Design for Internet of Things

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Lecture - 39
Introduction to Low Power Wireless - 01

Welcome back. Let us start this module on low power wireless, which comprises of Bluetooth Low Energy then which is has an IEEE standard. Then there is the ZigBee, well-known ZigBee protocol. Then there is the well-known Wi-Fi protocol. All of them are wireless radios and they operate in a certain frequency range, right?

See this is a course on design, right? So you must know how to choose a particular radio for a given application and what are the minute settings that you have to do such that you will be able to use the radio in an effective manner. How do you design such a node? How do you design a wireless node with a wireless connectivity?

What are the issues in the design of such a node and what is its impact on performance. Broadly this is what we will do. Getting into the details of the protocol, understanding the nuances of the protocol I am sure there are many documents which will help you to read it. So I will not go into that detail because it is already out there in open literature.

I am just going to tell you from a design perspective what are the challenges that you will have to encounter and understand the data sheets when a manufacturer put something in front of you. If you understand that you will know how to design because everything is based on commercially available components, okay.

Now having said that, I wanted to drive you to a very important point that is if you take a wireless transmitter and a wireless receiver what is the easiest way to visualize such a chain, transmit chain and a received chain, okay. What are the basic blocks?

Irrespective of the radio these blocks will be there, just that they will be tuned for different technologies and they will be tuned for different transmission powers and so on, different types of antenna and so on. Apart from that the basic chain will continue to remain the same. Modulation schemes may widely change, right?

If you take ZigBee which uses OQPSK right and it uses direct spread spectrum technique that may be one type. Then the Bluetooth Low Energy may be doing it differently, okay. It may do frequency hopping spread spectrum and it may have a certain hop sequence and all that. So that is apart from that the whole chain transmit and receive chain continue to be the same.

So what is such a generic block we have to understand because that is where the design comes into picture. I have put here a picture which is a clear I mean generic picture here.

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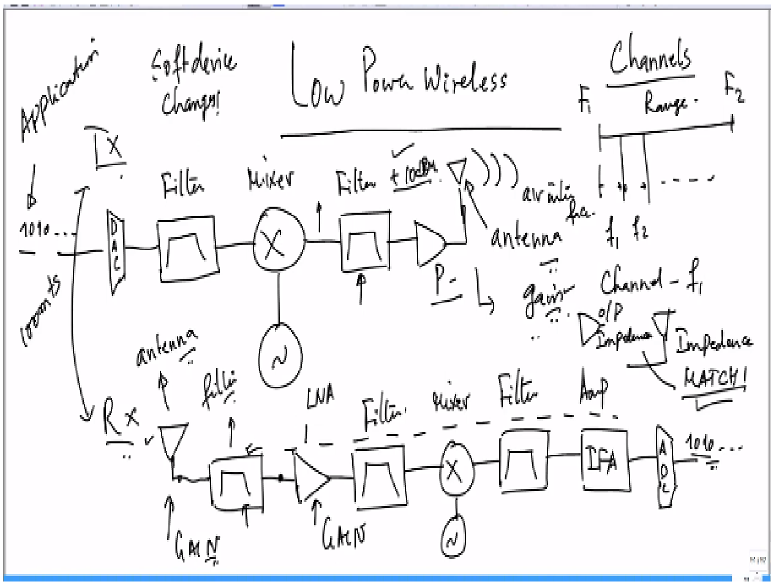

What you have is from an application you will get data bits, which will have to go out on the air interface. So this is coming from the application, right. And this is the transmit chain. So I will simply call it Tx which is the transmit chain. Now basically you have to convert those bits into an analog signal because your transmission is analog by nature. This is analog right, this is analog here.

So which means you have to convert all your signals into analog and modulate the carrier with this application data bits which are coming in. Now after you get it into an analog signal you have to ensure that you filter, apply an appropriate filter to ensure that certain frequencies are not transmitted. Only those frequencies in which the data is available, you will have to use those frequencies alone because now it is an analog signal.

It will be associated with an amplitude, it will be associated with a frequency component, all of that. So essentially you will have to pass it through a filter and then you have to upconvert. So this is your mixer. This is your mixer, right? Once you mix it it becomes a upconverted signal here. So now this upconverted signal again is analog by nature.

Again, you have to pass it through, usually pass it through a filter to ensure that you do not transmit in frequencies beyond what is allowed, beyond what is allowed by the FCC regulation. It is very tight. So you have to ensure that you have to give a frequency range and this range is divided into several frequency bands, small bands and you have to transmit within that band.

That is when you get different channels, okay? Channels come from a large band, this is the band, okay. I will call it, actually I should start using the right word. I will say range okay. This is a range of frequencies given to you. This is f 1, this is f 2. In fact, it may be our own convention. So let me use some nice things. I will call it F 1 and F 2 in capitals. Now this range is divided into small bands, right?

So you divide here. This can be f 1, this can be f 2, and so on, right? So essentially, this is a channel. The notion of channel comes in because you are talking of f 1 channel, f 2 channel, f 3 channel, small f 1, small f 2, small f 3, and so on. So essentially, all of that means you have to design this filter properly, so that there is no leak of energy from f 1 to f 2, and so on, right. They are very closely spaced, okay.

So there are terms like adjacent channel interference and so on, which you can avoid by designing very sharp filters so that no energy leak from one channel to another channel. That is all about analog design, we do not need to worry about it. What is available to you is this chip, which already has all this chain. Now this is important, this is a power amplifier, okay. And this is an antenna, okay.

This is an antenna. Folks, I have denoted it like this, but there are some super stuff out here which you have to understand very carefully. Only then you can actually design your IoT node appropriately, okay. Anyway, this is now transmitted on the air interface. This is the air interface. Now data is going out as an analog signal right on the air interface. Now once that signal goes, it comes to the receiver.

What happens here, exactly the opposite. You need an antenna to receive it. You need a filter to ensure that you are not accepting any other range and also any other channel because now this is tuned to a given channel. So it will get tuned there. And then this is the low noise amplifier. Signal is so small, so small that unless you apply a amplifier right at the beginning, you cannot even decode it accordingly, right.

So this is a low noise amplifier. Again after low noise amplification, you filter, you apply a filter and then you pass it through the mixer block again. So you do the demodulation and then apply a filter again here. And then you have amplifier again here and some amplifier here. And then the analog signal is fed to a ADC. Once you feed it to an ADC the output you get back is these bits which were transmitted.

So essentially this is the whole stuff that happens in a low power wireless radio as the same as any other radio, right? The usual stuff is out there. Now why is this important to learn is the question, right? Now supposing I put some value here, +10 dBm is the transmission power. Supposing I put, I tune this amplifier and apply +10 dBm here, +10 dBm of transmission power I apply here.

Okay, I should write it properly. I apply it here. Now what will be the power at which it is received here okay, you should know that. Only then you can actually see whether you are getting the signal decoded properly or whether it is not getting decoded properly. Now if you are not able to decode properly, you may have a problem anywhere here.

Because there may be too much noise up to this point or there may be a problem that the distance between, the distance between the transmitter the Tx and the Rx is large. Supposing you are not getting anything here. It could be because you had kept it at let us say 150m. The distance between the transmitter and the receiver was kept at 150m. Maybe you will start seeing reception if you bring it down to 100 meters.

Why? Because signal that arrives here, maybe sufficiently okay to come to this filter stage, passing through a low noise amplifier, filter, down convert, again filter and then some simple amplification and then get back your bits. So that may be work, that may actually work. Now how do you know at what distance what should be the value at which you will be able to receive this distance at which you will be able to receive.

Is there a number associated with it? And how do you qualify this number. All these things you should know folks. Only then you can actually decide, design your radio for any particular application. Now what is that term is the question right?

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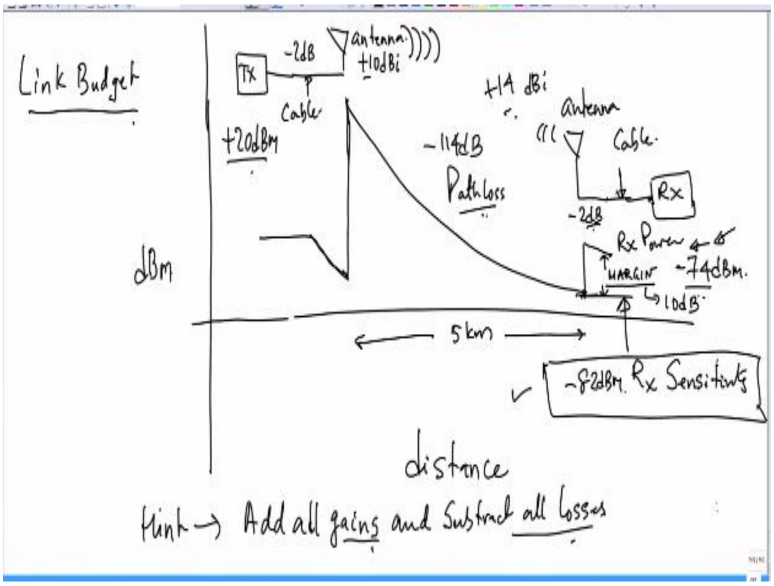

The term associated is receiver sensitivity. You must know this. This term is actually given by the vendor, is given by the manufacturer and you should be able to read the datasheet, understand everything about the receiver sensitivity. Well, okay. Now folks, it is not going to be simple for you to understand this term, because there are lot of small things right in the previous picture itself.

If you go to this picture, you may have come across several terms. Yeah, you did +10 dBm, you gave power to the power amplifier. But as engineers we know that antenna also will apply a certain gain; that is called the antenna gain, okay. The antenna will apply a certain gain. Passive gain, essentially it will also, it will give you, bring in certain energy.

It will focus the energy in a particular direction perhaps because the way the antenna is designed will give you a certain gain. And that gain will ensure that you may be actually be able to transmit to 100 meters, okay. The gain was sufficiently good to get it to 100 meters. But if you chose a different type of antenna for the same +10 dBm transmission power, you may have only got about 75 meters.

I am just talking in terms of what we normally are comfortable between the transmitter and the receiver distance is only 75 meters. So the game changes moment you change the antenna to a slightly high gain antenna, okay. If you design by an antenna which has certain amount of gain, then you may be able to move it 100 meters. You may actually say sir, why not I replace it with even bigger antenna and make it 150 meters?

Well that is, it is not going to work that way because your transmission power was only kept at +10 dBm. It can only have a finite distance over which you can actually receive the data, okay. You cannot infinitely keep increasing the distance anyway. You have to do other things in order to get to 150 meters which we will not get into at the moment because this basic understanding is what we are putting at.

So let us say your 100m distance is what let us fix it to 100 meters because you applied a certain type of antenna and that had a certain amount of gain. So you now know that this is okay, this is gain at the transmission side. What about the gain at the receiver side? I can also have another antenna which is powerful enough which will apply a certain gain and then pass that signal through the filter and apply a certain power here, low noise amplifier.

This is an amplifier right, have a high gain amplifier. Increase the gain of the analog signal and then you apply to a filter and then down convert with mixer and so on, you can do that. Yes definitely this is a huge, benefit. This is the gain here, the low noise amplifier gain, the gain of the antenna receiver antenna. All of this really make an impact.

Therefore, when you talk about a receiver sensitivity, what does the manufacturer have in mind is the question. Is he talking about with the antenna or without antenna or does he fix the type of antenna, fix the type of antenna and then perform the experiment, the receiver sensitivity receiver sensitivity experiment. Why is this important is the question. I will show you that as we go along.

So you must be able to read the datasheet and interpret it properly. If you do not understand the datasheet go and look up the mailing lists. Go and look up what is the discussion on the receiver sensitivity about from that chip that you are actually buying. Because the chip essentially, if you take Nordic processors, no. If you take NRF 52840 or 52832, these are very powerful SOCs.

540, in fact is so powerful, it can support either ZigBee/Bluetooth/some other type of technologies as well. Single SOC can do all of that. So because why are they able to do? By a simple software change you can shift from ZigBee, to BLE to whatever. Why is that possible if you ask? Now you know the answer. Because the chain here, this chain that I showed you on top, and the chain below here are one and the same.

They are one and the same. That is why this discussion is important. What you do with BLE in terms of the transmission at the PHY layer, the physical layer can be different from what you do at the other layer for ZigBee. It will be just one more block that you will have to add in somewhere in order to ensure that it does direct spread spectrum modulation as compared to that of BLE doing something else, okay.

So but broadly the chain remains the same with minor modifications. Therefore, by software you can say I am going to remove this block, I am not going to energize this block, I will energize the other block. For example, those blocks which need not be changed are surely the power amplifier. What does the power amplifier care whether it is direct spread spectrum or whether it is frequency hopping.

You give it a signal, it is an amplifier. It has a certain frequency response. We all studied that in our undergrad. What is the frequency response of an amplifier? How do you find that out? You plot the frequency along the x axis, you plot the gain along the y axis, gain expressed in dB and you show how the gain is flat over a certain frequency range. I hope you remember that.

Just for your say this one sake, I will write it here. And I hope you will be able to recall this in your undergrad. So you will have some flattish performance over this range, right? Little bit dip maybe there here and there, but that will depend on how you characterize. So you say this has a flat performance, gives you good gain performance over this frequency range. You would have definitely studied that, anyway.

So what your the power amplifier really does not care what you do. You just give it some data analog signal with a certain range, it has a certain performance, it will apply a certain amplifier power +10 dBm in our case as an example we took and then push it out on the antenna. Now this is one part. Again folks, be very clear about it. I have abstracted this picture so much that I have hidden so many details to you.

And now I am going to tell you what is that story there, okay. Now let me remove this. See folks, this is not trivial at all. This is not trivial. Why it is not trivial? Because antenna will have, antenna will have a certain impedance, will have a certain, I will just write it here, impedance. Power amplifier will have an output impedance you have to match, you have to match the impedance.

Only then you have studied also how maximum power transfer actually happens. Unless you match the impedances you would not have the maximum power that is required is expected to be transmitted will never happen. Your +10 dBm is assumed that it is match, impedance matched. Therefore, receiver sensitivity comes back to the same problem. Are you talking about with impedance matching?

I hope you have, we are talking about receiver sensitivity with proper impedance matching. So this is mind boggling, right? You just now go back and look at this picture. Again here same problem, here. This will have a certain impedance. This guy will have a certain impedance. In fact this may be a passive filter here. This may see an impedance. But when you connect it unless you do proper impedance matching you do that.

In fact this may be performing that activity also. It may be doing a matching and then giving it to the low noise amplifier. It could also be for filtering out frequency ranges over and above what is expected to be neglected beyond a certain channel. May have certain functionality, again depends on each vendor, how the vendor puts out these blocks. So again low noise amplifier is a fixed block.

You do not need to do any changes to this block if you are changing from Bluetooth to Wi-Fi, I mean if you are changing from Bluetooth to the let us say the ZigBee it is just one soft device change, soft device, the soft device changes, okay. So that is about what this, and therefore this receiver sensitivity is indeed quite a critical story here.

So we have to continue understanding the fact that antenna has a certain gain and receiver sensitivity whether it is coated with antenna or without antenna. Whether the antenna is fixed and then you are doing receiver sensitivity calculations all of that. Now question is how to calculate, how to calculate, okay.

Before we get into the detail, let us put down one diagram which can be quite intuitive and look at the diagram and then from there put down the simple expression for calculation of receiver sensitivity. Now question is how to calculate, is it not? So for that what I did, I put one more picture and I will try to explain to you from that picture. This is the picture you will often see when people talk about link budget calculation, okay.

This actually comes from link budget calculation. If you Google for it, you will find it. Nothing to get scared about but it is just trying to put things together, link budget calculation. What actually it means is this picture is very straightforward because if you have understood this picture, you actually know the other picture.

Power amplifier is here, transmit antenna is here, receive antenna is here, the receiver amplifier circuits are here, right? And there are cables connecting from the antenna to the amplifier here. Similarly, there is a cable connecting from here to here. I mentioned to you about impedance matching and so on. So if you know this picture well, you actually know what is actually happening here.

So let us see what happens. So supposing you take a transmission of let us say +20 dBm. This is a random example I just picked it up, okay. It has nothing to do with Bluetooth or ZigBee or any one of them. Just a random example to drive home the point, okay. Now, actually yeah, okay. So let us build the story. So you have +20 dBm coming out from the power amplifier and it is connected to an antenna.

Now there is a cable that is connecting to the antenna. So this cable will introduce a certain loss. And that loss is shown here in this picture with a fall, okay. Then what happens? The signal goes and gets amplified because of the antenna. So you have a super steep rise up there. So this rise is because of the gain in the antenna.

Then it goes out on the air interface. And any electromagnetic signal out on the air interface dies down a square of the distance. This is something that we know very well and that is ideal, right. So you have something called a path loss which we apply and because there is a path loss, there is a huge attenuation in the signal, right? And that signal is coming up. You can see the loss that is shown there.

And that loss is quite a significant one. This is something like 114 dB over a 5 km link let us say, okay. This is as I said, it is a random example, so just to drive home a point. So this is what you are getting here. So it is really down, okay? And what actually happens is, once it comes here, it comes to the receiver antenna. Here there is an antenna gain, right? There is a antenna gain.

So that is what we wanted to show here. And this antenna gain is +14 dBm. Actually, it is called it is expressed in dBi, +14 dBi, isotropic. It is 14 dB over isotropic antenna. That is why it is called 14 dBi. So here it is 10 dBi antenna and this is 14 dBi antenna. Now this 14 dBi antenna receives the signal so the signal gets pumped up okay, it just comes up again. So let me draw it properly. So it comes up here.

But then there is again a cable which gives a -2 dB loss, reduces the gain by 2 dB. So there you have a 2 dB loss and then it goes to the receiver. And then this again from here you know all the processing actually happens. This radio assumes, the whole thing assumes that there is a receiver whose specification is -82 dBm given by the vendor. The vendor has said that the receiver sensitivity is -82 dBm.

Now the question is if the vendor has specified this, at what dBm did you receive the signal? Well it turns out if you do this calculation, a signal was received at -74 dBm. A clear 8 dB, a clear 8 dB gain is there. It is above receiver sensitivity. Not gain, I would say the signal is received 8 dB above the receiver sensitivity. And this is called the margin, okay. When you have a good margin, you will definitely receive the signal.

You should typically have a margin of about 10 dB, okay. If you have about 10 dB margin, then it will take care of any fading that happens in the wireless link. It will still be able to receive the signal successfully. So keep 10 dB as the received margin so that successful reception of the packet actually happens. Now you still have not resolved. What is this -82 dBm receiver sensitivity proposed by the vendor?

Is it with an antenna, without antenna and so on and so forth? I have postponed that answer for the moment, okay? I postponed it, but I am sure you already know that the vendor is talking about his electronics. He is talking about receiver sensitivity without considering any antenna. He is not talking about any antenna.

He is just talking about his electronics low noise amplifier, its sensitivity, its ability to amplify a signal and so on and so forth. So that is very important. I will show you how it connects, how you must map it back to when you buy you know radio SOC chips, which have radio. How you should look for it and what kind of discussion items come up when you are actually doing it.

But here if you see what I have done, I have given you this from the vendor datasheet I asked you to make. I did not show you how you calculated -74 dBm. I do not want to do it, I want you to try it. And I can give you one hint for it. You have to add all the gains and you have to subtract all the losses. Loss is here, cable there is a loss. Path loss you subtract. Then again this cable loss you subtract.

You add the gain, 10 dBi gain you add. +14 dBi you add. +20 dBm you add. You add these gains, you subtract all the losses, you should get a number and that number should be -74 dBm. And clearly it is much above or not significantly, but much above the receiver sensitivity specification as given out by the vendor.

So this is the way to you know look up and understand irrespective of whatever radio that you come across. Still I have not defined many terms. I am sure there are lot of questions in your mind. We will answer them as we go along. And I will show you something more. For example I have not even formally defined what is receiver sensitivity.

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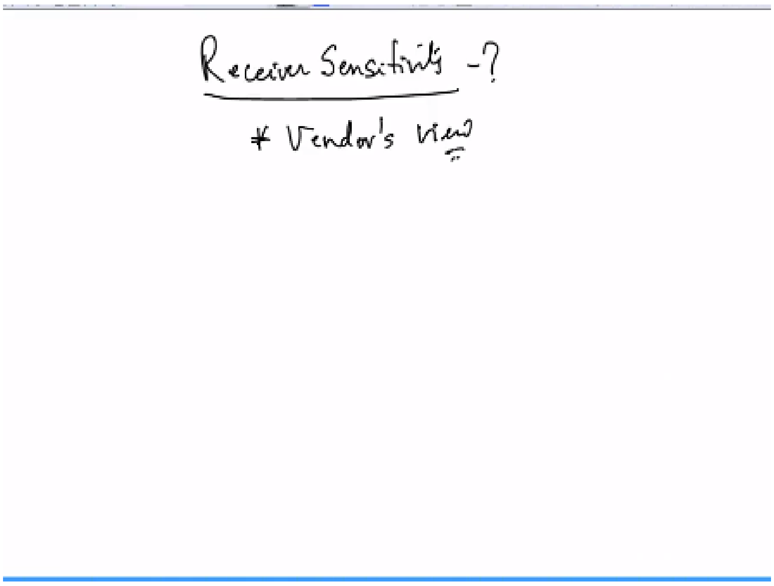

I only drove you by an example. And I showed you what is it actually, how is what is the actual meaning of this word receiver sensitivity and what are the vendor's views. Vendor's views on this is something that we will have to look up as we go along.