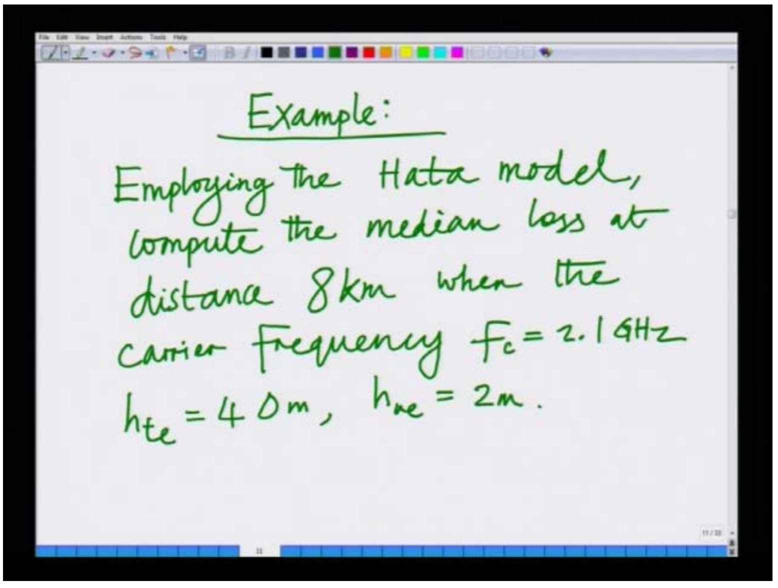

So, this is essentially Hata model which can essentially employee to characterize the path loss in an urban environment again similar to the Okumura model we can look at an example for this Hata model. Let us look at the same example that we have considered previously which is essentially employing the Hata model employing the Hata model compute the median loss compute the median loss at distance 8 kilometers at distance 8 kilometers.

When the carrier frequency when the carrier frequency f c equals 2.1 Giga Hertz and h t e equals 40 meters and h r e equals 2 meters. We are trying to again compute the similar thing that is we are consider a cell radius of 8 kilometers and when the carrier frequency is 2.1 Giga Hertz. The Transmitter height is 40 meters and the receiver height is 2 meters we are again trying to compute this received signal strength at this L h, but using the Hata model. So, that is what we are trying to use so use the using the Hata model, first we have to convert the frequency in to mega Hertz.

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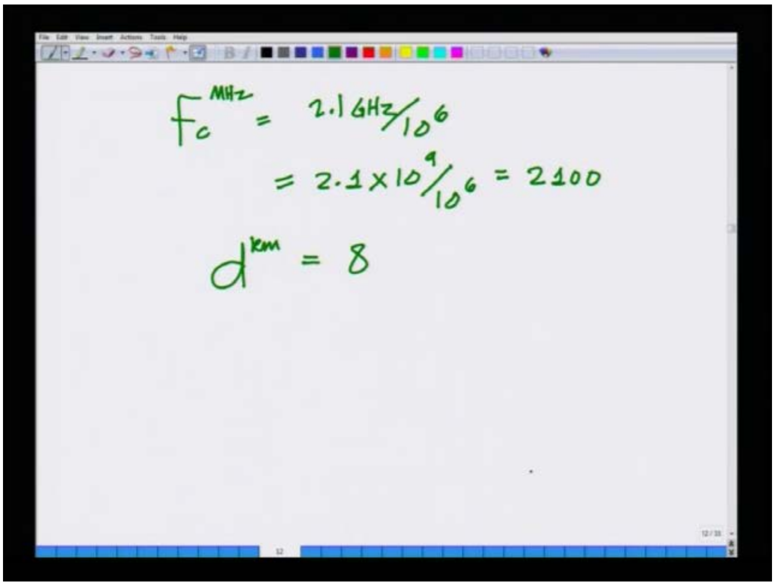

So, F c in mega Hertz is equal to 2.1 Giga Hertz divided by 10 power 6 that is nothing but 2.1 in to 10 power 9 divided by 10 power 6 that is nothing but 2100. So, the frequency in mega Hertz is 2100 mega Hertz and the distance in kilometer is distance is 8 kilometers and the distance is 16 kilometers is 8.

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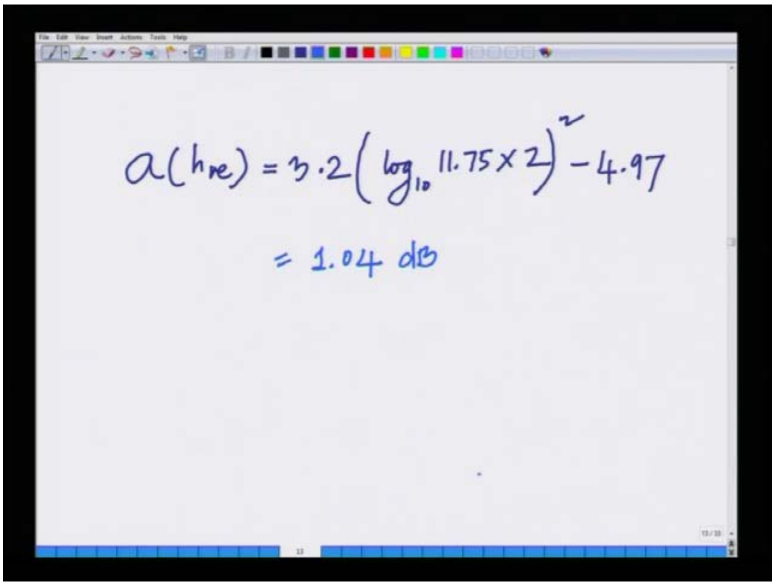

We have the mobile antenna correction factor and going back to this expression for the correction factor we know that the carrier frequency is 2.1 Giga Hertz greater than 300 mega Hertz. Hence, we use also it is given that it is a large city hence we use 3.2 log 10 11.75 h r e square, so let me compute here let me write here that it is a large city for a large city for a large city. Hence, the mobile antenna correction factor is nothing but 3.2 log 10 11.75 in to h r e which is 2 whole square minus 4.97 dB which is essentially equal to 1.04 dB, hence the mobile antenna correction factor is 1.04 dB.

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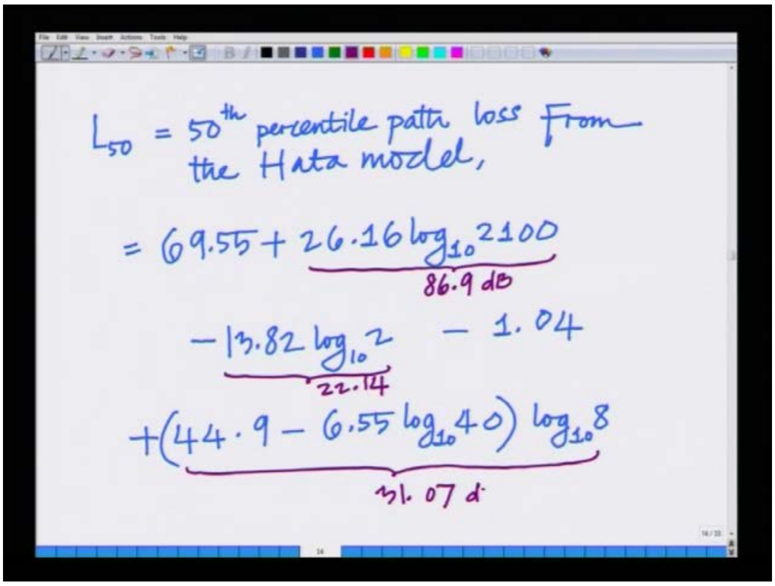

Hence, we have the fiftieth percentile path loss in the Hata model l 50 equals fiftieth percentile path loss from the Hata model. That is equal to 69.55 plus t26.16 log 10 to the base 2100. The carrier frequency in mega Hertz minus 13.82 into log 10 to the base 2 minus or mobile antenna correction factor which is 1.04 plus 44.9 minus 6.55 log 10 to the base 40 into log 10 log 8 to the base 10 where 8 is nothing but the distance in kilometers. This is essentially the net expression and these different values can be simplified as follows.

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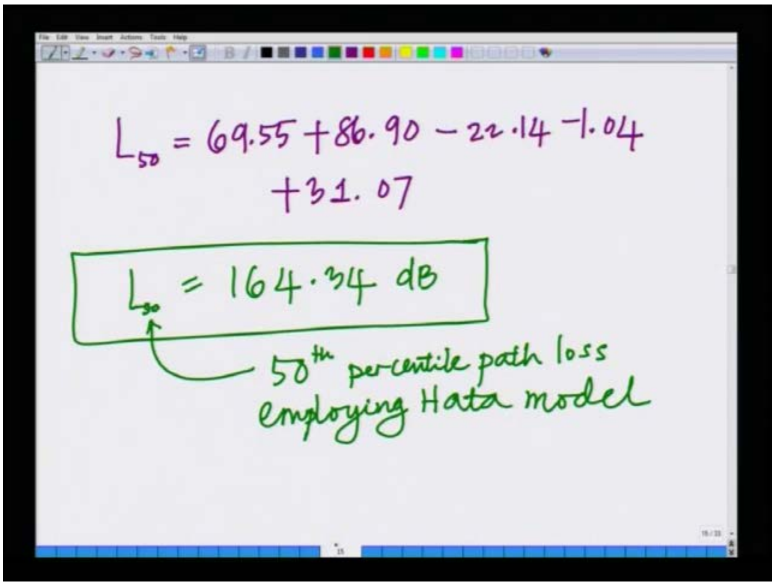

You can check these this is essentially eighty six point nine dB this is essentially 22.14 dB, this is minus 1.4 and this is essentially 31.07 dB. Hence, the net fiftieth percentile path loss is 69.55 plus it is 6.90 minus 22.14 minus 1.04 plus 31.07 which is essentially 164.34 dB. Hence, the L fifty employing this is nothing but the fiftieth percentile path loss employing the Hata model fiftieth percentile path loss employing Hata model is 164.34 dB.

If you remember, if you go back to the path loss employing the Okumura model that is about 167 dB and now we are saying in the Hata model the in the Hata model that is about 164 dB. Hence, these values are approximately closer about a difference of a dB over 2 that is 167, this is about 164 dB, hence the Hata model in the Okumura model.

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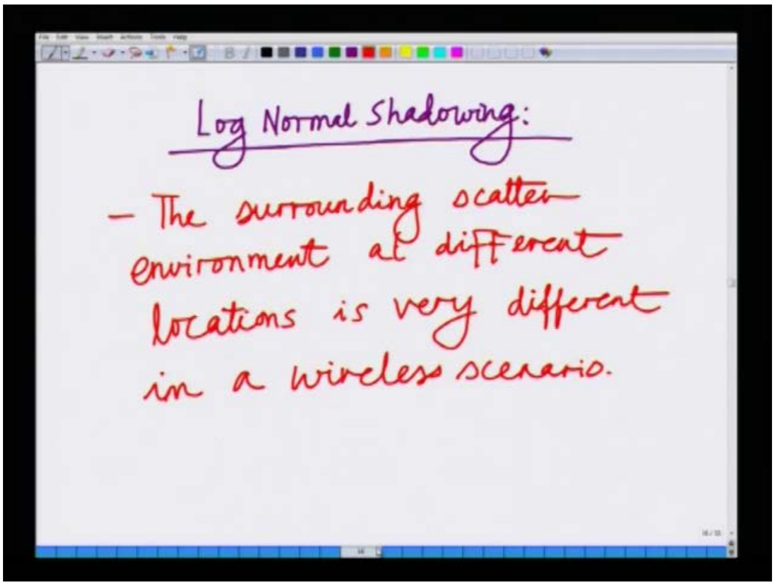

In the same signal strength predictions, these can essentially abuse but, the advantage of the Hata model. Now, essentially that the Hata model does not need the use of any graphical information like the plots that we are used in the Okumura model by using this expressions. One can succulently or comprehensively essentially characterize the path loss at a given distance which as I said is again very informative or very helpful especially in cellular scenarios.

When you need to characterize the received signal strength at the edge of the cell to count for the transmit power that has to be or the additional transmit power that has to be transmitted to account for the path loss for transmission to the cell edge users. Let us now consider the log normal shadowing that is the other aspect of a wireless communication system which is the log normal. Let us now consider the log normal shadowing in a cellular environment apart from path loss there can be other obstructions to the signal for instance like large walls large buildings and the user, if use occasionally behind this large obstructions.

This signal received signal strength can be severe lower severely lower, so apart from the path loss that exists in the cellular environment and signal environments. There are additional random factors depending on the surrounding clutter environment which cause additional loss hence the received signal strength. If you look at any place or any place at any distance in an environment is a random variable because it depends from place to place on the clutter environment. This in fact depends on time to time because the clutter environment such as vehicles and so on or mobile.

Hence, this clutter environment is essentially a random variable and this hence because of this clutter environment or because of this different scattering environment the received path, the path losses at the same distance vary versus different place. They also vary as a function of time hence this path loss at any particular instant is actually a random variable characterized by the fiftieth percentile. The mean path loss that we have derived earlier, so the surrounding scatter environment at any instant at any place the surrounding scatter environment at two different locations or at different locations.

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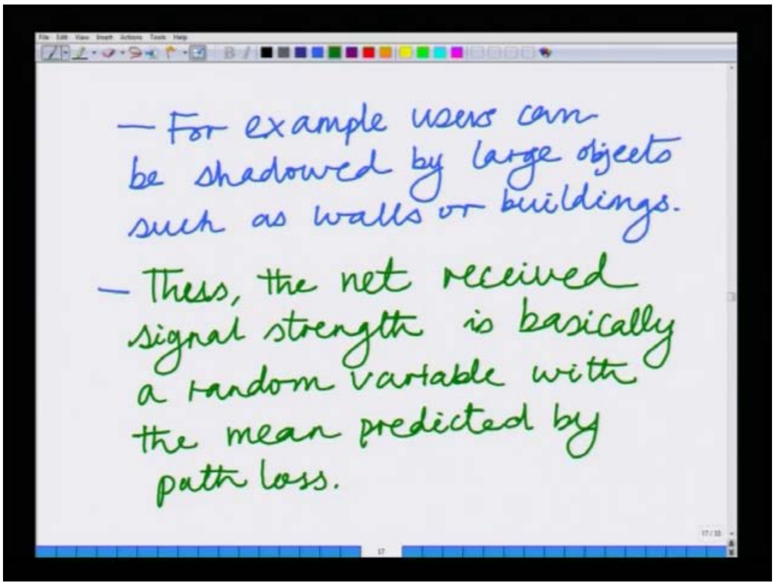

At different locations, may be very different in a wireless scenario or is very different in a wireless, so the scatter environment is very different in a wireless scenario. For instance a user can be shadowed by a large object such as walls or buildings. For example, users can be shadowed by large objects such as either walls or buildings; hence the received signal strength is actually a random variable because depending on the random clutter or scatter environment. The received signal strength is actually a random variable thus the net received signal strength is basically so thus the net received signal strength.

The net received signal strength is basically a random variable with the mid predicted by the path loss. Hence, the received signal strength is essentially a random variable with its mean predicted by the path loss. Remember, we derive to find the fiftieth percentile received signal strength and we said 50 percent of the time the received signal strength is greater than this, so 50 percent of the time it is lower than this n 50. That is essentially saying that this is a random variable depends on the scatter environment. The fiftieth percentile value is given by the L 50 from the Okumura or Hata model and the rest is essentially a random and then it is a deviation a random deviation about this fiftieth percentile.

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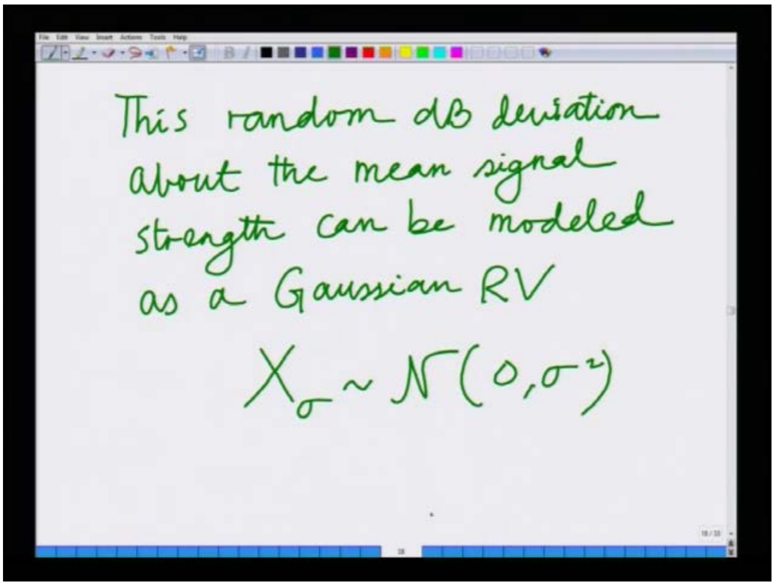

Hence, if you look at the net the random dB deviation is can be modeled and it is modelled as a Gaussian with a certain variance this is random dB deviation about the mean received signal strength this random dB deviation about the mean about the mean. Signal strength can be modelled as a Gaussian r v can be modelled as a Gaussian r v that is X sigma such that it is Gaussian with zero mean and variance sigma square. What we are saying is basically, this random deviation this deviation can be modelled k by Gaussian random variable with zero mean and variance sigma square.

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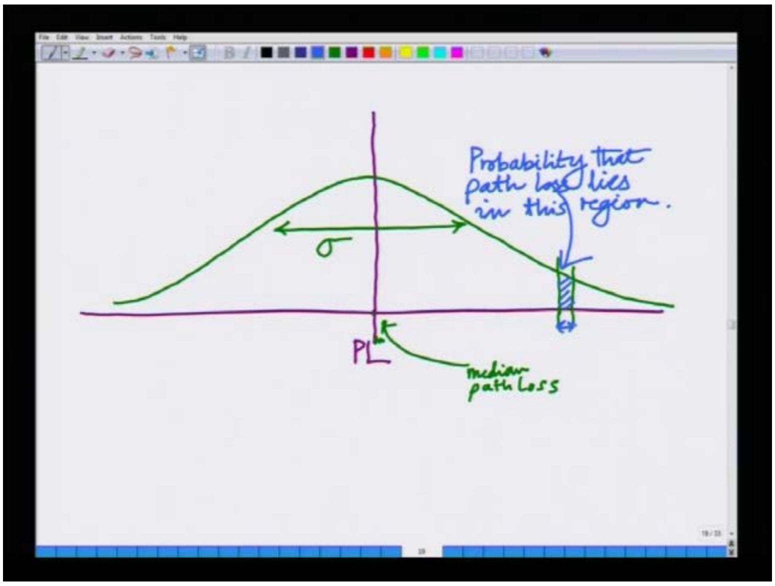

What we are saying is as follows that is if I look at my path loss my median path loss or my mean path loss is something that looks like this and then I have a random variation about this mean so this is the mean or the median this is median path loss. Then, there is a deviation about this with a spread this is the spread which is nothing but sigma.

Hence, for incidence the path loss can take any values in the range for instance we ask what is the probability that the path loss lies here that is essentially given by the probability that the path loss essentially lies in this small region. So, the path loss we are saying that fluctuate as a as a distance and time it is a random variable and hence we can only speak about a probability that the probability we can first say that this is the median value p, L 50 percent of the time.

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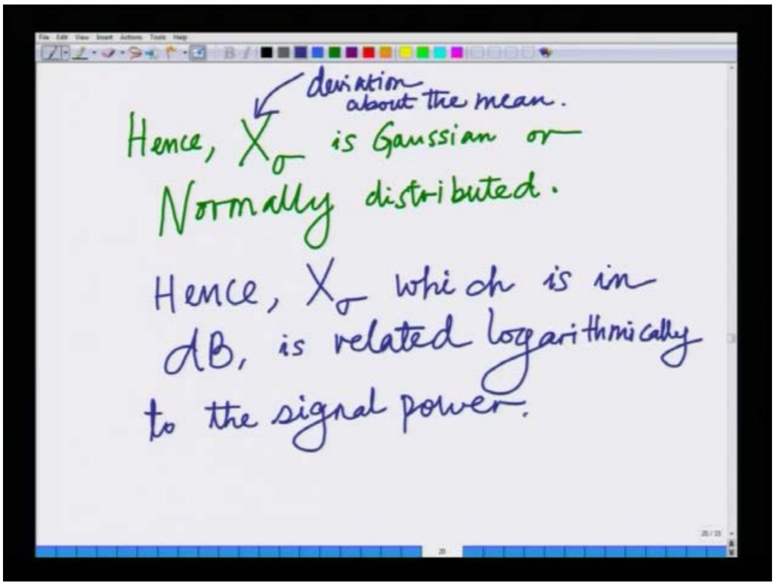

It lies above the median 50 percent of time, it is lower than the median and given any value we can characterize what is the probability, it takes value in that region that is obtained by this looking at this probability distribution. Further, if you look at this and this is nothing but, the probability that the path loss lies in this neighborhood this is the probability that path loss lies in it is the probability. The path loss lies in this region that is the in the small interval that is the probability that loss, hence now going back hence X sigma is Gaussian or normally distributed.

Hence, X sigma is Gaussian or normally distributed, so we said X sigma this deviation is Gaussian or normally distribution distributed and what is X sigma X sigma is nothing but deviation about X sigma is nothing but the deviation about the mean. However, X sigma is in dB remember X sigma is in dB hence X sigma is nothing but log 10 of received power. Hence, X sigma is in dB which is related logarithmically to the received power hence X sigma which is in dB is related logarithmically

This is related logarithmically to the received signal power, hence this is also termed as a log normal distribution it is normally distributed and logarithmically. Since, it is in dB it is logarithmically related to the signal power, hence this is also termed as a log normal distribution hence this is also termed, hence this is also this has a log normal distribution.

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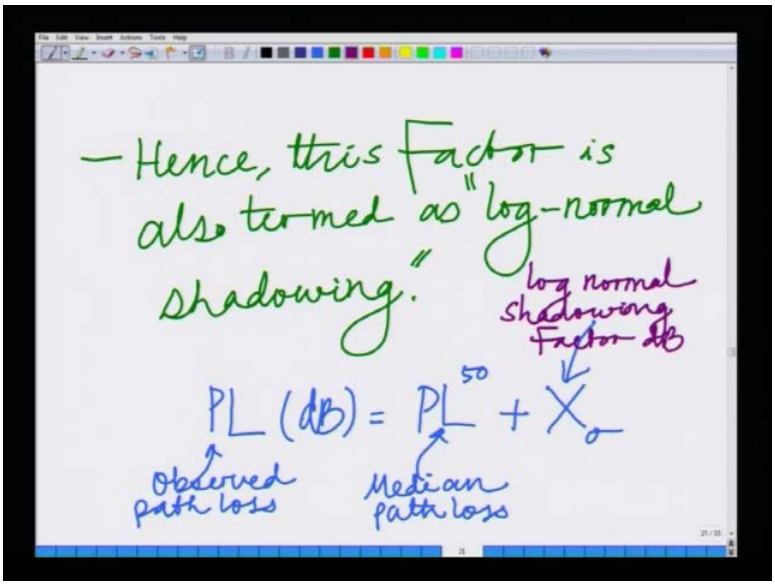

Hence, this as a log normal distribution this that is the region this is also termed as this shadowing is also termed as log normal shadowing. Hence, this factor this shadowing factor is also termed as log normal hence this shadowing factor is also termed as a log normal shadowing factor. So, what we are saying is we are saying that the path loss that the actual observed path loss is equal to observed path loss in dB is equal to the path loss the median path loss plus a log normal shadowing factor. So, this is the observed path loss this is the median path loss and this is a log normal shadowing factor. This is the log normal shadowing factor and this log normal shadowing is arising remember we said because of the clutter environment.

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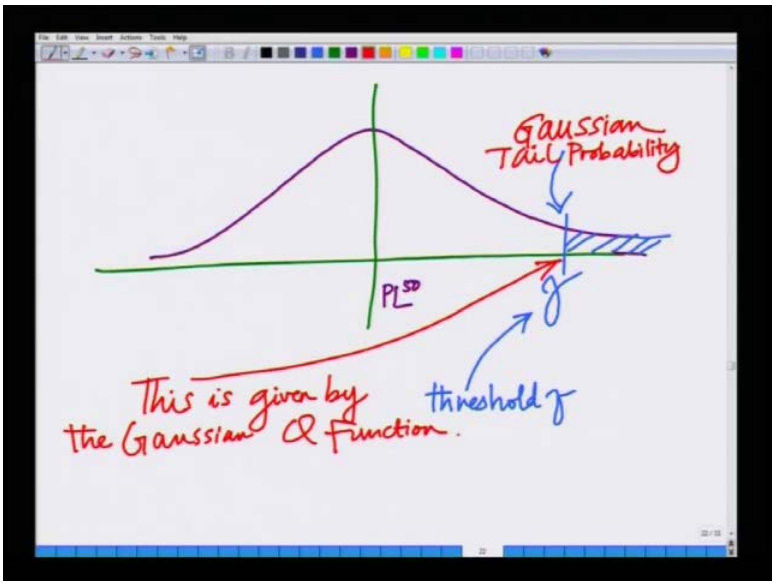

You might be behind a wall or a building which essentially causes additional deviation. So, if you model all such random factors that are arising you will essentially observe that the received signal strength looks like a random variable it has a certain mean which is what we computed using the Okumura model. Then, a deviation about this mean that is what essentially is observed and now let us go back again to look at this distribution we had of the path loss. If you look at the distribution now what we can talk about is we can talk about is the fiftieth percentile path loss.

Now, what we can talk about is we can talk about the path loss being greater than a certain threshold gamma this is let say a threshold and the path loss greater than this threshold gamma is nothing but the area under this curve. That is the probability that the path loss is greater than this threshold gamma is nothing but the Gaussian tail probability. This is nothing but the Gaussian tail probability that is the probability that this path loss is greater than a gamma and this probability is essentially given as the Gaussian q function this is nothing but q of gamma. This path loss is nothing this is essentially nothing but this is essentially nothing this is given the Gaussian tail probability is given by is given by the Gaussian.

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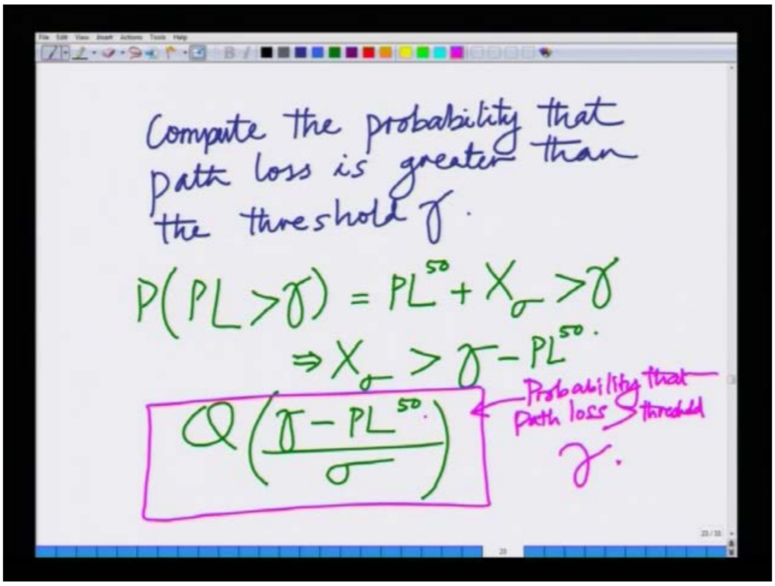

So, this path loss probability is given by the Gaussian q function let us specifically compute how this probability looks like, let us compute the probability that the path loss is greater than this threshold gamma compute. So, our problem is as follows compute the probability that path loss is greater than compute the probability that the path loss is greater than this threshold gamma that is nothing but the probability path loss is greater than gamma which is essentially the probability path loss.

Remember, this is nothing but fiftieth percentile path loss plus X sigma is greater than gamma. This is essentially the probability that implies X sigma is greater than gamma minus the fiftieth percentile path loss remember X sigma is a Gaussian random variable with standard deviation or with deviation sigma variance sigma square.

Hence, this probability this probability that X sigma is greater than gamma minus p l 50 minus is nothing but q of gamma minus p L fifty divided by sigma this is the net probability. That is the probability that path loss is greater than the threshold gamma, so this is the probability that the path loss is greater than the threshold gamma. The path loss is a random variable due to the random clutter environment, so we will stop this lecture at this point and we will continue from here in the next lecture.

Thank you.