Design for Internet of Things

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Lecture - 47
Introduction to Wide Area Technologies

You must know a little bit of RF. By no means this is complete. This is just giving you a tip of the iceberg kind of understanding so that you can refer to data sheets and move on with your designs, okay, I am just trying to make you very practical in terms of designing your systems. First point you have to notice about the fade margin, okay. But before we attack fade margin, think about an RF signal.

When the RF signal is emitted from the transmitter, the signal has to reach the receiver. That signal may take different paths. And several well-known phenomena occur to this signal. These are reflections, diffractions, okay and refractions, even refraction scattering can also happen. So you can have scattering, you can have reflections, and so on.

All these are impairments which happens which clearly indicate that no signal emitted actually goes in a straight line to a receiver. It may take many routes before it actually reaches the destination. And because every time it hits an object, it gets reflected from there. It can get scattered from there. It can get diffracted from there. It can get scattered, it can get reflected and so on.

All these phenomena really lead you to understanding the signal and how to characterize all these paths which are there. Essentially, the receiver has to get the signal. If there is a strong line of sight component, this receiver will be able to retrieve it. But if the line of sight component is absent and it takes all different routes to reach the receiver then the receiver has to have a difficulty, will have a difficulty in recovering the useful signal from that.

Because multiple copies will arrive and of course, multiple routes through multiple routes and different attenuated signals will come. Any electromagnetic signal, as you know if it propagates will get attenuated and there is a very famous I am sure you know about the free space path loss equation.

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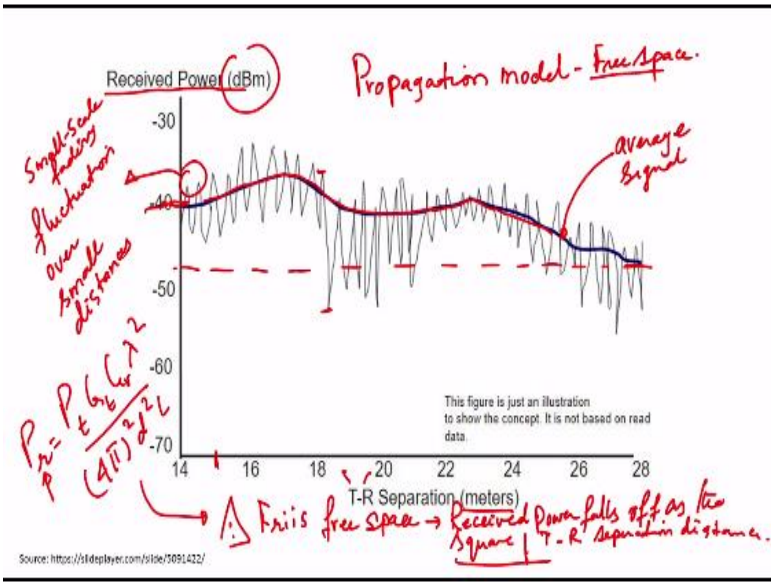

So let us look at this picture here. I have tried to put everything into this nice little picture. In fact this picture you can find in several books on wireless communication. The x axis is the transmitter receiver separation. This is given in meters, okay. And the y axis is the received power. Obviously when you say received power that is denoted in dBm. Now what you see here, this thick line by the way is the average line.

You can see this average itself slowly it varies like this. Over long distances it varies, gradually it varies right? Very gradually it varies over, as the distance increases, gradually the average power varies. But that is not the case. When you make the separation distance between the transmitter and receiver over short distances. Look at this distance. You are starting with 14 and this is 15.

And just by one meter when you move, look at the way the received power is fluctuating. It is a fluctuation over very small distances, quite rapid, okay. And this is actually there is a name for this and this is called small scale fading, okay. Small scale fading. It is called by this name. And why does this happen?

If you ask the physics of this, really this the reason for this is that the received signal is a sum basically, okay, a sum of many contributions coming from different directions, okay. So I think that is about what we can say because it is a lot more signal propagation theory, which may not be very useful. This whole picture itself is actually drawn for what is known as a free space propagation model, free space propagation model.

And for free space propagation model, the simple expression of received power is (Pt, Gt, Gr, lambda square) divided by ((4 pi) the whole square, d square, L). L is some term which you do not have to, you know worry so much about. It is called some system loss factor. It does not do anything to do with any related to any propagation. Lambda you know is the wavelength, it is given in meters.

Gt and Gr are the gain of the transmit antenna and the receiver antenna. Pt is the transmit antenna. And d is the separation distance between the transmitter and the receiver. And now if you look at this expression and connect it to the explanation, you see that the Friis free space expression actually is saying that the received power falls off as the square of the T-R distance separation distance.

So this is the most important aspect of propagation model if it is a free space propagation model. So let us use this as we go along. Therefore, keeping things very practical and understanding that multi path is an issue, you have to consider the fading which happens. Now what is fading? Fading is a very simple thing if you understand it from the simple BE Tech level experiments that you did.

You wanted to understand the frequency response of an amplifier. What did you do? You plotted the change in frequency along the x axis. Let me draw this picture for you.

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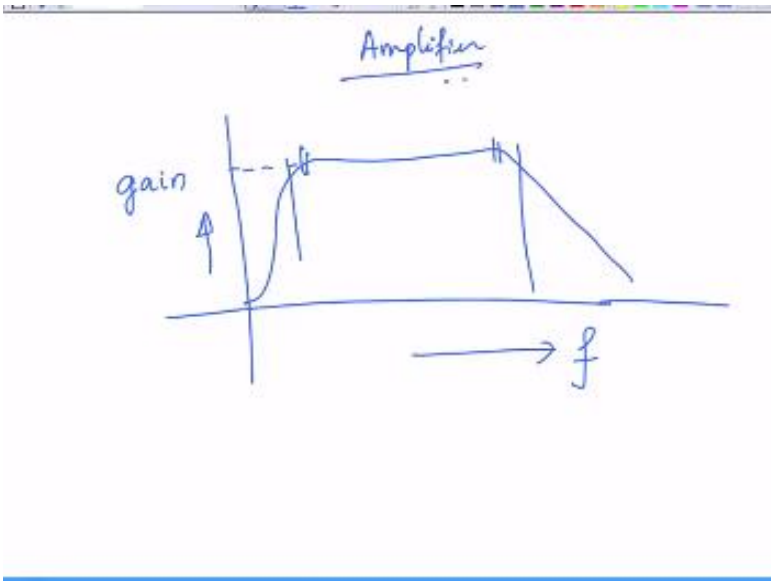

So you would have, what you would have done to get the frequency response? You would have plotted the frequency along the x axis. And you would have plotted the gain on the y axis, right? You know the gain, amplifier will have a gain. Then you know that it will give you some flat response to some point and then starts falling down. Then you will say that maybe it may not be so bad.

If it is bad you may have to kick so maybe I will draw an ideal thing because it is easy to answer in the class, right? And then you say okay there is some 3dB difference between these points and then you say 3dB bandwidth is so much. And this is the range over which the gain is uniform. This is the good thing about it. The gain is fixed or more or less uniform in the frequency range.

This is what you would do with an amplifier, okay. And this is the amplifier's frequency response. Quite like that the channel also has a frequency response. It is as simple as that. Think about it like an amplifier. Think about a frequency response of the channel. And as you design different amplifiers to meet certain requirements, you will have different type of channels also.

Particular channel may be well suited for a particular frequency but not all that great for other frequencies. In other words what it will do is it will attenuate some of the important frequencies so much and some of the frequencies it may not even attenuate. It may not attenuate significantly. Anyway attenuation will go a square of the distance, right? That we have already said it will follow free space path loss you know phenomena.

But on top of that the channel will start fading. So there is a formal definition for all of this which you should keep in mind.

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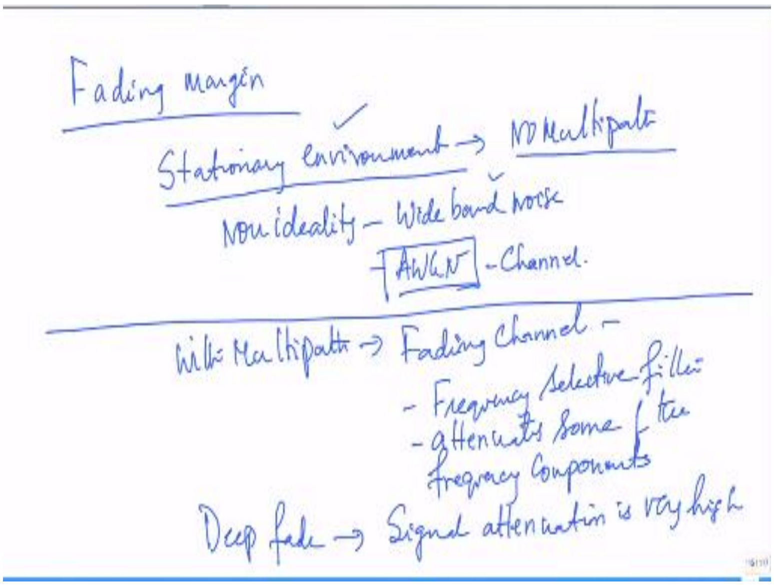

And I would like to tell you about that here. See if you have a stationary environment, that means there is no multi path at all which is very ideal. It is impossible to have a situation like that, okay. This non I mean without any multipath means it is a stationary environment, okay. The only thing that you can think of in such a stationary environment and one non ideality without multipath will be just the additive white Gaussian noise channel, okay.

And that is why several books on communications we will be looking at AWGN channels. That is the only non-ideality which is basically a wideband noise channel. But that is as I said, it is impossible, right? This is really what you find in books and nothing more.

Maybe closest that you can think of if you want to get to additive white Gaussian noises, take the transmitter, connect a cable okay with suitable connectors and all that and then directly connect it to a receiver with suitable attenuations. You have to attenuate it because the receiver cannot get RF power directly. It is used to looking at certain impedance which is matched to the antenna and so on.

So you have to connect a attenuator and feed the output of the attenuator directly to the receiver of the Rx part of the receiver, okay. If you do that, and if you subtract the losses due to the cable, then maybe it can be regarded as a, it cannot be regarded as ideal as AWGN but you can say that this is something that you can say closest to what a additive white Gaussian noise channel would look like.

Because the transmitter electronics will have certain noise. The receiver electronics also will have certain noise. The receiver's electronics noise will be called noise figure anyway. So those can be used for calculating and then saying, okay, I am not allowing the signal to go in different routes. I am just allowing a single path. And that is no multipath here. It is just one single straight line.

And it is traveling through a wired cable and so on. But nobody wants to do that, right? It is no fun to connect. When you say wireless, why do you want to use wires? It is just an example. Therefore, there is never like a AWGN channel at all. You will definitely have fading of the channel. You will have frequencies which are getting attenuated.

You will have situations where some frequencies do good, and some frequencies completely get lost. And therefore your information signal, which is comprising of several frequencies is actually, you are not, it is not available anymore.

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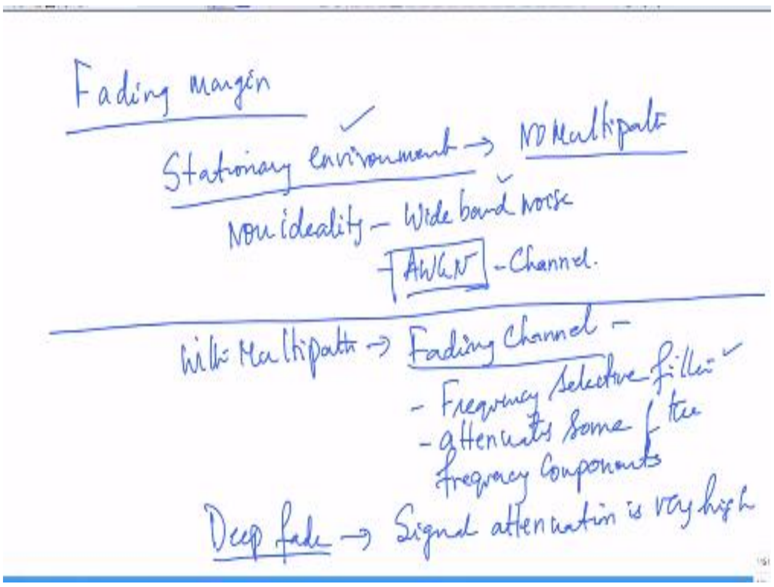

Therefore, such a channel is actually called a fading channel. Now when you say fading channel, you are actually talking about frequency selective filter, as I mentioned already. And it attenuate some of the components, frequency components. And you say a channel is considered to be under deep fade, when the signal attenuation of some of these frequencies is so intense that you cannot recover the signal at all. So much so now it comes to why this discussion, right?

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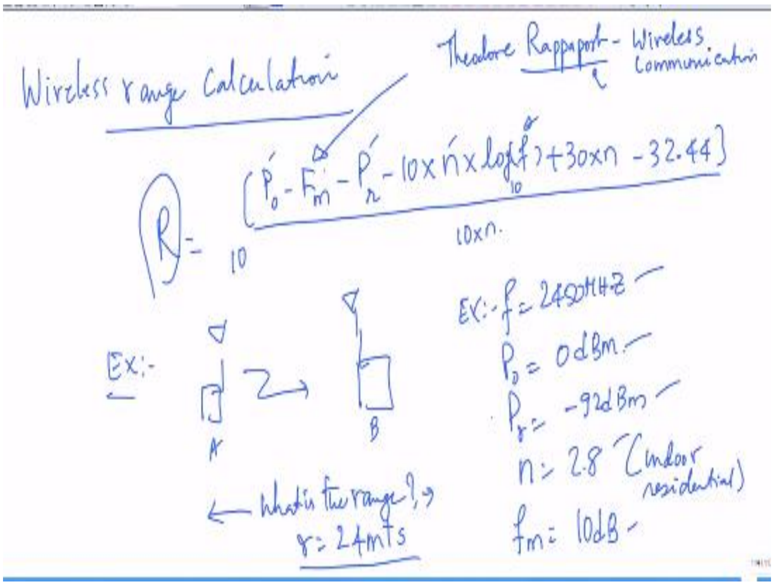

Which clearly indicates that when you design your range, when you are interested in your range computation, you must give a margin for the fading. And that is essentially coming up here in this expression. To calculate the range, you apply typically this expression, okay. I would not go into the details of this expression because that is little bit out of scope. But I just want to show you that this is the equation.

And how to use it I will show you how to use it, but think about the equation in this form. ‘Po’ is 0 dBm that is output power, transmit power. ‘Pr’ is the received power much way lower than the transmit power because it has to follow Friis law, -92 dBm. ‘n’ this is the what is known as the path loss exponent. For indoor environments, it is not now going square of the distance, but it is going 2.8.

So this ‘n’ indeed is 2.8. Now ‘fm’ is the fade margin, which you see here now as I mentioned to you. So this is received power, this is the transmit power, this is the path loss exponent, which is 2.8. You have to consult tables in order to use the right ‘n’. If you are interested in knowing the tables for different environments, look up

Rappaport textbook Rappaport. I forget the title of the book, but I think it is called wireless.

Yeah, I think it is wireless communications, wireless communications, Introduction to Wireless Communications by Theodore Rappaport. You should be able to Google and find this book, beautiful book. In fact, several of these concepts, you can look up in that book as well. Now you know the frequency at which your center frequency that is your ‘f’ here.

And then these are other terms, which I do not want to elaborate at this stage, because it may include the antenna gain and other related parameters. So just use it directly. You will be able to get the range. I thought I will give you an example of how to use this equation.

If you take ‘f’ of 2450 megahertz, the transmit power of 0 dBm, received power of -92 dBm and ‘n’ of 2.8 and the fade margin of 10 dB, you will get a range of 24 meters. That is the basic idea of explaining all this background. I would like to point you to the data sheets.

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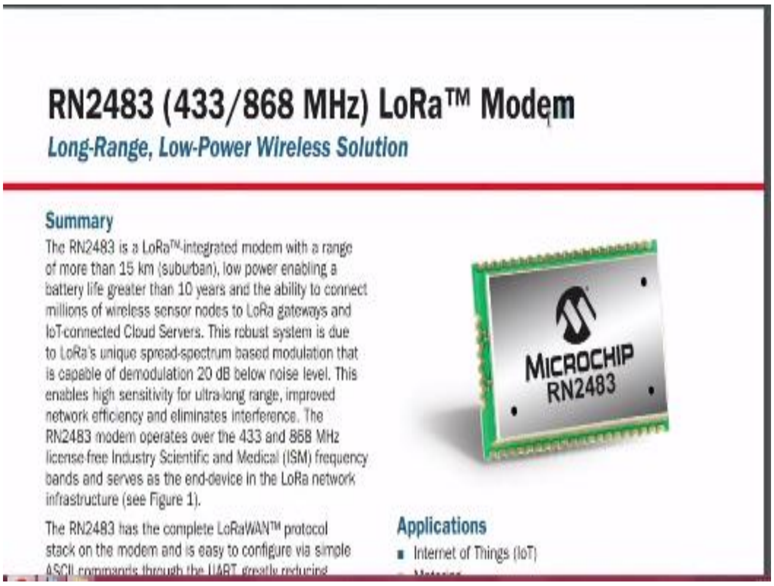

And I want to take you to the data sheet related to LoRa, okay. We are looking at LoRa data sheet. You are looking at LoRa communication. What is LoRa, we will explain all that. But it is indeed the one of the biggest and the most popular solution for low power wide area network, which is the crux of this little module that we are discussing. Now what is LoRa I mentioned here in this. I will come to LoRa explanation in detail.

But I would like to complete this discussion on range for you by using LoRa's datasheet. Without even understanding what LoRa is, let us use its datasheet.

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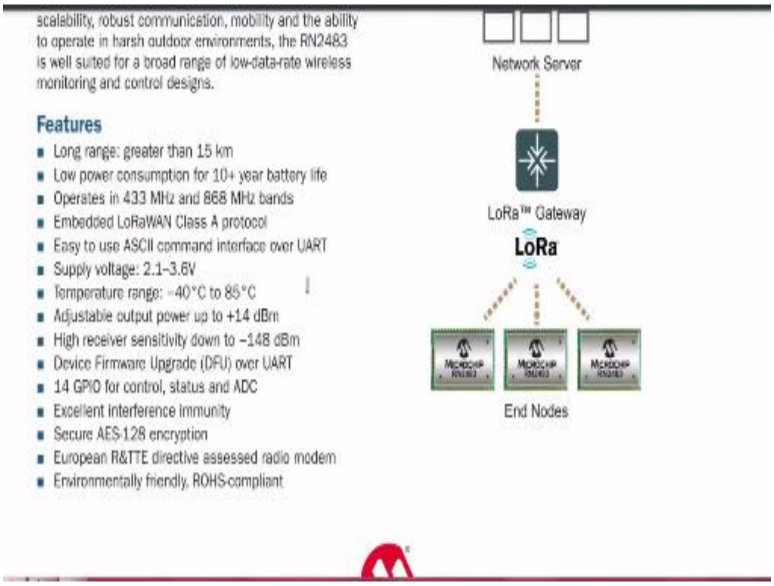

What does it have here? It has the following here, okay. Long range it says is greater than 15 kilometer it can give you. So 'R' computation is now trivial for us because we know the basic expression and we know several things about how to substitute the values in order to get the range. So let us see what all it does. 15 kilometer, the thing we have been harping about that it is 10 plus years battery life is here.

It operates in different frequencies, let us take 868 if you are interested. Embedded LoRaWAN class A protocol. Leave that because we are not going to elaborate it now, okay. What we are interested in is output power which is 'Po' as we have discussed, which is +14 dBm. Receiver sensitivity is down to -148 dBm, best in class, even better than what GPS modules can actually provide or maybe around the same range.

And then so many other related things. Now let us see how to get to this 15 kilometer range. That may be of interest to you how to substitute that equation which I sort of know now. Is there a simple link budget calculator that I can kick up, I can switch on and put in these values and then try to see what we can do. So for that I go to this site.

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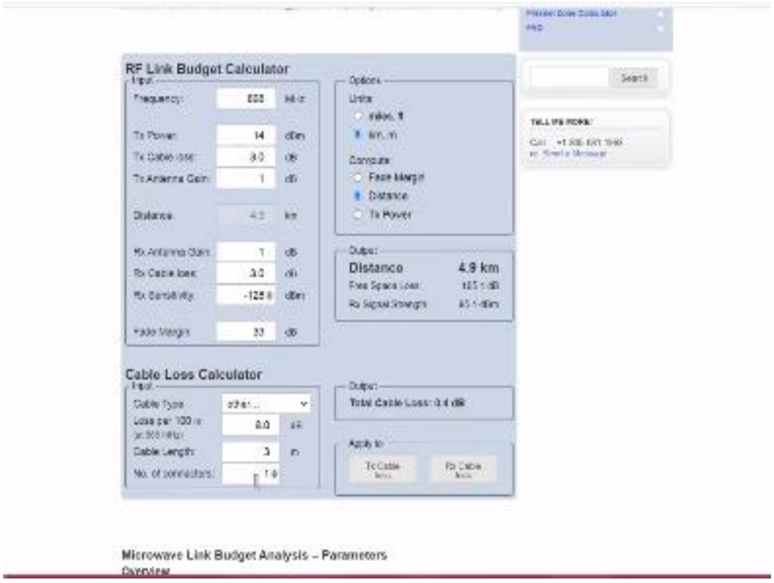

When I go to this site, I punch in these values. This is a straightforward RF link budget calculator which is available on the internet. You just kick up Google for afar.net you will see an RF link budget. In fact, this is one of the many such link budget calculators which are available. Each one is a little different from the other and but more or less they give you the same information. What all can you punch in from the LoRa datasheet?

You punch in the frequency of interest in 868 is allowed in India. So we will use 868. Transmit power is 14 dBm. That is also punched in. Cable loss.

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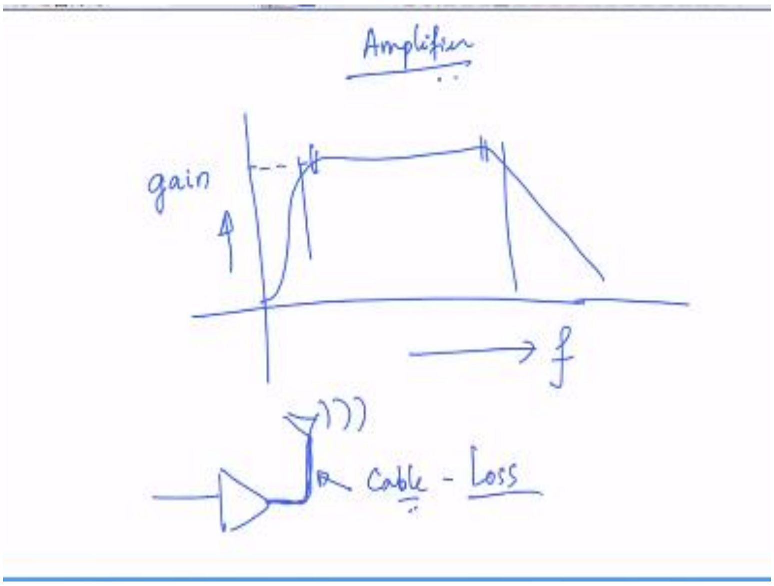

See the power amplifier is here. And I typically denote it like this right? I show you that this is the antenna. Now what about this cable that is connecting here, this ‘L’?

This is the cable. So you will have what is known as a cable loss. I mentioned this already that cable loss you have to subtract, okay, so let us go back. So you type in the cable loss, but you also have to type in the antenna gain, okay.

I punched in 1. When we got receiver antenna gain also we take as 1. Cable loss, we took as 3 here. And receiver sensitivity we punched in as -148, again from the datasheet. And we gave a fading margin of 43 dB, much higher than what the receiver sensitivity is. And you can see that we were able to match the 15 point a little or 15 kilometer range that LoRa is promising us to do.

Now we had to see if some of these parameters can be adjusted, can we get higher and higher distances. For example, supposing I reduce the fade margin to 43. Instead of 43, I make it 33. Now look up what actually happens. 48 kilometers, okay. So you can see that as you keep reducing the fade margin, you will get a larger range. Need not necessarily play with the fade margin.

If you have better radios, maybe -58 dBm radio, you may get even better range. If you have a poorer radio, let us do that. Let us make -158, 158. You can see it is 153 kilometers now. Now instead of making it 148, let us make it 138; 138, okay. So you are getting around 15.4. If you make it 128, if you make it 128, it is 4.9. So poorer radios can give you shorter range. If your receiver sensitivity is low, then your range is also low.

So you have to look at the datasheet in order to decide what kind of distances you are looking at, and what kind of receiver sensitivities have to be supported. This is folks the main crux of what LoRa is all about. And I am going to tell you more about LoRa, and the exciting things that LoRa can do when we talk about long range connection of data, okay.

Typically, one important reason, one important point I want to tell you, which is sort of a intuitive understanding you must have is the following folks. Let me just show you another intuition, which I think you must use these as basic understanding, okay.

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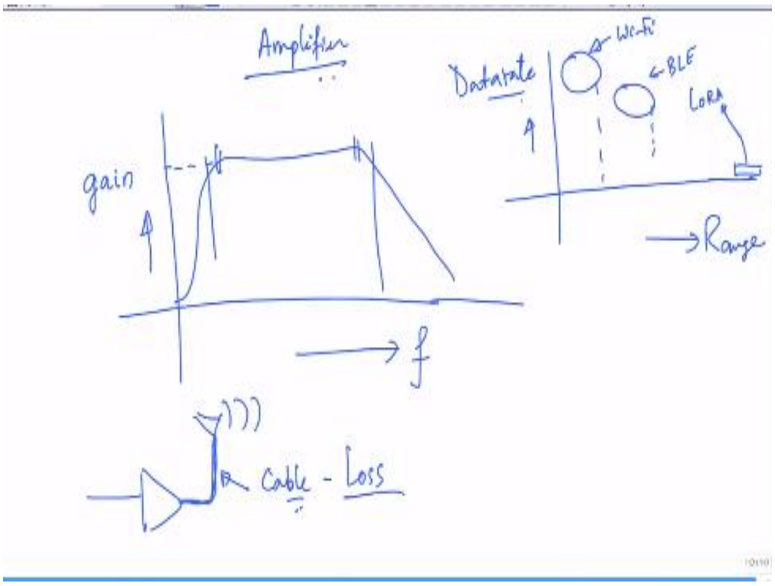

Supposing you are plotting range and you are plotting range versus data rate, okay. You are plotting range versus data rate. I am telling you this from basic physics, okay.

I want you to look up and then look up that and then arrive at why I am saying so many things. If you look at very high data rates you are bound not to have not much of a range. If you reduce the data rate maybe you will go and get a slightly larger range. And if you reduce it even further, you may actually end up with a superly large range, okay. So you can see that there is no comparison at all of the range.

This is typical of what Wi-Fi does. This is typical of what Bluetooth low energy does. This is typical of LoRa, okay. You will definitely appreciate now because the data rate is so low, so low in LoRa, the range is actually very high.

The way to understand this idea is that the way to get a desired range is either to increase the transmission power, very high transmission power, like the old days AM radios, amplitude modulated radios, where it used to be in kilowatts of transmission power. Or you reduce the rate at which the data transmission happens. Either this or that will give you good amount of range.

Increasing the transmission power does not make sense because we are discussing low power wide area networks. So that is ruled out. We are not even blasting power at all. And there are FCC regulations which will tell you that you cannot blast beyond the range and so on. The only way is you have to reduce the data rate. And therefore, LoRa is out there, okay. LoRa is out here.

And LoRa says I will give you very low data rates and I will give you super amount of range. What used to be a few hundreds of tens of meters with BLE, and maybe 150 to 200 meters in Wi-Fi, you are getting 15 kilometres just like that, folks. And how is that possible? Because it is trading the data rate to the range, okay. So that is the key point.

This brings you to a very important point that you should never, ever forget. And never, ever ask the question again to me, okay. Do not compare BLE, Wi-Fi with LoRa. Do not, just do not compare. They are different, right? Because that is a different game altogether. BLE and Wi-Fi are a different game altogether. They are wireless technologies all right, but you have no way to compare them.

Find out where to apply them in its requirements, for its requirements. LoRa definitely has a number of applications, compelling applications, which require LoRa kind of connectivity. For example, large scale soil moisture monitoring. Big amount of area, you are monitoring soil moisture. One sample you need every one hour, let us say. You do not need high data rates.

But you want a long range because the farms are many hectares, right. So you want one receiver to get all the data from several farms. Therefore, whenever you have applications like low data rate applications, think about LoRa. Think about low power. Think about 10 years lifetime, two samples per day, three samples per day, LoRa is the best.

You are looking at pollution monitoring, morning, afternoon, evening and night, four samples per day, in busy cities use LoRa. You cannot afford to use cellular connectivity for everything folks. You have to look at alternatives. You have to look at alternatives which are as attractive as cellular technologies. But only transmitting sensor data.

And that is where LoRa comes in a big way. We will spend more time understanding this technology. And then we will get into some more details on technical details on LoRa, including a small demonstration.

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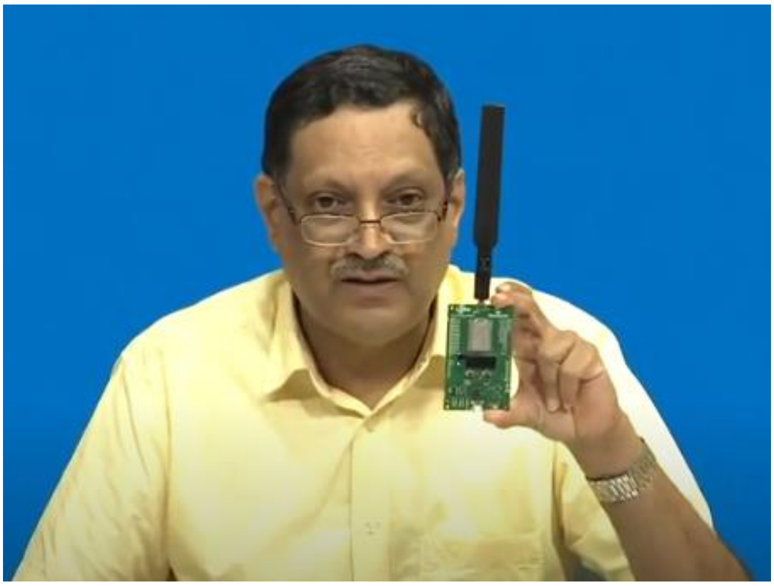

But before I close, I want to show you that this is how the LoRa modem works. This is the antenna and this is the LoRa modem which is there out there in our lab. I thought you should have a look at it. And once you see this, you realize that it is something that can give you 10 years lifetime, can give you 15 kilometer range and all that beautiful features of it. What kind of magic happens? Let us get into the details of LoRa and understand them better. Thank you very much.